Circular and Dynamic Manufacturing Supply Chain Orchestration and Optimisation

D5.1 Early versions of 3 Pilot Demonstrators			
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Abbreviations

Acronym	Description
AI	Artificial Intelligence
BPMN	Business Process Model and Notation
CE	Circular Economy
interior CLT	Cross-laminated timber for interior usage
CM	Circular Manufacturing
EBSI	European Blockchain Services Infrastructure
ERP	Enterprise Resource Planning
EU	European Union
EXDs	Experiments for Demonstration
IoT	Internet of Things
KPIs	Key Performance Indicators
LCA	Life Cycle Assessment
LCI	Life Cycle Inventory
LCC	Life Cycle Cost
MSMEs	Manufacturing Small & Medium Enterprises
PP	Polypropylene
rPP	Recycled polypropylene
SCDT	Supply Chain Digital Twin
SCOPT	Supply Chain Optimization
TRL	Technology Readiness Levels
WWT	Waste Water Treatment

Executive Summary

The pilots presented in this deliverable aim to enhance the sustainability and circularity of MSMEs in three EU regions—Spain, the Netherlands, and Hungary—across the plastic, wood, and leather sectors, respectively. The goal is to facilitate the transition towards a CE across Europe by developing a strategy that supports entrepreneurs in making decisions to improve the circularity and sustainability of their operations. By implementing circular strategies, these businesses will not only gain economic benefits but also environmental advantages, positioning themselves as leaders in the shift towards a more sustainable and circular future.

This document outlines the current operational scenarios of the project pilots within the plastic, wood, and leather sectors, along with the advancement reached so far in the CIRCULOOS project. Based on these developments, new scenarios are proposed and will be evaluated from a sustainability perspective using LCA techniques. These evaluations aim to highlight both economic and environmental benefits, aligned with predefined KPIs, with a particular focus on reducing carbon footprint. The deliverable describes both the AS-IS and TO-BE scenarios, including BPMN models and flow diagrams to outline the data collection process via the CIRCULOOS data platform. Additionally, the integration of CIRCULOOS data platform with GRETA is covered, where process data is collected in the platform and exchanged with GRETA. GRETA analyzes the data to calculate environmental indicators (emissions) and economic costs, returning this information to the CIRCULOOS data platform. The interaction within these two software components is key to ensuring that data-driven sustainability impact analysis certifies the achievement of the circularity goals of the pilots.

This deliverable D5.1 corresponds to "Early versions of 3 Pilot Demonstrators", within the Execution of Demonstrators Work Package (WP5) and the Pilots Execution Task (T5.1). It aims to establish the foundational requirements for the final version of the 3 Pilot Demonstrators (D5.2), which will build upon the findings and advancements presented in this deliverable.

This deliverable is structured into sections covering the current and proposed business scenarios, the sustainability assessment methodology, and the integration of key tools like CIRCULOOS data platform and GRETA. It provides valuable insights into the processes and data required for assessing sustainability impacts to support informed decision-making. Furthermore, it serves as a key resource for the upcoming open calls, offering guidance to interested companies on the data they need to provide and how businesses—particularly in the plastic, wood, and leather sectors—can achieve similar improvements.

1   Introduction

1.1   Project Introduction

The overarching vision of the present research project, CIRCULOOS, is to empower MSMEs to become integral members of Circular Manufacturing (CM) value chains. The project delivers a suite of tools designed to optimize and orchestrate end-to-end supply chains, integrating planning, execution monitoring, and transparent, real-time communication. By combining these capabilities with direct calculations of product sustainability and circularity profiles—accessible to both internal and external partners—CIRCULOOS enables the configuration and execution of innovative circular manufacturing processes. These processes promote sustainable production throughout the entire product life cycle, from recovering the value of end-of-life products to utilizing recycled and remanufactured materials.

To achieve this vision, CIRCULOOS deploys in its pilots the following key components:

- **Circular Supply Chain Orchestration**: an end-to-end system for collaborative workflows that incorporates planning and execution metrics, along with advanced, multimodal visualization and analytics.
- **Supply Chain Digital Twin (SCDT):** simulates and visualizes supply chain arrangements and factory workflows to provide a visual representation of the factory inputs, outputs, and internal processes as well as the interaction between the factories in the supply chain.
- **Supply Chain Optimization Tool (SCOT):** continuous monitoring of global (across the supply chain) and local (within the factory) processes, inputs, outputs, and configuration parameters. This enables data-driven decision-making, supporting ongoing optimization of performance and sustainability metrics.
- **Dynamic Sustainability Assessment (GRETA)**: a tool to explore alternative supply-chain scenarios—varying in materials, technologies, suppliers, and circular economy practices—and rapidly assess their environmental sustainability and circular economy impact.
- **CM-Specific Tools:** advanced machine vision and robotics for automatic recognition of recyclable parts, optimizing selection flows in the recycling process.
- **RAMP Data Platform:** leveraging the RAMP IoT platform, CIRCULOOS delivers a robust CM ecosystem, enabling Manufacturing SMEs to adopt and scale circular practices.

1.2   Deliverable Purpose

The purpose of this deliverable is to provide a comprehensive overview of the WP5 – Execution of Demonstrators, which focuses on the practical implementation of circular manufacturing principles through real-world pilots and experiments. This work package aims to leverage the early versions of circularity enablers (WP3) and the integrated platform (WP4) to facilitate the successful execution of the pilots and selected experiments, known as EXDs. The task ensures that both internal and external EXDs are executed smoothly with the support of mentors, ensuring that the defined KPIs are met and successful outcomes are achieved. A key objective of this WP is scaling the results from the EXDs to higher Technology Readiness Levels (TRL), enabling the developed solutions to be ready for market deployment. By integrating feedback from the pilots and EXDs, the deliverable also supports the continuous improvement of the CIRCULOOS platform, enhancing its ability to drive circularity and sustainability across supply chains.

This work focuses on the Pilots Execution Task (T5.1). This task entails implementing the supply chain demonstrators in real-world environments, following the architecture and utilizing the integrated platform from WP4, the enablers from WP3, and the pilot scenarios defined in WP2. The final goal is to create an integrated digital space where real-world entities, computational systems, tools, processes, and people can coexist and interact within a digital framework. This approach marks a departure from traditional hierarchical automation models, shifting towards a more collaborative and interconnected view of the supply chain, considering it as a unified team rather than focusing on individual factory needs. The demonstration takes place within the participating factories, allowing for the validation of novel circular manufacturing business models and services. Through this process, advanced tools will be employed to optimize sustainability performance and ensure the effective implementation of circular economy practices (Pachon et al., 2024). The outcomes will be used to develop success stories, which will be disseminated to showcase the potential and impact of the demonstrators, while also supporting further scaling in the upcoming open calls.

Specifically, this deliverable (D5.1 – Early Versions of 3 Pilot Demonstrators) aims to document the initial implementation of the three pilots conducted in Spain, the Netherlands, and Hungary across the plastic, wood, and leather sectors. It presents the AS-IS and TO-BE scenarios for each pilot, the methodology used for assessing their sustainability performance, and the tools employed (such as the CIRCULOOS platform and GRETA) to support data-driven analysis. The content of this deliverable lays the foundation for the final pilot evaluation to be presented in D5.2.

1.3   Overview of the Deliverable

This document is organized to provide a comprehensive description of the current (AS-IS) and prospective (TO-BE) process scenarios under study, as well as the steps taken to prepare for future LCA analysis.

In the Methodology section, the descriptions of the AS-IS and TO-BE scenarios for the wood, leather and plastic pilots are assessed. Within this part, the BPMN models and flow diagrams are created to define the variables that will be considered in future LCA analyses. At the end of the methodology section, a detailed explanation of the integration of the CIRCULOOS data platform and GRETA is included to clarify how data will be collected and how both tools are interconnected to carry out LCA calculations in later deliverables.

The Process and Data Flow section details how data will be collected through the CIRCULOOS data platform and how it will flow between the platform and GRETA for the subsequent life cycle calculations in the next deliverables.

Overall, the current deliverable is focused on process description, defining key variables, and preparing for upcoming analyses, with the actual LCA calculations and concrete results to be presented in subsequent deliverables.

2   Methodology

2.1   BPMN Models for the Pilots

BPMN (Business Process Model and Notation) models are standardized diagrams used to visually represent and document business processes. These models provide a clear and detailed depiction of the steps, tasks, and interactions that occur within a process, using a set of symbols and notations that are easily understood by business professionals and stakeholders. BPMN is widely used to analyze, improve, and communicate business processes, offering a common language for discussing workflows, roles, and outcomes (Compagnucci et al., 2021).

In the context of the CIRCULOOS project, BPMN models are essential for illustrating both the AS-IS and TO-BE scenarios of the pilots. The AS-IS model represents the current state of the business processes, showing how the operations are currently conducted, while the TO-BE model outlines the desired future state, reflecting the improvements and optimizations that will be implemented. By creating these models, inefficiencies, gaps, and opportunities for improvement in the existing processes can be identified and more efficient and sustainable solutions can be proposed. Moreover, the created BPMN models constitute a blueprint for the implementation of the project pilots.

In this project, the BPMN models have been developed using Camunda vs.7, a powerful open-source platform for workflow and decision automation. Additionally, asynchronous feedback between the pilots and the rest of the consortium has played a key role in refining the models. This collaborative approach ensures that all stakeholders have provided input and adjustments to the models as the project progresses, allowing for continuous improvement and alignment with the project's goals.

These BPMN models are crucial for the pilots as they provide a clear framework for understanding and communicating the flow of operations, ensuring that all stakeholders are aligned on the objectives and processes involved. Additionally, they serve as a valuable tool for tracking progress and measuring the success of any changes made during the project, ultimately helping to achieve the goals of efficiency, sustainability, and competitiveness in the business models.

The BPMN models have been developed to represent various components of the CIRCULOOS platform's architecture. These models have been developed for the pilots presented in this deliverable and are provided and explained in the following chapters (Figures 1-6). In the BPMN diagram, one box illustrates operations performed by human workers, which do not require electricity. Another box represents the ERP system, where data from these operations are digitally recorded. A third box depicts the machinery involved in specific processes, where energy usage (either electricity or heat) must be accounted for in the CIRCULOOS platform.

Connections within the same plant are shown with solid lines, while connections between different components are represented by dashed lines. Data required by the LCA tool, GRETA, are collected from the CIRCULOOS data platform and are indicated by an envelope symbol. This means that the data must be transferred to the platform at the specific points marked in the BPMN model.

2.2 Description of AS-IS Scenarios

This section outlines the three current business models of the three pilots involved in the CIRCULOOS project. The objective is to gain a clear understanding of the existing business operations in each case, which will help identify the previously recognized weaknesses highlighted in Deliverable 2.1. The three pilots are associated with the wood, plastic, and leather industries, and are located in the Netherlands, Spain, and Hungary, respectively.
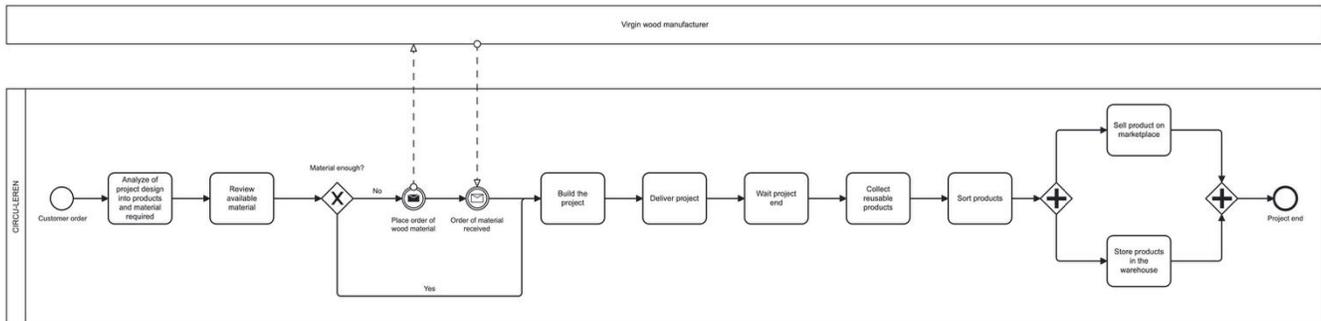
2.2.1 Wood Pilot AS-IS

Three independent wood-related companies have joined forces within the CIRCULOOS framework to participate in the Wood Pilot. The three companies operate in the Netherlands and specialize in different aspects of the wood supply chain independently.

Circu-leren is a company specializing in modular wood projects, such as wooden houses, using both virgin and recycled wood. The company focuses on modular building materials designed for assembly and disassembly, ensuring an extended lifecycle for their products. This approach allows furniture or houses to be dismantled and repurposed once the customer no longer requires them, enabling the materials to be reused for new constructions and minimizing waste. Although the company demonstrates a strong commitment to sustainability and circularity, it still relies on virgin materials, primarily because using recycled wood requires significant effort. There are few suppliers available, the process is slower, and placing orders is not always easy.

HERSO is another company that specializes in collecting and processing waste wood, recycling it into new, high-quality materials for various purposes. They are experts in crafting new furniture from reclaimed wood, giving discarded materials a second life. The company is largely human-driven, meaning that every time HERSO collects waste wood, the owner's expertise plays a crucial role in optimizing the process. The owner makes all the decisions regarding the design of specific furniture. They do not produce waste, as any leftover material from the fabrication of a specific piece is stored and can be used in future designs.

Finally, **Plennid** focuses on repurposing wood from urban trees that have been removed due to disease, storm damage, or city maintenance in Rotterdam. Instead of allowing this wood to go to waste, they process and distribute it to third parties interested in using high-quality reclaimed urban wood, promoting a more sustainable approach to raw material sourcing.

Figure 1 BPMN model for the Wood Pilot - AS-IS

Two independent companies specializing in plastics and one company focused on robotics for component identification in materials are participating in the so-called Plastic Pilot.

Thermolympic, based in Zaragoza, Spain, specializes in manufacturing plastic parts for the automotive and home appliance industries using various molding technologies. They rely on virgin raw materials for their products. In an effort to improve the sustainability of their business, they evaluated the possibility of incorporating recycled plastic into their feedstock. However, the company faced challenges in integrating recycled materials into the automotive industry due to customer requirements for high-quality, functional, and aesthetically precise parts. So far, they have not been able to implement recycled materials in their supply chain. Nevertheless, they are aware that some other clients, such as those in the home appliance industry, might be willing to accept recycled plastic if it meets specific characteristics. Currently, Thermolympic does not recycle its plastic waste, choosing incineration instead. This approach makes their processes less efficient, releases pollutants, and contributes to environmental impact.

Contenedores Lolo, the second company located in Spain, focuses on collecting and processing waste plastics. They purchase and collect plastics from wholesalers and retailers, aiming to provide high-quality recycled materials for various applications.

Canonical Robots acts as a third-party contributor to this pilot. While their involvement in the initial phase of the project is not planned, they are expected to play a significant role in the upcoming phases, particularly through open calls. They offer technological solutions to improve recycling processes. Specializing in robotics and automation, they focus on the identification and classification of recycled plastics. Their technology optimizes the recycling process by automating the sorting and qualification of plastics to ensure they meet the required standards for reuse in manufacturing new products. Currently, they collaborate closely with Contenedores Lolo to assist in qualifying the recycled and processed plastics.
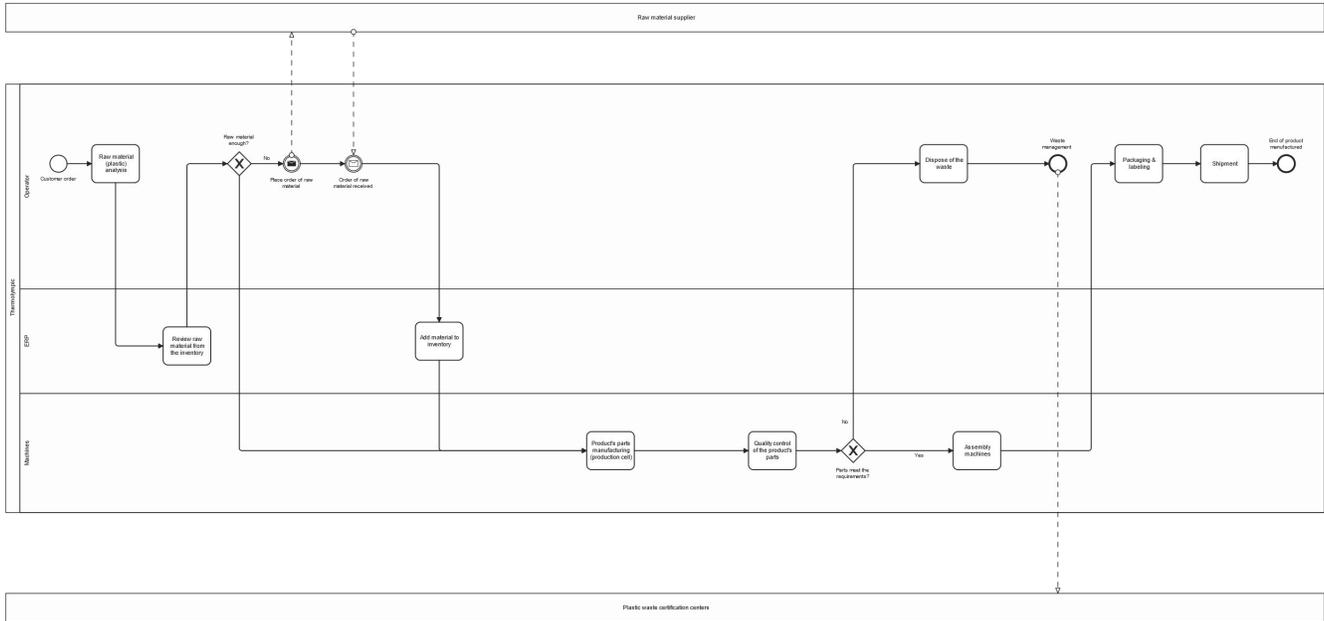
Figure 2 BPMN model for the Plastic Pilot - AS-IS

2.2.2 Leather Pilot AS-IS

Two independent companies in the leather goods industry, based in Hungary, have joined the CIRCULOOS project to establish the Leather Pilot. The companies, Mototextil Kft. (which replaces the previous partner KHOANI with same role in the pilot) and B&A Kft., each specialize in different aspects of leather goods production and have operated independently up to this point.

Mototextil specializes in manufacturing leather and textile products. The company use a wide range of fabrics, including automotive upholstery, artificial leather, and genuine leather. They also use in production processes various upholstery accessories and materials, emphasizing high-quality raw materials and customer service. At the beginning of the project, they only relied on virgin raw material and landfilled leftovers.

B&A focuses on producing small leather goods and generates waste during their manufacturing processes. The company, like the previous one, relies exclusively on virgin raw materials and wastes leftovers, leading to significant environmental impact.
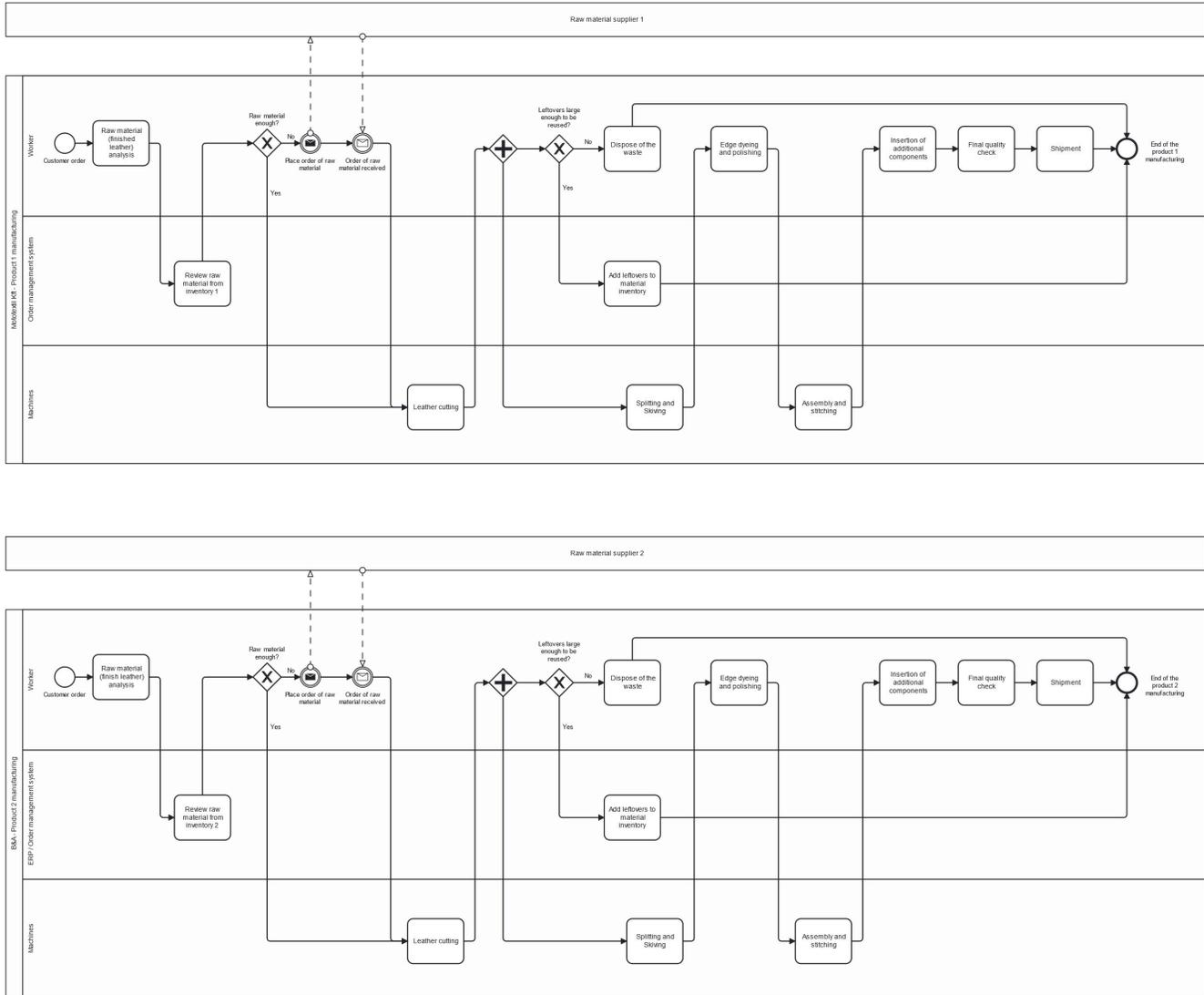
Figure 3 BPMN model for the Leather Pilot - AS-IS

2.3 Identification and Definition of TO-BE Scenarios

This section presents the proposed future business models for the three pilots involved in the CIRCULOOS project. The objective is to define an improved operational framework that addresses the previously identified weaknesses highlighted in Deliverable 2.1, ensuring greater efficiency, sustainability, circularity and resilience in each case.

2.3.1 Wood Pilot TO-BE

In an effort to develop a more sustainable, efficient, and resilient business model, the three independent wood-related companies have united under a consortium within the Wood Pilot. This pilot seeks to

integrate their operations, fostering a circular economy approach that minimizes dependence on virgin wood raw materials, optimizes resource utilization, and enhances overall competitiveness and innovation within the industry.

By working together, these companies streamline production processes and create higher-value products from reclaimed materials. Circu Leren plans to use building blocks manufactured by HERSO using recycled wood from Plennid's reclaimed urban timber, offering a sustainable alternative to traditional cross-laminated timber (interior CLT) panels. The integration between Plennid, HERSO, and Circu Leren is designed to create a seamless and efficient supply chain that maximizes the value of reclaimed wood. Plennid specializes in sourcing and collecting urban timber, which is then processed by HERSO, an expert in recycling and refining wood materials. Once the wood is repurposed, Circu Leren buys the wooden building panels from Herso.

This collaborative workflow will be assessed using life cycle thinking to ensure the establishment of a closed-loop system, where materials are continuously reused, and the industry's carbon footprint is measured and compared against the benchmark—interior CLT panels—to evaluate its environmental benefits.

This initiative exemplifies how collaborative circular economy models can drive both environmental and economic benefits, particularly for SMEs in the wood industry. Beyond environmental impact, this partnership aims to boost profitability, strengthen market positioning, and serve as a scalable blueprint for broader industry transformation. If successful, the model could be expanded to include additional companies, fostering a more circular and regenerative wood sector while encouraging widespread adoption of sustainable business practices.

Figure 4 represents the TO-BE scenario, highlighting in "green" the differences with the AS-IS scenario (illustrated in Figure 1).

Figure 4 BPMN model for the Wood Pilot – TO-BE

2.3.2 Plastic Pilot TO-BE

In an effort to establish a more sustainable and efficient business model, the two independent companies in the plastics sector (Thermolympic and Contenedores Lolo) have formed a synergie within the Plastic Pilot. This pilot project aims to integrate their operations, fostering a circular economy approach that maximizes resource utilization, minimizes waste, and enhances overall competitiveness in the industry.

Thermolympic plans to utilize recycled plastics processed by Contenedores Lolo, incorporating them into their manufacturing processes to produce a specific component that meets both recycled content and quality requirements. This component is a white plastic product used in the home appliance industry,

specifically designed to hold detergent inside washing machines. The collaboration between these two entities will be assessed using Life Cycle methodologies to evaluate the benefits of their integration. The current product will be evaluated against the proposed new product to highlight potential improvements in reducing reliance on virgin plastic resources and environmental impact.

This partnership exemplifies a circular economy model within the plastics industry, demonstrating how small enterprises can collectively achieve significant sustainability objectives, enhance profitability, and strengthen market positions. If successful, this approach could be expanded to include additional companies, further promoting CE principles in the plastics sector.

Figure 5 represents the TO-BE scenario, highlighting in "green" the differences with the AS-IS scenario (illustrated in Figure 2).
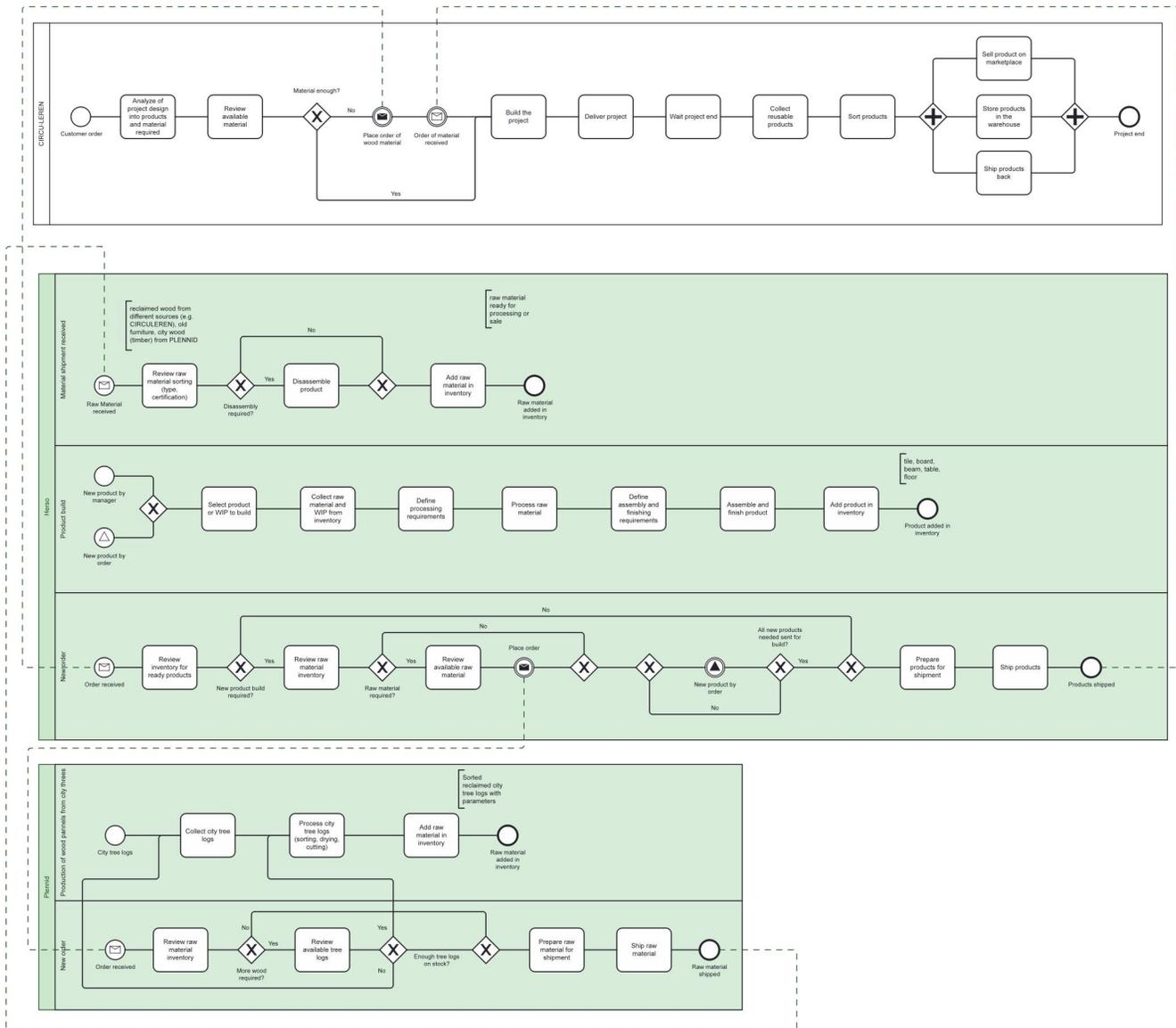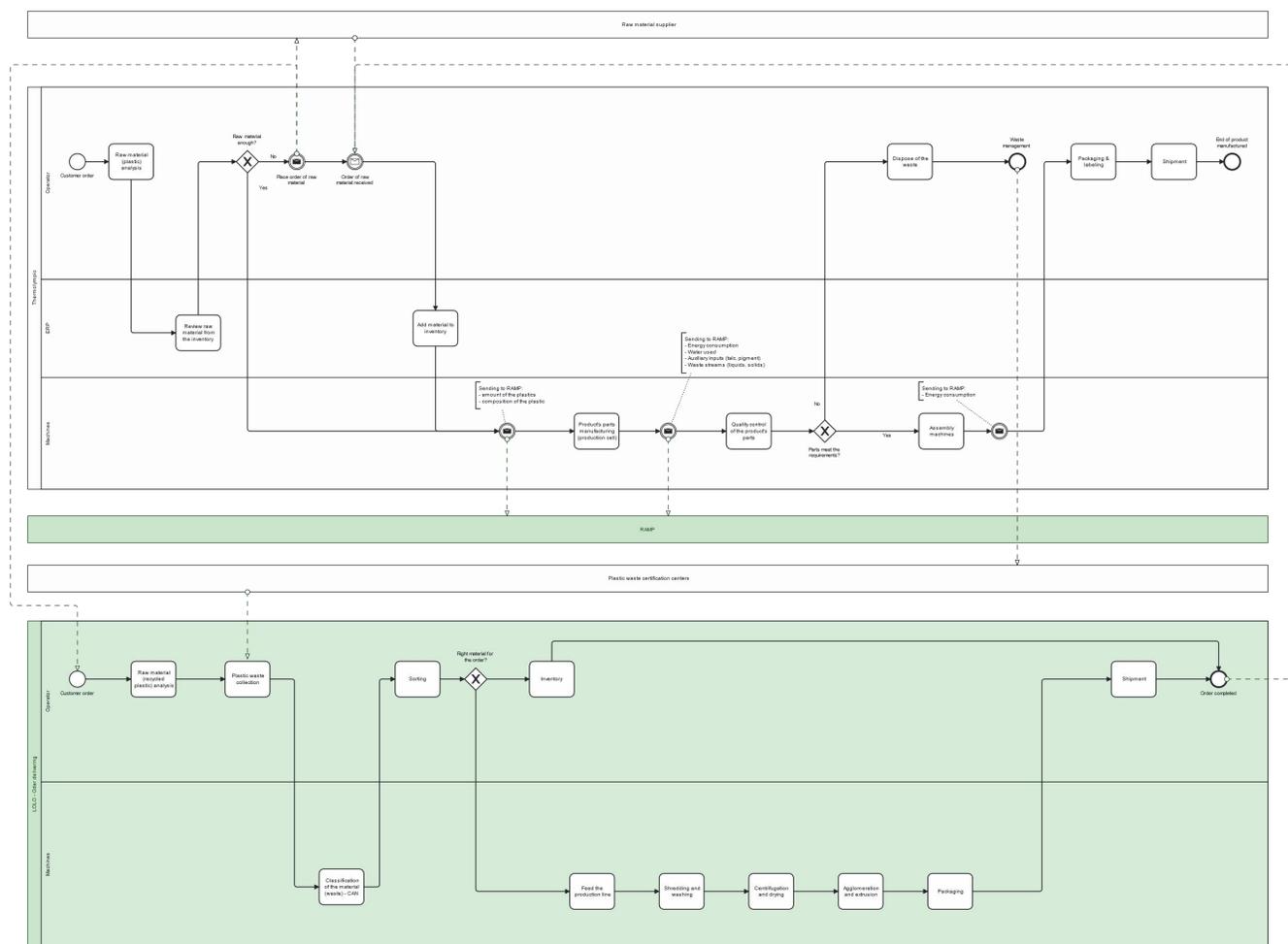

Figure 5 BPMN model for the Plastic Pilot - TO-BE

2.3.3 Leather Pilot TO-BE

In this pilot, two independent companies in the leather goods industry located in Hungary have formed the Leather Pilot to improve the sustainability of their leather goods products. This pilot aims to integrate their operations, fostering a CE approach that minimizes waste, and enhances overall competitiveness in the leather goods industry.

Through this collaboration, Mototextil will supply its leather leftovers to B&A for repurposing into new products, effectively reducing waste and minimizing the need for virgin materials. Any materials (leftovers) not utilized by B&A will be listed on a shared marketplace, allowing other interested parties to repurpose them, further promoting sustainability within the industry.

This partnership exemplifies a circular economy model within the leather goods industry, demonstrating how small enterprises can collectively achieve significant sustainability objectives, enhance profitability, and strengthen market positions. If successful, this approach could be expanded to include additional companies and other reusers (schools, kindergartens, etc.), further promoting CE principles in the leather goods sector and among consumers and broader society

Figure 6 represents the TO-BE scenario, highlighting in "green" the differences with the AS-IS scenario (illustrated in Figure 3).
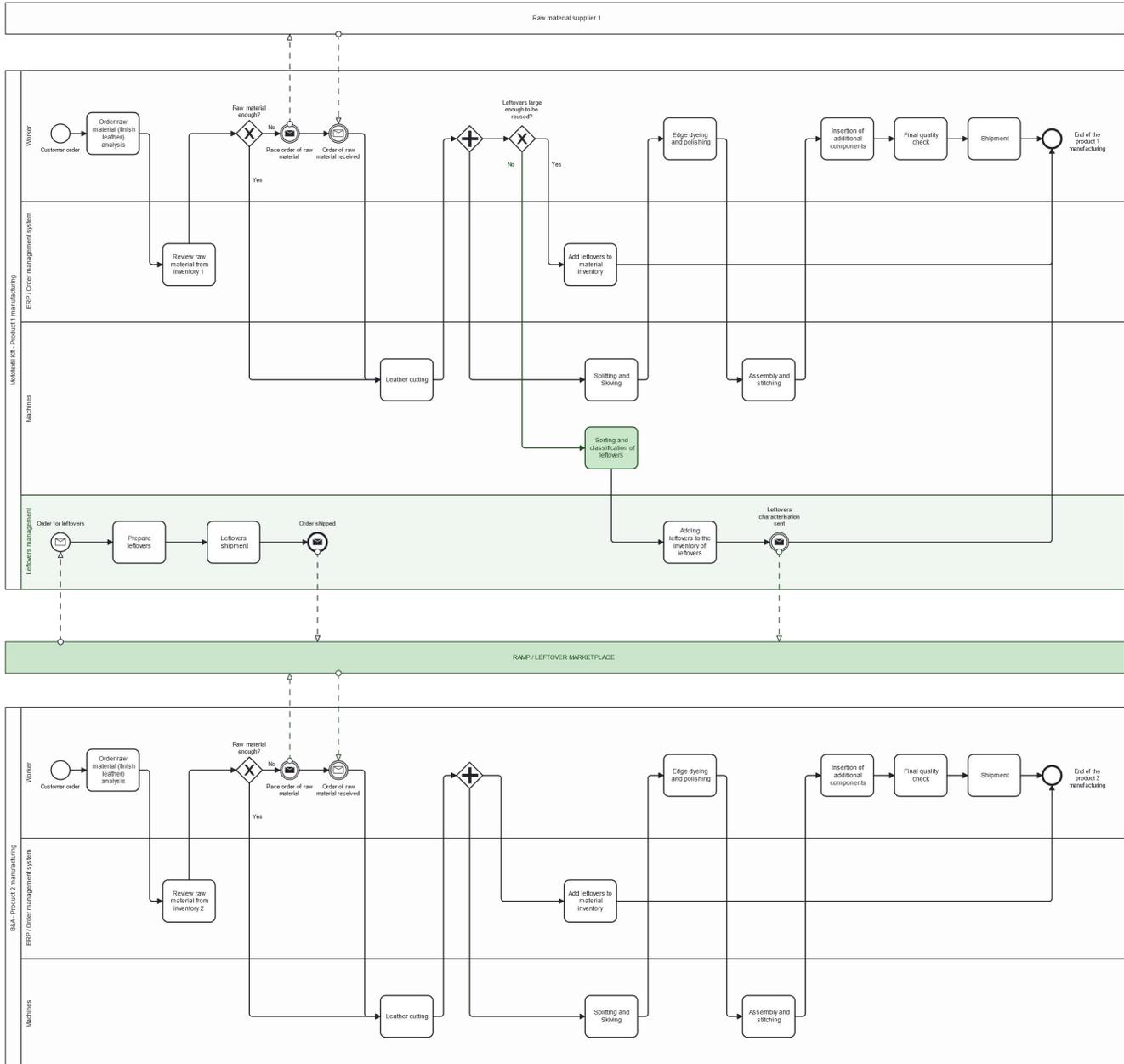
Figure 6 BPMN model for the Leather Pilot - TO-BE

2.4 Flow Diagrams for Process Mapping

Flow diagrams have been developed to identify the key variables that need to be connected with industrial processes in order to integrate them into GRETA, the LCA tool. By mapping out these processes, it is possible to pinpoint critical inputs, outputs, and interdependencies that influence environmental performance (Pachón et al., 2020). This structured approach ensures that all relevant data flows are properly captured and aligned with the requirements of the LCA methodology (Jordaan et al., 2021),

allowing for a more accurate and comprehensive assessment of the sustainability impacts of the pilot projects.

The AS-IS and TO-BE flow diagrams for each pilot were created using *draw.io*, an open-source software for process diagramming. These diagrams are based on the system boundaries defined in D2.1, which encompass all stages required to produce the material and energy inputs for the pilot process. They also include the emissions released during the process and the handling of both liquid and solid waste, including treatment through local wastewater facilities or incineration of solid waste nearby.

The flow diagrams for all scenarios are presented in the following figures, with black rows representing mass flows and colored rows representing energy flows (electricity in yellow and heat in red). All rows correspond to the closure of both the energy and mass balances in the process.
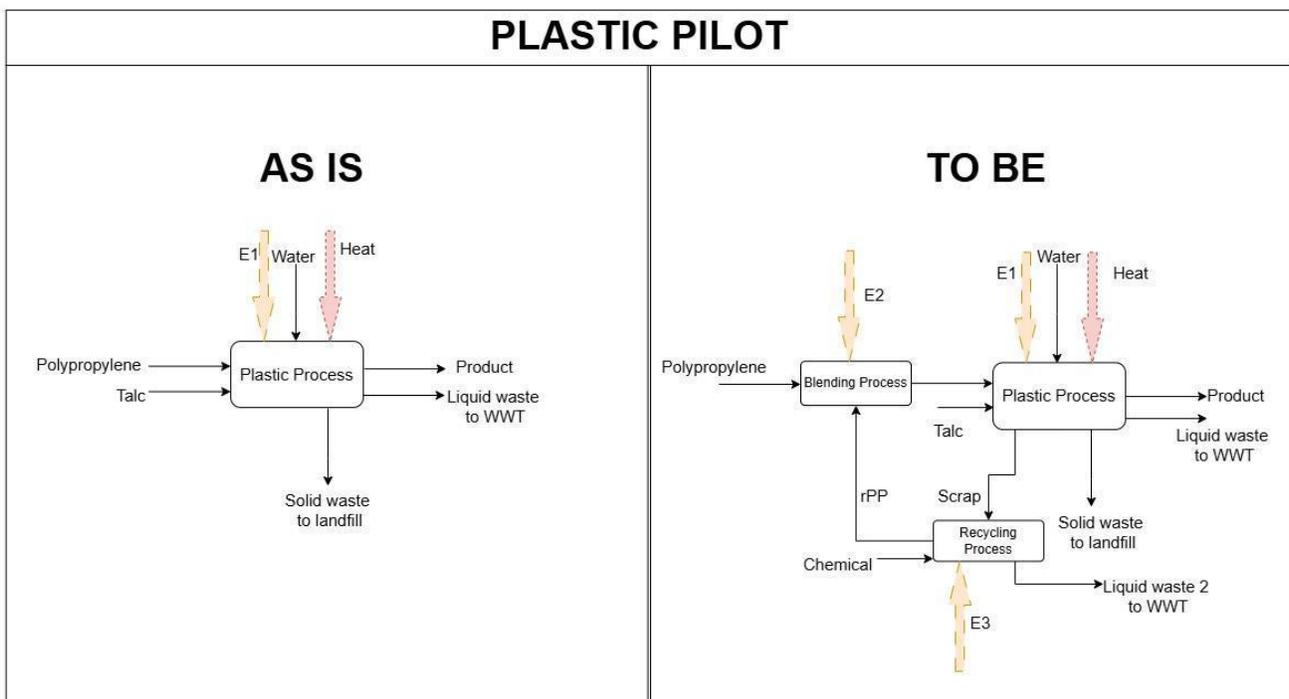
Figure 7 AS-IS and TO-BE Flow Diagrams for the Plastic Pilot within the LCA system boundaries.

The AS-IS flow diagram for the Plastic Pilot presents a black box where all material and energy streams involved in the manufacturing of the "AS-IS Product" are integrated, considering only the inputs entering the system. This approach allows the LCA to be calculated with all indicators referred exclusively to the Product.

In the TO-BE diagram, an additional box is introduced to include the streams associated with the recycling of production scraps. While in the AS-IS scenario scraps are incinerated, the TO-BE model accounts for the inputs and outputs of the recycling process in the calculation of the indicators for the "TO-BE Product".
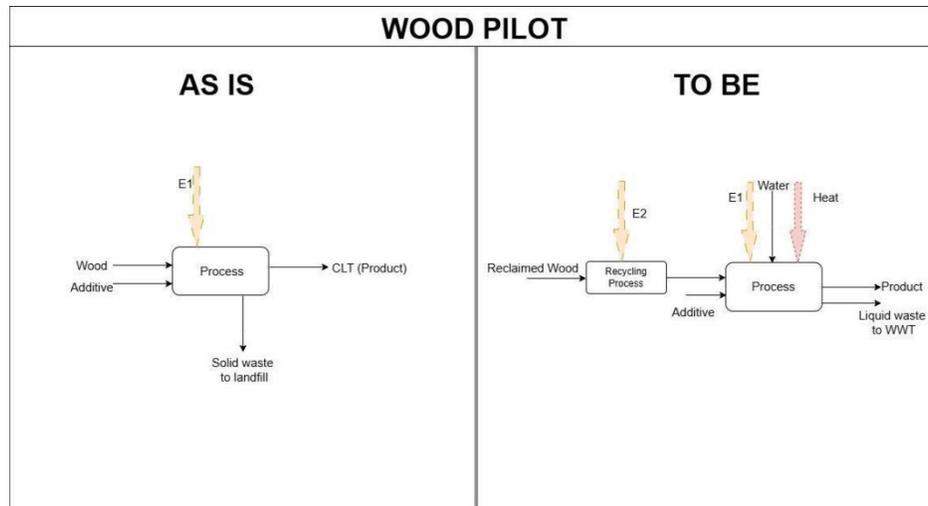
Figure 8 AS-IS and TO-BE Flow Diagrams for the Wood Pilot within the LCA system boundaries.

The AS-IS flow diagram for the Wood Pilot presents a black box that integrates all material and energy streams involved in the manufacturing of commercially available interior CLT. In this scenario interior CLT is produced from fresh wood, with the environmental load assigned to the use of virgin raw materials.

In the TO-BE diagram, an additional box labeled "Recycling Process" is introduced to capture the input streams associated with the recycling of reclaimed wood, which serves as the feedstock to manufacture the "TO-BE Product". In this diagram, the so-called "Recycling Process" represents all the steps needed to transform reclaimed wood into material suitable for the production of the alternative interior CLT.
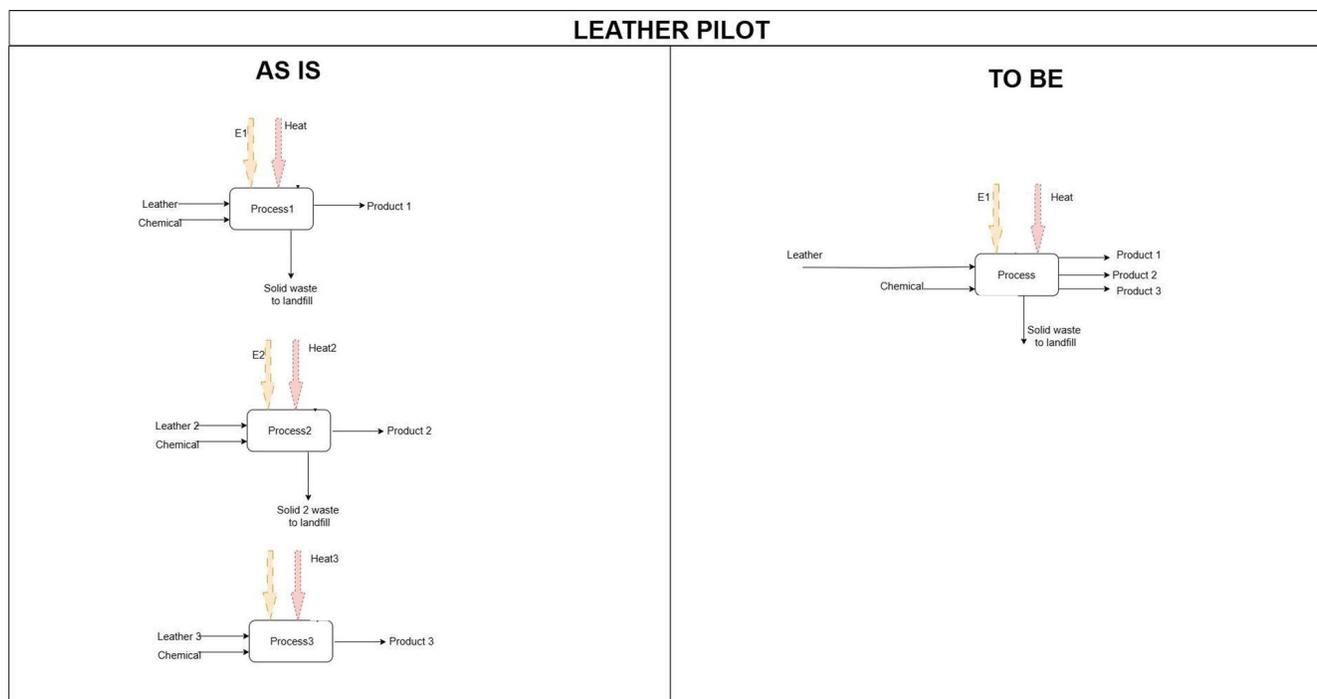
Figure 9 AS-IS and TO-BE Flow Diagrams for the Leather Pilot within the LCA system boundaries.

The AS-IS flow diagram for the Leather Pilot presents three black boxes, each representing the material and energy streams involved in the manufacturing of three different "AS-IS Products": a large leather product (e.g., a bag), a medium-sized item (e.g., a sunglasses case), and a small item (e.g., for school crafting). All these products are manufactured from virgin raw materials.

The TO-BE diagram illustrates the integration of all processes, where leftovers from the production of the first product are used in the second, and the leftovers from the second are further used for school crafting. This approach exemplifies a cascading use of resources, ultimately creating a single multiproduct process that results in three different products.

2.5 Key Variables for LCA

To conduct an LCA, a comprehensive global mass and energy balance of the process must be established. In this regard, data on energy requirements, including both heat and electricity consumed during the process, as well as input material consumption for the product's manufacture must be collected. This information is essential for constructing the Life Cycle Inventory (LCI), which serves as the foundation for performing the LCA. A functional unit will be selected to ensure that all collected data is applied consistently to this unit, allowing for a meaningful and comparable LCA.

2.6 Tools integration

2.6.1 RAMP: Data Collection and Process Tracking

RAMP is a platform specifically designed for SMEs. Its goal is to facilitate the collection and analysis of factory data, enabling SMEs to understand and optimize their production processes. By providing detailed insights into operations, RAMP helps in making informed decisions regarding investments in automation technologies and assessing their full impact. The platform is built on open FIWARE technology, ensuring flexibility in choosing future automation solutions for factories.

The platform facilitates data sharing and the formation of new partnerships, unlocking the circular value of inter-organizational cooperation. Additionally, RAMP offers training and upskilling opportunities through free online courses, webinars, best practice guides, and success stories from pilots and EXDs. Throught the document RAMP is named as CIRCULOOS data platform.

2.6.2 GRETA Tool: LCA and LCC

GRETA is a web-based, microservices-driven application designed to assess the sustainability and circularity performance of products and processes in manufacturing contexts. It provides both diagnostic and advisory functionalities, helping users optimize manufacturing practices and make data-driven decisions. Tailored for manufacturing companies focused on sustainable early-stage product design, GRETA enables users to generate and compare different production and usage scenarios, even when only limited data is available during the preliminary design phase. It evaluates the sustainability performance of products and processes, showing how impacts are distributed across different life cycle phases.

GRETA allows end-users to customize production processes modeled by sustainability experts, providing specific values needed for LCA analysis. Once customization is complete, the assessment can be executed, delivering valuable insights through interactive charts. Beyond assessing individual products, GRETA enables comparisons between different products and process alternatives—an essential feature for eco-design (Gnansounou et al, 2015). It also allows manufacturers to compare multiple products using a radar chart. Thanks to its real-time calculation engine, manufacturers can adjust scenario parameters during the eco-design process to optimize impacts and compare results against previous setups or alternative scenarios. The assessment results, including comparisons, can be automatically compiled into a PDF report, summarizing all alternatives, sustainability parameters, and indicators generated by the analysis.

One key feature of GRETA is its flexibility. It includes an integration layer that can be leveraged in various integration scenarios:

GRETA can automatically gather IoT data to populate customization parameters and execute assessments using data collected in near real-time from external sources. Notably, the data source can be an IoT device, an MQTT broker, a REST API, a database, etc. GRETA also enables users to export assessment data to external data sources. In this case, the data can be sent to external platforms, stored in a database, or transmitted to an MQTT broker, among other options. The functionalities of GRETA are exposed via a set of REST APIs, allowing other services to integrate with GRETA as a sustainability service.

3   Process and Data Flow

3.1   Explanation of data collection through the CIRCULOOS data platform

In this phase of the project, the pilots will be analyzed to assess improvements in sustainability and the percentage material cost decrease, as established in the predefined KPIs. The CIRCULOOS data platform will be used to collect process data and transmit it to GRETA, which will calculate various environmental and cost indicators by applying life cycle thinking. The integration mechanism embedded in GRETA is effectively applied within the CIRCULOOS project, facilitating seamless data exchange with CIRCULOOS data platform.

Since GRETA supports both LCA and LCC methodologies, it enables a comprehensive evaluation of environmental and economic performance for each CIRCULOOS pilot, comparing the AS-IS and TO-BE scenarios. This dual approach helps manufacturers achieve predefined KPIs related to carbon footprint reduction and process cost-efficiency. Since GRETA can automatically gather IoT data to populate LCI and execute assessments using data collected from external sources, the results of the environmental and cost indicators will be returned to the CIRCULOOS data platform. The indicator results obtained from the assessment can be shared with the CIRCULOOS data platform in a JSON-LD format, utilizing the defined semantic context. This will serve as a valuable tool for decision-making, providing insights into the impact of the processes in terms of both sustainability and cost efficiency (Fontana et al., 2024).

Within the CIRCULOOS project, the CIRCULOOS data platform and GRETA tools play a crucial role in fostering collaboration among manufacturing SMEs and decision-making.

3.2   Detailed Description of Process Variables for Further Analysis

This section describes the process variables required to conduct the LCA and LCC for each pilot in both current and future scenarios.

3.2.1 Plastic Pilot

In the case of the Plastic Pilot, the TO-BE scenario strategy aims to enhance the circularity and sustainability of the brand by achieving zero waste and improving process efficiency through the recycling of their own waste. The functional unit for this study is the product, meaning all indicators will be related to the product under analysis. The product under study is a detergent drawer, part of the home appliance industry. Currently, this detergent drawer is made from virgin PP (AS-IS), but the goal is to produce it from a blend of virgin PP and rPP (TO-BE).

To assess the benefits, the indicators of both products—one made solely from virgin PP and the other incorporating rPP—will be compared. Sustainability indicators will be calculated based on the variables shown in Figure 7. However, additional variables not displayed in the figures will also be required for the calculations. These include factors related to processes occurring beyond the gates of Thermolympic or Contenedores Lolo, such as the production of PP, talc, and other material inputs purchased by the company, as well as natural gas production (for heating) and electricity generation based on the local energy mix.

Regarding outputs, variables related to waste disposal—such as liquid flows to wastewater treatment (WWT) or solid waste sent to landfill— and emissions are also considered. However, this data is not

directly obtained from the pilot. Instead, all variables occurring outside the pilot facilities are sourced from the Ecoinvent database or relevant literature when not available there.

3.2.2 Wood Pilot

In the case of the Wood Pilot, the TO-BE scenario strategy aims to demonstrate the circularity and sustainability of the brand by using reclaimed wood instead of the virgin wood traditionally used.

The functional unit for this study is cross-laminated timber (interior CLT), a construction material recognized as a sustainable alternative to concrete and steel. This engineered product is created by bonding multiple layers of solid wood boards in perpendicular orientations, enhancing its strength, stability, and durability.

Currently, commercially available interior CLT is made from virgin wood, but the goal is to produce it using reclaimed wood in the TO-BE scenario. To assess the benefits, the indicators of both products, one made solely from virgin wood the other reclaimed, will be compared. Sustainability indicators will be calculated based on the variables shown in Figure 8. However, additional variables not displayed in the figures will also be required for the calculations. These include factors related to processes occurring beyond the gates of Circu-leren, HERSO or Plennid, such as the growing of the trees, logging, logistics and other material inputs purchased by the companies, as well as natural gas production (for heating) and electricity generation based on the local energy mix. All variables occurring outside the pilot facilities are sourced from the Ecoinvent database or relevant literature when not available there.

3.2.3 Leather Pilot

In the case of the Leather Pilot, the TO-BE scenario strategy aims to showcase the brand's commitment to circularity and sustainability by integrating the two leather goods producer companies involved in the pilot. In this approach, one company utilizes the leftovers from the other, while the remaining scraps are sold in an online marketplace to potential buyers interested in smaller leather remnants.

Currently, leftover materials from commercially available leather bags and leather keyholders are landfilled. The goal of the TO-BE scenario is to integrate both processes in a single multi-products system.

For this pilot, the functional unit is set at 1 bag and 1 keyholder, ensuring that the LCA comparison effectively assesses material utilization and waste management impacts across scenarios.

To evaluate the benefits, sustainability indicators will be analyzed based on 2 products (bag and keyholder). These indicators will be calculated using the variables shown in Figure 9, along with additional factors not explicitly displayed. These include processes beyond the leather factory gate, such as material inputs purchased by the company, as well as natural gas production (for heating) and electricity generation based on the local energy mix (there is a solar power plant in the factory). Another process to be considered in the comparison is the "leftover to marketplace" stage when B&A requirements are already satisfied. In this case, it refers to the process of using leather scraps for crafting in schools. Therefore, data on leather processing for school crafts will also be assumed from external sources. When data is unavailable, relevant information will be sourced from the Ecoinvent database (Moreno-Ruis et al., 2023) or other credible literature.

4   KPIs Analysis

The analysis of the Key Performance Indicators (KPIs) for each pilot focuses on two key aspects: environmental impact and cost reduction. The environmental KPI evaluates whether the CO_2 emissions associated with the products in the TO-BE scenarios are lower than those in the AS-IS scenarios, while the economic KPI assesses whether the circular improvements in the TO-BE scenarios lead to a reduction in overall costs.

In the Wood Pilot, both CO_2 emissions and associated costs of building materials are expected to improve in the TO-BE scenario, due to the use of raw materials classified as waste, which replaces the need for virgin input.

In the Plastic Pilot, the TO-BE scenario is expected to reduce both environmental impact and costs, as less virgin raw material will be purchased thanks to increased circularity.

Similarly, in the Leather Pilot, the evaluation will consider the reduction in carbon footprint and the economic benefits of processing products without relying on virgin materials.

Overall, the KPIs of each pilot aim to demonstrate that circular strategies can simultaneously improve environmental performance and generate economic value. The calculation of those KPIs will be reported in the next D5.2.

5   Conclusions

The three pilots involved in the CIRCULOOS project represent different industries, each with their own challenges and opportunities for implementing CE models. These sectors, including wood, plastic, and leather, are working towards more sustainable practices by utilizing recycled materials and optimizing resource use. Each industry requires tailored strategies to promote sustainability based on the specific characteristics of the materials and processes involved.

Adopting CE models not only creates benefits for the environment, but it also offers economic advantages through resource optimization and reduced reliance on virgin materials. However, challenges remain in implementing the TO-BE scenarios, such as the availability of recycled materials, customer quality expectations, and the necessary infrastructure. In the wood industry, despite advances in urban wood reuse, the use of recycled wood remains limited due to a lack of suppliers and the complexity of the recycling process. In the plastic sector, integrating recycled plastics into automotive components is difficult due to high-quality standards, although other sectors, such as home appliances, show more willingness to accept recycled content. Similarly, in the leather industry, companies focus on repurposing waste materials, but they still rely heavily on virgin raw materials. Collaboration among companies within the same supply chain is proving valuable in addressing these challenges. The alliance in the wood industry between Circu-leren, HERSO, and Plennid aims to create a circular economy by efficiently using recycled wood materials. Similarly, in the plastic and leather sectors, collaborations between Thermolympic, Contenedores Lolo, Mototextil, and B&A focus on optimizing recycling processes and reducing waste.

Tools like the CIRCULOOS data platform and GRETA play a crucial role in assessing the environmental and economic impact of the business models, allowing for a comparison of the AS-IS and TO-BE scenarios. By analyzing the LCA and LCC, these tools identify opportunities for reducing carbon footprints and operational costs, aiding decision-making and continuous process improvement. Continuous monitoring and data collection through the platforms are essential for tracking progress toward sustainability goals. This process ensures transparency and continuous improvement in industrial practices.

While the pilots represent SMEs, their success could positively impact the broader industry by serving as scalable models for other companies within each sector.

In this context, the next steps of WP5 will focus on: completing the necessary activities to validate the TO-BE scenarios within each pilot, enabling a quantitative comparison with the current practices (AS-IS) as well as the SCDT implementation of pilots. The upcoming months will be critical for several key activities: identifying KPIs in collaboration with the pilots, finalizing data collection by clearly defining the variables required for the LCA (using a standardized template to map energy and mass flows within each company), conducting the sustainability assessment using GRETA, and implementing the necessary technological integrations within the pilot environments. The table below summarizes the planned activities and expected outcomes for the remaining months of Task 5.1, outlining the path towards the completion of the pilot execution and preparation for the final sustainability evaluation.

Table 1 Activities planning for T5.1

Project Month	Period	Key Activity	Partners Involved	Expected Output
M21	Mid-May 2025	Data collection for AS-IS scenarios	All Pilot Owners	Complete datasets describing current (AS-IS) processes
M21	By End of May 2025	Sustainability assessment of AS-IS scenarios using GRETA and KPIs definition	SUPSI	Initial LCA and LCC results for AS-IS scenarios
M21	Mid-June 2025	Integration and testing of CIRCULOOS technologies within the pilot environments	SUPSI, Pilot Owners, ED, CAN	Successful deployment and testing of enabling technologies
M22	Mid-June 2025	Data collection for TO-BE scenarios	All Pilot Owners, ED	Complete datasets describing future (TO-BE) processes
M22	By End of June 2025	Analysis and comparison between AS-IS and TO-BE scenarios	SUPSI	Sustainability performance evaluation and results analysis

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