ACCELERATING THE TRANSITION TO CIRCULAR ECONOMY

The development of a CE visibility evaluation framework for blockchain-enabled data pipeline solutions

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TU Delft

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Accelerating the transition to Circular Economy

The development of a CE visibility evaluation framework for blockchain-enabled data pipeline solutions

by

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Acknowledgments

This research project signs the end of my studies. My educational experience equipped me with an interdisciplinary background in mechanical engineering and technology management. I believe that engineering teaches a discipline that crosses smoothly into the world of business. Thereby, I decided to study a combination of technical and business concepts and become familiar with the endless opportunities that technology provides for the development of new products and services in today's technical world. This project provided me with the opportunity to focus on my academic interests and intellectual pursuits by exploring the potential of blockchain-enabled information infrastructures to tackle societal challenges, such as the transition to Circular Economy.

At this point, I would like to express my appreciation towards the people that played a significant role in my research project. Firstly, I would like to deeply thank my first supervisor, Dr. Jolien Ubacht, for supporting and guiding me for the last six months. Without our weekly conversations and her constructive criticism, I would not be able to produce such a solid research outcome. Undoubtedly, my thesis would not be materialized without the valuable contribution of Prof. dr. Yao-Hua Tan. His inspiring ideas, critical feedback, and expertise in the supply chain domain enabled me to formulate such a novel and intriguing research project.

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Enjoy reading,

Angelos Kofos

Delft, August 2021

Summary

The modern world is under the pressure of dealing with resource exhaustion and environmental destruction threatening its longevity. The root of these sustainability issues lies in the linear economic model established after the industrial revolution as the most efficient way to conduct business. This economic model relies on two fundamental principles, limitlessness and easily accessible resources and unlimited earth regenerative capacity. The economy thrives by consuming ever more planetary resources to manufacture products and generating wastes by disposing of products in the landfills or incinerating them when they are no longer desirable or useful. However, the growing planet's population and the limited regenerative earth capacity make this model unsustainable.

The circular economy (CE) represents an effective alternative to the current consumption pattern. It is an economic model aspiring to limit the use of virgin resources in the production systems and eliminate the waste streams by promoting a closed resource loop. In other words, it aims at reaping the maximum value of produced goods by prolonging their lifecycle. Products are reintroduced to the market upon consumption through value retention strategies, namely, repair, reuse, remanufacturing, and recycling. The transition to CE is recently high on the agendas of policymakers and private organizations (e.g., banks and venture capitals), defined as CE auditing actors, which have launched policy instruments to accelerate it. Such policy instruments vary from regulations to taxes on landfilling and incineration.

The policy instruments aiming at stimulating the CE transition are prone to manipulations when there is a lot at stake. An indicative example is the recent case, in which it was disclosed that plastic waste exported from the Netherlands to Turkey for recycling or reuse was illegally dumped. To prevent such adverse effects, the CE auditing actors need a solid monitoring system to control the implementation of their policy instruments and enforce compliance when necessary. Such a system should provide visibility in the flows of raw materials and products in a closed-loop supply chain and detect frauds. Nevertheless, its development may be proved a challenging task due to the information fragmentation besetting international trade. The data about materials or products is distributed among various actors, who may be reluctant to share it.

The need for a CE monitoring system can be addressed by harnessing the research on the data pipeline concept. A data pipeline is an IT infrastructure capturing data at the source where it is generated. It equips government authorities with original data shared by the businesses voluntarily and in real-time. This data pertains to the flows of goods from a seller in an exporting country to a buyer in an importing country. Traditionally, data pipelines have been used by customs to access information stored in the traders' information systems willing to be transparent. This data sharing allows them to execute their risk assessment more efficiently and offer trade simplification in return.

The voluntary business to government data sharing, expressed through data pipelines, can play an essential role in enforcing compliance with the CE policy instruments. However, the supply chain visibility currently captured by data pipelines is not sufficient to serve CE. Thereby, they need to be extended to monitor the entire journey of materials and products in the CE context. Furthermore, to unleash the full potential of the shared data, the CE auditing actors need to have trust in the data and its quality. That is to say, they need to be confident that the data has not been manipulated. This condition can be satisfied by using blockchain-enabled data pipelines.

Blockchain is a distributed ledger shared across a public or private network of parties that records encrypted pieces of information. It is a highly promising technology that can be the backbone of a CE monitoring system since it can ensure data integrity. Data integrity is achieved thanks to its unique characteristics, decentralization, auditability, and immutability. Blockchain is appropriate for facilitating the exchange of data in trustless environments, where actors are unwilling to communicate their information. The supply chain (the domain of this research) is such an environment involving geographically dispersed actors with competing interests, different policies, and cultures.

The thesis project dives into the research domain of blockchain-based data pipeline solutions by investigating their ability to support the CE transition. For that reason, it develops a framework that evaluates their ability to enforce compliance with CE policy instruments by acting as monitoring systems. The evaluation framework identifies the information requirements needed to be captured by such architectures to monitor the journey of materials and products in a closed-loop supply chain. The research objective is explicated in the main research question: *"How can a CE visibility evaluation framework for blockchain-enabled data pipeline solutions facilitate the monitoring of compliance with the policy instruments established to foster the CE transition?"*.

The thesis addresses the main research question by following the design science research approach, which defines the activities that researchers should carry out to develop an innovative and well-grounded artifact. The research activities are the following: problem identification and motivation, definition of the objectives of a solution, design and development, demonstration, evaluation, and communication. To produce the CE visibility evaluation framework, the research starts with exploiting the insights provided by the literature. The literature around the information requirements for CE compliance purposes proves to be incomplete. The thesis bridges this knowledge gap by exploiting the empirical data offered by three blockchain-based architectures, TradeLens, FoodTrust, and Vinturas.

The CE visibility evaluation framework is a valuable contribution to academic society. The research on mobilizing the latest digital innovations, especially blockchain, to foster the CE transition is an underdeveloped scientific domain. Moreover, as far as the thesis is concerned, this is the first attempt to develop a framework that assesses the available blockchain-based information infrastructures on their potential to enforce compliance with the CE policy instruments. Whereas the academic literature lacks evaluation frameworks focused on blockchain, in general.

The societal contribution of the research outcome is two-fold. On the one hand, the CE auditing actors can use it to evaluate and, if applicable, select among the available blockchain-based information systems the most appropriate one to help them realize their CE agendas. Such a development could produce considerable benefits for society by preserving planetary resources, restricting environmental degradation, and revitalizing the world economy (CE transition could create additional employment opportunities and boost GDP). On the other hand, the IT developers can leverage it to identify the data needed to be stored by their IT infrastructures to be deployed as CE monitoring systems.

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List of Abbreviations

API Application Programming Interface
B2B Business to Business
B2G Business to Government
BTS IBM Blockchain Transparent Supply
CE Circular Economy
CRC Centralized Return Centre
DI Digital Infrastructure
DPP Digital Product Passport
DSR Design Science Research
EC European Commission
EMF Ellen Macarthur Foundation
EPREL European Product Database for Energy Labelling
EU European Union
FRQ Functional Requirement
GDPR General Data Protection Regulation
HS Harmonized Commodity Description and Coding System
IBM International Business Machines Corporation
IoT Internet of Things
IS Information System
LSP Logistics Service Provider
MFDSR Method Framework for Design Science Research
MoT Management of Technology
MP Materials Passport
MRQ Main Research Question
NEN Royal Netherlands Standardization Institute Foundation
NFRQ Non-functional Requirement
OECD Organisation for Economic Co-operation and Development

OEM Original Equipment Manufacturer

P2P Peer-to-Peer

REACH Registration, Evaluation, Authorisation and Restriction of Chemicals

RFID Radio Frequency Identification

SOA Service-Oriented Architecture

SRQ Sub-research Question

URL Uniform Resource Locator

VIN Vehicle Identification Number

WCO World Customs Organization

WEEE Waste Electrical and Electronic Equipment Directive

1
Introduction

This research project was conducted at the Delft University of Technology in collaboration with the International Business Machines (IBM) in the Netherlands. It constitutes a response to the appeal of Zeiss et al. towards the Information systems (IS) community to reap the benefits of digital innovations to eliminate the wicked problem of resource depletion and environmental destruction. As presented, Circular Economy (CE) is an economic model that can provide decisive answers to the aforementioned sustainability issues. The thesis aims at catalyzing the CE transition by developing an evaluation framework for assessing the potential of blockchain-enabled data pipeline solutions to support the implementation of CE policy instruments launched by both policymakers and private companies.

This chapter constitutes the backbone of the research project. Initially, it describes the essence of the research by introducing the main research problem, identifying the research gap in the extant literature, and formulating the main objective. Subsequently, it presents the main research question (MRQ), which captures the thesis contribution towards both the academic community and society. Moreover, the research approach is demonstrated, which encloses the method adopted by the study to address the MRQ and developing the framework. Finally, the chapter illustrates the thesis outline by providing an overview of the thesis chapters and the activities carried out in each chapter.

1.1. Problem Statement

Today's world comes up against the enormous challenge of moving towards more sustainable practices. The growing planet's population in conjunction with the heightening economic activity are leading to resource depletion and environmental degradation. These developments require a radical shift of human lifestyle towards a more environmentally friendly one. The business world is currently held accountable by both society and the state for safeguarding human eudaemonia and altering its production and operations practices (Narayan & Tidström, 2020).

The concept of Circular Economy has recently received noteworthy attention by policy-makers, academic community, and businesses as an effective response to sustainability issues. Its underlying purpose is to minimize the use of natural resources in the production systems by fostering a closed resource loop. In other words, society should aim at receiving the maximum utility from materials, renewable resources, and products (Ellen MacArthur Foundation, 2016; Genovese, Acquaye, Figueroa, & Koh, 2017; Zeiss, Ixmeier, Recker, & Kranz, 2020).

This new economic model has attracted the attention of governments and private organizations (e.g., banks, and institutional investors) around the world, which have initiated various policy instruments to stimulate its integration into business activities. Such policy instruments could vary from regulations to additional taxes for eco-unfriendly goods and green loans (Dewick, Bengtsson, Cohen, Sarkis, & Schröder, 2020). Indicatively, the European Union (EU), by initiating the "The European Green Deal", aims at becoming climate neutral in 2050. This goal will be attained through the adoption of CE-related initiatives, the promotion of an environmentally friendly culture, and the support of industrial innovation (European Commission, 2020b).

The monitoring of these policies by the government and private sector fall short, mainly due to the absence of a solid monitoring system able to govern the flows of materials and products in the supply chain. This lack of visibility enables agents to manipulate the CE policy instruments to pursue their interests (Rukanova et al., 2021). Equally influential is considered the data fragmentation among various actors involved in the supply chain. In other words, the information about a product, such as the production process and sustainability practices used, is scattered among several actors and information systems. Consequently, access to that information can be limited or even impossible, while its validity is considered controversial (Rukanova, Henningsson, Zinner Henriksen, & Tan, 2018; van Engelenburg et al., 2020).

According to Zeiss et al., the Information Systems (IS) academic community can play a pivotal role in accelerating CE transition by exploiting the latest digital innovations. Digital infrastructures (DI) can stimulate the development of a reliable monitoring system, which can boost supply chain visibility and enforce compliance with CE policies (Rukanova et al., 2018). Among the several DI initiatives that can be found in the literature, data pipelines have gained significant attention by plenty of researchers (Hesketh, 2009a, 2009b; Klievink et al., 2012; Pugliatti, 2011; Rukanova et al., 2018).

The data pipeline is defined as an *"IT information infrastructure that enables capturing data at the source"* (Klievink et al., 2012, p.14). It relies on the idea of reusing business data (e.g., bill of lading, invoice, purchase order, etc.) stored in various information systems available in the supply chain to facilitate governmental control. The governmental authorities (e.g., policymakers, customs) can receive real-time access to original data voluntarily shared by parties. Traditionally, data pipelines have been deployed by businesses to exchange information with authorities to experience benefits in return, such as trade simplification (Hesketh, 2010; Klievink et al., 2012; Rukanova, Huiden, & Tan, 2017; Rukanova et al., 2018).

This study extends the application of data pipelines by implementing them in the CE context.

Such a choice can enable the actors interested in promoting CE transition (defined as CE auditing actors by the thesis, e.g., policymakers, customs, and banks) to enforce compliance with their policies by reaping the benefits of the available business data. However, an essential prerequisite for unleashing the full potential of shared data to serve the public good is the need for trust in the data and its quality. In other words, the data recipients need to be confident that the shared data has not been tampered with. This requirement can be satisfied by deploying blockchain-based data pipelines.

Blockchain is a distributed ledger shared across a public or private network that stores various types of information, such as transaction data or events by using cryptography (Landerreche & Stevens, 2018; Pahl, El Ioini, & Helmer, 2018; Ølnes, Ubacht, & Janssen, 2017). It is a highly-promising technology that exceeds the capabilities of traditional information systems thanks to its four characteristics, namely, decentralization, auditability, immutability, and smart contracts (Cole, Stevenson, & Aitken, 2019; Saberi, Kouhizadeh, Sarkis, & Shen, 2019). The technology is particularly suitable for networks of actors in which no trust exists, making parties reluctant to share information. Therefore, it has the potential to combat the data fragmentation that besets global trade, and enhance supply chain visibility facilitating the monitoring of CE flows (Abeyratne & Monfared, 2016; Saberi et al., 2019).

Blockchain has already been implemented in the supply chain domain, producing promising results and dealing with crucial hiccups of international trade (DHL, 2018). Its undeniable potential incentivized the thesis to explore its suitability for serving the CE purposes. The execution of such a study can benefit from the exploitation of tangible evidence granted by commercially launched blockchain platforms. More specifically, the research can receive valuable insights from blockchain initiatives focused on providing end-to-end supply chain visibility, as they are likely to be used by auditing parties (e.g., policymakers, customs, and banks) as monitoring systems to support their agendas and enforce compliance within the supply chain domain. In simple words, the CE auditing actors can deploy them to trace a product throughout the supply chain and realize whether it integrates circular characteristics.

1.2. Research Gap

The focal problem at hand is the wicked problem of resource depletion and environmental destruction due to economic activities. The topic is contemporary, being at the top of the agendas of both policymakers and the business world (Dewick et al., 2020). CE research emerged in the 1960s when the scientific world engaged in discussions around the waste and resource management. In the course of time, the research evolved towards its existing version, emphasizing the need to close the materials loops and retain their economic value (Zeiss et al., 2020).

Undoubtedly, the academic community has been mobilized to address the CE challenges. However, its efforts have been focused on approaching the topic from a more technical perspective, such as examining the transition from fossil fuels to renewables. The research on the use of digital technologies for supporting CE initiatives is relatively scarce (Rukanova et al., 2021; Zeiss et al., 2020). As described by Zeiss et al., the IS academic community has not been actively involved in addressing this societal challenge.

The primary research objective is to bridge the gap identified by Zeiss et al. by investigating the potential of blockchain-based information infrastructures to support CE transition. The transition to more sustainable practices depends on the actions of legislative bodies or private companies (e.g., banks, and institutional investors), which can incentivize the industry to abandon the traditional 'take-make-waste' economic model (Dewick et al., 2020; Genovese et al., 2017). As discussed earlier, the success of such initiatives requires the deployment of a monitoring system able to bring visibility in the materials flows throughout the supply chain. In other words, the supervision of CE policy instruments requires access to business data, such as the bill of lading and invoices.

The data pipeline concept is a suitable tool for enabling business to government data sharing (B2G) (Hesketh, 2009a, 2009b; Klievink et al., 2012; Pugliatti, 2011; Rukanova et al., 2018). However, the data stored through data pipelines so far is not sufficient for monitoring the implementation of CE policy instruments and supporting the CE transition. Data pipelines offer rich insights regarding shipping goods by storing crucial trade data (e.g., bill of lading or packing list), capturing shipment events (e.g., the opening of a container on its way to the final destination), and mapping the stakeholders involved in the shipment. Even though such information could contribute to CE monitoring, Rukanova et al. (2021) highlight the need for extending data pipelines to provide additional visibility in production, on secondary raw resources, and at national borders, considering that materials could cross several jurisdictions throughout their journey. This research project works towards that direction by following this recommendation.

The value of the thesis is also justified by the research conducted by Shojaei et al. (2021). According to their findings, the deployment of blockchain-enabled information systems in the CE context is a new research domain with a limited number of available studies. Such research could bring great benefits to society, as blockchain-based systems can enable auditing actors to view the current status of materials or goods and track their entire path in the supply chain. The existing material tracing systems are very far away from offering the desired visibility, so this research domain is worth exploring (Shojaei, Ketabi, Razkenari, Hakim, & Wang, 2021).

1.3. Research Objective

The thesis aims at developing a framework that fills the knowledge gap identified in the literature. The framework focuses on evaluating the suitability of blockchain-enabled data pipeline solutions to act as monitoring systems for CE purposes. This research objective is achieved by identifying the information requirements needed to be captured in such architectures to monitor the journey of goods or materials in a closed supply chain. In other words, the research output covers the missing elements outlined in the literature about data pipelines and CE. The developed artifact is a valuable research output, as a negligible number of frameworks for evaluating the suitability of blockchain-based applications, in general, have been developed (Casino, Dasaklis, & Patsakis, 2019).

Equally considerable is the practical contribution of the project. The thesis output can be beneficial for agents interested in fostering CE transition (e.g., policymakers, customs, banks, institutional investors) by launching policy instruments. They can use the framework to evaluate the potential of available blockchain-based information systems to enforce compliance with CE policies by acting as monitoring systems. For instance, a national government can use the thesis outcome to evaluate and, if applicable, select among the various available blockchain-based infrastructures the most appropriate one. Such output can help the government to trace a product throughout the supply chain by analyzing business data and realize whether the product is circular.

The study takes as a starting point the CE diagram (Figure 1.1) developed by the Ellen Macarthur Foundation (EMF), which makes explicit the CE flows and sheds light on the processes that are subject to monitoring. The description of the CE flows provided by the CE diagram is of pivotal importance for research, enabling researchers to select the processes that they will focus on in their study. However, this description is provided at a high-level. In other words, the model gives a generic illustration of the flow of materials, nutrients, components, and products (Ellen MacArthur Foundation, 2017).

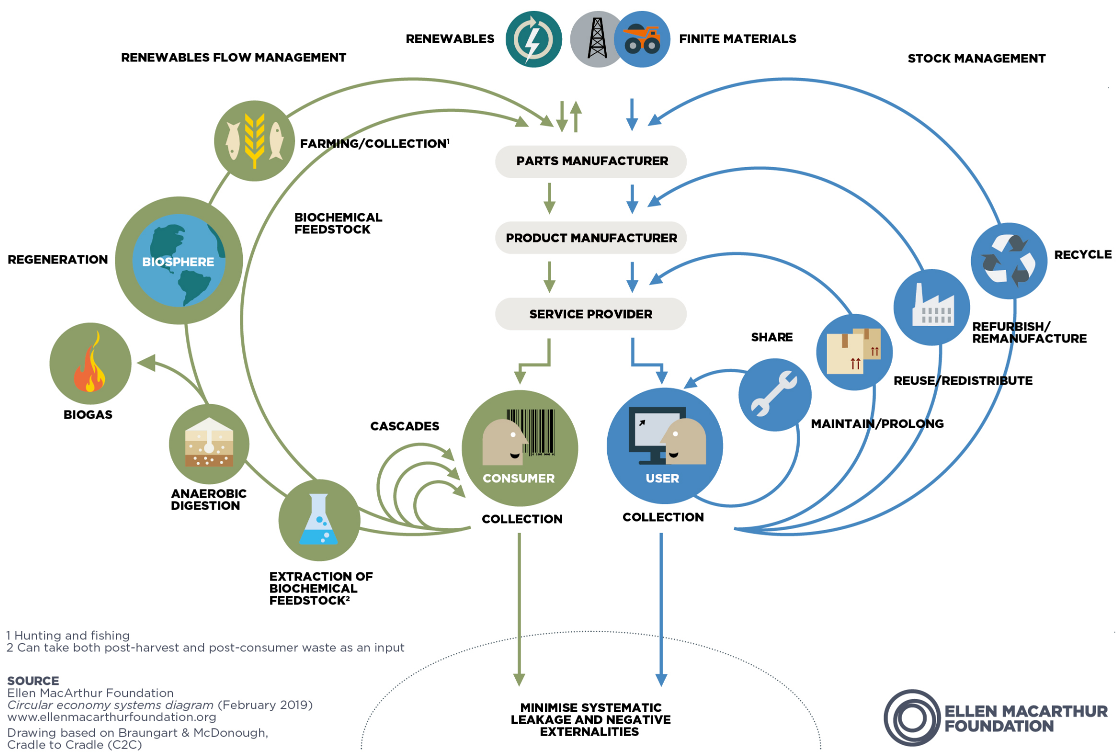


Figure 1.1: Circular economy diagram (Ellen MacArthur Foundation, 2016)

The thesis focuses on the right-hand side of the diagram, which is related to materials, such as plastic and aluminum. These materials are finite and non-biodegradable, and therefore, society should aim at prolonging their life-cycle and minimizing their usage (Ellen MacArthur Foundation, 2016). Namely, the thesis concentrates on two CE processes, reuse/redistribute, and recycle. The first process is about extending the technical lifecycle of products by remarketing and reusing them. The second process is related to returning a product to its basic materials so as to produce new products (Calvo-Porral & Lévy-Mangin, 2020; Ellen MacArthur Foundation, 2016).

The motivation for focusing on the right-hand side and the abovementioned processes stems from the urgent need of policymakers and private companies (e.g., institutional investors) to eliminate the waste streams for incineration and landfilling by establishing policy instruments (Rukanova et al., 2021). For instance, the Dutch government raised the taxes related to burning or disposing of materials and initiated various policy instruments to encourage recycling (Rijksoverheid, 2019). The thesis tries to identify the information needed to be captured by blockchain-based information systems to monitor the flows of materials and goods that insert into these processes.

1.4. Scientific Relevance

The research on the deployment of digital technologies for supporting CE initiatives is considered relatively scarce (Zeiss et al., 2020). Therefore, the primary objective of the research is to explore the potential of digital innovations to achieve end-to-end supply chain visibility and support the implementation of CE initiatives. By taking as starting point the fundamental pillars of CE, as described by the EMF, the thesis dives into the research on blockchain-enabled data pipeline solutions by researching their role in fulfilling sustainability goals. By doing so, the gap identified by Zeiss et al. in IS research can be bridged and CE monitoring can be facilitated.

The thesis output also contributes to the discussion regarding the real potential of blockchain to tackle grand societal challenges. Currently, IT specialists perceive blockchain as a panacea to multiple real-world problems and envisage its deployment in various projects. Undeniably, the technology has the potential to revolutionize the modern world and bring tremendous benefits. However, one should thoroughly examine its suitability before considering its implementation. According to the literature, a negligible number of frameworks for investigating the suitability of blockchain-based applications have been developed (Casino et al., 2019; Saberi, Kouhizadeh, & Sarkis, 2018). Therefore, the thesis fills this gap in the extant literature and ensures a more sober and cynical analysis of blockchain solutions.

1.5. Societal Relevance

The thesis focuses on assisting policymakers, customs authorities, or private companies (e.g., banks) with realizing their CE agendas. As already discussed, the evaluation framework can be used by these agents to assess the potential of blockchain-based data pipelines to be deployed as CE monitoring systems. A solid CE monitoring system can enable them to fulfill their auditing role and force the industry to abandon the traditional ‘take-make-waste’ economic model, which leads to resource exhaustion and environmental destruction. In other words, the research output aims at facilitating the mission of these actors by supporting the implementation of their CE policy instruments, such as laws, taxes, and green loans. The successful application of these policy instruments is of pivotal importance for the modern world. According to the literature, such actions incentivize the industry to adopt the circular business model (Govindan & Hasanagic, 2018; Shojaei et al., 2021).

The thesis, by promoting the deployment of blockchain-based CE information systems, aims also at enabling auditing actors to access reliable information. In this way, it deals with a crucial hiccup of today’s world. Blockchain technology, apart from facilitating data exchange, ensures trust in the shared data, its quality, and originality. Consequently, auditing actors could be confident about the data integrity and leverage them to trace the real journey of a material in the supply chain and make informed decisions. This aspect discriminates blockchain technology from the Internet, which is simply used to disseminate copies of information (Shojaei et al., 2021).

Finally, the research output can encourage the parties with an auditing role to reap the full benefits of data produced throughout the supply chain. As described by IBM, the modern world exploits less than 0.5% of data produced, whereas 80% of worldwide data is trapped in organizational silos (IBM, 2021). Blockchain provides a safe environment in which actors can share their data and benefit from such an exchange (Saberi et al., 2019). Promoting blockchain-based data pipelines as a suitable tool for CE purposes can incentivize multiple agents to adopt (e.g., authorities, businesses) the technology for exchanging information. Such a development can increase supply chain efficiency and save billions of dollars, benefiting society (Saberi et al., 2018).

1.6. Main Research Question

The thesis dives into the blockchain-enabled data pipeline solutions by exploring their potential to support the CE transition. This research domain is still underdeveloped, so the study undertakes the initial step of examining the suitability of the systems for the case at hand. For that reason, the development of a framework that serves the research objective is of paramount importance. A suitable digital technology needs to provide additional visibility than that currently offered by data pipelines. Namely, visibility in three additional directions is required, in production, on secondary materials, and at national borders (chapter 3 contains a detailed explanation of these aspects). The research objective is captured in the following main research question (MRQ):

“How can a CE visibility evaluation framework for blockchain-enabled data pipeline solutions facilitate the monitoring of compliance with the policy instruments established to foster the CE transition?”

The study addresses the MRQ by utilizing the Design Science Research (DSR) approach, a methodology that defines a set of activities that researchers should follow to develop a novel artifact, such as an evaluation framework (Johannesson & Perjons, 2014; Peffers, Tuunanen, Rothenberger, & Chatterjee, 2007). The development efforts start by eliciting the essential information requirements for CE monitoring from the literature. This activity leads to the design of a tentative version of the framework. Subsequently, the thesis focuses on refining it further by receiving empirical data from three blockchain-based platforms (use cases), applied to the framework in an iterative way. Finally, the developed artifact is evaluated by experts, and it is improved further based on their feedback.

1.7. Research Approach

As discussed in the previous section, the research outcome provides a solution to a vital problem that humanity currently experiences, resources depletion and environmental destruction. This research goal aligns with the objective of Design Science Research, which focuses on producing artifacts that can deal with concrete problems of general interest (Johannesson & Perjons, 2014). In DSR, a broad perspective is adopted during the development efforts. Design Science researchers, apart from designing a solution, generate knowledge about it, evaluate its impact and communicate it to an audience (Peffers et al., 2007).

DSR engages in the development of novel artifacts that incorporate research contribution in their design and address a not hitherto practical problem. In other words, DSR focuses on developing artifacts with both practical and theoretical importance. March and Smith (1995) recognize four types of artifacts as possible DSR products: *"constructs (vocabulary and symbols), models (abstractions and representations), methods (algorithms and practices), and instantiations (implemented and prototype systems)"* (Hevner et al., 2004, p. 77). However, this typology is considered too broad and vague and can be distinguished into sub-categories. Chapter D (Appendices) presents the various sub-categories originating from the initial typology. As Table D.3 illustrates, a framework is defined as *"a logical structure for organizing complex information"* and belongs to the model category (Sangupamba Mwilu, Comyn-Wattiau, & Prat, 2016).

According to the literature, DSR projects should meet some fundamental requirements to materialize their mission. Initially, they should utilize well-established and rigorous scientific methods to produce novel knowledge. At the same time, the generated knowledge should rely on the existing knowledge base and the results should be communicated to specialists in the domain. By meeting these requirements, the projects can ensure that their outcomes are both well-grounded and innovative (Johannesson & Perjons, 2014).

1.7.1. The three-cycle view

The need for research rigor and relevance with the existing knowledge base can be satisfied by deploying the theoretical framework, the three-cycle view, developed by Hevner (2007). Hevner depicts DSR as three cycles, the relevance cycle, the rigor cycle, and the design cycle. The relevance cycle aims at connecting the environment of the research project, where the novel artifact will be introduced, with the design science research. It places particular attention on the application domain, consisting of people and organizational or technical systems. The rigor cycle bridges the design science activities with the extant body of knowledge, including scientific theories and available experience, competencies, and artifacts in the domain. Finally, the design cycle focuses on building and evaluating the developed artifact through an iterative process (Hevner, 2007).

The problem at hand can be divided into several elements, which should be considered so as to address the main research question. Figure 1.2 depicts these elements by associating them with the theoretical concepts of the three-cycle view. As presented, the environment contains the information fragmentation that besets the global trade, the information requirements needed to support the trace of an item throughout the supply chain, the agents (governments and private companies) interested in promoting CE, the actors able to provide this information, and the blockchain platforms used in the research (FoodTrust, TradeLens and Vinturas). The representation of these components provides opportunities for improving the status quo and the acceptance criteria for the assessment of the research outcome. For that reason, the research results should return as an input to the environment for evaluation, which will specify the need for further iterations (Hevner, 2007).

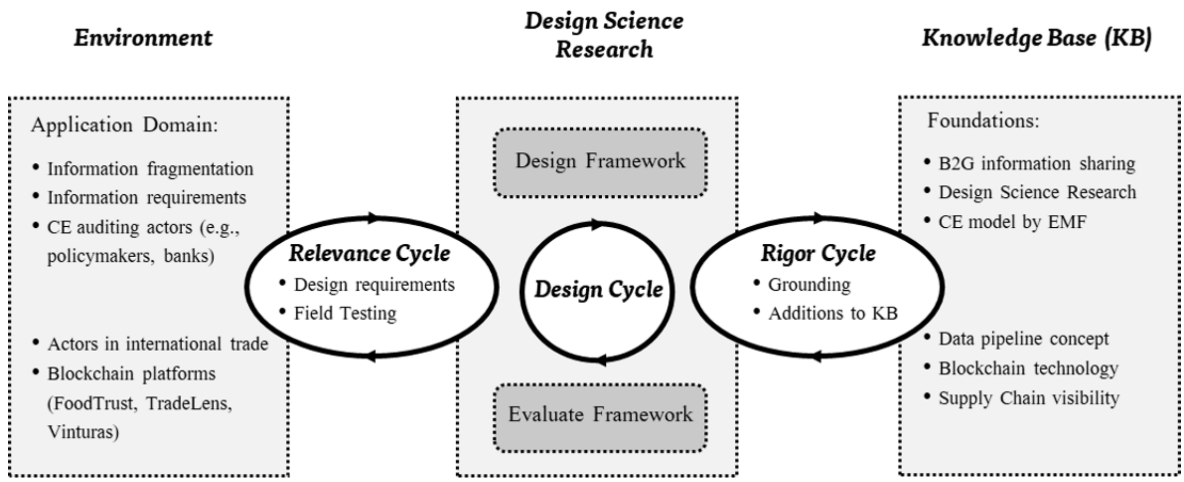


Figure 1.2: DSRM cycles, based on Hevner (2007)

The knowledge base encloses the fundamental knowledge derived from the literature, which lays the foundations for the research project (Hevner, 2007). The study derives essential insights from the B2G information sharing scientific discipline, which focuses on how business data can be exploited by the public sector to serve the general public interest

(European Commission, 2020d). Equally influential are the fundamental thesis concepts discussed earlier, including the DSR, the DI that can support B2G information sharing (data pipeline concept and blockchain-based data pipelines), the CE model developed by the EMF, and the supply chain visibility concept. Thorough research on these concepts can ensure that the research project will produce an innovative and original outcome (Hevner, 2007).

1.7.2. The Method Framework for Design Science Research

A suitable method for providing a direction to research approach is "Method Framework for Design Science Research (MFDSR)" (Johannesson & Perjons, 2014; Peffers et al., 2007). The framework can benefit a study by providing structure and rigor and ensuring results of high-quality. Furthermore, it is a widely accepted process that enables reviewers or scholars to understand and evaluate the research outputs. MFDSR defines a set of activities or guidelines that researchers should follow during a DSR project to produce solid and valid results. The activities described by the framework are: *"problem identification and motivation, definition of the objectives of a solution, design and development, demonstration, evaluation, and communication"* (Peffers et al., 2007, p. 46).

The output of each research activity can serve as an input to the following one. However, this sequential relationship is not restrictive in DSR, considering that it is an iterative process, researchers move forward and backward across all the activities during the project. In other words, any step can receive inputs and generate outcomes for all the other steps (Johannesson & Perjons, 2014; Peffers et al., 2007).

The remainder of this subsection focuses on addressing the main research question by formulating a set of sub-research questions (SRQ) by means of the MFDSR. The sub-questions cover the elements of the DSRM cycles and connect the environment, the knowledge base, and design science activities. Moreover, they contribute to the research project by narrowing the topic and providing structure and guidelines for the data collection and analysis.

Activity 1: Problem identification and motivation

This activity aims at scrutinizing the problem at stake and surfacing its root causes. The central research problem should be precisely described and justified to highlight the urgency of dealing with it (Peffers et al., 2007). As mentioned earlier, the issue should be of public interest, meaning that it should be of significance for various stakeholders (Johannesson & Perjons, 2014). The problem definition should be complemented by a thorough literature review on the topic, which will ensure focus on the research (Doyle, Sammon, & Neville, 2016; Hevner, 2007; Peffers et al., 2007).

Initially, this step is covered by the chapter 1 of the thesis, which defines the research problem and objective and establishes a direction for the project. Such an output can incentivize the audience to adopt the suggested solution by justifying its value (Doyle et al., 2016; Peffers et al., 2007). In other words, it can motivate the actors interested in catalyzing CE transition (e.g., policymakers, banks, and institutional investors) to use the framework and experience the benefits that it provides, which have been analyzed earlier. Subsequently, the study focuses on setting the foundations for the artifact development by executing a literature review on the core thesis concepts (CE transition, data pipeline, blockchain, and supply chain visibility). This sub-activity is addressed by the first sub-research question.

SRQ1: What is the knowledge base on which the development of a CE visibility evaluation framework for blockchain-enabled data pipeline solutions should rely?

Activity 2: Define the objectives of the artifact

The second activity is about translating the explicated problem into objectives or the so-called requirements. The objectives can be expressed in either quantitative terms, such as the percentage that the produced solution is more efficient than the existing one, or qualitative terms, such as an analysis of how the generated artifact can provide a solution to a problem not hitherto tackled. The output of this activity is used as a performance measurement at the evaluation phase, which judges the potential of the new artifact to address the research problem (Doyle et al., 2016; Peffers et al., 2007). The objectives of the thesis can be formulated in qualitative terms, as the developed framework is expected to illustrate the information requirements that information systems should capture to support the implementation of CE policy instruments. This step will be addressed by the following sub-research question.

SRQ2: What are the essential information requirements needed to support the trace of an item throughout its life cycle in the CE context?

The SRQ2 is firstly answered through a literature review on the CE, the supply chain visibility, and the CE policy instruments, which can surface the CE auditing actors' needs. Subsequently, a literature review is executed on the information tools (information sources) that can be used to enhance CE visibility and incentivize businesses to abandon the linear "cradle-to-grave" economic model. An indicative example of such a tool is the digital product passport (DPP), which can provide critical information regarding a product, such as the materials used in its production, or its reusability and recyclability (Pardo, 2018).

The output of the second activity is of pivotal importance for the research project setting the requirements for the blockchain-enabled data pipeline solutions aspiring to serve CE purposes. In other words, the answer identifies the information needed to be included in blockchain-based information systems to trace an item throughout its life cycle. The term "life cycle" includes the complete journey of an item from its production or harvest to final consumers and afterward its re-introduction to the market through value retention strategies, such as reuse or recycling. The term "item" captures every material, component, or product that can enter the CE processes.

Activity 3: Design and develop artifact

This activity develops an artifact that can deal with the problem at hand by considering the objectives identified in the previous step. Designing the artifact requires decisions regarding its structure. The central output will be prescriptive knowledge that can be incorporated into the developed artifact and descriptive learning concerning the design choices (Johannesson & Perjons, 2014; Peffers et al., 2007). This step is crucial since it produces the research outcome and its is addressed by the SRQ3 and SRQ4.

SRQ3: How can the information requirements needed to support the trace of an item throughout its life cycle serve as a basis for the CE visibility evaluation framework?

The SRQ3 receives as an input the information requirements identified by SRQ2 and uses them to develop an initial version of the evaluation framework. In addition, it executes a literature review on reverse logistics and the closed-loop supply chain to cover some knowledge gaps surfaced by the data provided by the SRQ2.In other words, this sub-question addresses the first phase of the design process analyzed in detail later in this subsection.

The insights offered by the SRQ3 are not sufficient for developing a thorough evaluation framework. The literature around the information requirements for CE purposes is incomplete. In other words, the thesis cannot fulfill its objective to develop a framework that evaluates blockchain-enabled information systems on their potential to monitor the flows of materials and products in the CE context by simply using the literature. Thereby, it tries to bridge this knowledge gap by deploying the information provided by three blockchain-based information systems acting as use cases, TradeLens, FoodTrust, and Vinturas. The use cases offer rich and multifaceted insights.

TradeLens contributes to the design phase by giving valuable information about tracing a cargo from a seller in an exporting country to a buyer in an importing one. It offers visibility on a container-level by capturing shipment events and documents (TradeLens, 2021b). However, enforcing compliance with the CE policy instruments also requires visibility on both ingredient-level (raw materials) and item-level (products). This aspect is currently missing by TradeLens, which does not capture detailed insights about the products included in a container.

This knowledge gap in the CE visibility can be covered by FoodTrust. FoodTrust traces the journey of ingredients and items in the supply chain before consumption (IBM, 2021). As its name indicates, it focuses on the food industry, which refers to the left-hand side of the CE diagram (presented in Figure 1.1). Even though the thesis is not interested in food products, which are biodegradable and return to the environment, the platform plays a pivotal role in the design efforts by surfacing the visibility needed in some fundamental CE processes, described in chapter 4, such as materials sourcing. Furthermore, the thesis argues that, from a technological perspective, the visibility offered by FoodTrust for food products can be also provided for non-food products.

Finally, Vinturas is an automotive consortium created by several European logistics service providers (LSPs). It provides visibility in the journey of vehicles from production to dealer.

Its specialization in the transportation aspect of the vehicle industry refines the framework by offering unique insights. Indicatively, the platform mainly covers inland transportation, an aspect not addressed by TradeLens and FoodTrust. Equally valuable for the research is that Vinturas deals with the transportation element of the remarketing of second-hand vehicles (Vinturas, 2021a). The remarking process resembles the reuse and redistribute CE process illustrated in the CE diagram (Figure 1.1).

The motivation for selecting these use cases stems from their ability to offer the craved visibility in the journey of materials and products from materials sourcing to consumption. In other words, they cover a significant part of the CE flows. Consequently, they can be a useful tool for the CE auditing actors in their efforts to enforce compliance with their policy instruments. Each information system covers different parts of this supply chain, making their combination a worth-exploring scientific domain. Moreover, it should be mentioned that the research had great access to information about these blockchain-enabled architectures.

The use cases also satisfy one of the primary research objectives, extending data pipelines for CE compliance purposes. As the thesis proves at the end, TradeLens is a complete data pipeline solution integrating all the characteristics of this IT information infrastructure. Namely, it captures business data at the source, enables voluntary and real-time data sharing for governmental control, and offers visibility from a seller in an exporting country to the buyer in an importing one. However, to enforce compliance with CE policy instruments, data pipelines (e.g., TradeLens) need to be extended to offer additional visibility (Rukanova et al., 2021). This requirement can be satisfied by examining the connection of TradeLens with other blockchain-based information systems, such as FoodTrust and Vinturas.

The thesis tries to refine the first version of the CE visibility evaluation framework produced by the SRQ3 by formulating the SRQ4. The SRQ4 receives as an input the framework under development and applies it to the use cases in an iterative way. Each iteration produces an elaborated version of the CE visibility evaluation framework based on the insights gained. The answer to this sub-question is elicited by analyzing documents provided by IBM and Vinturas. Even though it is not its primary objective, the research also delves into the blockchain design characteristics of the examined information systems to enrich its knowledge base.

SRQ4: What information requirements for CE visibility are captured by the examined blockchain-enabled information systems and how do the insights derived from them contribute to the further development of the CE visibility evaluation framework?

Figure 1.3 shows the process followed during the development of the evaluation framework. As presented, the design process is divided into three phases. Initially, a tentative version of the framework is developed based on the literature review conducted on both information requirements needed to trace an item in the supply chain and the information tools that can provide CE visibility. Subsequently, the framework is refined further as a result of the insights gained by the use cases. Finally, the consolidation phase produces the ultimate research output.

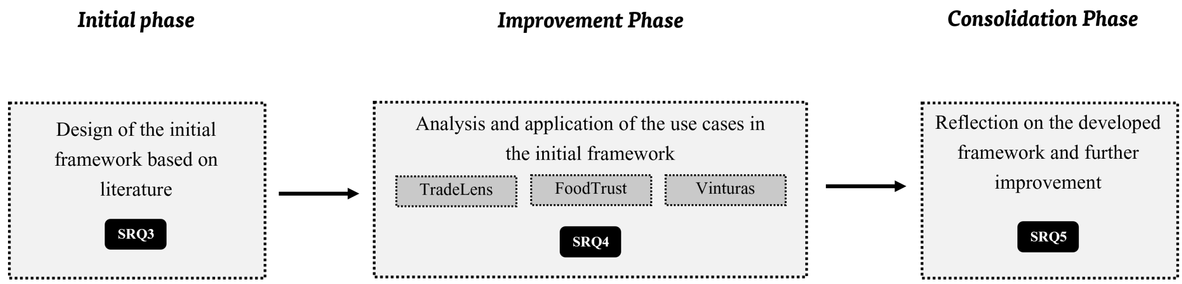


Figure 1.3: Design process

The design process aligns with the views identified in the literature. Hevner et al. (2004) depict DSR as an iterative and incremental process. According to their paper, the testing of an artifact, carried out through the application of use cases in this thesis, enhances the quality of both the design process and the developed solution by providing meaningful feedback. Similarly, March and Smith (1995) claim that the application and test of a solution during the design process leads to the development of complete research output.

Kuechler and Vaishnavi also endorse this research process by emphasizing the importance of enriching the understanding of an issue through the act of building an artifact. In their paper, they define the knowledge acquired in practice as circumscriptions. Circumscriptions can take place at both the development and evaluation phase, revising the knowledge base. Their way of thinking relies on the assumption that any knowledge base is incomplete by nature, so it has to be used to be considered valid in specific circumstances (Kuechler & Vaishnavi, 2012).

Activity 4: Demonstrate and evaluate artifact

The fourth activity combines two activities described by Peffers et al, the demonstration and evaluation of the artifact. Therefore, it can be divided into two sub-activities. The first sub-activity demonstrates the developed framework (proof of concept) to prove that it can attain its purpose by solving a practical problem (Doyle et al., 2016; Johannesson & Perjons, 2014; Peffers et al., 2007). The second sub-activity is about evaluating the potential of the artifact to achieve the objectives articulated in the second activity and tackle the practical problem of the research, monitoring CE flows (Doyle et al., 2016; Johannesson & Perjons, 2014; Peffers et al., 2007). The SRQ5 covers this research activity.

SRQ5: To what extent does the developed framework evaluate the ability of blockchain-enabled data pipeline solutions to provide the visibility needed to support CE policy instruments?

The SRQ5 demonstrates the framework produced from the previous sub-questions and evaluates its ability to serve its purpose. As discussed earlier, to support the CE initiatives, data pipelines need to provide visibility in production, on the flows of secondary raw materials, and at national borders. The output of interviews is used as an input to the development efforts, leading to the ultimate version of the framework.

The final version of the CE visibility evaluation framework is used to evaluate the three blockchain platforms (TradeLens, FoodTrust, Vinturas) on their ability to act as monitoring systems for CE purposes. In other words, the framework assesses to what extent the platforms capture the information requirements identified through the literature review and the analysis of the use cases. This sub-activity specifies “data gaps” in the blockchain platforms, which can be addressed with further development efforts. For instance, the platforms may not cover the collection of used products by consumers or users. This phase is of great significance for CE compliance since it signs the beginning of the second product lifecycle.

Activity 5: Communicate artifact

The last research activity is about communicating the contribution of the thesis to both the real-world and knowledge base. This two-fold contribution separates the DSR from the pure development of artifacts (Doyle et al., 2016). Accordingly, this step communicates the research problem and its urgency, the evaluation framework and its utility, efficacy, and originality to the appropriate audience, such as researchers and practitioners (Peffers et al., 2007). The last chapter covers this research phase, by answering the MRQ, discussing the research output, its contribution to both science and society, and the limitations of the study. Finally, the thesis provides directions for future research.

1.7.3. Thesis Outline

Table 1.1 depicts the sub-questions, the research strategy adopted to address them and their deliverable.

	Research Question	Research Strategy	Deliverable
SRQ1	What is the knowledge base on which the development of a CE visibility evaluation framework for blockchain-enabled pipeline solutions should rely?	Literature Review	Knowledge Base
SRQ2	What are the essential information requirements needed to support the trace of an item throughout its life cycle in the CE context?	Literature Review	Information Requirements
SRQ3	How can the information requirements needed to support the trace of an item throughout its life cycle serve as a basis for the CE visibility evaluation framework?	Data provided by SRQ2 and literature	Initial Framework
SRQ4	What information requirements for CE visibility are captured by the examined blockchain-enabled information systems and how do the insights derived from them contribute to the further development of the CE visibility evaluation framework?	Data provided by IBM and Vinturas	Refined Framework
SRQ5	To what extent does the developed framework evaluate the ability of blockchain-enabled data pipeline solutions to provide the visibility needed to support CE policy instruments?	Expert Interviews	Final Framework

Table 1.1: Research questions strategies

Figure 1.4 illustrates the thesis outline, presenting the research activities, the chapters of the thesis, the strategies followed in each chapter, and the connection between chapters and research questions. The thesis follows a structure similar to that suggested by Gregor and Hevner (2013). In their paper, Gregor and Hevner provide a publication schema for DSR projects, claiming that a DSR project should include the following contents: *"introduction, literature review, method, artifact description, evaluation, discussion, conclusions"*. However, the recommended structure is not meant to be excessively prescriptive (Gregor & Hevner, 2013).

1.8. Conclusions

This chapter laid the foundations for the research project. It initiated the reader to the research problem, the wicked problem of resource depletion and environmental destruction. As presented, Circular Economy constitutes a decisive response to the aforementioned issues aiming at minimizing the consumption of natural resources in the production systems by promoting a closed resource loop. This economic model has attracted the interest of the academic community, which has been translated into important research efforts. However, most of the literature has focused on addressing more technical aspects of the topic. As claimed by Zeiss et al, the research on the use of digital technologies to support CE is relatively scarce.

The thesis aims at bridging that knowledge gap by developing a framework that evaluates the suitability of blockchain-enabled data pipeline solutions to act as monitoring systems for CE purposes. Such monitoring systems are needed by actors that have initiated CE policy instruments to ensure their proper implementation and enforce compliance if necessary. The research objective is fulfilled by pinpointing the information requirements needed to be captured in such systems to trace the path of goods or materials in a closed supply chain. The thesis goal is captured in the main research question: *"How can a CE visibility evaluation framework for blockchain-enabled data pipeline solutions facilitate the monitoring of compliance with the policy instruments established to foster the CE transition?"*

The CE evaluation framework will be designed by following the DSR method. An approach that defines the activities that researchers should conduct to produce solid and valid results. The activities prescribed by the approach are the following: problem identification and motivation, the definition of the objectives of a solution, design and development, demonstration, evaluation, and communication. These activities benefit the study by dividing the main research question into sub-questions and driving the design efforts. The chapter also presented the research strategy adopted to address each research question, such as literature review and data analysis. As described, the thesis derives insights from three blockchain initiatives focused on providing supply chain visibility. Their contribution is of great importance, as the literature around the information requirements is incomplete.

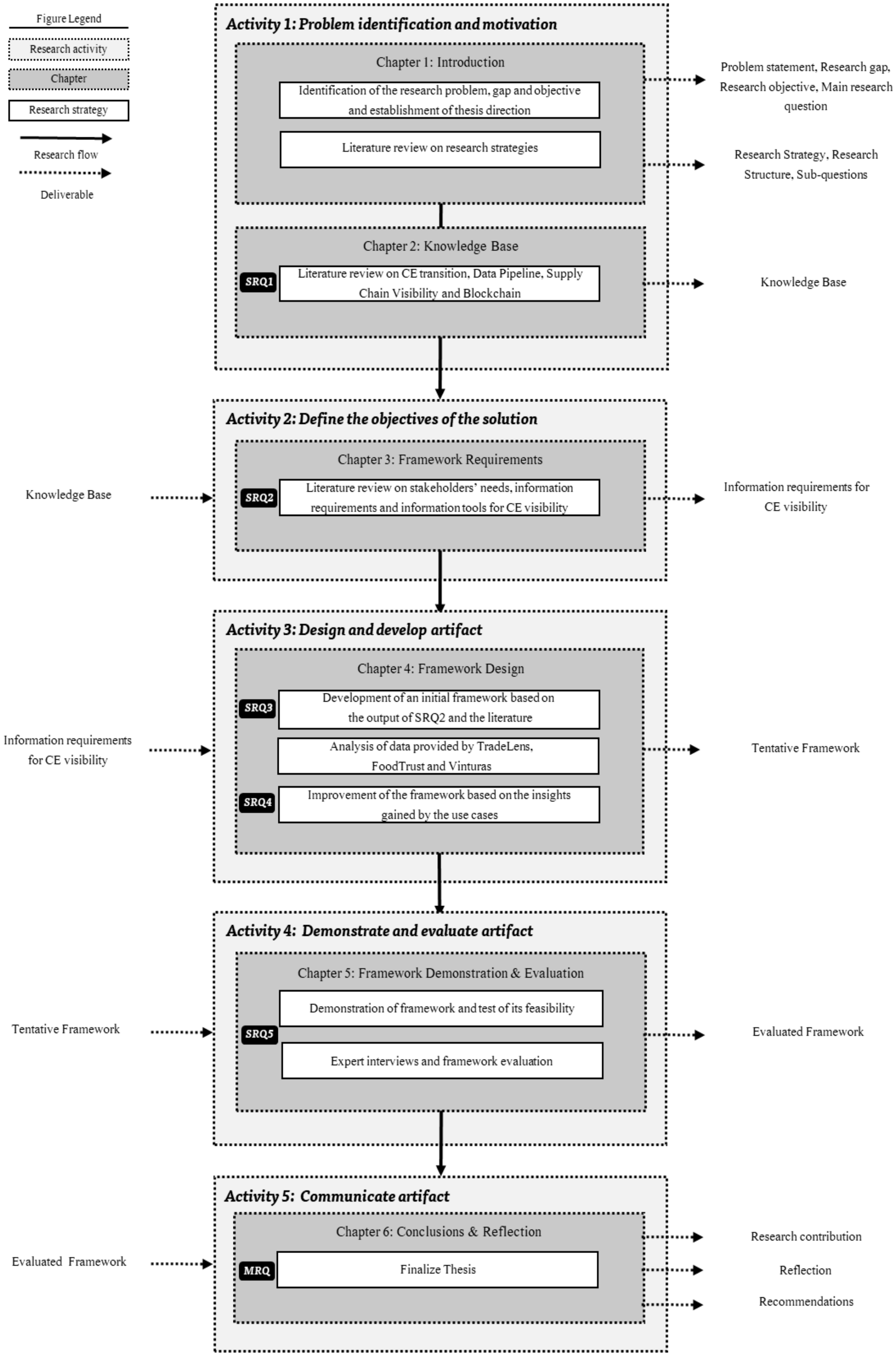


Figure 1.4: Research flow diagram, based on Johannesson & Perjons (2014)

2

Knowledge Base

This chapter covers the first activity of the MFDSR, problem identification, and motivation, by addressing the SRQ1: *"What is the knowledge base on which the development of a CE visibility evaluation framework for blockchain-enabled data pipeline solutions should rely?"*. The answer to this question derives from a literature review on the fundamental concepts of the thesis, circular economy, data pipelines, supply chain visibility and blockchain. This activity sets the basis for the framework development by explaining in more detail the problem that it tackles, highlighting the importance of deploying a blockchain-enabled data pipeline for CE purposes, and justifying the value of the produced artifact.

The chapter starts with introducing circular economy and explaining how the business world can be incentivized to adopt this economic model (section 2.1). As presented, its adoption depends on the actions of both policymakers (or customs) and private companies (e.g., banks, and institutional investors), which can launch CE policy instruments for that purpose. However, such policies are prone to manipulations when there is a lot at stake. Therefore, these actors need to constantly monitor the implementation of their policies and enforce compliance when necessary. This requirement can be addressed by the deployment of a solid monitoring system, which can trace the materials flows in the supply chain.

Section 2.2 argues that the need for a monitoring system can be satisfied by leveraging the research around data pipelines. Data pipelines can equip the interested agents with original data that companies possess in their information systems about the goods. However, a prerequisite for getting the full benefits of this data is the need for trust in the data and its quality. Sections 2.3 and 2.4 suggest that blockchain-enabled information systems can meet this requirement, thanks to their unique characteristics. Finally, a sub-conclusion of this chapter is presented in section 2.5.

2.1. Circular Economy

2.1.1. The transition towards Circular Economy

Humanity currently faces the colossal challenge of dealing with resource consumption and ecological degradation due to increasing economic activities. The root of this problem lies in the traditional "take-make-waste" economic model (presented in Figure 2.1) that the business world adopted after the advent of the industrial revolution. This economic model follows a simple rationale, in which companies harvest crops or mine materials to produce goods and subsequently sell them to end-consumers, who discard them in the landfills or incinerate them when they are no longer functional or useful (Ellen MacArthur Foundation, 2013; Oppen, Croon, & Bijl de Vroe, 2020). The economy thrives by consuming more planetary resources to produce goods and generating more waste. This linear economic model relies on two fundamental assumptions, limitlessness and easily-accessible resources, and unlimited earth regenerative capacity (Wautelet, 2018).

The adoption of the linear economic model by the business world was combined by a sales strategy, named planned obsolescence, which purposely limits the technical product life-cycle (Oppen et al., 2020). In other words, the businesses produce products with a limited lifecycle to ensure steadily increasing sales and profits. However, the growing global population and the limited regenerative earth capacity make this model unsustainable (Oppen et al., 2020). More specifically, the global population is about to reach 9.7 billion in 2050 (United Nations, 2019). To meet the global demand, the economy will need approximately three times the raw materials presently used, leading to depletion of natural resources. Therefore, it is evident that a new economic model should be embraced since this consumption pattern cannot be continued forever (Wautelet, 2018).

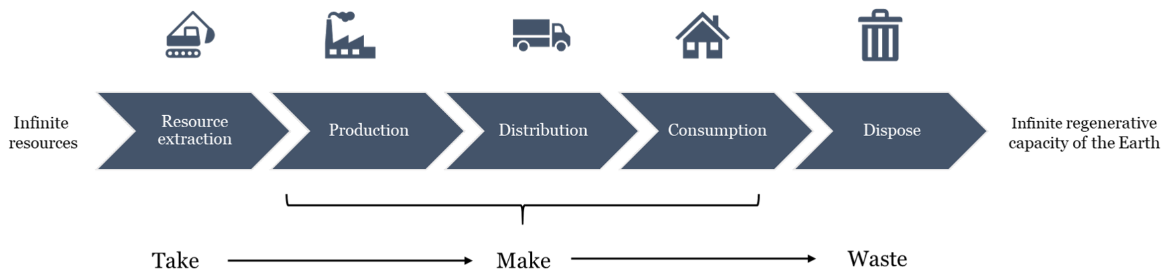


Figure 2.1: Linear economic model, based on Wautelet (2018)

The concept of Circular Economy evolved as a response to the above-described problem. CE (presented in Figure 2.2) is an economic model that focuses on reducing the use of virgin resources in the production systems, eliminating the waste streams, and maximizing the value retention of resources. Its underlying purpose is not to stifle productivity, but to encourage the industry to produce enduring products. The product lifecycle can be prolonged through value retention strategies, namely, repair, reuse, remanufacturing, and recycling (Ghisellini, Cialani, & Ulgiati, 2016; Oppen et al., 2020). In other words, when a product reaches the end of its lifecycle, it is reintroduced in the market. Furthermore, CE sets guidelines for the business processes, (e.g., production process), which should comply with its fundamental principles by deploying sustainable practices, restructuring their operations, improving product design, and minimizing waste (Ghisellini et al., 2016; Loorbach & Wijsman, 2013; Oppen et al., 2020). Consumers play also a pivotal role in ensuring product circulation by thoughtfully using and repairing the products or by introducing them to a closed materials loop through reuse, remanufacturing and recycling (Oppen et al., 2020).

Figure 2.2: Circular economic model, based on Calvo-Porral & Lévy-Mangin (2020)

One of the most leading proponents of CE is the Ellen MacArthur Foundation (EMF). The EMF is a UK-based charity foundation, established in 2009, which focuses on catalyzing the transition towards CE. To fulfill its mission, it closely cooperates with policymakers, academics, and businesses aspiring to inculcate them a "circular mindset". For that reason, it published several influential reports, which have played a crucial role in CE academic and business domain (Ellen MacArthur Foundation, 2013, 2016, 2017, 2019; Geissdoerfer, Savaget, Bocken, & Hultink, 2017).

EMF defines CE as *"an industrial system that is restorative and regenerative by design"* (Ellen MacArthur Foundation, 2016, p. 31). CE relies on three major pillars, *"preserving and enhancing natural capital, optimizing resource yields, and fostering system effectiveness"* (Ellen MacArthur Foundation, 2016, p. 32). The first pillar refers to fostering the efficient use of finite resources and balancing the use of renewable resources. The second pillar is about retaining the value of products, components, and materials by using them over and over again. Finally, the third pillar is related to minimizing the waste streams disposed in the landfills and negative externalities, like air pollution and land use (Ellen MacArthur Foundation, 2016).

Illustrative is also the description provided by Genovese et al. (2017) who depict the planet as a closed system ruled by the first law of Thermodynamics. Namely, *"the amount of resources consumed in a period is equivalent to the amount of waste used in that period"* (Genovese et al., 2017, p. 345). Even though the law of conservation is not applicable to practice, CE aspires to maintain this circulation of resources by converting waste into resource (Genovese et al., 2017).

The above analysis related to shifting from a linear economic model towards a circular one constitutes the foundation of the thesis, which works towards accelerating this transition. However, to close the materials loops, it is critical to make the materials flow explicit and to deeply understand the processes that are subject to monitoring and regulation. This need can be satisfied by deploying the already discussed CE diagram (Figure 2.3) developed by the EMF (Ellen MacArthur Foundation, 2016).

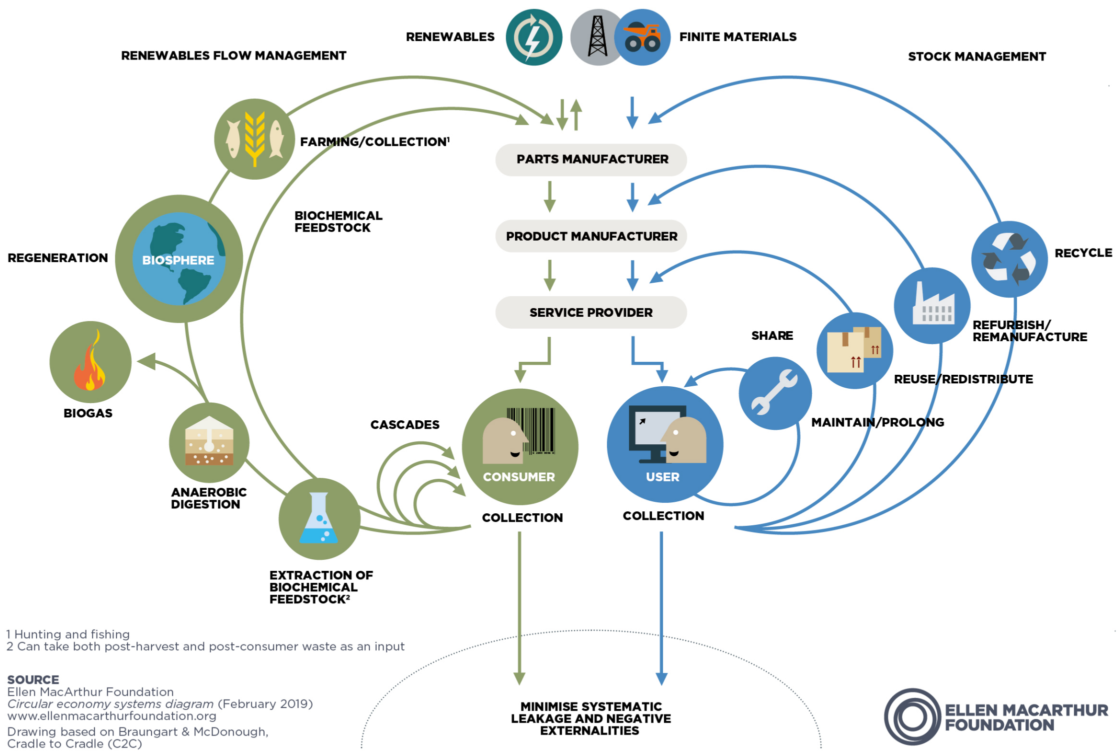


Figure 2.3: Circular economy diagram (Ellen MacArthur Foundation, 2016)

The diagram thoroughly captures all the concepts associated with the CE. The central part of the diagram shows the linear economic model, in which the Earth's resources are transformed into products, which are later incinerated or discarded in landfills. Subsequently, the diagram connects the linear model with two loops, one related to renewables (biological cycle) and one about finite materials (technical cycle). There is a clear distinction between these two cycles (Ellen MacArthur Foundation, 2016).

The biological cycle (left-hand side) refers to the regenerative aspect of the CE by dealing with renewable resources. Renewables are not depleted when used and can decompose when they return to nature (biodegradable materials), such as wood, paper, and oil. CE aims at retaining these materials by enabling them to return positively and safely to the economy or returning them to the environment in a sustainable way. As illustrated, this can be achieved through various ways, such as extracting chemicals, energy, or other materials from biological resources. The cascades are about devising new additional uses for resources (Ellen MacArthur Foundation, 2016). For example, clothes can be reused for various purposes, like insulation materials for buildings (Costa, 2020). As highlighted in Chapter 1, the thesis does not address this side of the CE diagram.

The right-hand side of the diagram is related to the restorative aspect of the CE focusing on materials that are finite and non-biodegradable, like plastic and aluminum (Ellen MacArthur Foundation, 2016). As discussed, the thesis concentrates on the technical cycle. This choice stems from the imperative need of tackling the consumption of virgin resources and minimizing the volume of materials discarded in landfills or incinerated (Oppen et al., 2020). By doing so, the modern world can fulfill its moral commitment to sustain natural capital so as not to deprive future generations of the ability to meet their needs (Poel & Royakkers, 2011). The CE diagram suggests that technical materials can be restored and their life can be prolonged through the following processes: shared use of products, maintenance, reuse/redistribution, refurbishment/remanufacturing, and recycling (Ellen MacArthur Foundation, 2016).

The reuse/redistribution process tries to prolong the technical life of products. Such a solution can be supported by the establishment of channels for enabling the collection, maintenance, and redistribution of products no longer desirable for a user. Similar channels can be formed for serving the purposes of the refurbishment/remanufacturing process. They can be utilized for collecting obsolescent products that cannot be repaired. These products should be dismantled allowing the reuse of their components for the manufacturing of new ones. In case that none of the above-described processes is realizable, the materials should be recycled to produce new products, materials, or components, which will serve either their original purpose or a new one (Calvo-Porral & Lévy-Mangin, 2020; Ellen MacArthur Foundation, 2016).

The thesis focuses on two value retention strategies, reuse/redistribution, and recycling. The motivation for examining recycling stems from the interest that this process has from a CE compliance perspective. Recycling returns products to their basic materials (raw materials) to be used again in the production of new products. This process involves a transportation element that CE auditing actors could be particularly interested in monitoring and regulating by accessing business data. Namely, after recycling raw materials should be transported to the production systems to complete a closed loop (Calvo-Porral & Lévy-Mangin, 2020; Kalmykova, Sadagopan, & Rosado, 2018). The thesis aims at facilitating the CE auditing actors' mission to enforce compliance in recycling by considering this process in the CE visibility evaluation framework.

However, recycling should be the last resort when considering the appropriate CE process (e.g., reuse, remanufacturing, recycling). A fundamental CE concept is receiving the maximum utility from materials, that is retaining their integrity for as long as possible. In this way, the modern world can ensure environmental sustainability. Recycling is an intensive process, which discards the value contained in products, such as labour, energy, capital, and materials, and impacts the environment by consuming, for example, energy and water.

Consequently, deploying one of the other CE strategies, like redistribution, is usually a more desirable choice (Ellen MacArthur Foundation, 2013; European Environment Agency, 2017). This notion is expressed in the principle “the power of the inner circle” described by the EMF, which favours the inner circles of the CE diagram (see Figure 2.3). In simple words, the principle states that the tighter the circle, the faster is the reintroduction of a product to the market, as less reprocessing is required (Ellen MacArthur Foundation, 2013).Considering this principle, the thesis opted for promoting the adoption of one of the other CE strategies by studying the reuse/redistribution disposition option.

2.1.2. Fostering Circular Economy

There is no doubt that the business model presented by the EMF through the CE diagram is highly beneficial from an environmental point of view. However, it may not have clear benefits from an economic perspective, making its adoption by the industry a less attractive alternative than the linear one (Genovese et al., 2017). The modern world has been designed to be linear, this consumption pattern has been optimizing for quite a long time. Consequently, a shift in everyone’s attitude could be a challenging task (Oppen et al., 2020; Hartley, van Santen, & Kirchherr, 2020). It asserted that moving towards more sustainable practices will require significant investments in terms of infrastructures and innovation (Deloitte, 2019). For that reason, Genovese et al. (2017) urge the government to enact policy instruments that can incentivize the private sector to shift towards circular practices.

Such CE policies can be traced back to 1996 when Germany pioneered in the field by initiating the enactment of the “Closed Substance Cycle and Waste Management Act” (Su, Heshmati, Geng, & Yu, 2013). The legislation emphasized the need of establishing a closed-loop for waste through recycling and reuse and ensuring the environmentally safe disposal of waste. Thereafter, various governing bodies launched CE policies aspiring to integrate environmental concerns into private organizations, such as Japan in 2002 and China in 2009 (Geissdoerfer et al., 2017; Su et al., 2013).

Nowadays, the topic of moving towards a sustainable way of living is contemporary, being at the top of the agenda of most policymakers. Policymakers strive to promote CE by deploying a plethora of mechanisms including regulations, taxes, or economic incentives (Dewick et al., 2020). For instance, the European Union (EU) by initiating the “The European Green Deal” wants to become climate neutral in 2050. It will try to fulfill this goal by taking various actions, such as encouraging the efficient use of renewable and non-renewable resources, investing in eco-friendly technologies, supporting industrial innovation, and decarbonizing the energy sector (European Commission, 2020b).

Similar initiatives can be noticed on a national level, where national governments formulate policies to move towards a more clean and circular economy. Indicatively, the Dutch government replied to this call by composing the “CE Implementation Programme 2019-2023”, which constitutes a stepping stone for evolving into a resource-efficient economy (Rijksoverheid, 2019). Its principal objective is to achieve CE by 2050. To materialize this ambitious plan, the Netherlands has formulated an intermediate goal, the 50% reduction in the consumption of natural resources by 2030. Its agenda sets as priority five sectors that have the greatest impact on the CE transition, namely, plastics, manufacturing industry, construction domain, biomass, and food and consumer products (Deloitte, 2019). Working in that direction, the government increased the tax related to landfilling and incineration and encouraged recycling through investments. Finally, a measure currently under discussion, on a global level, is the introduction of additional taxes for non-eco-friendly goods (OECD, 2020).

The CE transition is at the top of the agenda of the private sector as well. Organizations such as banks, venture capitals, and auditing firms have launched several initiatives, including zero-waste, green loans for plastic, loans with discounted interest, and reverse manufacturing. The establishment of CE can benefit them by reducing costs associated with linear risks and dependence on finite raw materials (Dewick et al., 2020; Ellen MacArthur Foundation, 2017; Geissdoerfer et al., 2017; Deloitte, 2019). As proof, BlackRock, a global leader in asset management, announced investments of $20 million to companies adopting the CE paradigm (Dewick et al., 2020). Similarly, the Dutch banks ABN AMRO, ING, and Rabobank announced "Circular Economy Finance Guidelines" to build a common understanding regarding financing CE on a global level (Rabobank, 2018).

The efforts of the policymakers and private organizations with an auditing role (e.g., banks, and institutional investors) to stimulate CE transition do not always produce the anticipated results. As described by Rukanova et al. (2021), the CE policy instruments can be manipulated when there is a lot at stake. An indicative example is a recent case, in which it was revealed that plastic exported from the Netherlands to Turkey for recycling or reuse was illegally dumped (Wester, 2020). This instance indicates that the deployment of policy instruments is not sufficient to realize CE transition. The actors interested in CE transition need to monitor the application of these policy instruments and enforce compliance when necessary. In other words, they need a solid monitoring system to make sure the proper implementation of their CE policies. Such a CE monitoring system should provide end-to-end visibility on the CE flows throughout the supply chain (Rukanova et al., 2021).

The monitoring of the CE flows is also affected by the information fragmentation that besets the global supply chain. In simple words, the information about a product, such as production process and sustainability practices used, is scattered among various actors and information systems located even in different countries. For example, the information about the use of secondary raw materials for the production of new products is possessed by specific parties (Rukanova et al., 2021). This phenomenon becomes worse by the reluctance of several parties to share information due to either legal constraints or other reasons (e.g., competition). Therefore, policy-makers and other actors involved in promoting CE (e.g., banks) have limited access to information about the flow of goods, while the available data can be inaccurate and of low quality (Rukanova et al., 2018; van Engelenburg et al., 2020). This lack of reliable information makes the detection of risks related to compliance concerning CE policies a challenging task.

The absence of a reliable monitoring system able to govern the CE flows and tackle the information fragmentation in the supply chain can be addressed by leveraging the research around digital infrastructures (DI) and specifically, data pipelines. As stated by Rukanova et al. (2021), these digital solutions have the potential to bring the necessary visibility to the materials flows, enforce compliance, and consequently support the shift towards CE.

2.2. Data Pipeline Concept

A digital infrastructure (DI) can be defined as a "system-of-systems" aiming at limiting the information fragmentation between businesses and governments by exceeding organizational and system boundaries. A DI achieves its mission by bringing together several autonomous and operatable information systems and creating a network of them, which facilitates the exchange of information for some time (Rukanova, Henningsson, Henkriksen, & Tan, 2016). The problem that DI is called to solve in this study is the absence of a solid monitoring system, which can enable efficient and timely detection of risks related to compliance with CE policies by using reliable and accurate data provided by businesses.

Among the several DI initiatives that can be found in the literature, data pipelines have gained significant attention by plenty of researchers driven by the idea of capturing business data (bill of lading, invoice, purchase order, etc.) produced throughout the supply chain to facilitate governmental control (Hesketh, 2009a, 2009b; Klievink et al., 2012; Hesketh, 2010; Pugliatti, 2011; Rukanova et al., 2018). This concept is particularly useful for this study, considering that the agents with an auditing role (e.g., policymakers, customs, banks) need to control the CE flows.

The data pipeline was conceptualized as a tool that can improve visibility and transparency in the global supply chain by facilitating B2B (business-to-business) and B2G (business-to-government) data sharing (van Stijn, Klievink, Janssen, & Tan, 2012). Its efficient operation relies on the deployment of Service-Oriented Architectures (SOA). In other words, it needs access to the information systems possessed by the various actors involved in the supply chain, such as inter-organizational information systems operated by freight forwarders and information systems used by importers or customs authorities. By accessing this data, it can integrate multiple sources of information currently scattered across the supply chain and captured in different documents (Klievink et al., 2012; van Stijn et al., 2012).

Data pipelines store data about stakeholders, products, and commercial transactions granted voluntarily and originated from their original source, where it is generated. The participants feed their information to the system in real-time to produce the craved supply chain visibility. The information can be enriched constantly throughout the movement of products, by using tracking and monitoring technologies, like RFID tags or container seals. An interesting aspect is that the shared data remain in the possession of its source and become visible solely to the authorized actors through clever linking of data. For instance, authorized parties can get data about the container content granted by a shipping company by using a Uniform Resource Locator (URL) (Klievink et al., 2012).

The understanding of the data pipeline can be enriched by using the model developed by Hesketh and Heijmann (Figure 2.4), which concentrates on three layers. The physical layer represents the movement of cargo from the exporting country to the importing one (Klievink et al., 2012). It constitutes the layer of interest for the actors aspiring to monitor the CE flows since it presents the flow of materials, nutrients, or goods. Such information can help them to realize whether the technical resources enter a closed loop through the CE processes discussed in the previous section (e.g., recycling) and identify possible frauds. Undeniably, such visibility is not currently captured by data pipelines and is not depicted in Figure 2.4, but this study works towards materializing it (Klievink et al., 2012; van Stijn et al., 2012).

The organizational level provides an overview of the parties involved in data pipelines. Data pipelines are global DIs developed to be workable for complicated networks of actors consisting of both public and private organizations. The private actors range from the sellers of products to the buyers and cover all the intermediate parties, including freight forwarders, logistic service providers, terminal operators, and so on. The public group of actors encompass national agents (e.g., customs, inspection and port authorities, ministries) supra-national agents (e.g., EC), and international agents (e.g., United Nations, World Trade Organization) (Klievink et al., 2012; van Stijn et al., 2012; Veenstra, 2014). Deep knowledge of these groups of stakeholders is of great importance for the actors interested in promoting CE. Such understanding enables them to pinpoint the sources of information that they need and enforce compliance when necessary.

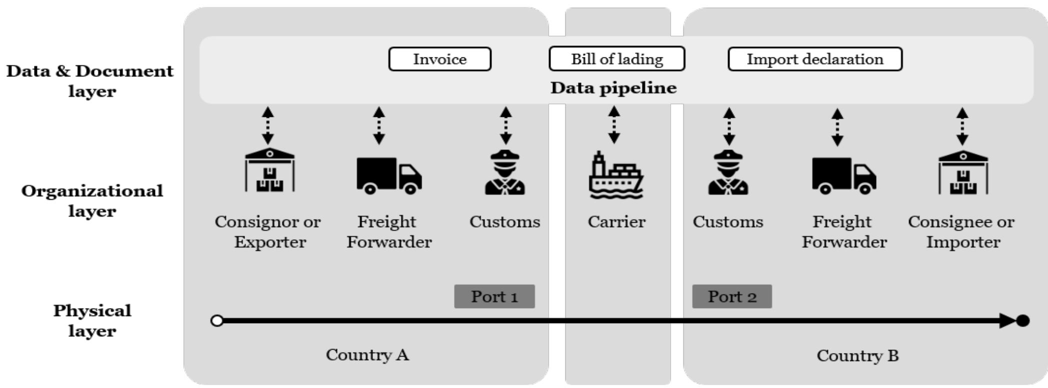


Figure 2.4: Data pipeline, based on Klievink et al. (2012)

The data and document layer represents the information exchanged among actors, like the bill of lading, invoices, and packing list. Such data constitutes a valuable source of information, providing details regarding the goods included in a container, their weight and value, the real buyer and seller, which can be different in the customs declaration, and so on. As highlighted earlier, this information is fragmented among several actors and information systems. Data pipelines try to make this information available to interested parties and improve supply chain visibility. Supply chain visibility refers to the ability of a private or a public organization to understand the real status of products in the supply chain by getting access to transaction data. This visibility is very important to make informed decisions (Klievink et al., 2012; van Stijn et al., 2012).

The actors with a CE auditing role can leverage the business data by using the so-called "piggybacking". Piggybacking refers to using business data for fulfilling different purposes than the original one (Tan, Bjørn-Andersen, Klein, & Rukanova, 2011). In other words, data pipelines enable the re-use of business data for governmental control purposes, like carrying out a risk assessment and inspections, or enforcing compliance. Such rationale requires a radical shift from the old-fashioned and paper based B2G data sharing, in which businesses give to auditing agents only the necessary data. Piggybacking relies on the idea that the data produced and used by the private companies for their operational activities is of higher quality than the one currently shared with authorities. Consequently, auditing actors can benefit by accessing them (Klievink et al., 2012; van Stijn et al., 2012). The piggybacking can be complemented by the adoption of a "data pull" approach, in which auditing actors can pull data out of the information systems (Tan et al., 2011).

The analysis of the data pipeline concept highlighted its potential suitability for acting as a monitoring system for CE purposes. To control the CE flows and prevent the occurrence of any adverse effects regarding the implementation of their CE policy instruments, the interested actors need to access accurate and reliable business data (Rukanova et al., 2021). Data pipelines can satisfy this need by providing the original data that companies possess in their information systems about the shipment of goods (Klievink et al., 2012; van Stijn et al., 2012). Nonetheless, a prerequisite to reap the full benefits of this data for serving the public good is the need for trust in the data and its quality. In other words, actors with CE policies need to be sure that the data has not been tampered with. As presented in the following section, blockchain technology can address this requirement.

2.3. Blockchain Technology

The advent of blockchain dates back to 2008 when a mysterious person or group of people named Satoshi Nakamoto launched a peer-to-peer electronic cash system (bitcoin) that eliminates the need for a trusted third party, e.g., financial institution (Nakamoto, 2008). Blockchain became widely known as the fundamental technology deployed for the operation of bitcoin, however, its capabilities were truly discovered later, after 2016, when its potential implementation to a wide range of sectors, including supply chain and logistics (Abeyratne & Monfared, 2016; DHL, 2018; Saberi et al., 2019; Underwood, 2016), healthcare domain (DHL, 2018; Srivastava, Bhadauria, Dhaneshwar, & Gupta, 2019) and food safety (Behnke & Janssen, 2020), was conceptualized.

The central rationale behind blockchain is not radical but relies on the old concept of deploying a ledger to store transactions during a time period. From old times, such ledgers are possessed by one party, like a bank, and managed by an administrator, who can alter the ledger without asking for permission from the stakeholders of the ledger (DHL, 2018). On the other hand, blockchain (a chain of blocks) is a distributed ledger shared across a public or private network of parties (peer-to-peer network, P2P) that records encrypted pieces of information, called transaction data. In simple words, each party in the network has a copy of the ledger. By distributing the ledger, blockchain eliminates the need for a central administrator to act as a trusted party, and updates on the ledger can be done by all the stakeholders through a consensus mechanism (Abeyratne & Monfared, 2016; DHL, 2018;

Ølnes et al., 2017).

The transition towards a decentralized and distributed system, promoted by blockchain, can release the data trapped in organizational silos and lead to the development of a reliable CE monitoring system (DHL, 2018). This great potential of the technology is justified by its four unique characteristics, decentralization, auditability, immutability, and smart contracts. These characteristics differentiate the technology from the existing information systems (Cole et al., 2019; Saberi et al., 2019).

Decentralization refers to the distribution of a ledger across a network of actors (called nodes). The ledger holds a list of transaction data, named blocks, and it is constantly updated, once new transactions take place and new blocks are added to the chain. By doing so, the blockchain prevents the occurrence of adverse incidents, such as hacking or crashing and increases confidence in the system. In case of breakdown of a node, the whole system will not collapse (Nofer, Gomber, Hinz, & Schiereck, 2017; Ølnes et al., 2017; Pahl et al., 2018).

Figure 2.5 depicts how new blocks are appended to the blockchain and exemplifies the concept of auditability. When a participant creates a new piece of information that needs to be added to the chain, a consensus mechanism (prespecified rules) is activated. That is to say, the nodes of the system are asked to validate the transaction. If the nodes decide that the transaction is legitimate and give their consent, the new transaction is appended to the chain as a new block and distributed across the network. Otherwise, if a transaction is fraudulent, the network rejects it. The ledger is constantly growing due to the addition of new blocks (called mining), the last block of the chain captures the latest true state of the blockchain. An important contribution of the consensus mechanism is that it prevents a small group of participants to control the network (Buterin, 2015; Ølnes et al., 2017; Pahl et al., 2018; Saberi et al., 2019).

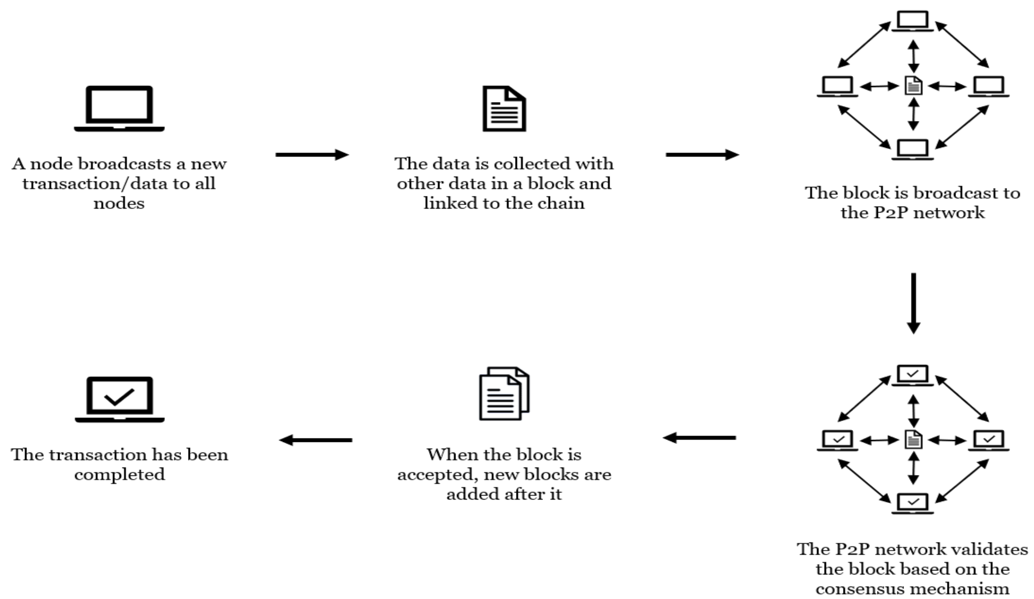


Figure 2.5: Transaction process, based on Saberi et al. (2019)

The distribution of the ledger across the P2P network and the deployment of the consensus mechanism enhance the security of the blockchain. However, the security is also ensured by the immutability that characterizes the ledger, meaning that agreed transactions cannot be tampered with. This becomes possible due to a cryptographic mechanism integrated into the blockchain (depicted in Figure 2.6) that makes the alteration of any block extremely difficult and time-consuming (Landerreche & Stevens, 2018).

As Figure 2.6 demonstrates, the blocks are time-stamped collections of valid transaction data (recorded in chronological order). For security purposes, each block contains a hash and the hash of the previous block. Hash is a unique string, or a number used to identify a block and its content. Hashes enable blockchain to tighten its security by linking all the blocks and deterring malicious participants from changing a single one. If a hacker adulterates a block, the hash of the block will change and the consistency of the chain will be disrupted, as each block is connected with the previous one. Consequently, the hacker would need to alter all the blocks, which is time-consuming and intensive in terms of computing power (Landerreche & Stevens, 2018). The most important contribution of the hash mechanism is that participants can detect possible adulterations in the chain and audit the chain history (Ølnes et al., 2017).

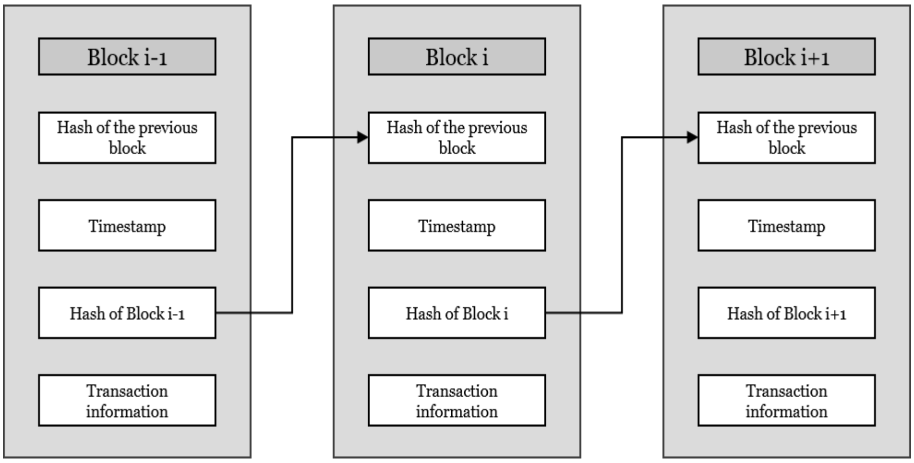


Figure 2.6: Cryptographic hash function, based on Rogerson & Parry (2020)

The above-described characteristics (decentralization, auditability, and immutability) contribute to the case at hand is by ensuring data integrity. In other words, the data recipients (actors interested in promoting CE transition) can be confident that the information included in the system is a representation of reality and has not been tampered with (Ølnes et al., 2017; Saberi et al., 2019). According to Ølnes et al. (2017), data integrity is a multifaceted concept that ingrates notions, such as security, reliability, consistency, persistency (every participant has a genuine copy of the ledger), and non-adulteration.

The aforementioned aspects are of pivotal importance for trustless environments, such as fragmented supply chains, enabling actors to interact and exchange digital assets with each other without the need for a trusted third agent (Abeyratne & Monfared, 2016; Ølnes et al., 2017; Saberi et al., 2019). Nonetheless, blockchain is not unchangeable, and data integrity can be compromised. Indicatively, when the proof of work (an algorithm deployed to verify a transaction and create a new block) is used as consensus protocol, a group of malicious participants can agree to control the network and manipulate the data history by getting more than 50% of the blockchain power (Gervais et al., 2016; Ølnes et al., 2017).

Smart contracts constitute an aspect of the technology that has been widely discussed, being able to revolutionize the way that transactions are performed. A smart contract is a computer code that contains terms that have been agreed upon among participants and it is executed once the conditions are satisfied (Delmolino, Arnett, Kosba, Miller, & Shi, 2015; Swan, 2015). For instance, it can enable the automatic payment of a vendor, when the customer confirms the delivery of the product (Behnke & Janssen, 2020). Smart contracts foster trust, accountability, and transparency among parties, enabling the execution of transactions without the need for a third party (Saberi et al., 2019). However, participants should have a deep understanding of programming logic incorporated in the code to prevent the occurrence of undesired events, like frauds and logical errors (Behnke & Janssen, 2020).

Blockchain can be divided into three categories, depending on technological design. More specifically, the blockchain architecture relies on the decisions that have to be taken concerning the provision of permission to the participants for joining the network and accessing the data (permissioned or permissionless), the anonymity of the participants, and the existence of a central entity for monitoring the reliability of the state of the system (Behnke & Janssen, 2020; Ølnes et al., 2017; Pahl et al., 2018).

The permissionless blockchain (public) is entirely open, meaning that users are free to join the network and access its data. Moreover, it protects the participants' privacy by deploying encryption keys and pseudo-identities. An illustrative example of this system is Bitcoin. On the other hand, a permissioned blockchain is controlled by its owners who set restrictions on the number of participants and their access rights. It can be further separated into private and consortium, the difference between them lies in the fact that in the former, a central entity controls the system (centralization), while in the latter, control is spread among participants. In a private blockchain, the user's anonymity may not be preserved, since the identification of participants may be of importance (Pahl et al., 2018; Rogerson & Parry, 2020; Saberi et al., 2018; Tan, Rukanova, van Engelenburg, Ubacht, & Janssen, 2019).

2.4. Blockchain Technology for Circular Economy

The actors interested in promoting CE can ensure the correct implementation of their policy instruments by monitoring the materials flows. Such visibility can be achieved by the use of an information system that contains accurate and valid business data. This section suggests that blockchain can be the backbone of such an information system since it can ensure data integrity and facilitate the collaboration and exchange of data between actors located in trustless environments (Ølnes et al., 2017; Saberi et al., 2019; Shojaei et al., 2021).

The development of a monitoring system for CE purposes requires the integration of data that resides in the information systems of multiple supply chain entities. However, this is a challenging task, as these entities are geographically dispersed and usually have competing interests, different policies, and cultures. As a consequence, they may be reluctant to share their business data, while even if they do so, no one can ensure its validity and accuracy, as the supply chain can suffer from frauds and lack of trust (Abeyratne & Monfared, 2016; Saberi et al., 2019).

According to the extant literature, blockchain can alleviate the actors' concerns with regards to data sharing and prevent actors from exchanging inaccurate data (Saberi et al., 2019; Shojaei et al., 2021). Therefore, its suitability for the case at hand is highly justified. Shojaei et al. (2021) claim that a centralized information system is not an appropriate choice for the collection, storage, and share of information due to the existing fragmentation in the supply chain domain. In contrast, they assert that blockchain, thanks to its unique characteristics, can incentivize the industry to share its information and facilitate the collaboration among the stakeholders. Therefore, they promote the deployment of blockchain-based CE information infrastructure for the built environment (Shojaei et al., 2021).

Similarly, Alexandris et al. (2018) dismiss the use of a central database operated by the government. Such a database deprives data owners of the ability to keep absolute control of their data and hinders the development of trust between businesses and policymakers. Furthermore, decentralization eliminates the possibility of system failure due to hacking, mistake, or fraud (Alexandris, Katos, Alexaki, & Hatzivasilis, 2018). Finally, Abeyratne and Monfared (2016) assert that relying on a single agent for storing business data is highly insecure. Such a choice will enable this agent to acquire a lot of power, which can be used to harm the other participating actors.

A few researchers have highlighted the significance of deploying a permissioned blockchain-based system (private or consortium) in the CE context (Rogerson & Parry, 2020; Saberi et al., 2019). Their argument relies mainly on the fact that such a decision can protect participants' data (private companies), increase efficiency, considering that the consent of a few parties or a single entity is needed to approve a transaction, and improve its scalability. On the contrary, a public blockchain-based system is cumbersome since a consensus between a great number of parties is needed, and the stored data is visible to everyone (Rogerson & Parry, 2020; Saberi et al., 2019).

The aspect of data visibility is of pivotal importance for the case at hand. On the one hand, auditing actors need to identify the data owners to conduct their supervision tasks, so pseudo-identities should not be used. On the other hand, such sensitive and valuable business data should not be visible to every participant. This barrier can be overcome through the creation of blockchain sub-networks (the so-called channels), allowing data sharing in the channel and preventing data leakage to other channels (Tan et al., 2019).

Smart Contracts can be proved particularly important for CE, considering that they can set rules regarding the interactions among participants. This is facilitated by the existence of digitized documents and real-time shipment data fostered by blockchain, as this information can be utilized for the formation of the contracts (Segers, Ubacht, Rukanova, & Tan, 2019). Such a development can establish trust among parties, considering that their obligations are clearly defined by the contract, which is executed once agreed conditions are fulfilled (Swan, 2015).

2.5. Conclusions

This chapter answered the SRQ1 through a literature review: *"What is the knowledge base on which the development of a CE visibility evaluation framework for blockchain-enabled data pipeline solutions should rely?"*. As SRQ1 indicates, the output is the knowledge base needed for the development of the CE visibility evaluation framework. In other words, chapter 2 elicited influential concepts from the literature that can support the design efforts and lead to the development of an innovative and well-grounded outcome.

Initially, the chapter presented the definition and the main pillars of CE by EMF, which constitute the most influential thesis concepts. These concepts explicated the mission of CE and set the foundations for the research project. That is to say, they clarified that society should abandon the traditional "take-make-waste" economic model, reduce the use of virgin resources in the production systems and eliminate the waste streams. This can be achieved by closing the materials loops through value retention strategies. To do so, it is critical to make the materials flow explicit and deeply understand the processes that are subject to monitoring and regulation. The CE model developed by EMF satisfied this requirement. The model enabled the identification of the CE processes on which the thesis will focus, reuse/redistribution and recycling. The produced framework identifies the information requirements needed to trace a good or material that inserts into these processes.

Subsequently, the chapter pinpointed the recipients of the produced framework, the actors that have initiated policy instruments to promote the CE transition (defined as CE auditing actors by the thesis), such as policymakers and banks. As highlighted, the CE policy instruments are prone to manipulations when there is a lot at stake. For that reason, these agents need a reliable monitoring system to trace the materials flows and detect potential frauds. The chapter suggested that this need can be fulfilled by tapping into the research around data pipelines. The data pipeline concept provides supply chain visibility from the seller in the exporting country to the buyer in the importing country.

Finally, chapter 2 presented the fundamental pillars of blockchain technology. By doing so, it justified the selection of the thesis to focus the framework on blockchain-enabled data pipeline solutions. As discussed, blockchain should be the backbone of such an information system since it can ensure data integrity and facilitate the collaboration and exchange of data between actors located in trustless environments, such as the supply chain. The suitability of blockchain for the case at hand is also supported by the extant literature. The sections about data pipelines and blockchain deepened the reader's understanding enabling him to better grasp the analysis of the blockchain architectures in chapter 4.

3

Framework Requirements

This chapter deals with the second activity of the MFDSR, define the objectives of the solution, by answering the SRQ2: *"What are the essential information requirements needed to support the trace of an item throughout its life cycle in the CE context?"*. It translates the problem at hand into requirements or objectives that can be used for the framework development. The requirements identification becomes possible through a literature review on the stakeholders' needs (e.g., policymakers, banks, institutional investors), the information requirements, and the information tools for CE visibility. By doing so, chapter 3 aims at capturing the information needed to be included in blockchain-based information systems that can be used as monitoring systems by the actors that have introduced CE policy instruments.

The first section sets the foundations for the chapter by defining the requirements and classifying them into two categories, functional and non-functional. Subsequently, section 3.2 describes the functional requirements, organized into five subsections. Subsection 3.2.1 presents the visibility that CE monitoring systems need to provide, that is to say, the kind of information that such systems need to capture to serve CE. Subsection 3.2.2 delves into the need of extending data pipelines to offer visibility into more directions, whereas subsection 3.2.3 highlights the significance to work towards realizing blockchain interoperability. Subsection 3.2.4 explicates the necessity of mapping the relevant stakeholders and subsection 3.2.5 emphasizes the importance of exploiting the available information tools for receiving additional visibility on some aspects of CE. Section 3.3 concentrates on the non-functional requirements by surfacing some properties that should be present in the CE visibility evaluation framework to meet the stakeholders' needs. Finally, section 3.4 concludes the chapter by answering the SRQ2 and presenting an overview of the requirements.

3.1. Requirements Classification

The second activity focuses on surfacing the requirements for the framework development. In simple words, the explicated problem is transformed into requirements. A requirement is defined as *"a feature of an artifact perceived as desirable by the stakeholders, which can be used for driving the development efforts"* (Johannesson & Perjons, 2014). The stakeholders of the case at hand are the actors that have launched policy instruments to catalyse the CE transition (the CE auditing actors). They can use the framework to evaluate the potential of available blockchain-based information systems to act as monitoring systems and enforce compliance.

According to the literature, the requirements can be classified into functional and non-functional. The functional requirements are the functions that an artifact should provide and rely on both the problem at hand and the stakeholders' needs (Johannesson & Perjons, 2014). In this case, the functional requirements express the information needed to be included in a blockchain-enabled information system that can be used as a CE monitoring system. In contrast, the non-functional requirements refer to general conditions and properties, such as usability and supportability (Johannesson & Perjons, 2014).

The identification of the functional requirements became possible through a literature review. Firstly, the thesis executed a literature review on the CE, the supply chain visibility, and CE information tools. The term "information tools" refers to information sources that can be used by the CE auditing actors to monitor the implementation of their policy instruments. Furthermore, to surface the CE auditing actors' needs, the thesis reviewed several fundamental CE policy instruments. Finally, a literature review around the DSR led to the pinpointing of some non-functional requirements.

3.2. Functional Requirements

The motivation for the research project stems from one pivotal requirement that CE auditing actors (e.g., policymakers, customs and banks) currently have with regards to getting end-to-end supply chain visibility (Rukanova et al., 2021). The term "supply chain visibility" refers to the ability of a private or a public organization to understand the real status of products in the supply chain by receiving access to business data (Klievink et al., 2012; van Stijn et al., 2012). In other words, these actors should be able to view the current status of material or good and trace its entire journey in the supply chain, including its provenance (Shojaei et al., 2021).

The end-to-end supply chain visibility could help them realize their CE policy agendas by finding out whether a product integrates circular characteristics and detecting non-compliances, such as the case about the plastic disposed of in Turkey. The developed framework can facilitate their mission by empowering them to evaluate the available blockchain-based information systems regarding their ability to offer the craved visibility. However, to fulfill its purpose, the framework should be able to illustrate all the necessary information requirements. This need is satisfied by the following analysis, which surfaces the information requirements by reviewing fundamental concepts (e.g., CE and supply chain visibility), CE policy instruments, and information tools.

3.2.1. The visibility required in CE compliance

This subsection uses the definition of supply chain visibility, as described by Francis (2008), to identify the visibility that CE monitoring systems need to provide. In other words, it aims at surfacing the kind of information (e.g., status, condition) that such systems need to capture to serve the CE purposes. Francis defines supply chain visibility as *"the identity, location, and status of entities moving in the supply chain, captured in timely messages about events, along with the planned and actual dates/times for these events"* (Francis, 2008, p. 182).

Francis introduces several interesting concepts (e.g., identity, location, status, etc.) that play a crucial role in the thesis. More specifically, these concepts are translated into functional requirements at the end of this subsection. The thesis argues that a solid CE monitoring system needs to capture every aspect described in Francis' definition. Therefore, the CE auditing actors need to consider the elements of the definition when evaluating blockchain-based data pipelines regarding their ability to support the CE transition. The following analysis sheds light on the abovementioned definition by analyzing its aspects.

An entity is any physical object that transits the supply chain and takes one of the forms suggested by the following hierarchy. An entity can be an item (e.g., product), a package (e.g., carton), a client's order, a type of packing for the order (e.g., pallet), a shipment (e.g., different client's orders with a similar place of acceptance and place of delivery), a standardized form of unitizing cargoes (e.g., container, trailer) and transport means (e.g., truck, ship) (Francis, 2008).

The entity hierarchy (illustrated in Figure 3.1) presents in a very straightforward way the loss of visibility about the shipping products when moving towards the higher layers of the hierarchy. In other words, visibility about a product becomes challenging when products are bundled in a carton; cartons form a client's order; orders are packed in a pallet; pallets are combined in a shipment, shipments are unitized in a container; containers are loaded in a ship (Francis, 2008).

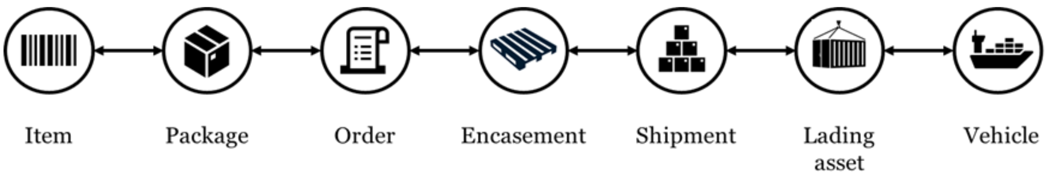


Figure 3.1: Entity hierarchy, based on Francis (2008)

The thesis aspires to equip CE auditing actors with detailed information, enabling them to have complete knowledge about a product (item) in a container transported by a ship. This is not currently the case, as auditing actors focus on monitoring discrete events by demanding business data through regulations and laws. Such an option is not efficient since not all necessary data may be available. For instance, an import declaration does not capture details about the content of a container (Hofman, 2011). A data pipeline solution can overcome this barrier and offer continuous monitoring by piggybacking original business data.

By leveraging business data, auditing actors can get accurate information concerning an entity (the so-called message in Francis's definition). A well-communicated message should contain insights about the identity, location, and status of an entity. The identity is a piece of information that identifies a physical object, such as a container identification number. The location represents the specific position of an entity, like the location of a ship, and can pinpoint the place of origin and the place of destination of an entity. The status is related to the state of a physical object, such as loading in progress (Francis, 2008).

A message also transmits information about the events that an entity goes through. An event expresses the time when a specific process takes place, such as the arrival of a ship or the loading of a container. A process changes the position or the state of an object (Francis, 2008). Finally, the planned and actual times of events are about the relationship between the time when an event is projected to happen and the time when it really happens. Francis suggests that interested parties can use this information to detect anomalies about the happening of an event and assess their ramifications on the supply chain visibility (Francis, 2008). In other words, such knowledge can be used by private companies to pinpoint inefficiencies in their internal operation. However, the thesis focuses on receiving supply chain visibility for compliance purposes, and such knowledge does not contribute to this research objective. Therefore, the planned and actual times of events will not be considered further in the thesis.

The analysis based on Francis's definition surfaced the information that CE monitoring systems should capture to monitor the flows of supply chain entities in an efficient way. Namely, such systems need to contain information about the identity, location, and status of supply chain entities and capture the events that they go through. These aspects form a group of functional requirements for the produced framework. In other words, the thesis argues that the CE auditing actors (e.g., policymakers, customs, banks) need to use Francis's definition when evaluating the ability of information systems to support the CE transition. However, the supply chain entity hierarchy described by Francis does not fully serve the CE. It should be extended to capture one additional aspect, the ingredients (raw materials) that form an item (product). As presented by the CE diagram (Figure 2.3), CE also involves the movement of materials or parts of the products. The thesis captures this aspect in the term "ingredients".

FRQ.1: The CE visibility evaluation framework should capture the Francis's supply chain entity hierarchy.

FRQ.2: The CE visibility evaluation framework should assess blockchain-enabled data pipelines based on their ability to capture the identity of the supply chain entities.

FRQ.3: The CE visibility evaluation framework should assess blockchain-enabled data pipelines based on their ability to capture the location of the supply chain entities.

FRQ.4: The CE visibility evaluation framework should assess blockchain-enabled data pipelines based on their ability to capture the status of the supply chain entities.

FRQ.5: The CE visibility evaluation framework should assess blockchain-enabled data pipelines based on their ability to capture the events of the supply chain entities.

FRQ.6: The CE visibility evaluation framework should extend the supply chain entity hierarchy by including ingredients.

Jayaraman et al. (2008) also emphasize the importance of capturing the condition (e.g., damages, exposure to high temperature) of the ingredients or items as they move in the supply chain. The condition could play a crucial role in the selection of the value retention strategy (e.g., recycling) that should be implemented in used materials. For that reason, information systems should contain information regarding the changes that materials or products undergo (Jayaraman, Ross, & Agarwal, 2008). For example, the characteristics of steel may alter after its exposure to fire consequently, it may not be suitable for direct reuse, further processing may be necessary (Adisorn, Tholen, & Götz, 2021).

FRQ.7: The CE visibility evaluation framework should assess blockchain-enabled data pipelines based on their ability to capture the condition of the supply chain entities.

3.2.2. Extending the data pipeline concept

The data pipeline concept can be a useful tool for eliciting a part of the information requirements. Data pipelines provide visibility from the seller in exporting country to the buyer in the importing country. More specifically, they contain detailed insights concerning the shipping goods by storing original trade data (e.g. bill of lading or packing list), capturing logistics events (e.g. the opening of a container on its way to the final destination, signals from smart seals), and mapping the stakeholders involved in the shipment (Klievink et al., 2012; Rukanova et al., 2021; van Stijn et al., 2012).

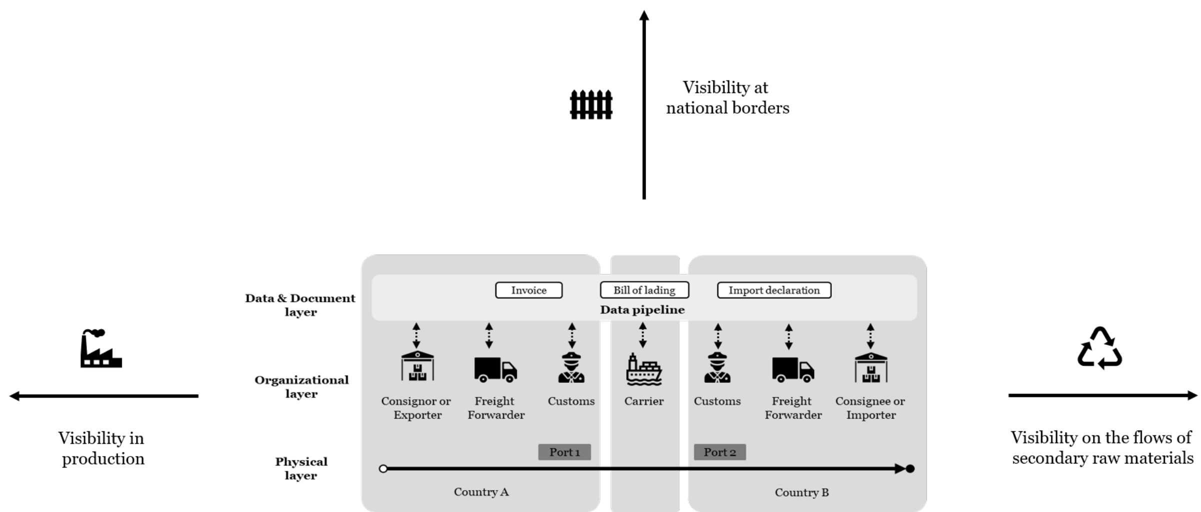


Figure 3.2: CE visibility, based on Rukanova et al. (2021)

Undoubtedly, the information captured by data pipelines could be important for monitoring CE flows. However, Rukanova et al. claim that such visibility is not sufficient for the case at hand. As illustrated in Figure 3.2, the CE requires an extension of data pipelines so as to provide additional visibility in three directions: production, use of secondary raw materials, and national borders (Rukanova et al., 2021).

FRQ.8: The CE visibility evaluation framework should assess blockchain-enabled data pipelines based on their ability to provide visibility from the seller in the exporting country to the buyer in the importing country.

Direction 1: Visibility in production

The analysis of chapter 2 regarding the linear and circular economic model highlighted the crucial role that production plays in CE. As presented, the linear economic model focuses on producing goods by solely receiving as inputs the earth's resources. In other words, this model dismisses the use of secondary materials originated from value retention strategies, such as recycling. This rationale is considered the root of the wicked problem of resource consumption and environmental destruction, considering that planetary resources are finite and should not be disposed of or incinerated when they are no longer functional or practical (Ellen MacArthur Foundation, 2013; Oppen et al., 2020; Wautelet, 2018). CE evolved as a response to this issue by emphasizing the need to minimize the use of raw materials in the production systems (Ellen MacArthur Foundation, 2016).

To ensure the adoption of cleaner production by the business world, the auditing actors need to access additional business data about the use of raw materials, components, and other products in the production. That is to say, they need to assess the extent to which companies are circular by using secondary materials. To receive such visibility, data pipelines need to be extended to capture information regarding the actors involved in the channels related to reuse and recycling of materials, such as suppliers (organizational layer) and the materials flows (physical layer). Moreover, it is important to include information about the production process (data and document layer), such as bills of materials, product recipes, and blending methods (Rukanova et al., 2021).

Furthermore, the European Commission (EC) highlights the need of monitoring the product design and establishing design requirements and performance criteria (European Commission, 2019, 2020b). As illustrated in the study of the strategy "planned obsolescence" (see section 2.1), the product design plays a crucial role in preserving planetary resources. The existing strategy of purposely limiting the technical product lifecycle depletes raw materials and increases the waste streams (Oppen et al., 2020). Hence, production should adopt circular design principles developing durable, repairable, maintainable, recyclable, upgradable, dismantlable, less-resource intensive (e.g., low use of fossil fuels), and non-hazardous (e.g., free of toxic substances) outputs (ABN AMRO, ING, & Rabobank, 2018; Deloitte, 2019; European Commission, 2019, 2020a; Hartley et al., 2020; Shojaei et al., 2021).

For instance, the electrical and electronical industry is among the greatest waste producers in the EU because of planned obsolescence. Namely, plenty of its products are disposed of when they are no longer functional, as they are not reparable, some components cannot be replaced (e.g., battery), dismantled or recovered, or their software cannot be updated (European Commission, 2020a). CE aspires to tackle this problem by encouraging the design of modular electronic devices consisting of components that can be easily repaired, upgraded, or remanufactured (European Commission, 2020a; European Environment Agency, 2017).

Another contributor to resource depletion is packaging. As described by EC, Europe consumes a huge volume of materials for producing packages, while this number is constantly rising. The industry should limit packaging waste and utilize reusable or recyclable packaging. Similarly, manufactures should simplify their offerings and stop coupling them. For example, a new electronic device should not be coupled with a charger, and the charger should be common for every device. In this way, users will be able to reuse their existing chargers and prevent the consumption of virgin resources (European Commission, 2020a). Therefore, the CE auditing actors also require visibility on these aspects associated with production.

The above-described analysis surfaced several aspects related to production, such as manufacturing, product design, and packaging, in which the CE auditing actors need to acquire visibility. In essence, CE sets some guidelines for the development of products, with which the industry should comply. The thesis integrates these aspects in the broad term of "production" and translates them into the following requirement.

FRQ.9: The CE visibility evaluation framework should assess blockchain-enabled data pipelines based on their ability to provide visibility in production (including product design).

Direction 2: Visibility on the flows of secondary raw materials

The analysis about production underlined also the second direction in which visibility is needed, the flows of secondary raw materials. This aspect refers to accessing information regarding the actors associated with the CE processes (reuse and recycling) and the path that materials or products follow when entering these processes (Ellen MacArthur Foundation, 2016; Rukanova et al., 2021). In essence, auditing actors should be in a position to trace the route of a resource from production to consumption and subsequently its reintroduction to the market through one of the value retention strategies.

A plethora of CE policies emphasize the pivotal role that consumers (businesses or private parties) play in ensuring product circulation (Deloitte, 2019; European Commission, 2019, 2020b, 2020a; European Environment Agency, 2017; Hartley et al., 2020; Rijksoverheid, 2019). They constitute the ending point of the existing linear economic model converting products into waste. However, CE treats waste as an important resource that should be reintroduced into the market through value retention strategies (Ellen MacArthur Foundation, 2016).

This reintroduction can become a reality through the collection and treatment of waste, products, and materials. These processes cover a broad range of activities, including collecting and separating waste, removing toxic substances, repairing, creating secure secondary materials, recycling, recovering the value of end-of-life products or valuable materials, and redistributing them (European Commission, 2019, 2020b; European Environment Agency, 2017; Rijksoverheid, 2019). By receiving such visibility, the CE auditing actors can make sure that the processes comply with the established standards and legislations and consequently they are suitable for producing reprocessed products of high quality.

Indicatively, the Royal Netherlands Standardization Institute has established standards regarding plastics recycling. Plastics are prone to adverse effects during their lifecycle, such as contamination or damage, which may affect their potential for recycling. In that instance, the recyclers should deploy a qualified recycling process to remove the contamination or repair the damage and guarantee the quality of the recycled plastics. This recycling process should be tested and certified with regard to its suitability for processing products for recycling purposes (NEN, 2007).

Figure 3.3 shows the materials routes and explicates the closed-loop concept on which the produced artifact should rely. Initially, it presents the typical process that products or materials go through during their lifecycle, from sourcing to consumption and use. Nonetheless, at this stage, the CE concept applies to support the reintroduction of materials into the market when no longer useful or desirable. The collection and disposal phase decides the most suitable CE process for the products. If the products do not require further processing, they can be directly resold through a reuse strategy. Alternatively, products can be recycled to enter the raw-material procurement phase and be used in the production of new products (Jayaraman et al., 2008; Kalmykova et al., 2018).

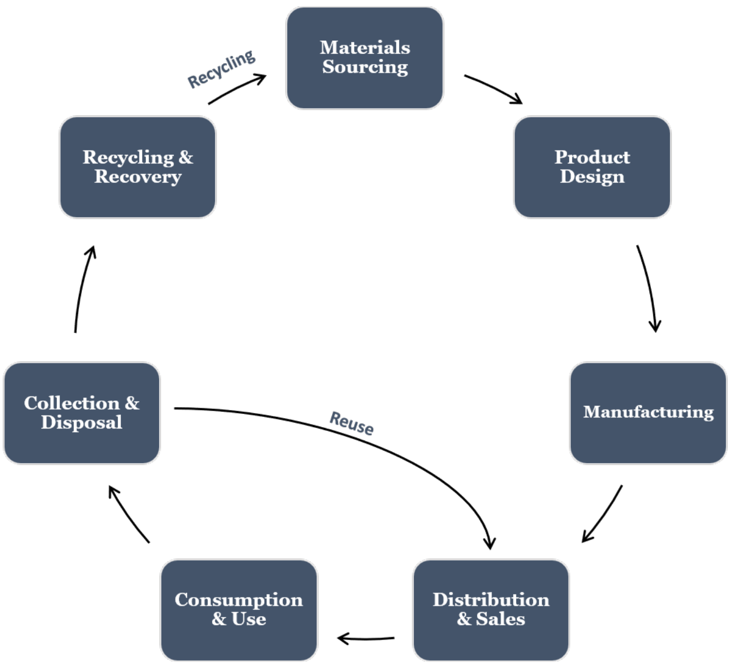


Figure 3.3: CE flows model, based on Kalmykova et al. (2018)

FRQ.10: The CE visibility evaluation framework should assess blockchain-enabled data pipelines based on their ability to provide visibility in the flows of secondary raw materials.

Direction 3: Visibility at national borders

The monitoring of CE flows encloses a cross-border aspect, taking into account that goods or materials could cross several jurisdictions throughout their journey. This aspect emphasizes the need to extend visibility at national borders. As described by Rukanova et al. (2021), authorities currently utilize various technologies at the national borders, like technologies that can identify the chemical product composition and other laboratory devices. Such technologies can offer valuable insights regarding the circularity of a product and enable authorities to detect fraud.

Equally pivotal is to capture insights possessed by customs. For example, customs authorities currently use a product classification system, the Harmonized Commodity Description and Coding System (HS), to classify goods when calculating duties and taxes. The HS code can offer information about the goods, which can be leveraged for CE purposes. Indicatively, the structure of the code expresses some important product characteristics, such as fabric manufactured by using cotton (WCO, 2018). Subsection 4.1.4 contains a detailed analysis of HS codes, clarifying their role in CE compliance. All this information available at national borders can facilitate the auditing actors' mission by allowing them to cross-validate the information declared by the companies and detect frauds (Rukanova et al., 2021).

Such visibility could also facilitate the policymakers' mission to ban the imports of non-sustainable products in their jurisdictions and the exports of waste. Namely, EC aims at restricting the illicit export of its waste to third countries and promote its vision for domestic reuse and recycling (European Commission, 2020a). Indicatively, in 2019, the EU exported 1.5 million tons of plastic waste, primarily to Turkey and Asian countries, like China, Malaysia, and Indonesia (European Commission, 2020c). Moreover, EC wants to forbid the entry of materials or products that do not meet the circular economy principles, such as durability, reparability, and recyclability, into the European market (European Commission, 2020a).

This analysis surfaced the crucial role that visibility at national borders can play in CE compliance. Every day a great number of materials or products cross jurisdictions, and authorities need to evaluate their suitability to enter the market or exit their territory. Visibility at national borders is not currently provided by data pipelines. Consequently, the thesis argues that the CE visibility evaluation framework should consider the significance of having such visibility to enforce compliance with CE policy instruments.

FRQ.11: The CE visibility evaluation framework should assess blockchain-enabled data pipeline solutions based on their ability to enforce compliance at national borders.

3.2.3. Blockchain interoperability

The research objective is to enable CE auditing actors to monitor the flows of materials and products in a closed supply chain by accessing business data stored in blockchain-based information infrastructures. As proved later in the thesis, none of the examined information infrastructures offer complete visibility on these flows. Whereas it is almost beyond doubt that there are no information systems currently available that capture data about the entire journey of materials and products in the CE context. Therefore, the CE auditing actors should access several different information systems to get supply chain visibility from materials sourcing to recycling.

In today's world, blockchain-based information systems capture a variety of data, which can offer insights about different parts of a closed-loop supply chain. For example, an information system may cover the transportation of products from a manufacturer to a consumer, while a different one may address the collection of used products by consumers or users and their transit from a collector to a processor. The linking of the data stored in these two blockchain-based information systems can equip CE auditing actors with valuable visibility in the flows of products, enabling them to enforce CE compliance. This aspect emphasizes the imperative need to work towards blockchain interoperability.

Blockchain interoperability refers to the ability of distinct blockchain platforms to communicate and exchange information with each other, without compromising their unique characteristics, such as irreversibility and traceability (Jin, Dai, & Xiao, 2018). This interaction should be conducted seamlessly and directly, without the involvement of intermediates to read the information from one source and transfer it to another. Such intermediates can endanger the stored data by manipulating their content consciously or unconsciously (Hardjono, Lipton, & Pentland, 2020; Monika & Bhatia, 2020; Schulte, Sigwart, Frauenthaler, & Borkowski, 2019).

The necessity for materializing blockchain interoperability should become explicit in the developed framework. By illustrating the parts of the closed-loop supply chain covered by the examined information systems, the framework can incentivize the responsible actors (e.g., IT developers) to develop interoperable systems and facilitate the CE transition.

FRQ.12: The CE visibility evaluation framework should highlight the need to work towards blockchain interoperability.

3.2.4. The ecosystem of blockchain-based data pipelines

Identifying the participants of blockchain-based data pipelines could be of great importance for the case at hand. Such insight can facilitate the CE auditing actors' duty by enabling them to identify the sources of the necessary information. Moreover, in case of any anomalies or frauds concerning the materials flows, the auditing actors would be able to pinpoint the responsible parties and take corrective actions. The data pipeline concept equipped the study with an extensive overview of the public and private parties involved in trade flows. Nevertheless, a more exhaustive stakeholders' analysis is required since the research should also consider the actors involved in the production, in the CE flows, and at national borders. This subsection highlights the role that the participants of blockchain-based data pipelines can play in CE compliance and translates it into a functional requirement.

FRQ.13: The CE visibility evaluation framework should guide the auditing actors to identify the ecosystem of blockchain-based data pipelines.

3.2.5. Information tools

To monitor the CE flows and prevent any possible manipulations of the CE policy instruments, the auditing actors (e.g., policymakers, banks) can receive insights from various information tools available today. This subsection presents some illustrative examples of such information tools identified in the literature that can enhance CE visibility and increase auditing actors' confidence in the environmentally related declarations of businesses.

Product passport:

EC defines a product passport as *"a set of information about components and materials that a product contains, and how they can be disassembled and recycled at the end of the product's useful life"* (European Commission, 2013; Pagoropoulos, Pigosso, & McAloone, 2017; Portillo-Barco & Charnley, 2015). The product passport, by storing such valuable product information, enables the stakeholders involved in the various stages of a product lifecycle to make decisions that promote sustainability and maximize the product utility. For instance, manufacturing companies can be informed regarding the repair and dismantling options that a product offers and opt for the alternative that better serves the CE purposes (Adisorn et al., 2021).

The clear contribution of product passport to CE has incentivized national governments to explore further its potential. The German Federal Ministry for the Environment, Nature Conservation, and Nuclear Safety encourages its application to every product and service, prioritizing the resource- and energy-intensive ones (Adisorn et al., 2021). An indicative example of a product passport is the materials passport (MP) developed in the EU project, Buildings as Material Banks. MP is a product passport focused on the construction industry, an industry consuming approximately 40% of the global material resources (Heinrich & Lang, 2019).

MP is a digital dataset focusing on depicting the characteristics of building materials, components, and products and conveying their potential for current use, recovery, and reuse (Heinrich & Lang, 2019). For instance, it can provide information concerning the value for recovery of a material or the dismantlability of a product. MP treats buildings as materials banks and aspires to make information about them accessible to relevant stakeholders in the building sector enabling them to keep materials in circulation. The information stored in MP is classified into several categories, including physical, chemical, biological, health and safety, unique product identifiers, design and production, transportation and logistics, construction-related (material and product locations in the building), use-related, and CE characteristics (potential for disassembly, reversibility, reuse, and recycling) (Heinrich & Lang, 2019).

Another example of a product passport is the cradle-to-cradle passport used by the freight company Maersk for a portion of its fleet of ships. Like materials passport, its objective is to foster recycling of materials at the end of their lifetime by storing CE-related data. Indicatively, it presents the locations of the materials in a ship and their quality characteristics. By doing so, the passport aims at fostering reuse of materials at the end of their product lifecycle, eliminate waste production, limit the use of virgin resources (Adisorn et al., 2021).

Internet of Things (IoT):

IoT is related to equipping objects (e.g., materials, products, devices, machines) with sensors and actuators, which allow them to communicate by creating an information network (Bressanelli, Adrodegari, Perona, & Saccani, 2018; Pagoropoulos et al., 2017). In simple words, it converts typical objects into smart ones. The potential of a smart object to communicate within a network provides abundant opportunities for CE auditing actors. Thank to IoT, auditing actors are able to monitor in real-time the status, condition, use, and location of CE flows, identify potential frauds, and consequently ensure the successful implementation of their CE policy instruments (Bressanelli et al., 2018). In essence, the technology satisfies the requirements for CE visibility set in subsection 3.2.1 based on the Francis's definition (2008).

Driven by the great potential of deploying IoT in the CE context, Gligoric et al. (2019) presented an IoT-based structure able to detect changes in the environment, an aspect that could be useful for CE. More specifically, they developed a SmartTags technology able to provide item-level identity. The SmartTags technology makes use of printed sensors for creating dynamic QR codes (a label attached to a product that contains information about it). Printed sensors are simple in structure, thin and light-weight sensing devices produced by printings methods. Two interesting examples of such sensors are the temperature and luminosity sensors made of reversible or irreversible functional ink, which react to environmental conditions by changing color (Gligoric et al., 2019).

The contribution of SmartTags technology to the case at hand is that it exceeds the capabilities of the traditional QR codes. QR codes usually contain a simple set of information, such as the recyclability of a product or its components. However, the SmartTag technology embeds to them one additional aspect providing insights on the environmental conditions in which a product has been exposed. This information can become known by using a scanning device, while it can be stored in a product passport. In this way, the SmartTags technology fulfills two fundamental CE requirements highlighted earlier, visibility on product characteristics (e.g., composition, reuse, and recycling potential) and condition (Gligoric et al., 2019).

Radio Frequency Identification (RFID):

The RFID technology has gained notable attention due to its potential to catalyze the CE transition. It enables the identification and trace of an object, which has been attached to a tag, by making use of electromagnetic fields. These attributes are critical for CE compliance. The interested parties can get information regarding the CE product characteristics, such as recyclability, and monitor the materials throughout the supply chain (Pagoropoulos et al., 2017). The RFID tags are divided into three categories based on their energy source. The active RFID receives energy from a battery, whereas the passive one is powered by the energy provided by a reader signal. Finally, the semi-passive has similar functionality to the passive one but contains a battery usually used to power a sensor (Condemi, Cucchiella, & Schettini, 2019).

Product labelling:

Product labeling can be beneficial for CE by conveying reliable information regarding the product characteristics. There are multiple product labels available in today's world focusing on informing interested parties about the sustainability aspects of products (e.g., circular characteristics, durability, repairability) or advising them how to maximize their utility, for example, through recycling (Meis-Harris et al., 2021). A notable label is the EU Ecolabel, attached to products and services that meet high sustainability standards. It contributes to CE by setting criteria that force the industry to produce durable, dismantlable, repairable, and recyclable products (European Commission, 2021b). Like EU Ecolabel, the FSC label is awarded to forest products, like wood and paper, developed through recycling or with resources from properly managed forests (FSC, 2021).

This subsection pinpointed some widely discussed information tools, which can equip the CE auditing actors with valuable information regarding the product characteristics and their journey in the supply chain. By accessing this information, these actors can cross-validate the product-related declarations by the businesses and avert the manipulation of their CE policy instruments. Thereby, the CE visibility evaluation framework should take these information tools into account and derive insights from them.

FRQ.14: The CE visibility evaluation framework should reap the benefits of available CE information tools.

3.3. Non-functional Requirements

Equally important for the development of the CE visibility evaluation framework is the identification of the non-functional requirements. Seemingly, these requirements do not cover aspects related to the functionality of the framework but represent crucial properties that should be present to meet the stakeholders' needs (e.g., policymakers, customs, banks).

3.3.1. Usability

As already pointed out, the framework can be used to evaluate blockchain-based information infrastructures concerning their ability to capture the information needed to trace an item throughout its life cycle. Such systems usually contain vast amounts of data since their users are companies related to the supply chain, a data-intensive domain (Brunekreef & Pournader, 2018). Whereas the ever-increasing number of IoT devices accelerates the produced and stored data (He, Xue, & Gu, 2020). This large volume of data could affect the applicability of the framework to an information system. In other words, it may not be straightforward to illustrate the information stored by these systems in the framework. This challenge highlights the need of developing an easy-to-use framework that can illustrate the visibility offered by the blockchain-enabled data pipeline solutions in a simple way.

NFRQ.1: The CE visibility evaluation framework should be able to illustrate the visibility offered by the blockchain-enabled data pipeline solutions in a simple way.

The acceptance of the evaluation framework by the users (e.g., policymakers, customs, banks) could be affected by the terms used in the framework. The users' background knowledge on the topic and the supply chain terminology may vary from basic to expert (Ullah, Iqbal, & Khan, 2011). This aspect needs to be considered in the development efforts. It can be addressed by using standardized terms, which will prevent the occurrence of any misunderstandings and will stimulate the framework adoption.

NFRQ.2: The CE visibility evaluation framework should contain standardized terminology.

3.3.2. Supportability

To fulfill its purpose, the evaluation framework needs to illustrate the extent to which each blockchain-based data pipeline serves the CE. That is to say, it should be able to depict the degree to which each information system meets the fundamental requirements highlighted earlier regarding supply chain visibility (FRQ.1 to FRQ.13). For instance, it should present whether a system provides visibility on an item-level or container-level.

NFRQ.3: The CE visibility evaluation framework should illustrate the extent to which a blockchain-based data pipeline serves CE purposes.

3.4. Conclusions

Chapter 3 addressed the SRQ2 through a literature review: *"What are the essential information requirements needed to support the trace of an item throughout its life cycle in the CE context?"*. Following the classification suggested by Johannesson and Perjons (2014), the requirements were divided into functional and non-functional. The functional requirements are the functions that the CE visibility evaluation framework should provide. They were pinpointed by a literature review on the supply chain visibility, the CE, and the available information tools (information sources that can be used by the CE auditing actors). Furthermore, the thesis reviewed a plethora of policy instruments launched by policymakers or private organizations to surface their requirements. This activity contributed to the acceptability of the framework, considering that these actors constitute the recipients of the produced artifact. Subsequently, the non-functional requirements were defined based on a literature review on the properties that a DSR output should cover. Table 3.1 presents an overview of the framework requirements.

Code	***Description***
FRQ.1	The CE visibility evaluation framework should capture the Francis's supply chain entity hierarchy.
FRQ.2	The CE visibility evaluation framework should assess blockchain-enabled data pipelines based on their ability to capture the identity of the supply chain entities.
FRQ.3	The CE visibility evaluation framework should assess blockchain-enabled data pipelines based on their ability to capture the location of the supply chain entities.
FRQ.4	The CE visibility evaluation framework should assess blockchain-enabled data pipelines based on their ability to capture the status of the supply chain entities.
FRQ.5	The CE visibility evaluation framework should assess blockchain-enabled data pipelines based on their ability to capture the events of the supply chain entities.
FRQ.6	The CE visibility evaluation framework should extend the supply chain entity hierarchy by including ingredients.
FRQ.7	The CE visibility evaluation framework should assess blockchain-enabled data pipelines based on their ability to capture the condition of the supply chain entities.
FRQ.8	The CE visibility evaluation framework should assess blockchain-enabled data pipelines based on their ability to provide visibility from the seller in the exporting country to the buyer in the importing country.
FRQ.9	The CE visibility evaluation framework should assess blockchain-enabled data pipelines based on their ability to provide visibility in production (including product design).
FRQ.10	The CE visibility evaluation framework should assess blockchain-enabled data pipelines based on their ability to provide visibility in the flows of secondary raw materials.
FRQ.11	The CE visibility evaluation framework should assess blockchain-enabled data pipeline solutions based on their ability to enforce compliance at national borders.
FRQ.12	The CE visibility evaluation framework should highlight the need to work towards blockchain interoperability.
FRQ.13	The CE visibility evaluation framework should guide the auditing actors to identify the ecosystem of blockchain-based data pipelines.
FRQ.14	The CE visibility evaluation framework should reap the benefits of available CE information tools.
NFRQ.1	The CE visibility evaluation framework should be able to illustrate the visibility offered by the blockchain-enabled data pipeline solutions in a simple way.
NFRQ.2	The CE visibility evaluation framework should contain standardized terminology.
NFRQ.3	The CE visibility evaluation framework should illustrate the extent to which a blockchain-based data pipeline serves CE purposes.

Table 3.1: Overview of the framework requirements

4

Framework Design

Chapter 4 addresses the third activity of the MFDSR, design and develop the artifact. By answering the SRQ3 and SRQ4, it produces the CE visibility evaluation framework. The framework should enable the CE auditing actors to evaluate the available blockchain-enabled information systems on their ability to enforce compliance with the CE policy instruments.

Section 4.1 uses the literature to answer the SRQ3: *"How can the information requirements needed to support the trace of an item throughout its life cycle serve as a basis for the CE visibility evaluation framework?"*. It receives as an input the knowledge gained in chapter 3 and develops a basic CE visibility evaluation framework that depicts the fundamental CE processes. However, this initial framework describes the CE flows on a high level. Therefore, the thesis focus on detailing it further by exploiting the insights offered by the literature and the use cases (TradeLens, FoodTrust, and Vinturas).

Section 4.1 also studies some information tools to identify their potential to equip the CE auditing actors with valuable insights on the fundamental CE processes presented in the basic CE visibility evaluation framework. This analysis surfaces that they can offer visibility mainly in product design and facilitate compliance at national borders (HS codes). The thesis tries to fill in the knowledge gap related to the processes not covered by the information tools by exploiting every available resource (e.g., literature and use cases). The first gap refers to gaining visibility on the flows of products from consumption to recycling and subsequently their reintroduction to the market. This gap is bridged by using the literature around reverse logistics, closed-loop supply chains, and recycling.

The other knowledge gaps are associated with the journey that materials or products follow from materials sourcing to consumption and during the reuse disposition option. The thesis covers them by addressing the SRQ4: *"What information requirements for CE visibility are captured by the examined blockchain-enabled information systems and how do the insights derived from them contribute to the further development of the CE visibility evaluation framework?"*. Sections 4.2, 4.3, and 4.4 deal with SRQ4 by analyzing TradeLens, FoodTrust, and Vinturas, respectively. Section 4.5 combines the knowledge gained by the previous sections to produce the CE visibility evaluation framework. Finally, section 4.6 concludes the chapter by addressing the related sub-research questions.

4.1. Insights offered by the literature

4.1.1. The basic CE visibility evaluation framework

This section deals with the first design phase by receiving as an input the information requirements and the knowledge identified in chapter 3 and translating them into an initial version of the framework. An essential requirement highlighted by the previous analysis regarding the framework development is the need to capture the flows of materials and especially the flows of secondary ones. In this way, CE auditing actors can monitor their journey in the supply chain and identify potential frauds. Figure 3.3 is a very influential model for the thesis illustrating these materials routes and explicating the closed-loop concept. Therefore, it can constitute the basis of the development efforts. In other words, the produced framework will focus on shedding light on these routes but also diving deeper into them by showing a more detailed representation.

Equally pivotal for the CE visibility framework is to illustrate the components pointed out by the definition of supply chain visibility provided by Francis (2008) and discussed in chapter 3. That is to say, the produced framework should offer detailed information (identity, location, status, and events) about the supply chain entities depicted in Figure 3.1. This need can be partially satisfied using the domain model developed by Hofman et al. (forthcoming 2021). The domain model (presented in Figure 4.1) is a conceptual model describing the domain of interest for customs risk assessment, the global trade (Hofman et al., forthcoming 2021). It has been designed to enable customs to evaluate the quality and value of external data sources that can be used during the customs risk assessment. More specifically, customs are increasingly thinking of exploiting business data to better accomplish their mission, such as protecting national security and safety, and collecting taxes on imported commodities. Nevertheless, the value of this business data is uncertain, and for that reason, Hofman et al. developed their evaluation model (Hofman et al., forthcoming 2021).

The research perceives the domain model as the ideal pillar for relying on the development of the CE visibility evaluation framework. It has some captivating characteristics that make it a perfect foundation for the design phase. Initially, it serves a similar objective with the thesis, enforcing compliance in the flows of supply chain entities by exploiting external data sources. The domain model aims at facilitating the customs risk assessment of imported cargoes by promoting the use of business data stored in IT innovations (Hofman et al., forthcoming 2021). Whereas the CE visibility evaluation framework supports the piggybacking of business data by the CE auditing actors to enforce compliance with their policy instruments on the flows of materials and products.

Furthermore, both of them approach their problem from the same perspective or domain, the global trade, aspiring to enforce governmental control on the flows of supply chain entities. Specifically, the domain model focuses on the transportation of products from an origin to a destination (Hofman et al., forthcoming 2021). While the CE visibility evaluation framework covers a more holistic picture, the flows of materials and products in a closed-loop supply chain. It is essential to highlight that in the movements described by both the domain model and the CE visibility evaluation framework, different supply chain entities can appear. In other words, products can be packed into a package, packages can be stored in a container, and so on. Seemingly, the model captures four of the supply chain entities described by Francis, items (e.g., products), packages (e.g., goods), lading assets (e.g., containers), and vehicles (e.g., transportation means) (Hofman et al., forthcoming 2021).

The domain model also meets three functional requirements highlighted in chapter 3. Namely, it shows the association between the supply chain entities, the locations, and the events. For example, goods are stored in a container in the groupage center. Moreover, it illustrates the flows of supply chain entities in global trade clearly. This element is pivotal for the thesis since the CE context involves the transportation of various supply chain entities, including ingredients, products, packages, etc. Therefore, it is important to depict their involvement in a straightforward way. Finally, the domain model satisfies the first non-functional requirement (NFRQ.1), enabling the mapping of different data sources (blockchain-based information systems in the thesis) in a simple way.

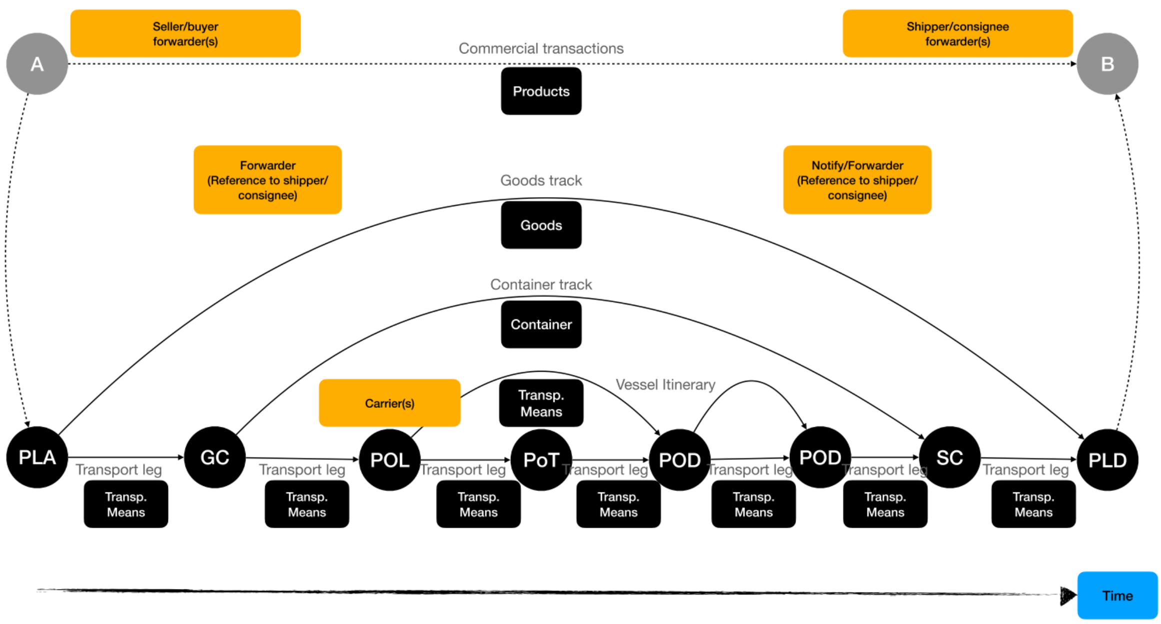


Figure 4.1: Domain model (Hofman et al., forthcoming 2021)

It is worth mentioning that Hofman et al. and Francis define the supply chain entities, the location, and the events similarly. Thereby, an entity is a physical object moving in the supply chain, a location is the specific position of an entity, and an event expresses the relationship in time between physical objects, the time when a process takes place, such as loading a container on a vessel. Time can refer to the past, present, or future (Francis, 2008; Hofman et al., forthcoming 2021). Moreover, Hofman et al. describe a transport leg as the transportation of goods or containers among two contiguous (in time) locations via one transport means.

Concerning the physical flows, Figure 4.1 depicts the movement of products from a place of acceptance (PLA) to a place of delivery (PLD). The flow starts with the transportation of the goods (packaged products) from the PLA to a groupage center (GC), where they are stored into containers to be shipped to a stripping center (SC). The containers are shipped from a port of loading (POL) to a port of discharge (POD), while a port of transshipment (POT) might exist between them. According to Figure 4.1, the vessel can go through two ports of discharge, the first one represents the port of entry of the vessel in the EU and the second one the port where the container is discharged. However, this a specific situation, the port of entry in the EU can be also the port of discharge. Finally, the actors involved in the commercial transaction are presented, like freight forwarders or carriers, who can provide the necessary information about the shipment, as well (Hofman et al., forthcoming 2021).

By receiving as input the CE flows model (Figure 3.3) and the domain model (Figure 4.1), the thesis designs a first version of the framework (Figure 4.2) presenting the fundamental resource flows in the CE context. Figure 4.2 captures the essence of CE in a clear way, but it describes the CE flows on a high level. Thereby, it needs further elaboration diving deeper into the materials flows. This will become possible by using the literature and the use cases. In other words, by using every available resource, the thesis will try to detail every process illustrated in Figure 4.2.

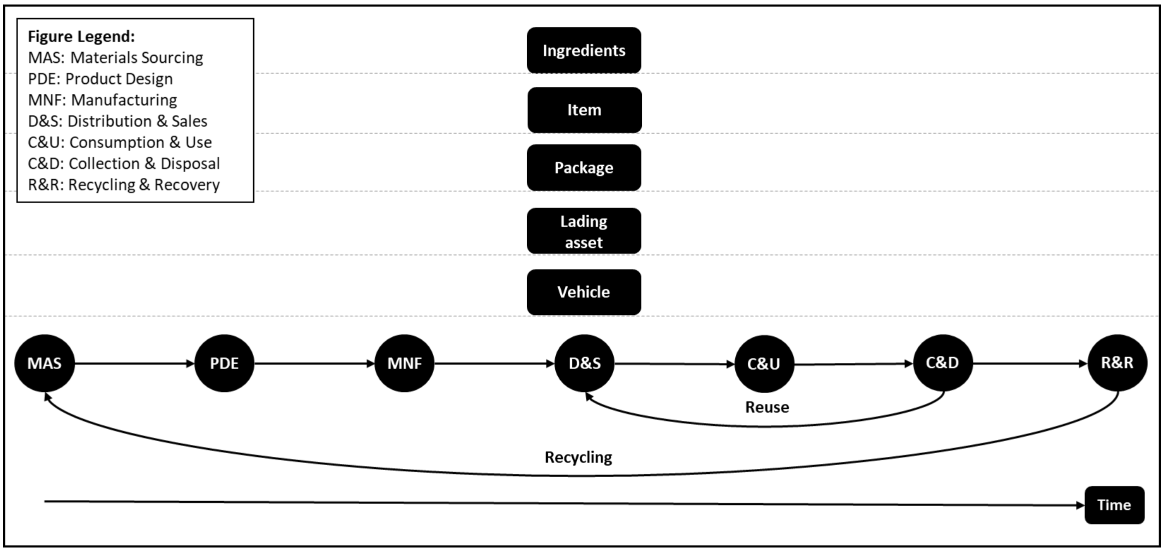


Figure 4.2: The basis of the CE visibility evaluation framework

Seemingly, the framework does not represent every level of the entity hierarchy (see Figure 3.1). Depicting every level could increase the complexity of the framework, making it difficult for the reader to understand it. Moreover, including the entities not considered by the thesis, order, encasement and shipment, will not enrich readers' understanding of CE visibility. This statement is justified by their definitions showing that these entities describe specific situations. More specifically, a customer's order is defined as one or several packages bundled together, an encasement is a form of packaging for the order, and a shipment expresses different customers' orders with similar places of acceptance and delivery (Francis, 2008). Therefore, the thesis deliberately excludes these entities. However, Figure 4.2 captures the ingredients of an item, that is to say, the raw materials used to produce an item. As discussed already, having visibility on this aspect is essential for CE.

4.1.2. Visibility offered by the information tools

This subsection focuses on identifying the potential of some information tools discussed in chapter 3 (e.g., product passport and product labelling) to provide visibility on the CE resource flows depicted in Figure 4.2. The EC, recognizing the significance of dealing with resource depletion, has been actively involved in incentivizing industry players to produce CE products, products in compliance with the CE principles. To fulfill its mission, it has obligated them to communicate product-related information to prove that they meet CE standards in practice (Adisorn et al., 2021). As presented in this subsection, such information-sharing could become possible via product labelling, product passports or other databases.

In March 2021, the EC obliged the manufacturers of 15 product groups (e.g., air conditioners, household cooking appliances, televisions, and household washing machines) to publish product-related information in both the product label and a database. The information required by the EC varies based on the product category. Indicatively, refrigerators producers have to include in their product labels the company name, the efficiency class, the annual electricity consumption, the volume of the refrigerator, and the maximum noise level. Moreover, they must submit further information than the one indicated on the label, like the duration of the product guarantee and product design. Manufacturers are charged by the EU with additional data-sharing information. More specifically, they must upload in an official EU database, named European Product Database for Energy Labelling (EPREL), the information captured in the product data sheet (e.g., technical characteristics and performance) and other essential technical documents. It is worth mentioning that consumers can access the data stored in EPREL by scanning a QR code attached to the product label (Adisorn et al., 2021; European Commission, 2021c).

The REACH (Registration, Evaluation, Authorisation, and Restriction of Chemicals) is another data-sharing initiative launched by the EC. REACH aims at protecting human health and the environment by obligating manufactures and importers to enter in a central EU database, information about the presence of chemicals or other toxic substances in products (Adisorn et al., 2021). Similar reporting obligations have the producers of electrical and electronic equipment. According to Waste Electrical and Electronic Equipment Directive (WEEE), they must provide recycling companies or other companies related to waste treatment with information about the disposal and the treatment of their products after the end of their product life. This information can be delivered in either printed paper or electronic form (Adisorn et al., 2021).

An over-discussed information tool for CE purposes is the product passport. As described in chapter 3, it is defined as *"a set of information about components and materials that a product contains, and how they can be disassembled and recycled at the end of the product's useful life"* (European Commission, 2013; Pagoropoulos et al., 2017; Portillo-Barco & Charnley, 2015). This data is collected from all the stages of the product lifecycle and can be deployed for improving the design, production, use, and disposal of products. Ideally, a product passport should be implemented to every product and service, prioritizing the resource- and energy-intensive ones, such as electrical equipment. Among the available product passports, the thesis discussed the MP and the Maersk passport. The former has been demonstrated but not applied yet, while the latter has been implemented already (Adisorn et al., 2021).

The remainder of this subsection focuses on the MP since it aspires to provide visibility in every process depicted in Figure 4.2. Therefore, it constitutes a more extensive source of information than the Maersk passport. MPs are digital datasets covering CE-related information about the building materials, components, and products, which can be extracted in the form of a report based on users' needs (Heinrich & Lang, 2019; Luscuere & Mulhall, 2018). They store information not currently captured by the documents or certifications available in the industry, particularly regarding CE (Heinrich & Lang, 2019).

MPs place considerable attention on storing information related to product design. Product design (e.g., how a product is designed) plays a pivotal role in the impact of a product on human health and the environment. Furthermore, it determines its future fate, that is to say, its usability at the end of its lifecycle. For that reason, MPs try to make CE-related product information (e.g., recyclability, repairability, durability, dismantlability, etc.) available to the interested parties. Namely, they contain essential information about the materials, components, and products, including their physical properties (e.g., maintainability, expected lifetime, recyclability, reusability, weight, etc.), chemical properties (e.g., chemical composition, environmental and human risks, etc.), biological properties (e.g., renewable, or non-renewable, recyclability, treated or non-treated decomposability, etc.) and material health (e.g., hazardous chemicals and materials, carcinogenic and mutagenic substances, etc.). Having rich knowledge about these aspects could be very useful for selecting the disposition options, as well. For instance, a chemically treated timber may need to go through thermal incineration (Heinrich & Lang, 2019).

MPs aspire to capture information about the other processes presented in Figure 4.2. Therefore, they offer visibility in the production of products (e.g., information related to the manufacturer, material and product composition, manufacturing process, production certifications, etc.), their transportation and logistics starting from the sourcing of raw materials to the end of their lifecycle (e.g., vehicles used, readings from RFID tags, carbon footprint, etc.), materials sourcing (e.g., the origin of materials, responsible sourcing, etc.) and disposition (e.g., appropriate handling at the end of product life, opportunities and barriers for recycling, etc.). To enable the tracking of materials and products throughout their lifecycle, the passports store product-related data and construction-related (e.g., material location in the building, etc.) data as well (Heinrich & Lang, 2019).

MPs give equal attention to capturing information about the use of products. In other words, users need to constantly update information stored in the database based on the changes made on the materials, components, and products. Such changes could be maintenance, upgrades, changes in ownership, damages, and other information that may play a role in the product utility. For instance, a radical alteration may affect the potential of a product for recycling. Indicatively, a fire could influence the properties of steel and consequently its reusability (Heinrich & Lang, 2019).

It is important to highlight that several other information tools that deliver product-related information exist, in addition to the above-described ones. However, based on the existing analysis, the thesis can derive some conclusions about the information that CE auditing actors can receive by accessing them. Seemingly, MPs provide visibility in every process of Figure 4.2 and could play a pivotal role in accelerating CE transition. Nonetheless, they have not been implemented in practice, and their applicability remains a matter of discussion (Adisorn et al., 2021; Heinrich & Lang, 2019). Taking into account the other information tools discussed in the thesis, which have already applied, it can be concluded that they can offer crucial information mainly about the product design. In other words, they do not provide detailed insights into the other processes depicted in Figure 4.2. The thesis will try to bridge this gap by analyzing the use cases presented in the following sections of the chapter. The use cases do not offer insights regarding the recycling process. Therefore, the thesis will cover this aspect by using the literature.

4.1.3. The information requirements about recycling

This subsection studies recycling, a process depicted in the basic CE visibility evaluation framework (Figure 4.2). The analysis of both the information tools (presented in section 4.1.2) and the use cases (presented in the remainder of this chapter) did not surface any insights about recycling. Thereby, the thesis tries to address this CE process and pinpoint its main subprocesses by using the literature about reverse logistics. Reverse logistics constitute a part of the closed-loop supply chain concept. A closed supply chain requires two flows of materials or goods, the forward flow from materials sourcing to consumer and reverse flow from consumer to sourcing of raw materials (Jayaraman et al., 2008). The forward flow is analyzed in the following study of the use cases.

Reverse logistics in the CE context start with the collection of products by consumers or users no longer desirable or functional. The collection can take place in various ways based on their kind and origin. From a theoretical point of view, every room in an office block is a potential collection point. Indicatively, waste plastics of households are usually gathered through the curbside collection, a service provided to households in urban or suburban areas for the receipt, handling, and management of wastes. On the other hand, electronics or vehicles are returned by consumers or users to their suppliers, who take the necessary actions to deliver them to specialized companies (Jayaraman et al., 2008; NEN, 2007). The existence of a plethora of potential collection points complicates the process, making the recycling of every product a challenging mission (Zuidwijk, Nunen, Eijk, & Hillegersberg, 2001). According to the literature, the activities involved in the gathering of end-of-life products by the consumers or users are represented by the subprocess, product acquisition (Banihashemi, Fei, & Chen, 2019; Doan, Amer, Lee, Phuc, & Dat, 2019; Jayaraman et al., 2008).

Subsequently, the collected products need to be delivered to specialized facilities for inspection, sorting, and disposition. Namely, consumers or users return products due to several reasons, such as defections and obsolescence. Consequently, the condition of returned products needs to be evaluated to identify the suitable disposition option, reuse, remanufacture, and recycling (Banihashemi et al., 2019; Doan et al., 2019; Jayaraman et al., 2008). Recycling is a CE process that returns products to their basic materials for producing new ones (Calvo-Porral & Lévy-Mangin, 2020; Ellen MacArthur Foundation, 2016). As discussed in section 2.1, it should be the last resort when considering the appropriate disposition option since it discards the value contained in products and impacts the environment (Ellen MacArthur Foundation, 2013; European Environment Agency, 2017). Collected products can be sorted according to their type (e.g., glass, paper, mixed waste, etc.), colour, previous functionality, or chemical composition. These activities (e.g., inspection, sorting, and disposition) can take place in a centralized return centre (CRC) (Jayaraman et al., 2008).

From the centralized return centre, products are transported to their next destination, recycling, where they are processed to regain their economic value and reintroduced to the market. The recycling process is product-specific to a great extent. In other words, it can vary per product type (Jayaraman et al., 2008). For instance, recycling polyethylene plastic involves pre-washing, relabelling, sorting, chopping, washing, float separation, rinsing, and drying (Shen & Worrell, 2014). Finally, the produced outputs are delivered as raw materials to manufacturing facilities for producing new products and reach again end-consumers (Doan et al., 2019; Jayaraman et al., 2008).

The remainder of this subsection focuses on detailing further the recycling process depicted in the basic CE visibility framework (Figure 4.2). To do so, it deploys a specific use case, the recycling of plastic. The motivation for studying this use case lies in the fact that the Royal Netherlands Standardization Institute Foundation (NEN) has published a thorough standard regarding recycled plastic that can be instrumental in the design efforts. More specifically, the standard indicates the procedures required for tracing recycled plastics (NEN, 2007). As already mentioned, the recycling process is very product-specific. Therefore, the following analysis may not be generalizable to other products.

A crucial aspect regarding recycling is the control of the input material. That is to say, recycling relies on knowing the product inserting the recycling process. Plastics that have been contaminated with other materials or have undergone damages, chemical or structural changes may not be appropriate for recycling or need further processing. In that case, recyclers should remove the contaminants from the plastic or repair the damages before starting the recycling process to such a degree that the input will not affect the produced recycled plastic. If this is not feasible, they should enter limited amounts of the contaminated or damaged plastic in the process, ensuring the production of high-quality recycled plastic. Thereby, it is evident that the success of recycling depends on the use of plastic throughout its lifecycle. However, tracing the use of a product can be challenging task (NEN, 2007). Such visibility is currently offered only by the MPs, in which users continuously update the product-related information.

The standard places equal attention on controlling the recycling process. The recycling process should meet specific requirements and quality criteria. Furthermore, it may be necessary to go through challenge tests, which deliberately add contaminants or damaged materials in specific quantities to estimate its ability to produce recyclate with desired properties. Recyclers should communicate the characteristics of the batch of recycled plastic (e.g., the quality controls performed, input materials, recycling process) with the related stakeholders based on applicable standards, such as EN 15342 and EN 15344. In general, any information communicated about the produced recycled plastic should be supported by reliable evidence. Finally, the standard highlights the importance of tracing the journey of the returned plastic. For that reason, the sorting centers should attach to every batch a unique identifier (e.g., serial number, RFID tag). This traceability should be continued throughout the route of the plastic until its reintroduction to the market (NEN, 2007).

The analysis presented in this subsection can be translated into an elaborated version of the basic CE visibility evaluation framework related to recycling. It is worth mentioning that the elaborated versions presented later in this chapter are derived by the analysis of the use cases, while this one is based on the literature and the abovementioned standard by NEN. The standard plays a vital role in highlighting the information requirements needed to trace recycled plastics. Such traceability is of great importance for ensuring recyclate of high-quality (NEN, 2007).

Origins	Material type/form
	Product type
	Type of waste e.g., pre-user, post-user, construction waste
	Place of origin (e.g., supplier identification)
	Date
	History of waste (e.g., known contamination with other materials)
Logistics	Way of collection (transporter's details, means of transportation)
	Sorting
	Batch size, identification and marking
	Pre-treatment (e.g., washing, grinding)
	Storage (e.g., outside)
Tests performed before processing	EN 15347- Recycled Plastics - Characterisation of plastics wastes
	Or any other standard suitable for the end-use application
Process parameters	Details of the recycling process
Tests performed after processing	EN 15342
	EN 15344
	EN 15345
	EN 15346
	EN 15348
	Or any other standard suitable for the end-use application
Intended application	Information about appropriate or inappropriate applications

Table 4.1: Information requirements for recycling (NEN, 2007)

The quality of recycled plastics relies on knowing the input materials, the recycling process, and the materials produced. To achieve such visibility, traceability should start at the CRCs, where end-of-life products are inspected and sorted. Table 4.1 indicates the information requirements needed to place confidence on recyclate. Any claim regarding a recycled product should be supported by evidence. For that reason, all stages involved in the treatment of wastes should be documented and recorded thoroughly. In this way, the CE auditing actors or other stakeholders will be able to estimate the recycled content of products, point out unwanted materials or defective products, and ban them from the market (NEN, 2007).

Figure 4.3 depicts the elaborated version of the basic CE visibility framework (Figure 4.2) regarding the recycling process. Namely, it delves deeper into the post-consumption phase of Figure 4.2, the journey that products follow from consumption or use (C&U) to recycling and recovery (R&R) and subsequently the transportation of produced raw materials in materials sourcing (MAS). The framework demonstrates four layers, the relationship between the main subprocesses and the visibility needed, the events and the documents that should be recorded, and the actors that can engage in recycling. It can be noticed that recycling involves the transportation of products or materials between the different subprocesses. This aspect is not addressed by this detailed version since, as the following analysis indicates, it is supported by TradeLens. TradeLens covers every potential shipment between a seller and a buyer. Finally, it is essential to highlight that Figure 4.3 describes recycling on a high level, so further research is required. However, it constitutes a first attempt to identify the information needed to trace materials or products at the end of their life.

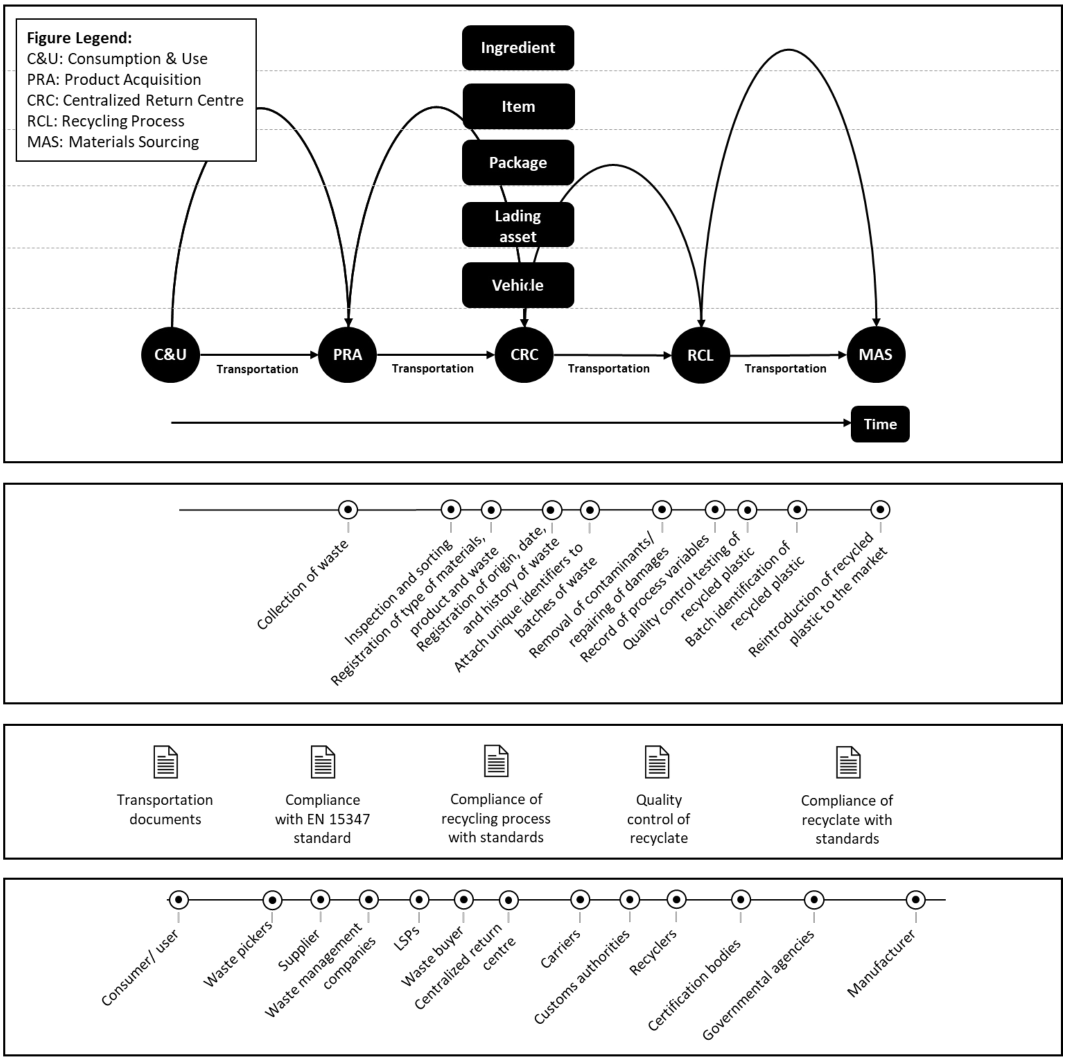


Figure 4.3: The CE visibility evaluation framework about recycling

4.1.4. Enforcing CE compliance at national borders

One of the requirements in the thesis is visibility at national borders. It emphasizes the need for getting the benefits of the technologies and other information tools available at borders to facilitate compliance with CE policy instruments. It is a broad topic that requires extensive analysis. The thesis covers it by studying the Harmonized Commodity Description and Coding System (HS). The HS is a nomenclature developed by World Customs Organization (WCO) that enables governments to categorize to a class all physical goods crossing national borders in a uniform and globally accepted way. In simple words, it is considered the *"language of international trade"* (WCO, 2018).

The HS is a multipurpose instrument used by both governments and businesses involved in global trade. Its primary objective is to classify the merchandise and consequently facilitate the assignment and collection of import duties and taxes by the customs. Nevertheless, thanks to its versatile format, it can be deployed for a plethora of other areas, including statistical analysis related to trade, monitoring of imported products (e.g., wastes, dangerous chemicals), identifying the place of origin, and collection of internal taxes (WCO, 2018).

The product classification system can also play an essential role in CE compliance. Policy-makers can exploit the categorization provided to promote circular products by offering financial incentives to their trading (e.g., duties reduction) and restricting the import of non-circular ones. Moreover, as presented later in this subsection, it can facilitate the establishment of legal measures and requirements towards the importers. Namely, public institutions, through HS, can obligate importers to submit the necessary documentation (e.g., certificates) to prove the circular or sustainable characteristics of the products being shipped.

Regarding its structure, the HS is a nomenclature consisting of four-digit headings, which are separated further into five- and six- subheadings. The four-digit headings categorize similar products, whereas their subdivision enables particular treatment in the case of special needs. Governmental or private organizations can use the subheadings to subdivide the initial categories based on their requirements. In other words, they can further classify products within a heading. This design choice increases the flexibility and the usability of the system. Notably, almost every country uses the same HS code numbers up to six digits (WCO, 2018).

The HS 2017 is organized into 1,222 headings, divided into 96 chapters, and subdivided into 21 sections. The first two digits of the heading (four-digit code) denote the chapter where the transportable goods are grouped, while the last two digits show the exact position within the chapter. The remaining digits of the HS code, which refer to the subheadings, express more specific information. In this way, HS 2017 contains 5387 categories of products (WCO, 2018). The following example clarifies the use of the codes.

The EC has developed a platform that enables interested actors, such as importers, to insert every HS code and receive access to the rules applied to every good being shipped [1].

[1] See: `https://ec.europa.eu/taxation_customs/dds2/taric/taric_consultation.jsp?Lang=en`

Specifically, they can be informed about the tariffs levied and other legal requirements. The thesis shows the information provided by this platform by using an example of a nomenclature code: 2205101000. Its four-digit heading indicates that the good belongs to chapter 22 (beverages, spirits, and vinegar) and section 4 (prepared foodstuffs; beverages, spirits, and vinegar; tobacco and manufactured tobacco substitutes). The first two digits of the subheading (101000) express that the wine falls into the category of containers having 2 liters or less, and the second two digits show that it fits into the group related to actual alcoholic strength by volume of 18 % vol or less. The last two digits are zero indicating that there is no further subdivision.

By inserting this nomenclature code in the platform, the importers get information related to import, such as eligibility for exemption from customs duties, import duties, prohibitions applied, and other legal measures. An interesting reference is an obligation imposed on those claiming, advertising, or indicating in the product label that the wine has organic characteristics. In particular, they are obliged to prove their claims by submitting a certificate of inspection. This aspect of the HS code can play a key role in CE compliance. Similar documentation requirements can be dictated to those declaring that the transportable goods have been produced following circular principles.

The remainder of this chapter focuses on addressing the SRQ4: *"What information requirements for CE visibility are captured by the examined blockchain-enabled information systems and how do the insights derived from them contribute to the further development of the CE visibility evaluation framework?"*. The insights provided by the literature were insufficient for detailing the basic CE visibility evaluation framework presented in Figure 4.2. Thereby, the thesis exploits the empirical data provided by the use cases (TradeLens, FoodTrust, Vinturas) to bridge this knowledge gap and develop a thorough framework that evaluates blockchain-enabled information systems on their ability to monitor the flows of materials and products in the CE context.

4.2. TradeLens

This section focuses on TradeLens, a blockchain-enabled container shipping platform that can enable CE auditing actors to monitor a cargo flow from a source to a destination by accessing logistics data and trade documents. To provide such visibility, TradeLens connects every actor involved in the shipment of goods, such as ocean carriers, inland truckers, and shippers (TradeLens, 2021a). The platform plays a vital role in the thesis. By reflecting on Figure 4.2, it can be observed that several different supply chains are involved in the CE flows. In other words, materials or products can be shipped from a seller to a buyer during every CE process. Indicatively, one can recognize the shipment of raw materials from sourcing to manufacturing, the shipment of finished products from manufacturing to sales, or the shipment of used products from use to collection and disposal. The thesis argues that TradeLens can support every possible shipment of materials and products from a seller to a buyer depicted in Figure 4.2.

4.2.1. TradeLens Overview

TradeLens is a consortium permissioned blockchain-based infrastructure developed by IBM and GTD Solution, a subsidiary of A.P. Moller Maersk. It connects the subjects involved in international trade, such as carriers and shippers, by allowing them to share shipment events (e.g., loading a lading asset on a vessel) and business documents (e.g., bill of lading and packing list). Its ultimate goal is to reduce information fragmentation, enhance transparency and ensure complete visibility throughout the route of a container (Rukanova et al., 2021; TradeLens, 2021b). These offerings are of paramount importance for international trade that suffers from bureaucracy, fraud, and data fragmentation (Popper & Lohr, 2017).

The surge of international trade in recent years thanks to globalization and eradication of trade barriers has exposed humanity to new risks enabling malicious actors to commit various frauds (Tan et al., 2011). According to the EU, these frauds can be classified into two broad categories, declared fraud and non-declared fraud. The first category contains the frauds related to mis-declaration of origin, mis-declaration of value, and mis-declaration of classification, whereas the latter refers to smuggling contraband, such as drugs and weapons (European Parliament, 2019). These illegal activities threaten the national economy, safety, and security, so their elimination is crucial. To address them, customs authorities intensified the inspections on cargoes crossing national borders and increased the data requirements from shippers (Tan et al., 2011).

Besides the apparent benefits of increased inspections for society, these measures are considered an enormous burden by traders influencing their efficiency and increasing their costs. Indicatively, the expenses related to customs compliance and clearance can range from 12.5 and 23 billion euros in the EU. This enormous amount includes direct costs, like the costs of providing the documentation needed for the goods shipments, delays, and opportunity costs. However, these estimations fail to capture indirect costs, such as procedural delays, such as time spent on inspections, spoilage or expiration of products, and lost sales (Urciuoli, Hintsa, & Ahokas, 2013). TradeLens deals with the abovementioned hiccups by enabling the supply chain ecosystem to exchange the necessary information in a secured, timely and confidential way. This information sharing can boost international trade by 15% benefiting national economies and creating new jobs (TradeLens, 2021a).

4.2.2. TradeLens Platform

Figure 4.4 captures the essence of the TradeLens, illustrating the shipping events and shipment data (structured data integrated in trade documents and unstructured data, such as scans and images) stored by the platform. As presented, the platform includes a broad range of information produced throughout the route of cargo from the seller in the exporting country to the buyer in the importing one, such as cargo details, trade documents, sensor readings, and custom filings. Seemingly, the shared information is associated with the ocean shipping industry, which amounts to 80% of total shipping goods (TradeLens, 2021a).

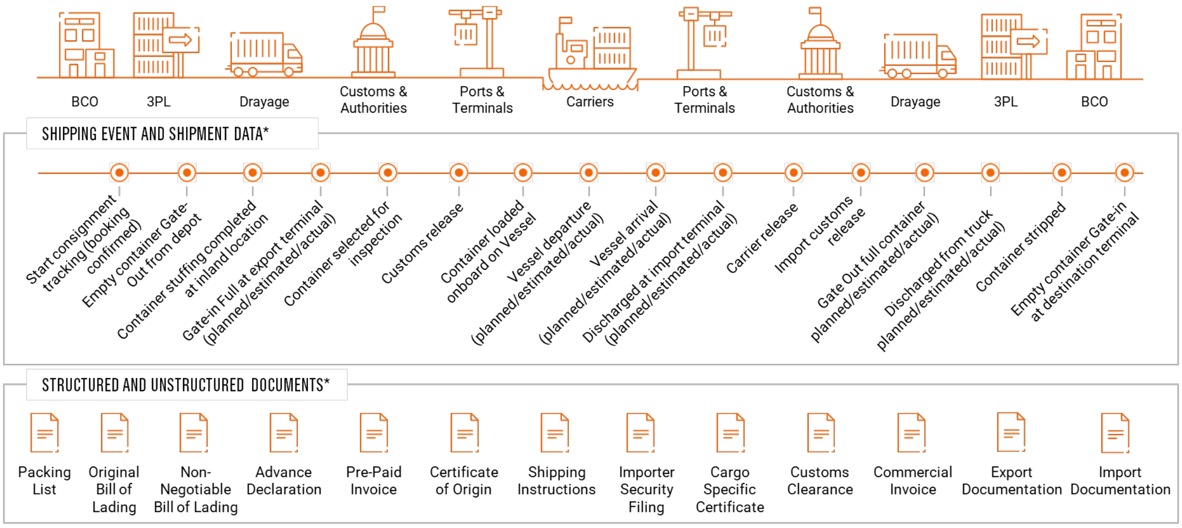


Figure 4.4: TradeLens platform (TradeLens, 2021a)

An interesting aspect about the above-described information is that is granted by its source. For instance, the commercial invoice and the packing lists are uploaded by the party that issues them, the seller (Rukanova et al., 2021; TradeLens, 2021a). As discussed in section 2.2, this information is of higher quality, considering that it is produced and used by the companies for their internal operational activities. By piggybacking this information, the CE auditing actors can better execute their mission, such as carrying out a risk assessment and inspections or enforcing compliance (Klievink et al., 2012; Tan et al., 2011; van Stijn et al., 2012). Currently, the uploading of this information to the platform is conducted via a user interface. However, this process can be automated further in the future through open Application Programming Interfaces (APIs) (Rukanova et al., 2021).

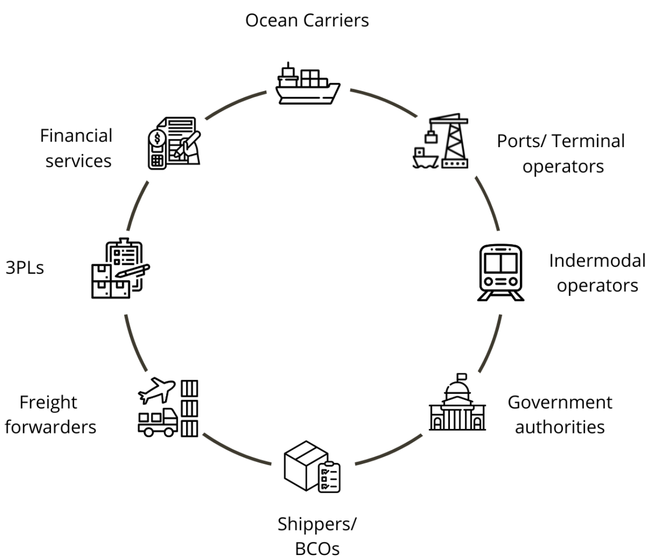


Figure 4.5: TradeLens ecosystem (TradeLens, 2018)

Equally beneficial is the collaboration and trust fostered among the ecosystem made up of all parties involved in global trade. Shippers, freight forwarders, state authorities, carriers, and customs brokers are a few illustrative examples of the network members, depicted in Figure 4.5. TradeLens, by dealing with data fragmentation, provides participants with the necessary means to carry out their mission more efficiently. For instance, custom authorities, by accessing business data, are able to carry out informed and more efficient risk assessments, crosscheck their data and reduce manual paperwork. Similarly, the availability of centralized information benefits shippers by providing them with the means needed to enhance the predictability of their activities, reduce safety stock inventory and validate fees and surcharges (TradeLens, 2021a).

It is vital to point out that TradeLens is not an obligatory information system that trade actors should use to exchange information with authorities. In contrast, the platform relies on voluntary data sharing between businesses and authorities. This voluntary aspect is articulated in the contractual agreement that parties accept when joining the platform. In particular, the interested parties agree that their information stored in the system can become available to the authorities involved in monitoring the flow of goods through national borders (Rukanova et al., 2021; TradeLens, 2021a). Such voluntary data sharing can also benefit participants by enabling them to experience benefits like trade facilitation (Rukanova et al., 2018).

TradeLens is a blockchain platform owned by IBM and GTD Solution, however, its goal is to be an open and neutral platform able to serve all the actors involved in the supply chain. In simple words, it aspires to enable various industry players with even competing interests to join the platform and engage in the collective choices, such as determining the participants' operational rights and making decisions regarding the platform design. For that reason, TradeLens has formed the TradeLens Industry Board, a group of actors that plays an important role in the development efforts of the platform (Rukanova et al., 2021; TradeLens, 2018). Currently, two leading carriers have joined the board, the CMA CGM and MSC (TradeLens, 2019).

Regarding its architecture, TradeLens is an open-source consortium permissioned blockchain platform relying its performance on the distribution of permissioned ledger across the network of parties. As discussed in chapter 2, a distributed ledger establishes a single source of truth and incentivizes the supply chain entities to share their information. The ledger (chain of blocks) contains copies of the shared documents, such as supply chain events and authority approval status, and maintains a full audit history. The immutability offered by blockchain makes tampering with the blocks an almost impossible task, whereas the attachment of new information results in the creation of new blocks. These transactions can become possible only with the consensus of the network. The consensus mechanism deployed by TradeLens is called proof-of-authority and allows only the authorized participants (parties involved in a specific shipment) to append new transactions to the chain (Rukanova et al., 2021; TradeLens, 2018).

Figure 4.6 illustrates the deployment model of TradeLens, which uses a cloud-based approach. The platform relies on the Hyperledger Fabric, an open-source permissioned modular and configurable blockchain platform developed by the Linux Foundation, which can act as a basis for the development of enterprise blockchain applications (Hyperledger Fabric, 2021; TradeLens, 2021a). The documents uploaded by the ecosystem participants are stored in a secured cloud document store provided by IBM. In other words, the data is not stored in the platform. Instead, TradeLens stores hash pointers of the data and documents on the platform, including a hash of the data or documents and a link to their specific location in the cloud storage. Therefore, as participants add an updated version of documents or data in the chain, a new hash pointer is appended in the chain (Rukanova et al., 2021; Tan et al., 2019).

Hash pointers are used for overcoming the privacy concerns arising from the enactment of the General Data Protection Regulation (GDPR). More specifically, GDPR entitles data owners to request the deletion of their personal data from information infrastructures ("the right to be forgotten"). However, the data captured on a blockchain platform cannot be erased, and consequently, data owners are unable to exercise their rights. Thereby, the deployment of hash pointers and the off-chain data storage enabled TradeLens to deal with privacy-related issues (Tan et al., 2019).

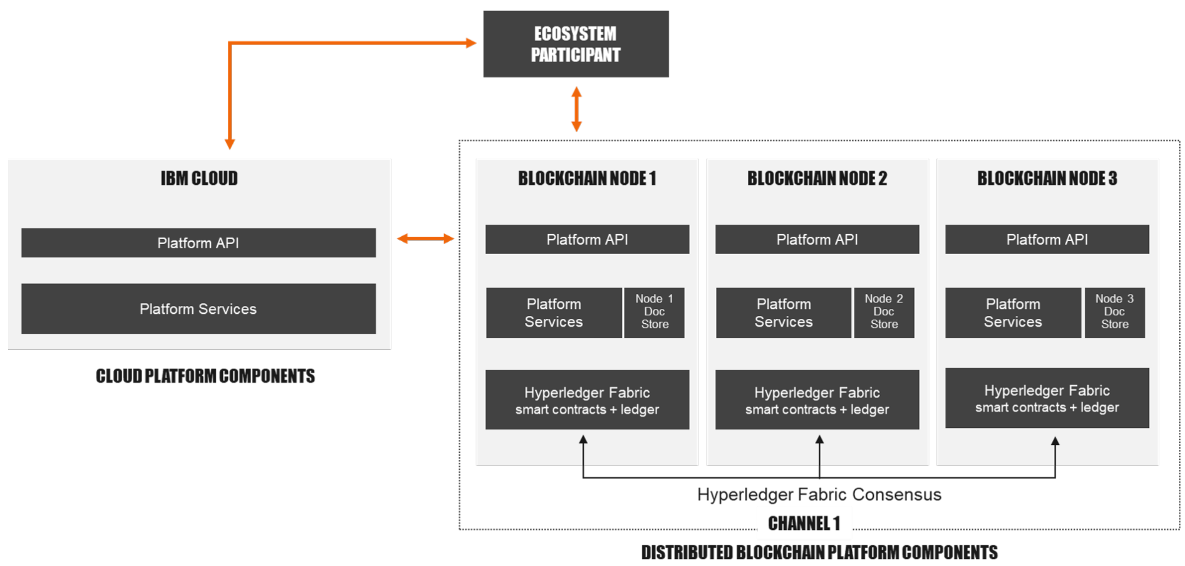


Figure 4.6: TradeLens deployment model (TradeLens, 2018)

To protect the data confidentiality of its participants, TradeLens broke down its network into smaller sub-networks, called channels. As highlighted in section 2.4, the creation of channels can prevent the leakage of sensitive and valuable business data to every network participant (Tan et al., 2019). This aspect is crucial in the supply chain domain consisting of geographically dispersed entities with often competing interests, different policies, and cultures (Abeyratne & Monfared, 2016; Saberi et al., 2019). Indicatively, carriers do not desire to share their data with their competitors. Taking this aspect into consideration, TradeLens developed separate channels for each participating ocean carrier. Each channel includes several nodes (actors/computers that possess a copy of the ledger), hosted and managed by the participants (TradeLens team, ocean carriers, etc.) (TradeLens, 2018). For the time being, solely the carriers and the TradeLens team can become nodes in a channel, however, more parties, like freight forwarders, are expected to be able to become nodes in the future (Rukanova et al., 2021). The data shared via each node are stored in dedicated blockchain-managed data storage (TradeLens, 2018).

Figure 4.7 illustrates the network topology, which can be described as a permission matrix. This topology ensures that documents or data shared via a channel are stored only in the participating nodes and can be accessed only by the channel participants. Channel participants get selected based on their organization's role, while their identity is not known to the network thanks to the deployment of cryptographic mechanisms. This permission structure prevents the disclosure of commercially sensitive data to actors participating in different channels (Rukanova et al., 2021; TradeLens, 2021a).

Figure 4.8 dives deeper into the permission matrix by depicting the access and operational rights granted to participants. These rights are defined according to the TradeLens Data Sharing Specification, which articulates the foundational data sharing rules. Finally, the TradeLens node enables the other supply chain actors (e.g., shippers, freight forwarders, and financial services providers) to access the data stored in the platform or use the platform services without possessing their node, in case they are allowed to get such visibility (Rukanova et al., 2021; TradeLens, 2021a).

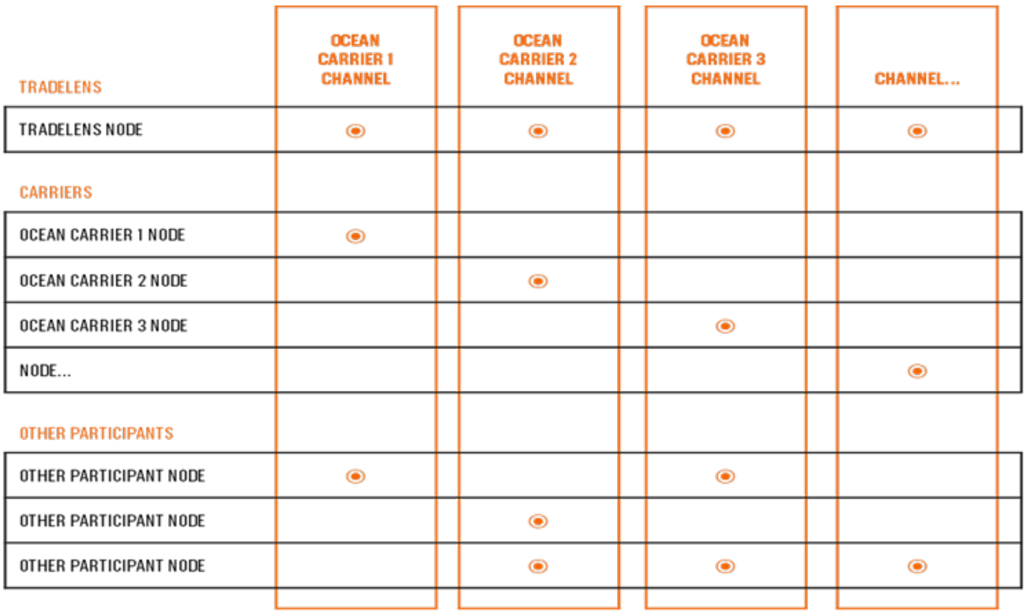


Figure 4.7: TradeLens network topology (TradeLens, 2021a)

Another essential element of TradeLens is the application of smart contracts for controlling the transactions that can be recorded to the ledger. The platform codifies vital business processes and distributes them across the network, specifying the responsibilities of each ecosystem participant. For instance, the import and export clearances are organized into the blockchain (TradeLens, 2021a).

Events	Transport Service Buyer	Consignor	Consignee	Origin 3PL Agent	Destination 3PL Agent	Export Customs Broker	Import Customs Broker	Request Party	Import Authority	Transport Service Provider	Origin Marine Terminal	• • •
Planned stuffing start	○	◉	○	◉	○	○	○	○	○	○	◉	
Planned stuffing completed	○	◉	○	◉	○	○	○	○	○	○	◉	
Actual loaded on truck	○	○	○	◉	◉	○	○	○	○	◉	○	
Estimated gate out	○	○	○	◉	◉	○	○	○	○	◉	◉	
Actual gate in	○	○	○	◉	◉	○	○	○	○	◉	◉	
• • •												
Documents												
Booking Confirmation	○	○	○	○	○	○	○	○	○	◉	◌	
Shipping Instructions	○	◉	○	○	○	○	○	◉	○	○	◌	
Bill of Lading	○	○	○	○	○	○	○	○	○	◉	◌	
Sea Waybill	○	○	○	○	○	○	○	○	○	◉	◌	
House Bill of Lading	○	○	○	◉	○	○	○	○	○	◉	◌	
• • •												

◉ Participant has an obligation to provide (publish) the data, where relevant/applicable

○ Participant has read access (can subscribe) to the data

◌ Participant has no access to the data

Figure 4.8: TradeLens data sharing model (TradeLens, 2021a)

4.2.3. The visibility provided by TradeLens

Figure 4.4 shows in a straightforward way the visibility currently provided by TradeLens. Namely, the container shipping platform provides visibility from the seller in the exporting country to the buyer in the importing one. To offer this visibility, it brings together the actors involved in international trade and incentivizes them to exchange logistics data and trade documents via the platform interface. An important aspect regarding the information captured by the platform is that it is provided by its source in real-time. Open APIs enable the data owners to directly publish their data and communicate them across their ecosystem. In this way, TradeLens contains accurate, complete, timely, and reliable data concerning containerized goods (TradeLens, 2021a).

This section delves deeper into the visibility provided by TradeLens by explaining some key trade documents (presented in Table 4.2) that can be a vital source of information for CE purposes. Section C.1 (Appendices) presents examples of some of these documents. In addition to them, TradeLens captures some product-related documents, such as health certificates, veterinary certificates, fumigation certificates, and inspection certificates. It is important to highlight that when documents are uploaded to the platform, they become available to all authorized parties in real-time. However, the data remains under the control of its owner. That is to say, only the members of a channel can access them (TradeLens, 2021b). Regarding the key events captured by the platform, Figure 4.4 illustrates the most crucial ones.

Trade documents	Description	Information
Commercial invoice	A legal document serving as the contract and proof of sale between the seller and the buyer. It is used by the customs during the clearance process for estimating duties and taxes (TNT, 2021).	Seller, buyer, purchase order number, invoice number, carrier, quantity, item code, price, total sale amount, seller's bank information and account, payment terms, country of origin of goods (Rukanova & Tan, forthcoming 2021).
Packing list	An exhaustive description of the contents of a container. It is not obligatory during customs clearance, but its inclusion in a shipment can facilitate the process (FreightRight, 2021).	Seller, purchase order number, carrier, ship, quantity, item code, weight, ship, seller's bank information and account, payment terms, country of origin of goods, carrier, seal number, driver's signature (Rukanova & Tan, forthcoming 2021).
Certificate of origin	A document certifying that goods included in an export shipment have been procured, produced, or processed in a specific country. It is used by customs in the importing country to advocate whether goods are eligible to enter their jurisdiction or receive special treatment (ICC, 2021).	Buyer, seller, country of origin, transport details, remarks, marks and number of items, number and kind of packages, description of goods, quantity, seller's declaration, certification body (ICC, 2021).
Shipping instructions	A document prepared for the carrier including details about the goods and requirements regarding their shipment (DCSA, 2020).	Shipper, consignee, notify party, weight, quantity, shipping mark, place of origin and destination, booking number, vessel, port of loading and discharge, container number, seal number, payment terms, description of goods (DCSA, 2020).
DGD document	A document issued for carriers describing dangerous goods or materials contained in a shipment. It certifies that the cargo has been packaged, labelled, and declared based on the applicable regulations (DCSA, 2020).	Shipper, consignee, carrier, transport document number, additional handling information, number and date of the vessel, port of loading and discharge, destination (IATA, 2021).
Bill of lading	A legal document containing information regarding the kind, the quantity, and the destination of the goods being shipped and confirms the receipt of goods by the carrier (DCSA, 2020).	Bill of lading number, booking number, export references, vessel, port of loading and discharge, purchase order number, type and brand of goods, pieces, weight, measures, freight charges, export fee, document service and terminal handling service (Rukanova & Tan, forthcoming 2021).
ENS declaration	A safety and security declaration submitted to the customs that provides information regarding the goods being shipped (European Commission, 2021d).	Description of cargo, EORI (Economic Operators Registration and Identification) number of shipper and consignee, items code, weight, number and type of packages, container and seal number and place of loading, route (countries that passed), border entry point, vehicle (Hardy, 2020).
Importer security filing	A legal document providing details about the goods being imported (European Commission, 2021a).	Exporter, importer, invoice number, shipment reference, sender's VAT no, receiver's VAT no, description of goods, quantity, value, weight, commodity code, type of export, reason for export (DHL, 2021).
Importer security filing	A legal document requested by customs for all ocean cargo imports and used for identifying high-risk shipments (CBP, 2009).	Seller,buyer, importer of record number / FTZ applicant identification number,consignee number, manufacturer (or supplier), ship-to party, country of origin,commodity harmonized tariff schedule number, vessel stow plancontainer status messages (CBP, 2009).

Table 4.2: Key trade documents stored by TradeLens

The visibility provided by TradeLens is very important for refining the CE visibility evaluation framework. TradeLens offers insights about the cargo flow from a source (Place of acceptance, PLA) to a destination (Place of delivery, PLD). The thesis argues that TradeLens can support every possible shipment of materials or products in a closed supply chain. As discussed, the CE flows contain several different supply chains, that is to say, several different shipments, such as the shipment of raw materials from sourcing to manufacturing, and the shipment of used products from use to collection and disposal.

Figure 4.9 illustrates how the basic CE visibility evaluation framework (Figure 4.2) can be detailed based on the insights offered by TradeLens. Seemingly, TradeLens provides visibility on a container-level, it does not contain insights about the products stored in a container.

However, it enables the monitoring of a shipment from a place of acceptance to a place of delivery. Figure 4.9 depicts four layers, the visibility provided by TradeLens, the events stored, the documents stored, and the actors involved in a shipment. The first layer related to visibility resembles the domain model (Figure 4.1). The reason is that the domain model was developed to evaluate the quality and value of external data sources associated with the movements of products from a place of acceptance to a place of delivery via vessel. Therefore, it captures the same supply chain processes supported by TradeLens. Section 4.1.1 described the processes involved in a shipment in detail. Finally, it is essential to mention that the different curves related to the vehicle refer to different itineraries.

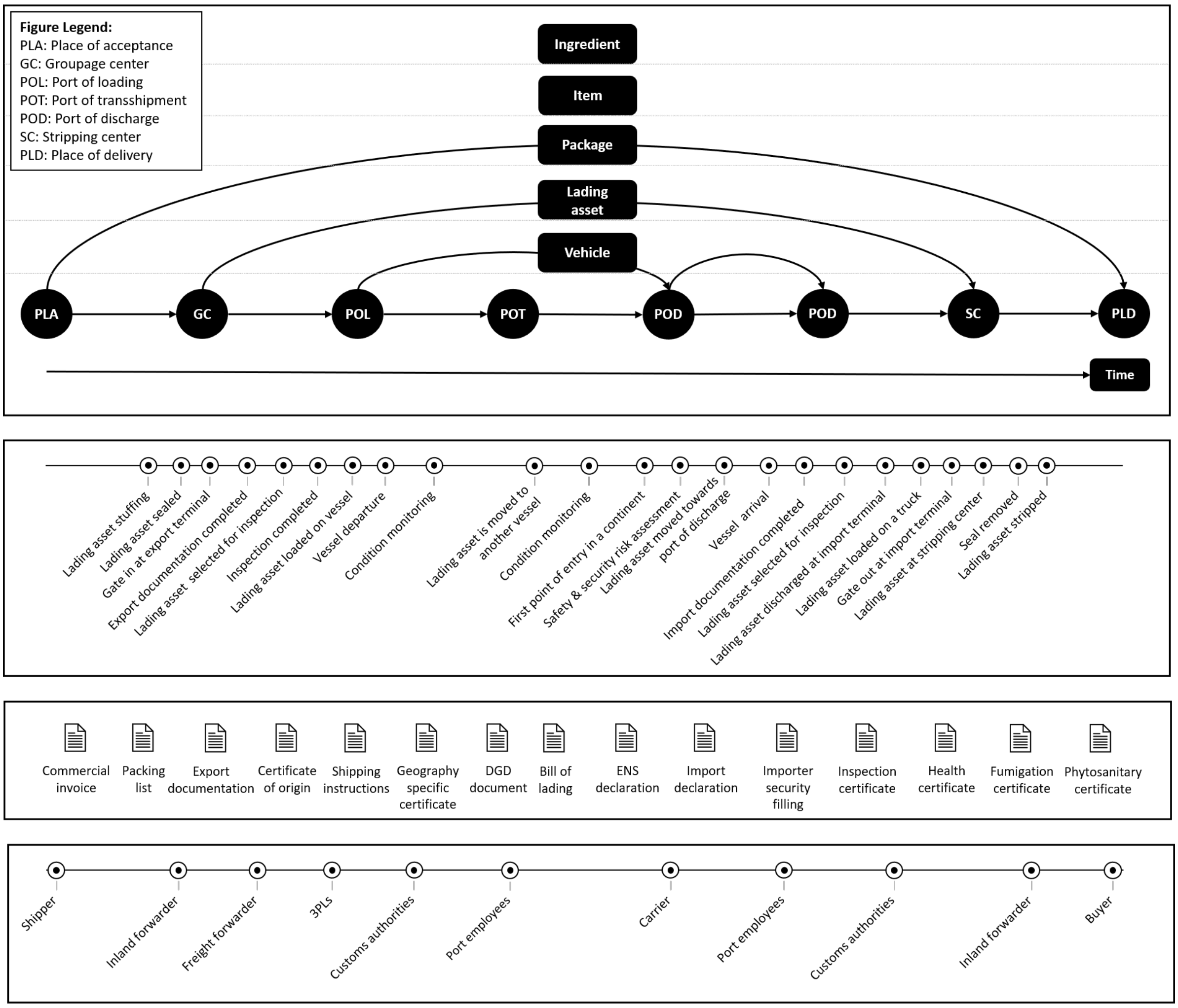


Figure 4.9: The CE visibility evaluation framework based on TradeLens

4.3. FoodTrust

This section analyzes FoodTrust, a blockchain-enabled platform that can play a crucial role in the monitoring of CE policy instruments. The platform can enable the CE auditing actors to trace the provenance of products and get insights into the sustainability of the practices used during the sourcing of raw materials and production. As its name indicates, FoodTrust aims at establishing transparency and trust in the food system by leveraging the data trapped in organizational silos (IBM, 2021). Although, FoodTrust deals with food products, which are not the focus of the thesis, the visibility that it provides can be valuable for detailing the basic CE visibility evaluation framework (Figure 4.2). The thesis studies this use case to identify how item-level visibility can support CE transition. It is argued that the visibility offered by FoodTrust about food products can be also offered for non-food products, such as electronic components. This argument is supported by the existence of the Blockchain Transparent Supply (BTS) platform, analyzed in this section, which enables companies to develop their blockchain network and trace any asset. BTS is closely related to FoodTrust, considering that IBM developed it by extracting the core software behind FoodTrust.

4.3.1. Blockchain Transparent Supply

The Blockchain Transparent Supply is a blockchain-based platform developed by IBM. The platform enables companies to design their own data-sharing ecosystem consisting of their supply chain partners and foster supply chain visibility. In this way, IBM aims at assisting the business world to tackle vital modern problems, described already in the thesis, such as data fragmentation, paper-based and inefficient data sharing, and the occurrence of frauds. Blockchain has the potential to connect actors dispersed throughout the supply chain by allowing them to maintain a distributed ledger acting as a single point of truth (IBM, 2020b, 2020a).

BTS is an open-source permissioned blockchain platform, based on Hyperledger Fabric, that distributes a ledger across a network of authorized and authenticated participants. Participants are able to upload their data and documents to the ledger and decide who has the right to access them. Thanks to the immutability provided by the blockchain, the information captured in the ledger cannot be tampered with, removed, or changed. Like TradeLens, this information is not stored on the platform, but on a secured cloud document store provided by IBM. The platform only stores the hash pointers of the data and documents, a design choice described in more detail in section 4.2.2 (IBM, 2020a).

BTS leverages the immutability, finality, and transparency offered by blockchain to deal with provenance issues. Identifying the provenance of goods depends on having information about their origin, source, and the history of their ownership. By creating a single and untampered history of an asset (from the outset to decommission or from source to consumer), blockchain enables businesses and consumers to trace its entire journey throughout the supply chain. The availability and the distribution of such a wealth of information across a diverse group of actors boost transparency and enhance trust. In today's world, trust in a brand relies on communicating to consumers information regarding the ethical and sustainable characteristics of business processes and the product characteristics. In brief, BTS provides proof of authenticity (thanks to the availability of uncorrupted evidence), traceability, transparency, and trust (IBM, 2020a).

An interesting aspect regarding BTS is that it helps companies to develop their platform based on their needs and IBM helps them to run it securely and at scale. Companies can select a use case of their interest, create their business model, build their network, and decide the terms of engagement. In this way, companies reap the benefits of the IBM development capabilities and do not need to develop a blockchain-enabled platform from the scratch. BTS platform can be implemented in several use cases related to shipping and logistics, tracing the provenance of foods, drugs, materials, or valuable products, and proving the authenticity of materials. So far, the platform has been used in the establishment of seven networks, Farmer Connect (coffee network), ATD (tire network), ATEA (seafood network), VinAssure (wine network), PharmaPortal (pharma network), eChain (electronic component), IBM FoodTrust (food trust network), while a Pizza network will be launched in the future. Except for FoodTrust, the other networks are corporate convened (IBM, 2020a).

Indicatively, ATEA is a data-sharing platform developed for seafood companies in the Nordics that enables them to share information to consumers regarding the path of seafood in the supply chain. Moreover, the aquaculture farms can communicate the sustainability of their practices. The platform exploits the capabilities of IoT devices to monitor the temperature of the food in real-time, improve food freshness, expand shelf life, and limit waste. VinAssure is a wine network developed to inform consumers about wine's origin and quality. The platform provides visibility from vineyard to consumer, stores data related to the temperature conditions and the handling of wine in the supply chain and facilitates dispute settlement in case of low wine quality (IBM, 2020a).

It is important to highlight that BTS and FoodTrust are two different IBM offerings. As Figure 4.10 shows, FoodTrust allows companies to participate in a global food network consisting of farmers, suppliers, processors, distributors, retailers, and consumers. On the other hand, BTS provides companies with the opportunity to create their self-branded network (IBM, 2020a). Even though the thesis focuses on FoodTrust, a well-documented platform by IBM, BTS can be proved vital for CE purposes. BTS can enable the creation of various independent networks focused on materials or products to promote multi-company collaboration, transparency, and trust, deal with provenance issues and offer traceability on an item-level (IBM, 2020a).

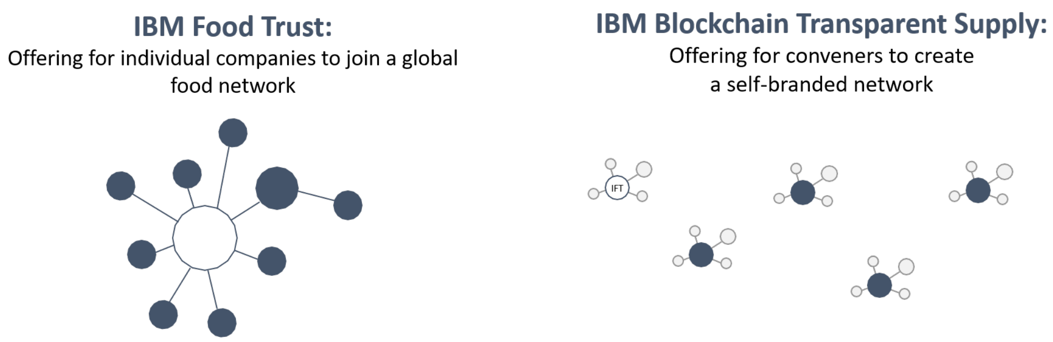


Figure 4.10: Comparison between FoodTrust and BTS (IBM, 2020a)

Figure 4.11 illustrates the capabilities of the BTS platform. Through the core BTS solution, companies can receive a set of modules, capabilities, and services that enable them to develop their data-sharing ecosystem. More specifically, the solution makes possible the tracing of an asset throughout the supply chain in a few seconds, provides essential document management and sharing features, onboarding, member management, and technical support services. Furthermore, these capabilities can be extended to offer real-time inventory and cold chain insights (temperature data via IoT devices), allow the establishment of smart contracts and the integration of other capabilities and APIs on top of the BTS platform, and enable consumers to access product information via QR codes and a mobile app (IBM, 2020b, 2020a).

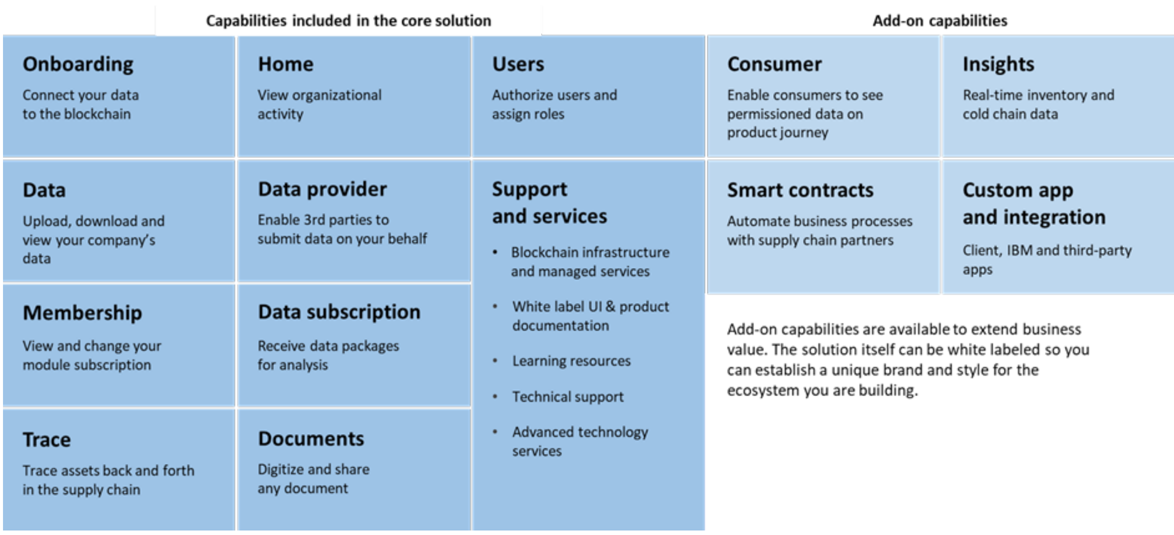


Figure 4.11: Capabilities of IBM Blockchain Transparent Supply (IBM, 2020a)

4.3.2. FoodTrust

FoodTrust is a cloud-based permissioned blockchain platform developed by IBM. FoodTrust constitutes the basis on which the BTS platform was developed. In other words, IBM extracted the core software from FoodTrust and integrated it into a new blockchain offering that enables companies to develop their own blockchain network. The difference between these offerings lies in the fact that IBM is actively involved in the exploitation of FoodTrust, while in the BTS platform, IBM has the role of the technology provider (IBM, 2020a).

As its name indicates, FoodTrust focuses on establishing transparency and trust in the food system by bringing together the actors involved, from the farmer to the end consumer, and enabling them to exchange information (IBM, 2020b, 2020a). The issues that FoodTrust is called to solve are contemporary. In today's world, consumers are able to buy any food product, irrespective of the season, the location, or the environment. This food availability has exposed the food supply chain to new dangers and has increased its complexity. That means that trust in the food supply chain is not given. Consumers are increasingly demanding more information regarding the provenance and the quality of food products. FoodTrust aims at fulfilling this demand by harnessing the capabilities of blockchain, dealing with information fragmentation, getting the benefits of the data produced throughout the supply chain, and making this information available to end consumers (FoodTrust, 2018; IBM, 2021).

The availability of such data insights enables interested actors to trace food products throughout their journey from the farmer to consumers and take immediate action when needed. For example, in case of crop diseases, authorities or retailers can locate the infected lots by accessing the “blockchainized information” and carry out targeted recalls. In this way, the platform limits the possibilities of delivering infected food to the market and increases consumers’ trust in the food ecosystem. An indicative example of the traceability provided by the platform is the Walmart case. Walmart wanted to improve its responsiveness in case of a foodborne illness outbreak. For that reason, it incentivized its suppliers of leafy greens to join FoodTrust and upload their data to the platform. By storing all the data related to harvesting, processing, packaging, and shipping in FoodTrust, Walmart managed to reduce its trace time from roughly 7 days (when using manual processes) to 2.2 seconds (IBM, 2020a; Miller, 2018).

Moreover, FoodTrust fosters trust in the food ecosystem by allowing the efficient and timely detection of food frauds. The digitization and storage of data in the ledger in conjunction with the decentralization and data immutability offered by the technology bring transparency to the system and prevent malicious actors from committing any type of fraud. This trust offered by the platform can be translated into an enhanced brand reputation and increased economic gains for the network participants (FoodTrust, 2018). Namely, “green” companies, by communicating the sustainability of practices, can grow their profitability, as environmentally conscious consumers are willing to purchase eco-friendly products regardless of their cost (Saberi et al., 2019).

Equally pivotal are the productivity improvements and cost reduction that ecosystem participants can experience by adopting the technology. More specifically, participants are provided with a wealth of information, which can help them pinpoint possible process deficiencies, optimize their business activities, forecast demand, prolong the shelf-life of their products, eliminate waste, and manage their inventory more effectively (FoodTrust, 2018).

To fulfill its mission, FoodTrust equips participants with a shared, replicated, and permission-based ledger, which contains documents and events about the food ecosystem. Participants have limited operational and access rights, specified based on their needs and role. In other words, they can edit and view only a portion of the published content. This permission model is vital for preserving privacy and safeguarding actors’ interests. The data recorded on the ledger is secured thanks to the immutability provided by the blockchain, that is to say, it cannot be modified or deleted. Data editing can be done solely by appending new information. This aspect creates an audit trail of all data uploaded and edited (IBM, 2021).

The architecture of FoodTrust is similar to that of the BTS platform. In other words, it is designed based on Hyperledger Fabric and deploys a cloud-based approach. An interesting aspect is the deployment of Trust Anchors as a consensus mechanism (Practical Byzantine Fault Tolerance consensus mechanism). Trust Anchors are leading network participants, like wholesalers or food retailers, responsible for keeping up the integrity of the ledger and safeguarding security, privacy, and permission guarantees. They possess a full copy of the ledger on their node, and they are able to verify transactions, view the submitters and the hashes. However, they do not have access to the decrypted data (FoodTrust, 2018; IBM, 2021; Lacity, Steelman, & Cronan, 2019).

As already discussed, FoodTrust collects a wide range of data to accomplish its mission. While it is worth mentioning that IBM does not own the data shared via the platform and cannot exploit them or share them to satisfy its commercial or economic interests (IBM, 2021). The collected data can be classified into the following five categories:

1. Master data: data related to facility locations, trade products, and lots.
2. Business transactions: data concerning purchase orders, shipping, and receipt confirmations.
3. Documents data: documents, like critical certificates, inspection documents, deployment of sustainable practices, scores, and expiration dates.
4. EPCIS (Electronic Product Code Information Services) events: real events occurring throughout the supply chain. These events are: Observation (an observation like scanning a good), Transformation (irreversible transformation of an item, like a sliced fruit), Commission (creation of an item, like harvesting), Decommission (deletion of an item), Aggregation (grouping items), and Disaggregation (ungrouping items).
5. Payload data: important data regarding food, such as temperature and humidity.

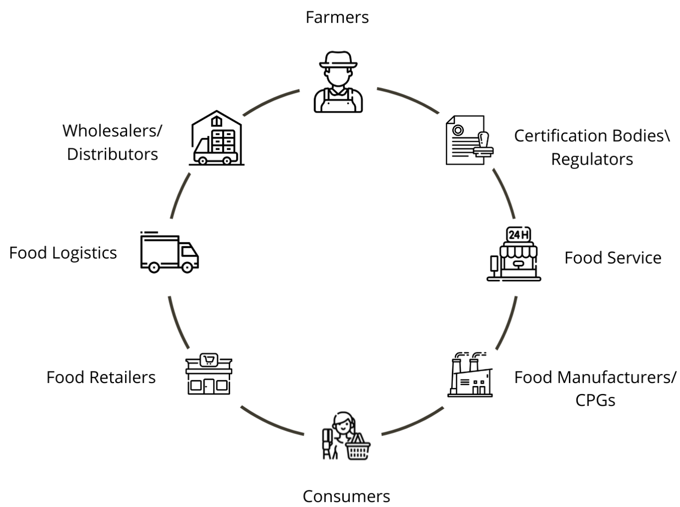


Figure 4.12: FoodTrust ecosystem (FoodTrust, 2018)

Figure 4.12 depicts the groups of actors that have joined FoodTrust, so far. To develop an efficient data-sharing system and enhance trust in the food industry, the members have to collaborate closely, regardless of their interests. However, their interests can be shielded through the IBM Food Trust Advisory Council, consisting of members' representatives.

The Advisory Council ensures the integrity of the platform by assisting with establishing the principles of engagement and monitoring the application of the governance model. Its primary responsibility is to make sure that FoodTrust is beneficial for the community members by ensuring that the policies satisfy their needs and values and that the platform evolves continuously (FoodTrust, 2018).

Finally, FoodTrust provides participants with the opportunity to automate business decisions, through the use of smart contracts. Smart contracts refer to pre-agreed terms or business rules deployed to automate costly and time-intensive processes and deal with possible conflicts among agents. The participants can create a smart contract in a private channel within two or more parties who have their personal node. The contracts run on company-specific nodes in a private channel, to which only the involved parties have access. An illustrative example is the monitoring of storage conditions for dispute resolution in case of low quality (FoodTrust, 2018; IBM, 2021).

4.3.3. The Carrefour Case

Carrefour S.A. is a French multinational retail company having its headquarters in Boulogne-Billancourt, France. The company possesses more than 12,000 shops dispersed in three different geographic regions, Europe, Latin America, and Asia, and operates its own e-commerce websites. It operates a wide variety of shops, including hypermarkets, supermarkets, smaller supermarkets, convenience stores, cash and carry shops, and hyper cash stores. It offers a broad spectrum of food products (e.g., vegetables, meat, fish), nonfood products (e.g., clothes, toys, books), and services (e.g., vehicle hire and pharmacies) (Carrefour, 2021a; Reuters, 2021).

Following its corporate mission to provide its customers with services and products of high quality, Carrefour partnered with IBM and joined the FoodTrust network in 2008. Interestingly, the company was among the first adopters of FoodTrust, together with other key industry players, such as Walmart, Nestle, Dole, and Kroger. Carrefour's objective was to initiate a global food traceability standard across its supply chain, from farmers and producers to consumers. In this way, it wanted to meet the consumers' demands for more transparency in the food industry. Through FoodTrust, Carrefour could equip consumers with reliable information regarding its products, including their origin, quality, nutritional properties, the presence of allergens or uncertain substances, and other specific characteristics. Consumers could access this information by scanning QR codes on the product label with their mobile phones (Carrefour, 2018; IBM, 2020a).

In March 2018, Carrefour blockchainized its first product, chicken. By scanning a QR code, consumers could get a great deal of information about the chicken, such as the breeding location, feed, antibiotic use, a relevant video, and its journey in the supply chain. Over time, Carrefour has implemented blockchain to more food products, like tomato, citrus fruits, Norwegian salmon, and infant milk. Its vision is to blockchainize all its premium Filière Qualité Carrefour (FQC) food products, by 2022 (Ledger Insights, 2021; Neerman, 2018). It is important to highlight that Carrefour focuses solely on communicating this information with consumers and not with authorities. In other words, unlike TradeLens, authorities are not part of its current ecosystem.

An interesting example of a blockchainized product by Carrefour is Mousline purée. In 2019, Carrefour collaborated with Nestle, one of the founding members of FoodTrust, to provide its consumers with visibility on the entire supply chain of the product. This case has more complex characteristics than the former one, considering that a potato puree contains multiple ingredients needed to be traced. Figure 4.13 depicts the insights that consumers get via their mobile phones. Namely, consumers can follow the path of the product from the Nestlé factory to Carrefour shops. Furthermore, they can obtain information about the manufacturing facilities, the product composition (e.g., the variety of potatoes used), the farmers of the potatoes, the production data (e.g., the specific product line), the production process, quality control parameters, storage times the packaging (e.g., made by recyclable materials) and the location of warehouses (Nestle, 2019). It is worth mentioning that Carrefour is about to enrich the data provided to consumers by deploying IoT devices able to monitor product conditions, such as temperature. Such a development can increase consumers' trust in each product. Moreover, FoodTrust can support any type of information that Carrefour or any other company wants to add, such as certificates.

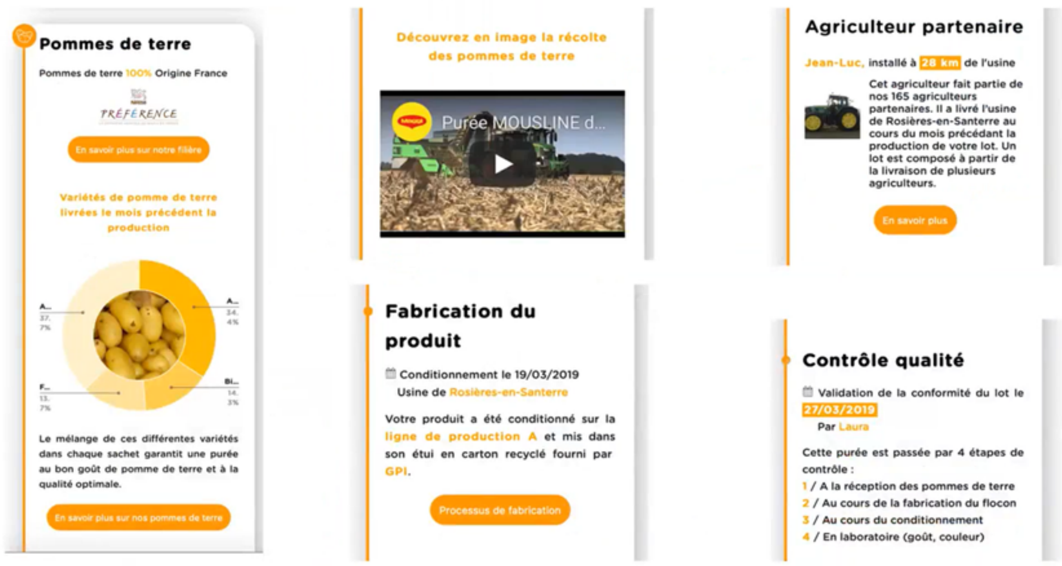


Figure 4.13: Example of the traceability offered by FoodTrust (IBM, 2020a)

The next section focuses on organic textiles, the first non-food product blockchainized by Carrefour (Ledger Insights, 2021; Spencer, 2021). By utilizing the information that Carrefour offers to consumers, the thesis highlights the visibility provided by FoodTrust. FoodTrust can be applied to various products providing different visibility based on the peculiarities of the use case. However, all the use cases have one characteristic in common, the need for equipping interested actors with reliable information about the provenance of a product. This aspect makes FoodTrust a worth-exploring platform for CE purposes, as the traceability that it offers for food products can be offered for finite materials and technical products, as well. The existence of the BTS platform, which deals with every possible traceability issue and enables companies to develop their own network, reinforces this argument.

4.3.4. The visibility provided by FoodTrust

In March 2021, Carrefour announced the expansion of blockchain traceability to its organic textile products. The company has been owning a textile brand named TEX BIO related to home textiles and baby clothes produced by 100% certified organic cotton, originating from sustainable agriculture. Organic cotton is a plant fiber, cultivated by natural fertilizers, without using chemical products from non-GMO (Genetically Modified Organisms) seeds. Carrefour's objective was to reassure its consumers that the cotton is non-GMO and produced in certified farms, which meet the standards of organic production and offer excellent working conditions to their employees. The company started deploying blockchain for the products distributed in France and Spain, but its future plan is to expand this initiative to other countries (Deslandes, 2021; Spencer, 2021; Ledger Insights, 2021).

Carrefour shows a significant focus on producing organic textiles of high quality. Every step of cultivation and production is based on high standards, and it wanted to communicate this information with consumers. Regarding cultivation, it collaborates with more than 4500 small organic cotton farmers in the regions of Maharashtra and Madhya Pradesh in central India. India has a suitable climate, know-how, and experience in producing excellent organic cotton, and Carrefour wanted to leverage these advantages (Deslandes, 2021; Spencer, 2021; Ledger Insights, 2021).

Cotton cultivation is carried out based on traditional natural methods and respects the organic requirements. Similar high standards are kept at every phase of processing, from farming to finished goods (e.g., home textiles or baby clothes). In addition to that, each stage is monitored by independent bodies. The organic cotton used by Carrefour complies with two certificates, a GOTS certificate (a certificate denoting that each phase of manufacturing satisfies strict regulations) and an OEKO-TEX standard 100 certificate (a certificate awarded to textiles that do not contain harmful substances). Furthermore, Carrefour provides its partners with good working conditions and compensates them fairly (Deslandes, 2021; Spencer, 2021; Ledger Insights, 2021).

Similarly, Carrefour enables consumers to access all the blockchainized information via their mobile phones. Consumers can receive information about the place and date of production, the cotton composition, the practice of cotton farming, the method of production, environment-related certificates, and the journey of cotton in the supply chain. In this way, Carrefour fosters transparency and well-informed consumption (Deslandes, 2021; Spencer, 2021; Ledger Insights, 2021).

The remainder of this section will concentrate on the visibility that FoodTrust offered to consumers regarding the path of specific baby clothing (Baby X3 TEX BIO Long Sleeve Bodies) in the supply chain. Its journey started with the sourcing of materials (e.g., cotton in this case), which took place in the regions of Maharashtra and Madhya Pradesh from

1/6/2019 to 12/31/2019. The cotton cultivation was done without using synthetic pesticides (non-GMO) and produced in certified farms meeting the standards of organic production. Carrefour sourced the cotton through a trusted third party, Cotton Connect. Cotton Connect is a company headquartered in London that assists brands with the sourcing of sustainable cotton and other natural fibers from India or other areas. Cotton Connect closely monitors the processes from cultivation to ginning. Moreover, Cotton Connect engages in several activities, such as training the farmers on sustainable practices, protecting human rights, and ensuring ethical production (Carrefour, 2021b).

Subsequently, the organic cotton was ginned between 10.12.2019 to 01.07.2020 by the company, Shree Ram Fibres India Pvt. Ltd. Ginning is a process that follows harvesting and separates cotton fibers from their seeds. The cotton produced revived a GOTS certificate n ° 3939393, valid until 8/9/2021. Next, the organic cotton was span at the infrastructure of Nagreeka Exports Ltd. Spinning transformed cotton into cotton threads, used later for producing the final product (Carrefour, 2021b).

The cotton threads were converted into cotton fabric through weaving, and then the fabric was treated and dyed to get a color. These processes took place at two separate companies, Sharanya Fabs and KPR Mill Ltd. The quality of these phases was guaranteed by the OEKO-TEX standard 100 certificate, ensuring the absence of dangerous chemicals, safety, and the quality of the fabric. The last step of manufacturing involves the cutting and the sewing of cotton to produce the final product. The manufacturing was done by Kitex Ltd, between 7/9/2020 and 11/1/2021. The company is GOTS certified 10/31/2020, that is to say, consumers can be confident that the organic qualities of the product. Section C.2 (Appendices) contains examples of the abovementioned certificates. Finally, the finished product was shipped to France, from 5/1/2021 to 11/1/2021 (Carrefour, 2021b).

The above-described analysis about the visibility provided by FoodTrust to final consumers can be used for further refining the basic CE visibility evaluation framework, presented in Figure 4.2. FoodTrust plays a crucial role in the thesis since it can fill in the existing visibility gap between sourcing of raw materials and manufacturing and offer some valuable insights regarding sales, such as information about the retailer (the Carrefour in this case). Furthermore, FoodTrust stores some data related to product design, like the use of organic cotton for the production of baby clothes. Figure 4.14 depicts the refined and elaborated CE visibility framework based on the insights gained by the Carrefour case. Seemingly, FoodTrust offers visibility on both ingredients and items, an aspect currently missing by TradeLens. However, a black box can be noticed between manufacturing and sales since FoodTrust gives limited information concerning the distribution of products. Moreover, it does not store data related final consumer. As discussed earlier, such visibility is of great importance for CE purposes.

It is worth mentioning that the examined case is simple in terms of the locations, where the key processes take place. In other words, the sourcing of raw materials (e.g., harvesting) and every phase of manufacturing are carried out in the same country, India. However, this is not always the case, these processes may take place in different jurisdictions. In this case, more black boxes in the visibility offered by FoodTrust will emerge, considering that FoodTrust does not provide insights about the distribution of products or materials. TradeLens can address such lack of visibility, as presented in section 4.2, it can support every shipment of materials and products.

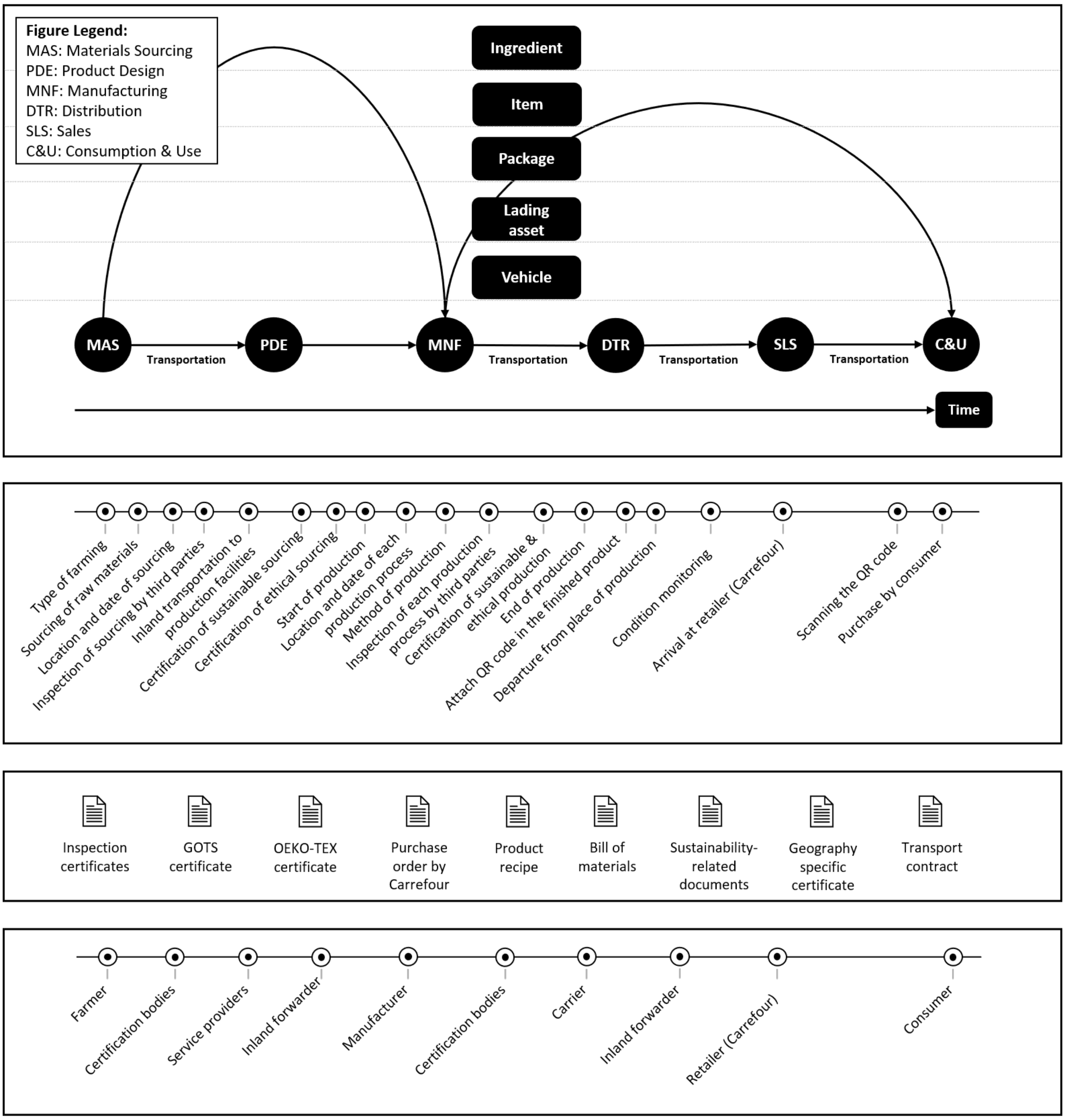


Figure 4.14: The CE visibility evaluation framework based on FoodTrust

4.4. Vinturas

This section studies Vinturas, a consortium formed by a number of European logistics service providers (LSPs) operating in the supply chain of finished vehicles. Vinturas offers real-time visibility in the journey of vehicles from production to dealer by exploiting the unique blockchain capabilities (Vinturas, 2021b). The platform plays an essential role in the thesis. Apart from providing insights regarding the transportation (mainly inland transportation) of items (e.g., vehicles), it can inform the CE auditing actors about the transportation part of the remarketing of second-hand vehicles. Remarketing resembles the reuse disposition option described by EMF, in which a product is resold without any further processing (Ellen MacArthur Foundation, 2016).

4.4.1. Vinturas Overview

Vinturas is a consortium formed by several European LSPs in the finished vehicle industry, Axess Logistics, NVD, Koopman, AutoLink, and Groupe CAT. These LSPs combined their forces to harness the opportunities that blockchain provides to develop a data-sharing digital platform that fosters collaboration and trust between the industry players (depicted in Figure 4.15). In this way, the consortium can tackle crucial challenges in the domain and deliver high value for all participating actors (Vinturas, 2021a).

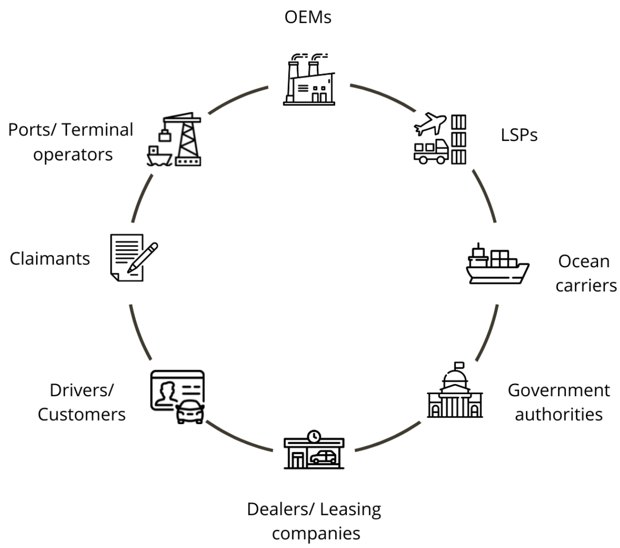


Figure 4.15: Vinturas ecosystem (Vinturas, 2021a)

The supply chain of finished vehicles suffers from a lack of real-time supply chain visibility due to paper-based processes. Most transactions are currently conducted manually, based on the exchanging of papers. Papers that contain critical information, such as damage reports, usually travel throughout the supply chain alongside the vehicle. Consequently, the actors involved in transportation cannot get real-time information about the status of the asset and make informed decisions. For instance, dealers cannot view the state of a vehicle in the supply chain and organize the delivery process to their customers professionally. The lack of instant visibility also prevents original equipment manufacturers (OEMs) from identifying inefficiencies in the delivery of their products (Vinturas, 2021a).

Equally problematic is the business inefficiency observed in the industry. The industry players have not devoted their efforts and investments to developing a solid and common IT-based solution, and as a result, they may face serious operational challenges in the future. Indicatively, OEMs' costs may grow significantly due to capacity shortage. While at the same time, they may fail to meet the increasing consumers' demands for receiving superior services. The transportation of vehicles is prone to plenty of inefficiencies during all stages, such as damages, missing vehicles, and lack of collaboration, which hamper the on-time delivery. The lack of a coherent approach puts a strain also to LSPs, who may experience serial issues due to drivers' shortages. An IT solution can foster a collaborative business model, enabling them to maximize their benefits by consolidating their shipments and using fewer drivers (Vinturas, 2021a).

Inefficiencies can be also noticed in the remarketing automotive industry. The industry is expanding over time, moving from a national level to a European level. This development involves growing cross-border transactions exposing industry players to new dangers and challenges. The remarketing business relies its performance on timely delivery, as the value of a second-hand car is depreciating day by day. Thereby, any potential barriers in the supply chain, like missing documents, can impact the business. Furthermore, the industry is susceptible to integrity issues, like mileage and VAT fraud (Vinturas, 2021a). An indicative example is that importers may damage a vehicle purposely to reduce the payable taxes as fewer taxes are imposed in case of damages [3].

Vinturas addresses the above-described pains of the new and used vehicle supply chain by digitalizing all paper-based processes and offering real-time supply chain visibility to stakeholders involved (e.g., LSPs, OEMs, fleet owners and dealers). Supply chain visibility can reduce frauds, improve business processes and delivery time, enhance customers' experience, and lower costs. This is feasible thanks to the trusted environment, auditability, and immutability provided by the blockchain (Vinturas, 2021a).

4.4.2. Vinturas Platform

Figure 4.16 shows the underlying principle on which Vinturas relies its functionality. LSPs play a pivotal role in the platform by sharing documents and events about the journey of a vehicle in the supply chain (e.g., transportation, delivery) in the network. In this way, the platform offers real-time end-to-end visibility to the dealers and OEMs, the primary data consumers. This visibility is currently offered to many European regions, including Scandinavia, Ireland, Benelux, Baltics, and France. Interestingly, Vinturas is open to every other stakeholder involved in the finished vehicle supply chain (e.g., leasing companies) and interested in using its digital services and collaborating with the other industry players. Blockchain facilitates data sharing by establishing a trusted environment that ensures the integrity of the transactions and promotes collaboration (Vinturas, 2021a, 2021b).

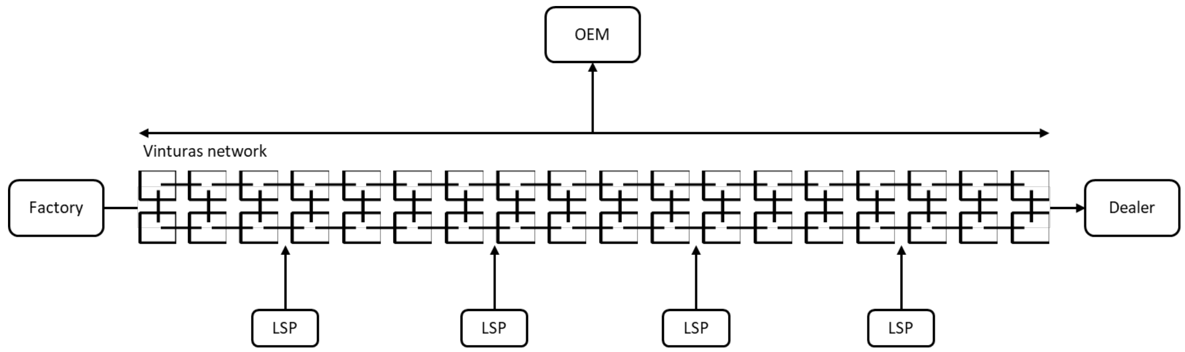


Figure 4.16: The underlying principle of Vinturas (Vinturas, 2021b)

An important aspect regarding the functionality of Vinturas is the collaboration that it enables between LSPs and subcontractors or charters. LSPs usually collaborate with third parties, offering transport services, to carry out the transportation of their vehicles. In this way, they reduce their operational costs, since they can adjust the use of trucks based on their business. That is to say, they can employ more trucks during hectic times and less when they have few transport jobs. Vinturas enables LSPs and subcontractors to exchange the necessary information (e.g., transportation instructions, documents, or damages reports) via its platform (see Figure 4.17). Moreover, to accelerate real-time data sharing, Vinturas equips drivers with a mobile application. This offering is very important for LSPs, as they are able to monitor the status of every outsourced transport, identify inefficiencies and provide better services to their customers (Vinturas, 2021b).

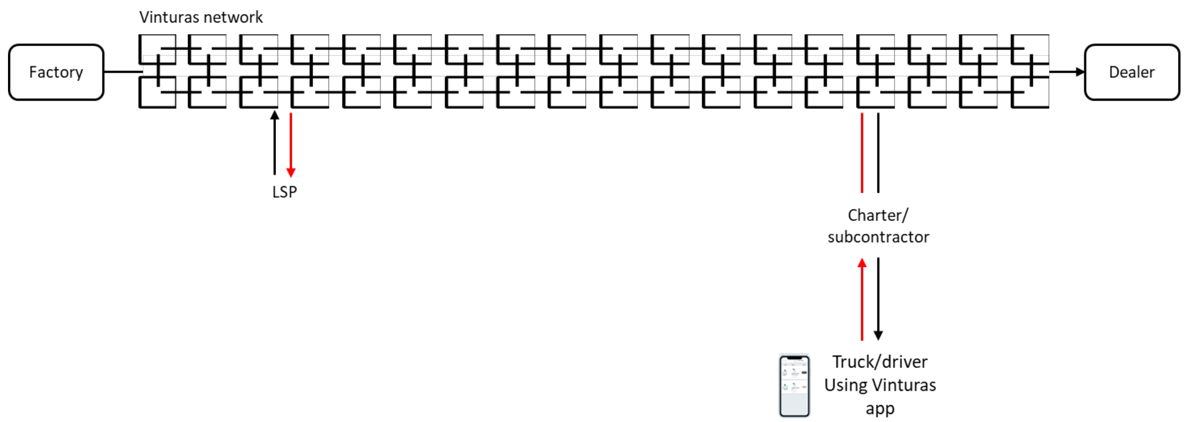


Figure 4.17: Collaboration between LSPs and subcontractors/charters (Vinturas, 2021b)

As discussed earlier, one of the major pains in the finished vehicle supply chain is damages to vehicles. Damages during transportation constitute a considerable cost for businesses since they need immediate repair. On many occasions, it could be challenging to identify their source and consequently the party responsible for taking corrective actions mostly due to lack of transparency. As presented in Figure 4.18, Vinturas facilitates the capturing of damages throughout the supply chain by facilitating data sharing between the LSPs involved in the handling of a vehicle, including transportation, storage, or other value-added services.

In case of damages, the responsible party uploads in the network a damage report and informs the ecosystem about the incidence. This real-time visibility enables participants to organize repairs before the arrival of the vehicle and avoid hampering its journey in the supply chain (Vinturas, 2021b).

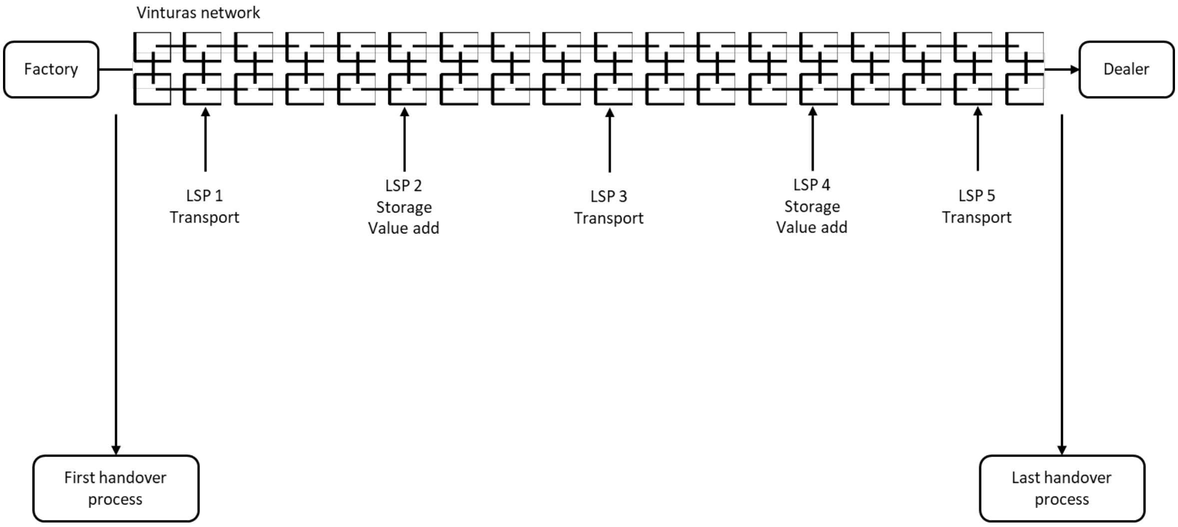


Figure 4.18: Handling of damages (Vinturas, 2021b)

The objective and real-time reporting of damages eliminate disputes among parties regarding responsibility for the damages. Via Vinturas, LSPs can share the related data with claimants that want to submit a claim for damage facilitating and speeding up the process. LSPs can also communicate the damage data with OEMs enabling them to acquire an overview of all registered damages in the supply chain. Such knowledge can help OEMs to pinpoint the root causes and undertake corrective measures to prevent such incidences in the future. By doing so, they can enhance customer experience by offering faster and better services and consequently improve the brand image (Vinturas, 2021a, 2021b).

Concerning its architecture, Vinturas is a consortium permissioned blockchain platform. It distributes a ledger that contains documents and events related to the supply chain of finished vehicles across a network of authorized and authenticated participants. The data stored in the ledger remains under the possession of its owner and becomes visible only to specific parties. In other words, participants can decide to whom they want to make their data available. For instance, LSPs can permit authorities to access their data to receive facilitation regarding inspection and auditing processes (Vinturas, 2021a, 2021b).

By deploying the unique blockchain characteristics (e.g., decentralization, immutability, auditability), the platform establishes a single and uncorrupted truth. As a result, it discourages the commitment of frauds in trading processes or the occurrence of other adverse incidents, such as disputes on deliveries and damages. It is important to highlight that like TradeLens and FoodTrust, Vinturas does not store the data on the platform but uses hash-pointers overcoming privacy concerns related to the GDPR (Vinturas, 2021a, 2021b).

4.4.3. The visibility provided by Vinturas

Vinturas is a blockchain-based data-sharing platform operating in the supply chain of finished vehicles. In other words, it focuses on the segment from the factory to the dealer. As illustrated in Figure 4.19, several parties can participate in the process between these two ends, including LSPs, sea carriers, port terminals, and customs. Vinturas does not capture information related to the use of a vehicle or the consumer. In other words, a car out of the distribution chain is not traced by the platform. However, tracing can arise again if the car reenters the supply network through remarketing (Vinturas, 2021b).

Remarketing refers to the purchase of a used vehicle by a dealer and resembles the reuse disposition option described by EMF. However, Vinturas covers solely the transportation aspect related to the remarketing process. Afterward, a dealer may carry out a wide range of value-added activities to the asset, such as technical inspection, damage expertise, and maintenance. It is worth mentioning that also a new vehicle may go through value-added activities throughout the supply network by an LSPs or a dealer, such as software upgrades [3].

Seemingly, Vinturas does not cover the journey of vehicles in the supply chain after their lifecycle. That is to say, the transportation of scrapped vehicles for dismantling or disposal purposes. Such processes usually involve a cross-border element since non-functional cars are moved to regions with lenient regulations, outside of the EU. For example, second-hand cars can be exported to another continent for dismantling, and subsequently, their parts can be shipped to another one. This case is against EU regulations, as the EU aims at retaining components and materials within its territory for direct reuse [3].

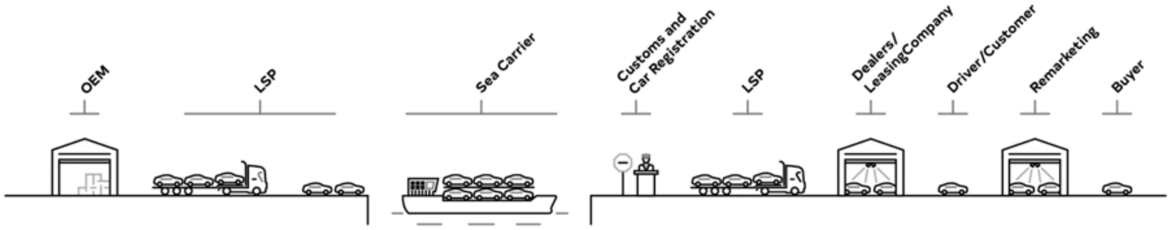


Figure 4.19: The processes covered by Vinturas (Vinturas, 2021a)

Vinturas is an initiative launched by LSPs interested in gaining supply chain visibility. For that reason, the platform captures in real-time all the events (logistics and technical data) and documents related to the path of a vehicle in the supply chain. The underlying principle behind its operation is that LSPs produce a considerable amount of data (e.g., starting a transport, delivering a vehicle, etc.) that may be useful to share with both each other and other stakeholders. In addition to that, any essential information regarding the configuration of a vehicle, like mileage and technical history, can become available, benefiting the network. From a technical point of view, Vinturas can capture any data produced during the journey of a vehicle from producer to dealer (Vinturas, 2021a).

Vinturas achieves real-time tracking of vehicles by integrating all the data (events and documents) available in the supply chain. Figure 4.20 provides an overview of the visibility offered by Vinturas. As presented, dealers can view the identity and any other product-related information (e.g., brand, color) of a vehicle, access the technical (e.g., mileage, damages, maintenance, inspections) and logistics status, track its location, access key documents, and estimate the arrival time at their premises. In addition, they can obtain an overview of every previous and future delivery, monitor the performance of their network, and pinpoint every actor involved in transportation. In simple words, the entire provenance of an asset is captured by the platform (Vinturas, 2021b). Table 4.3 contains information about three data sources that convey essential information about a vehicle. Section C.3 (Appendices) presents examples of the documents discussed in this section.

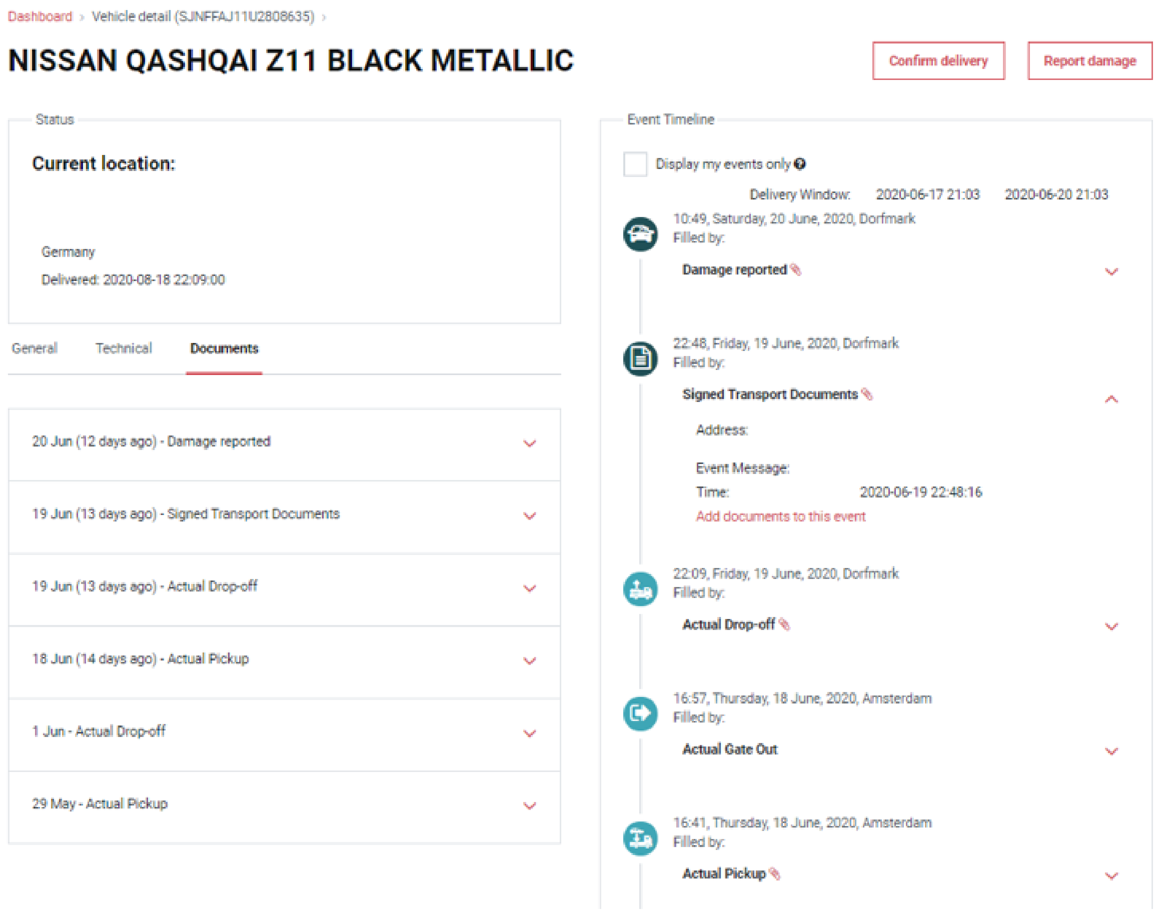


Figure 4.20: Example of the traceability offered by Vinturas (Vinturas, 2021a)

Data	***Description***	***Information***
Vehicle Identification Number (VIN)	A unique code that identifies a vehicle, composed of 17 characters (numbers and capital letters) (Scully, Fildes, & Logan, 2005).	Country of origin, manufacturer, vehicle type, model, body type, restraint system, transmission type, engine code, model year, the plant that assembled the vehicle and the serial number (Scully et al., 2005).
CMR	A convention that governs the international transportation of freight by road. It is conside-red the bill of lading of road transportation. It is obligatory and identifies the transporters' responsibilities (GEFCO, 2021).	Date of the document, transporter's details (identity, address, registration number), description of goods (nature, quantity, weight, volume), expediter's identity, recipient's identity, place of loading and unloading, number of packages, packaging method, charges about the transportation of goods, instructions for customs formalities, confirmation of compliance with CMR regulations (GEFCO, 2021).
CVO	A document that determines the origin of a product, the country where a product was produced (KVK, 2021).	Consignor, consignee, country of origin, transport details, remarks, description of goods, quantity, verification of the origin of the goods by authorities (KVK, 2021).

Table 4.3: Key data sources stored by Vinturas

The visibility provided by Vinturas plays a key role in the design efforts. Vinturas can help with further elaborating the basic CE visibility framework (Figure 4.2) by offering insights regarding the transportation of items (e.g., vehicles) from production to end-consumer. A noteworthy difference between Vinturas and TradeLens, also involved in the transportation of goods, is that the former covers transportation by road as well. Equally valuable for the thesis is the visibility offered concerning the remarketing process of second-hand vehicles, which resembles the reuse disposition option described by EMF.

Figure 4.21 depicts the elaborated version of the CE visibility framework based on the knowledge gained by Vinturas. Vinturas covers the supply chain of finished vehicles from production to dealer and the remarketing process, offering visibility both on a vehicle- and item-level. More specifically, the visibility on a vehicle-level is related to the distribution of a vehicle by transport means, such as a truck, vessel, or train. It is important to mention that the platform mostly covers inland transportation, an aspect currently missing from TradeLens and FoodTrust. Tracing the movement of vehicles by vessel is not currently among its main functionalities. However, in the proof of concept executed, the platform captured the data provided by a sea carrier. On the other hand, item-level visibility refers to capturing data (e.g., documents and events) related to the vehicle. The different curves presented in the model refer to different itineraries of either the item or the transport means.

The framework is divided into four layers, namely, the level of visibility by the platform, the events captured, the documents stored, and the actors involved, respectively. Being a consortium formed by European LSPs, Vinturas currently covers vehicle transportation in the EU. Its reach can be expanded to new territories by adding new actors to the platform. It is worth highlighting that the platform mostly focuses on transportation by road. However, during the proof of concept, a short sea shipment of vehicles was tested, proving that such visibility can be easily supported [3].

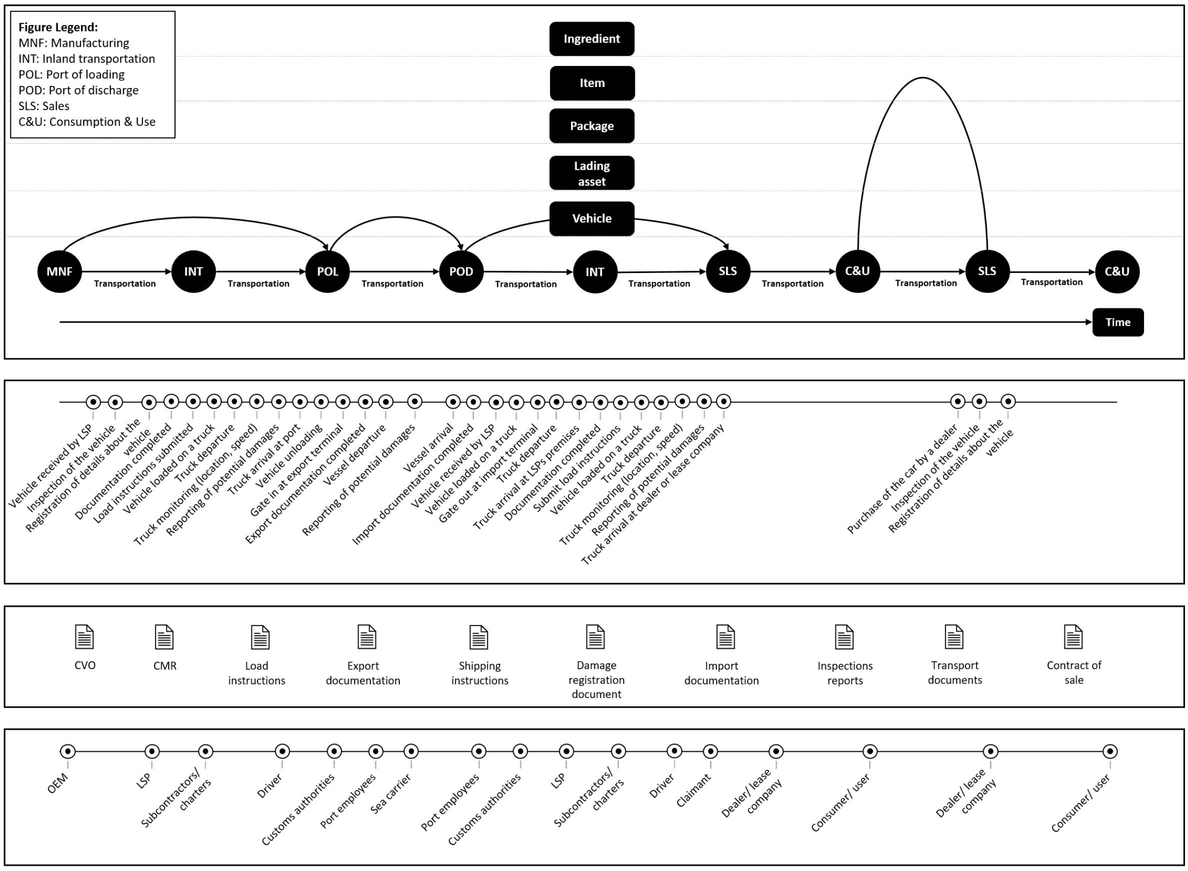


Figure 4.21: The CE visibility evaluation framework based on Vinturas

4.5. The CE visibility evaluation framework

This section focuses on translating the knowledge acquired so far in this chapter into the final CE visibility evaluation framework. The framework needs to fulfill its primary objective, enabling the CE auditing actors (e.g., policymakers, customs, banks) to assess the available blockchain-based data pipeline solutions on their ability to act as CE monitoring systems and enforce compliance with the CE policy instruments. A CE monitoring system should shed light on the journey of materials and products in a closed-loop supply chain.

The flows of materials and products became explicit in the basic CE visibility evaluation framework presented in Figure 4.2. However, Figure 4.2 does not capture the visibility required in every CE process, and consequently, it cannot be used as the final framework. For that reason, the thesis elaborated it further by exploiting the insights provided by the literature and the use cases. Namely, the study of the literature and the use cases produced four detailed versions of the framework that delve deeper into the fundamental processes depicted in Figure 4.2.

The development of the four elaborated frameworks (Figure 4.3, Figure 4.9, Figure 4.14, and Figure 4.21) surfaced the visibility needed to be offered in every process covered by these frameworks. For instance, the framework produced based on FoodTrust highlighted that blockchain-based information systems need to provide ingredients-level visibility during the sourcing of raw materials and item-level visibility during production and sales. The knowledge acquired regarding the level of visibility required in every process involved in both from sourcing of raw materials to consumption and during the disposition options (e.g., reuse and recycle) should be illustrated by the final evaluation framework. This illustration can be done by following the way of thinking presented in the domain model (Figure 4.1) developed by Hofman et al. (forthcoming 2021).

To identify the level of visibility provided by examined blockchain-based applications, the thesis scrutinized the events and documents captured by them. This scrutinization showed that the blockchain-based applications apply Francis's definition of supply chain visibility in the real world. Francis points out the need to capture the identity, location, status of the entities transiting the supply chain and the events that they undergo. For instance, TradeLens implements this definition by storing data related to the identity, location, status, and events of a lading asset (container). Vinturas captures the same insights for the supply chain of finished vehicles (item).

Furthermore, it can be noticed that the information systems capture the condition of the supply chain entities. Indicatively, Vinturas captures the damages that vehicles may experience during transportation. While FoodTrust uses IoT devices to monitor the condition (e.g., temperature) of food products moving the supply chain (IBM, 2021). Carrefour has not yet exploited the capabilities offered by the IoT devices, but it is among its future plans. Monitoring this aspect is essential in the CE context. Potential damages, chemical and structural changes, or other contaminations can influence the suitability of materials or products for recycling or direct reuse (Jayaraman et al., 2008; NEN, 2007).

The observations regarding the need to capture the identity, location, status, events, and condition of the supply chain entities should be considered in the design of the final output. In simple words, the CE visibility evaluation framework should assess the available blockchain-based information systems based on their ability to offer the above-described insights (e.g., location, status, etc.). Equally significant for the final output is to depict the information tools discussed in this chapter (e.g., product labeling, EU-driven databases, materials passports, and HS codes). In this way, the framework will inform the CE auditing actors about the visibility that can be provided by other available sources. For instance, product labels can inform them about the design choices of products, like dismantlability and recyclability.

Taking into account the requirements identified in chapter 3 (Table 3.1) and the analysis of this chapter, the design phase produces the CE visibility evaluation framework presented in Figure 4.22. The framework consists of three layers. The first layer represents the desired CE visibility. In other words, it describes the aspects that blockchain-based information systems need to cover to accelerate the CE transition. The thesis claims that such systems need to offer visibility on the complete journey of materials and products in a closed supply chain. The grey rectangles illustrate the level of visibility required in every stage of the supply chain. In addition, the first layer can act as an evaluation layer enabling the CE auditing actors to visualize the parts of the supply chain covered by the examined information infrastructures.

In this way, they can realize which parts are not covered by the existing infrastructures and incentivize the development of new ones. This aspect becomes clear in section 5.1, where the thesis maps the examined blockchain-based information systems on the framework.

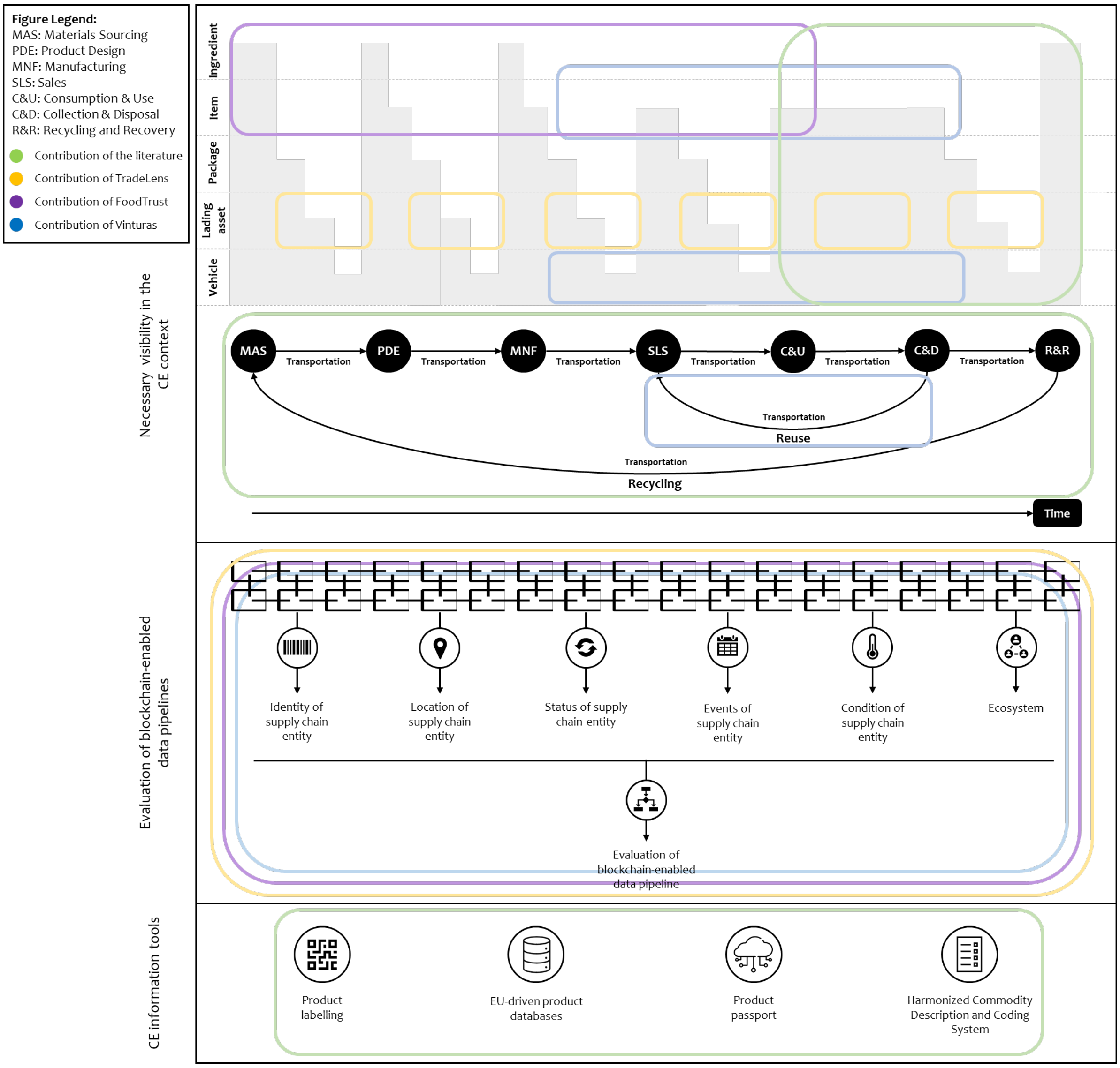


Figure 4.22: The CE visibility evaluation framework produced by the design phase

The second layer informs the CE auditing actors regarding which information they need to extract from the blockchain-enabled information systems to evaluate their potential to serve the CE purposes. The thesis argues that to conclude about the parts of the supply chain covered by a system, the auditors should examine the data captured. This data needs to capture the identity, location, status, events, and condition of the supply chain entities. Furthermore, the auditors should examine the ecosystem of the infrastructures under evaluation, that is to say, their participants. As highlighted by the functional requirement, FRQ.13, having such knowledge can facilitate their mission to enforce compliance with CE policies. The third layer presents four information tools that can offer valuable insights about the materials or products.

Figure 4.22 shows also the contribution of the literature (section 4.1) and the use cases (section 4.2, section 4.3, section 4.4) to the produced CE visibility evaluation framework. The literature review set the foundations of the final framework by surfacing the underlying processes in the CE context (see Figure 4.2). Moreover, it dived deeper into the recycling process, highlighting the visibility needed in the post-consumption phase of the framework. This aspect was covered by Figure 4.3, developed by using the literature around reverse logistics, the closed-loop supply chain, and recycling. The literature also contributed to the final framework by identifying some additional information sources or tools that can be exploited by the CE auditing actors.

The empirical data provided by the use cases (TradeLens, FoodTrust, and Vinturas) determined the level of visibility needed in the processes involved before consumption. Indicatively, TradeLens highlighted the container-level visibility needed in the transportation of materials and products. FoodTrust explicated the ingredient-level visibility required in the materials sourcing and product design and the item-level visibility needed from product design to sales. Finally, Vinturas pinpointed the vehicle- and item-level visibility required in the transportation of vehicles. It should be mentioned that neither the examined architectures nor the literature offered insights into the package-level visibility. However, such visibility is important in the CE context since several products can be packed into a package to be transported.

Equally pivotal was the contribution of the use cases to the identification of the type of data needed to be accessed by the CE auditing actors when evaluating a blockchain-enabled information system. Namely, it was proved that each examined blockchain-based architecture captures data about the identity, location, status, events, and condition of the supply chain entities and the actors involved. Therefore, the thesis suggests that a blockchain-enabled information system needs to offer these insights to serve CE purposes. This aspect is illustrated in the second layer of the evaluation framework.

4.6. Conclusions

This chapter addressed the third activity of the MFDSR, design and develop the artifact. It produced the CE visibility evaluation framework by answering the SRQ3 and SRQ4. The design phase elicited information from both the literature and the use cases (TradeLens, FoodTrust, and Vinturas).

Initially, it answered the SRQ3: *"How can the information requirements needed to support the trace of an item throughout its life cycle serve as a basis for the CE visibility evaluation framework?"*. To do so, it received as input the knowledge acquired by the SRQ2 and developed a basic CE visibility evaluation framework (see Figure 4.2). This framework depicted the basic processes that materials or products go through in the CE context. However, it could not serve as the final research output considering that it did not satisfy all the framework requirements identified in chapter 3.

To overcome this deficiency, the research focused on further elaborating the basic framework by exploiting the information offered by the literature, namely, information tools (product labeling, EU-driven databases, product passport, and HS codes), reverse logistics, and recycling. The literature review enriched the knowledge base of the project and detailed some aspects of the framework, but it could not offer solid insights regarding the path that materials or products follow from materials sourcing to consumption and during the reuse disposition option. For that reason, the thesis studied three blockchain-based information systems. In this way, it dealt with the SRQ4: *"What information requirements for CE visibility are captured by the examined blockchain-enabled information systems and how do the insights derived from them contribute to the further development of the CE visibility evaluation framework?"*.

The first information system examined was TradeLens. TradeLens is a blockchain-based container shipping platform that can enable the CE auditing actors to monitor a cargo flow from a place of origin to a place of destination. To do so, it captures shipment events and documents. The platform played an essential role in the development efforts. The thesis pinpointed that the CE context may involve multiple shipments of materials or products between a seller and a buyer that can be supported by TradeLens. The insights derived by this iteration created a detailed version of the basic CE visibility evaluation framework (see Figure 4.9). This model clarified the visibility offered by the platform. TradeLens offers visibility on a container-level, but it does not contain detailed insights about the products or materials stored in a container. This aspect is crucial for CE compliance, so the thesis examined FoodTrust, as well.

FoodTrust is a blockchain-based application that can allow CE auditing actors to track the provenance of products. The platform played an essential role in the thesis by leading to the development of an elaborated version of the basic evaluation framework (see Figure 4.14). The model showed that the platform can contribute to CE compliance by capturing data about materials sourcing, product design, manufacturing, and sales. This visibility is offered on ingredient- and item-level. The analysis surfaced a compelling finding of FoodTrust. Namely, IBM has extracted the core software behind it and developed a new blockchain platform called BTS. BTS enables companies to select a use case of their interest, develop their blockchain network, and trace any asset. These offerings made BTS a worth-exploring platform since it can provide the same visibility as FoodTrust for non-food products as well, such as electronic components.

Chapter 4 also studied Vinturas, a consortium of European LSPs operating in the supply chain of finished vehicles. The platform can allow the CE auditing actors to receive visibility about the path of vehicles from production to dealer. Moreover, it covers the transportation element of the remarketing of second-hand vehicles, an interesting aspect for CE compliance. Remarketing resembles the reuse disposition option, which expresses the direct reuse of products without further processing. Vinturas can expand the capabilities of the CE auditing actors by offering visibility to an aspect not addressed by the other platforms, the transportation of products by truck. The information derived by this iteration led to a new detailed version of the framework (see Figure 4.21), which revealed that Vinturas provides visibility on both vehicle- and item-level.

The insights derived from the literature and the use cases contributed to the development of the CE visibility evaluation framework, presented in Figure 4.22. However, it remains an open issue whether the produced framework has fulfilled its objective. This issue is tackled by chapter 5, which demonstrates the framework and evaluates its effectiveness.

5

Framework Demonstration & Evaluation

Chapter 5 deals with the fourth activity of the thesis by answering the SRQ5: *"To what extent does the developed framework evaluate the ability of blockchain-enabled data pipeline solutions to provide the visibility needed to support CE policy instruments?"*. This activity combines two activities described by Peffers et al, the demonstration and evaluation of the artifact. Thereby, it is divided into two sub-activities (demonstration and evaluation).

The demonstration phase demonstrates the CE visibility evaluation framework produced in the design phase and describes how it can be used by the CE auditing actors to support their CE agendas. Subsequently, it implements the framework to a case to test its feasibility. This step constitutes a weak form of evaluation, as if the framework addresses the problem in one case, then it might be able to do likewise in other cases.

The evaluation phase evaluates the demonstrated CE visibility evaluation framework. Its goal is threefold. Initially, it assesses the ability of the framework to achieve its purpose. Secondly, it judges whether the requirements defined in chapter 3 have been satisfied. Thirdly, it tries to identify opportunities for refining the framework further (formative evaluation). The thesis fulfills these goals by executing an ex-ante and naturalistic evaluation strategy.

The chapter is divided into four sections. Section 5.1 contains the demonstration of the CE visibility evaluation phase. Whereas Section 5.2 tests its feasibility by applying it to a case about the journey of glass bottles in the closed-loop supply chain. Afterward, Section 5.3 evaluates the produced framework trying to attain the abovementioned three goals. Finally, Section 5.4 concludes the chapter by answering the SRQ5.

5.1. Framework Demonstration

This section demonstrates the artifact produced in the design phase (chapter 4). Figure 5.1 illustrates the demonstrated CE visibility evaluation framework and clarifies how it can be deployed to facilitate CE compliance. The CE auditing actors can use the first layer of the framework to map the examined blockchain-enabled information systems and realize which parts of the closed-loop supply chain are covered by them. In this way, they can reach a conclusion regarding the extent to which the information systems serve their interests by monitoring the CE flows. Moreover, they can pinpoint black boxes in CE visibility, non-covered parts of the closed-loop supply. Box 5.1 contains a detailed description of the CE visibility evaluation framework aiming at helping the CE auditing actors to understand its useability.

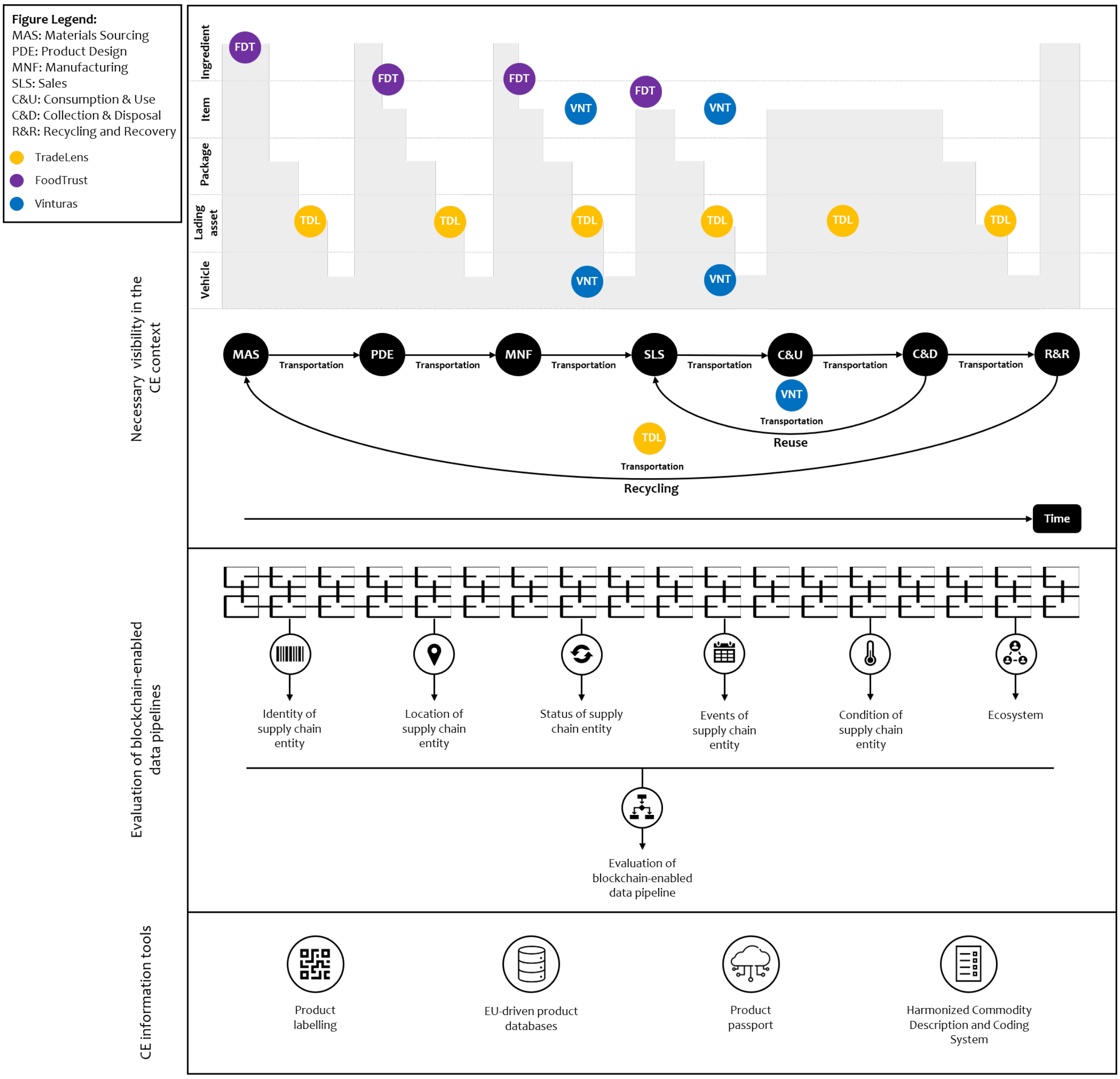


Figure 5.1: The demonstrated CE visibility evaluation framework

By showing the segments currently covered by the examined platforms (TradeLens, FoodTrust, and Vinturas), Figure 5.1 leads to a preliminary conclusion. Namely, it can be noticed that none of them covers the entire closed supply chain, so a combination of them is required. This aspect emphasizes the need to work towards developing IT solutions that are interoperable with each other. Furthermore, it can be observed that they do not offer visibility on the journey of products from consumption to recycling and subsequently their reintroduction to the market as raw materials. In other words, they do not cover the second product lifecycle. However, it is crucial to point out that Vinturas cover the reuse disposition option for vehicles.

Box 5.1: Description of the CE visibility evaluation framework

The CE visibility evaluation framework serves the actors aiming at accelerating the transition to Circular Economy (CE) by launching policy instruments (e.g., policy-makers, customs, banks). It enables them to evaluate the ability of the available blockchain-enabled information systems to act as monitoring systems. A monitoring system should trace the journey of materials and products in a closed-loop supply chain and enforce compliance with CE policies. The framework consists of three layers.

The first layer represents the necessary CE visibility. It describes the aspects of a product lifecycle needed to be covered by blockchain-based information systems. The product lifecycle starts with the sourcing of raw materials where materials are mined, or crops are cultivated to become final products through manufacturing. In between these processes, product design is involved. Product design expresses the design principles adopted in the engineering of products. Manufacturers should adopt various design principles developing durable, repairable, maintainable, recyclable, upgradable, dismantlable, less-resource intensive, and non-hazardous products. Upon manufacturing, final products are transported to retailers to be sold to end-consumers or users.

In the CE context, when products are no longer useful or desirable can be reintroduced to the market through value retention strategies. The framework depicts two such strategies, reuse and remanufacture. The collection and disposal phase decides the best strategy for the products. If the products do not require further processing, they can be directly resold through a reuse strategy. Alternatively, products can be recycled to enter the raw-material procurement phase. Between each process, the framework shows a transport leg, visualizing the movement of products or materials from one location to another by vessel, truck, or train. This transportation may involve crossing of national borders.

The first layer also illustrates the different supply chain entities involved in the CE context. A supply chain entity is any physical object that transits the supply chain and takes one of the forms suggested by the following hierarchy.

- Ingredient: raw materials used to produce a product.
- Item: a final product.
- Package: a form of packaging for the item, such as carton.
- Lading asset: a standardized form of unitizing cargoes, such as container.
- Vehicle: transport means, such as truck and vessel.

The grey rectangles express the level of visibility required in every stage of the supply chain. For instance, in production visibility on item-level is needed. Moreover, the first layer acts as an evaluation layer enabling the visualization of the visibility (e.g., ingredient, item, package, lading asset, and vehicle) and the parts of the supply chain covered by the examined information infrastructures. In this way, it becomes apparent to which extent the examined infrastructures can enforce compliance with CE policy instruments.

The second layer shows the type of information needed to be accessed by the evaluators to reach a conclusion about the potential of a blockchain-enabled information system to monitor the flows of materials and products in the CE context. They need to access data related to the identity (an identification number), location (the specific position), status (the state), events (changes on the status or the location), and condition (the situation) of the supply chain entities. Furthermore, they need to examine the ecosystem of the infrastructures, their participants. If the evaluators access this information, they can identify the parts of the closed supply chain covered by an information system.

The third layer demonstrates four information tools that can offer valuable insights about the materials or products. Product labeling and EU-driven databases (e.g., EPREL and REACH) can convey information regarding the product design. Product passports are databases that contain information about components and materials of a product, and how they can be disassembled and recycled at the end of the lifecycle. The Harmonized Commodity Description and Coding System is a nomenclature that enables the categorization of all physical goods crossing national borders to a class in a uniform and globally accepted way. Apart from defining the import duties, it facilitates the establishment of legal measures and requirements regarding the products being imported.

5.2. Testing the feasibility of the framework

This section demonstrates the CE visibility evaluation framework (Figure 5.1) by applying it to a case related to the journey of a product in a closed-supply chain. In this way, it tries to test its feasibility to offer visibility on the CE flows and thereby enable the CE auditing actors to monitor them by using business data. According to Johannesson and Perjons (2014), the demonstration of the produced artifact can act as a weak method of evaluation. If the artifact tackles the research problem in one case, then it might be able to do likewise in other cases. Furthermore, this activity helps the thesis to communicate the output to an audience in a clear and persuading way (Johannesson & Perjons, 2014). The use case contains both real-life and fictitious data. The materials and the processes presented rely on real-world evidence found in the literature. However, the locations and relationships between the actors involved are fictitious. Johannesson and Perjons (2014) endorse the use of both real-life and imaginary data in the demonstration phase.

The thesis decided to use the CE visibility evaluation framework to trace the path of glass containers in a closed supply chain. Glass containers constitute a suitable example for the demonstration phase since they can be reused or recycled. Their reusability and recyclability enable the thesis to test the potential of the framework to offer visibility on the second lifecycle of products. Moreover, as presented later, glass containers consist of minerals, which are finite resources. The thesis focus on these resources by aiming at preserving them and fostering a closed resource loop.

The lifecycle of glass containers starts with the sourcing of raw materials. The raw materials used to produce glass are usually sand, soda ash, and limestone. It is worth mentioning that limestone is a non-renewable resource. In other words, it is depleted when used. In addition to these materials, glasses typically contain a material, called cullet, small pieces of used broken glass (Carr & Kim, 2017; Golara, Mousavi, Tarokh, & Hosseinzadeh, 2013). For demonstration purposes, the thesis assumes that both the sourcing of raw materials (including sourcing of cullet) and production are carried out by two different companies located in Japan.

Once the supplier of raw materials (seller) receives a purchase order from the producer (buyer), he has to store the raw materials in a form of a package (e.g., bag) and load them in trucks to be transported to the factory. The producer is responsible for both designing the final product and producing it. Seemingly, the product design integrates circular characteristics, considering that the glass contains cullet, a material produced by a recycling process. The production process involves three main steps, namely, mixing, melting, and molding (Auer, Bey, & Schäfer, 2017) [1].

The Japanese producer collaborates with a Dutch retailer. This relationship involves a transaction between a seller (producer) and a buyer (retailer) [2]. Specifically, after the receipt of the purchase order, the seller packages the products (items) into boxes (package) and loads them in a container. To do so, the seller receives empty containers from the depot. After completing the loading of the boxes, he transports the container to the terminal by using trucks. This stage requires the completion of the shipping (e.g., shipping instructions, bill of lading, commercial invoice) and export documentation and the potential inspection of the container by the customs. Figure 4.9 presents the events, the documents, and the actors involved (e.g., carrier) in the shipment of goods from a seller in the exporting country to a buyer in the importing one. In this case, the container with the glass bottles is shipped from the port of Nagoya in Japan to the port of Rotterdam in the Netherlands.

It is important to highlight that the HS code for importing glass bottles in the EU is 70109043. By inserting this code in the EU platform described in subsection 4.1.4, the importer can see import duties and the documentation requirements [3]. Currently, there are no import obligations related to proving the circularity of a product, but this is an aspect that can

[1] As presented in the Carrefour case, FoodTrust (or BTS platform) can cover every process about the sourcing of raw materials (e.g., mining) and production. Moreover, a platform similar to Vinturas can address the transportation of ingredients (e.g., raw materials) or products by trucks.

[2] TradeLens can cover every shipment between a seller in an exporting country to a buyer in an importing country.

[3] See: `https://ec.europa.eu/taxation_customs/dds2/taric/measures.jsp?Lang=en&SimDate=20210623&Area=&MeasType=&StartPub=&EndPub=&MeasText=&GoodsText=&op=&Taric=`

be added in the future. For instance, if the producer claims in the product label that the bottle contains recycled glass, the customs authorities can oblige him to submit the related certificates.

The first point of entry for the container in the EU is the port of Antwerp, in Belgium, where customs authorities execute the first safety and security risk analysis. If the container complies with the import requirements, customs authorities allow it to reach the port of Rotterdam in the Netherlands. In the port of Rotterdam, Dutch customs perform the final risk analysis and permit the product to enter the market. The transportation from Japan to the Netherlands may also involve the transshipment of products from one vessel to another (Rukanova & Tan, forthcoming 2021). The retailer receives the glass bottles from the port and transports them to its premises by truck [4]. At this stage, the end-consumers purchase the glass bottles and sign the end of the first product lifecycle.

When the consumers think that the glass bottles are no longer useful (e.g., due to damages) or desirable for them, they place them into a curbside recycling bin, together with other recyclable products, like plastic (Carr & Kim, 2017). From this point, the returned products are transported by a distributor to a CRC (Centralized Return Centre), where inspection, sorting, and disposition take place. More specifically, the responsible actors separate the glass bottles from the other recyclable and remove other materials from the glass, such as product labels. Thereafter, they evaluate the condition of the bottles. If the bottles are still functional and do not need further processing, they are transported for direct reuse (Jayaraman et al., 2008; Kalmykova et al., 2018).

Alternatively, the glass bottles are sold to a glass processor for recycling [5]. Through recycling, the products reenter the market as raw materials, called cullet. The cullet is small pieces of broken glass, which can be used for manufacturing new glasses. The highest quality cullet is transformed into glass bottles, where the lower one is converted into fiberglass insulation. Any remaining particles are transformed into glass asphalt or beach supplement. Glass is recycled endlessly only when the cullet is used to produce new glass bottles, the other applications (e.g., fiberglass) are non-recyclable (Carr & Kim, 2017).

To sum up, the glass bottle case proved that the CE visibility evaluation framework is able to depict the journey that materials or products follow in a closed-loop supply chain. Therefore, the thesis concludes that the framework can be used by the CE auditing actors to evaluate the potential of the available blockchain-based information infrastructures to monitor the CE flows.

70109043&search_text=goods&textSearch=&LangDescr=en&OrderNum=&Regulation=&measStartDat=&measEndDat=

[4] A platform similar to Vinturas can cover the inland transportation from the port to the retailer premises.

[5] This transaction may involve a shipment from a seller (CRC) to a buyer (processor), which TradeLens can trace.

5.3. Framework Evaluation

This section evaluates the demonstrated CE visibility evaluation framework (Figure 5.1). Its main goal is to identify to what extent the framework fulfills its primary objective. Its objective is to enable the CE auditing actors (e.g., policymakers, banks) to assess the available blockchain-enabled information systems regarding their ability to enforce compliance with CE policies by acting as monitoring systems. A monitoring system needs to trace the flows of materials and products in a closed-loop supply chain. To serve the CE auditors the framework should meet the requirements defined in chapter 3 (Table 3.1). Thereby, this section also evaluates to what degree it satisfies the requirements.

The third goal of this activity is to point out opportunities for further refinement. To do so, it conducts a formative evaluation. This strategy evaluates an artifact, which is still under development seeking information that can improve the design. As discussed in section 1.7, the evaluation is part of the iterative design process and will produce a final and refined version of the CE visibility evaluation framework (Johannesson & Perjons, 2014).

5.3.1. Design of the evaluation phase

To select the most efficient evaluation strategy, the thesis should first consider its context. In simple words, it needs to identify the resources available for the framework evaluation in terms of time and access to knowledgeable interviewees and organizations (Johannesson & Perjons, 2014). Considering that a master thesis project should be completed within a predetermined time, the thesis cannot opt for a time-consuming evaluation strategy. Furthermore, it cannot test the artifact in the real world to reach a better conclusion about its effectiveness due to time and budget limitations. However, it has good access to knowledgeable interviewees (IT specialists and policymakers) who can offer their insights and refine the final output.

Taking into consideration its context and evaluation goals, the thesis has to decide on a suitable evaluation strategy. Johannesson and Perjons (2014) discriminate four different evaluation paths based on the researcher's choices. A researcher can select between ex-ante and ex-post evaluation and between naturalist and artificial evaluation. The ex-ante evaluation judges the artifact while it is still under development, that is to say, without implementing it in practice. In contrast, ex-post evaluation applies the complete artifact in an actual environment, such as an organization, and observes its use. The naturalistic evaluation assesses the research output in reality, in the domain where it is about to be implemented, by involving real stakeholders. On the other hand, the artificial one takes place in an artificial context, such as a laboratory (Johannesson & Perjons, 2014).

The thesis opted for an ex-ante and naturalistic evaluation strategy. In other words, it selected a not very time-consuming strategy that involves the participation of stakeholders, and consequently, it is suitable for exploring the effectiveness of the artifact. Participants should be experts on the topic and willing to assess the framework. However, the strategy runs the risk of false positives, the framework can be judged to be more effective than it is since the participants will evaluate a preliminary version. The most effective option could have been an ex-post and naturalist assessment. Nevertheless, such a choice would have required access to an actual environment to implement the framework and a lot of time and budget (Johannesson & Perjons, 2014). For instance, the framework could have been used by policymakers to evaluate blockchain-based information systems.

Johannesson and Perjons (2014) recommend three research methods for an ex-ante and naturalistic evaluation strategy, namely, action research, focus group, or interviews. The thesis chose to conduct interviews with experts. This method is suitable for collecting experts' views regarding the useability and value of an artifact. Furthermore, it enables the researcher to get deeper insights and clarify any misconceptions by asking follow-up questions. Nonetheless, the results rely on interviewees' interests, viewpoints, and expertise, so their interpretation should be done carefully. Moreover, interviews are prone to false positives due to personal interaction. That is to say, interviewees may restrain from criticism wanting to be polite (Johannesson & Perjons, 2014).

5.3.2. Evaluation based on researcher's arguments

This subsection constitutes an activity of the ex-ant evaluation strategy. It focuses on evaluating the demonstrated CE visibility evaluation framework by using the researcher's arguments. In other words, the researcher formulates arguments to assess whether the demonstrated framework has achieved its objective and met the requirements identified in chapter 3 (Table 3.1). Johannesson and Perjons (2014) call this method "informed argument" and claim that it is a weak, quick, and inexpensive form of evaluation. However, it is highly biased by the researchers' perspective and interest, and it is prone to false positives (Johannesson & Perjons, 2014). To execute this evaluation activity, the researcher revisited the framework requirements and research objective to examine whether the framework design has satisfied them. Table 5.1 captures the results of this activity, which can be used to further refine the framework design, in case of deficiencies, and identify opportunities for future research.

Code	***Evaluation***	***Explanation***
FRQ.1	Fulfilled	The CE visibility evaluation framework demonstrates the entities of Francis's supply chain entity hierarchy that are important in the CE context, namely, item, package, lading asset, and vehicle. The other entities (order, encasement, and shipment) were intentionally omitted since they describe specific situations and do not enrich readers' understanding of CE visibility.
FRQ.2	Fulfilled	The second layer of the CE visibility evaluation framework shows that a blockchain-based data pipeline needs to capture the identity (e.g., identification number) of the supply chain entities.
FRQ.3	Fulfilled	The second layer of the CE visibility evaluation framework shows that a blockchain-based data pipeline needs to capture the location (e.g., the specific position) of the supply chain entities.
Continued on next page		

Code	***Evaluation***	***Explanation***
FRQ.4	Fulfilled	The second layer of the CE visibility evaluation framework shows that a blockchain-based data pipeline needs to capture the status (e.g., the state, like loading in progress) of the supply chain entities.
FRQ.5	Fulfilled	The second layer of the CE visibility evaluation framework shows that a blockchain-based data pipeline needs to capture the status (e.g., the state, like loading in progress) of the supply chain entities.
FRQ.6	Fulfilled	The CE visibility evaluation framework has expanded Francis's supply chain entity by also demonstrating the ingredients of an item, the raw materials used to produce a product.
FRQ.7	Fulfilled	The second layer of the CE visibility evaluation framework shows that a blockchain-based data pipeline needs to capture the condition (e.g., the situation, such as damages) of the supply chain entities.
FRQ.8	Fulfilled	It is addressed by the transportation aspect depicted in the first layer of the CE visibility evaluation framework and the representation of the parts covered by TradeLens. It expresses the need to illustrate the visibility currently provided by the data pipelines. TradeLens is a complete data pipeline solution. Therefore, its representation clearly shows the parts of the closed-loop concept covered by the current form of data pipelines. Data pipelines offer visibility from the seller in an exporting country to a buyer in an importing one. Such transactions can appear between every phase of the closed supply chain.
FRQ.9	Fulfilled	The first layer of the CE visibility evaluation shows that blockchain-based information systems need to offer visibility in the production and product design by capturing related data and documents. Moreover, to enforce compliance in the production, the systems need to cover the flows of materials that enter the production process. In other words, they need to store data related to the sourcing of raw materials as well.
FRQ.10	Fulfilled	The first layer of the CE visibility evaluation framework presents the flows of materials after consumption and their reintroduction to the market through either reuse or recycling. The decision regarding the suitable disposition option for a product is taken in the collection and disposal node based on the product condition.
FRQ.11	Partially	It has been addressed partially, and further research is needed. It is covered by the transportation aspect presented between each node and the Harmonized Commodity Description and Coding System illustrated in the third layer. During transportation, materials or products may cross national borders, enabling customs to inspect their circular characteristics and identify frauds. At the same time, the HS codes can enforce compliance with the CE policy instruments at national borders by enforcing documentation requirements.
FRQ.12	Fulfilled	The CE visibility evaluation framework clearly shows the parts of the closed-loop supply chain covered by the examined blockchain-based information system. As demonstrated, none of them offers complete visibility on the CE flows, but each of them addresses different parts. Consequently, blockchain interoperability is required enabling different systems to communicate with each other and provide the craved CE visibility.
FRQ.13	Fulfilled	The second layer of the CE visibility evaluation framework informs the CE auditors about the need to analyze the ecosystem (participants) of the blockchain-based information system under evaluation. Such analysis can enable them to identify better the visibility offered by the systems (the parts of the closed-loop supply chain covered). Moreover, in case of frauds, they can directly pinpoint the responsible parties and take corrective actions.

Continued on next page

Code	*Evaluation*	*Explanation*
FRQ.14	Fulfilled	The third layer of the CE visibility evaluation framework presents four information tools that can play a crucial role in CE compliance by offering essential information to the CE auditing actors. These information tools (product labeling, EU-driven databases, product passports, and HS codes) have been analyzed thoroughly throughout the thesis.
NFRQ.1	Fulfilled	By using the grey rectangles and connecting them with the fundamental CE processes (e.g., materials sourcing and production), the CE visibility evaluation framework enables the users to map the visibility offered by the blockchain-based information system in a simple way.
NFRQ.2	Fulfilled	The CE visibility evaluation framework contains standardized terminology, which a user with a basic background in CE, supply chain management, and blockchain-based information systems can understand. This statement is proved by the fact that the framework uses the terminology discussed in the literature.
NFRQ.3	Fulfilled	The CE visibility evaluation framework clearly shows the parts of the supply chain covered by the examined blockchain-based information systems and the visibility offered by them. This requirement is satisfied thanks to the grey rectangles and the representation of their relationship with the fundamental CE processes (e.g., materials sourcing and production). For example, it depicts that FoodTrust covers materials sourcing, production, and sales and provides visibility on ingredient- and item- level. However, FoodTrust cannot act as a complete CE monitoring system since visibility in more aspects is needed for CE purposes. The same conclusion holds for the others examined information systems.

Table 5.1: Evaluation of framework requirements

Apart from supporting the fulfillment of the requirements defined in chapter 3, the thesis claims that it has fulfilled its primary objective. In other words, it asserts that the CE visibility evaluation framework enables the CE auditing actors to evaluate the available blockchain-based information systems on their ability to act as monitoring systems and enforce compliance. This claim relies on the fact that the framework illustrates every aspect that they need to monitor, that is to say, the flows of materials and products in the CE context. Moreover, it addresses the main supply chain entities (ingredient, item, package, lading asset, and vehicle) that they need to trace in the CE context to enforce compliance.

In addition to that, the analysis of the use cases (TradeLens, FoodTrust, and Vinturas) support the criteria set by the framework concerning the evaluation of the blockchain-based information systems (second layer of the framework). Every examined information system captures information about the identity, location, status, events, and condition of a supply chain entity. Thereby, the thesis can confidently state that every information system needs to contain such information to promote the CE transition.

5.3.3. Execution of the evaluation phase

This subsection presents the execution of the ex-ante and naturalistic evaluation. This activity relied on carrying out interviews with stakeholders who have a solid background on the topic and are willing to assess the framework. For that purpose, the thesis conducted two interviews with blockchain experts and one workshop with experts from multiple disciplines. Chapter A (Appendices) contains a list of the people participated in the evaluation phase. The interviews and the workshop were semi-structured, both prespecified and open (based on the discussion) questions were asked and lasted one hour. The meetings were video recorded and subsequently analyzed.

5.3.3.1. The interviews with blockchain experts

This subsection discusses the two interviews conducted with blockchain experts, Norbert Kouwenhoven, IBM EU Solutions Leader, and member of Core TradeLens Team (Customs and Authorities Lead), and Jon Kuiper, CEO of Vinturas. The interviewees' solid background on the potential of the blockchain-based information infrastructures to support the CE transition enabled the thesis to elicit safe conclusions about the effectiveness of its output and receive ideas for further improvement. The interviewees also evaluated the models developed based on their platforms (Figure 4.9, Figure 4.14, and Figure 4.21). For instance, Jon Kuiper reviewed Figure 4.21. As a result, the thesis can be confident about the correctness of the conclusions elicited by the use cases.

The primary objective of the interviews was to evaluate the effectiveness of the CE visibility evaluation framework on its potential to fulfill its goal. The framework can be considered effective if it enables the CE auditing actors (e.g., policymakers, customs, banks) to assess the available blockchain-based information systems on their ability to monitor the flows of materials and products in a closed-loop supply chain. Furthermore, the completeness of the framework was investigated, searching for missing aspects that are important to be addressed in the design efforts (formative evaluation). The meetings also examined whether the interviewees consider the representation of the framework logical or if they have any other suggestions for further improvement. Namely, the questions asked were the following:

- To what extent does the CE visibility evaluation framework enable the CE auditing actors to evaluate the available blockchain-enabled information systems on their potential to act as monitoring systems and enforce compliance with CE policy instruments?
- Is the CE visibility evaluation framework complete?
- Do you miss any important elements that should be included in the CE visibility evaluation framework?
- Is the representation of the CE visibility evaluation framework logical to you?
- Do you have any suggestions to improve the CE visibility evaluation framework?

In the interviews with the experts, the thesis also examined whether the CE visibility evaluation framework satisfies the requirements defined in chapter 3 (Table 3.1). To do so, an evaluation form (see chapter B, Appendices) was distributed to the interviewees asking them to assess the fulfillment of the requirements. Their responses are presented in Table 5.2.

Objective and Requirements		Norbert Kouwenhoven	Jon Kuiper
FRQ.1	The CE visibility evaluation framework should capture the Francis's supply chain entity hierarchy.	Yes	Yes
FRQ.2	The CE visibility evaluation framework should assess the blockchain-enabled data pipelines based on their ability to capture the identity of the supply chain entities.	Yes	Yes
FRQ.3	The CE visibility evaluation framework should assess the blockchain-enabled data pipelines based on their ability to capture the location of the supply chain entities.	Yes	Yes
FRQ.4	The CE visibility evaluation framework should assess the blockchain-enabled data pipelines based on their ability to capture the status of the supply chain entities.	Yes	Yes
FRQ.5	The CE visibility evaluation framework should assess the blockchain-enabled data pipelines based on their ability to capture the events of the supply chain entities.	Yes	Yes
FRQ.6	The CE visibility evaluation framework should extend the supply chain entity hierarchy by including ingredients.	Yes	Yes
FRQ.7	The CE visibility evaluation framework should assess the blockchain-enabled data pipelines based on their ability to capture the condition of the supply chain entities.	Yes	Yes
FRQ.8	The CE visibility evaluation framework should assess blockchain-enabled data pipelines based on their ability to provide visibility from the seller in the exporting country to the buyer in the importing country.	Yes	Yes
FRQ.9	The CE visibility evaluation framework should assess blockchain-enabled data pipelines based on their ability to provide visibility in production (including product design).	Yes	No
FRQ.10	The CE visibility evaluation framework should assess blockchain-enabled data pipelines based on their ability to provide visibility in the flows of secondary raw materials.	Yes	Partially
FRQ.11	The CE visibility evaluation framework should assess blockchain-enabled data pipeline solutions based on their ability to enforce compliance at national borders.	Yes	Partially
FRQ.12	The CE visibility evaluation framework should highlight the need to work towards blockchain interoperability.	Yes	Yes
FRQ.13	The CE visibility evaluation framework should guide the auditing actors to identify the ecosystem of blockchain-based data pipelines.	Yes	Partially
FRQ.14	The CE visibility evaluation framework should reap the benefits of available CE information tools.	Yes	Partially
NFRQ.1	The CE visibility evaluation framework should be able to illustrate the visibility offered by the blockchain-enabled data pipeline solutions in a simple way.	Yes	Yes
NFRQ.2	The CE visibility evaluation framework should contain standardized terminology.	Yes	Yes
NFRQ.3	The CE visibility evaluation framework should illustrate the extent to which a blockchain-based data pipeline serves CE purposes.	Yes	Yes
Goal	The development of a framework that evaluates the potential of available blockchain-based information systems to enforce compliance with CE policy instruments by acting as monitoring systems.	Yes	Yes

Table 5.2: Framework evaluation by the interviewees

As Table 5.2 shows, both interviewees claimed that the CE visibility evaluation framework has fulfilled its primary goal. In other words, it enables the CE auditing actors to evaluate the potential of the available blockchain-based information systems on their ability to monitor the flows of materials and products. Moreover, it was proved that the framework has satisfied most of the requirements defined in chapter 3.

The evaluation interviews surfaced one contradictory observation. On the one hand, the CE visibility evaluation framework was characterized as simple to use, clear, and effective [1]. On the other hand, it was supported that the framework is complicated in use and not self-explanatory. This statement relied on the fact that the framework is not complemented by a supporting text with explanations of the concepts depicted. Therefore, it is difficult for a user to understand its useability and value. The supporting text should contain definitions of the related concepts and describe the flows of materials and products in the closed-loop supply chain [3]. Undeniably, this is an essential piece of advice; the thesis has partially addressed by creating the description of the CE visibility evaluation framework (Box 5.1). Moreover, it will deal with this feedback by designing a method with the steps that the CE auditing actors need to follow when using the framework.

The thesis also was advised to expand the aspects depicted in the second layer of the framework (identity, location, status, events, and condition), adding one additional parameter, the coverage level of the closed-loop supply chain from an information system. This parameter can steer the CE auditing actors to explore which parts of the closed supply chain are covered by a blockchain-based information system under evaluation [1]. For example, if an information system captures data about materials sourcing or manufacturing. In other words, it was stated that the CE auditing actors can realize the extent to which the information system supports their CE agendas by having information about its coverage level. The thesis decided not to add this parameter in the framework since it expresses the conclusion that the users of the framework should make when evaluating information systems. Nevertheless, this advice shows that the thesis should communicate in a more straightforward way how the CE auditing actors can use the framework since it may not be clear what they can conclude by using it.

An interesting suggestion for the framework design was to capture the case in which different flows of materials or products with a similar place of origin and delivery are combined. That is to say, in a real-world supply chain, packages or pallets of different products ordered by different clients can be united to be shipped together towards a common destination. In that case, it would be of great importance for CE auditing actors to access data and monitor the consolidation of different products into a shipment and subsequently their journey in the supply chain [1]. This aspect is not currently become explicit in the framework design. Consequently, the CE auditing actors will not seek blockchain-based information systems offering visibility in this aspect, and by extension, they will not be able to enforce compliance in consolidated flows of materials or products. That scenario may have an impact on fully realizing their CE agendas. This case has been described by Francis (2008) as a supply chain entity called shipment. However, the thesis has deliberately omitted this entity since it expresses a specific situation and does not enrich readers' understanding of CE visibility.

Another observation about the demonstrated CE visibility evaluation framework was related to representing product design as a supply chain process. Product design is an overarching business process that influences all the other processes depicted in the framework, such as materials sourcing, transportation, and manufacturing. It is a process that impacts the entire product lifecycle by deciding crucial product characteristics, including its quality, its composition, and its CE elements (e.g., recyclability, maintainability, dismantlability, etc.). In simple words, it is not an event in a supply chain that a product goes through. Therefore, having visibility into that aspect cannot enable the CE auditing actors to trace products or materials in the CE context and enforce compliance with their CE policy instruments [3].

This observation highlighted a limitation of the CE visibility evaluation framework. The framework design relied on a logistics model (the domain model by Hofman et al.), which depicts the flows of supply chain entities in relationship with time. However, product design does not belong in that chain, as after sourcing, materials are transported to manufacturing facilities to be transformed into finished products. Consequently, it is not logical to represent product design as a process that an entity goes through between materials sourcing and manufacturing. Nevertheless, the literature review on both CE and CE policy instruments showed product design plays a key role in the CE transition by signing the product lifecycle. Thereby, the CE auditing actors need to have visibility on that aspect to realize whether it complies with the circular principles by developing products that can be repaired, reused, remanufactured, and recycled.

Moreover, the interviews emphasized that the CE visibility evaluation framework should address the path that materials or components follow when they are dismantled after consumption [3]. Dismantling refers to the case when materials or components of used products are in a good condition and can be reused to produce new products without undergoing further processing. This strategy is expressed by the remanufacturing disposition option described by EMF. Remanufacturing is a value retention strategy that can benefit the environment by dealing with resource depletion. Therefore, the CE auditing actors should force the business world to adopt it in their practices by launching related policy instruments and monitoring their implementation. That means that it is essential for the produced framework to capture the journey that materials follow during remanufacturing. The thesis decided not to address this strategy in the framework due to time and data limitations. However, it will use this suggestion to call for future research in the following chapter.

Finally, Table 5.2 presents that the framework has not met every requirement. This feedback relies on the fact that the thesis does not clarify the role of some aspects in the framework (production, product design, national borders, ecosystem, and information tools). Therefore, it is not clear for the reader how the framework deals with these aspects. For example, the framework by itself does explain the contribution of the information tools in CE compliance. As discussed earlier, the thesis has tried to address his feedback by presenting the description of the CE visibility evaluation framework (Box 5.1) and will also create a method for the use of the framework.

5.3.3.2. The evaluation workshop

This subsection presents the insights derived from the evaluation workshop, in which experts from various disciplines participated. Namely, there were representatives from the Dutch Customs, the Ministry of Infrastructure and Water Management, and IBM. Given the limited available time (1 hour) and the large number of participants, the research posed only one question to the workshop: *"To what extent does the CE visibility evaluation framework fulfill its primary objective?"*. Moreover, it did not distribute the evaluation form (see chapter B, Appendices). Consequently, it did not extract such detailed feedback compared to the above-described interviews.

However, the workshop was very insightful clarifying the effectiveness of the demonstrated framework and rising various questions that should be addressed with future research. The participants confirmed the fundamental rationale behind the framework development, which lies in the fact that it is almost impossible to develop a unique information system that monitors the flows of materials and products in a closed-loop supply chain. For that reason, blockchain interoperability is needed to combine the various fragmented blockchain-based information systems covering different parts of the CE flows. The framework was characterized as efficient in explicating this aspect and mapping the available blockchain-based information systems.

Equally positive was the feedback related to the visibility presented by the framework. It was supported that the CE visibility layer (first layer) of the framework thoroughly captures the aspects that the CE auditing actors need to monitor to enforce compliance with their policy instruments. Especially, policymakers are increasingly interested in receiving ingredient- and item-level visibility to enforce regulations in production systems, and the framework satisfies their need. Indicatively, EC is investigating the possibility of launching a carbon adjustment mechanism to control the carbon content of a product. In this case, EC will require visibility in production to monitor the implementation of its policy measure. The framework can serve its interests by showing that a platform similar to FoodTrust can equip it with the necessary business data. Another valuable contribution of the framework is that it illustrates the black boxes in CE visibility needed to be bridged with future development efforts. For example, it was discussed that policymakers want an information system that covers the path of products from consumers to recyclers in order to ensure that products do not end up in landfills [4].

A critique of the CE visibility evaluation framework was that it does not deal with the double-spending problem. In blockchain terms, the double-spending problem refers to the risk of spending a currency twice (Nakamoto, 2008). In the thesis, this problem refers to having two different blockchain-based information systems that capture the same data in terms of different supply chain entities. For example, a platform may track a product on a container-level, and a different one may track the same product on an item-level leading to storing the same information twice [6,7]. Seemingly the research project has not addressed this potential issue since it was not among its objectives but urges the academic community to work towards this direction. Additionally, the framework does not show how the data stored in different systems can be combined to offer CE auditing actors the craved CE visibility.

Each system has its own data model making the connection of the various data models a challenging mission [1].

Interestingly, the evaluation workshop also clarified the role of customs, which are among the primary framework recipients, in fostering the CE transition. So far, customs do not have an active role in CE, being a party not engaging in initiating CE policy instruments. Traditionally, customs play a monitoring role in public policymaking by ensuring the implementation of measures that involve a cross-border element. This is the role that they can also play in CE compliance [5]. If policymakers are interested in enforcing compliance with their CE agendas at the national border, then customs can be their mean of enforcement.

The evaluation workshop did not surface any missing elements for the CE visibility evaluation framework or any suggestions for further improving it, leading the thesis to the conclusion that it has fulfilled its objective. However, the experts identified several issues needed to be addressed to enforce compliance with CE policy instruments by exploiting the data stored in various information systems available in the supply chain. The following chapter deals with these issues by formulating recommendations for the academic community, policymakers, and IT providers.

To sum up, the interviews did not discover any changes that should be done to improve the effectiveness of the CE visibility evaluation framework. However, it was pointed out that the framework can become complex for a user. The thesis has partially addressed this feedback by forming the description of the framework (Box 5.1). To fully deal with critique, it presents the following method (Box 5.2) that describes the steps that CE auditing actors need to follow when evaluating blockchain-enabled information systems.

Box 5.2: Method of the CE visibility evaluation framework

Users: Actors that have launched policy instruments to promote the CE transition.

Goal: Evaluate a blockchain-enabled information system on its ability to enforce compliance with the CE policy instruments.

Method:

1. Select a blockchain-enabled information system.
2. Identify the supply chain entity (ingredient, item, package, lading asset, vehicle) tracked by the blockchain-enabled information system.
3. Go through the data captured by the blockchain-enabled information system. Namely, analyze data related to the identity, location, status, events, and condition of a supply chain entity and the platform ecosystem.
4. Identify the CE visibility (the parts of the closed-loop supply chain that it covers) provided by the blockchain-enabled information system by reflecting on the data captured.
5. Map the blockchain-enabled information system in the first layer of the CE visibility evaluation framework, based on the supply chain entity and the parts of the closed-loop supply chain that it addresses.

6. Determine to what extent the blockchain-enabled information system serves the CE transition by offering visibility in the journey of materials or products in a closed-loop supply chain.
7. Pinpoint black boxes in the visibility required to enforce CE compliance, parts of the closed-loop supply chain not addressed by the blockchain-enabled information system.

5.4. Conclusions

This chapter addressed the fourth and the fifth phase of the MFDSR, demonstration and evaluation, by answering the following sub-research question: *"To what extent does the developed framework evaluate the ability of blockchain-enabled data pipeline solutions to provide the visibility needed to support CE policy instruments?"*. For this purpose, it demonstrated the CE visibility evaluation framework produced in the design phase and described its functionality. Afterward, it concentrated on evaluating the extent to which it fulfills its primary objective. Its objective is to enable the CE auditing actors to assess the available blockchain-enabled information systems on their potential to act as CE monitoring systems. The evaluation was executed into two stages.

Initially, the thesis tested the feasibility of the demonstrated framework by implementing it into a fictitious case. The case confirmed its ability to capture the fundamental processes that materials or products go through in the CE context. This conclusion enabled the research to assume that the framework has satisfied its mission by enabling its users to monitor the CE flows. This stage served as a light and inexpensive method of evaluation. The thesis assumed that if the framework addresses the problem in one case, then it might do the same in other cases.

Subsequently, the thesis evaluated the demonstrated framework by deploying an ex-ante and naturalistic evaluation strategy. This strategy assessed the framework by using two methods, informed arguments, and interviews. The informed arguments relied on the researcher's statements on how the framework deals with the requirements and meets its primary goal. The interviews involved the execution of semi-structured questions aiming at eliciting feedback about the effectiveness of the framework and receiving ideas for further improvement. The thesis conducted two interviews with blockchain experts and one workshop with experts from multiple disciplines.

6

Conclusions & Reflection

This chapter covers the last research activity of the MFDSR, communicate artifact. Its primary objective is to address the MRQ: *"How can a CE visibility evaluation framework for blockchain-enabled data pipeline solutions facilitate the monitoring of compliance with the policy instruments established to foster the CE transition?"*. To do so, section 6.1 answers the sub-questions formulated to divide the MRQ into separate parts. Based on the responses, the thesis deals with the MRQ in section 6.2. Subsequently, section 6.3 communicates the scientific and societal contribution of the research project. Section 6.4 identifies the limitations that stem from the research choices and section 6.5 formulates recommendations towards the academic community, policymakers, and IT providers. Finally, section 6.6 presents the connection between the research and the master's program.

6.1. Addressing Sub-research Questions

To address the main research question, the thesis implemented the Method Framework for Design Science Research. A method that defines the activities that researchers should follow to design an artifact of high quality. The activities are the following: problem identification and motivation, definition of the objectives of a solution, design and development, demonstration, evaluation, and communication (Peffers et al., 2007). The thesis covered them by formulating a set of sub-research questions, answered in this section.

6.1.1. Sub-research question 1

What is the knowledge base on which the development of a CE visibility evaluation framework for blockchain-enabled data pipeline solutions should rely?

The SRQ1 covered the first activity of the MFDSR, problem identification, and motivation, identifying the knowledge base on which the design of the CE visibility evaluation framework relied. That is to say, by doing a literature review, it extracted essential concepts and theories that set the foundations of the design efforts and led to the development of an innovative and well-grounded artifact.The knowledge base touched upon several essential concepts, including the transition to CE, the data pipeline concept, and the blockchain technology.

The development of the CE visibility evaluation framework was conceptualized thanks to the efforts of the EMF. EMF has pointed out that society can deal with sustainability issues by abandoning the traditional “take-make-waste”, which depletes planetary resources and generates an ever-increasing number of wastes. To drive such transition, it has launched the CE business model, promoting the development of a restorative and regenerative industrial system. In other words, it fosters the creation of a closed-loop system (presented in the CE diagram, Figure 2.3) that receives the maximum utility of natural resources. Materials and products are reintroduced to market through value retention strategies, namely, shared use, maintenance, reuse/redistribution, refurbishment/remanufacturing, and recycling. The thesis decided to focus on two value retention strategies, reuse/redistribution, and recycling.

Even though CE is highly beneficial from an environmental perspective, it may not produce clear benefits from an economic perspective. For that reason, national governments, and private organizations (e.g., banks, and institutional investors), defined as CE auditing actors, have initiated policy instruments to incentivize the business world to shift towards CE. However, these policy instruments are prone to manipulations when there is a lot at stake. For that reason, the CE auditing actors need a solid monitoring system able to trace the flows of materials and products and detect frauds.

The thesis claimed that this need can be satisfied by exploiting the research around data pipelines. Data pipelines are IT information infrastructures that equip governmental authorities with data voluntarily shared by the businesses in real-time. They provide supply chain visibility from a seller in an exporting country to the buyer in an importing one. Traditionally, businesses have used them to exchange information with authorities to experience benefits in return, such as trade simplification.

A crucial requirement for getting the value of the shared data for monitoring purposes is the need for trust in its quality. In other words, the data recipients need to be sure that the data has not been tampered with. This condition can be addressed by deploying blockchain-enabled data pipelines. Blockchain is a technology that ensures data integrity and facilitates the collaboration and data sharing between actors located in trustless environments, such as the supply chain. This statement justifies the research choice to focus on blockchain-based information systems.

6.1.2. Sub-research question 2

What are the essential information requirements needed to support the trace of an item throughout its life cycle in the CE context?

The SRQ2 addressed the second activity of the MFDSR, define the objectives of the solution. In simple words, it translated the research problem into requirements, features considered desirable by the CE auditing actors. Following the classification recommended by Johannesson and Perjons (2014), the requirements were divided into functional and non-functional. The functional requirements expressed the functions that the CE visibility evaluation framework should provide. They were pinpointed through a literature review on the stakeholders' needs (e.g., policymakers, banks, institutional investors), supply chain visibility, and the information tools for CE visibility. The non-functional requirements represented general conditions and properties the CE visibility evaluation framework should have. Their identification became possible through a literature review on the properties that a DSR output should integrate. Table 6.1 summarizes the requirements defined by the second activity.

Code	***Description***
FRQ.1	The CE visibility evaluation framework should capture the Francis's supply chain entity hierarchy.
FRQ.2	The CE visibility evaluation framework should assess blockchain-enabled data pipelines based on their ability to capture the identity of the supply chain entities.
FRQ.3	The CE visibility evaluation framework should assess blockchain-enabled data pipelines based on their ability to capture the location of the supply chain entities.
FRQ.4	The CE visibility evaluation framework should assess blockchain-enabled data pipelines based on their ability to capture the status of the supply chain entities.
FRQ.5	The CE visibility evaluation framework should assess blockchain-enabled data pipelines based on their ability to capture the events of the supply chain entities.
FRQ.6	The CE visibility evaluation framework should extend the supply chain entity hierarchy by including ingredients.
FRQ.7	The CE visibility evaluation framework should assess blockchain-enabled data pipelines based on their ability to capture the condition of the supply chain entities.
FRQ.8	The CE visibility evaluation framework should assess blockchain-enabled data pipelines based on their ability to provide visibility from the seller in the exporting country to the buyer in the importing country.
FRQ.9	The CE visibility evaluation framework should assess blockchain-enabled data pipelines based on their ability to provide visibility in production (including product design).
FRQ.10	The CE visibility evaluation framework should assess blockchain-enabled data pipelines based on their ability to provide visibility in the flows of secondary raw materials.
FRQ.11	The CE visibility evaluation framework should assess blockchain-enabled data pipeline solutions based on their ability to enforce compliance at national borders.
FRQ.12	The CE visibility evaluation framework should highlight the need to work towards blockchain interoperability.
	Continued on next page

Code	***Description***
FRQ.13	The CE visibility evaluation framework should guide the auditing actors to identify the ecosystem of blockchain-based data pipelines.
FRQ.14	The CE visibility evaluation framework should reap the benefits of available CE information tools.
NFRQ.1	The CE visibility evaluation framework should be able to illustrate the visibility offered by the blockchain-enabled data pipeline solutions in a simple way.
NFRQ.2	The CE visibility evaluation framework should contain standardized terminology.
NFRQ.3	The CE visibility evaluation framework should illustrate the extent to which a blockchain-based data pipeline serves CE purposes.

Table 6.1: Framework requirements

6.1.3. Sub-research question 3

How can the information requirements needed to support the trace of an item throughout its life cycle serve as a basis for the CE visibility evaluation framework?

The SRQ3 addressed the first phase of the design activity. It developed a basic CE visibility evaluation framework that depicts the fundamental CE processes (see Figure 6.1) by receiving as input the information requirements and the knowledge identified in SRQ2. However, Figure 6.1 cannot act as the final evaluation framework since it does not fulfill all the framework requirements (Table 6.1). It does describe the flows of materials and products in the CE context, but it does not offer insights regarding the visibility needed. Thereby, it needs further elaboration to tackle the research problem and enable the CE auditing actors to realize their CE agendas. For that reason, the thesis tapped into the information offered by the literature.

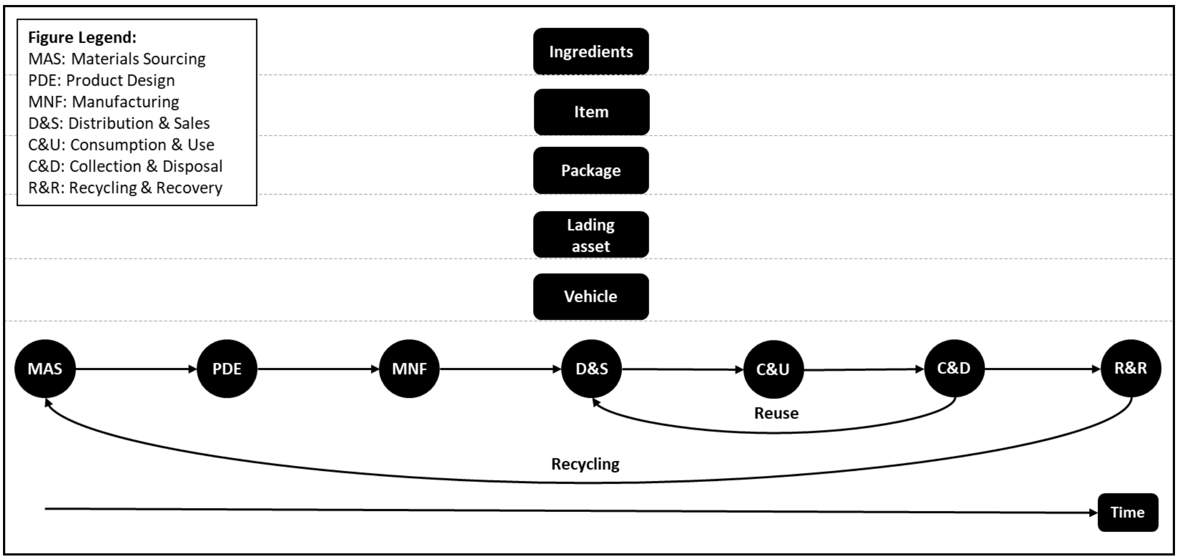


Figure 6.1: The basis of the CE visibility evaluation framework

By doing a literature review, the thesis pinpointed several information tools (or information sources) that can provide valuable insights about the processes depicted in Figure 6.1. Two interesting ones are product labels and EU-driven databases (e.g., EPREL and REACH). These information tools can be an essential source of information for the CE auditing actors by conveying information about the product design. Equally informative can be the product passports, databases that contain information about components and materials of a product, and how they can be disassembled and recycled at the end of the lifecycle. An over-discussed product passport is the materials passport, a digital database containing CE-related information about the materials, components, and products of the building. Materials passports aspire to provide visibility in every process of Figure 6.1 and consequently can be deployed for CE monitoring purposes. However, they have not been implemented in practice, and their applicability remains a matter of discussion.

Finally, the literature review discovered the Harmonized Commodity Description and Coding System. A nomenclature that enables the classification of all physical goods crossing national borders to a class in a uniform and globally accepted way. Its primary objective is to facilitate the collection of import duties and taxes by the customs. Nevertheless, it can play a crucial role in enforcing CE compliance at national borders. Policymakers can use it to promote circular products by offering financial incentives to their trading and banning the import of non-circular ones. Furthermore, it can encourage the imposition of legal measures and requirements towards the importers.

The above-described information tools (except materials passport) and the use cases did not offer detailed insights about the journey of products during the recycling disposition option. Consequently, the thesis conducted a literature review in reverse logistics and recycling to cover this knowledge gap. This activity created an elaborated version of Figure 6.1 regarding the recycling of plastic (see Figure 4.3). The thesis studied this use case because it gained access to a thorough standard published by NEN, which indicates the procedures required for tracing recycled plastics. It is worth highlighting that the collection of waste and the recycling process can be very product-specific, so this model may not be generalizable to other products.

To sum up, the SRQ3 exploited the insights offered by the literature aspiring to develop the CE visibility evaluation framework. The contribution of this design activity is illustrated in Figure 4.22 by the green rectangles. However, as proved, the literature could not offer detailed insights about every aspect represented in Figure 6.1. For that reason, the thesis studied three use cases, examined by the following sub-question, to elaborate further on the framework.

6.1.4. Sub-research question 4

What information requirements for CE visibility are captured by the examined blockchain-enabled information systems and how do the insights derived from them contribute to the further development of the CE visibility evaluation framework?

The SRQ4 dealt with the second activity of the design phase by exploiting the insights offered by the use cases to detail further the basic CE visibility evaluation framework (Figure 6.1). For this reason, it implemented Figure 6.1 to the use cases in an iterative way. Each iteration generated an elaborated version of the CE visibility evaluation framework (Figure 4.9, Figure 4.14, and Figure 4.21).

The first iteration focused on TradeLens, a blockchain-based container shipping platform that can enable the CE auditing actors to gain visibility in a cargo flow from a source to a destination. To offer such visibility, it captures shipment events (e.g., loading a lading asset on a vessel) and documents (e.g., bill of lading and packing list). The platform played an essential role in the design phase. In Figure 6.1, it can be noticed that different supply chains are involved in the CE context. That is to say, various shipments of materials or products between a seller and a buyer can emerge, such as the shipment of raw materials from a supplier to a manufacturer. The analysis of TradeLens proved that every shipment can be monitored by having container-level visibility. Figure 4.22 explicates its contribution to the development of the evaluation framework (orange rectangles).

It is worth mentioning that TradeLens is the only blockchain-based information system examined in the thesis that enables authorities to access business data without requesting permission. The data is shared voluntarily by businesses to receive benefits in exchange. This voluntary data sharing becomes explicit in the contractual agreement that parties accept when joining the platform. In essence, TradeLens integrates all the characteristics of a data pipeline solution, including capturing business data at the source, voluntary and real-time data sharing with authorities, and supply chain visibility from a seller in an exporting country to the buyer in an importing one. However, this means that it needs to be expanded to fully serve CE purposes, offering visibility in every CE flow.

The second iteration refined the evaluation framework by studying FoodTrust. As its name indicates, FoodTrust is a blockchain-enabled platform aiming at bringing transparency and trust to the food system by equipping consumers with rich information about the provenance of food. FoodTrust is a global food network consisting of various businesses interested in reaping its benefits. Among its first adopters was Carrefour, a French multinational retail company. The use of FoodTrust by Carrefour enabled the research project to get tangible data regarding the visibility offered by the platform. The company has blokchainized a plethora of food products, including tomato, citrus fruits, infant milk, and mashed potato. However, the thesis studied the case of organic textile, the first non-food product blockchainized by Carrefour.

The insights derived by this case detailed the basic framework (Figure 6.1) by clarifying that monitoring materials sourcing and product design require ingredient-level visibility. While item-level visibility is needed to control the processes from product design to sales. Its contribution to the research is depicted in Figure 4.22. It is worth highlighting that the examined case was simple in terms of locations since both sourcing of raw materials (harvesting) and manufacturing took place in the same country, India. However, this is not always the case. In other words, these processes may take place in different areas involving even the shipment of raw materials from a supplier to a producer. That scenario would have offered richer insights to the research since it would have involved a cross-border element, which is crucial in enforcing CE compliance.

The visibility provided by FoodTrust for food products can be offered also for non-food ones, such as finite materials, which are the focus of this research. IBM has extracted the core software behind FoodTrust and developed a new blockchain platform called Blockchain Transparent Supply (BTS). BTS enables companies to select a use case of their interest and develop their blockchain network. The difference between the two platforms lies in the fact that IBM is actively involved in FoodTrust, while in the BTS platform, IBM has the role of the technology provider. BTS can play a key role in CE compliance by allowing the CE auditing actors to monitor the provenance of products and potentially realize whether their ingredients originate from disposition options, such as recycling.

The third iteration concentrated on detailing Figure 6.1 by exploring Vinturas, a consortium of European LSPs operating in the supply chain of finished vehicles. The blockchain platform offers visibility in the journey of vehicles from production to dealer. Additionally, it addresses the transportation element of the remarketing of second-hand vehicles. This aspect is of great importance for CE compliance since remarketing resembles the reuse disposition option depicted in the CE diagram by EMF (Figure 1.1), where products are directly resold after collection without further processing. Unlike TradeLens, Vinturas coves the transportation of products (e.g., vehicles) by truck. The unique data provided by this use case pointed out that both vehicle- and item-level visibility is required in the transportation of finished products in the CE context. The blue rectangles in Figure 4.22 illustrate its contribution to the development efforts.

Finally, the use cases contributed to the CE visibility evaluation framework by determining the type of data needed to be extracted from the blockchain-based information infrastructures by the CE auditing actors when assessing their potential to support their CE agendas. In particular, it was demonstrated that each examined information system captures information regarding the identity, location, status, events, and condition of the supply chain entities and the actors involved. Thereby, the thesis suggests that blockchain-based information systems need to store such data to serve CE purposes. This aspect is represented by the second layer of the produced artifact (see Figure 4.22).

6.1.5. Sub-research question 5

To what extent does the developed framework evaluate the ability of blockchain-enabled data pipeline solutions to provide the visibility needed to support CE policy instruments?

The SRQ5 dealt with the demonstration and evaluation phase of the MFDSR. In other words, it demonstrated and evaluated the CE visibility evaluation framework produced in the design phase. The evaluation criterion was the extent to which the framework fulfills its objective, enabling the CE auditing actors to evaluate the available blockchain-based information infrastructure on their ability to act as monitoring systems for CE purposes. This criterion was examined in two different ways.

Firstly, the thesis tested the framework by applying it to a case. The case proved its ability to capture the journey of materials and products in a closed supply chain. This finding was of pivotal importance, as the thesis derived the preliminary conclusion that its artifact has achieved its objective. This statement relied on the assumption that if the framework sheds light on the CE flows in a thorough way, it can also evaluate the available information systems on their potential to monitor these flows. This activity acted as a light form of evaluation. According to Johannesson and Perjons (2014), if an artifact tackles a problem in one case, then it can do likewise in other cases. It is essential to mention that the thesis has not studied the complete closed-loop concept (presented by EMF in Figure 1.1) but limited its focus on closing the materials loops through reuse and recycling.

Afterward, the study evaluated the demonstrated framework by using an ex-ante and naturalistic evaluation method. This method assessed the framework by forming informed arguments and conducting interviews. More specifically, the thesis carried out two interviews with blockchain experts and one workshop with experts from multiple disciplines (Dutch Customs, the Ministry of Infrastructure and Water Management, and blockchain experts). This phase proved that the CE visibility evaluation framework attained its objective. In other words, it confirmed that the framework can evaluate blockchain-enabled data pipelines solutions on their ability to offer the visibility required to support the CE policy instruments.

6.2. Addressing Main Research Question

The thesis focused on catalyzing the CE transition by developing a CE visibility evaluation framework. To fulfill its research objective, it formulated the following main research question:

"How can a CE visibility evaluation framework for blockchain-enabled data pipeline solutions facilitate the monitoring of compliance with the policy instruments established to foster the CE transition?"

The study addressed the MRQ by utilizing Design Science Research. The method explicated the steps needed to be followed to produce a novel artifact. By executing several activities, expressed by the sub-research questions, the thesis developed the final CE visibility evaluation framework, presented in Figure 6.2. The framework enables the CE auditing actors (actors that have launched policy instruments to promote the CE transition, such as policymakers and banks) to evaluate the available blockchain-based information systems on their ability to act as monitoring systems and serve the CE purposes. A monitoring system needs to trace the journey of materials or products in a closed-loop supply chain and enforce compliance with CE policy instruments. Box 5.1. and Box 5.2. contain the description of the framework and the method on how to use it, respectively.

The framework allows the CE auditing actors to evaluate and, if applicable, select among the various available blockchain-based infrastructures the most appropriate one for CE monitoring purposes. By doing so, they can monitor the flows of materials and products, ensure the effectiveness of their policy instruments, and identify potential frauds. In this way, they can force the business world to abandon the traditional linear economic model and adopt the circular one. For instance, policymakers could have prevented the disposal of plastic in Turkey by exploring business data stored in information systems about the journey of the plastic after consumption.

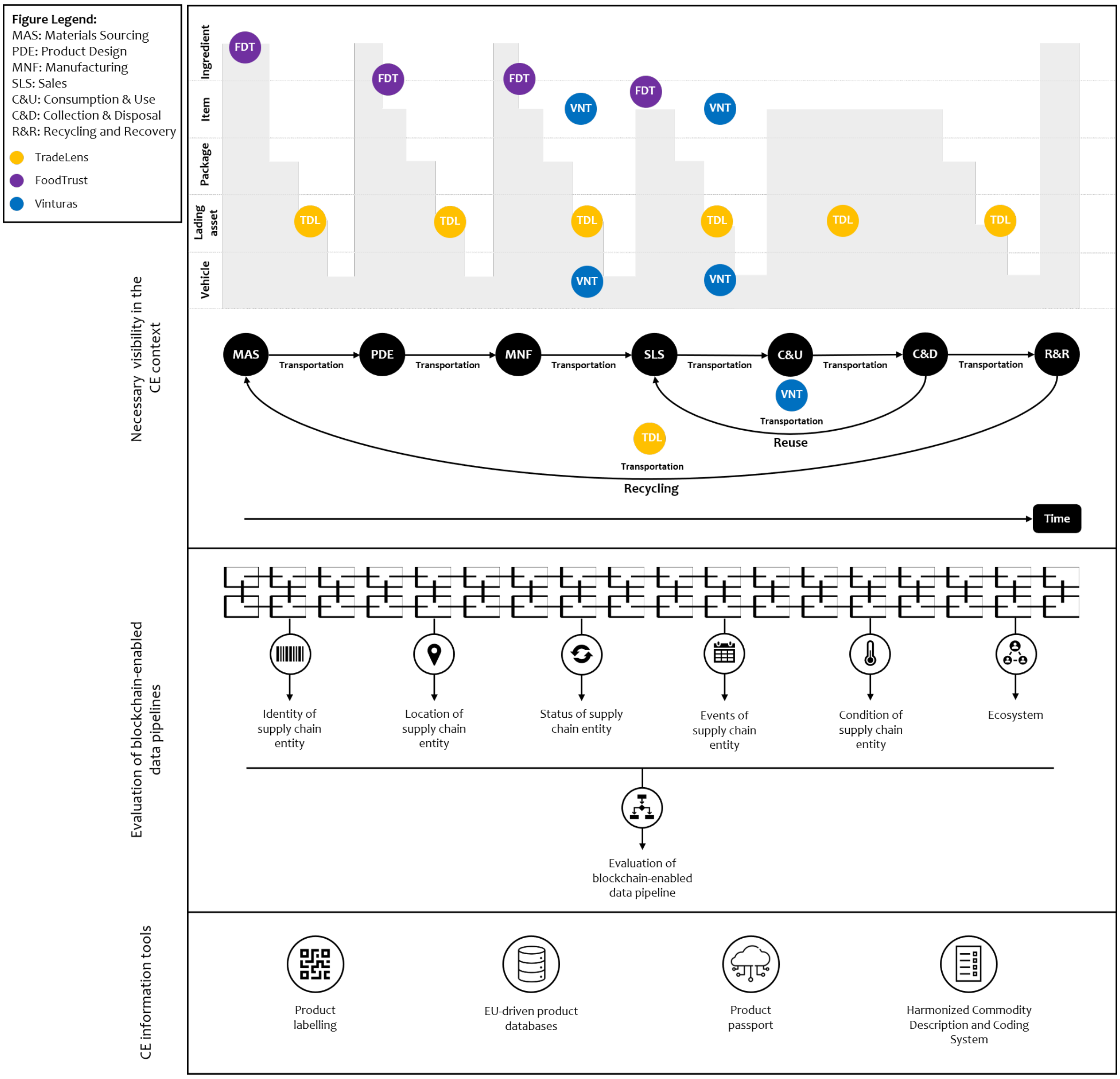


Figure 6.2: The CE visibility evaluation framework

6.3. Research Contribution

6.3.1. Scientific Contribution

The research focused on promoting CE as an effective solution to the enormous challenge that humanity currently faces regarding resource exhaustion and environmental destruction. This topic has been widely discussed in the literature, starting from the 1960s when the scientific community engaged in discussions about waste and resource management. Nowadays, the CE transition is a well-explored scientific domain. However, it has been approached from a more technical perspective, such as studying the appropriate technologies for recycling plastic. The research on the deployment of information infrastructure for accelerating the CE transition is a relatively undiscovered domain (Rukanova et al., 2021; Zeiss et al., 2020). For that reason, Zeiss et al. (2021) urged the IS community to concentrate its efforts in this direction.

The project bridged the knowledge gap surfaced by Zeiss et al. by developing the CE visibility evaluation framework. The research output is a valuable contribution to the scientific community. According to Casino, Dasaklis, and Patsakis (2019), there is a limited number of frameworks that evaluate blockchain-based infrastructures available in the literature. Moreover, as far as the thesis is concerned, this is the first one that assesses the extent to which blockchain-based applications can serve the CE transition by enforcing compliance. Whereas exploring the role of blockchain technology in the CE context is a novel scientific domain with a small number of available studies (Shojaei et al., 2021).

The evaluation framework contributed to the academic community by expanding the domain model developed by Hofman et al. (illustrated in Figure 4.1). The domain model depicts the flows of the supply chain entities from a place of acceptance to a destination, focusing solely on the logistic part. However, the CE visibility evaluation framework went beyond this level, showing the flows of supply chain entities in the CE context. It is important to underline that it also dived deeper into the supply chain entity hierarchy of the domain model by capturing the journey of ingredients (raw materials).

Equally essential for the academic society is the research conducted on expanding data pipelines to enforce compliance with the CE policy instruments. This idea has been formulated initially by Rukanova et al. (2021). The thesis implemented this suggestion and proved that data pipelines need to offer visibility in the entire flows of materials and products in a closed-loop supply chain. In other words, they need to cover their journey from materials sourcing to consumption and their reintroduction to the market through value retention strategies (e.g., reuse, recycling). Furthermore, data pipelines should be extended to enforce compliance at national borders, considering that the materials and products could cross several jurisdictions in the CE context.

Another scientific contribution is the concrete evidence provided about the need to work towards blockchain interoperability to enforce CE compliance. The analysis of the three blockchain platforms highlighted that none of them monitors the full path of materials and products. Every platform covers parts of the closed-loop supply chain. It is also safe to conclude that there is no system available in today's world that can fully serve CE. This observation emphasizes the imperative need to enable different blockchain platforms to communicate and exchange information with each other without the involvement of any intermediates (Hardjono et al., 2020; Monika & Bhatia, 2020; Schulte et al., 2019). Blockchain interoperability is a new scientific area, discussed by the thesis, which is worth exploring further since it can unleash the potential of both blockchain and business data.

Additionally, the thesis defined CE visibility by expanding Francis's definition of supply chain visibility. Francis defines supply chain visibility as *"the identity, location, and status of entities moving in the supply chain, captured in timely messages about events, along with the planned and actual dates/times for these events"* (Francis, 2008, p. 182). The thesis claimed that in the CE context this definition needs to be expanded by pointing out the need to have additional insights into the condition of entities moving in the supply chain. Condition plays a central role in deciding the suitable value retention strategy (e.g., recycling) for a product after consumption. Damages, changes in chemical composition, or other alterations may affect the potential of a product for recycling or direct reuse (Jayaraman et al., 2008; NEN, 2007). Thereby, information systems should also monitor this aspect.

The project also suggested that the supply chain entity hierarchy (Figure 3.1), as described by Francis, should be expanded since CE also involves the movement of raw materials (ingredients). The use of this extended hierarchy clarified the level of visibility needed for CE compliance. According to the thesis, the CE auditing actors should contain insights about the ingredients, items, packages, lading assets, and vehicles transiting the supply chain. Finally, it was noticed that CE includes several different supply chains, with different actors involved. That is to say, materials or products can be transported in every CE stage, such as from materials sourcing to production and from collection and disposal to recycling. This finding deserves further investigation since monitoring the CE flows requires visibility in every distinct supply chain.

6.3.2. Societal Contribution

The framework assists the actors (e.g., policymakers, banks) that have launched policy instruments to promote the transition to CE to fulfill their goals. The CE transition cannot be realized without the active involvement of these actors. The modern world has been designed to be linear. This business model has been optimizing for a very long time, and now it has been established as a profitable way to carry out business. Indicatively, the global economy was nine percent circular, in 2019 (Hartley et al., 2020). A shift in that mindset requires an external force, and policy instruments (e.g., regulations and taxes) can play this role. However, such instruments are prone to manipulations when the stakes are high. For that reason, the CE auditing actors need a monitoring system, which can prevent "greenwashing", false claims regarding the circularity of products.

The framework enables the CE auditing actors to evaluate and, if applicable, select among the available blockchain-based information systems the most appropriate one to serve their purpose. An appropriate information system should trace the path of materials and products in a closed-supply chain, at least to some extent based on the CE auditing actors' interests. For example, a government may be interested in getting visibility solely in materials sourcing. By realizing their CE agendas, the CE auditing actors will force the business world to abandon the traditional "take-make-waste" economic model and embrace the circular one.

There is no doubt that the linear economic model is unsustainable. The growing planet population and limited earth regenerative capacity put a strain on our planet leading to resource depletion and environmental destruction. Consequently, the CE transition, promoted by the thesis, is the only way to tackle these sustainability challenges. CE relies on receiving the maximum value of materials and products by retaining them in circulation. This rationale reduces the use of new materials and energy in the production systems and as a result benefits the environment.

In addition to the environmental benefits, EMF emphasizes the economic benefits of the CE transition. Modeling of the CE benefits for plastic packaging has proved that CE can produce savings of 200 billion USD on an annual basis and generate 700,000 additional employment opportunities. Dutch research discovered 810,000 jobs related to CE, including repairing, remanufacturing, recycling, and developing CE business models (Ellen MacArthur Foundation, 2021). Furthermore, the Dutch Organization for Applied Scientific Research (TNO) identified that CE could yield an additional €7.3 billion, create 54,000 jobs, and grow the GDP by an amount between €1.5 up and €8.4 billion (Deloitte, 2019).

The CE visibility evaluation framework can also contribute to IT development for CE purposes. It explicates what type of information is needed to be included in information systems to be used to enforce CE compliance. More specifically, it supports that such systems need to cover the identity, location, status, events, and condition of the supply chain entities. Moreover, it clarifies the black boxes, parts of the closed-loop supply not covered by the examined blockchain-based application. This contribution can be exploited by IT developers to develop new information systems or improve further the existing ones to be able to be used for the CE transition.

6.4. Research Limitations

The starting point of the thesis was the CE diagram by EMF (Figure 2.3), which makes explicit the flows of materials and products in the CE context. The diagram captures the closed-loop concept by connecting the linear economic model (presented in the central part) with two loops, one regarding renewables (biological cycle) and one about finite materials (technical cycle). The thesis focused on the technical cycle, which deals with finite and non-biodegradable materials. The motivation for concentrating on these materials stemmed from the imperative need to prolong their lifecycle and minimize their use in the production systems due to their characteristics. The technical cycle preserves planetary resources by suggesting four value retention strategies, namely, shared use of products, reuse/redistribution, refurbishment/remanufacturing, and recycling. The thesis decided to study two strategies, reuse/redistribution, and recycling.

The abovementioned choices, not studying the biological cycle and two value retention strategies (shared use and remanufacturing) constitute a research limitation. The CE visibility evaluation framework cannot fully serve its purpose since it does not fully cover the closed-loop concept. In other words, the CE auditing actors can use the framework when evaluating blockchain-based information systems on their ability to monitor the flows of finite materials and products from materials sourcing to consumption and their journey during reuse and recycling. It should be noted that the recycling model developed in chapter 4 (see Figure 4.3) may not be generalizable to every type of product, since the recycling process (from the collection of waste to recovery) is very product-specific. Furthermore, this model is not exhaustive, it does not capture every information requirement due to data limitations. The thesis did not study a blockchain-enabled application that addresses recycling. However, it is a first attempt to identify these information requirements and Figure 4.3 can be improved further.

The thesis decision to use TradeLens, FoodTrust and Vinturas for eliciting information requirements could have influenced the generalizability of its output. Generalizability refers to *"the extent to which a research finding in one organizational setting can be generalized to other settings"* (Sekaran Bougie, 2016, p.22). Considering the outcome of the evaluation phase, which proved that the produced framework fulfilled its objective, it can be concluded that the use cases did not affect the generalizability. However, there is no doubt that the study of more blockchain-based information systems would have increased the generalizability and refined the generated framework. Such systems could have covered the value retention strategies (shared use of products, maintenance, and refurbishment/remanufacturing) or the supply chain entities (order, encasement, and shipment) not studied by the thesis. It is worth mentioning that the selection of the use cases could have added bias to the research output, being associated with the ease of accessing business data. Subsection 1.8.2 explained in detail the motivation for selecting these use cases.

One more limitation arises from the research decision to rely the evaluation framework on the domain model by Hofman et al. The domain model is a logistics model focusing on representing the flows of goods in relationship with time. However, as proved by the CE visibility evaluation framework, CE compliance goes beyond logistics. In simple words, enforcing governmental control in the CE flows also requires data about non-transportation activities. An indicative example is product design, which, as discussed in subsection 5.3.3, does not belong in the logistics chain. The choice of the domain model as a basis in the design efforts led the thesis to depict product design as an activity that takes place between materials sourcing and manufacturing. This is an artificial representation that deviates from reality since raw materials after their sourcing are transported to production facilities. The research limitation to represent product design as part of the chain needs to be bridged by future research.

The applicability of the CE visibility evaluation framework is also influenced by the fact that it describes the CE flows on a high level. It depicts the fundamental processes that materials or products go through in the CE context. However, every product has its own peculiarities, and the framework may be unable to cover them. Indicatively, it cannot be directly applied to electronic devices or vehicles. These products consist of multiple other products (components) produced by parts manufacturers, not addressed by the framework.

Similar limitations can emerge in the waste collection, which is very product-specific. For example, electronic devices are returned by consumers to suppliers, while plastics are placed into a curbside recycling bin, together with other recyclable products (NEN, 2007). Undoubtedly, the produced artifact does not capture these peculiarities, but it can be used as a basis for the development of sub-frameworks focused on different product categories.

Another limitation is associated with the research choice to focus on four aspects of the supply chain entity hierarchy, as defined by Francis (2008). Namely, the thesis deliberately omitted in the design phase the order, encasement, and shipment since these entities describe specific situations that could have increased the complexity of the framework, without enriching the reader's understanding of CE visibility. However, this omission means that the CE visibility framework does not cover every entity moving in the closed-loop supply chain. Therefore, it is unable to serve specific situations. For example, it does not capture the cases in which orders of different buyers with the same place of acceptance and delivery are grouped and shipped together.

The thesis is also prone to limitations due to the evaluation method selected in chapter 5. The output would have been more efficient if the thesis had opted for an ex-post evaluation. An ex-post evaluation strategy would have implemented the framework in practice, such as in public decision making, and it would have reached a better conclusion with regards to its ability to serve the CE transition. Moreover, it would have avoided the occurrence of false positives, described in subsection 5.3.1. However, it was not feasible to conduct such an evaluation due to limited time, budget, and access to public or private organizations to test the framework.

The applicability of the CE visibility evaluation framework may be limited because of the interviews executed for its evaluation, which are prone to false positives. The interviewees may have withheld criticism wanting to be polite and nice. That means that they may have claimed that the framework is more efficient than it actually is (false positives). Furthermore, the framework was evaluated by stakeholders with a solid background on the topic. Thereby, it remains a matter of question whether stakeholders with less expertise in the domain can understand its rationale and use it. Finally, a limitation results from the research decision to interview experts in logistics and blockchain, but not experts in CE compliance. For example, actors (policymakers, banks, institutional investors) that have launched CE policy instruments. Consequently, it is still under discussion whether the framework serves their interests.

6.5. Recommendations

6.5.1. Recommendations for future research

This section identifies opportunities for future research mainly based on the research limitations discussed in the previous one. Undoubtedly, the CE visibility evaluation framework does not fully serve the CE auditing actors, actors that have launched policy instruments to promote CE transition. The framework should enable them to evaluate the available blockchain-enabled information systems on their potential to act as monitoring systems for CE purposes. However, as surfaced in the previous section, it does not cover every aspect of the closed-loop concept presented in the CE diagram by EMF (Figure 2.3). Since it has not addressed the biological cycle and two value retention strategies, remanufacturing and shared use of products. Moreover, the model developed for recycling (Figure 4.3) is not exhaustive. Consequently, further research is needed to study these aspects and lead to the development of a more elaborated CE visibility evaluation framework that can fully serve its purpose, enforcing CE compliance.

Future research should also delve deeper into the thesis choice to use a logistics model (the domain model by Hofman et al.) as a foundation in the design phase. As discussed in the previous section, this decision comes with certain limitations since CE compliance entails some fundamental issues that are unrelated to logistics. Indicatively, the framework represented product design as a supply chain process that involves a transportation element and raw materials go through it between their sourcing and manufacturing. However, product design is an overarching activity that governs every process illustrated in the CE visibility evaluation framework, such as transportation, manufacturing, reuse, and recycling. The thesis encourages the academic society to explore further the role of product design in CE compliance and overcome the limitations of the produced framework originating from the deployment of a logistics model. A suggestion could be to represent product design as the first activity in the framework, prior to materials sourcing and manufacturing.

The thesis developed a framework that describes the processes that materials and products go through on a high level. It depicts a simple business model in which production receives as input raw materials, transforms them into finished goods, and distributes them to retailers. However, this model can become more complex by involving the manufacturing of product parts (components) by one producer, subsequently transported to other producers who can use them to manufacture new products. An illustrative example could be the production of electronic devices. This gap can be bridged by further research, increasing the applicability and useability of the framework. Furthermore, a future study could investigate a blockchain-based application, if available, that offers visibility on the sourcing of finite materials and their use in the production system. The thesis studied a product, organic textile, not consisting of finite materials, which were its focus. However, it should be highlighted that this use case proved that it is technologically possible for the CE auditing actors to gain visibility in materials sourcing and manufacturing.

An interesting aspect of the research project that can be explored further is the role of standards in eliciting information requirements for CE compliance. Namely, chapter 4 deployed a recycling standard about plastics by NEN to identify the information needed to be captured by IT infrastructures to trace used plastic. The standard proved to be a valuable information source producing an elaborated version of the CE visibility evaluation framework (see Figure 4.3). Undoubtedly, there are various such standards available in today's world, and the academic community can harness them to identify the types of information requirements needed to trace materials or products in the CE context.

Further investigation could also explore the significance of the supply chain entities not covered by the thesis (order, encasement, and shipment) in achieving CE visibility. The omission of these entities influences the framework applicability in some cases, such as the combination of different clients' orders, which may be important for the CE auditing actors. However, to examine these entities, a research should study more blockchain-based information systems that cover them. In general, the thesis claims that the CE visibility evaluation framework can become more effective with the study of new information systems. These systems can be analyzed similarly as the thesis did in chapter 4.

Future studies could also examine other criteria that can be used to evaluate blockchain-based information systems on their ability to enforce compliance with the CE policy instruments. The thesis examined only the information requirements needed to be captured by such systems. However, the CE auditing actors may need also to evaluate them based on other aspects, such as the quality of the data stored. The research by Hofman et al. (forthcoming 2021) could be highly insightful for such a study since it has developed a data quality and data value evaluation framework that can be deployed by customs to assess the value of external data sources. Namely, Hofman et al. exploit a study conducted by Strong et al. on data quality. Strong et al. define high-quality data as *"data that is fit for use by data consumers"* and group it into four categories, intrinsic data quality, accessibility data quality, contextual data quality, and representational data quality (Strong, Lee, & Wang, 1997).

The academic community could also investigate an intriguing research finding. The thesis discovered that it is relatively easy to develop a system that monitors the flows of materials and products in a closed-loop supply chain from a technological perspective. However, to receive such visibility, the active involvement of different actors is required. In other words, multiple actors need to collaborate in an IT environment sharing their data and dealing with the information fragmentation that besets the business world. The literature review and the interviews conducted surfaced that supply chain actors are reluctant to share their data hampering the development of such a solid monitoring system. Therefore, future research could investigate the reasons influencing the parties' willingness to share their data (e.g., competition, mentality) and the incentives that can facilitate such data sharing (e.g., governmental policy). It should be noted that blockchain has proved that it can be the backbone of such a system thanks to its unique characteristics that ensure data integrity.

Another open issue is related to developing blockchain-based information systems that cover the black boxes in CE visibility. The thesis discovered that none of the examined information systems covers the parts after consumption. Whereas it is unknown whether there are information systems available in today's world that offer such visibility. Therefore, the research project suggests that future IT development efforts should bridge this gap. In other words, new blockchain-enabled information infrastructures should be launched to enforce compliance in the post-consumption phase. However, it remains a matter of question who can drive these development efforts. Various stakeholders could be this driving force, including policymakers, IT developers, and consumers. Future research could investigate how such information systems for CE compliance purposes can be introduced.

The thesis claimed that developing a monitoring system that covers the complete journey of materials and products in the CE context is not feasible. For that reason, it urges the academic community to work towards realizing blockchain interoperability, enabling the various blockchain-enabled information systems to communicate with each other without the participation of intermediates. Such research should also deal with the double-counting problem that may emerge when connecting data from various information sources. In other words, a system may trace an ingredient or item on a container level, and another one may trace the same ingredient or item on an ingredient- or item-level. Such double-counting could cause issues in the monitoring of the ingredient or item.

Additional research could also be done on examining the role of national borders in enforcing CE compliance. National borders are involved in the transportation aspect of the CE when materials or products cross different jurisdictions. Due to their location, the authorities at national borders could inspect these flows of materials and products and realize whether they integrate circular characteristics. Enforcing compliance at national borders was among the framework requirements, and the thesis has stated that it has fulfilled it partially. Therefore, it calls for further study on this concept.

Finally, further research efforts could apply the CE visibility evaluation framework in practice to identify whether it can support the CE agendas. That is to say, policymakers could use the framework to evaluate blockchain-based information infrastructure on their ability to monitor the flows of materials and products in the CE context. Such activity could be conducted firstly for resource-intensive products that have a higher impact on the environment. It should be highlighted that the CE visibility evaluation framework is a general framework applicable to various product types. However, upcoming research could adjust it to different product types improving its effectiveness. For example, a new CE visibility evaluation framework for electronic devices could be developed. The use of the framework by the CE auditing actors could also help them design more effective CE policy instruments based on the visibility that they can receive by accessing business data. As discussed in section 6.4., the produced framework can be refined by executing interviews with stakeholders that have a solid background in CE compliance, such as policymakers, banks and investors or parties with less expertise in the domain.

6.5.2. Recommendations for policymakers

The thesis has claimed that the transition to Circular Economy is a challenging task. Today's world has been designed to be linear. This business model has been optimizing for so long, and now it has been established as an effective way to conduct business. Thereby, a radical shift to everyone's mindset cannot be realized without an external force. As highlighted by the literature review, this driving force could be governmental policy. Public policymaking could increase the attractiveness of the circular business model and accelerate the transition by establishing a wide range of policy instruments, such as regulations and taxation. Undoubtedly, policymakers have been actively involved in materializing this shift. However, the academic literature suggests that uptake is falling behind, considering that in 2019 only nine percent of the global economy was circular (Hartley et al., 2020). This finding urges for deeper investigation regarding the deployment of CE policy instruments.

The CE visibility evaluation framework could play an essential role in improving policymaking by making explicit the processes that are subject to regulation. So far, policymakers have mostly concentrated their efforts on the post-consumption phase (the last part of the framework), that is to say, waste management, reuse, and recycling. However, their efforts have been proved insufficient, failing to yield the desired results (Hartley et al., 2020; European Environment Agency, 2017). Therefore, they may also need to steer their policy measures towards other aspects of the CE visibility evaluation framework.

The thesis urges policymakers to direct their CE agendas also towards product design and manufacturing, the processes that decide the circularity of products. Product design expresses the principles adopted in the engineering of products, such as dismantlability, recyclability, repairability, durability, etc. In simple words, it determines the product lifecycle. For that reason, policy measures focused on this business process could force businesses to abandon the strategy "planned obsolescence" and develop products with a prolonged lifecycle. Equally conducive for the CE transition could be the policy focus on production. Production constitutes the place that transforms raw materials into finished goods. To ensure the manufacturing of circular products, policymakers should regulate this process, forcing producers to use raw materials originating from value retention strategies (e.g., recycling) and generally adopt sustainable practices.

CE policymaking should also follow the principle "the power of the inner circle" described by the EMF and discussed in subsection 2.1.1. In other words, they should favor the inner circles of the CE diagram (see Figure 2.3), starting with firstly stimulating repair, subsequently reuse and remanufacturing. Recycling should be their last resort since it is an intensive process that discards the value contained in products, such as labor, energy, and capital. An interesting policy instrument is the one initiated by Sweden in January 2017. Sweden decreased the value-added tax on repairing bicycles, clothes, and shoes from 25% to 12% to boost the implementation of this disposition option. Moreover, it enabled consumers to request a refunding of half of the labor cost for repairing electric appliances through income tax (European Environment Agency, 2017). Similar policy measures can be launched at an EU level stimulating the markets for repair, reuse, and remanufacturing. The produced evaluation framework can enable it to monitor the implementation of such policies.

An over-discussed topic in the thesis is the need for policymakers to reap the benefits of the data stored in various information systems available in the supply chain to enforce CE compliance. The thesis discovered that the examined blockchain-based information systems can play a key role in CE compliance by offering visibility in different parts of the closed-loop supply chain. However, only TradeLens currently enables authorities to access the stored data for serving their interests. This means that policymakers should incentivize the ecosystem of FoodTrust, Vinturas, or other platforms to share their business data voluntarily to support the CE transition. Furthermore, legislators should develop close relationships with IT developers urging them to design new information systems or expand the existing ones to cover the black boxes in CE visibility pointed out by the thesis. Legislators could strengthen such collaboration and facilitate the development of CE monitoring systems by funding IT companies.

The CE transition is an interdisciplinary challenge. It will be realized only with the active participation of all the actors involved in the journey of materials and products in the closed supply chain. These actors need to constantly feed their business data in information systems enabling the auditing actors to obtain the craved visibility. Nonetheless, to make this scenario a reality, policymakers need to figure out the appropriate incentives for these actors. In other words, they need to give them benefits in return for communicating this information. Such benefits could be tax reduction or relaxation of the bureaucratic barriers currently imposed on them. As far as the thesis is concerned, several stakeholders (e.g., collectors, recyclers, waste management companies, waste buyers, etc.) are not currently involved in such information systems. This calls for further governmental action in helping them perceive the benefits of participating in such systems.

A valuable source of CE-related information is consumers, involved in the consumption or use of products. They are not part of the examined blockchain-based platforms, whereas it seems impossible to motivate them to participate in such platforms. Materials passports aspire to encourage them to communicate information about the use of products, enabling policymakers to get visibility in that aspect. Nevertheless, it remains a matter of question whether such visibility can become a reality since it depends on consumers' willingness to feed their data in the system continuously. The thesis advises policymakers to devise policy measures that can stimulate this data sharing. Additionally, consumers should be incentivized to alter their behavior, keeping the products in circulation (e.g., recycling) and opting for products integrating circular characteristics.

The flows of materials and products in the CE context can cross several national borders. This cross-border element emphasizes the vital role that customs can play in enforcing compliance with CE policy instruments. The evaluation workshop pointed out that the customs currently have a limited role in promoting CE transition. Customs administrations do not engage in launching CE policy instruments, but they can contribute to this scope as a means of enforcement. The thesis advises policymakers to upgrade the role of customs in CE compliance, enabling them to monitor whether products crossing national borders have circular characteristics. This cross-border element also calls for intergovernmental collaboration (especially at the international level). Various governments should collaborate exchanging information about the transported goods.

Finally, the thesis recommends EU develop blockchain-enabled materials passports to overcome some barriers regarding their adoption. Materials passports want to cover any CE-related information about the products, components, or materials used in buildings. However, such information may be confidential, making stakeholders reluctant to share it due to competing interests or other factors. Blockchain can address such confidentiality issues by enabling participants to retain ownership of their data and decide to whom they want to make their data available. Moreover, it can increase data recipients' confidence in the data quality thanks to its unique capabilities. Therefore, the thesis argues that blockchain can increase the attractiveness of materials passports and accelerate their adoption.

6.5.3. Recommendations for IT providers

The CE visibility evaluation framework can serve the IT providers' interests by informing them about the information needed to be captured by blockchain-based information infrastructure to serve the CE purposes. Such infrastructures need to monitor the journey of materials and products in a closed-loop supply chain. To do so, they need to store data about the identity, location, status, events, and condition of the supply chain entities. The insights offered by the framework can be used by the IT developers interested in supporting the CE transition to develop new information systems or improve the existing ones.

The framework (see Figure 6.2) shows that the platforms examined can cover mainly the parts before consumption. TradeLens monitors the shipment of containers from a seller to a buyer. FoodTrust (or BTS) offers visibility in materials sourcing, product design, manufacturing, and sales. While Vinturas focuses on the supply chain of finished vehicles covering mostly inland transportation. Seemingly, every platform addresses separate parts of the closed-loop supply chain. For that reason, the thesis urges IS community to work towards materializing blockchain interoperability, enabling the platforms to communicate with each other without the involvement of intermediates.

The abovementioned advice could be valuable for IBM, which owns two of the examined platforms (TradeLens and FoodTrust). IBM can develop a powerful CE monitoring system that covers almost the complete flows of materials and products from materials sourcing to sales by realizing such communication. Furthermore, it would be beneficial for it to extract the core idea behind Vinturas (connecting LSPs in one network) and develop a new blockchain-enabled platform that provides visibility in the inland transportation of materials or products. Such a development can give IBM a leading role in CE compliance since it will be able to equip the CE auditing actors with complete visibility from materials sourcing to sales.

A connection between TradeLens and FoodTrust could also play a vital role in enforcing compliance at national borders. Customs, when carrying out their risk assessment, access data stored in TradeLens. TradeLens provides visibility on a container level, storing shipment data and documents. In other words, it does not contain detailed information about the products stored in a container. This deteriorates the authorities' mission, who have to evaluate the suitability of the products to enter the national territories based on insufficient information. However, the information that authorities need, such as evidence about the sustainability of the products, is captured by FoodTrust. Thereby, IBM can become an essential partner for customs and increase its market reach by linking the two systems.

CE places particular attention on finite and non-biodegradable materials, aiming at prolonging their technical life by keeping them in circulation through value retention strategies. To ensure this circulation, the CE auditing actors need visibility in materials sourcing, product design, and manufacturing, that is to say, the aspects covered by FoodTrust. However, FoodTrust deals with food products and cannot satisfy the CE auditing actors' needs. This role can be played by BTS, which can be implemented to more product types. Recognizing the great potential of BTS in CE compliance, the thesis recommends IBM develop it further.

BTS needs to shed light on the production process (sustainability and ethical aspects), the flows of materials entering the production systems (especially when originating from value retention strategies), and the product design principles. IBM could firstly apply BTS to resource-intensive products. EC prioritizes electronics, ICT, textiles, furniture, and high-impact intermediary products, like steel, cement, and chemicals (European Commission, 2020a).

The thesis also suggests IT companies develop information systems that deal with the flows of products upon consumption. None of the examined systems offers such visibility. However, the thesis has examined a negligible number of systems. They could start providing visibility from the collection of products since it may not be possible or necessary to get insights during consumption. The elaborated model developed in chapter 4 for recycling could contribute to these development efforts. It presents the fundamental processes that products go through during recycling, the actors involved, and some key events and documents needed to be captured.

Moreover, IT companies should get the benefits providing by the available information sources, such as databases and product passports, to expand the reach of their systems. For example, IBM could close the loop to a great extent by connecting FoodTrust with a database possessed by waste collectors. Waste collectors may attach an identification number to collected products (e.g., glass bottles) and feed this information into a database to track the products during their transportation to producers. Equally useful could be to link blockchain-based information systems with materials passports, if applied to practice, since they are the only tool aspiring to cover the use of products by consumers.

Finally, the thesis recommends FoodTrust (or BTS) and Vinturas embrace the rationale of TradeLens regarding data sharing with authorities to increase their potential to serve the CE transition. TradeLens enables authorities to access its data without requesting permission. Participants when joining the platform agree to share their data with them voluntarily to experience benefits in return. This aspect facilitates B2G data sharing and makes TradeLens a powerful information tool for governmental control. The thesis argues that FoodTrust and Vinturas can expand their capabilities by implementing this design choice.

6.6. Relevance to MoT program

The research conducted on this topic completely aligns with the objectives of the master's program in Management of Technology (MoT). MoT aims at teaching students how to use abundant technological opportunities to tackle grand societal challenges. The CE visibility evaluation framework enables the CE auditing actors to enforce compliance with their policy instruments and consequently accelerate the CE transition. Such a development will bring considerable environmental and economic benefits. Apart from dealing with the wicked problem of resource depletion and environmental destruction, it will benefit the economy by creating additional employment opportunities and increasing GDP. Thereby, there is no doubt regarding the relevance of the thesis to the MoT program.

The outcome of the research relates also to the knowledge acquired throughout the master's program. As surfaced by the literature review, the analysis of the use cases, and interviews, blockchain has the potential to facilitate the CE transition. Thanks to its unique characteristics, it satisfies the need of CE auditing actors for trust in the data shared with them and its quality. Furthermore, it can address the information fragmentation that prevents the development of a solid CE monitoring system. The technology provides a safe environment that incentivizes actors operating in trustless environments to share their data and collaborate. Undeniably, the supply chain domain constitutes such an environment involving various geographically dispersed actors with competing interests, different policies, and cultures.

The thesis, by providing evidence that blockchain can indeed catalyze the CE transition, proved that the technology is not at the phase "peak of inflated expectations" of the hype cycle, described in the course "Emerging and Breakthrough Technologies". The hype cycle illustrates the maturity and adoption of technologies and explores their potential to tackle real-world problems. It describes that a technology goes through five distinct phases, "technology trigger", "peak of inflated expectations", "trough of disillusionment", "slope of enlightenment", and "plateau of productivity" (Dedehayir & Steinert, 2016).

Finally, the research project was benefited from the courses "Logistics and Supply Chain Innovations" and "Supply Chain Gaming", which equip students with a solid background on the basic thesis concepts. Apart from enriching their understanding of supply chain management and international trade, the courses familiarize them with the fundamentals of CE, data pipeline, and blockchain. More specifically, these courses introduce the students to the crucial problems that beset international trade and the potential of the latest digital innovations to eliminate them. This perspective was relevant to this thesis, which focused on addressing sustainability issues by exploiting data produced in the supply chain.

References

Abeyratne, S. A., & Monfared, R. (2016). Blockchain Ready Manufacturing Supply Chain Using Distributed Ledger. *International Journal of Research in Engineering and Technology*, *05*(09), 1–10. doi: 10.15623/ijret.2016.0509001

ABN AMRO, ING, & Rabobank. (2018). Circular Economy Finance Guidelines. , 1–4. Retrieved from `https://www.abnamro.com/nl/images/Documents/040_Duurzaamheid/Publications/ABN_AMRO_Circular_Economy_Finance_Guidelines_2018.pdf`

Adisorn, T., Tholen, L., & Götz, T. (2021). Towards a Digital Product Passport Fit for Contributing to a Circular Economy. *Energies*, *14*(8), 2289. Retrieved from `https://www.mdpi.com/1996-1073/14/8/2289` doi: 10.3390/en14082289

Alexandris, G., Katos, V., Alexaki, S., & Hatzivasilis, G. (2018). Blockchains as Enablers for Auditing Cooperative Circular Economy Networks. In *Ieee international workshop on computer aided modeling and design of communication links and networks, camad* (Vol. 2018-Septe). Institute of Electrical and Electronics Engineers Inc. doi: 10.1109/CAMAD.2018.8514985

Auer, J., Bey, N., & Schäfer, J. M. (2017). Combined Life Cycle Assessment and Life Cycle Costing in the Eco-Care-Matrix: A case study on the performance of a modernized manufacturing system for glass containers. *Journal of Cleaner Production*, *141*, 99–109. Retrieved from `http://dx.doi.org/10.1016/j.jclepro.2016.08.096` doi: 10.1016/j.jclepro.2016.08.096

Banihashemi, T. A., Fei, J., & Chen, P. S.-L. (2019). Exploring the relationship between reverse logistics and sustainability performance. *Modern Supply Chain Research and Applications*, *1*(1), 2–27. doi: 10.1108/mscra-03-2019-0009

Behnke, K., & Janssen, M. (2020). Boundary conditions for traceability in food supply chains using blockchain technology. *International Journal of Information Management*, *52*. doi: 10.1016/j.ijinfomgt.2019.05.025

Bressanelli, G., Adrodegari, F., Perona, M., & Saccani, N. (2018). The role of digital technologies to overcome Circular Economy challenges in PSS Business Models: An exploratory case study. *Procedia CIRP*, *73*, 216–221. Retrieved from `https://doi.org/10.1016/j.procir.2018.03.322` doi: 10.1016/j.procir.2018.03.322

Brunekreef, H., & Pournader, M. (2018). *Supply Chain Big Data Series: How big data is shaping the supply chains of tomorrow* (Tech. Rep.). KPMG.

Buterin, V. (2015). *A Next-Generation Smart Contract and Decentralized Application Platform* (Tech. Rep.).

Calvo-Porral, C., & Lévy-Mangin, J.-P. (2020). The Circular Economy Business Model: Examining Consumers' Acceptance of Recycled Goods. *Administrative Sciences*, *10*(2), 28. doi: 10.3390/admsci10020028

Carr, A. S., & Kim, J. (2017). Closed loop supply chain for glass recycling: Current practices and challenges. *International Journal of Integrated Supply Management*, *11*(4), 316–331. doi: 10.1504/IJISM.2017.089845

Carrefour. (2018). *Food traceability: Carrefour, a blockchain pioneer in Europe, has joined the IBM Food Trust platform to take action on a global scale* (Tech. Rep.). Retrieved from www.carrefour.com,

Carrefour. (2021a). *Activities | Carrefour Group.* Retrieved from https://www.carrefour.com/en/group/activities

Carrefour. (2021b). *Production of BABY BODIES X3 TEX BIO Long Sleeves.* Retrieved from https://tracabilite.carrefour.com/grp/bio/coton-kitex/?ean=3616181093631&marque=texbio&production=A

Casino, F., Dasaklis, T. K., & Patsakis, C. (2019). A systematic literature review of blockchain-based applications: Current status, classification and open issues. *Telematics and Informatics*, *36*(May 2018), 55–81. Retrieved from https://doi.org/10.1016/j.tele.2018.11.006 doi: 10.1016/j.tele.2018.11.006

CBP. (2009). *Importer Security Filing and Additional Carrier Requirements Bulk and Break Bulk Cargo How Will the Rule be Enforced? Where Can I Find More Information?* (Tech. Rep.). Retrieved from http://www.cbp.gov/xp/cgov/trade/cargo_security/carriers/security_filing/.www.cbp.gov

Cole, R., Stevenson, M., & Aitken, J. (2019). Blockchain technology: implications for operations and supply chain management. *Supply Chain Management*, *24*(4), 469–483. doi: 10.1108/SCM-09-2018-0309

Condemi, A., Cucchiella, F., & Schettini, D. (2019). Circular Economy and E-Waste: An Opportunity from RFID TAGs. Retrieved from www.mdpi.com/journal/applsci doi: 10.3390/app9163422

Costa, M. P. (2020). *Butterfly Diagram: Journey to Circularity.* Retrieved from https://www.beecircular.org/post/butterfly-diagram-journey-to-circularity

DCSA. (2020). *Glossary of terms: Industry Blueprint - Container shipping* (Tech. Rep.).

Dedehayir, O., & Steinert, M. (2016). The hype cycle model: A review and future directions. *Technological Forecasting and Social Change*, *108*, 28–41. Retrieved from http://dx.doi.org/10.1016/j.techfore.2016.04.005 doi: 10.1016/j.techfore.2016.04.005

Delmolino, K., Arnett, M., Kosba, A., Miller, A., & Shi, E. (2015). *Step by Step Towards Creating a Safe Smart Contract: Lessons and Insights from a Cryptocurrency Lab* (Tech. Rep.).

Deloitte. (2019). Quick Scan-Taxonomy Circular Economy: Analysis based on input from Dutch financial institutions. (May). Retrieved from https://ec.europa.eu/eurostat/documents/3859598/5902521/KS-RA-07-015-EN.PDF

Deslandes, M. (2021). *Tex (Carrefour) uses blockchain to ensure its textile traceability - News: industry (# 1270452).* Retrieved from https://fr.fashionnetwork.com/news/Tex-a-recours-a-la-blockchain-pour-assurer-sa-tracabilite-textile,1270452.html

Dewick, P., Bengtsson, M., Cohen, M. J., Sarkis, J., & Schröder, P. (2020). Circular economy finance: Clear winner or risky proposition? *Journal of Industrial Ecology*, *24*(6), 1192–1200. Retrieved from https://onlinelibrary.wiley.com/doi/10.1111/jiec.13025 doi: 10.1111/jiec.13025

DHL. (2018). Blockchain in logistics. *DHL Customer Solutions & Innovation*, 1–28. Retrieved from https://www.logistics.dhl/content/dam/dhl/global/core/documents/pdf/glo-core-blockchain-trend-report.pdf

DHL. (2021). *Custom support | DHL Express.* Retrieved from https://www.dhlexpress.nl/en/customs-support-online-booking-tool

Doan, L. T. T., Amer, Y., Lee, S. H., Phuc, P. N. K., & Dat, L. Q. (2019). E-Waste reverse supply chain: A review and future perspectives. *Applied Sciences (Switzerland)*, *9*(23), 5195. Retrieved from www.mdpi.com/journal/applsci doi: 10.3390/app9235195

Doyle, C., Sammon, D., & Neville, K. (2016). A design science research (DSR) case study: building an evaluation framework for social media enabled collaborative learning environments (SMECLEs). *Journal of Decision Systems*, *25*, 125–144. Retrieved from http://dx.doi.org/10.1080/12460125.2016.1187411 doi: 10.1080/12460125.2016.1187411

Ellen MacArthur Foundation. (2013). *Circular Economy Report - Towards the Circular Economy Vol. 1* (Tech. Rep.). Retrieved from https://www.ellenmacarthurfoundation.org/publications/towards-the-circular-economy-vol-1-an-economic-and-business-rationale-for-an-accelerated-transition

Ellen MacArthur Foundation. (2016). The New Plastics Economy: Rethinking the future of plastics. Retrieved from https://www.ellenmacarthurfoundation.org/assets/downloads/EllenMacArthurFoundation_TheNewPlasticsEconomy_Pages.pdf

Ellen MacArthur Foundation. (2017). *Achieving "growth within": A € 320-billion circular economy investment opportunity available to Europe up to 2025* (Tech. Rep.).

Ellen MacArthur Foundation. (2019). *Artificial Intelligence and the Circular Economy* (Tech. Rep.). Retrieved from https://www.ellenmacarthurfoundation.org/assets/downloads/Artificial-intelligence-and-the-circular-economy.pdf

Ellen MacArthur Foundation. (2021). Universal circular economy policy goals: Enabling the transition to scale.

European Commission. (2013). *European resource efficiency platform pushes for 'product passports.* Retrieved from https://ec.europa.eu/environment/ecoap/about-eco-innovation/policies-matters/eu/20130708_european-resource-efficiency-platform-pushes-for-product-passports_en

European Commission. (2019). *Accelerating the transition to circular economy: Improving access to finance for circular economy projects* (Tech. Rep.). Retrieved from http://europa.eu doi: 10.2777/983129

European Commission. (2020a). *Circular economy action plan: For a cleaner and more competitive Europe* (Tech. Rep.). Retrieved from https://ec.europa.eu/environment/circular-economy/pdf/new_circular_economy_action_plan.pdf

European Commission. (2020b). *A European Green Deal | European Commission.* Retrieved from https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal_en

European Commission. (2020c). *Plastic waste shipments: new EU rules on importing and exporting plastic waste.* Retrieved from https://ec.europa.eu/environment/news/plastic-waste-shipments-new-eu-rules-importing-and-exporting-plastic-waste-2020-12-22_en

European Commission. (2020d). Towards a European strategy on business-to-government data sharing for the public interest Final report prepared by the High-Level Expert Group on Business-to-Government Data Sharing.

European Commission. (2021a). *Customs declaration | Taxation and Customs Union.* Retrieved from https://ec.europa.eu/taxation_customs/business/customs-procedures/general-overview/customs-declaration_en

European Commission. (2021b). *The EU Ecolabel.* Retrieved from https://ec.europa.eu/environment/ecolabel/

European Commission. (2021c). *Rules and requirements for energy labelling and ecodesign | European Commission.* Retrieved from https://ec.europa.eu/info/energy-climate-change-environment/standards-tools-and-labels/products-labelling-rules-and-requirements/energy-label-and-ecodesign/rules-and-requirements_en

European Commission. (2021d). *Security: Taxation and Customs Union.* Retrieved from https://ec.europa.eu/taxation_customs/general-information-customs/customs-security/security_en

European Environment Agency. (2017). *Circular by design: Products in the circular economy* (Tech. Rep.). Retrieved from https://www.eea.europa.eu/publications/circular-by-design

European Parliament. (2019). Protection of EU financial interest on customs and VAT: Cooperation of national tax and customs authorities to prevent fraud.

FoodTrust. (2018). *About IBM Food Trust* (Tech. Rep.). Retrieved from www.ibm.com/food

Francis, V. (2008). Supply chain visibility: Lost in translation? *Supply Chain Management*, *13*(3), 180–184. doi: 10.1108/13598540810871226

FreightRight. (2021). *What is Packing List?* Retrieved from https://www.freightright.com/kb/packing-list

FSC. (2021). *What It Means When You See the FSC Labels on a Product.* Retrieved from https://fsc.org/en/fsc-labels

GEFCO. (2021). *What is CMR ?* Retrieved from https://www.gefco.net/en/glossary/definition/cmr/

Geissdoerfer, M., Savaget, P., Bocken, N., & Hultink, E. J. (2017). The circular economy a new sustainability paradigm?', Journal of cleaner production. , *143*, 757–768. Retrieved from http://creativecommons.org/licenses/by-nc-nd/4.0/Tel:+44 doi: 10.1016/j.jclepro.2016.12.048

Genovese, A., Acquaye, A. A., Figueroa, A., & Koh, S. C. (2017). Sustainable supply chain management and the transition towards a circular economy: Evidence and some applications. *Omega (United Kingdom)*, *66*, 344–357. Retrieved from http://dx.doi.org/10.1016/j.omega.2015.05.015 doi: 10.1016/j.omega.2015.05.015

Gervais, A., Karame, G. O., Wüst, K., Glykantzis, V., Ritzdorf, H., & Čapkun, S. (2016). On the Security and Performance of Proof of Work Blockchains. *Proceedings of the ACM Conference on Computer and Communications Security*, *24-28-Octo*, 3–16. Retrieved from https://dl.acm.org/doi/10.1145/2976749.2978341 doi: 10.1145/2976749.2978341

Ghisellini, P., Cialani, C., & Ulgiati, S. (2016). A review on circular economy: The expected transition to a balanced interplay of environmental and economic systems. *Journal of Cleaner Production*, *114*, 11–32. Retrieved from http://dx.doi.org/10.1016/j.jclepro.2015.09.007 doi: 10.1016/j.jclepro.2015.09.007

Gligoric, N., Krco, S., Hakola, L., Vehmas, K., De, S., Moessner, K., … Van Kranenburg, R. (2019). Smarttags: IoT product passport for circular economy based on printed sensors and unique item-level identifiers. *Sensors (Switzerland)*, *19*(3). doi: 10.3390/s19030586

Golara, S., Mousavi, N., Tarokh, M. J., & Hosseinzadeh, M. (2013). Closed-Loop Supply Chain Network Design with Recovery of Glass Containers. *International Journal of Strategic Decision Sciences*, *3*(4), 1–26. doi: 10.4018/jsds.2012100101

Govindan, K., & Hasanagic, M. (2018). A systematic review on drivers, barriers, and practices towards circular economy: a supply chain perspective. *International Journal of Production Research*, *56*(1-2), 278–311. doi: 10.1080/00207543.2017.1402141

Gregor, S., & Hevner, A. R. (2013). Positioning and presenting design science research for maximum impact. *MIS Quarterly: Management Information Systems*, *37*(2), 337–355. doi: 10.25300/MISQ/2013/37.2.01

Hardjono, T., Lipton, A., & Pentland, A. (2020). Toward an Interoperability Architecture for Blockchain Autonomous Systems. *IEEE Transactions on Engineering Management*, *67*(4), 1298–1309. doi: 10.1109/TEM.2019.2920154

Hardy, R. (2020). *Safety and security declarations* (Tech. Rep.). Retrieved from https://cdn.website-editor.net/d68fe857c8034ebdb171b1f2619ad5d2/files/uploaded/Safety_Security.pdf

Hartley, K., van Santen, R., & Kirchherr, J. (2020). Policies for transitioning towards a circular economy: Expectations from the European Union (EU). *Resources, Conservation* *and Recycling*, *155*(June 2019), 104634. Retrieved from https://doi.org/10.1016/j.resconrec.2019.104634 doi: 10.1016/j.resconrec.2019.104634

He, L., Xue, M., & Gu, B. (2020). Internet-of-things enabled supply chain planning and coordination with big data services: Certain theoretic implications. *Journal of Management Science and Engineering*, *5*(1), 1–22. Retrieved from https://doi.org/10.1016/j.jmse.2020.03.002 doi: 10.1016/j.jmse.2020.03.002

Heinrich, M., & Lang, W. (2019). *Materials Passports - Best Practice.*

Hesketh, D. (2009a). Global Trade Facilitation Conference 2011 Connecting International Trade : Single Windows and Supply Chains in the Next Decade Discussion paper developed with the support of the :. *World Customs Journal*, *3*(1), 27–32.

Hesketh, D. (2009b). Seamless electronic data and logistics pipelines shift focus from import declarations to start of commercial transaction. *World Customs Journal*, *3*(1), 27–32.

Hesketh, D. (2010). Weaknesses in the supply chain: Who packed the box? *World Customs Journal*, *4*(2), 3–20.

Hevner, A. R. (2007). A Three Cycle View of Design Science Research. *Scandinavian Journal of Information Systems*, *19*(2), 87–92. Retrieved from https://www.researchgate.net/publication/254804390_A_Three_Cycle_View_of_Design_Science_Research

Hofman, W. (2011). Supply chain visibility with linked open data for supply chain risk analysis. *CEUR Workshop Proceedings*, *769*, 20–31.

Hofman, W., Migeotte, J., Labare, M., Rukanova, B., & Tan, Y.-h. (2021). Using Business Data in Customs Risk Management: Data Quality and Data Value Perspective. , *3*, 1–16.

Hyperledger Fabric. (2021). *Why Hyperledger Fabric?* Retrieved from https://www.hyperledger.org/wp-content/uploads/2020/03/hyperledger_fabric_whitepaper.pdf

IATA. (2021). *DG Shipper's Declaration (DGD) and e-DGD.* Retrieved from https://www.iata.org/en/programs/cargo/dgr/shippers-declaration/

IBM. (2020a). *IBM Blockchain Transparent Supply - Presentation* (Tech. Rep.).

IBM. (2020b). *IBM Blockchain Transparent Supply: Solution Brief* (Tech. Rep.).

IBM. (2021). *IBM Food Trust - Blockchain for the world's food supply | IBM.* Retrieved from https://www.ibm.com/blockchain/solutions/food-trust

ICC. (2021). *Certificates of Origin - ICC - International Chamber of Commerce.* Retrieved from https://iccwbo.org/resources-for-business/certificates-of-origin/

Jayaraman, V., Ross, A. D., & Agarwal, A. (2008). Role of information technology and collaboration in reverse logistics supply chains. *International Journal of Logistics Research and Applications*, *11*(6), 409–425. doi: 10.1080/13675560701694499

Jin, H., Dai, X., & Xiao, J. (2018). Towards a novel architecture for enabling interoperability amongst multiple blockchains. *Proceedings - International Conference on Distributed Computing Systems*, *2018-July*, 1203–1211. doi: 10.1109/ICDCS.2018.00120

Johannesson, P., & Perjons, E. (2014). *An introduction to design science* (Vol. 9783319106328). Springer International Publishing. doi: 10.1007/978-3-319-10632-8

Kalmykova, Y., Sadagopan, M., & Rosado, L. (2018). Circular economy - From review of theories and practices to development of implementation tools. *Resources, Conservation and Recycling*, *135*(October 2017), 190–201. Retrieved from `https://doi.org/10.1016/j.resconrec.2017.10.034` doi: 10.1016/j.resconrec.2017.10.034

Klievink, B., Van Stijn, E., Hesketh, D., Aldewereld, H., Overbeek, S., Heijmann, F., & Tan, Y. H. (2012). Enhancing visibility in international supply chains: The data pipeline concept. *International Journal of Electronic Government Research*, *8*(4), 14–33. doi: 10.4018/jegr.2012100102

Kuechler, W., & Vaishnavi, V. (2012). *A Framework for Theory Development in Design Science Research: Multiple Perspectives* (Vol. 13; Tech. Rep. No. 6).

KVK. (2021). *Certificate of Origin (CO) - Chamber of Commerce.* Retrieved from `https://ondernemersplein.kvk.nl/certificaat-van-oorsprong/`

Lacity, M., Steelman, Z., & Cronan, P. (2019). Blockchain Governance Models: Insights for Enterprises. , 1–53.

Landerreche, E., & Stevens, M. (2018). On Immutability of Blockchains. *Proceedings of the ERCIM Blockchain Workshop 2018, Reports of the European Society for Socially Embedded Technologies*(10), 1–8. Retrieved from `https://dl.eusset.eu/bitstream/20.500.12015/3158/1/blockchain2018_02.pdf%0Ahttps://dl.eusset.eu/bitstream/20.500.12015/3157/1/blockchain2018_10.pdf%0Ahttps://www.fim-rc.de/Paperbibliothek/Veroeffentlicht/756/wi-756.pdf` doi: 10.18420/blockchain2018

Ledger Insights. (2021). *Carrefour expands blockchain traceability to textile products - Ledger Insights - enterprise blockchain.* Retrieved from `https://www.ledgerinsights.com/carrefour-expands-blockchain-traceability-to-textile-products/`

Loorbach, D., & Wijsman, K. (2013). Business transition management: Exploring a new role for business in sustainability transitions. *Journal of Cleaner Production*, *45*, 20–28. Retrieved from `http://dx.doi.org/10.1016/j.jclepro.2012.11.002` doi: 10.1016/j.jclepro.2012.11.002

Luscuere, L., & Mulhall, D. (2018). Circularity information management for buildings. In *Designing for the circular economy* (pp. 369–380). Routledge. Retrieved from `https://www.taylorfrancis.com/https://www.taylorfrancis.com/chapters/edit/10.4324/9781315113067-34/circularity-information-management-buildings-lars-luscuere-douglas-mulhall` doi: 10.4324/9781315113067-34

March, S. T., & Smith, G. F. (1995). Design and natural science research on information technology. *Decision Support Systems*, *15*(4), 251–266. doi: 10.1016/0167-9236(94)00041-2

Meis-Harris, D. J., Klemm, D. C., Kaufman, D. S., Curtis, D. J., Borg, M. K., & Bragge, D. P. (2021). What is the role of eco-labels for a circular economy? A rapid review of the literature. *Journal of Cleaner Production*, 127134. Retrieved from `https://doi.org/10.1016/j.jclepro.2021.127134` doi: 10.1016/j.jclepro.2021.127134

Miller, R. (2018). *Walmart is betting on the blockchain to improve food safety | TechCrunch.* Retrieved from https://techcrunch.com/2018/09/24/walmart-is-betting-on-the-blockchain-to-improve-food-safety/

Monika, & Bhatia, R. (2020). Interoperability Solutions for Blockchain. , 381–385. doi: 10.1109/icstcee49637.2020.9277054

Nakamoto, S. (2008). *Bitcoin: A Peer-to-Peer Electronic Cash System* (Tech. Rep.). Retrieved from www.bitcoin.org

Narayan, R., & Tidström, A. (2020). Tokenizing coopetition in a blockchain for a transition to circular economy. *Journal of Cleaner Production, 263.* doi: 10.1016/j.jclepro.2020.121437

Neerman, P. (2018). *Carrefour uses blockchain to create "transparent" chicken | RetailDetail.* Retrieved from https://www.retaildetail.eu/en/news/food/carrefour-uses-blockchain-create-transparent-chicken

NEN. (2007). Plastics - Recycled Plastics - Plastics recycling traceability and assessment of conformity and recycled content.

Nestle. (2019). *Nestlé and Carrefour give access to blockchain platform for Mousline.* Retrieved from https://www.nestle.com/media/news/carrefour-consumers-blockchain-mousline-puree-france

Nofer, M., Gomber, P., Hinz, O., & Schiereck, D. (2017). Blockchain. *Business and Information Systems Engineering, 59*(3), 183–187. doi: 10.1007/s12599-017-0467-3

OECD. (2020). *Green budgeting and tax policy tools to support a green recovery - OECD.* Retrieved from https://read.oecd-ilibrary.org/view/?ref=137_137215-2knww1hckd&title=Green-budgeting-and-tax-policy-tools-to-support-a-green-recovery

Ølnes, S., Ubacht, J., & Janssen, M. (2017). Blockchain in government: Benefits and implications of distributed ledger technology for information sharing. *Government Information Quarterly, 34*(3), 355–364. doi: 10.1016/j.giq.2017.09.007

Oppen, C. v., Croon, G., & Bijl de Vroe, D. (2020). *Circular Procurement in 8 steps.* Copper8.

Pagoropoulos, A., Pigosso, D. C., & McAloone, T. C. (2017). The Emergent Role of Digital Technologies in the Circular Economy: A Review. *Procedia CIRP, 64,* 19–24. Retrieved from http://dx.doi.org/10.1016/j.procir.2017.02.047 doi: 10.1016/j.procir.2017.02.047

Pahl, C., El Ioini, N., & Helmer, S. (2018). A decision framework for blockchain platforms for IoT and edge computing. *IoTBDS 2018 - Proceedings of the 3rd International Conference on Internet of Things, Big Data and Security, 2018-March*(March), 105–113. doi: 10.5220/0006688601050113

Pardo, R. (2018). *How the Circular Economy can benefit from the Digital Revolution* (Tech. Rep.). Retrieved from www.epc.eu

Peffers, K., Tuunanen, T., Rothenberger, M. A., & Chatterjee, S. (2007). A design science research methodology for information systems research. *Journal of Management Information Systems*, *24*(3), 45–77. doi: 10.2753/MIS0742-1222240302

Poel, v. d., & Royakkers, L. (2011). *Ethics, technology, and engineering : an introduction.* Wiley-Blackwell. Retrieved from `https://research.tue.nl/en/publications/ethics-technology-and-engineering-an-introduction`

Popper, N., & Lohr, S. (2017). *Blockchain: A Better Way to Track Pork Chops, Bonds, Bad Peanut Butter? - The New York Times.* Retrieved from `https://www.nytimes.com/2017/03/04/business/dealbook/blockchain-ibm-bitcoin.html?_r=1`

Portillo-Barco, C., & Charnley, F. (2015). Data requirements and assessment of technologies enabling a product passport within products exposed to harsh environments: A case study of a high pressure nozzle guide vane. *International Journal of Product Lifecycle Management*, *8*(3), 253–282. doi: 10.1504/IJPLM.2015.074145

Pugliatti, L. (2011). Cloud single window: Legal implications of a new model of cross-border single window. *World Customs Journal*, *5*(2), 3–20.

Rabobank. (2018). *ABN AMRO, ING and Rabobank launch finance guidelines for circular economy.* Retrieved from `https://www.rabobank.com/en/press/search/2018/20180702-abn-amro-ing-and-rabobank-launch-finance-guidelines-for-circular-economy.html`

Reuters. (2021). *Carrefour SA Profile | Reuters.* Retrieved from `https://www.reuters.com/companies/CARR.PA`

Rijksoverheid. (2019). *Circular Economy Implementation Programme 2019-2023.* Retrieved from `https://hollandcircularhotspot.nl/wp-content/uploads/2019/09/Circular-Economy-Implementation-Programme-2019-2023.pdf`

Rogerson, M., & Parry, G. C. (2020). Blockchain: case studies in food supply chain visibility. *Supply Chain Management*, *25*(5), 601–614. doi: 10.1108/SCM-08-2019-0300

Rukanova, B., Henningsson, S. ., Henkriksen, H. Z. ., & Tan, Y.-H. (2016). The anatomy of digital trade infrastructures. *Citation.* Retrieved from `http://doi.org/10.4233/uuid:59931d65-26d5-4255-973b-04fe395bfbc7` doi: 10.4233/uuid:59931d65-26d5-4255-973b-04fe395bfbc7

Rukanova, B., Henningsson, S., Zinner Henriksen, H., & Tan, Y.-H. (2018). Digital Trade Infrastructures: A Framework for Analysis. *Complex Systems Informatics and Modeling Quarterly, 01*(14), 1–21. doi: 10.7250/csimq.2018-14.01

Rukanova, B., Huiden, R., & Tan, Y.-H. (2017). Coordinated border management through digital trade infrastructures and trans-national government cooperation: The FloraHolland case. In *Lecture notes in computer science (including subseries lecture notes in artificial intelligence and lecture notes in bioinformatics)* (Vol. 10428 LNCS, pp. 240–252). Springer Verlag. Retrieved from `https://doi.org/10.1007/978-3-319-64677-0_20` doi: 10.1007/978-3-319-64677-0{_}20

Rukanova, B., & Tan, Y.-H. (2021). The Van den Ban case.

Rukanova, B., Tan, Y.-H., Hamerlinck, R., Heijmann, F., & Ubacht, J. (2021). Digital Infrastructures for governance of Circular Economy: A research agenda. *Proceedings of Ongoing Research, Practitioners, Workshops, Posters, and Projects of the International Conference EGOV-CeDEM-ePart 2021.*.

Rukanova, B., Ubacht, J., van Engelenburg, S., Tan, Y.-H., Geurts, M., Sies, M., ... Slegt, M. (2021). Realizing value from voluntary business-government information sharing through blockchain-enabled infrastructures: The case of importing tires to the Netherlands using TradeLens. *Proceedings of 22nd Annual International Conference on Digital Government Research. Association for Computing Machinery (ACM).*

Saberi, S., Kouhizadeh, M., & Sarkis, J. (2018). Blockchain technology: A panacea or pariah for resources conservation and recycling? *Resources, Conservation and Recycling*, *130*(November 2017), 80–81. Retrieved from `https://doi.org/10.1016/j.resconrec.2017.11.020` doi: 10.1016/j.resconrec.2017.11.020

Saberi, S., Kouhizadeh, M., Sarkis, J., & Shen, L. (2019). Blockchain technology and its relationships to sustainable supply chain management. *International Journal of Production Research*, *57*(7), 2117–2135. Retrieved from `https://doi.org/10.1080/00207543.2018.1533261` doi: 10.1080/00207543.2018.1533261

Sangupamba Mwilu, O., Comyn-Wattiau, I., & Prat, N. (2016). Design science research contribution to business intelligence in the cloud — A systematic literature review. *Future Generation Computer Systems*, *63*, 108–122. doi: 10.1016/j.future.2015.11.014

Schulte, S., Sigwart, M., Frauenthaler, P., & Borkowski, M. (2019). Towards Blockchain Interoperability. *Lecture Notes in Business Information Processing*, *361*, 3–10. doi: 10.1007/978-3-030-30429-4{_}1

Scully, J., Fildes, B., & Logan, D. (2005). *Quality Criteria for the Safety Assessment of Cars Based on Real-World Crashes: Use of Vehicle Identification Number for Safety Research* (Tech. Rep.).

Segers, L., Ubacht, J., Rukanova, B., & Tan, Y. H. (2019). The use of a blockchain-based smart import declaration to reduce the need for manual cross-validation by customs authorities. In *Acm international conference proceeding series* (pp. 196–203). Association for Computing Machinery. Retrieved from `https://doi.org/10.1145/3325112.3325264` doi: 10.1145/3325112.3325264

Sekaran, U., & Bougie, R. (2016). *Research methods for business: A skill-building approach* . Retrieved from `https://www.worldcat.org/title/research-methods-for-business-a-skill-building-approach/oclc/947135192`

Shen, L., & Worrell, E. (2014). Plastic Recycling. In *Handbook of recycling: State-of-the-art for practitioners, analysts, and scientists* (pp. 179–190). Elsevier Inc. doi: 10.1016/B978-0-12-396459-5.00013-1

Shojaei, A., Ketabi, R., Razkenari, M., Hakim, H., & Wang, J. (2021). Enabling a circular economy in the built environment sector through blockchain technology. *Journal of Cleaner Production*, *294*, 126352. Retrieved from `https://doi.org/10.1016/j.jclepro.2021.126352` doi: 10.1016/j.jclepro.2021.126352

Spencer, M. (2021). *Carrefour Extends Blockchain Technology to Textiles.* Retrieved from https://wwd.com/business-news/technology/carrefour-blockchain-textiles-technology-arianee-1234779099/

Srivastava, S., Bhadauria, A., Dhaneshwar, S., & Gupta, S. (2019). Traceability and transparency in supply chain management system of pharmaceutical goods through block chain. *International Journal of Scientific and Technology Research*, *8*(12), 3201–3206.

Strong, D. M., Lee, Y. W., & Wang, R. Y. (1997). Data quality in context. *Communications of the ACM*, *40*(5), 103–110. Retrieved from http://web.mit.edu/tdqm. doi: 10.1145/253769.253804

Su, B., Heshmati, A., Geng, Y., & Yu, X. (2013). A review of the circular economy in China: Moving from rhetoric to implementation. *Journal of Cleaner Production*, *42*(March), 215–227. doi: 10.1016/j.jclepro.2012.11.020

Swan, M. (2015). *Blockchain : blueprint for a new economy* (1. ed. ed.). Beijing: O'Reilly.

Tan, Y.-H., Bjørn-Andersen, N., Klein, S., & Rukanova, B. (2011). *Accelerating global supply chains with IT-innovation: ITAIDE tools and methods.* Springer Berlin Heidelberg. Retrieved from https://research.cbs.dk/en/publications/accelerating-global-supply-chains-with-it-innovation-itaide-tools doi: 10.1007/978-3-642-15669-4

Tan, Y.-H., Rukanova, B., van Engelenburg, S., Ubacht, J., & Janssen, M. (2019). Developing Large Scale B2B Blockchain Architectures for Global Trade Lane: Are the design principles derived based on the upscaling of the Internet applicable for upscaling global blockchain-enabled infrastructures? *6th Innovation in information infrastructures (III) workshop*(September 2020).

TNT. (2021). *Completing Commercial Invoices | Customs Requirements | TNT Direct.* Retrieved from https://direct.tnt.co.uk/company/completing-commercial-invoices

TradeLens. (2018). *TradeLens Overview - Presentation.*

TradeLens. (2019). *Major ocean carriers CMA CGM and MSC to join TradeLens.* Retrieved from https://www.tradelens.com/post/major-ocean-carriers-cma-cgm-and-msc-to-join-tradelens

TradeLens. (2021a). *TradeLens Overview - Presentation.*

TradeLens. (2021b). *TradeLens Platform | TradeLens.* Retrieved from https://www.tradelens.com/platform

Ullah, S., Iqbal, M., & Khan, A. M. (2011). A survey on issues in non-functional requirements elicitation. *Proceedings - International Conference on Computer Networks and Information Technology*, 333–340. doi: 10.1109/ICCNIT.2011.6020890

Underwood, S. (2016). Blockchain Beyond Bitcoin. Retrieved from http://www.ibm.com/blogs/ doi: 10.1145/2994581

United Nations. (2019). *World Population Prospects 2019: Highlights | Multimedia Library - United Nations Department of Economic and Social Affairs.* Retrieved from https://www.un.org/development/desa/publications/world-population-prospects-2019-highlights.html

Urciuoli, L., Hintsa, J., & Ahokas, J. (2013). Drivers and barriers affecting usage of e-Customs - A global survey with customs administrations using multivariate analysis techniques. *Government Information Quarterly*, *30*(4), 473–485. Retrieved from http://dx.doi.org/10.1016/j.giq.2013.06.001 doi: 10.1016/j.giq.2013.06.001

van Engelenburg, S., Rukanova, B., Hofman, W., Ubacht, J., Tan, Y. H., & Janssen, M. (2020). Aligning Stakeholder Interests, Governance Requirements and Blockchain Design in Business and Government Information Sharing. *Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics), 12219 LNCS*, 197–209. doi: 10.1007/978-3-030-57599-1{_}15

van Stijn, E., Klievink, B., Janssen, M., & Tan, Y.-H. (2012). Enhancing business and government interactions in global trade. *Third International Engineering Systems Symposium CESUN 2012*(June), 18–20.

Veenstra, A. (2014). *Compliance and control in global supply chains* (Tech. Rep.). Retrieved from www.tue.nl/taverne

Vervo. (2021). *CMR convention | Freight invoice.* Retrieved from https://vervo.lv/en/useful-information/cmr-convention

Vinturas. (2021a). Vinturas: A collaboration of Finished Vehicle Suppliers.

Vinturas. (2021b). *Vinturas - Presentation.*

Wautelet, T. (2018). *Exploring the role of independent retailers in the circular economy: a case study approach* (Doctoral dissertation). doi: 10.13140/RG.2.2.17085.15847

WCO. (2018). *The Harmonized System: A universal language for international trade* (Tech. Rep.).

Wester, J. (2020). *Dutch plastic illegally dumped in Turkey.* Retrieved from https://www.nrc.nl/nieuws/2020/10/16/nederlands-plastic-illegaal-gestort-in-turkije-a4016257

Zeiss, R., Ixmeier, A., Recker, J., & Kranz, J. (2020). Mobilising information systems scholarship for a circular economy: Review, synthesis, and directions for future research. *Information Systems Journal*(December 2019), 1–36. doi: 10.1111/isj.12305

Zuidwijk, R., Nunen, J., Eijk, D., & Hillegersberg, J. (2001). Supporting return flows in the supply chain. *Commun. ACM*, *44*, 74–79. doi: 10.1145/376134.376172

Appendices

A

List of interviews

[1] N. Kouwenhoven, EU Solutions Leader and Member of TradeLens (Customs and Authorities Lead), IBM, February 10, 2021, June 21, 2021 & June 30, 2021, Microsoft Teams Interview

[2] M. Bahurel, Client Technical Advisor and Member of FoodTrust, IBM, May 7, 2021, Microsoft Teams Interview

[3] J. Kuiper, CEO, Vinturas, May 20, 2021 & June 22, 2021, Microsoft Teams Interview

[4] R. Hamerlinck, Team Leader on Economic and Fiscal Policy, Dutch Ministry of Infrastructure and Water Management, June 30, 2021, Microsoft Teams Interview

[5] F. Heijmann, Director National Committee on Trade Facilitation and Head of Trade Relations, Customs Administration of the Netherlands, June 30, 2021, Microsoft Teams Interview

[6] M. Sies, Business Development Executive and Member of TradeLens, IBM, June 30, 2021, Microsoft Teams Interview

[7] S. Jeacocke, Associate Partner, Global Customs Lead and Member of TradeLens, IBM, June 30, 2021, Microsoft Teams Interview

B

Evaluation Form

Date

Interviewer: Angelos Kofos, TU Delft

Interviewee:

This document is for the evaluation of the CE visibility evaluation framework produced during the research project "Accelerating the transition to Circular Economy: The development of a CE visibility evaluation framework for blockchain-enabled data pipeline solutions". The purpose of the interview is to evaluate the effectiveness of the framework and the fulfillment of the identified requirements.

Please evaluate whether the requirements and the research objective presented in the following table are addressed sufficiently by the CE visibility evaluation framework. The requirements are classified into two categories:

- Functional requirements (FRQ): the functions that the framework should provide.
- Non-functional requirements (NFRQ): general qualities that the framework should have.

Objective and Requirements		***Response***		
		Yes	No	Partially
FRQ.1	The CE visibility evaluation framework should capture the supply chain entity hierarchy.			
FRQ.2	The CE visibility evaluation framework should assess the blockchain-enabled data pipelines based on their ability to capture the identities of the supply chain entities.			
FRQ.3	The CE visibility evaluation framework should assess the blockchain-enabled data pipelines based on their ability to capture the location of the supply chain entities.			
FRQ.4	The CE visibility evaluation framework should assess the blockchain-enabled data pipelines based on their ability to capture the status of the supply chain entities.			
				Continued on next page

FRQ.5	The CE visibility evaluation framework should assess the blockchain-enabled data pipelines based on their ability to capture the events of the supply chain entities.			
FRQ.6	The CE visibility evaluation framework should extend the supply chain entity hierarchy by including ingredients.			
FRQ.7	The CE visibility evaluation framework should assess the blockchain-enabled data pipelines based on their ability to capture the condition of ingredients or items.			
FRQ.8	The CE visibility evaluation framework should assess blockchain-enabled data pipelines based on their ability to provide visibility from the seller in the exporting country to the buyer in the importing country.			
FRQ.9	The CE visibility evaluation framework should assess blockchain-enabled data pipelines based on their ability to shed light in production (including product design).			
FRQ.10	The CE visibility evaluation framework should assess blockchain-enabled data pipelines based on their ability to shed light in the flows of secondary raw materials.			
FRQ.11	The CE visibility evaluation framework should provide assess blockchain-enabled data pipeline solutions based on their ability to enforce compliance at national borders.			
FRQ.12	The CE visibility evaluation framework should highlight the need for blockchain interoperability.			
FRQ.13	The CE visibility evaluation framework should explicate the importance of identifying the participants of blockchain-based data pipeline solutions.			
FRQ.14	The CE visibility evaluation framework should reap the benefits of available CE information tools.			
NFRQ.1	The CE visibility evaluation framework should be able to illustrate the visibility offered by the blockchain-enabled data pipeline solutions in a simple way.			
NFRQ.2	The CE visibility evaluation framework should contain standardized terminology.			
NFRQ.3	The CE visibility evaluation framework should illustrate the extent to which a blockchain-based data pipeline serves CE purposes.			
Goal	The development of a framework that evaluates the potential of available blockchain-based information systems to enforce compliance with CE policy instruments by acting as monitoring systems.			

Please write below if you have any suggestions to improve the CE visibility evaluation framework (e.g., missing elements, better design).

Thank you for your participation,

Angelos Kofos

C

Key documents stored by the platforms

This chapter contains examples of some of the documents discussed in Chapter 4. The documents can play an important role in the CE context by acting as information sources for the CE auditing actors (e.g., policymakers, customs authorities, banks). Section C.1 contains some shipping documents stored by TradeLens, namely, commercial invoice, packing list, bill of lading, and dangerous goods declaration (DGD). Section C.2 presents two certificates related to organic cotton stored by FoodTrust, the GOTS certificate, and the OEKO-TEX standard 100 certificate. The former certificate denotes that each phase of manufacturing satisfies strict regulations, while the latter one is awarded to textiles that do not contain harmful substances. Finally, section C.3 shows two key documents captured by Vinturas, the CMR and the CVO.

C.1. Documents stored by TradeLens

XXX

Date	Invoice #
XXXX	XXXX

Bill To
XXX

Ship To
XXXX

P.O. Number	Terms	Rep	Ship Date	Due Date	Via
XXXX	XXXX	XXX	XX		XXX

Quantity	Item Code	Description	Price Each	Amount
XX	XXX	XXXX Amount per HS code: XXX pcs Weight per HS code: XXXkgs Total amount in dollars of HS code : USD XXXX	XXX	XXXX
		TOTAL QTY: XXX PCS CONTAINER: XXX TOTAL CONTAINER WEIGHT: XXX KGS		
		Delivery Term: XXX Country of origin of the goods: XXXX		
		Bank Information: XXX XXX XXXXX XX Payment Term: XXX		

XXX	**Total**	XXXX

Figure C.1: Commercial invoice (Rukanova & Tan, forthcoming 2021)

XXXX

XXX

Date	Invoice #
XXXX	XXXX

Phone # XXX
Fax # XXX

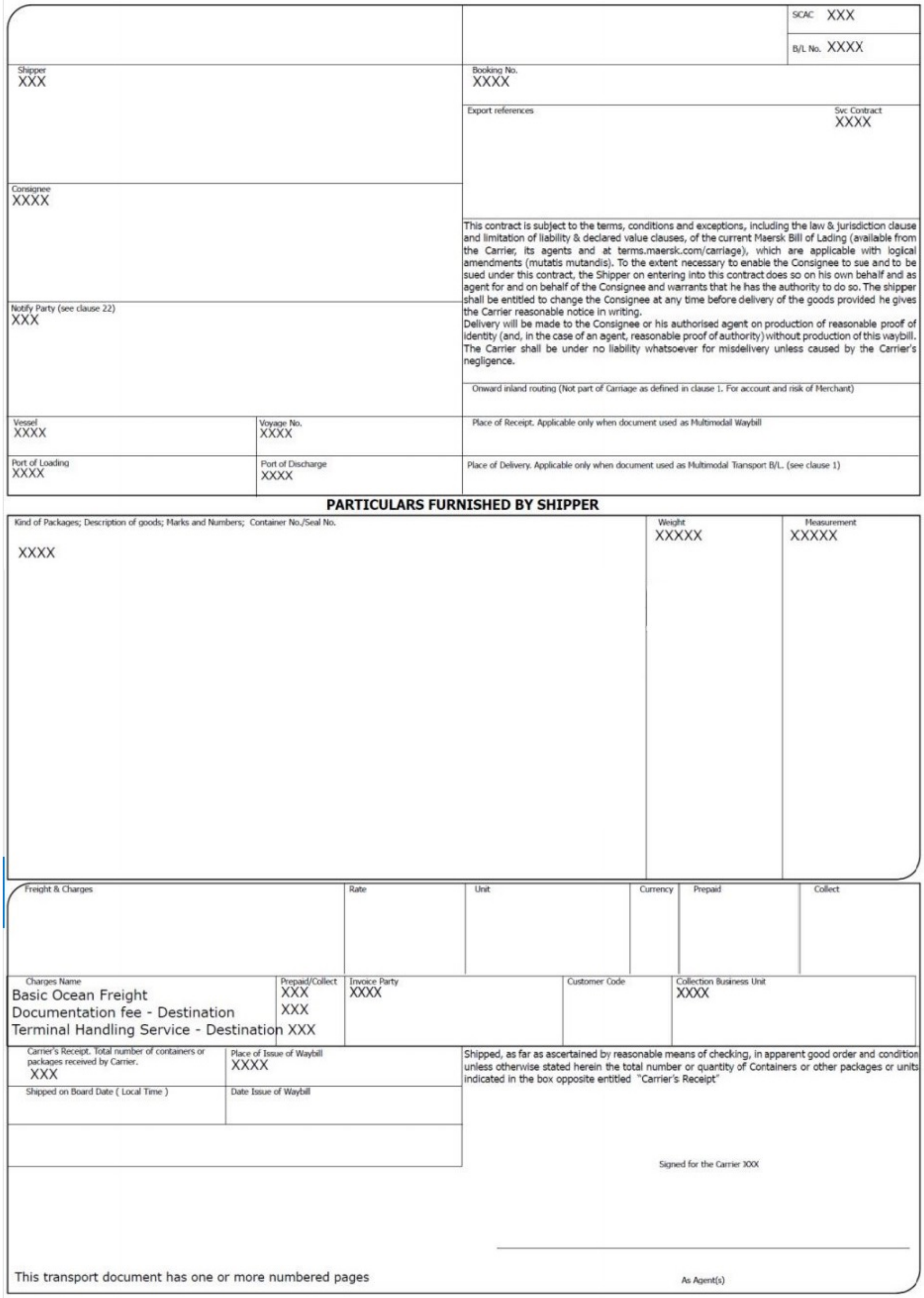
Ship To
XXXX

P.O. No.	Ship	Via	APPT
XXXX	XXXX	XXXX	

Quantity	Item Code	Description	Weight
XX	XXXX	XXX	
		TOTAL QTY: XXXX CONTAINER: XXXX	
		Bank Information: XXX	
		Our Acct #: XXX Bank ABA #: XXX	
		Payment Term: XXX	
		Delivery Term: XXX	
		Country of origin of the goods: XXXX	

Carrier:	Driver Signature:
Seal #	

Figure C.2: Packing list (Rukanova & Tan, forthcoming 2021)



SCAC XXX

B/L No. XXXX

Shipper
XXX

Booking No.
XXXX

Export references

Svc Contract
XXXX

Consignee
XXXX

This contract is subject to the terms, conditions and exceptions, including the law & jurisdiction clause and limitation of liability & declared value clauses, of the current Maersk Bill of Lading (available from the Carrier, its agents and at terms.maersk.com/carriage), which are applicable with logical amendments (mutatis mutandis). To the extent necessary to enable the Consignee to sue and to be sued under this contract, the Shipper on entering into this contract does so on his own behalf and as agent for and on behalf of the Consignee and warrants that he has the authority to do so. The shipper shall be entitled to change the Consignee at any time before delivery of the goods provided he gives the Carrier reasonable notice in writing.
Delivery will be made to the Consignee or his authorised agent on production of reasonable proof of identity (and, in the case of an agent, reasonable proof of authority) without production of this waybill. The Carrier shall be under no liability whatsoever for misdelivery unless caused by the Carrier's negligence.

Notify Party (see clause 22)
XXX

Onward inland routing (Not part of Carriage as defined in clause 1. For account and risk of Merchant)

Vessel	Voyage No.	Place of Receipt. Applicable only when document used as Multimodal Waybill
XXXX	XXXX	

Port of Loading	Port of Discharge	Place of Delivery. Applicable only when document used as Multimodal Transport B/L. (see clause 1)
XXXX	XXXX	

PARTICULARS FURNISHED BY SHIPPER

Kind of Packages; Description of goods; Marks and Numbers; Container No./Seal No.	Weight	Measurement
XXXX	XXXXX	XXXXX

Freight & Charges	Rate	Unit	Currency	Prepaid	Collect

Charges Name	Prepaid/Collect	Invoice Party	Customer Code	Collection Business Unit
Basic Ocean Freight	XXX	XXXX		XXXX
Documentation fee - Destination	XXX			
Terminal Handling Service - Destination	XXX			

Carrier's Receipt. Total number of containers or packages received by Carrier.	Place of Issue of Waybill
XXX	XXXX

Shipped on Board Date (Local Time)	Date Issue of Waybill

Shipped, as far as ascertained by reasonable means of checking, in apparent good order and condition unless otherwise stated herein the total number or quantity of Containers or other packages or units indicated in the box opposite entitled "Carrier's Receipt"

Signed for the Carrier XXX

This transport document has one or more numbered pages

As Agent(s)

Figure C.3: Bill of lading (Rukanova & Tan, forthcoming 2021)

IMO DANGEROUS GOODS DECLARATION

This form meets the requirement of SOLAS 74 chapter VII, regulation 5;
MARPOL 73/78 ANNEX III, regulation 4 and the IMDG CODE, General introduction, section 9

Shipper [1]

Reference number(s) [2]
Page 1 of 1
Shipper's Reference Number

Consignee [3]

Carrier: [4]

Container packing certificate/vehicle declaration

DECLARATION

It is declared that the packing of the container/vehicle has been carried out in accordance with the General Introduction, IMDG Code, paragraph 5.4.2

TO BE COMPLETED FOR SHIPMENTS IN CONTAINERS OR VEHICLES

Name/status, company/organization of signatory [5]

Place and date

Signature on behalf of packer

Ship's name and voyage No. Port of loading [6]

Instructions or other matter [7]

Port of discharge [8]

Marks Nos. If applicable, identification or registration number(s) of the Unit	Number and kind of packages, proper shipping name *, IMO hazard class/division, UN number, packaging group (where assigned) * *, flashpoint (in ºC.c.c.) * *, control and emergency temperatures * *, identification of the good as MARINE POLLUTANT* *, EmS No. and MFAG Table No.***	Gross mass (kg,), net quantity/mass* *

[9] Goods delivered as:
☐ Breakbulk cargo
☐ Unitized cargo
☐ Bulk packages

Type of unit (container, trailer, tank vehicle, etc.)
☐ Open
☐ Closed

Insert "X" in approriate box

(This column may be left empty apart from the heading, in which case insert appropriate description)

* Synonyms should not be used. Proprietary/trade names alone are not sufficient. If applicable:(1) the word "WASTE" should precede the nam
(2) "EMPTY UNCLEANED" or "RESIDUE-LAST CONTAINED" should be added
(3) "LIMITED QUANTITY" should be added.

* * When required in paragraph 9.3 of the General Introduction to the IMDG code; * * * When required.
The IMDG Code page number should not appear on this form.

ADDITIONAL INFORMATION [10]
(In certain circumstances special information/certificates are required, see IMDG code, General Introduction, paragraphs 9.7.1/9.7.2/9.9.1 and 9.10.

DECLARATION

I hereby declare that the contents of this consignment are fully and accurately described above by the proper shipping name(s), and are classified, packaged, marked and labeled/placarded, and are in all respects in proper condition for transport according to applicable international and national governmental regulations.

Name/status, company/organization of signatory [11]

Place and Date

Signature on behalf of shipper

Figure C.4: DGD document (DHL, 2021)

C.2. Documents stored by FoodTrust

CU Inspections & Certifications India Pvt. Ltd.
22nd Floor,Arihant Aura, TTC Industrial Area, Turbhe MIDC, Opposite Turbhe Station,, 400705, Navi Mumbai, Maharashtra, India
+91 22 61294200
www.petersoncontrolunion.com

SCOPE CERTIFICATE

Scope Certificate Number: CU829345GOTS-2020-00087144

Control Union Certifications declares that

Kitex Limited
License Number: 829345
PB#4, Kizhakkambalam, Aluva,
683562 Ernakulam, Kerala
India

has been inspected and assessed in accordance with the

Global Organic Textile Standard (GOTS)
- Version 5.0 -

and that products of the categories as mentioned below (and further specified in the annex) comply with this standard:

Product categories: Men's apparel, Women's apparel, Babies' apparel, Dyed yarns, Dyed fabrics, Undyed fabrics, Children's apparel, Carried accessories, Greige fabrics

Processing steps / activities carried out under responsibility of the above-mentioned company (by the operations as detailed in the annex) for certified products

Dyeing, Finishing, Subcontracting, Wet processing, Yarn dyeing, Knitting, Sizing, Storing, Weaving, Washing, Printing, Exporting, Manufacturing, Trading

This certificate is valid from:
2019-12-07
This certificate is valid until:
2021-03-06

This Scope Certificate provides no proof that any goods delivered by its holder are GOTS certified. Proof of GOTS certification of goods delivered is provided by a valid Transaction Certificate (TC) covering them.
Accredited by: International Organic Accreditation Services (IOAS); Contract No 81

CONTROLUNION

CU Inspections & Certifications India Pvt. Ltd.
POST • 22nd Floor,Arihant Aura, TTC Industrial Area, Turbhe MIDC, Opposite Turbhe
T • +91 22 61294200 • F • • cuindia@controlunion.com •

This electronically issued document is the valid original version.

Figure C.5: GOTS certificate (Carrefour, 2021b)

HOHENSTEIN Textile Testing Institute GmbH & Co. KG
Schlosssteige 1, 74357 Bönnigheim, Germany

OEKO-TEX®
INSPIRING CONFIDENCE

CERTIFICATE

The company

Kitex Limited
P.B. No. 4, Kizhakkambalam, Aluva
Kerala - 683 562, INDIA

is granted authorisation according to STANDARD 100 by OEKO-TEX® to use the STANDARD 100 by OEKO-TEX® mark, based on our test report **19.0.92850**

OEKO-TEX®
CONFIDENCE IN TEXTILES
STANDARD 100
13.HIN.29568 HOHENSTEIN HTTI
Tested for harmful substances
www.oeko-tex.com/standard100

for the following articles:

Knitted ready-made garments (T-shirts, sleep suits, pyjama sets, caps, bibs, rompers, booties, nightgowns, vests, briefs, leggings, boxers, baby body suits, shorty pyjamas, slips, hipsters, singlets, spaghetti tops, shorties, panties, sweaters, mittens) made of CO, CO/EL in white, reactive solid piece and yarn dyed as well as fibre dyed (only mélange), CO/PES in white, solid piece and yarn dyed (reactive & disperse), organic CO, organic CO/EL, CO/CV and organic CO/CV in fibre dyed (only mélange), with or without pigment print on all qualities and on all mélange qualities, reactive print (only CO), water based non-PVC, flock, puff, glitter (silver and gold) and foil (silver and gold) print on CO, organic CO, CO/CV in white, dyed and on mélange as well organic CO in raw white, woven garments (bags, boxers, pyjamas) made of CO in white, reactive piece dyed, all organic cotton (GMO not detectable), including accessories (sewing and embroidery thread, heat transfer sticker, elastic, twill and satin tape, woven and printed label, metal accessory, snap button [metal & PES], zipper, interlining, PES button, bow); produced by using materials certified according to STANDARD 100 by OEKO-TEX®.

The results of the inspection made according to STANDARD 100 by OEKO-TEX®, Appendix 4, **product class I** have shown that the above mentioned goods meet the human-ecological requirements of the STANDARD 100 by OEKO-TEX® presently established in Appendix 4 for baby articles.

The certified articles fulfil requirements of Annex XVII of REACH (incl. the use of azo colourants, nickel release, etc.), the American requirement regarding total content of lead in children's articles (CPSIA; with the exception of accessories made from glass) and of the Chinese standard GB 18401:2010 (labelling requirements were not verified).

The holder of the certificate, who has issued a conformity declaration according to ISO 17050-1, is under an obligation to use the STANDARD 100 by OEKO-TEX® mark only in conjunction with products that conform with the sample initially tested. The conformity is verified by audits.

The certificate 13.HIN.29568 is valid until 31.10.2020

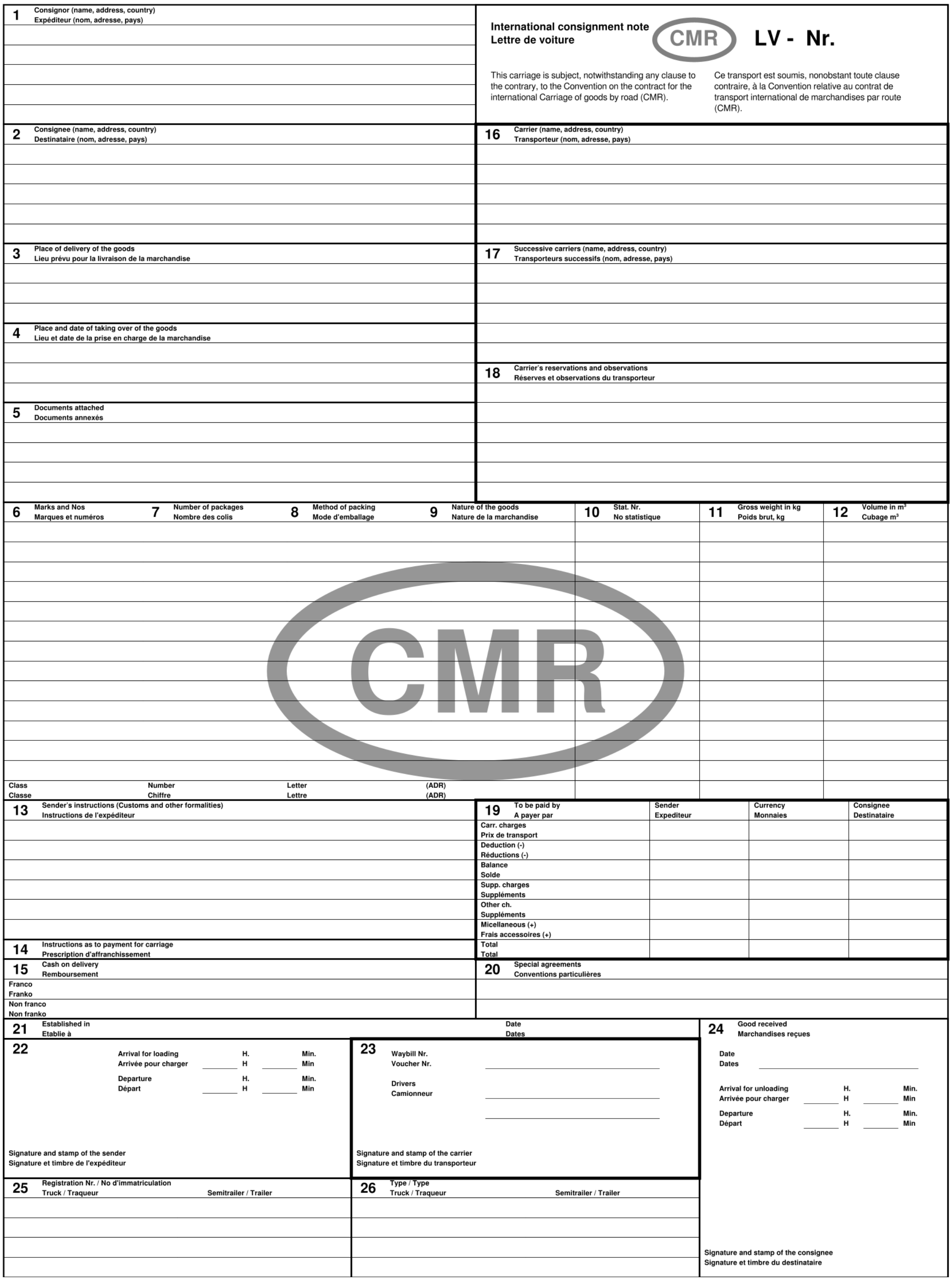
Boennigheim, 20.11.2019

Dipl.-Ing. (FH) Ivonne Schramm
Head of Certification Body OEKO-TEX®

OEKO-TEX® Association | Genferstrasse 23 | P.O. Box 2006 | CH-8027 Zurich

Figure C.6: OEKO-TEX certificate (Carrefour, 2021b)

C.3. Documents stored by Vinturas


1 Consignor (name, address, country) / Expéditeur (nom, adresse, pays)

International consignment note / Lettre de voiture — CMR — LV - Nr.

This carriage is subject, notwithstanding any clause to the contrary, to the Convention on the contract for the international Carriage of goods by road (CMR).

Ce transport est soumis, nonobstant toute clause contraire, à la Convention relative au contrat de transport international de marchandises par route (CMR).

2 Consignee (name, address, country) / Destinataire (nom, adresse, pays)

16 Carrier (name, address, country) / Transporteur (nom, adresse, pays)

3 Place of delivery of the goods / Lieu prévu pour la livraison de la marchandise

17 Successive carriers (name, address, country) / Transporteurs successifs (nom, adresse, pays)

4 Place and date of taking over of the goods / Lieu et date de la prise en charge de la marchandise

18 Carrier's reservations and observations / Réserves et observations du transporteur

5 Documents attached / Documents annexés

6 Marks and Nos / Marques et numéros
7 Number of packages / Nombre des colis
8 Method of packing / Mode d'emballage
9 Nature of the goods / Nature de la marchandise
10 Stat. Nr. / No statistique
11 Gross weight in kg / Poids brut, kg
12 Volume in m³ / Cubage m³

CMR

Class / Classe — Number / Chiffre — Letter / Lettre — (ADR) / (ADR)

13 Sender's instructions (Customs and other formalities) / Instructions de l'expéditeur

19 To be paid by / A payer par	Sender / Expediteur	Currency / Monnaies	Consignee / Destinataire
Carr. charges / Prix de transport			
Deduction (-) / Réductions (-)			
Balance / Solde			
Supp. charges / Suppléments			
Other ch. / Suppléments			
Micellaneous (+) / Frais accessoires (+)			
Total / Total			

14 Instructions as to payment for carriage / Prescription d'affranchissement

15 Cash on delivery / Remboursement

Franco / Franko / Non franco / Non franko

20 Special agreements / Conventions particulières

21 Established in / Etablie à — Date / Dates

22 Arrival for loading / Arrivée pour charger — H. / H — Min. / Min
Departure / Départ — H. / H — Min. / Min
Signature and stamp of the sender / Signature et timbre de l'expéditeur

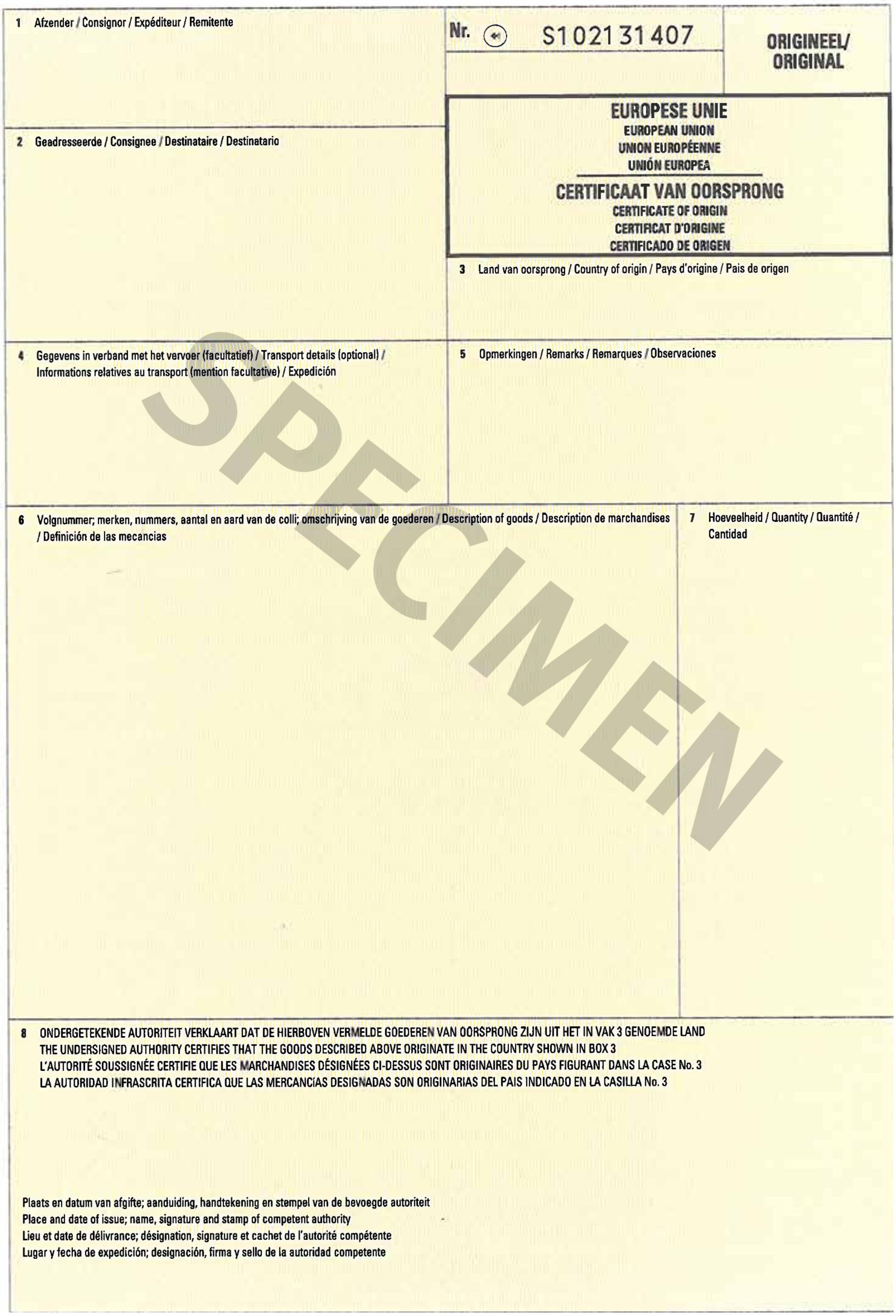
23 Waybill Nr. / Voucher Nr.
Drivers / Camionneur
Signature and stamp of the carrier / Signature et timbre du transporteur

24 Good received / Marchandises reçues
Date / Dates
Arrival for unloading / Arrivée pour charger — H. / H — Min. / Min
Departure / Départ — H. / H — Min. / Min
Signature and stamp of the consignee / Signature et timbre du destinataire

25 Registration Nr. / No d'immatriculation — Truck / Traqueur — Semitrailer / Trailer

26 Type / Type — Truck / Traqueur — Semitrailer / Trailer

Figure C.7: CMR document (Vervo, 2021)



1 Afzender / Consignor / Expéditeur / Remitente

Nr. S1021 31407

ORIGINEEL/ ORIGINAL

EUROPESE UNIE
EUROPEAN UNION
UNION EUROPÉENNE
UNIÓN EUROPEA

CERTIFICAAT VAN OORSPRONG
CERTIFICATE OF ORIGIN
CERTIFICAT D'ORIGINE
CERTIFICADO DE ORIGEN

2 Geadresseerde / Consignee / Destinataire / Destinatario

3 Land van oorsprong / Country of origin / Pays d'origine / Pais de origen

4 Gegevens in verband met het vervoer (facultatief) / Transport details (optional) / Informations relatives au transport (mention facultative) / Expedición

5 Opmerkingen / Remarks / Remarques / Observaciones

6 Volgnummer; merken, nummers, aantal en aard van de colli; omschrijving van de goederen / Description of goods / Description de marchandises / Definición de las mecancias

7 Hoeveelheid / Quantity / Quantité / Cantidad

8 ONDERGETEKENDE AUTORITEIT VERKLAART DAT DE HIERBOVEN VERMELDE GOEDEREN VAN OORSPRONG ZIJN UIT HET IN VAK 3 GENOEMDE LAND
THE UNDERSIGNED AUTHORITY CERTIFIES THAT THE GOODS DESCRIBED ABOVE ORIGINATE IN THE COUNTRY SHOWN IN BOX 3
L'AUTORITÉ SOUSSIGNÉE CERTIFIE QUE LES MARCHANDISES DÉSIGNÉES CI-DESSUS SONT ORIGINAIRES DU PAYS FIGURANT DANS LA CASE No. 3
LA AUTORIDAD INFRASCRITA CERTIFICA QUE LAS MERCANCÍAS DESIGNADAS SON ORIGINARIAS DEL PAIS INDICADO EN LA CASILLA No. 3

Plaats en datum van afgifte; aanduiding, handtekening en stempel van de bevoegde autoriteit
Place and date of issue; name, signature and stamp of competent authority
Lieu et date de délivrance; désignation, signature et cachet de l'autorité compétente
Lugar y fecha de expedición; designación, firma y sello de la autoridad competente

SPECIMEN

Figure C.8: CVO document (KVK, 2021)

D

Outcomes in DSR

Table D.1 summarizes the main research outputs of DSR and their definitions.

DSR Output	***Definition***
Construct	A conceptualization used to describe problems and identify solutions.
Model	A set of propositions or statements expressing relationships among constructs.
Method	A set of steps used to perform a task.
Instantiations	The realization of an artifact in its environment.

Table D.1: Research outputs in DSR, taken from Brady et al. (2013)

The following tables present the sub-categories of the above-described main categories.

DSR Output	***Definition***
Language	A set of concepts or symbols, rules for combining them, and rules for interpreting combinations.
Meta-model	A set of concepts graphically represented, with rules for combining them.
Concept	A new construct added to an extant language or meta-model.

Table D.2: Artifacts in construct category, taken from Sangupamba Mwilu et al. (2016)

Artifact	*Definition*
System design	A structure or behavior-related description of a system.
Ontology	An explicit formal specification of a shared conceptualization.
Taxonomy	A classification of objects in a domain of interest, based on common characteristics.
Framework	A logical structure for organizing complex information.
Architecture	High-level structures of systems.
Requirement	A condition or capability that must be possessed by a system.

Table D.3: Artifacts in models category, taken from Sangupamba Mwilu et al. (2016)

Artifact	*Definition*
Methodology	A predefined set of steps and guidelines, with associated techniques and tools.
Guideline	A suggestion regarding behavior in a particular situation.
Algorithm	An executable sequence of operations for performing a specific task.
Method fragment	A method component that can be treated as a separate unit and reused in a different context.
Metric	A function that assigns a number or symbol to an entity to characterize an attribute or a group of attributes.

Table D.4: Artifacts in methods category, taken from Sangupamba Mwilu et al. (2016)