Product Passport through Twinning of Circular Value Chains

Deliverable 1.6

CRIS Requirements and specifications V2

WP1: Digital circular value chain framework

Editor:	Elias Kriticoglou
Lead beneficiary:	BIT
Version:	1.0
Status:	Final
Delivery date:	20/12/2024
Dissemination level:	PU (Public)

This project has received funding from the European Union's Horizon Europe research and innovation programme under Grant Agreement No 101092008

Document Factsheet

Grant Agreement No.	101092008
Project Acronym	Plooto
Project Title	Product Passport through Twinning of Circular Value Chains
Start date	01/01/2023
Duration	36 months

Deliverable Name	D1.5 CRIS Requirements and specifications V2
Related WP	WP1 Digital circular value chain framework
Due Date	31/12/2024

Author	Elias Kriticoglou (BIT)
Contributor(s)	Loukas Antoniou (BIT), Margherita Forcolin, Kostas Kalaboukas, Dimitris Verlekis (MAG), Klemen Kenda, Iztok Renčelj, Matej Kovačič (JSI), Georgios Zois, Stathis Plitsos, Georgios Doukidis (AUEB), Foivos Psarommatis (UiO), Nikolaos Sifakis, George Tsinarakis, Alexandros Chachalis, Maria Aryblia, George Arampatzis (TUC), Jose Gonzalez (EUT), Kostas Christidis, Vassilis Xiros (FRONT), Olga Serifi (KPAD), Maria Zoidi, Stamatis Zomenos (AEGIS)
Reviewer(s)	Andreas Katsigiannis (KPAD), Georgios Zois (AUEB)
Approved by	All partners

Document History

Version	Date	Author(s)	Organization	Description
0.1	17/11/2024	Elias Kriticoglou	BIT	ToC and assignments
0.2	20/11/2024	Klemen Kenda Georgios Zois Nikolaos Sifakis Olga Serifi Maria Zoidi, Jose Gonzalez Kostas Christidis	JSI AUEB TUC KPAD Aegis EUT FRONT	Contribution from partners in relation to their services and tools.
0.3	27/11/2024	Margherita Forcolin Andreas Katsigiannis George Tsinarakis	MAG KPAD TUC	Contributions concerning architecture and components
0.4	03/12/2024	Maria Aryblia Nikolaos Sifakis Foivos Psarommatis Margherita Forcolin	TUC UiO MAG	Contributions concerning Simulation components, IMF models for Italian pilot, and service gateway specification.
0.5	10/12/2024	Dimitris Verlekis Foivos Psarommatis Konstantinos Dritsas	MAG UiO TUV	Complete version for internal review
0.6	18/12/2024	Georgios Zois Andreas Katsigiannis	AUEB KPAD	Peer review
0.7	19/12/2024	Elias Kriticoglou	BIT	Complete version addressing the comments from internal reviewers
0.10	19/12/2024	Armend Duzha	MAG	Quality Check
1.0	20/12/2024	Elias Kriticoglou	BIT	Final version ready for submission

Executive Summary

This document is the final version of the *CRIS Requirements and specifications* and describes the activities carried out in Task 1.5 for the specification of a Circular and Resilient Information System (CRIS) to support the pilots in their digital and circular transition. Additionally, it provides an overview of the technical results achieved in all tasks of WP1, showing how they will be used and integrated in CRIS to provide a unique solution that fulfils the user's needs.

The document builds on the V1 of the same deliverable, highlighting, where relevant, the new or updated content.

The adopted methodological approach relies on consolidated software development practices, starting from an in-depth analysis of the customer's (pilot) needs. The enhanced pilot stories constitute the basis for requirements elicitation. The derived requirements allowed to draft the first version of the architecture, and the specification of its components. In this second version additional requirements have been elicited based on the enhanced pilot scenarios and feedback from the usage of the implemented tools.

Each pilot to-be scenario has been described, specifying the intended use of the different modelling tools (at supply chain level as well as at internal process level) and different services (analytics, Optimization simulation, etc.) which will be provided within WP2. This exercise allowed to derive the functional and non-functional requirement for CRIS leading to the system architecture. The architecture has been described in terms of its internal components and its relationships with tools and services to be implemented in WP2.

In this second version, the technical components as well as the to-be scenarios have been updated to take into consideration the feedback received and the results from the first iteration of pilot operation. Moreover, the architecture specifications have been updated to handle the new requirements that have emerged.

For completeness, each tool and service described in version 1, has been revised accordingly.

Finally, the deliverable presents the approach for implementing the Digital Product Passport (DPP), defining the data structure and the procedural aspects and explaining how these are implemented using the different features provided by CRIS.

Table of Contents

List of Figures

List of Tables

Acronyms and Abbreviations

Acronym	Description
AI	Artificial Intelligence
API	Application Programming Interface
BSC	Balanced Score Card
CPW	Citrus Peels Waste
CPWW	Citrus Peels Wastewater
CRIS	Circular and Resilient Information System
DA	Digital Asset
DPP	Digital Product Passport
DSP	Data Space Protocol
DT	Digital Twin
EDC	Eclipse Dataspace Component
GBA	Global Battery Alliance
HIR	Hierarchical Inheritance Registry
HTTPS	Hypertext Transfer Protocol Secure
IAM	Identity Access Management
IDSA	International Data Space Association
IMF	Information Modelling Framework
LCA	Life Cycle Assessment
MFN	Material Flow Network
PDCS	Product Circularity Data Sheet
PM	Permanent Magnet
PSM	Process Simulation and Modelling
SBSC	Sustainability Balanced Scorecard
SRM	Secondary Raw Material
SSM	Specialized Magnetic Materials
SSN	Secure Socket Network
SSO	Single Sign-On
REE	Rare Earth Element

Acronym	Description
REO	Rare Earth Oxide
R&D	Research and Development
UAV	Unmanned Aerial Vehicles
UI	User Interface
WEEE	Waste Electric and Electronic Equipment
WS	Web Service

1 Introduction

Climate change introduces fresh risks and amplifies pre-existing vulnerabilities in communities globally, posing existential challenges concerning human health and safety, overall quality of life, and the pace of economic growth. The Fourth National Climate Assessment[1], published in 2018, alerted that if we do not curb greenhouse gas emissions and start to adapt, climate change could seriously disrupt the U.S. and global economy.

This requires a profound change in mentality that not only promotes the adoption of virtuous practices (e.g., Reduce, Reuse, Recycle) but also influences the very economic fabric of our society. The prevailing economic paradigm must shift from pure profit-centric models to more holistic ones where economic strategies are intricately woven with sustainability goals. Circular economies and recognizing waste as a resource are pivotal in this transformation.

Embracing circularity is integral to this transformation. The traditional linear model, where resources are extracted, used, and discarded, is no longer sustainable. Circular economy promotes the continual use, recycling, and repurposing of materials, minimizing waste and environmental degradation.

Circularity thus, provides a unique opportunity to transform the climate crisis into an opportunity for business and economic growth. The adoption of innovative technologies and sustainable practices that link environmental sustainability to economic viability can support enterprises in the circular transition, fostering economic growth while mitigating environmental harm.

In line with the above considerations, Plooto aims to provide a *Circular and Resilient Information System that enables waste reduction and end-to-end traceability of Secondary Raw Materials*. Plooto will provide innovative interconnected digital services that, based on digital transformation strategy tailored to process industries, allow 1) the administrative management of circular supply chains, 2) the monitoring and tracing of materials and used resources throughout the whole supply chain, and 3) can produce certifications of materials and products (Digital Product Passport).

1.1 Purpose and Scope

This deliverable provides an overview of the technologies and tools that will be developed and integrated into the Plooto Circular and Resilient Information System (CRIS), and specifies the characteristics of CRIS architecture, identifying the main components and their connections.

Although the main focus is on the architecture, the document also presents the initial technical results achieved in WP1. Additionally, it describes the holistic user-centred methodological approach where the description of pilot scenarios was used to 1) identify the needs of the pilots, 2) derive the initial set of technical requirements, 3) specify – for each pilot- the use of the different

[1] https://nca2018.globalchange.gov

horizontal services, and 4) design the architecture.2) derive the initial set of technical requirements, 3) specify – for each pilot- the use of the different horizontal services, and 4) design the architecture.

1.2 Relation with other deliverables

The CRIS architecture design proposed in this document sets the foundations for the technical implementation and integration of the different components and services. It takes as input information concerning the pilots' scenarios and goals from D1.1 and information related to relevant KPIs from *D1.3 Sustainability Balanced Scorecard Framework*.

The deliverable mainly contributes to WP2 and WP3 (Figure 1), and indirectly to WP4. In WP2, the architecture diagrams, the initial set of requirements, and the pilot-specific data structures, set the stage for the different services that will be implemented, and documented in *D2.2 Plooto complete suite of services*, while the described approach to Data Spaces will be support the realization of the Row Material recovery and waste Data Space that will be documented in *D2.1 RM-recovery and waste Data Space.* In WP3 the deliverable provides information for the implementation of the Digital Product Passport (D3.1), for Plooto balanced scorecard (D3.3) and for CRIS integrated platform (D3.2).

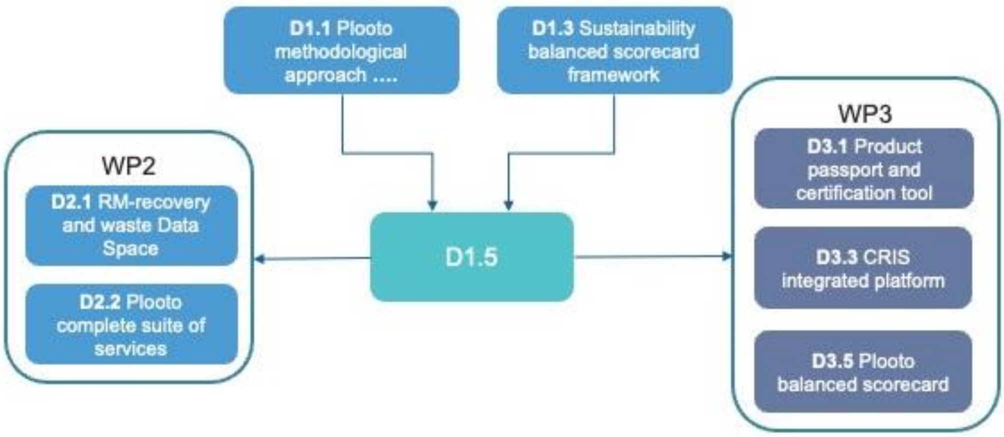


Figure 1: Relations with other deliverables

Additionally, the deliverable outlines the boundaries and features of the pilots' to-be scenarios, therefore it has an indirect relationship with WP4.

1.3 Structure of the document

The document is structured as follows:

- **Section 2** describes the adopted methodological approach.
- **Section 3** describes the user needs and derives functional and non-functional requirements describing the platform.

- **Section 4** introduces the Information Modelling Framework (IMF) and describes how it is used for semantic interoperability and formalization of the DPP.
- **Section 5** Introduces the proposed architecture and describes the main components, services, and tools that will be integrated and made available to the pilot users.

1.4 Summary of changes from version 1

The following table offers an overview of the main updates of this version providing the reference in the document, a brief description of the update and the motivation. A different text colour (blue) has been used to highlight all major updates and enhancements respect the previous version. The table does not include all minor enhancements to improve the readability of the deliverable, such as typos, punctuation, and grammar.

Table 1: Changes and enhancements from V1

Document reference	Change/enhancements motivation
Section 2	**New content**: Added small paragraph concerning the activities in the second year.
Section 3.1.1	**New content:** Added new text and image describing the updated version of the Italian pilot. **Revised Section 3.1.1.1 - Process modelling and simulation**: To be consisted with the updated version of the Italian pilot. **Updated Figure 5** To be consisted with the updated scenario. **Minor updates in Section 3.1.1.1 – Analytics** – rephrasing of some paragraphs to improve readability. **Minor updates in Section 3.1.1.1 – Optimization:** Small paragraph confirming the scope and results of optimization service for the new Italian Pilot scenario. **Revised Section 3.1.1.1 - Supply chain and internal process(es) models Updated Figure 6** to be coherent with the new scenario. The related **Table 2** has been updated accordingly. Minor updates in the text.
Section 3.1.2	**Revised Section 3.1.2.1** - Process modelling and simulation. Enriched information concerning the pilot. **Updated Figure 7** Has been corrected to adhere to the industrial process. **Updated Figure 8** Simplified process. **Revised Section 3.1.2.1 - LCA** Significant improvement of LCA description. **Section 3.1.2.1 - Optimization has been replaced** by a paragraph explaining why the optimization service is not usable in the Greek pilot. **Minor updates in Section 3.1.2.1 - Supply chain and internal process(es) models** Added reference to D2.3 where the DT process models have been implemented.

Document reference	Change/enhancements motivation
Section 3.1.3	**Revised Section 3.1.3.1 - Process modelling and simulation** Enriched information concerning the pilot. **Minor updates Section 3.1.3.1 - Supply chain and internal process(es) models**. Added reference to D2.3 where the DT process models have been implemented.
Section 3.2	**Table 4** Added new functional requirements starting from FR-16. **Table 5** Added new non-functional requirements starting from NF-10.
Section 4	**Revised Section 4.1** Figures related to the functional aspects and production aspects for IMA, IMDEA, and FERIMAT have been replaced by enhanced IMF models of the General and detailed view of the value network. **New Section 4.2** Added IMF models for Italian pilot. **New Section 4.3** Added IMF models for Greek pilot
Section 5	Minor update Section 5.1.4 In the *Blockchain* and in the *IDS Connectors* paragraphs.
	Revised content in Section 5.1.5. Data Spaces part has been made ore adherent to the Plooto scope and approach. **New content in Section 5.2** Added information and figures concerning the specialization of Analytics, Simulation, and Optimization services done during the second year. Added specification for the service gateway enhancements, and link to Section 5.6 for the enhancements in the DPP. **Revised Section 5.4.1** Enriched information concerning the tool. **Revised Section 5.4.3** Updated information concerning the tool. **Revised Section 5.5.3** Enriched information concerning the service. **Revised Section 5.3.1** Significant changes to describe the approach taken in the development of Plooto IDS connectors in Task 2.1. **Revised Section 5.3.2** Enriched information concerning the use of Blockchain. **New content in Section 5.5.1:** Added brief description on how to configure and run an external service. **Revised Section 5.5.2:** Predictive and anomaly detection have been separated. **Revised Section 5.6** Added **new sub section 5.6.1** describing the approach to product certification **New section 5.6.2.1** Brief outline of the implementation approach to DPP. **New section 5.8** Detailing CRIS approach to performance (software compatibility and adaptability) and sustainability
Appendixes	**New** Appendix C: IMF models for the Spanish pilot. **New** Appendix D: IMF models for the Italian pilot **New** Appendix E: IMF models for the Greek pilot

2 Methodological approach

Since the beginning of the project, WP1 involved the pilots and all technical partners from WP2 in active discussions to precisely define the scenarios that will be implemented in Plooto. The pilot stories have been described in collaborative living documents, which detailed the operational and technical needs as well as the main aspects to be monitored and evaluated in the pilot processes. Such documents provided a solid basis from which to define the methodological approach to draft CRIS architecture and provide a concrete innovation that supports the digital and circular transition fulfilling the needs of the industry. The adopted approach consists of an iterative process represented in Figure 2.

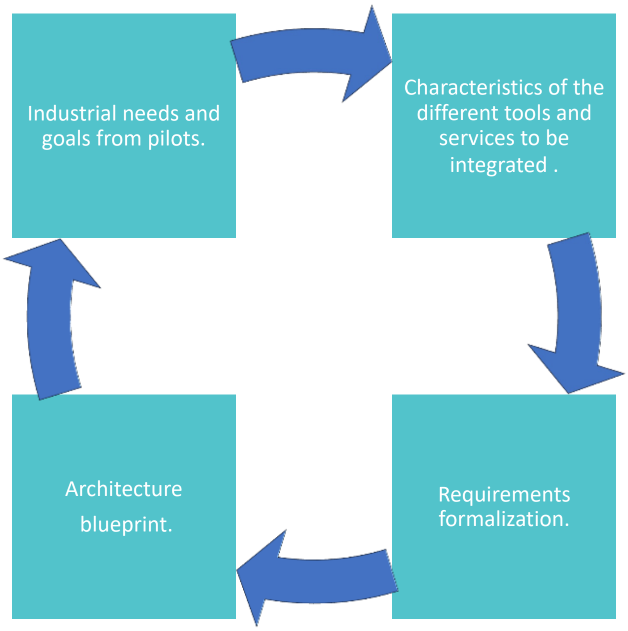


Figure 2: Methodological approach

More specifically:

<u>Define Industrial needs and goals from pilots</u>: consists in the formalization of to-be scenarios focusing specifically on the goals that the pilot wants to achieve, and which services or tools will be useful to achieve the goals.

<u>Understanding the characteristics of the different services and tools to be integrated:</u> consists in defining how the different services (e.g., analytics, optimization, simulation, etc.), tools (e.g., PSM, SBSC), and technologies (e.g., IDS connectors, Blockchain), that Plooto will integrate, will be used within each pilot.

<u>Formalize needs and technical characteristics into requirements</u>: a textual analysis has been carried out on pilot specific living documents to identify the required *behaviours* (functional requirements), the constraints, required performance, and needed services (non-functional requirements) that the platform should provide. Refer to Section 3.2 for further details.

Draft the architecture blueprint: this activity is based on consolidated best practices, standards, and the elicited requirements. Based on the draft architecture, an initial integration approach has been proposed (See Section 5.7).

During the second year, the pilot users have been involved in partial demonstrations of the platform features and services as soon as these were made available. This allowed the refinement of the user stories, the elicitation of further requirements, and the enrichment of the architecture specifications described in this deliverable.

3 User needs and requirements elicitation

Plooto aims to provide the environment for stakeholders to manage the operational aspects of their collaboration and to monitor the entire supply chain and internal processes, while still safeguarding privacy, ownership and confidentiality. The goal is to model the whole supply/value chain, the internal processes, and to obtain ways and metrics to monitor a given process and to manage the exchange between the different actors in the supply chain.

For the scope of this deliverable, the information concerning the pilot stories has been synthesised to better focus on the features that the platform should provide. The following sections in this chapter, provide an overview of the three pilots. Each section reproduces the working process carried out that can be summarized as follow: design the to-be scenarios, design the representational process models, define the scope of each service in relation to the pilot, model the processes - and eventually the supply chain - in terms of Digital Twins (DTs).

Besides a necessary step to draft CRIS architecture, the work done provides valuable insights for the tools and services that will be implemented in WP2, and to design the ICT framework and usage scenarios encompassing all needed features and foreseen artefacts (e.g., Digital Product Passport (DPP)).

3.1 Pilot stories

3.1.1 Italian pilot

The use of Carbon Fiber Reinforced Polymer (CFRP) composites is rapidly increasing due to their peculiar characteristics (lightness, strength, durability, versatility), which open the way to endless applications in different domains, such as automotive, aeronautics, maritime and leisure. Before being used in production, CFRPs need to be stored at low temperature to avoid their degradation. The production waste consists of *scraps of cured material* coming from the cutting operations or *partial rolls of uncured material* that have reached the expiration date. This waste must be disposed, due to the lack of recycling /reuse alternatives, representing both an environmental challenge and an economic loss for the manufacturer. Composite materials are considered special waste requiring dedicated and costly disposal procedures. Disposal fees can range from 250 to 300€/ton and increase exponentially if the waste is considered hazardous, as in the case of uncured prepregs.

The Italian pilot aims to identify best practices and procedures to extend the usability of CFRPs. Through the establishment of a virtuous circle among key partners operating in the sector, the goal is to recover scrap and expired material, re-qualify it to extend its shelf-life, allowing the use of the reconfigured material in other applications.

Specifically, the supply chain, which is graphically represented in Figure 3, involves 4 partners: HP Composites (HPC), Cetma Composites (CC), Cetma, and Accelligence (ACCELI).

HPC is a world leader in the design and production of CFRP components for the aerospace, automotive, motorsport, naval, industrial and design sectors. The amount of waste from the production line amounts to approximately 30 tons of uncured prepreg scraps per year.

CC is an innovative SME whose current business includes the production and sale of CFRP composite material products for sport, furniture and leisure sectors.

CETMA is a Research Centre with extensive expertise in materials engineering, recycling, computer engineering and industrial design.

ACCELI is a Cyprus-based company, engaged in cutting edge R&D activities on Unmanned Aerial Vehicles (UAVs), haptics and other robotic activities. ACCELI manufactures custom UAV prototypes, with different characteristics based on customer's requirements.

Pilot scope: Recover scrap and expired material, re-qualify it to extend its shelf-life, allowing the use of the reconfigured material for the production of drone parts based on ACCELI specifications. Such products should be characterized by high performance, reduced cost and lower environmental impact.

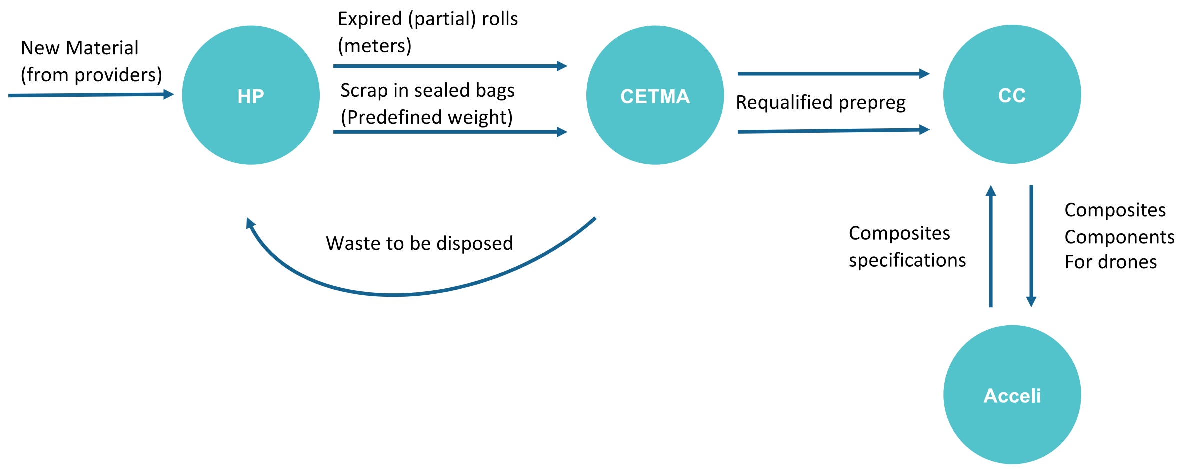


Figure 3: Italian pilot supply chain (initial version)

The overarching objective of the pilot is to drastically reduce the amount of CFPR waste that ends up in landfills and to transform the waste into a sort of Secondary Raw Material (SRM) to be used in the production of new products.

This will be achieved by developing practices and guidelines that increase CFPR shelf-life (CETMA) through the definition of requalification processes. The requalification process determines the new process window for the material (working temperature and pressure). The requalified CFPR can then be used for new productions.

Updated representation of Italia Pilot Value network

The first iteration of pilot activities allowed to gain a better understanding of Plooto capabilities, which led to an enhanced description of the value network that better adhered to the business constraints. two major limitations:

CETMA needs only a small amount of material to perform the analysis, therefore, there is no need to send all the expired material to CETMA. In case the material is not re-qualifiable, it must be sent back to HPC for the disposal, with logistics challenges and increased transport costs.

Moreover, logically, the flow should start when CC receives an order from ACCELI requesting the production of drone parts. Based on the Order CC would know what the needed type of material is and request the material to HPC.

The new supply chain is represented in the figure below.

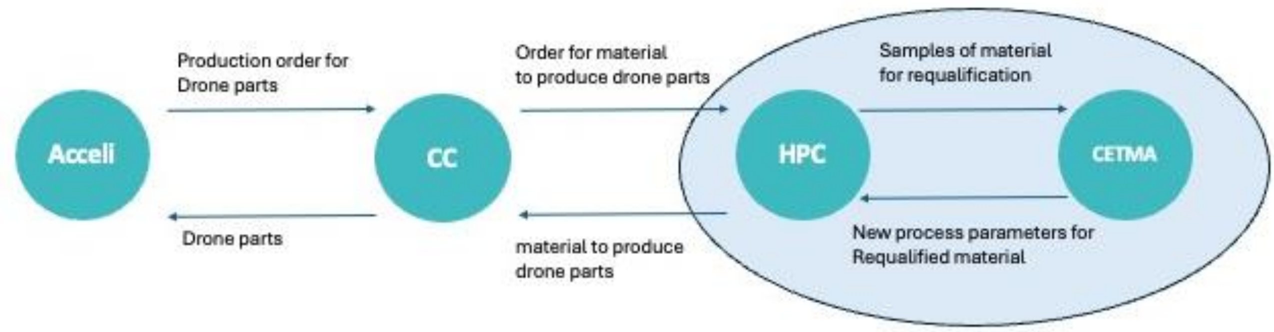


Figure 4: Italian pilot supply chain (updated version)

From a temporal perspective, there is an element of discontinuity as the communication between HPC and CETMA is not chronologically related to requests received from CC. HP produces scrap raw material daily. This scrap consists of expired rolls or prepreg scraps from the cutting process. A small sample of each scrap should be sent to CETMA for requalification. CETMA only returns information concerning the requalified material, if the material cannot be requalified, HP can proceed with disposal. This eliminates the backflow (CETMA → HPC) and minimizes the overall material flow and related costs.

The information concerning the requalified material - basically the new process window details and revised expiration date - should be stored by HPC into a *catalogue of requalified material* that should be made available to CC.

After receiving an order from ACCELI, CC accesses *HPC catalogue of requalified material* and can forward a request for a specific item (i.e., material) indicating the desired quantity.

HPC can accept or decline. If the request is accepted the material is sent, and the catalogue should be updated accordingly.

The new scenario generates new requirements: specifically

1. HPC should be able to create the Catalogue of requalified material that is a collection of assets corresponding to the different materials that have gone through the requalification process valorising the telemetries based on the results of the requalification process
2. The assets in the catalogue are characterized by the following telemetries: LOT, Code, Weight, Type, Expiration date, Process window temp, Process window pressure, Process window time
3. CC should be able to access the catalogue and see the available requalified materials and their telemetries.
4. HPC should be able to modify telemetries of an asset (e.g., the quantity of a given LOT when only partially used)

Of these, #1 and #4 are relevant to the platform and are included in Table 4, the others are to be considered by pilot partners when enhancing the Italian pilot ecosystem.

3.1.1.1 Italian pilot technical needs

Process modelling and simulation

Italian pilot ecosystem comprises a linear four-actor value chain. Figure 5 provides an overview of the production process.

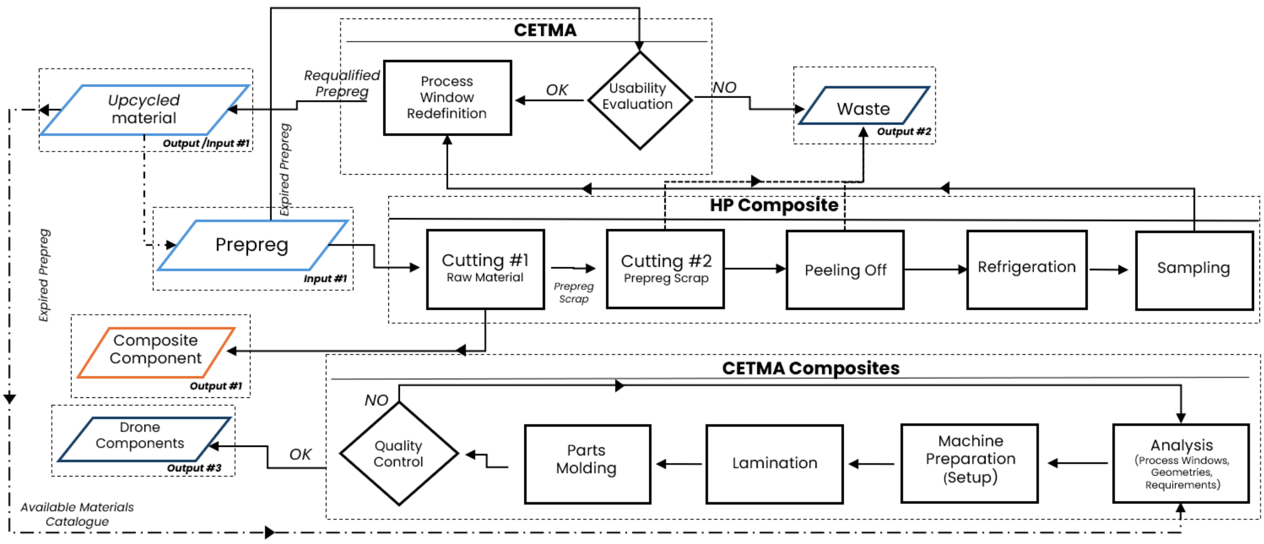


Figure 5: Italian pilot: value chain and process model

Scope: The primary focus of the PSM tool is to develop process models for (a) prepreg scrap management (HPC), (b) usability evaluation and requalification procedures (CETMA), (c) parts constructions and quality control (CC), on alignment with the requests' specifications and properties of end-products (drone parts) (ACCELI). To be noted that ACCELI is the final customer, as such it does not participate into the production phase.

Impact: The PSM tool significantly enhances the modelling and optimization of the circular value chain for prepreg scrap management, usability evaluation, requalification procedures, and construction of parts aligned with end-product specifications. By providing a comprehensive representation of processes across multiple stages, the tool accommodates the requirements of multiple actors and stakeholders within the supply chain. This includes mapping of inputs, outputs, interactions, and the flow of materials, energy, and data, effectively enabling multi-actor coordination and decision-making. The PSM tool enables and uses advanced agent-based modelling to capture the dynamics of individual components, while integrating them into a holistic system. It acts as an interpreter, seamlessly connecting analytics-driven insights (decision-making) with optimization tools to deliver robust, data-driven solutions. The tool supports scenario analysis, including root-cause identification, what-if modelling, and comparative assessments, enhancing its utility across varying operational contexts. As a reusable, adaptable, and API-enabled digital solution, the PSM tool facilitates traceability, monitoring, and governance within the circular value chain. Its integration within the PLOOTO suite of services (CRIS) ensures real-time evaluation, optimization, and end-to-end traceability, fostering the achievement of resilience and circularity in industrial systems while enabling informed decision-making through advanced data analytics and modelling.

Data Requirements: A detailed analytical description of the processes involved in this multi-actor pilot case, including a comprehensive overview of the available machinery (both basic and auxiliary), is essential. This should encompass quantitative characteristics such as setup times, processing durations, maximum equipment capacities, transfer times, initial stock levels, and energy demand volume for each process. Additionally, the data must capture the importance and configurations of equipment used at each process step to enable precise modeling and simulation. Furthermore, it is crucial to evaluate the potential use of primary inputs, such as requalified prepreg and prepreg scraps, detailing their flow, transformation, and integration within the processes. Secondary inputs/outputs including energy consumption per operation, cooling requirements, and any supplementary variables, must also be quantified. This data will facilitate the accurate mapping of resource utilization, equipment efficiency, and overall process dynamics, serving as a foundation for operational improvement.

Analytics

In modern manufacturing, data-driven analytics plays a pivotal role in enhancing efficiency, quality, and decision-making processes. In the Italian pilot, the analytics focuses explicitly on the anomaly detection within the manufacturing process as well as on the evaluation and classification of prepreg material – a critical component with a limited lifespan depending on the history of storage conditions.

The drone production pipeline relies on prepreg material as a fundamental component. Prepreg material, being perishable, requires careful evaluation (based on measurements) to ensure optimal utilization in the manufacturing process. Data-driven analytics has been envisioned to be integrated into three key junctures within the pipeline: the assessment of uncured prepreg, the categorization of cured prepreg, and the monitoring of the production process.

In the initial **prepreg classification** scenario, data-driven analytics is employed to evaluate the suitability of uncured prepreg material for the curing procedure. This application uses a classification algorithm designed to make informed decisions based on data inputs. The primary variables considered in this classification algorithm include:

- **Storage History:** A time series of temperature and pressure data are available for each batch of prepreg material. This historical data provides critical insights into how the prepreg material has been stored, enabling the algorithm to make informed predictions.
- **External Data Sources:** Complementing the internal data are external data sources that can further enrich the classification process. These may encompass weather conditions, humidity levels, or other factors that could influence prepreg quality.

Time series data from the manufacturing process will be pre-processed in a way that relevant derived features are extracted and used in feature vectors for classification. The classification process for uncured prepreg material can manifest in two primary scenarios:

- **Binary Classification:** The algorithm classifies the material into two distinct categories - 'positive' and 'negative.' A 'positive' classification implies that the material is suitable for the curing procedure, while a 'negative' classification suggests otherwise. If the algorithm is successful, it could partially omit the need for testing of certain materials (e. g. those batches that will be classified as waste after the physical testing).
- **Multiclass Classification:** In this scenario, the algorithm expands its categorization beyond a binary system, drawing insights from existing literature. Multiple prepreg classes are defined based on their specific characteristics and attributes, enabling a more nuanced evaluation. Such classification could even be performed with additional measurement data.

Data-driven analytics is equally beneficial in the **classification of cured prepreg material**. Similar to the uncured prepreg scenario, this phase employs classification algorithms guided by literature-based insights. The goal is to categorize the cured prepreg into classes that reflect its properties and quality. All analytics scenarios will later be used for process modelling or optimization.

We estimate that leveraging machine learning and data analysis techniques, can enable more efficient decision-making, enhance material utilization, and contribute to the overall efficiency and quality of drone production.

It is important to acknowledge the risk that **classification algorithms may face limitations**, especially when dealing with stochastic environmental factors or incomplete data (e. g. some relevant feature has not been measured). These issues should also be considered within the

Italian pilot. Stochastic factors, such as abrupt temperature or pressure fluctuations or way of handling of materials, can introduce noise and data inconsistencies, making it challenging for algorithms to assess prepreg material quality accurately. Additionally, the presence of stochastic elements can amplify uncertainty in the classification process, making it difficult to distinguish between material affected by environmental fluctuations and genuinely unsuitable material.

Human expertise should complement machine learning (and machine learning experts) in order to mitigate these issues. Domain experts can provide valuable insights and judgment in cases where classification results are uncertain or data is incomplete, suggesting improvements of the modelling approaches. Human experts can also benefit from learned models and their explainability, which can help them understand additional principles linked to the product quality.

The **initial anomaly detection** scenario is implemented on the top of the timeseries data from the manufacturing process and is used for early detection of failures and predictive maintenance. By discovering anomalies within the timeseries, the anomaly detection component can alert the operator. Typical errors that can be spotted with anomaly detection are: vacuum failure (due to equipment fatigue) or temperature curve inconsistencies.

Optimization

Scope: The optimization model is designed to enhance the efficiency of HPC, CETMA, CC, and ACCELI within the context of their value network. Specifically, it *decomposes each order originating from ACCELI into a series of subproblems*, corresponding to the diverse CFRP components required for drone construction. For every individual part, the optimization service *dynamically generates a network that encapsulates various process states,* illustrating alternative pathways for producing the specified component within the broader value network. The service's output comprises the *optimal path/flow within this constructed network, along with the selection of optimal operating scenarios for each processing stage*. The overarching goal of the optimization process is to *minimize the total energy consumption within the value network*. This approach not only streamlines the production of CFRP parts but also contributes to a more sustainable and energy-efficient operation across the entire value network.

Impact: The growing utilization of CFRP has raised environmental concerns, particularly regarding the disposal of waste composites. Failing to appropriately manage the disposal or repurpose these composites poses significant environmental risks and results in the squandering of a valuable resource. Consequently, it is imperative to devise efficient technologies for recycling waste CFRP composites, aligning with environmentally friendly and sustainable development principles. While analytics offers insights into the connections between alternative requalification strategies and cured prepreg, the optimization process orchestrates the entire workflow across the value network. This comprehensive approach yields *solutions that are optimal from a global perspective, ensuring efficiency and sustainability throughout the entire process.*

<u>Data Requirements:</u> The optimization service is intricately dependent on data sourced from experts within the value network, analytics, and simulation. This critical data encompasses *mappings that establish connections between diverse requalification processes, linking various classes of uncured prepreg to their corresponding requalified uncured prepreg counterparts*. Likewise, we need access to *mappings between requalified uncured prepreg and cured prepreg, guided by alternative process window options.* Possessing these mappings is crucial as they dynamically inform the generation of alternative operating scenarios for each process. Furthermore, it is imperative to have access to data detailing the *energy requirements for each alternative process stage and operating scenario.* This information is indispensable for our comprehensive analysis, ensuring a thorough understanding and optimization of the overall system.

The scope of the optimization service for the Italian pilot remains unchanged in the new scenario. The rearrangement of the value network does not affect the optimization decisions. The optimization service has been developed in Task 2.5 and documented in D2.3, submitted in June 2024.

Supply chain and internal process(es) models

The *DT supply chain model* involves all pilot partners as depicted in Figure 6. The figure and the related Table 2 have been changed to be consistent with the new scenario described in Section 3.1.1).

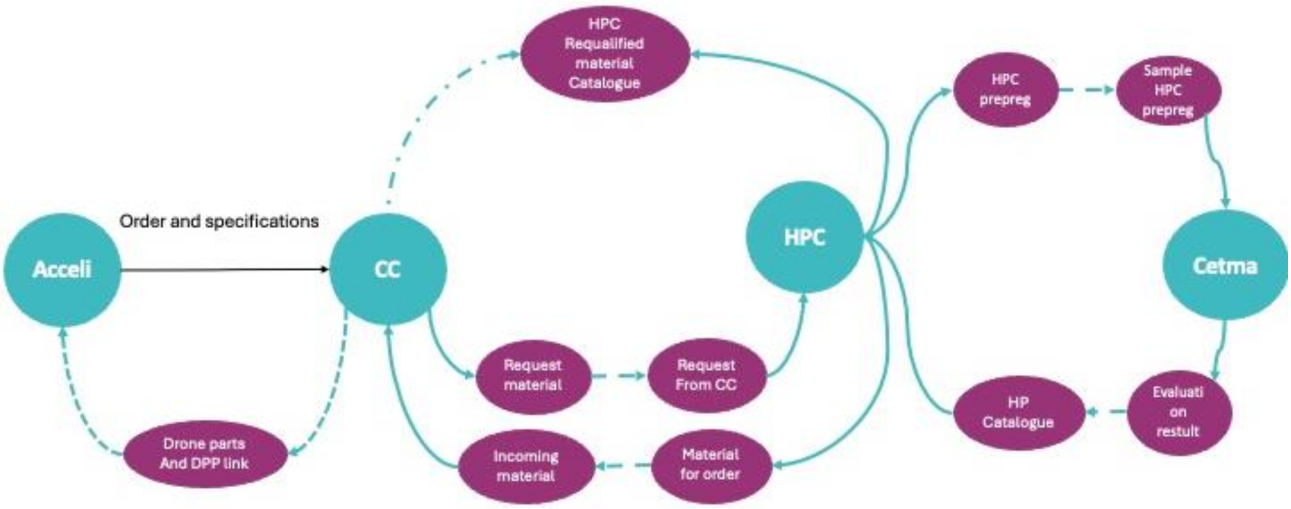


Figure 6: Italian Pilot DT supply chain model

Table 2: Italian pilot key processes and roles

Partner	Process	Roles
ACCELI	CCs drone production	Start the supply chain by sending an order to CC requesting the production of drone parts. This is done off-line sending also the specification of the parts to be produced.

Partner	Process	Roles
CC	CC material characteristics and availability	Accesses HPC *catalogue of requalified material* to verify the availability of requalified material with needed characteristics (process parameters). Then requests the needed material asset to HPC.
CC	HPC material acquisition	Obtains requalified material from HPC
CC	Requalified material to CCs for drones	Used requalified material from HPC to produce components for Drones (based on specifications from ACCELI).
HPC	Scrap and expired prepreg collection	Collects scrap and expired prepreg from their industrial production. Samples of the waste material are sent to CETMA for requalification.
CETMA	Waste to requalified material	Analyses waste received from HPC and determines if it is usable – providing new process windows details and new expiration date – or not.

The supply chain has been modelled and configured within Task 2.1, using corresponding features presented in the Digital Twin modeller described in Section 5.4.2. The configuration of the supply chain concerns the data to be exchanged among the parties (Task 2.1).

The DT process models, based on the processes described in Figure 5, concern essentially the production process in CC, and will focus on the performance and energy consumption of the production. They have been implemented within Task 2.1 and described in D2.3, submitted in June 2024.

3.1.2 Greek Pilot

ASPIS is a company based in Argos, Greece that produces a great variety of fruit juices and fruit purees, aromas & oils, fruit preparations and canned products. Currently, it operates two processing plants in two different regions in Greece, namely at Argos and Irinoupoli.

The Greek pilot involves the processing plant at Argos. This plant processes citrus and deciduous fruits and vegetables to produce fruit juices and purees, citrus oils & aromas, fruit preparations, mixtures, and animal feed from citrus peel.

The pilot focuses on processing the waste stream from the main production line (orange juice) to obtain additional products - that could be relevant in other sectors - and significantly reduce waste. The main aim is to minimize the high energy demands of the production streams.

The processing of the solid phase of the waste generates several secondary products, such as various types of molasses, citrus silage, and pellets that are used to produce animal feed. From an economic perspective, molasses is the most significant secondary product, due to its high value, while the other two (citrus peel oil and citrus pellets) represent interesting products that can be reused and ultimately enhance circular economy.

The aforementioned products from the processed waste are very interesting from a circularity perspective, because their valorisation facilitates the overall waste reduction, while creating new business opportunities.

Another interesting aspect concerns the use and the disposal of produced wastewater. The wastewater stream from the main production line is produced from the rinse of the fruits. Another wastewater stream (CPWW) free from hazardous contaminants or sludge is produced after the centrifuge stage, at the main production line, and can be either disposed to the environment or used in other products (i.e. fertilizers) without further processing.

The Greek pilot aims to demonstrate how the reduction of energy consumption within a single process line can be achieved by data analytics, PSM tool and online LCA. Moreover, the environmental benefits of the energy consumption achieved will be highlighted using Life Cycle Assessment (LCA). Regardless, this pilot represents a very interesting case from an environmental point of view.

Figure 7 provides a synthetic overview of the Greek pilot value chain focusing on the main production outcomes. The value chain is internal to ASPIS with no collaboration with third parties (either providers or customers). Figure 8 offers a detailed description of the internal processes and the main outcomes.

Pilot scope: Improve the energy intensive processes of the waste valorisation processing line that produces animal feed components of high nutritional value, aiming at an improvement of the environmental footprint and a reduction of the energy demand.

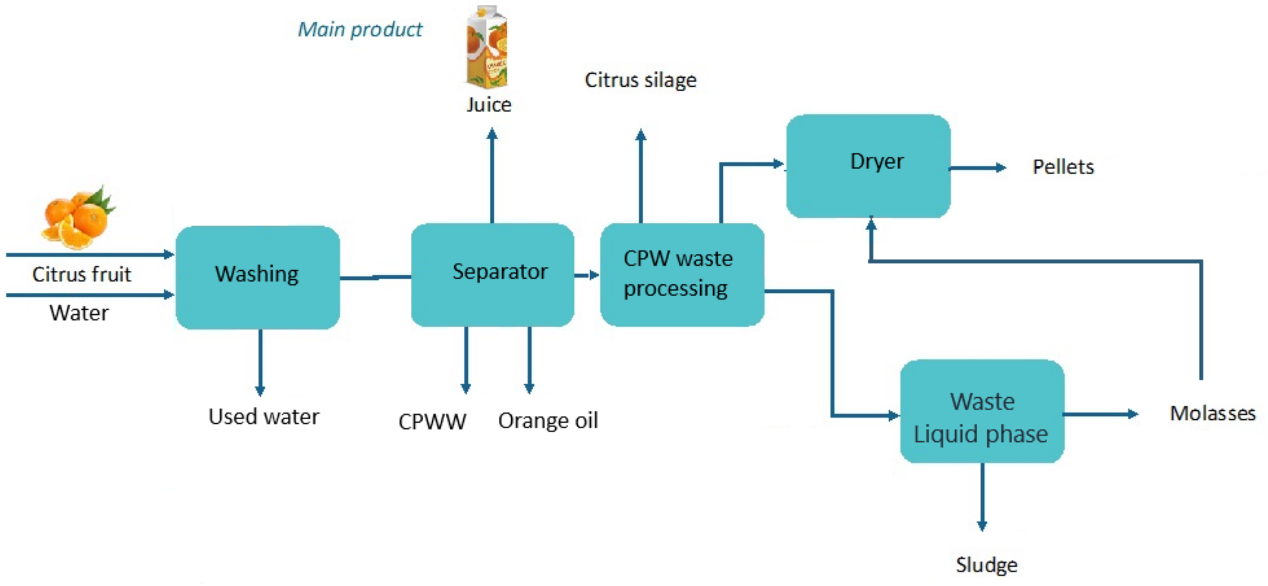


Figure 7: Greek pilot value chain

The overarching objective of the pilot is to significantly reduce the amount of energy consumption within the waste valorisation processing lines. This decrease in the energy consumption will be further highlighted via the LCA analysis be achieved using the outputs of the optimization provided by the relevant partners. Moreover, Plooto's impact can also be highlighted by the residual wastes of the processing line, which will be water - free from any hazardous contaminants - and sludge that can either be disposed in the environment or be utilized in other terms (i.e. fertilizers).

3.1.2.1 Greek pilot needs

Process modelling and simulation

The Greek pilot pertains to a linear single-actor (ASPIS) value chain (Figure 8).

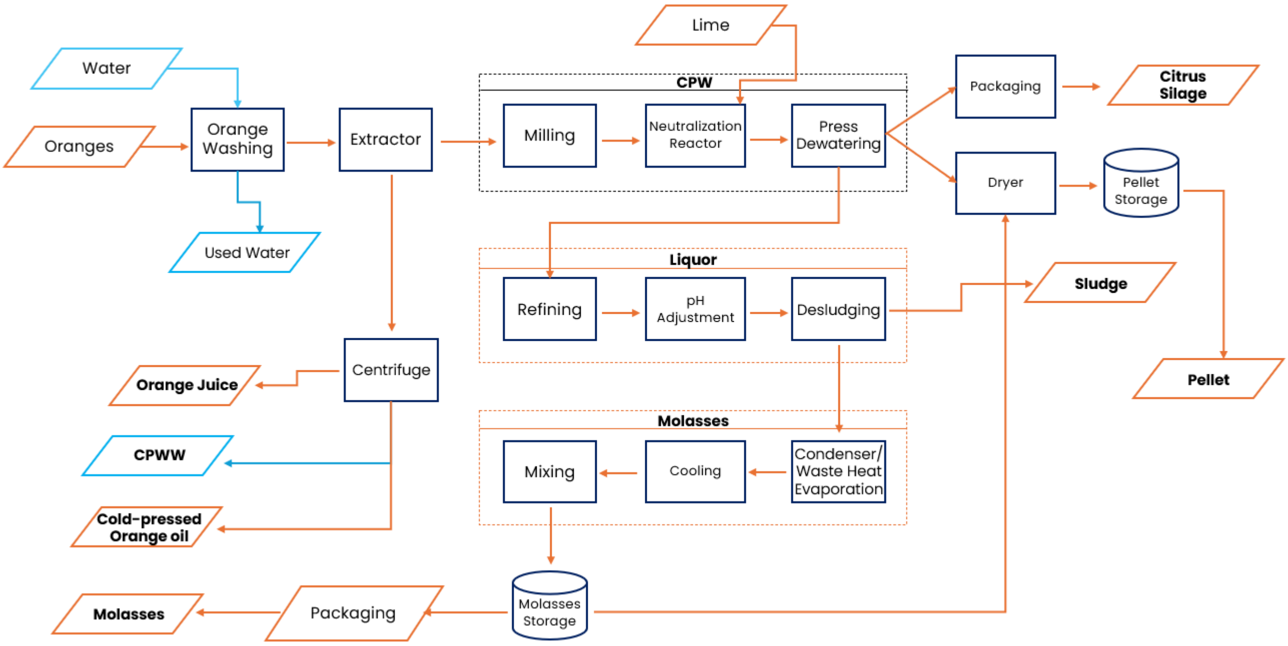


Figure 8: Greek pilot process model

Scope: The PSM tool is responsible for developing the process model depicting (a) the main production line regarding citrus management and juice extraction, (b) the wastewater and waste' management coming from the primary production activity, as well as (c) the production of molasses, citrus pellets, sludge, orange oil, and citrus-processing wastewater (secondary products).

Impact: The PSM tool models and enables the simulation of the entire value chain by offering a comprehensive and detailed representation of processes. It effectively maps out inputs, outputs, physical connections, interactions, and the flow of materials, data, and energy within the value chain. Acting as a crucial interpreter, PSM enables the integration and actual operation of the analytics services. By accurately mapping inputs, outputs, physical connections, and the flow of materials, energy, and data, it ensures precise system comprehension. The tool enables the capturing of the complexity of interconnected processes while concurrently paying particular attention to energy-intensive processes like desludging. PSM integrates seamlessly with analytics, leveraging analytics-driven insights to assess energy usage, adjust operational parameters, and reduce consumption, thereby enabling users to identify inefficiencies, implement targeted solutions, and advance resource management, circular economy principles, and sustainability goals. It supports various scenario analyses, including root-cause identification, what-if assessments, and comparative evaluations, allowing stakeholders to simulate diverse operational and sustainability strategies effectively. Designed for reusability, adaptability, and scalability, the PSM tool is API-enabled, ensuring smooth integration with other digital services within the Plooto suite.

Data Requirements: A comprehensive and detailed description of the value chain processes, as modelled by the PSM tool, is fundamental to effectively represent the diverse operations within the citrus management and juice extraction processes. This includes the precise definition of primary and secondary production lines, including processes such as citrus washing, juice extraction, and the valorisation of waste streams into molasses, citrus pellets, orange oil, and sludge. For accurate simulation, the quantitative attributes—such as material flows, energy consumption, processing durations, and operational capacities—must be exhaustively documented through the provision of timeseries data. Furthermore, the understanding of the highly impacting parameters controlling each process stage, is critical for ensuring the PSM tool's adaptability in what-if scenario analysis and decision-making, including equipment setup, and flow dynamics. Such detailed dataset is crucial in enabling efficient root-cause analysis, what-if scenarios, and the comparative evaluation of operational strategies to refine the value chain's performance and sustainability.

LCA

The primary goal of the Life Cycle Analysis (LCA) service is to analyse and evaluate the environmental impacts of the production processes. LCA would indicate the processes that should be reconsider in terms of environmental footprint, indicating hot spots regarding energy consumption. The analysis will be performed on a Life Cycle basis, according to the ISO 14040 standards. Additionally, the service will be able to evaluate the environmental impacts from proposed simulations and what-if scenarios derived from PSM tool and analytics service. The main focus of this pilot case is to minimize energy consumption from the production lines. Simultaneously, the Citrus Peels Waste-Water (CPWW) will undergo re-evaluation in order to minimize the requirements for fresh water. Ultimately, our vision is to prove the improvement of environmental sustainability achieved by the proposed simulated changes of the waste valorisation process line.

Impact: The production process is characterized by high energy demands and significant environmental footprints. For that reason, it is imperative to reduce energy consumptions, due to stringent environmental constraints, while the risk of soil and water pollution associated with uncontrolled disposal should also be addressed. The impact of the LCA analysis will be the overall evaluation of the improvement of the environmental sustainability achieved by the proposed changes in the production line.

Data Requirements: A thorough and detailed depiction of the value chain processes is essential for accurately capturing the various processing steps involved. This entails clearly defining the production lines, covering steps like citrus washing, juice extraction, and the production of secondary products such as molasses, citrus pellets, and citrus peel oil. Additionally, it is crucial to comprehensively document quantitative parameters, such as material flows, energy usage, processing times, and operational capacities.

KPAD will utilize data from the processing line to perform the LCA analysis and evaluate the environmental impacts. Additionally, trough linkage with the PSM tool and the analytics service, the LCA will help with the reduction of the high energy demands and improve the sustainability footprints of the pilot's production line. The link between the services will be achieved using interconnected DTs from Plooto with an on-line LCA tool, whereas some of the results from the analysis will be available on the Digital Product Passport.

Analytics

Scope: Analytics is implemented along the main objectives of the pilot case, namely, to assist in minimizing the energy consumed for waste processing and help increase the value extracted from the by-products of the process. To this end, the analytics platform will examine the machine operations, heating and cooling systems, and periodicity of energy consumption. By monitoring the production processes, insights are extracted and anomalies are identified. Regarding by-products, we will identify the temporal and quality patterns in their production and classify them according to relevant dimensions. Additional information based on anomaly detection or unsupervised learning may be generated. Ultimately, our vision is to achieve the cost-effective reutilization of waste and the reduction of energy consumption, and to obtain additional by-products with potential applications across various sectors.

Impact: The impact of the analytics is expected to have both a financial and environmental impact. Changes based on analytics insights could include enhancing the overall flow of Citrus Process Waste (CPW) within the waste production line and reintroducing the treated Citrus Peels Waste Water (CPWW) within the production line, aiming to diminish the requirement for fresh water. A significant environmental benefit will be realized through repurposing by-products, and lowering the energy consumption. Also, from a financial standpoint, the proposed changes supported also by analytics, will provide a financial incentive for the industry.

Data Requirements: In order to provide valuable analytics, detailed historical timeseries data is required, which can be combined with real-time data points. Regarding energy consumption, the data needed refer to the time, type, and quantity of energy consumed in different stages on the production line. This could be machine configurations and run-time, as well as sensor data.

Moreover, analytics would need the quantitative and qualitative characteristics of the by-products, while additional insights from detailed manufacturing process data from sensors, and market data may be considered.

Optimization

The Greek pilot focuses on reducing the environmental footprint and energy consumption in the production line. Therefore, it does not involve other production partners, but it is limited to internal production processes. As such, the Greek pilot does not represent a usable case for the optimization service, which specifically considers optimization along the supply chain.

Supply chain and processes models

Given that the value chain of the Greek pilot is internal, the modelling needs to refer only to the relevant production processes as interconnected DTs (indicated as *DT process model*), for the monitoring and management of the different aspects of the production and be able to adjust the process and calculate the production-related KPIs.

The DT process models, based on the corresponding process models presented in Figure 8, concern the production performance, the efficiency of the waste management, the yield of the new products obtained by the waste treatment, and the water recycled/saved. These have been implemented within Task 2.1 and described in D2.3 submitted in June 2024.

3.1.3 Spanish pilot

Rare-Earth Elements (REEs) are becoming increasingly important for the transition to a green economy due to their essential role in several technologies and applications such as permanent magnets, lamp phosphors, catalysts, and rechargeable batteries. REEs are produced mainly in China, which accounted for over 70% of the global production in 2022[2]. In case of rare-earth permanent magnets (PMs) this reflects in the fact that 98% of them are imported from China [5]. The fact that the Chinese government imposes exportation quotas, raises concerns about REEs availability at European level. Despite vast research efforts on REEs recycling - mostly at laboratory scale - the recycling of REEs is still at early stages (less than 1% of the REEs were recycled until 2018) mainly due to inefficient collection, technological problems, and the lack of industries supporting the recycling process [1]. Therefore, a drastic improvement in the recycling of PMs from WEEE is an absolute necessity that can only be achieved by developing efficient, fully integrated recycling routes.

One of the goals of the Spanish pilot is to identify best practices and procedures to expand the reuse and recycling of WEEE. Through the creation of a virtuous circle between key partners active in the sector, the aim is to recycle and recover magnetic materials, process them to decontaminate them from hazardous substances and create Secondary Raw Materials (SRM), to

[2] https://www.statista.com/statistics/270277/mining-of-rare-earths-by-country/

be used in the production of new permanent magnets. This is expected to reduce WEEE disposed in landfills and produce secondary raw magnetic materials, thus diminishing the dependence on China and improving the resilience and economic return of European manufacturers.

Specifically, the supply chain involves 3 partners: FERIMET, IMDEA, and IMA.

FERIMET is the Celsa Group Company dedicated to the recovery and treatment of ferrous and non-ferrous materials. Nowadays FERIMET receives 24,8 Tn/year of WEEE containing different kind of motors and magnets. Each WEEE product contains 0.5 to 300 g Permanent Magnets (PMs) approximately (either bonded NdFeB, Sr-Ferrite, or sintered Sr-Ferrite) depending on the type of electrical motor or magnetic component contained.

IMDEA is an interdisciplinary research centre located in Madrid (Spain) and dedicated to the exploration of nanoscience and the development of applications of nanotechnology in connection with innovative industries. Notably, the Group of Permanent Magnets and Applications is part of the Nanotechnology for Critical Raw Materials and Sustainability Programme at IMDEA Nanoscience. This Programme focuses on the application of research and innovation to overcome the compelling economic, political, and social challenges faced by Europe concerning the procurement of critical raw materials essential for a sustainable technological development.

IMA is a Spanish company leader in the magnetic sector, with more than 30 years of experience and a globally recognized magnet supplier with customers from more than 60 countries. IMA's core business is the development of technologies to improve the process of transformation, rectification, magnetization and customization of magnets.

Pilot scope: WEEE recovered by Ferimet, are processed and transformed into magnetic pellets by IMDEA, and subsequently used by IMA for the production of new magnets upon customers' request. The focus of the pilot is to optimize the energy consumption of the production line, and minimize the import of Raw Materials, thus creating an integrated circular economy framework towards maximizing the use of SRM.

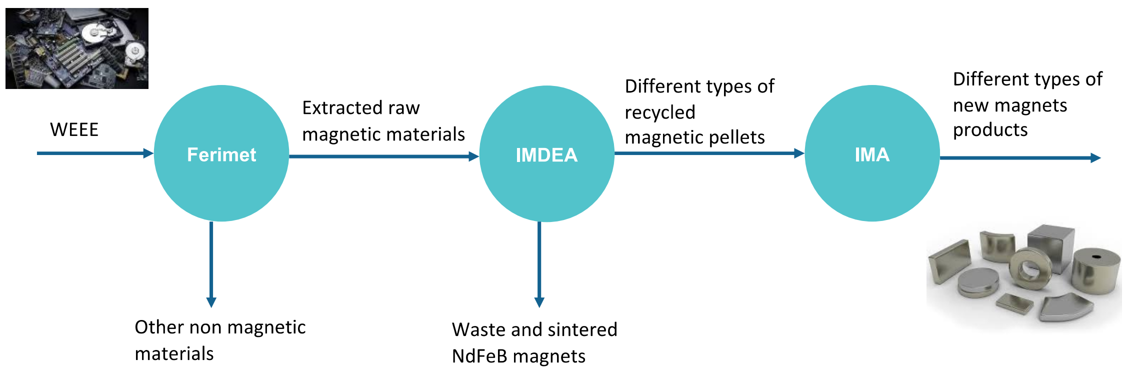


Figure 9: Spanish pilot value chain

Figure 9 provides a description of the Spanish pilot value chain and the main outcomes. The internal processes are fully described in Figure 10.

3.1.3.1 Spanish pilot needs

Process modelling and simulation

The Spanish pilot ecosystem is comprised by a linear three-actor value chain (Figure 10).

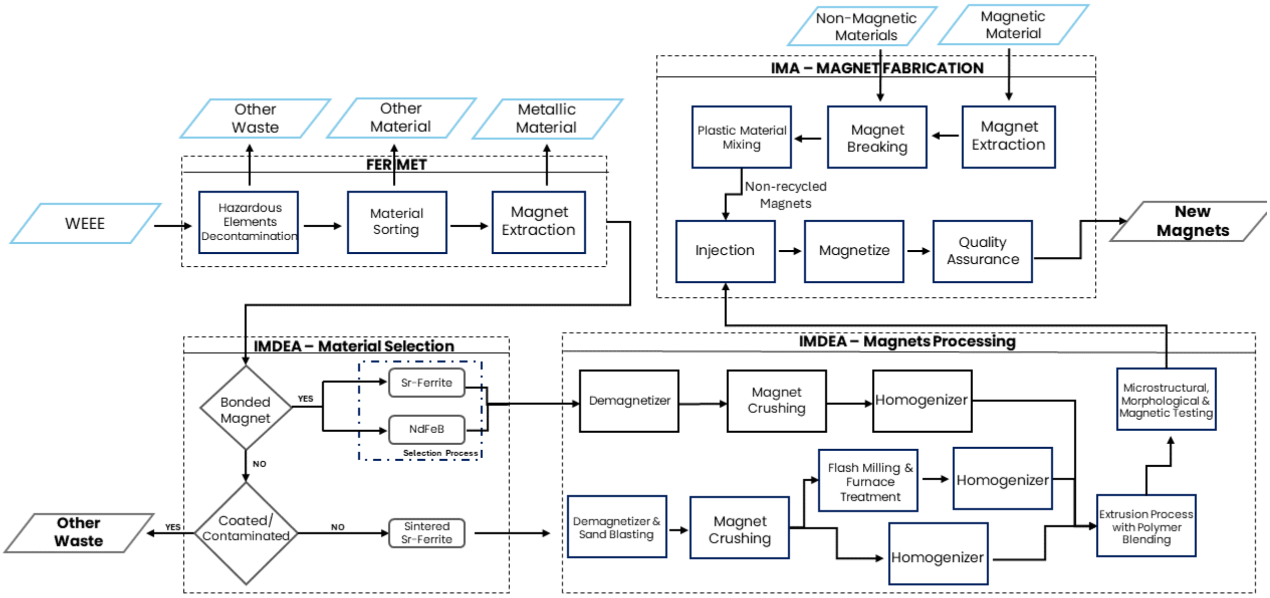


Figure 10: Spanish pilot: value chain and process model

<u>Scope</u>: The PSM tool is focused on developing a process model of the value chain regarding (a) management of Waste from Electrical and Electronic Equipment (WEEE) and magnet extraction (FERIMET), (b) magnet sorting and material selection (IMDEA), (c) magnet processing and magnetic pellets construction (IMDEA), and (d) new magnets manufacturing and quality assurance (IMA).

<u>Impact</u>: The PSM tool specifically models the multi-actor value chain for magnet recovery and fabrication from WEEE in this pilot case. It provides a detailed representation of the processes. Every step is mapped with precision, capturing inputs and outputs, while also physical and energy flows are considered, to reflect real-world operational dynamics. The PSM tool takes advantage of analytics to optimize energy-intensive stages, identifying inefficiencies and supporting targeted improvements that enhance resource recovery and minimize energy consumption. It integrates seamlessly with optimization services, enabling scenario-based assessments, including what-if analyses, comparative evaluations, and root-cause investigations. As a reusable, expandable, and API-enabled platform, the PSM tool aligns with the unique requirements of this pilot, facilitating collaboration among actors and streamlining decision-making processes. Its design ensures adaptability to evolving operational needs while enhancing the magnet recovery and fabrication value chain's efficiency, traceability, and sustainability.

Data Requirements: A precise and structured analytical description is essential to effectively represent each stage of the magnet recovery and production processes, as depicted in the associated workflow. This involves a detailed breakdown of each operational phase, including processes such as decontamination from hazardous compounds, material sorting, magnet extraction, and subsequent processing of the magnetic materials. For each stage, specific machinery and the respective operational parameters, such as setup times, throughput, and maximum capacities, must be documented to enable accurate modelling and simulation. In addition, it is crucial to identify the inputs utilized in the workflow, including primary inputs such as recovered magnets, non-recycled magnets, and secondary materials like non-magnetic and plastic components. Quantitative attributes, such as material flow rates, energy consumption per process, and required material ratios, must be analytically provided. These data points are critical for assessing the efficiency and sustainability of several important processes. Moreover, capturing the specifications of intermediate and final outputs is essential to ensure the alignment of production outcomes with desired performance and quality standards.

Analytics

The magnet recycling pipeline contains different points where analytics can be applied allowing to serve different scopes in the pilot. The Spanish pilot use case first relies in obtaining the maximum quantity of magnets for each type of the defined magnet types, and then it has different nodes in the production of pellets where the change of manufacturing parameters can affect the properties of the produced magnetic powder.

In the magnet type prediction use case, data-driven methodologies are going to be used with the data generated from the magnets' extraction at Ferimet, where the WEEE source of the magnet will be recorded in their DPP. This use case will utilize recorded data to generate a classification from each source of WEEE used to extract the magnets and predict the type of magnet contained in the WEEE before it is dismantled. This will be performed by multiclass classification algorithms, that for each type previously extracted WEEE magnets, that will give a probability to recover each type of magnet.

The second use case for data-driven applications in the supply-chain, is the prediction of magnetic properties of the magnetic powder used to produce the pellets. This prediction can be performed based in the initial magnets to be recycled and the different manufacturing parameters. For that, IMDEA supplies manufacturing data not related with the DPP that will be used to train data driven models to predict the final magnetic properties of the magnetic powder and develop an AI assistant for the selection of manufacturing parameters.

For the prediction of the magnetic properties, it is important to acknowledge that AI based methodologies may face limitations due to possible bias in the data and the presence of stochastic factors or hidden variables that are not currently measured. For this reason, the collaboration with a research centre recycling the magnets assure the presence of the required human expertise to validate the results and mitigate any issue identified during the development of the data-driven algorithms and the analysis of their results.

Optimization

Scope: The focal point of optimization in this pilot case is to *reduce the energy consumption of the production line while minimizing the use of raw materials*. In essence, the optimization service operates upon the flow of WEEE within the value chain and decides the optimal operating strategy of different process units. The whole proposal is built around the circular economy paradigm to reduce the amount of WEEE that ends up in landfills. The result is also anticipated to reduce the import of raw materials from abroad by 30% and at the same time to enhance the economic performance of the enterprises involved in this project, by the reduction of imports, resulting in the economic development.

Impact: The optimization model is designed to significantly *improve the overall efficiency of the flow involving three key magnetic materials Bonded Sr-Ferrite, NdFeb, and Sintered Sr-Ferrite, within the waste recycling process. The primary goal is to produce high-quality recycled magnetic pellets.* To achieve this, the waste flow undergoes various processes, including the separation of recyclable, non-recyclable, and hazardous materials. This facilitates the extraction of the targeted magnetic materials from the waste stream. Additionally, the optimization model incorporates the strategic injection of supplementary materials, such as polymeric and plastic components. This is done in order to meet specifications dictated by the corresponding demand. By tailoring the composition of the recycled magnetic pellets, the approach ensures the production of Secondary Raw Materials (SRMs); specifically Specialized Magnetic Materials (SMMs) that possess the exact properties required for the final products. This method aligns the production process with the dynamic demands of the market, guarantees the fulfilment of product requirements, and optimizes the overall recycling flow.

Data Requirements: To evaluate the effectiveness of each category, comprehensive data regarding the quantity and types of magnets present in WEEE is essential. Initially, knowing the *minimal required treatment for each specific type of WEEE to extract the magnetic materials* having the highest usable content is crucial. Subsequently through the IMDEA processes the aim is to leverage innovative and more efficient methods for processing magnetic materials. Thus, it is necessary to gather *information on the energy consumption associated with each device and process per product unit*. Additionally, *details on device settings, operating conditions, and processing costs for the three distinct materials* (Bonded Sr-Ferrite, NdFeb, and Sintered Sr-Ferrite) are essential for a comprehensive analysis. Furthermore, given the blending procedures involved in both IMDEA and IMA, where magnetic materials are combined with different substances like polymers, obtaining *data on quantities and ratios* is vital. This information is crucial for ensuring the production of the correct product that meets quality standards, ultimately contributing to the manufacturing of high-quality permanent magnets.

Supply chain and processes models

The *DT supply chain model* involves all pilot partners, as depicted in Figure 11.

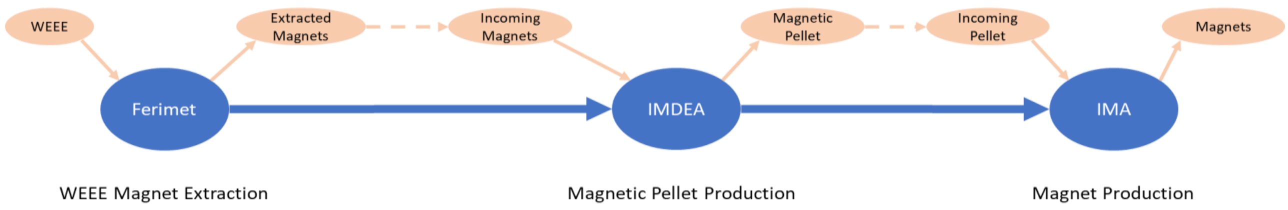


Figure 11: Spanish Pilot DT supply chain model

Table 3: Spanish pilot key processes and roles

Partner	Process	Roles
Ferimet	WEEE Magnet Extraction	Starts the recycling supply chain. Receives WEEE to extract the magnets present in different components.
IMDEA	Magnet Pellet production	Transformation of the raw material (extracted magnets) into a secondary product (pellets).
IMA	Magnet production	Transformation of the secondary product (pellets) into the final product (new magnets).

The supply chain will be modelled using corresponding features presented in the Digital Twin modeller described in Section 5.4.2. The configuration of the supply chain concerns the data to be exchanged among the parties (Task 2.1).

The **DT process models,** based on the processes described in Figure 10, concern essentially the activities performed by IMDEA for the extraction of magnets, and the production of new magnets by IMA, with a focus on sustainable production and maximising the use of SRM. They have been implemented within Task 2.1 and described in D2.3, submitted in June 2024.

3.2 Requirements

A software requirement is a capability needed by the user to solve a problem or to achieve an objective. In other words, a requirement is a software capability that must be met or possessed by a system (or system component) to satisfy a contract, standard, specification, or other formally imposed documentation.

Therefore, *requirements* serve as a formalized expression of the actualities inherent in an IT system, deriving directly from the expectations and demands of the invested stakeholders—those entities that will be the primary beneficiaries or users of the system.

Requirements are categorized by different levels and types resulting in a hierarchy, as represented in Figure 12.

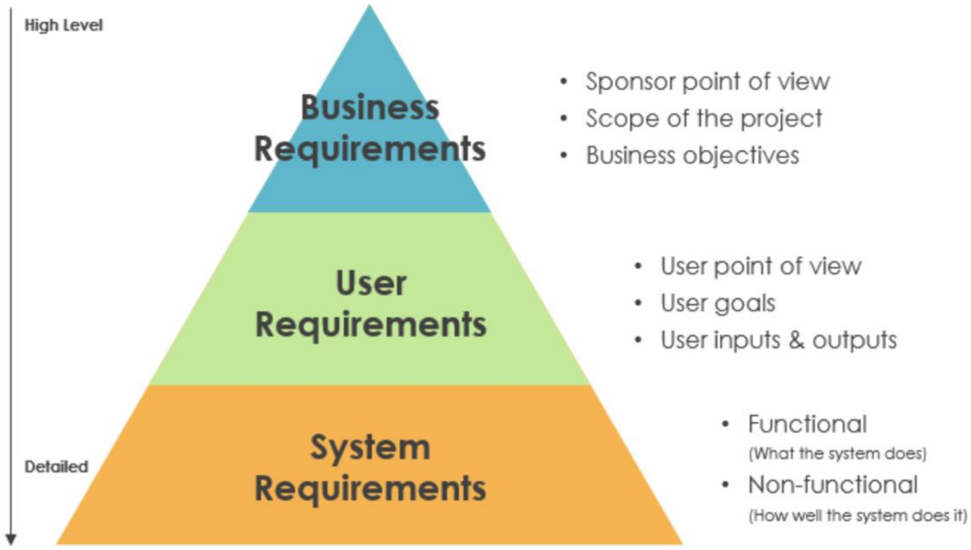


Figure 12: Requirements hierarchy[3]

The first step is to identify the **Business Requirements**. These include statements that represent the *customer point of view*, the scope and the main objectives and provide a high-level description of the system to be implemented. This initial vision is further detailed in **User Requirements**, addressing the *user point of view*. At this level the focus is more on operational aspects, describing how the user wants to use the system, what the user's goals are and the data that needs to be managed.

User requirements, which are usually expressed in natural language, need to be transformed into **system requirements** that are classified into two categories: **Functional requirements**, which elucidate the expected behaviour and the functionalities the system must offer to fulfil the user needs and desires, and **Non-functional requirements**, which transcend the functional aspect of the software. Non-functional requirements articulate specific criteria that can be employed to assess the system's performance, security, and availability, among other factors.

In the scope of this deliverable, the "business view" is that of the central platform that needs to satisfy different "customers" with different needs.

Therefore, this deliverable does not detail the business functionalities requested by a specific user, rather it aims to look at more general user needs that should be fulfilled in CRIS (Plooto platform).

The description of the pilot cases, which can be regarded as an expression of user requirements, allows to derive the **Functional requirements** that will be implemented as functionalities that the platform should expose to allow the execution of pilot scenarios. On the other hand, the existing constraints and required performance, as well as the specific horizontal functionalities and their

[3] https://www.visual-paradigm.com/project-management/different-types-of-requirements

communication protocols provided by technical partners, allow to specify **Non-Functional requirements**.

The **Functional** and **Non-Functional** requirements have been identified through the analysis of the pilots' needs and the proposed use of the tools and technologies provided by the project. They are reported in Table 4 and Table 5 respectively.

Table 4: Functional Requirements

Id	Requirement	Priority	Pilots
FR-01	The user should be able to establish and manage collaborations with other partners within the supply chain.	High	Italian Spanish
FR-02	Data exchanged among partners should be maintained in a secure way. Users should have access only to the information and features that are relevant to their case.	High	Italian Spanish
FR-03	The user should be able to use/combine tools/ technologies that locally available.	High	All
FR-04	The user should be able to define processes that eventually combine services and tools from different providers.	High	All
FR-05	The user should be able to monitor internal processes, having real-time information.	High	All
FR-06	The user should be able to use and integrate different types of assets.	High	All
FR-07	The user should be able to simulate the production process based on his/her defined parameters.	High	All
FR-08	The user should be able to simulate parts of the production process.	Medium	All
FR-09	The user should be able to execute process optimization scenarios based on his/her defined parameters.	High	All
FR-10	The user should be able to optimize the supply chain.	High	Italian Spanish
FR-11	The user should be able to use analytics services to gain insight about the processes and possible improvements.	High	Italian Spanish
FR-12	The user should be able to assess the production process and detect environmental hotspots and/or potential areas for improvement through LCA.	High	Greek
FR-13	It should be possible to compose the Digital Product Passport aggregating data from different processes.	High	All
FR-14	The Digital Product Passport should be maintained in a secure way, and it should be publicly available.	High	All
FR-15	The agreements among the parties in the supply chain should be managed within the platform	High	All
FR-16	It should be possible to create a catalogue as a collection of assets.	High	Italian
FR-17	It should be possible to modify telemetries of an asset (e.g., the quantity of a given LOT when only partially used).	High	Italian

Id	Requirement	Priority	Pilots
FR-18	It should be possible to link/connect/integrate tools to measure energy efficiency.	High	All
FR-19	It should be possible to link/connect/integrate tools that allow some forms of optimization.	High	Italian, Spanish
FR-20	The platform should support life cycle management and / or circular practices.	High	All
FR-21	The platform should provide/connect/integrate tools that can measure environmental impact.	High	All
FR-22	The platform should provide an intuitive user interface (UI) that allows the declaration of external services.	High	All
FR-23	The platform should be able to handle different services protocols (e.g., REST, GraphQL, SOAP).	High	All
FR-24	The platform should allow easy configuration of the service (input/output/ rendering options).	High	All
FR-25	It should be possible to use different data formats (JSON, XML, etc.).	High	All

Table 5: Non-Functional requirements

ID	Requirement	Priority
NF-01	The platform should be able to connect with external systems (mobile apps, legacy systems, open data sources etc.).	Low
NF-02	The platform should have UI customization features and offer customization display capabilities.	High
NF-03	The platform must be able to generate and send notifications and alerts.	High
NF-04	The platform must grant user-based and role-based access through secure protocols.	High
NF-05	The platform should be compliant with Data Spaces.	High
NF-06	The platform should be able to connect with external party's trough IDS-Connectors.	Medium
NF-07	The agreements (smart contracts) among the parties in a supply chain should be securely stored.	High
NF-08	It must be impossible to tamper the agreements (smart contracts) among the parties in a supply chain.	High
NF-09	The platform should provide access to the different modelling tools.	High
NF-10	The platform architecture should be modular, adaptable an easily maintainable, thus composed of distinct and independent components.	High
NF-11	Modularity metrics for the CRIS platform should be defined and measured. CRIS should rank within the top 10% of modularity metrics.	High
NF-12	The platform should be capable to adapt to evolving technologies and evolving/emerging users' needs, therefore highly compatible.	High
NF-13	New versions of the platform should not introduce disruptions in the functioning of previous features (100% backwards compatibility).	High

ID	Requirement	Priority
NF-14	The platform should provide mechanisms to interoperate with external systems (legacy systems, third-party tools, or newer technologies).	High
NF-15	Authentication and access control of external services should be managed by the platform.	High
NF-16	Service documentation should be made available through the platform.	Medium

4 Information modelling framework

This section reports the work done in Task 1.3 (led by UiO) to formalize the Information Modelling Framework (IMF) language that will be applied to the different pilot cases of Plooto. IMF is an intermediate language meant to be used by Engineers to model systems and, by extent, to facilitate the creation of formal ontologies for those systems without the need-to-know ontology modelling, which has been proven very challenging and difficult to be used by regular production engineers.

In Plooto, IMF is used to capture the semantics and specifications of the DPP, by creating the semantic model of Plooto and the ontology for the pilots. This ontology, when populated with the pilot data, will create the knowledge graph, which then can be used by the rest of the project partners for various reasons such as semantic interoperability and formalization of the DPP.

IMF was selected over other tools as it is an engineering-friendly language allowing engineers to create models using their own language. The created models can then be translated into a formal ontology.

The scope of the IMF models is to capture the basic entities of the pilots and their connections. Once the IMF models reach a certain level of maturity, they are going to be transformed to a formal ontology that can be used from the different partners. Once the ontology is produced, it will be populated with the Pilot data that will produce the knowledge graph. During the first year, the focus of the modelling efforts was limited to Spanish pilot, since the IMF language was still under development. During the second year, the IMF models for the Italian and Greek pilots have been completed and reported in the following sections.

For more details, and to improve the readability of the deliverable, IMF basic principles are presented in

Appendix A: Introduction to IMF – guidelines.

4.1 Spanish pilot modelling

The Spanish pilot illustrated in Figure 13 consists of 3 nodes (aka partners). Each node has a different role and different products. The Spanish pilot has served as a model to understand how the IMF language can be used in Plooto. In the first version of this deliverable a first draft version of the "Product" and "Function" aspects have been created. Those models were a preliminary form of the final models, as the models are continuously updated using information collected from the different Plooto partners. In this version the final forms of IMF models for the three pilots are presented. For completeness the initial models are attached at the end of Appendix C: IMF models for the Spanish pilot.

Figure 13: Spanish pilot nodes and products

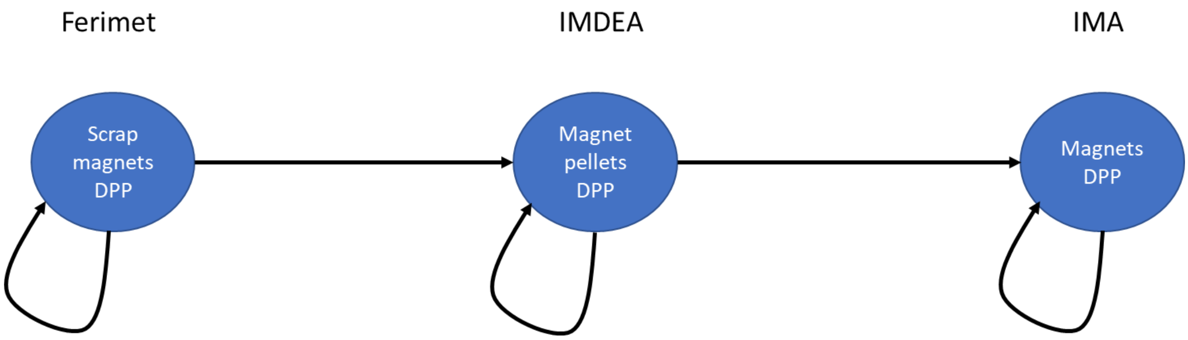


Figure 14: Data aggregation for the DPP

In engineering practice, it is typical to describe systems from different points of view, usually from the views of physical artefacts, activity, and location. IMF is a language designed for describing systems from such different points of view, which we refer to as "aspects". The notion of aspects is essentially the context of modelling that needs to be clarified before modelling, e.g., whether it is about the physical artefact or about the activity, what the purpose of the modelling is, and who the users are. Note that the aim of IMF language is to describe systems, not to define systems.

- The Function Aspect (yellow) is to specify the intended activity, e.g., the information about activity, performance, and function of a pump.
- The Product Aspect (cyan) is to specify the intended solution of a set of physical artefacts to perform the activity, e.g., the information about the physical artefacts of the pump.

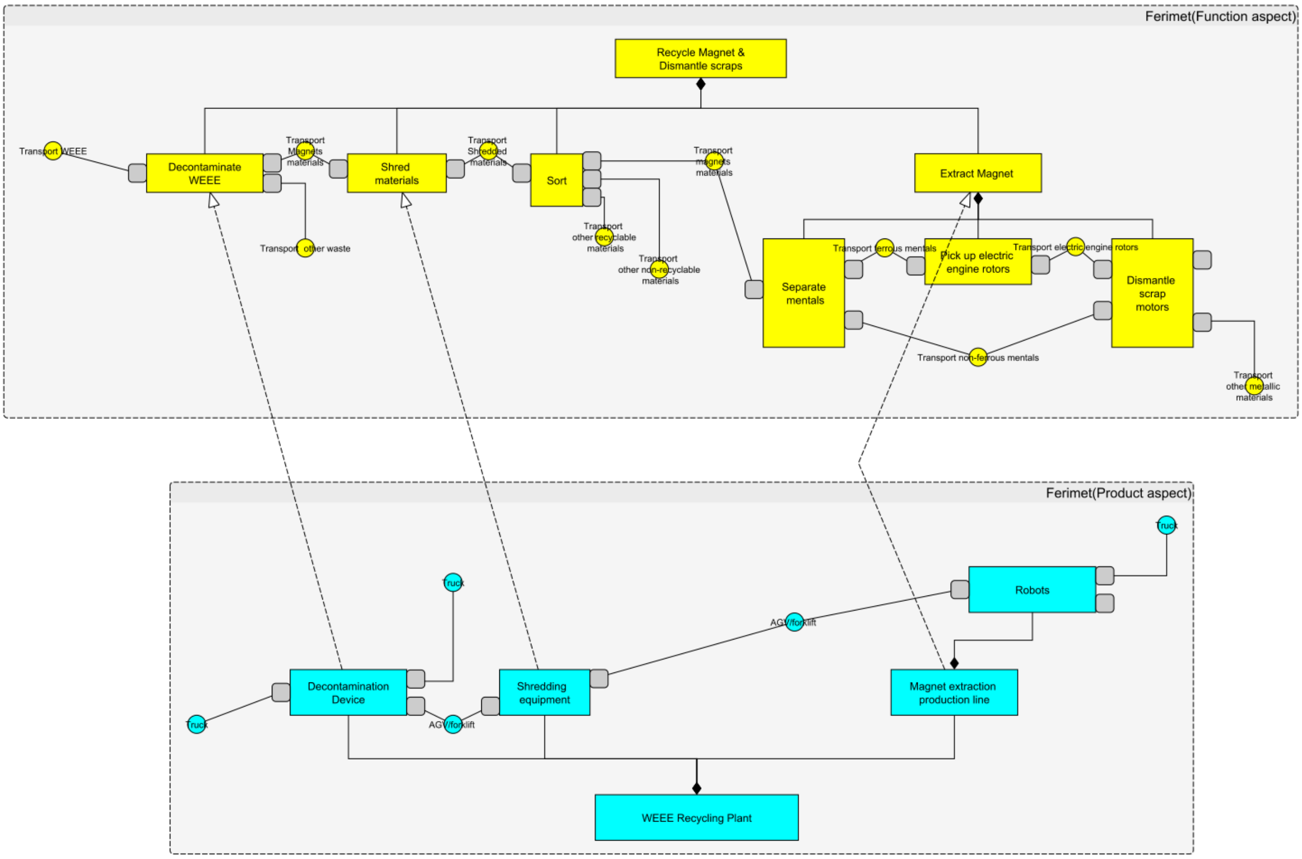


Figure 15: IMF Model Spanish pilot - Ferimet

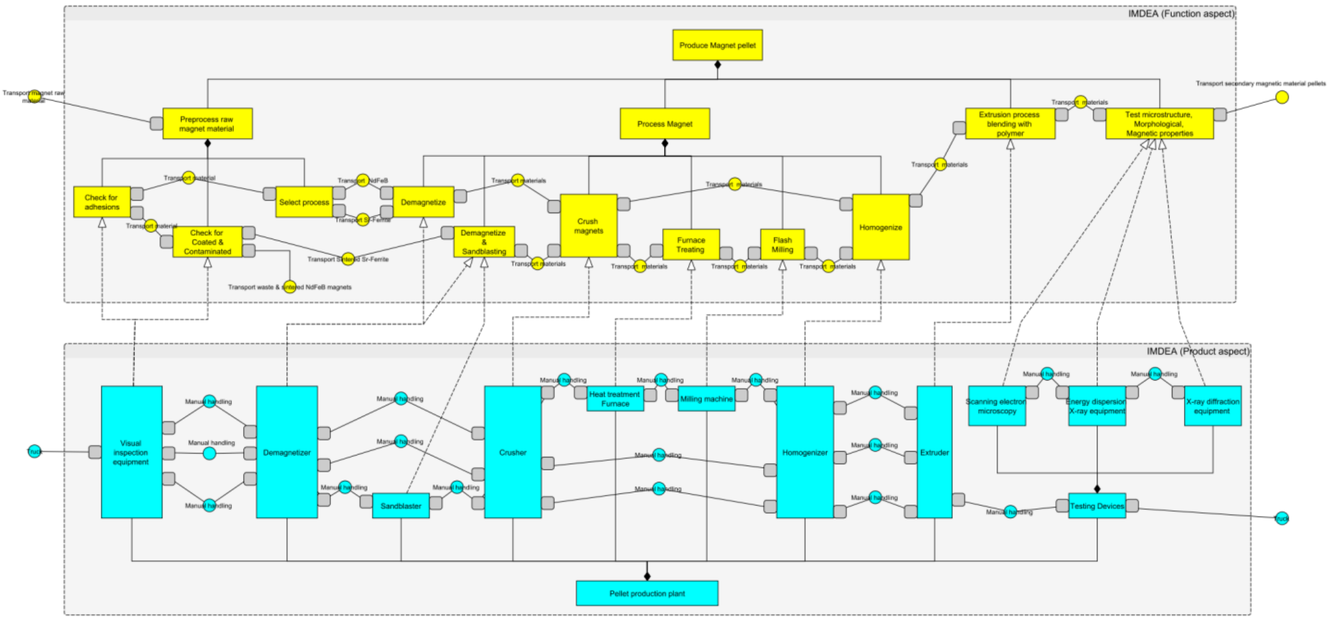


Figure 16: IMF Model Spanish pilot, IMDEA

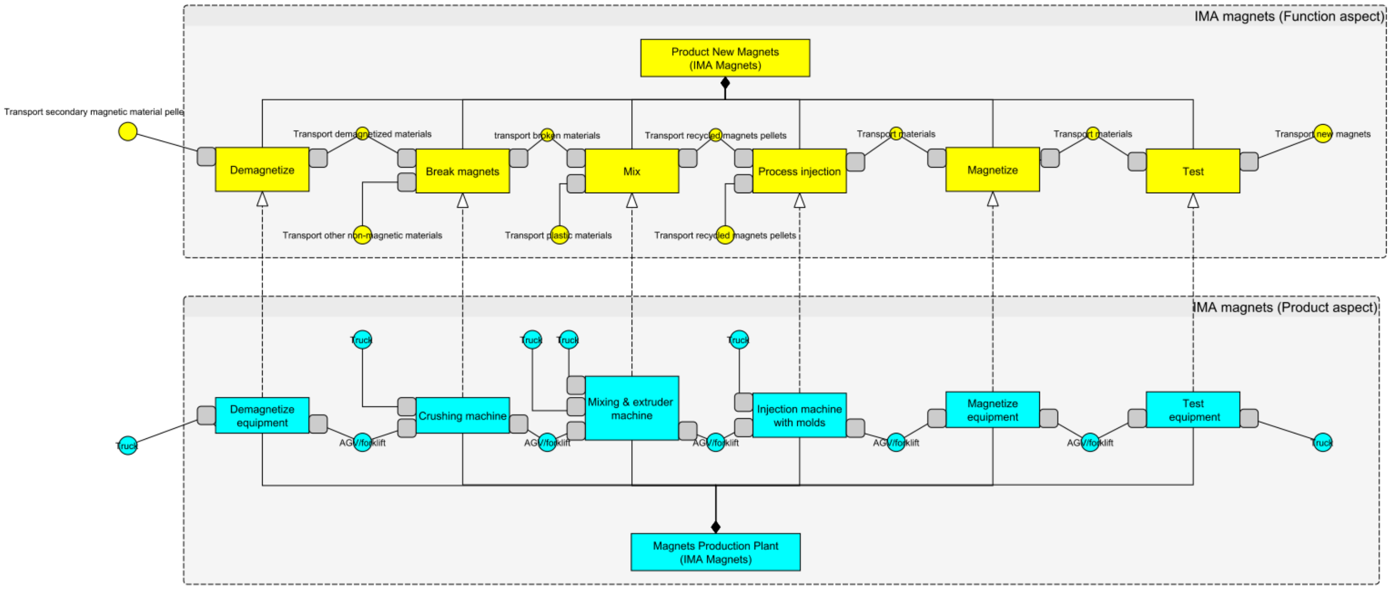


Figure 17: IMF Model Spanish pilot, IMA

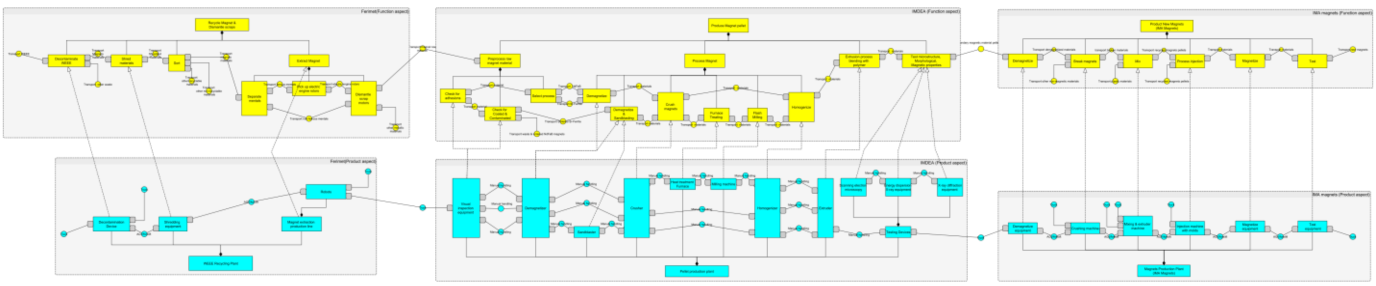


Figure 18: IMF model Spanish pilot, Whole value network

All diagrams are reported in larger scale in Appendix C: IMF models for the Spanish pilot

4.2 Italian pilot modelling

The Italian pilot illustrated in Figure 4 consists of 4 partners. Each of the nodes has a different role and different products as described in section 3.1.1. Using the IMF language, and following the same approach used for the Spanish pilot, the IMF models were created. These include detailed partner-specific and value chain diagrams. The latter are included hereafter, in particular, Figure 19 presents the overview of the main actions carried out along the value network, while Figure 20 provides additional details, specifically, it focuses on the tools that will be used in the different process.

To improve the readability of the deliverable, all diagrams are reported in a larger scale Appendix D: IMF models for the Italian pilot.

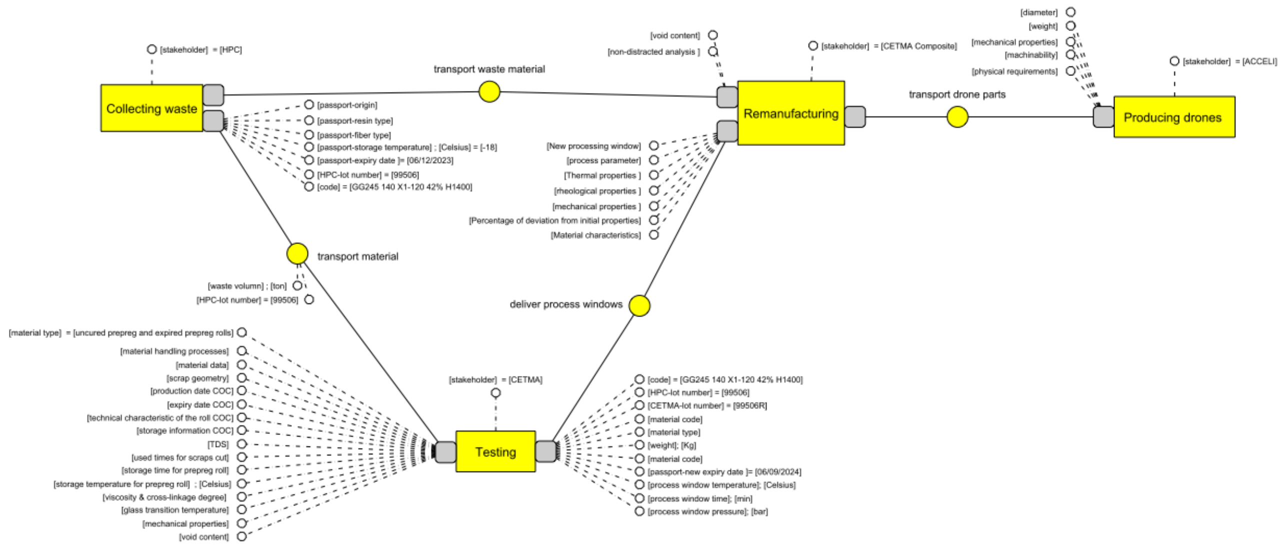


Figure 19: IMF Model Italian pilot - Overview

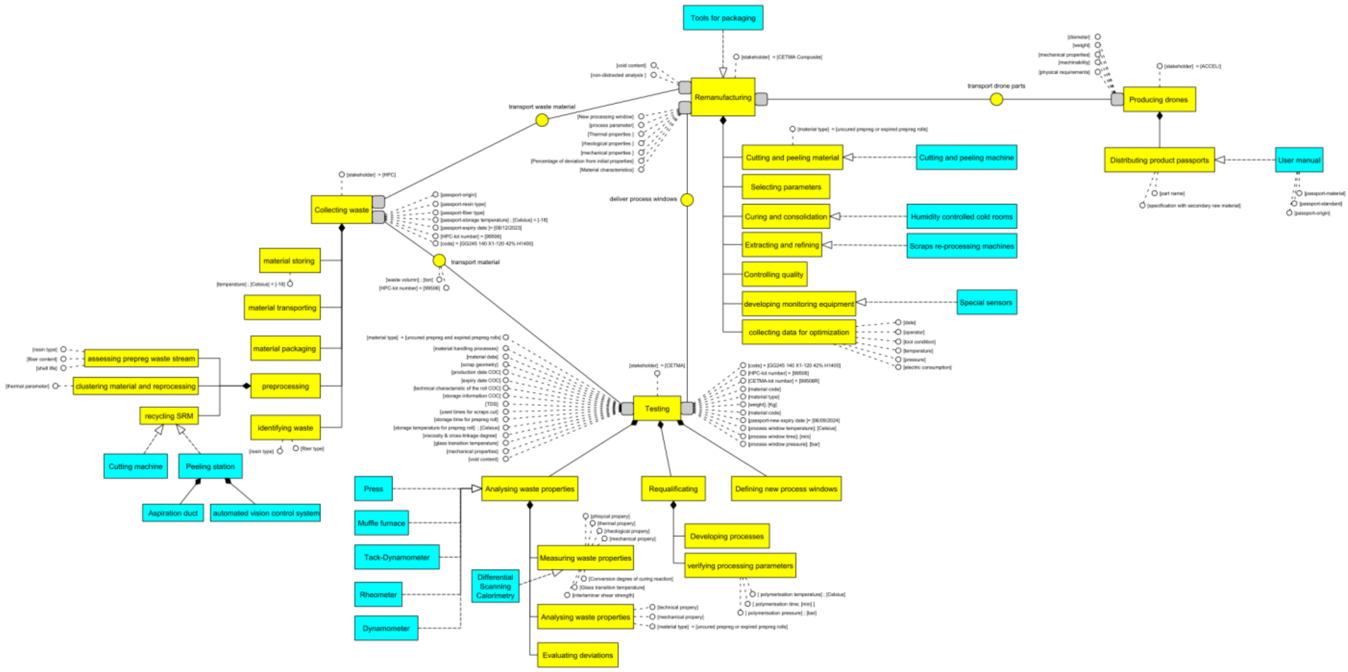


Figure 20: IMF model Italian pilot. Detailed view of the whole value network

4.3 Greek pilot modelling

Similarly, for the Greek pilot, which concerns only ASPIS, the IMF models have been created using the same approach used for the Spanish and Italian pilots. Figure 21 provides an overview of how the process has been broken down in blocks, while Figure 22 represents the detailed view of the whole process.

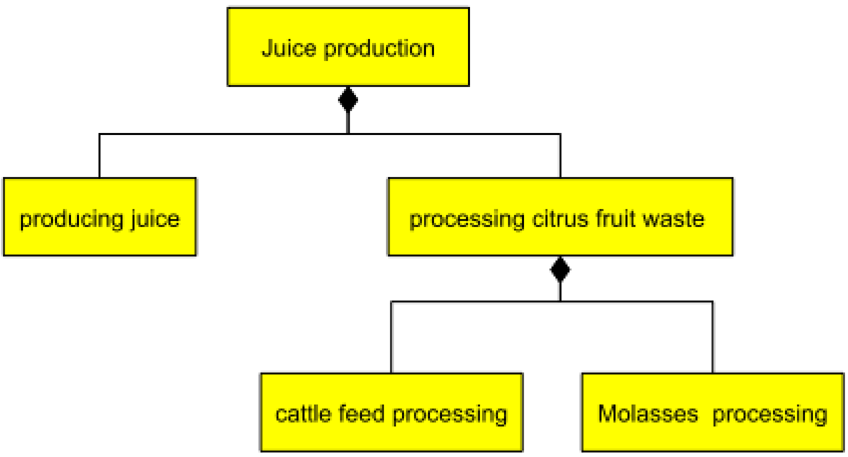


Figure 21: IMF Greek pilot process breakdown

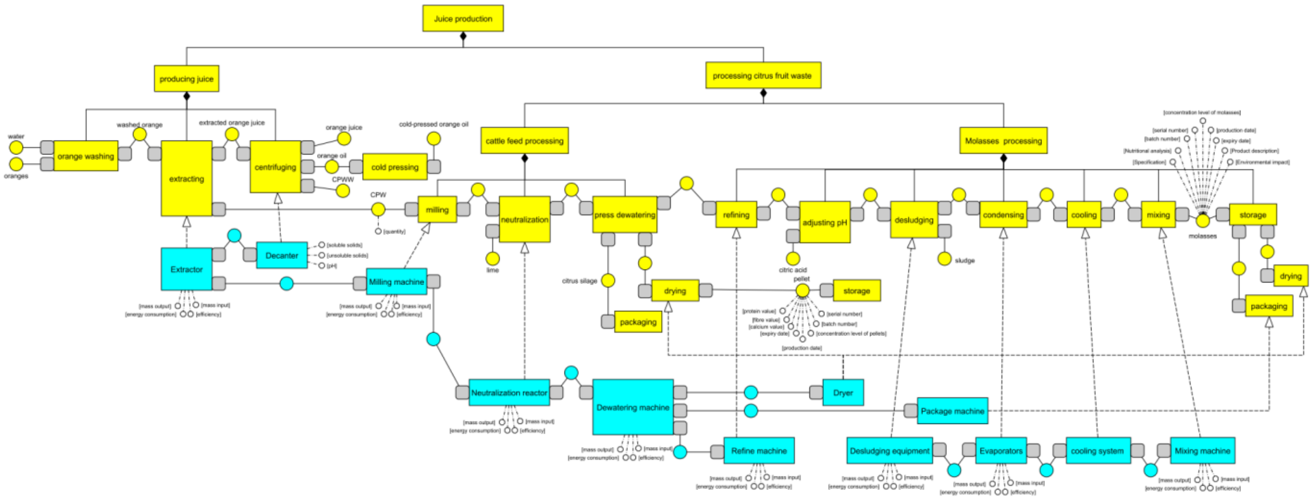


Figure 22: IMF model Greek pilot. Detailed view of the whole process

To improve the readability of the deliverable, all diagrams corresponding to the individual blocks Figure 21 are presented in a larger scale in Appendix E: IMF models for the Greek pilot

5 Architecture

CRIS aims to provide the environment where pilot users can model their system, monitor and operate the needed features (simulation, Optimization, analytics), trace resources and materials involved in the production, aggregate relevant product information in the Digital Product Passport (DPP), and finally assess and measure the efficiency and the different KPIs. The DPP is an artefact that follows the production throughout the supply /value chain. The needed information at each of the production steps is aggregated in a digital structure that will be secured and made available to the final customer. CRIS is an integrated system, in the sense that components, tools, and information stored in different subsystems and brought together into a single functioning unit.

The initial requirements have been analysed to construct the first draft of a layered architecture layout that is presented in Figure 23.

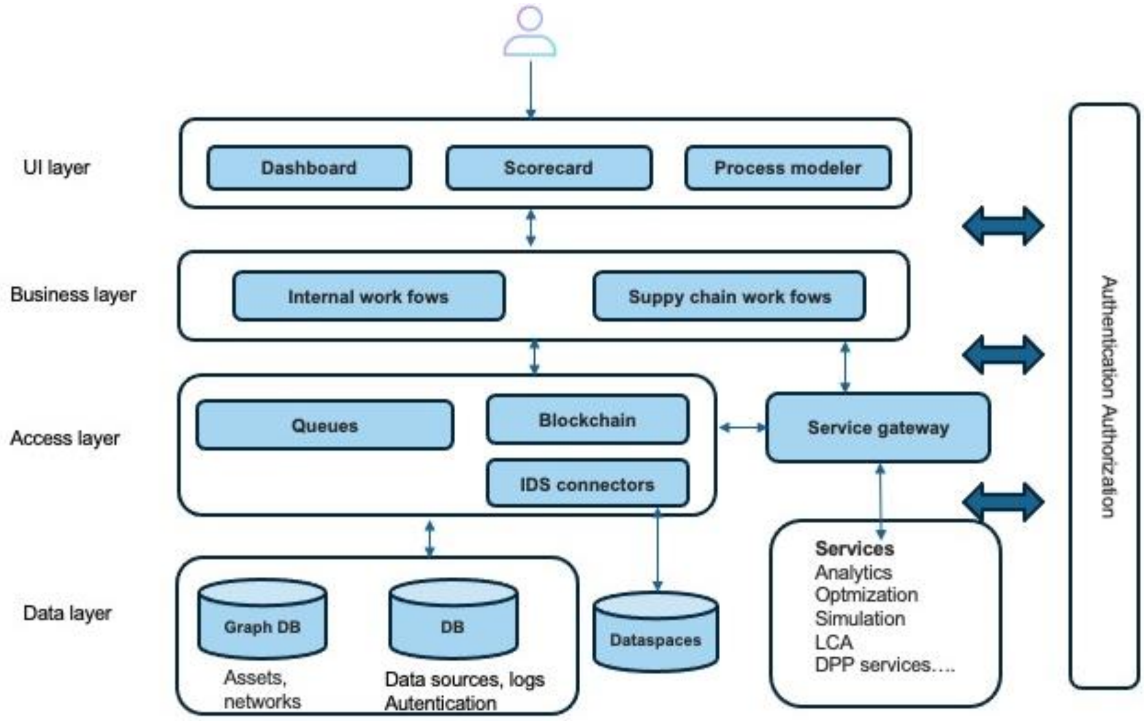


Figure 23: CRIS architecture, layered view

In the second year, the expected targets for CRIS performance — more specifically in relation to software compatibility and adaptability, linked to KPIs 2.2 and 2.3 — have been addressed. Additionally, CRIS's compliance with green and sustainable IT systems, as well as the use of digital twins for sustainability, have also been considered.

In order to avoid altering the structure of the present document, the work done during the second year is reported in Section 5.8.

5.1 Overview

CRIS architecture comprises four major layers: User Interface (UI), Business layer, Access layer, and Data layer. These layers are an aggregation of components / modules / tools, which provide functionalities that can be logically related. The architecture also includes horizontal features to manage the access to the platform (i.e., authentication/authorization). The service gateway is a logical component that allows the smooth integration of services provided either by the technical partners or – in the future – by third party providers. Finally, the architecture is designed to be compliant with Data Spaces – as an additional collaboration/data exchange channel – and blockchain for the secure maintenance and management of relevant data. Each layer and its modules are described in the following sections.

CRIS is built upon **MIRA**, a Digital Twin enabler platform developed by MAG in previous EU projects (i.e., FACTLOG, TREEADS and AquaSPICE). This platform is not a commercial solution but rather the first set of building blocks that are further enriched with additional components that implement the features needed by Plooto pilots and integrates the added value services that will be developed in WP2.

5.1.1 Authentication /Authorization

This layer aggregates the features implementing Identity Access Management (IAM) in Plooto. These two concepts are crucial to safeguard digital systems and sensitive data, thus ensuring the integrity, confidentiality, and availability of resources within the Plooto ecosystem.

Authentication is the process of verifying and establishing trust in the identity of an entity attempting to access the system. Authentication methods vary widely, encompassing something a user knows (such as passwords or PINs), something they have (like smart cards or security tokens), or something they are (biometric data such as fingerprints or facial recognition).

Authorization, on the other hand, determines what actions or resources an authenticated user is allowed to access or manipulate, ensuring that users are only able to perform actions or access information that aligns with their designated level of authority within the system. Authentication is responsible for granting or denying specific permissions, based on the authenticated user's roles, privileges, or attributes.

Together, authentication and authorization form a robust security framework that helps mitigate the risk of unauthorized access or misuse of sensitive information and helps maintaining the confidentiality, integrity, and availability of digital assets.

Authorization can be implemented following different strategies, depending on the specific requirements, complexity, and security goals of a given system or organization. The most used strategies to control access to digital resources are: *User-based authorization,* which grants permissions to individual users, and *Role-based authorization*, which grants permissions to predefined roles, for instance job roles, or position in a team. The first offers a higher granularity, but it also comes with a higher administrative burden, while the second simplifies management but might lack precision.

In CRIS, a combination of these two strategies will be used, thus ensuring a balance between flexibility and simplicity in access control while creating a comprehensive and effective access control framework and enhancing overall security in diverse digital environments.

5.1.2 User Interface layer

The user interface layer comprises visual tools that allow the user to have access to resources and to operate on assets and procedures.

From a functional perspective, the UI serves three main purposes; i) it provides the core features to model the pilot ecosystem in terms of interconnected Digital Twins, and to specify the assets to be monitored and the KPIs to be measured; ii) it provides the operational environment where pilot operation are executed; and iii) it provides access to supportive tools developed within Plooto (e.g., PSM tool where to simulate alternative configurations, or the Sustainability Balanced Scorecard (SBSC) to assess the impact of the process according to different parameters.

5.1.3 Business layer

The Business layer is where users can define and monitor their pilot in terms processes, and eventually in terms of supply chain.

MIRA, which is at the foundation of CRIS, provides the modelling features to design processes and supply chains. A process, designed with the PSM tool, can be modelled as a network of interconnected DTs, each having its characterizing properties, telemetries that provide data supporting the monitoring phase, and associated services (e.g., simulation, optimization, analytics, etc.).

The *Digital Twin consortium* provides the following definition "A digital twin is a virtual representation of real-world entities and processes, synchronized at a specified frequency and fidelity".[4]

This concept establishes a biunivocal relationship between the digital twin and its physical counterpart. Besides providing real-time information on the status of the DT, this synchronized biunivocal relationship allows to manipulate the structure and behaviour of the virtual object as in case of real object, for instance using appropriate services to simulate and predict the behaviours of the physical world.

The state of the physical system is reflected in the digital system and vice versa.

[4] Digital Twin Consortium (2023). Definition of a Digital Twin.

Although Digital Twins were initially associated to sensors and machineries, their applicability can be expanded to include people, organizational entities, services, and processes.

This more general concept, which can be referred as Digital Asset (DA), allows to use the DT approach to potentially everything and it is this concept used in CRIS. Therefore, the supply chain can be designed as interconnected DTs, defining the connection points and the data to be exchanged. However, in this case, additional precautions concerning data ownership and visibility need to be put in place.

Once the processes - and eventually the supply chain - have been modelled, the user can customize the home page in order to highlight the aspects that need to be monitored. The business layer is in fact connected on one hand with the Access Layer, which provides the mechanism to access data, and on the other hand with the Service gateway, which enables the user to invoke the needed services.

5.1.4 Access Layer

The Access layer contains all the components to access the actual data. These include:

Queues (e.g., RabbitMQ): these are used to collect requests or data from the outside, enqueue them before they are consumed, associated them to telemetries and stored them in the appropriate data bases.

Blockchain: This is a decentralized and distributed ledger technology that enables secure and transparent recording of transactions across a network. Due to its main characteristics (decentralization, transparency, and immutability), blockchain is the technology used to store data that requires more stringent security. The most significant characteristics of Blockchain are: *Data immutability* – which ensures that no data is corrupted. *Decentralization* – meaning that no authority or government, nor a group of persons, controls the entire network. *Transparency or provenance*: which ensures that every transaction can be traced from start to finish. Blockchain is based on the peer-to-peer protocol and each transacting entity is represented by a peer in the network.

IDS connectors from International Data Spaces Association (IDSA). These are increasingly proposed in multiple domains around Europe. In Plooto project, this component will serve as: a) an alternative channel for the incorporation of data stored in legacy systems of the pilots, b) an additional method for discovering assets, negotiating collaborations, and exchanging data with external partners not using Plooto and c) a clear way of integrating external data of future Plooto users into the ecosystem, without having to build custom software components to align with the systems. The second case facilitates data exchange, while the other two facilitate data ingestion.

IDS Connectors facilitate secure data access by only allowing data access on the basis of bilateral agreements, explicitly stating who has access to which data, and under what constraints. These architectural elements pose limit the movement of data in the data space, which guarantees data sovereignty and compliance with commonly accepted industry standards.

In the context of a digitally enabled circular economy, traceability and digital passports are of the utmost importance. Integration multiple data sources through IDS connectors ensures that critical information is exchanged in a timely and reliable manner in a business ecosystem. IDSA-compliant connectors, coupled with digital twin infrastructure, can provide the basis for fair data access, promoting cooperation among businesses, and enabling the development of innovative solutions in a competitive, yet collaborative environment.

To support the above functionality, IDS connectors are designed as complex, decentralized components that, in the context of Plooto, will be demonstrated in the different services and data storages. We plan to focus our efforts on both existing open-source and in-progress software solutions, adapting them to better fit the pilot needs.

5.1.5 Data layer

Data bases: The data layer contains all the databases, CRIS utilizes different types of data bases: graph-based data base, for instance Neo4J, is used to store information about the DT models and it maintains the graphical representation. While other types of data bases (e.g., SQL, NoSQL, or document-based) will be used to store other types of information and data, for instance transaction logs, authentication/authorization, or data characteristics of the pilot's assets and telemetries.

Dataspaces: Dataspaces have rapidly become a critical component of the data layer in businesses around Europe, and are also supported by the European Commission's vision of a unified market for data. A dataspace, is a virtual data sharing environment, which enables the direct exchange of data between businesses. Additionally, data spaces facilitate the exchange of information across the value chain, engaging various stakeholders such as research institutes, industries, and consumer associations.

In the scope of Plooto, no user data will be duplicated. All actual information is stored in various databases of the system, while dataspaces will be used as a mean of external data integration or collaboration mechanism with partners that have no access to the Plooto ecosystem. Utilizing a stable set of protocols, external partners will be able to discover, negotiate and share data with Plooto users, with dataspace connectors acting as standardized equivalents to custom APIs. Similarly, current or future users of Plooto will be able to seamlessly integrate their data from legacy systems or current solutions, a task that would otherwise require custom software development and integration.

5.2 Architecture Components

Figure 24 provides an overview of the main components of the CRIS architecture, which are briefly described in the following paragraphs.

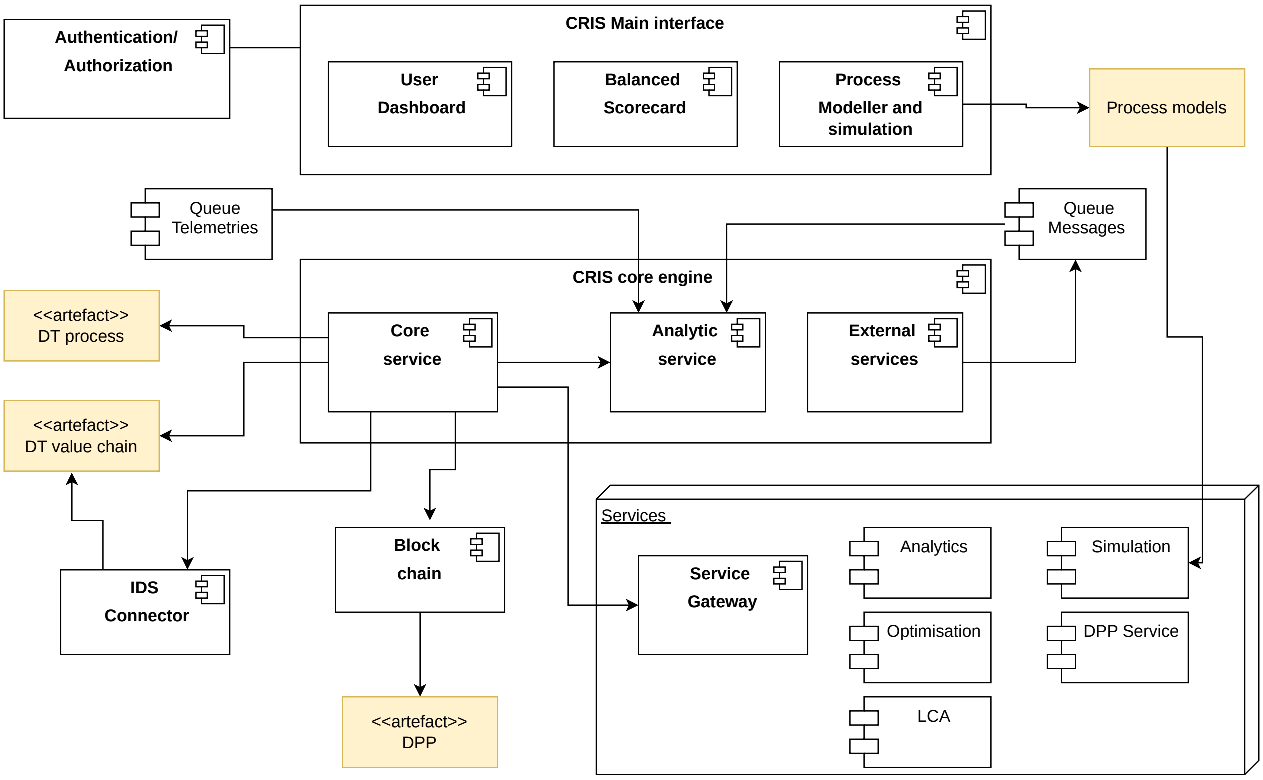


Figure 24: CRIS architecture - Component diagram

During the second year, the technical activities impacting the architecture involved the development and integration of services. In particular:

- the Analytics, Optimization, and Simulation components have been specialized for the different pilots.
- The DPP component has been further detailed defining the mechanisms allowing implementation of the DPP Templates, which provide the structure for the DPP instances, and the features - embedded in Plooto - that generate the DPP instances as a result of the Value network collaboration (See Section 5.6 for further details).

5.2.1 Service Gateway specification

During the second year of the project, the Service Gateway has been designed and developed to provide a uniform mechanism and a central point for managing external service integration. The service gateway is intended to enable the configuration and integration of external services into the users' environment.

The key requirements for the design of the service gateway are described below.

The platform should provide an intuitive user interface (UI) that allows users to include services, by performing the following steps:

- Declaration – Users declare the service to be included by providing basic service details and identifiers.
- Configuration – Users define the service settings, including:
    a. the access control - roles and permissions applied to the service,
    b. the required input - format and structure of the input data,
    c. the expected output - format and structure the service's output,
    d. the rendering mode - the visualization or presentation mode of the service output within the user's environment.
- Loading – the platform makes the configured service available in the user's environment,
- Validation – the platform allows to verify that the service operates correctly, and that the output is generated and appropriately rendered within the user's environment.

The platform should manage authentication and access control to ensure secure integration of any external services.

The platform should be able to handle different protocols (e.g., REST, GraphQL, SOAP) and data formats (JSON, XML, CSV, etc.), ensuring compatibility with diverse external services.

The functional and non-functional requirements for the service gateway, as described above, have been formalized in Table 4 and Table 5 respectively, developed within task 3.3, and will be documented in D3.4.

5.2.2 Analytics component specialization

Figure 25 provides an overview of how the Analytics component has been specialized to fulfil the needs of the different pilots.

Logically the components comprise the analytics services for the Greek pilots (2), those for the Spanish pilot (3) and those for the Italian pilot. The corresponding services are detailed in the corresponding pilots stories (Section 3.1) and in the Analytic service description below (Section 5.5.2).

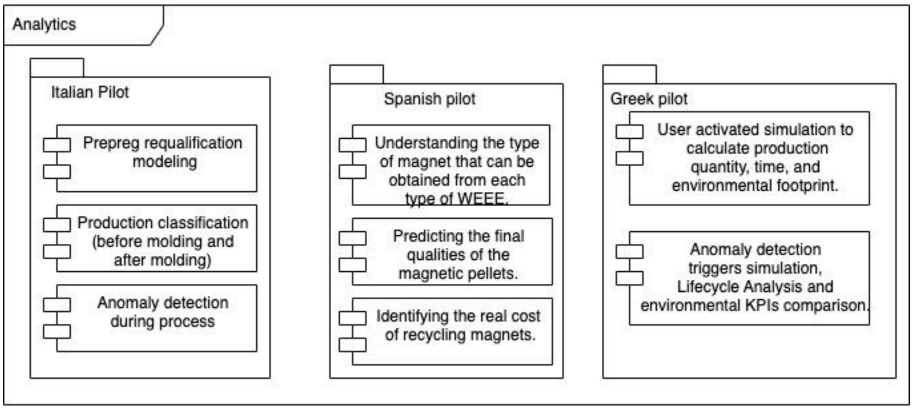


Figure 25: Analytics component specialization

5.2.3 Optimization component specialization

Similarly, Figure 26 provides an overview of how the Optimization component has been specialized to fulfil the needs of the Italian and Spanish pilots. The corresponding services are detailed in the corresponding pilots' stories (Section 3.1).

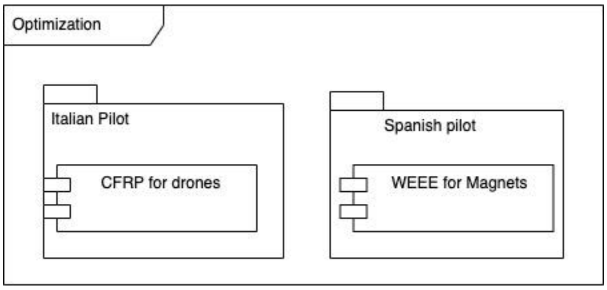


Figure 26: Optimization component specialization

5.2.4 Simulation component specialization

Finally, Figure 27 illustrates the specialized adaptation of the Simulation component that addresses the unique requirements of each pilot by leveraging pilot-specific PSM. These models provide a detailed representation of the multi-actor value chains, capturing inputs, outputs, and energy flows that will be used to optimize resource efficiency, enhance sustainability, and support scenario-based decision-making across diverse operational stages. The arrows inside each pilot's package indicate the natural flow of the simulation along the value network. The corresponding services are detailed in the corresponding pilot sections (Section 3.1).

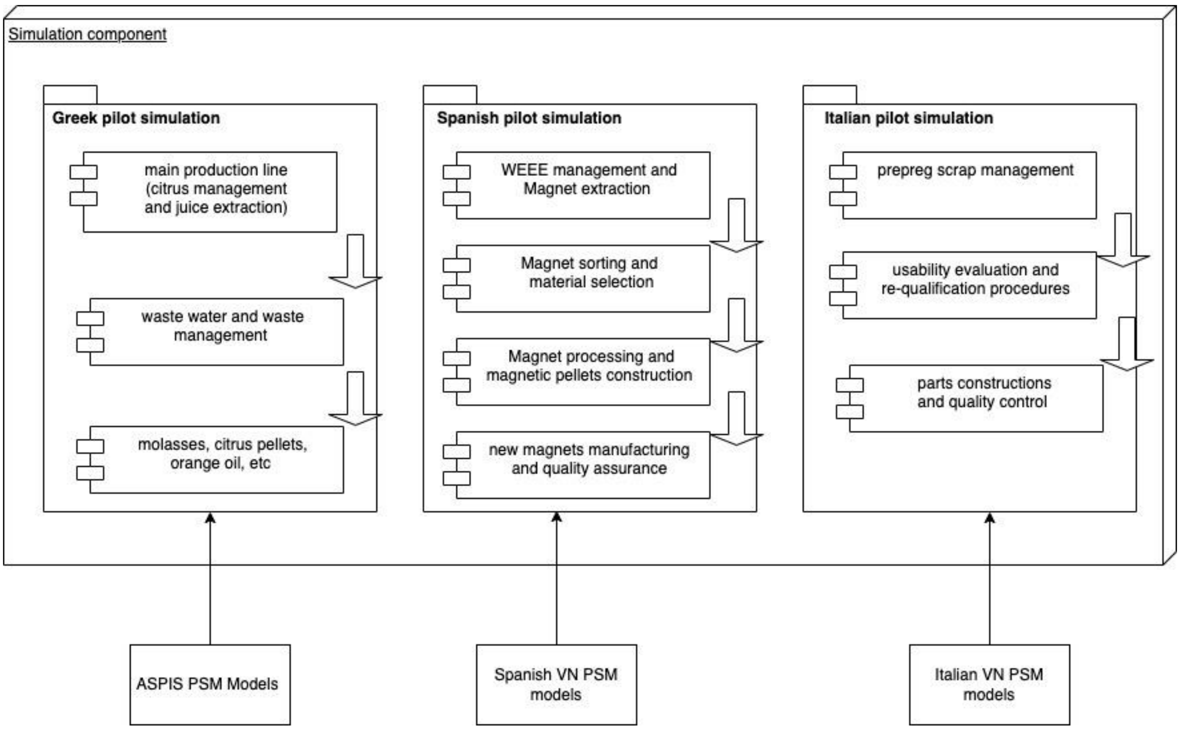


Figure 27: Simulation component specification

Understanding the characteristics and communication mechanisms of the different services, has been essential to formalize the requirements and develop the Service Gateway.

5.2.5 Authentication /Authorization

CRIS Identity and Access Management (IAM) authentication will be based on Keycloak[5], an open-source IAM solution designed to secure applications and services. The user credentials are stored in a PostgreSQL database. The Keycloak features relevant to Plooto are:

Single Sign-On (SSO): Enables users to log in once and gain access to multiple applications without needing to log in again, thus enhancing user convenience and security.

Authentication and Authorization: Offers flexible authentication mechanisms and supports fine-grained authorization policies, ensuring that users have the proper level of rights to access the resources

Token-Based Security: Utilizes tokens (such as JSON Web Tokens or JWTs) for secure communication and access control between applications and services.

5.2.6 CRIS Main Interface

This logical block aggregates the modalities to interact with the system: the dashboard, the Process Modeller and Simulation tool and the Sustainability Balanced Scorecard tool.

Dashboard

Represents the main user interface to the system. It is one of the native features provided by MIRA, allowing the modelling of the ecosystem in terms of Digital Twins and the operational monitoring and management of the user ecosystem. Users need to define the system they want to manage in terms of digital assets, networks and relationships, and define the processes to be managed. The dashboard can be customized to align better with the monitoring or operational needs of the user (for instance to connect to specific services, or to monitor relevant KPIs).

Sustainability Balanced Scorecard tool

The main webpage embeds the SBSC tool, which is based on the Plooto Sustainability and Governance Framework and allows monitoring of KPIs supporting an informed decision-making. A detailed description of the tool is provided in Section 5.4.3.

Process modeller and simulation tool

The main webpage embeds the PSM tool, which allow users to describe their internal processes and run simulations and what-if scenarios. A detailed description of the tool is provided in Section 5.4.1.

[5] https://www.keycloak.org

5.2.7 CRIS main engine

Core service

It is the core component of the platform that manages all requests coming from the users, propagates them to the appropriate CRIS service, and returns the responses that are rendered into the dashboard. The Core service manages the user business logic of the application concerning Networks, Assets, their relationships, and the processes the assets are involved in.

Analytics service

This service is responsible for batch-consuming messages from the telemetry logs queue and for storing the data in a database. This feature is propaedeutic for generating analytics. Users can post data regarding a given Data source to that queue. It can be used to send data streams related to a given telemetry or a group of telemetries.

External services

This component consumes messages sent by the Core service to Queue messages. It is used to send alerts and notifications via email to the involved stakeholders.

Queues

CRIS main engine uses two distinct queues: **Queue messages** consumed by the External service, and the **Queue telemetries** consumed by the Analytics service.

5.3 Connectors

5.3.1 IDS-Connector

The IDS-connector plays a pivotal role in enabling secure and trusted exchange in Plooto's distributed environment. The connectors aim to provide a standardized interface for the establishment of agreements with external partners, thereby ensuring data sovereignty. They enable interoperability among diverse systems and platforms, allowing seamless data exchange while adhering to predefined rules and policies.

We plan to use the Eclipse Dataspace Components (EDC)[6] as a framework for sovereignty and inter-organisational data sharing. In addition to the IDSA protocols, these components implement the IDS Dataspace Protocols (DSP), and relevant protocols associated with GAIA-X[7]. The existing Eclipse software will be extended and adapted to meet the specific needs of the pilots, while maintaining functionalities that are generalizable for actors in a circular economy setting.

[6] https://github.com/eclipse-edc
[7] https://gaia-x.eu/

In Plooto each digital twin Is translated into an asset. Thus, the dataset describing all the information regarding this digital twin is related to the corresponding asset. Different characteristics, metrics, or non-static descriptions that are listed as telemetries of the asset, comprise the dataset, which is the item of a negotiation or data exchange in a Plooto data space.

In order to align a Plooto asset with the standardized dataset object in a dataspace ecosystem, a one-to-one mapping has been designed. Assets are regarded as datasets. Different subsets of telemetries per asset are regarded as different distributions of the same dataset. The negotiable item onto which an access policy is assigned is a telemetry. The available actions that can be granted are “Access” and “Forward”. When sharing a telemetry, the asset’s owner grants “Access” to this telemetry. If the telemetry is necessary for a DPP and its contents must be carried across the value chain, then a duty to “Forward” the telemetry is also agreed upon.

The alignment process of assets with DCAT[8] and ODRL[9] terminology, which is depicted in figures 28 and 29 below, is thoroughly described in deliverable D2.1 and will be further enhanced with more recent updates in D2.2, due next spring.

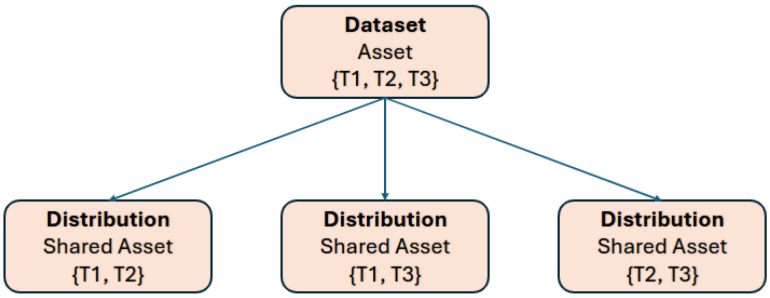


Figure 28: Various Distributions of an Asset

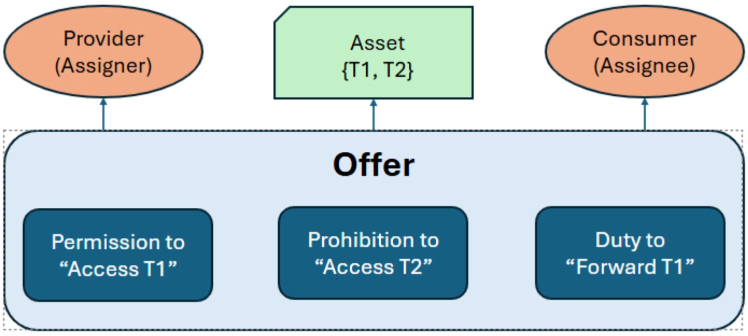


Figure 29: An Asset Negotiation Offer

For the scope of Plooto, the IDS connector will provide APIs for integration with external systems to support two use cases: a) collaboration with an external partner, and b) data ingestion from external data sources of current of future Plooto users. As an endpoint for data sharing, the connector will provide secure REST APIs for outsiders and a UI for Plooto users to monitor data

[8] https://www.w3.org/TR/vocab-dcat-3/
[9] https://www.w3.org/TR/odrl-model/

ingestion or exchange, as well as the negotiation and management of agreements with external parties.

The first use case which Plooto IDS Connector APIs need to support, demands the following actions, each one of which implies the generation of at least one separate endpoint to fulfil its task:

a) Publish a catalogue of assets available for sharing, along with their telemetries and default access rights.
b) Read a catalogue of external datasets available for sharing, in a form that can be mapped to assets.
c) Negotiate the incoming/outgoing sharing of an asset.
d) Transform appropriately and share an outgoing asset.
e) Receive and transform an incoming dataset appropriately.

The second use case of data ingestion may seem very different, but does not require any additional endpoints, since Plooto only needs to read a description of the incoming data, a requirement already covered by action b), and receive the input data in a way that supports its transformation into assets and telemetries, a requirement already covered by action e).

5.3.2 Blockchain

Blockchain technology will be utilized in the context of Plooto as part of the *access layer* to offer additional security and provide a robust template for sharing DPPs among organizations. It is the most appropriate technology to support circular value chains among organisations on a trusted environment.

The use of blockchain technology offers the canvas that organisations can use to issue contracts between them and the underlying sharing mechanism of the Digital Product Passports (DPPs). This functionality will be supported with the use of chaincode, a collection of smart contracts, which are self-executing programs that record the digital fingerprint of the agreement on the blockchain. Chaincode will dictate how organizations send and receive messages, including messages with embedded variables and free-text fields. Blockchain technology will also facilitate the reliable storage, retrieval, and updating of DPPs and their associated product data, along with any other critical information that partners wish to track. All transactions take place over an immutable and transparent ledger, ensuring that information recorded in the DPP is secure and tamper-proof. Blockchain guarantees that data is accessible only to authorized parties, fostering trust among stakeholders and consumers since the entire history of a product's life cycle is traceable among the peers of the network.

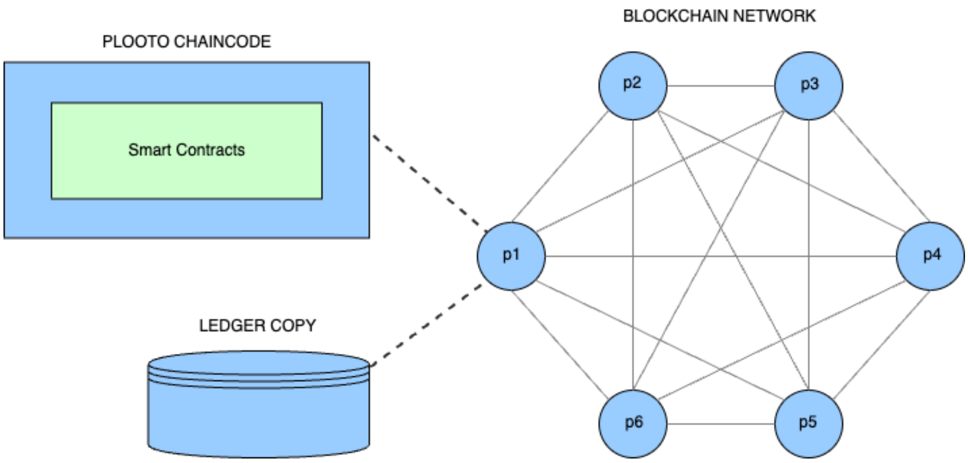


Figure 30: Blockchain chain code

For the needs of Plooto we utilize the Hyperledger Fabric[10] permissioned blockchain platform, which is provided by the Linux Foundation. This platform is open-source, and it provides a ledger copy for each peer. The chaincode, as depicted in Figure 30 above, is the executable program that hosts the smart contracts. It is designed to be flexible, supporting development in Go, JavaScript (Node.js), and Java, and it communicates with data in Protocol Buffers and JSON. This allows Plooto to integrate seamlessly with various services and components of the ecosystem, ensuring a smooth workflow for end users. Each smart contract can be seen as a function that will be triggered over REST API calls from the relevant Plooto components, offering the end user the ability to issue contracts, add product passports, read and track history of products, and even delete specific products. To be noted that, the concept of deleting a transaction from the blockchain is not possible. However, since it is a needed feature on many occasions, Hyperledger Fabric provides this functionality with the use of World state database. World state, shown in Figure 31 bellow, is what the end users view by default, and it is a snapshot of the last state of the blockchain ledger. In this database, a product can be deleted but the user is still able to look at the actual immutable ledger and track its complete transaction history. Thus, a dedicated function will be offered, which will crawl the blockchain ledger so that the end users will be able to track all past transactions and states of a product.

[10] https://www.hyperledger.org/projects/fabric

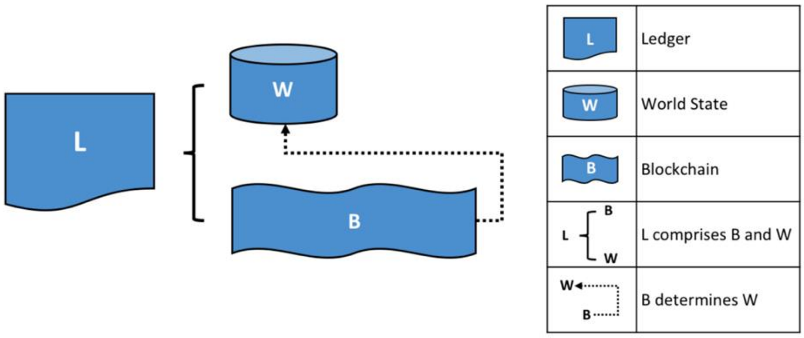


Figure 31: Blockchain world state

Any organization wanting to be part of the blockchain network, must abide by the rules that this network has. Additionally, it must comply with the chaincode that is agreed upon by the majority of the participants and drives this peer-to-peer network. The chaincode will be designed to map the transactions and functionalities needed and used by the Plooto communication mechanisms. As mentioned above, this will be offered as simple REST API calls, directly accessible from the service gateway. Internally, the blockchain network will also have its own authentication and access control mechanism that will dictate the permissions of the organizations over the network. The chaincode functions offered over endpoints integrate Keycloak authentication and the REST API calls can be queried using specified access tokens for each organization.

5.4 Tools

5.4.1 Process Modelling and Simulation tool

The general concept of the Process Modelling and Simulation (PSM) tool is to represent the process inputs (raw materials, energy, secondary materials, workload, etc.), the process sub-stages that convert inputs into in-process parts, and process outputs (final products, waste/scrap material, secondary products). Typically, the configuration of a model embodies all the entities implicated in its functioning, including a set of potential conditions in which the physical system may be established and the sequences of events (also described as system's behaviours) that might occur. In each process stage, appropriate equations are employed to represent the state, properties, and the changes of variable over time, during the simulation of the scenario. The PSM tool supports both continuous and discrete event modelling approaches, allowing users to model highly dynamic systems and time-sensitive industrial processes. By including multi-stage material flow and energy transformations, it enables detailed life cycle and production system analyses.

For the implementation of the pilot process models, four (4) distinct general datasets are required; these datasets will become tailored to the individual characteristics (operational policies, process network structure, resources availability, etc.) and needs (KPIs, Machine Usage, Indexing, etc.) of each pilot. The datasets are specified to address the requirements of the tasks described below.

- The initial task is the construction of the model's architecture. This encompasses the definition of the physical system components alongside their interconnections and mutual interactions.
- To effectively represent the dynamics of the system over time, quantitative parameters, regarding entities' states, properties and parameters are added to the process model.
- Any extra incoming information from output results of associate services is meticulously inserted to make the model more realistic.
- Validation and justification of the model's efficacy are accomplished through the simulation of a baseline scenario and its subsequent comparison with known results. This initial simulation confirms that the model execution achieves its intended purpose as measured by systems- and components-specific variables.

The PSM tool facilitates advanced optimization techniques, including predictive and prescriptive analytics, allowing for real-time decision-making, based on simulation outcomes. It can also support hybrid modelling, by combining data-driven and rule-based methodologies, making it suitable for a wide range of industrial applications.

The PSM suite is an advanced solution which enables complex process simulation and production systems modelling. MFN is an approach that facilitates modelling of the material, data, and energy flows, within varying production chains. This analysis supports users to detect bottlenecks and improve efficiency in resource usage, as well as to reduce the production environmental impact, resulting in sound ecological and economic decisions. PSM Hierarchical Inheritance Registry (HIR) contains variable structures that allow developers to build diverse industrial system models and to tailor each model to meet the specific needs and requirements, as indicated by the associated stakeholders (both external and internal), of a given value chain. The HIR also facilitates modular modelling, enabling users to define reusable sub-models that can be adapted to different stages of the process. This modularity significantly reduces the effort required for developing complex multi-stage simulations and ensures consistency across similar processes.

The Plooto holistic solution integrates and facilitates PSM, allowing easy access and utilization of its functionalities. This means that scenario development and data visualization tools that facilitate efficient modelling, as are also integrated in this application. Moreover, the platform's simple design enables users to further expand PSM's functionality. Available through the Plooto CRIS platform, PSM offers enhanced capabilities and accessibility for users and unique features in various industrial fields, such as:

- **Flexible Systemic Modelling**: Capable of modelling and simulating the entire value chain and related actors.
- **Bidirectional Interactive Models**: Turns process models into active components that interact bidirectionally with physical systems.
- **MFN Principle**: Utilizes MFNs for modelling material, data, and energy flows, making it fundamental for process analysis and evaluation.

- **Multi-faceted Integration Capability**: Seamlessly connects with Analytics, Optimization, and other tools, or methods from diverse scientific fields.
- **Advanced Modelling and Simulation Features**: Supports complex process model establishment, graphical representation, data exchange, and real-time visualization.

The PSM tool's integration capability includes interoperability with Digital Twins and Enhanced Cognitive Twin (ECT) systems, enabling continuous synchronization between physical assets and their digital counterparts for predictive maintenance and autonomous optimization. Through its integration into CRIS, the PSM tool is specially adapted and extended to be tailored to the unique requirements of the Secondary Raw Materials domain for each pilot case. This integration emphasizes the tool's adaptability and relevance to current and future industry needs. The key functionalities of the PSM tool that are available inside the Plooto platform include:

- **Graphical Model Design**: Users can design models graphically, making the process insightful and user-friendly.
- **Detailed Flow Specifications**: It allows specifying material, data, and energy flows, ensuring accurate and realistic modelling of industrial processes.
- **Comprehensive KPIs and Reporting**: Users can calculate a variety of KPIs (general, or tailored) not only for specific processing units and associated parties but also for the overall value chain, with results available in various formats for thorough analysis and easy reporting.

The desktop application of PSM tool interacts with the Plooto platform's web application back-end through an API (Figure 32). This interaction is essential for uploading and processing industry models and scenarios with various alternative parameters. The PSM tool and the Plooto platform provide API functionality for real-time simulation, monitoring, and on-demand modification of process models. This feature is particularly beneficial for adapting models to varying scenarios and requirements, enhancing the tool's feasibility and sensitivity in real-world cases.

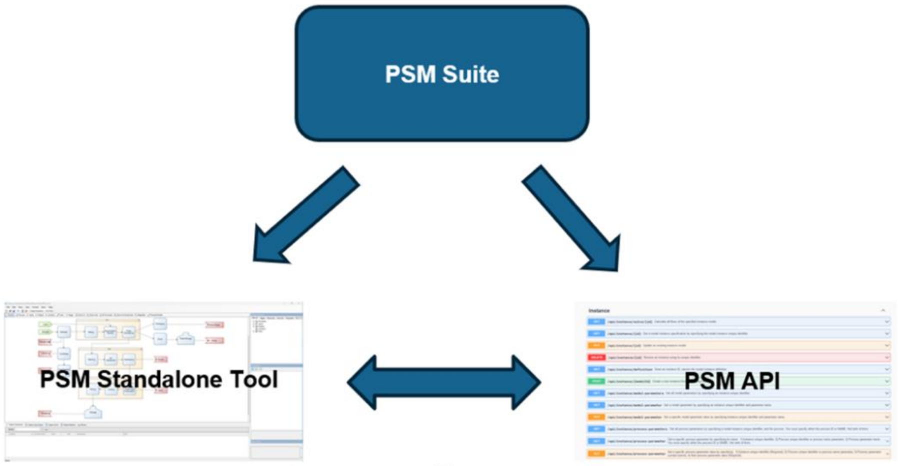


Figure 32: Process Modelling and Simulation Suite API capabilities

Last but not least, the PSM tool supports scenario-based optimization, allowing users to simulate various operational strategies and evaluate their impact on process efficiency, cost-effectiveness, and sustainability. This capability is crucial for exploring alternative solutions in dynamic production environments.

5.4.2 Digital Twins (assets and networks) modeller

CRIS embeds basic functionalities of MIRA for the modelling of user environment.

The user needs to define the internal processes to be monitored by:

- defining the Digital Assets that represent the objects to monitor and operate. It is also necessary to include the characterizing properties of the asset, as well as the telemetries that will provide data supporting the monitoring phase.
- aggregating the assets in networks that are related to a specific goal, ultimately establishing relationships among assets.
- selecting the services to be used (e.g., analytics, simulation, optimization, etc.). Once the services are integrated into the platform, they become available for selection and can be included in the user's system (see Section 5.2.1).

The result is the creation of *DT process models*. The design of DT process models is based on the corresponding process models (which are implemented in T2.6), but with a more operational purpose, which allows monitoring and management of the actual process through the execution of services, and the measurement of production-related KPIs through the collection of corresponding metrics.

After modelling the processes, the user can define *DT supply chain model*. A supply chain represents a collaboration among different parties that need to come to an agreement about: each partner's roles, responsibilities, and liability, the assets involved in the collaboration, the data to be shared along the supply chain, and the relevant metrics that can be measured to assess the efficacy and the circularity of the collaboration. Such agreements must be maintained in a secure way.

Both *DT process models* and *DT supply chain models are* implemented in Task 2.1, but briefly reported here for completeness.

The process to establish a supply chain consists of the following main phases:

a) Establish the collaboration between the related parties
b) Agree on the assets that are shared between the collaborative parties
c) Establish the network (supply chain)

more particularly, for each phase we have the following:

Establish collaboration: Plooto should provide the necessary functionality to establish a collaboration. More specifically, every partner using Plooto should create a list of predefined collaborators with whom they are working with. This fulfils the need for industries to have a formalized way to establish the supply chain with the agreed companies and only with those that comply with the internal processes.

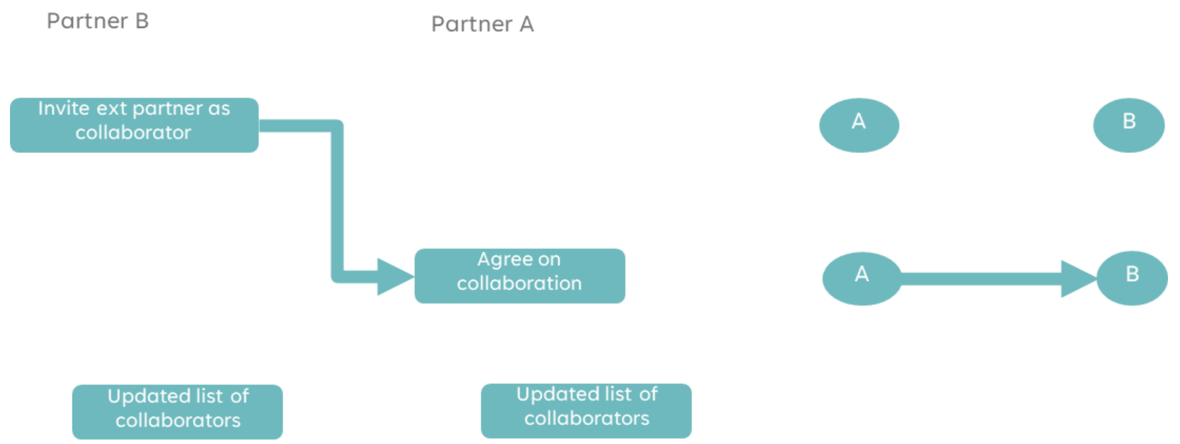


Figure 33: Establishing collaboration

The process for establishing collaboration will be:

1. Partner A requests B to become collaborator. In the invitation it is possible (optional) to attach a file that can be used as a reference agreement for the particular collaboration.
2. Partner B agrees and, in both Partner A and B, there will be a record of a new collaborator.

Plooto implements negotiation loops, i.e. partner requiring updates on the description or the agreement for the specific collaboration.

Link shared assets: in the context of a supply chain shared assets will be

1. Materials produced by partner A and used as incoming material for partner B.
2. Resources (machines) from partner A that can be used (as a service) to partner B.

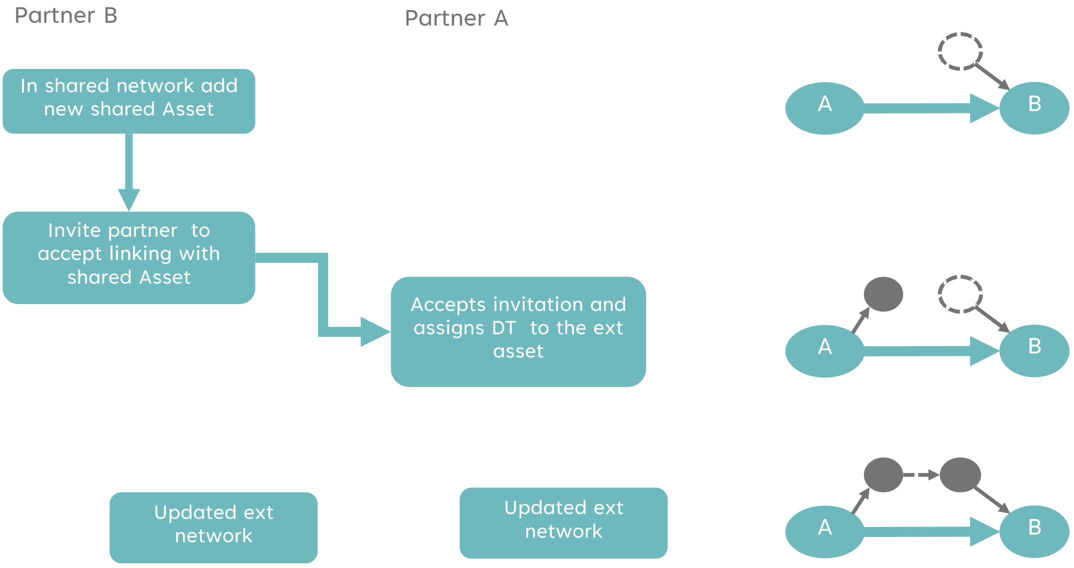


Figure 34: Link shared assets between collaborators

The process for establishing a linked asset will be:

- Partner A requests an external asset from partner B. There is also an option to send an agreement request about the particular shared asset.
- Partner B gets the request and if agrees assigns an internal asset to become a shared asset for A.
- In that particular shared asset, partner B selects which of its telemetries will be used for data sharing.
- Both partners agree on the shared asset details (name, description, telemetries…).
- Both partners will have a shared asset in their records:
    - Partner A will have an *incoming shared asset* with owner Partner B.
    - Partner B will have an *outgoing shared asset* for user Partner A.

Plooto implements negotiation loops also at shared asset level, i.e. modifications on the shared asset details (telemetries, terms of use, etc.).

Establish shared network

A shared network is the digital representation of the supply chain. Every partner in a shared network will view only the shared assets and collaborators, which he/she is directly linked to.

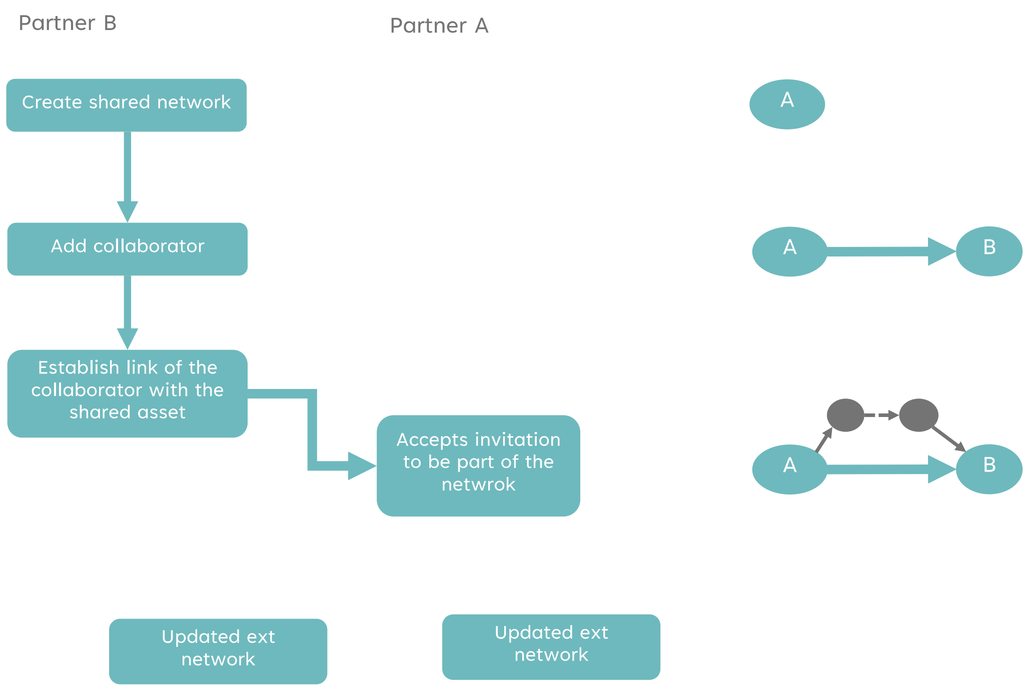


Figure 35: Create links for a shared network

The process to establish a new shared network is the following:

1. Partner B creates a new shared network in Plooto.
2. Partner B selects from the list of collaborators the stakeholders (Partner A) to create the link with B (whether input or output).
3. For the created link, partner B assigned the shared asset (outgoing or incoming).
4. Partner A confirms the participation.

The figure below illustrates how the supply chain DT will work on the Spanish pilot case. The Italian pilot value network has been modelled in the same way.

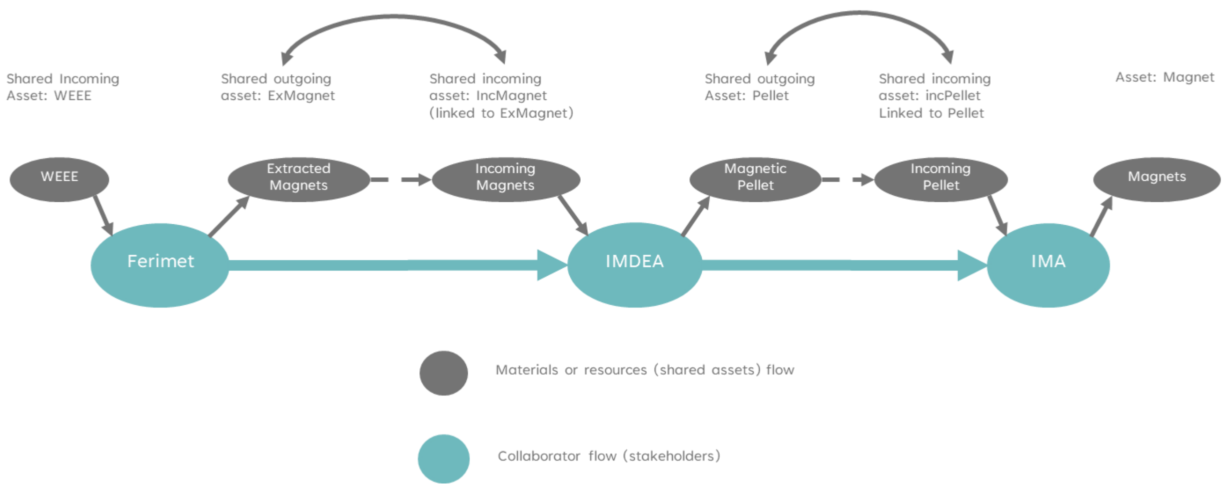


Figure 36: Shared assets flow in the Spanish pilot supply chain

This approach can be extended to a multi-tier supply chain; this means a distributed way, where several network links are established and all of them interconnected with a trace of the whole supply chain. For instance, partner B may have already a network with partner A and needs to integrate it with a new partner C (C invites B to work on a network).

In such case, partner will have to link the two networks with one of the following options:

- Either to include partner C in the existing network (i.e. keeping the same network id=A1)
- Or create a new network (id = A2) and link A2 with A1.

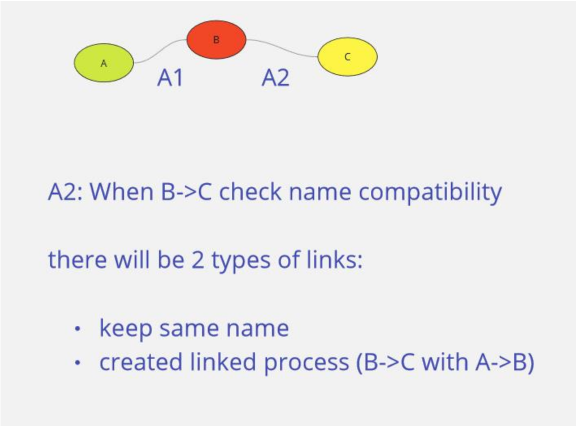


Figure 37: Multi-tier Supply chain approach

The above approach also ensures a distributed approach to supply chain DT. This means that in a multi-tier Supply chain, each actor can only view its direct interactions. For instance, in the supply chain below, company B will monitor only its interactions (with A and C).

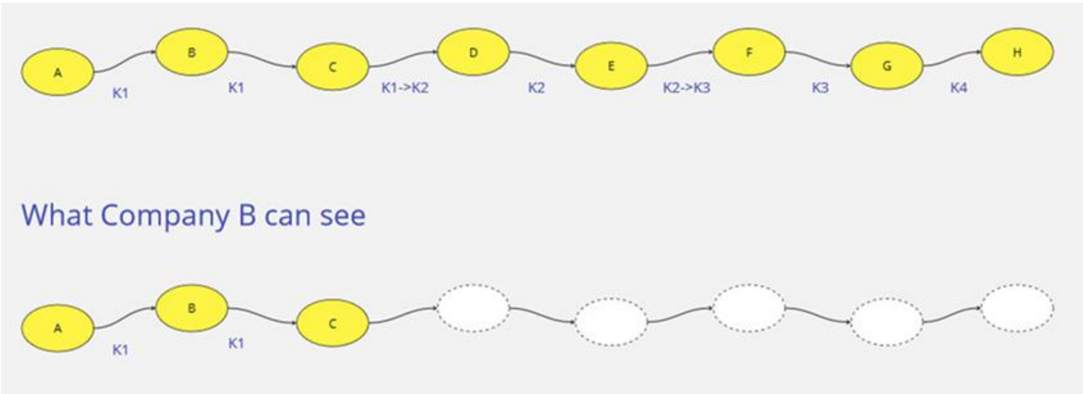


Figure 38: Multiple tier supply chain DT implementation

This approach is also in line with the IDS specifications, it actually extends its functionality. Through the shared asset concept, industries will have improved visibility of their supply chains, in which ones they participate, and what are the resources and data being shared in each network (materials flows). Through the IDS connectors the data will be shared with regard to the shared asset that has been configured and modelled in Plooto.

Once the system is modelled, the user can customize the dashboard to have a complete overview of inter- and intra-company processes, the assets involved, their status, and any critical issue. Additionally, the dashboard allows to operate on the system through selected services or specific functionalities.

5.4.3 Sustainability Balanced Scorecard

The Sustainability Balanced Scorecard (SBSC) is designed to serve within Plooto as a monitoring and decision-making tool, based on the Plooto Integrated Framework presented in D1.3. The Plooto Integrated Framework incorporates the Sustainability and Governance Framework, wherein models, standards and frameworks are analysed, capitalizing on successfully tested and validated methods (frameworks and standards) in assessing the performance of value chains with respect to their circularity, sustainability and resilience.

Building on the extensive review of available sustainability standards and frameworks, business governance models, and data governance aspects, a robust Framework has been compiled to become the foundations for the SBSC to build on it the SBSC. The SBSC draws up a hierarchic approach of strategic objectives for the assessment of the performance of the company/industry, considering four key aspects: (1) internal process, (2) financial, (3) growth and learning, and (4) customers. In Plooto, the realization of these assessments derives from the monitoring of a variety of indicators: for the environment, society, governance, economy and growth. Although the initial approach of Kaplan and Norton when introducing the Sustainability Balanced Scorecard (SBSC) in 2002, was to present the SBSC as a tool that "*takes into account non-monetary strategic success factors that significantly impact the economic success of a business*" [1], the increasing strategic importance of assessing the companies over their environmental, social, and ethical issues [4], evolved the SBSCs dynamic towards a more comprehensive point of view, especially in relevance to achieve the sustainability and resilience of industrial value chains.

The Plooto SBSC is designed to serve as a one-stop-shop tool for assessing circularity and sustainability across the industrial value chains. As such, it incorporates the principles of the traceability strategies for each pilot as defined in WP1 (Task 1.2), as well as the sustainability perspectives derived through the Plooto Sustainability and Governance Framework, and the extensive list of KPIs that has been developed under Task 1.4. The assessment in SBSCs derives from monitoring and measurement of selected KPIs that comprise **sustainability** (carbon footprint, resources, pollution, LCA), ***society*** (human capital, product assessment, stakeholders, opportunities), ***governance*** (corporate governance, corporate behaviour, litigation risks and corruption), and economy and **growth** (financial, customer, growth perspective), alongside with a group of pilot-related KPIs, aiming to serve as a configurable and personalized tool for each of the investigated industrial value chains. To ensure the quality of the results and to take into consideration the overall processes across the Plooto value chains, the SBSC has been built on the PSM Tool to serve as an interconnected module. To that end, it exploits the reliable virtual representations of the Plooto value chains, considering both their technical and operational characteristics, which are further enriched by society and governance related aspects. The results of the Plooto SBSC are visualized in Plooto via the API of PSM. The SBSC results identify the pain points of the value chain and indicate ways for improvement (i.e., processes, techniques, approaches), as well as potential opportunities for the overall performance of each value chain in terms of sustainability and circularity.

5.5 Services

5.5.1 Service gateway

As described in Section 5.2, the service gateway provides a single access point that acts as a proxy for multiple services. It receives requests from the core service and forward them to the invoked service.

During the second year of the project the Service Gateway has been developed within the platform (T3.2) to provide a uniform mechanism for managing external service APIs.

The **service configuration function** is available in the modelling environment (side menu *Services*). When adding a new service, the *service provider* needs to specify a brief description and the input/output data structures, the visualization mode and the services documentation. Each data structure must be associated with a datastore that channels the actual data to the services and to a specific asset or to a rendering form at run time.

The envisaged types of services are described hereafter.

5.5.2 Analytics

Analytics services in Plooto will be complementing process simulation and optimization services, particularly when dealing with intricately complex processes that are difficult if not impossible to model through conventional approaches. The analytical framework is expected to align with the principles of the big-data lambda architecture, with a specific emphasis on separating real-time model deployment from the model development process within the batch pillar of the architecture. This segmentation ensures that the analytics services operate efficiently and effectively, responding to dynamic real-time data while continuously improving models in a more controlled batch environment.

Analytics will be developed in Task 2.4 and envisions the following services to be provided:

1. **Data Ingestion and Cleaning Service (Expanded Anomaly Detection Service)**: This service is designed to ingest both real-time and historical batch datasets into the analytics independent databases, as they become available from pilot sites. Moreover, validation and cleaning techniques are utilized to ensure data integrity and reliability. **Envisioned integration:** Data ingestion and cleaning processes are executed

independently for every pilot. Data adapters allow the seamless integration within the Plooto platform, ensuring that clean, validated data are available for storage or utilization.

2. **Anomaly Detection Service:** The anomaly detection service will play a key role in detecting outliers in input data. The outcome of this service can be used to verify data quality, monitor analytics processes, or identify issues with production processes. **Envisioned integration:** Similar to raw or cleaned data ingestion, insights regarding data anomalies will be communicated directly to the Plooto Platform to be logged and reused. Real-time API integration allows prompt notification whenever anomalies are detected, supporting timely interventions and maintaining data reliability.
3. **Predictive Services:** Predictive services will be at the core of the analytics framework, offering predictive modelling capabilities (regression or classification). These services will be built on traditional machine learning techniques as well as on innovative graph-based methods. They will empower decision-makers with insights into future trends, potential issues, and optimization opportunities within the complex manufacturing and supply chain processes. **Envisioned integration:** The predictive services will be integrated as stateless components, exposing their functionality through an API, where API calls will provide the whole context for the predictive service. Alternatively, they can also be integrated directly into the data processing pipeline. This integration approach will enable continuous assessments of the production process. The predictive services will receive real-time data, either from a database or via a pub/sub mechanism and deliver results in a similar online fashion. This real-time integration ensures that the production process is under constant assessment and allows for prompt decision-making.
4. **Recommender System:** A recommender system will be integrated to identify and recommend novel opportunities within the manufacturing process, thereby enhancing efficiency and productivity. However, it's worth noting that the usability of the recommender system is still undergoing investigation, contingent on the specific needs and intricacies of the Spanish pilot. This adaptive approach ensures that the recommender system is tailored to meet the precise requirements of the pilot, maximizing its effectiveness. **Envisioned integration:** The recommender system is envisioned as a standalone component, primarily relying on static data provided during the design phase. This system will be incorporated into Plooto's platform following its defined API while it is deployed in an external server. It operates independently, to make recommendations drawing upon predefined data. Its integration strategy is designed to be static, ensuring that it functions efficiently based on the initial data provided.

In summary, the integration of these services within Plooto will be tailored to their specific functions and requirements. Data cleaning will work seamlessly with data adapters to maintain data quality, whereas predictive services can be integrated as stateless components or within the data processing pipeline to offer continuous assessments, and the recommender system will operate independently, leveraging static data for recommendations. Finally, the integration of these services will have to be further aligned with the objectives/requirements of Pilots.

The proposed analytics solution will provide a comprehensive distributed approach to data analysis across different stages of the value chains. The analytics service will be working in close cooperation with the organizational Digital Twins, adding value to the virtual representation of the physical processes and assets. Analytics allows for an expanded analysis, simulation, and optimization of the processes. The service will also be cloud-enabled, offering scalability, flexibility, and reliability, while containerization will guarantee the portability, scalability, and compatibility of the proposed solution.

5.5.3 Process Modelling and Simulation

PSM suite is a comprehensive solution for simulation that provides highly specific functionality while remaining secure and user friendly. The suite comprises the PSM Tool, which is a standalone desktop application, and the PSM Online Service (accessible through HTTPS API) which provides essentials functions throughout the process. PSM is a front-end interface built upon the .NET framework using Visual Basic and C# as development languages. It has user centric design that comprises different elements for smooth model management, editing, and specifying properties. PSM incorporates advanced agent-based modelling capabilities, enabling the representation of multi-actor dynamics, such as supply chains and distributed industrial systems. This ensures realistic simulations and supports scenario-based analysis, enabling advanced optimization and predictive modelling. The PSM suite is built upon the principles of MFNs, enabling detailed representation of material and energy flows across complex systems. This makes it particularly effective for mapping processes in continuous and multi-actor industrial systems.

The PSM Online Service complements the standalone tool, enabling broader and more dynamic interaction with the PSM suite through a HTTPS API. This facilitates the integration with external systems and platforms:

- **API-Driven Interaction:** The HTTPS API allows external systems and users to access the PSM tool, allowing for remote creation and manipulation of simulation models.
- **Asynchronous and Secure Communication:** Users can safely submit alternative simulation scenarios (jobs) and acquire the results later.

As for the data handling and integration aspect, the PSM tool adopts a fortified and secure approach, characterized by the usage of contemporary security protocols such as SSN (Secure Socket Network) and HTTPS (Hypertext Transfer Protocol Secure), which are fundamental for ensuring safe storage and reliable execution of the simulation models within the PSM local server. By leveraging such protocols, the PSM tool ensures the security of sensitive data while also enhancing the overall reliability and robustness of the suite.

- **Local Server Storage:** The PSM suite is designed to store the data on a local server, ensuring that each model can be executed at any time, adding an additional layer of security and reliability.
- **On-Demand Model Execution:** Provides users with significant flexibility, especially in cases where timely and accurate simulations are critical for decision-making or operational management.

The modular design of the PSM tool ensures adaptability to evolving requirements, and supports the integration with optimization and analytics services, or with external platforms/suites. It also facilitates the evaluation of KPIs for process efficiency and sustainability in both static and dynamic scenarios.

5.5.4 OptEngine – Optimization

OptEngine works as a shell around the optimization. Its architecture follows an asynchronous approach and is agnostic to optimization-specific data requirements. That is, optEngine receives, stores, and forwards the optimization data to the optimization service requested by the end-user.

Optimization requests along with the respective data are received via a web API. This API allows the actions described in the previous section. The communication with the API requires authentication, which is encrypted (https) and asynchronous, i.e., once an optimization job is submitted, the callee does not wait for its completion.

Data stores within optEngine work in a twofold manner:

- **Permanent storage** via a database (DB): this is where optimization requests and the related data are permanently stored, retrieved, and updated when necessary.
- **Temporal storage** via the use of queues: this is where optimization data is stored up to the point where they get consumed by the optimization services that read these queues.

Regarding the optimization data, both the DB and the queues are data-agnostic, following a general JSON schema. This allows the storage, permanent and temporal, of different data structures required from different optimization services.

The employed queues allow the asynchronous processing of an optimization job. Additionally, by being durable they ensure that when optEngine or an optimization service fails, the job along with data are still available in the respective queue. This means that optEngine, upon reception of a new optimization job, forwards it to the requested optimization service via a queue. Each optimization service listens for a new optimization job to a specific queue and writes status/progress updates to another queue. Last, optEngine listens to (a) a queue for status/progress updates and (b) multiple queues for optimization results.

The flow of data and the architectural approach of optEngine are depicted in the figure below.

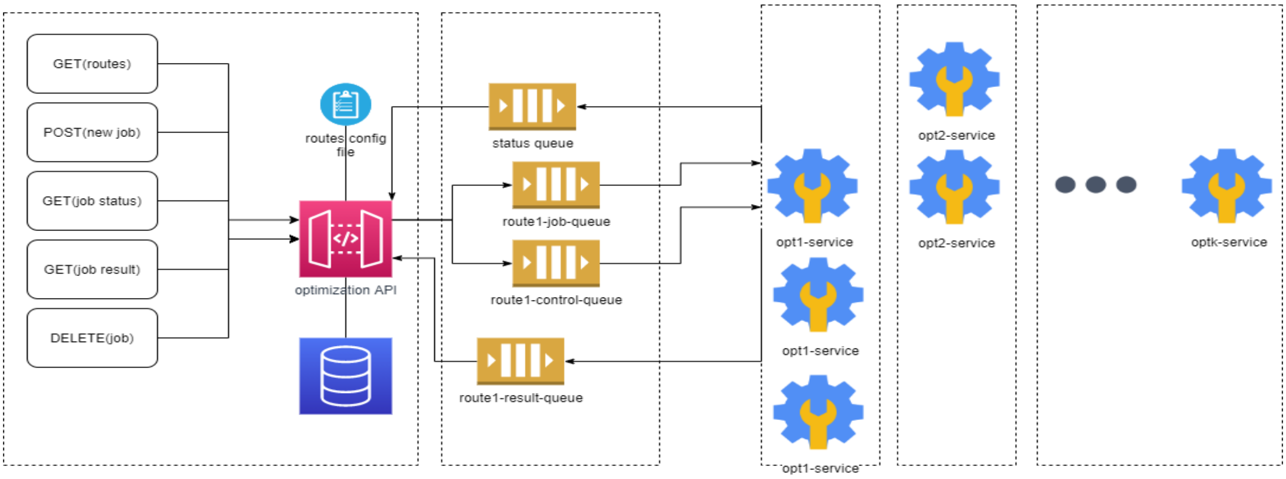


Figure 39: Optimization approach and data flow

5.5.5 Life Cycle Assessment

The Life Cycle Assessment (LCA) is a methodology used to evaluate the environmental impacts of a product, process, or service throughout its entire life cycle. This assessment considers various life cycle stages: from raw material extraction, production, use, to disposal or recycling. The main goal of an LCA is to understand the environmental hotspots and potential areas for improvement, to minimize negative environmental impacts. The LCA in Plooto is conducted based on the ISO 14040 standards, beginning with the definition of the scope. The scope of an LCA involves defining the system boundaries, which means determining what stages of the life cycle will be included in the assessment. It could encompass everything from cradle-to-grave (entire life cycle) or cradle to gate (until the product leaves the factory), depending on the specific goals and constraints of the analysis. The scope also involves identifying impact categories to be assessed, such as carbon footprint, water usage, or toxicity.

The role of LCA within Plooto is to assess the environmental performance of the waste valorisation line in the Greek pilot (ASPIS production plant) and demonstrate the environmental benefits from the reduction of the high energy demands and re-evaluation of the Citrus Peel Wastewater. Additionally, the service will be able to evaluate the environmental impacts from proposed simulations and what-if scenarios, derived from PSM tool and analytics service. The link between the services will be achieved using interconnected DTs from Plooto, with an on-line LCA tool. Currently, the outputs of the LCA analysis from the present production line of the Greek pilot are incorporated in the DPP of the produced molasses (Appendix B: DPP data structure for the three pilots)and can also be made available to platforms derived and composed during the project's lifetime (e.g. SBSC)..

5.6 Product Certification and Digital Product Passport

During the second year, the product certification topic has been broadened to provide the methodology for standardizing the DPP Certification process. This task has been assigned to TÜV Austria Hellas (TAH), a company specialized in Certification of products and services, Industrial

Audits, Live and Digital Training, Certification of Professional Qualifications, Regulatory Compliance, Laboratory Testing, Cybersecurity Services and Innovative Research by designing specialized services and applications, as well as creating pilot Standards.

5.6.1 Approach to product certification

5.6.1.1 Aim & Objectives of a pilot Certification Scheme

The aim of developing the DPP Private Scheme is to provide a trustworthy set of prerequisites established by TAH for the endorsement of an effective circular economy model. The validated features in terms of infrastructure and services accompanied by the globally recognized logo of TÜV give an added value of the proposed guidelines and gain the trust of the platform's users as well as the recognition of the international market.

The objective of such pilot scheme is to assure - in a systemic and constant way – that the requirements of circular economy will be met, through a monitoring mechanism that can be set, to verify - in advance - that each pre-requisite of the platform's capabilities fulfils and conforms to a representative set of quality criteria regarding the creation and functionality of the DPPs for the life cycle of each product, by-product and waste during the production process. This objective can be fulfilled:

a. By defining the appropriate quality pillars and their respective criteria to effectively and evidently support the certification claim of a pilot Certification Scheme, which shall offer a validated standardization process.
b. By building up and establishing an inspection mechanism to reliably and impartially verify the information that is presented in the Plooto platform, assuring the continuous alignment with the standards of the pilot Scheme.

The main outcomes of a pilot Scheme can validate that all participating parties have the provision to plan, support, properly communicate and continuously improve a set of actions, aiming to ensure the above-mentioned objectives to achieve a decrease in their environmental impacts. These actions set the proper basis to effectively monitor the integrity of the information provided by these cooperating parties, setting up a transparent control system, always in accordance with the principles of such a pilot Scheme.

The processes of importing, exchanging, and providing information between the participating parties should ensure that:

- They respect the privacy and confidentiality rules of the companies (privacy – trustworthiness).
- They offer security in receiving and transmitting information (safety, security).
- They respect the integrity of companies (sovereignty).
- They ensure that the commonly accepted Collaboration Agreements (mutually signed contracts – block chained) are respected.

- They ensure traceability throughout the products' Life Cycle (traceability)They ensure sustainability through the establishment of circular economy conditions (sustainability through adding and retaining value).

5.6.1.2 Task Phases & Structure of a Scheme

The tasks shall be divided into two distinct main phases. The initial Scheme's setup phase and the Assessment / Audit and Certification phase both complying with the Scheme's requirements.

"Scheme's Setup" component

For the initial phase, TAH shall proceed with creating the "Scheme Manual", which will be comprise the following parts:

1. **Definitions**: Each one of the analyses and descriptions for the definitions that shall be given shall be accepted merely for the purposes of communicating the content and the vision, as well as for evaluating the requirements of the Scheme.
2. **Audit Mechanism**: The mechanism will contain information about the application review, description of the Audit process, the different types of audits, how to organize the audit and how to evaluate the results, the conditions for providing the certification, the process of surveillance as well as the certification cycle.
3. **Quality Assurance** (Scheme Safeguarding): This part will contain information regarding the auditor's requirements, training and approval of assignment, management of complaints and appeals, conditions of reliability and confidentiality as well as conditions for independence and impartiality.
   To ensure the effective continuity of compliance with the requirements of the Scheme, Integrity Audits shall be selected after a risk assessment analysis or after a complaint or/and dispute between two participating parties.
4. **Audit Requirements:** This fundamental part of the Scheme will comprise a proposed detailed list of compliance criteria and principles aligned with the corresponding audit pillars, as well as the relevant potential documentation to justify conformity.
   The compliance principles will be: top management commitment and responsibility, communication of the Scheme's requirements, assignment of duties, monitoring of the operational effectiveness, assuring compliance, assessing, and evaluating the monitoring mechanism, communicating the results and achievements towards compliance, reporting of findings, handling emergency incidents, and handling of complaints.

TAH shall establish and coordinate the "Technical Project Team" that will be appointed for the needs of a corresponding task, undertaking the initial task of designating the critical legislative specifications recognized as pre-requisites for the participating parties and set them as fundamental. Alongside this, the Team shall determine additional criteria, capable of validating the claim of "achieving circularity" in all levels of production. Specifically, TAH shall adjust the specifications in an appropriate auditable form and structure to satisfy the principles that will be designated in the Scheme.

An important step in the Private Scheme's setup process will be the evaluation of the audit requirements corresponding to each of the pillars of the Scheme, followed by the relevant documentation to justify conformity. These requirements will constitute the main elements of the "Table of Requirements", necessary to achieve validation through the audit procedure, which is considered vital for certification.

The Pillars of the Scheme will be assessed according to all documentation provided, which aims to improve the circularity, energy performance, and overall environmental sustainability of products sold in the EU, the International Standards that have already been created, as well as the European Legislations and Requirements concerning Circular Economy.

This approach will be completed and delivered within Task 3.1 and documented in D3.2 (due by June 2025).

5.6.2 Digital Product Passport

The Eco-design Directive 2009/125/EC [1] and proposed modifications [5] establish a framework to set eco-design requirements for specific product groups to significantly improve their circularity, energy performance and other environmental sustainability aspects. It aims to enable the setting of performance and information requirements for almost all categories of physical goods placed on the EU market.

The framework will allow for the setting of a wide range of requirements, including on: a) product durability, reusability, upgradability and reparability; b) presence of substances that inhibit circularity; c) energy and resource efficiency; d) recycled content; d) remanufacturing and recycling; e) carbon and environmental footprints; and f) information requirements.

In line with the regulation, the DPP will provide information about products' environmental sustainability (i.e., framework requirements). This information will be easily accessible, and it will help consumers and businesses to make informed choices when purchasing products, facilitate repairs and recycling and improve transparency about products' environmental impacts. Additionally, it will enable to electronically register, process and share product-related information amongst supply chain businesses, authorities and consumers, which is intended to help public authorities to better perform checks and controls, create transparency, unlock circularity, and enable future and sustainable economic growth [6].

Plooto aims to set the foundations for the DPP in the three domains of the pilots. First of all, it is necessary to fill the information gaps along the supply chain, which are partially obscuring the actual footprint of a product, and to guarantee traceability throughout the product's life cycle.

Concerning the types of data to be included in the DPP and how to structure it, Plooto has looked at current initiatives, such as Product Circularity Data Sheet (PCDS)[11] or the Global Battery Alliance (GBA)[12].

Plooto will consider a generic approach to the DPP. This means that the platform should incorporate the necessary functionalities so that supply chains participants can model their own DPP format and monitor its execution and sharing in the operational phase. In principle, the DPP will consist of the following types of information:

- Textual information: about product, origin and anything that the company wants to incorporate into the DPP.
- System Information coming from sensors, services or other sources: this information will be integrated through the telemetries monitored inside Plooto.

The proposed structure for Plooto DPP is represented in the following figure. The corresponding structure for the three pilot has already been drafted and it is reported in Appendix B.

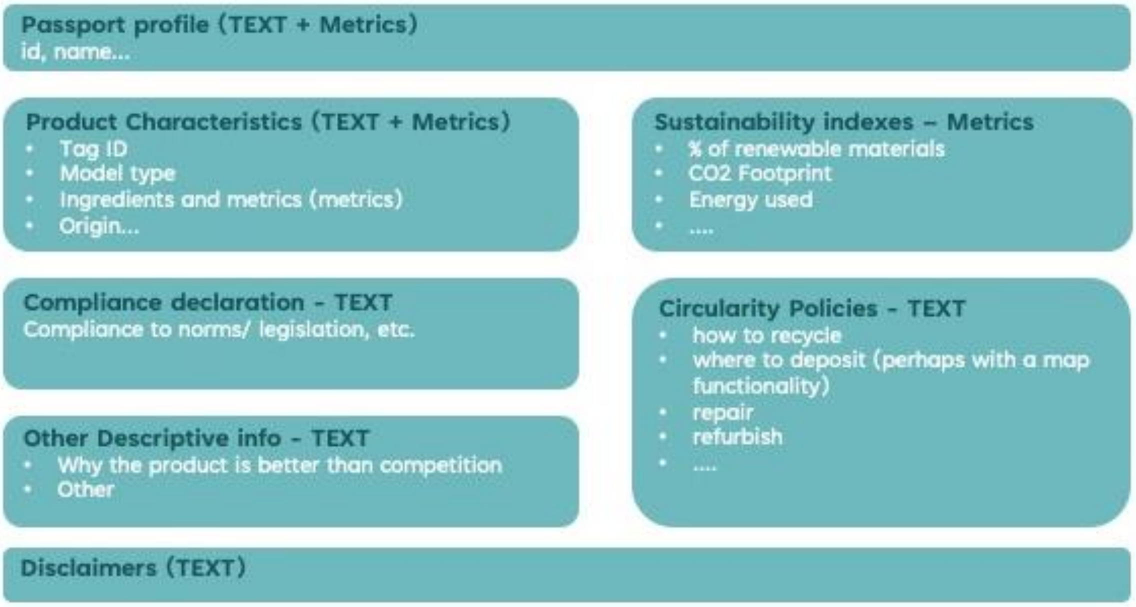


Figure 40: Plooto DPP data structure

The DPP needs to provide useful data to those who handle the product at the end, therefore it must be generated incrementally, adding data corresponding to individual components and material, as it passes along the chain.

Therefore, when detailing the collaborations along the supply chain (see Section 5.4.2), the DPP corresponding to the (semi-)final product should be included among the agreed shared data.

---

[11] https://pcds.lu/pcds-system/#glossary
[12] https://www.globalbattery.org/action-platforms-menu/pilot-test/

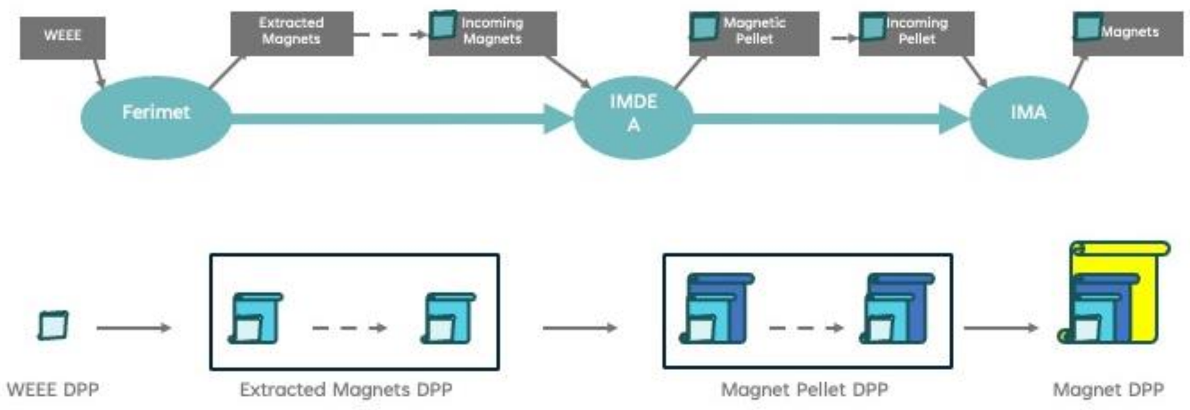


Figure 41: Linking assets with DPPs in value network

From an operational point of view, it means to link the shared asset and DPP in the value network. As it can be seen in Figure 41, the final DPP links all the DPPs from the previous steps, in this way it is possible to ensure traceability and assess the actual footprint of the final product.

Having modelled the supply chain as networks of DTs ensures the possibility to collect the necessary information that will be included in the passport from the corresponding (shared) assets and production telemetries.

Figure 42 provides a graphic overview of both business and operational actions of the DPP implementation.

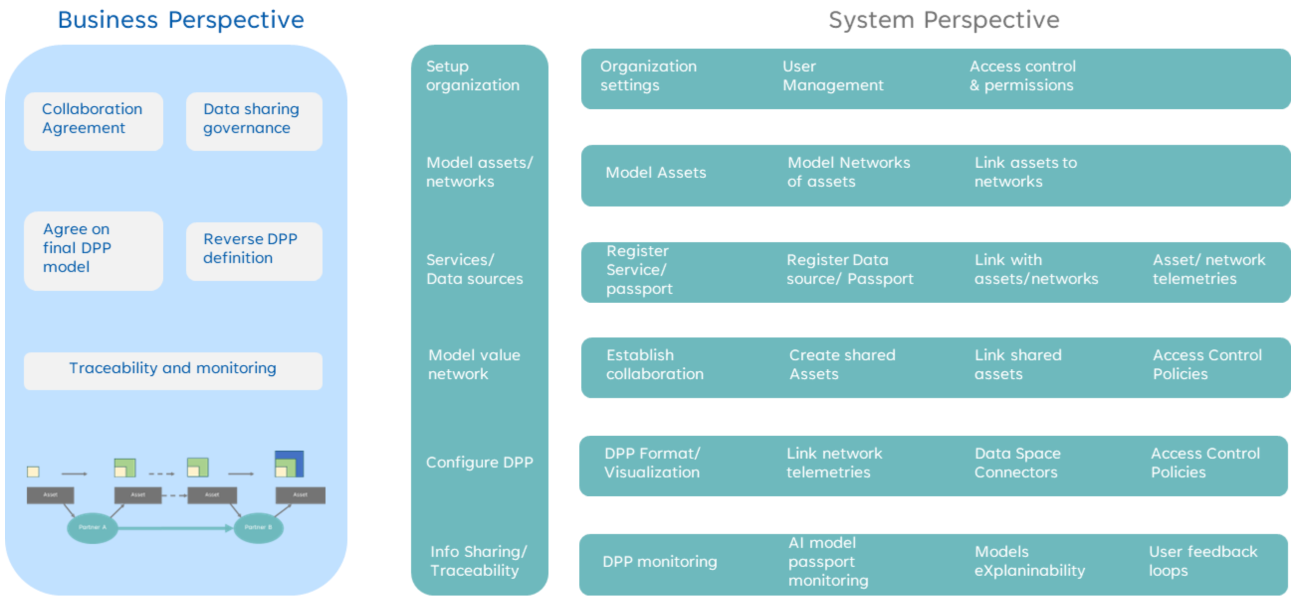


Figure 42: DPP main ICT framework and usage scenarios

The **business perspective** summarizes the actions to be performed at business level to establish the value chain. These include not only definition of the collaboration agreements, but also the identification of the data to be shared along the supply chain (in compliance with Plooto data governance) as well as the definition of strategies for traceability and monitoring along the supply chain.

The **system perspective** details the actions to be carried out on the platform. Here, the three bottom groups of functions are specific to the value chain and allow to model the supply chain as described in Section 5.4.2, as well as to configure the DPP, and define the data sharing and traceability strategies. These features have been implemented in Task 2.1.

The DPP will be securely stored (blockchain) and made available through readable artefacts (e.g. link in a web page, QRCode, etc. depending on the case).

5.6.2.1 Implementation approach

The approach to implement the Digital Product Passport, which is briefly outlined hereafter, has been fully described in D3.1 Product Passport and Certification Tools V1, submitted in June 2024.

The implementation is based on a four stage processes:

Configuration: refers to the creation of the DPP structure (template) associated to the product. The template may contain fixed text and real-time data related to the asset that will be shared, as well as complementary documentation.

Agreement: this step ensures that all parties are aligned when the product is passed along the value chain (for instance to be included in the production of other product). The data provided with the DPP is reliable and can be included in the DPP of other products.

Sharing/Monitoring: Allows all parties to view the information that has been shared and received, promoting transparency and effective communication among the value network.

Termination: this step occurs when the DPP is replaced by a new version with new/updated information.

The DPP template is associated to a shared asset and, consequently, to its data source and telemetries. This allows the automatic generation of the DPP instances (actual product passport) when the data sources are updated. Please refer to D3.1 for further details.

We are currently working on the public view of the DPPs, which will be finalized and documented in D3.2 (due by June 2025).

5.7 Approach to integration

In Plooto's vision, CRIS is the comprehensive environment that allows the use of several technologies that are not necessarily homogeneous. The *technologies* to be included range from APIs, Web Services (WS), data streams, and tools. The guidelines to their integration are briefly outlined below.

Data Streams - Feeds directly into the RabbitMQ → consumed by the analytics service, mapped into one (or more) asset(s) feeding the corresponding telemetries.

APIs/Web Services – An API or web service, needs to be implemented in a way that produces output in a format that can be directly digested by the platform (like data streams). Otherwise, it is necessary to implement an adapter that consumes data coming from the API, converts it to the expected format and pushes it into the dedicated queue. The implementation of the service gateway completes this integration pattern.

Tools – these should be regarded as a coherent system that serve a specific goal (i.e., to create/modify a process model) and have their own user interface.

To make such tools available through CRIS the iFrame mechanism will be used. CRIS will pass a token to the iFrame for authenticated and authorized users to ensure the compliance with the roles and policies defined by the organization in charge. The token serves to synchronize the application contained in the iFrame with the user credentials and other relevant data.

Additionally, to ensure the long-term sustainability of the platform after the project, it is essential to be able to establish supply chains with stakeholders outside Plooto. These will have their own IT infrastructure and might not be interested in adopting Plooto. In that case, on top of the patterns described above, it will be possible to ensure the connectivity and data-sharing via Plooto-IDS connectors.

5.8 CRIS performance and sustainability

5.8.1 CRIS performance: software compatibility and adaptability

CRIS is designed based on the adaptability and compatibility principles. Software adaptability refers to software that is flexible, maintainable, and changeable over time, while Software **compatibility** ensures that the software can work with/on a wide range of platforms, applications, and devices.

Software adaptability

Key concepts to achieve adaptability are modularity and encapsulation, which have been the core concepts upon which CRIS was designed and prototyped since the very beginning. The architecture diagrams in Figure 23 and Figure 24, show that CRIS is a layered architecture where each layer focus on one single aspect (e.g., user interface, business logic, data management, etc.) and it aggregates the independent components that are relevant for that layer. Each component has clear and contained responsibilities, with low coupling, which minimizes dependencies from other components.

In a nutshell, CRIS is highly modular, adaptable, and designed to be stable, maintainable, and changeable with minimal effort. Good modularity implies that the software is organized into distinct, independent components (modules), which makes it easier to maintain and adapt.

Modularity metrics will be defined within WP3 to evaluate the modular structure of the software. In particular:

Cohesion: measures how the responsibilities of a single module are closely related. A highly cohesive module focuses on doing one thing or a closely related set of things. Cohesion can be measured using **LCOM (Lack of Cohesion in Methods)**. LCOM is a common way to measure cohesion at class level. A low LCOM value indicates high cohesion, which is desired.

Coupling: measures the degree of interdependence between different modules., or to what degree one module depends on other modules. Lower coupling is desirable because it indicates that modules are independent of each other, making the software easier to change without affecting other parts. Coupling can be measured using **CBO (Coupling Between Objects) method.** CBO counts the number of other classes a class depends on. High CBO suggests tight coupling, which can make the system harder to maintain and adapt. Alternatively, **Fan-In / Fan-Out** methods can be used, **where Fan-In** indicates the number of modules that depend on a given module, while **Fan-Out** indicates the number of modules that a given module depends on. Low CBO or Fan-Out indicates that the modules are independent of each other.

Instability: measures the tendency of a module to change based on dependencies with other modules. High instability means that the module is more likely to be affected by changes in other parts of the system, which is not desire. It can be measured with **Instability Metric,** which is calculated by counting how often a module depends on other modules (afferent coupling) and how often other modules depend on it (efferent coupling). Instability ranges from 0 (very stable) to 1 (very unstable).

Modularity metrics will be assessed for the CRIS core platform, since tools, services and third party components are treated as black boxes, therefore independent modules by default.

Related KPI: KPI2.3: Software adaptability within the top 10% of modularity metrics e.g., cohesion, coupling, instability. **Top 10%** means that the software ranks better than 90% of other software systems, in terms of these metrics. This indicates that it is highly modular, adaptable, and designed to be maintainable and changeable with minimal effort.

Software compatibility

Plooto's adopted approach to software development aims to ensure high compatibility with a wide range of platforms, applications, and devices thus fostering seamless integration and operations.

This design principle - known as Software Compatibility by Design - is essential in cases like Plooto, where several systems need to interconnect and adapt to evolving technologies and evolving or emerging users' needs. It enables smoother integrations, better user experiences, and a more sustainable and scalable software ecosystem. The Key aspects of Plooto approach to achieve compatibility by design, are the modular architecture based on cohesive modules that can be easily and independently maintained or replaced, the use of APIs that facilitate integration with other systems and applications, and the use of industry standards (e.g., HTTP, REST, SOAP). Furthermore, modularity ensures adaptability and easy maintenance, guaranteeing that updates and new versions of software remain compatible with older versions(Backward Compatibility).

Additionally, compatibility by design favour software interoperability with other applications and systems - whether legacy systems, third-party tools, or newer technologies - which supports integration, scalability and extensibility, and minimizes the need for custom adapters or middleware.

Related KPI: KPI2.2: 100% backwards compatibility with legacy systems (Software Compatibility by Design adopted as a guiding principle in the de elopement of the platform, complemented by integration patterns - Task 3.2 – and IDS connector - Task 2.2)

5.8.2 CRIS sustainability

The information and communication technology (ICT) sector consumes 4 to 10% of the globally produced electricity and is responsible for 1.5 to 5% of the worldwide greenhouse gas emissions. While ICT technologies play a critical role in helping other industries in their green transition — driving research and fostering innovations that reduce emissions—the key challenge is to ensure that IT solutions themselves become more sustainable and energy-efficient, which means prioritizing climate-friendly, low-energy solutions within the ICT sector itself.[13]

The idea of Green IT responds exactly to this challenge. Green and sustainable IT systems are systems specifically designed to minimize environmental impact. The main focus areas of Green IT systems are: improve energy efficiency, optimize use of resource, and support a circular economy through recycling, reuse, and responsible disposal practices.

CRIS, with its tools and services, aims to support the different aspects of green IT as described hereafter.

Energy Efficiency: Energy efficiency is addressed in all three pilots: the Greek pilot aims to optimize the energy-intensive processes of the waste valorisation processing line, improve the environmental footprint, and reduce the energy demand. The Spanish and Italian pilots focus on the optimization of the energy consumption of the production lines.

[13] https://www.europarl.europa.eu/doceo/document/E-9-2022-002947_EN.html

Resource Optimization: The Italian and Spanish pilots use the optimization service to define the optimum composition for production that maximizes the use of secondary raw materials.

Lifecycle Management: Addressed in all pilots: in the Greek pilot the waste from the juice production is repurposed and transformed into molasses and other products. In the Italian pilot, scrap and CFRP expired material undergo a re-qualification process that extends its shelf-life, allowing their re-use for the production of drone parts. In the Spanish pilot WEEE, is reprocessed to extract the magnets, which are transformed into magnetic pellets (SRM), and used for the production of new magnets.

Digital Innovation for Sustainability: CRIS leverages technologies like Digital Twins and AI, allowing users to model their system, monitor the production and assess specific aspects (e.g. energy consumption), or KPIs across various processes and stakeholders.

Support circular practices: Plooto allows the dynamic definition, maintenance, and operation of circular supply chains, thus creating an integrated circular economy framework that maximizes the use of SRM.

A key element of CRIS sustainability is the use of Digital Twins, that are at the core of CRIS platform and allow to model and operate the pilot value networks.

Digital Twins can be used in several ways to improve sustainability. Being a virtual representation of physical assets, they can enable organizations to test and implement sustainable practices in a virtual environment, resulting in reducing waste, optimizing resource use, and minimizing environmental impacts, before applying those practices in the real world.

Key benefits of digital twins for sustainability include:
Resource Efficiency: By simulating various scenarios, digital twins help optimize the use of resources (materials, energy, and water).

In Plooto simulation services are used in all pilots. In the Italian pilot, simulation is used for prepreg scrap management, usability evaluation, requalification procedures, parts constructions and quality control. In the Greek pilot, simulation models concern the main production line - the wastewater and waste management coming from the primary production activity - and production of secondary products. In the Spanish pilot, simulation focuses on the management of WEEE, magnet extraction, magnet processing, magnetic pellets construction, new magnets manufacturing, and quality assurance.

Predictive Maintenance: Digital twins can forecast equipment performance, enabling timely maintenance that reduces energy consumption, extends the lifespan of assets, and lowers the need for replacement parts and materials.

In Plooto Analytics is also used to reduce energy consumption (Greek and Spanish pilot), and to predict. the quality of secondary raw materials (Italian pilot)

Carbon Footprint Reduction: Through monitoring and modelling, digital twins help track and manage emissions, making it easier to identify and implement low-carbon alternatives.
Plooto allows to define KPIs to be measured and automatically calculate their value at a given time. These metrics can be included in the sustainability balanced scorecard providing a more complete view of the environmental impact. Additionally, LCA is used to assess the environmental footprint of the Greek pilot.

Process Optimization: Digital twins can enhance manufacturing, logistics, and operational processes by identifying inefficiencies, thus helping reduce energy and resource usage across the entire value chain.

In Plooto Digital Twins are used both at the internal process level, as well as at the supply chain level. In this second case the material flows across the supply chain are optimized, based also on the results of optimization services, and the use of secondary raw material is maximized (Italian and Spanish pilots)

Sustainable Design and Innovation: Digital twins enable the testing of sustainable materials, energy-efficient designs, and renewable technologies virtually enabling companies to innovate without generating high amounts of physical waste.

Plooto combines a Digital Twins infrastructure with added value services (analytics, optimization, simulation, LCA) to operate the production in the most sustainable way. The Sustainability Balanced Scorecard allows assessing the performance of the pilot along different dimensions (economic, environmental, and societal) obtaining a comprehensive measure of sustainability.

The DPP services enrich the final product with information related to the whole production process, thus increasing transparency and traceability.

5.8.3 Performance and sustainability requirements

The concepts related to performance and sustainability outlined in previous sections, lead to the following additional functional and non-functional requirements.

- CRIS architecture should be modular, adaptable and easily maintainable.
- Modularity metrics for the CRIS platform should be defined and measured.
- CRIS architecture should have software adaptability within the top 10% of modularity metrics.
- CRIS architecture should be *compatible*, therefore capable to adapt to evolving technologies and evolving /emerging users' needs.
- New versions of the platform should not introduce disruptions in the functioning of existing features ensuring 100% backwards compatibility.
- CRIS architecture should be interoperable with external systems (legacy systems, third-party tools, or newer technologies).

- CRIS platform should provide /connect with tools that can measure energy efficiency.
- CRIS platform should provide /connect with tools that allow some forms of optimization.
- CRIS platform should support life cycle management and circular practices.
- CRIS platform should provide/connect with tools that can measure environmental impact.

These requirements have been listed in Table 5 and will be implemented and measured in WP3.

Conclusions

This document is the second and final version of CRIS Requirements and specifications (D1.6), which revises the previous version (D1.5), based on a better understanding of each pilot and the feedback from the first iteration of pilot operations.

In particular, it contains:

- A revised value network and business process for the Italian pilot.
- Revised process models, value network models, and analytics for the Italian pilot.
- Improved information concerning Process models, LCA and Analytics for the Greek pilot and Spanish pilots.
- Additional functional and non-functional requirements.
- Additional details regarding the architecture, namely the service gateway, the simulation, analytics and Optimization components.
- IMF models for the Italian and Greek pilot have been added, those related to the Spanish pilot have been updated to be consistent with the. new look and feel.
- A more general approach to product certification that will be implemented within task 3.1.
- The approach to achieve CRIS Performance and sustainability, as well as the related metrics, which will be implemented and measured in WP3.

These updates consolidate the foundations for the final iteration of the development of the different tools in WP2 and their integration in WP3.

References

[1] Directive 2009/125/EC of the European Parliament and of the Council of 21 October 2009 establishing a framework for the setting of eco-design requirements for energy-related products. Available at: https://eur-lex.europa.eu/eli/dir/2009/125/oj.

[2] Erin W. (2023), "Recycling rare-earth elements is hard — but worth it", Science News Explores. Available at: https://www.snexplores.org/article/recycling-rare-earth-elements-hard-reuse-greener-technology.

[3] Figge F., Hahn T., Schaltegger S, Wagner M. (2002), "The Sustainability Balanced Scorecard-Linking Sustainability Management to Business Strategy", Business Strategy and the Environment, Vol. 11, pp. 269–284, DOI: 10.1002/bse.339.

[4] Hansen E., Schaltegger S. (2016), "The Sustainability Balanced Scorecard: A Systematic Review of Architectures, Journal of Business Ethics, Vol. 133, pp. 193-221, DOI: 10.1007/s10551-014-2340-3.

[5] Proposal for a Regulation of the European Parliament and of the Council establishing a framework for setting eco-design requirements for sustainable products and repealing Directive 2009/125/EC. Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A52022PC0142

[6] Regulation (EU) 2024/1781 of the European Parliament and of the Council of 13 June 2024 establishing a framework for the setting of eco-design requirements for sustainable products, amending Directive (EU) 2020/1828 and Regulation (EU) 2023/1542 and repealing Directive 2009/125/EC. Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32024R1781&qid=1719580391746.

[7] Roland G., Carlo B., Frédéric C., Massimo G., Oliver G., Ian H., Milana K., Andreas K., Maija M., Bernd S., Reinhold S., and Badrinath V. (2021), Rare Earth Magnets and Motors: A European Call for Action. A report by the Rare Earth Magnets and Motors Cluster of the European Raw Materials Alliance, Berlin, Germany. Available at:

https://eit.europa.eu/sites/default/files/2021_09-24_ree_cluster_report2.pdf

Appendix A: Introduction to IMF – guidelines[14]

System

The concept of system lies at the core of IMF. We will use the following definition. *A system is a group of connected elements that interact through media to provide one or several functions, where:*

- *A function is understood as a capability to realize an activity*
- *Like the system itself, also its elements, called system elements, provide functions; the system elements functions are called sub-functions of the system.*
- *A medium is understood to be either material, energy, force, or signal-carrying information.*
- *Both the system and its system elements have terminals.*
- *Two system elements are connected via connecting a terminal of one system to a terminal of the other; the point at which the terminals connect is called a connection point.*
- *The set of connection points connecting terminals of one system to terminals of another is called the interface between the two systems.*
- *System elements of a system connect to elements outside the system boundary in the same way as they connect to system elements within the system boundary*.

Engineered System

An engineered system is designed with a purpose; the purpose is served by one of the system functions called the main function. Engineered systems whose main function is to transform a state of media at input terminals to a state of media at output terminals are of particular interest to IMF.

This definition is closely reflecting the definition in the Systems Engineering standard ISO/IEC/IEEE 15288, where a system is defined as a combination of interacting elements organized to achieve one or more stated purpose. Figure 43 graphically illustrates the definition in ISO/IEC/IEEE 15288.

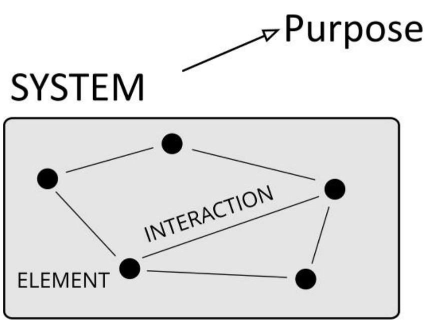


Figure 43: The system concept from ISO/IEC/IEEE 15288

[14] https://sirius-labs.no/imf/

Recursive Pattern

The concept of systems comprises a recursive pattern:

- The system elements of a system can themselves be systems; this results in a system breakdown
- System elements can connect to elements outside the system boundary, and these elements can themselves be systems and be elements of systems; this results in a topology
- These system breakdown and topology principles can be combined in a recursive matter

The points are substantiated in the following using a cooling system as an example. The elements of a cooling system may be artefacts such as pumps, pipes, chillers, etc. The purpose of the cooling system is to deliver heat exchanging. The main function of the cooling system is thus to provide a heat exchange function.

Breakdown

The system *breakdown* describes how a system is drilled down to system elements recursively. A complex system element of a system may be considered as a system with its own system elements (see Figure 44). This view of a system can be applied recursively, with system elements being drilled down into sub-systems until a desired level of detail is achieved. The process of drilling down a system element of one system to a system with its own system elements is called a *system breakdown*.

For example, a cooling system for an oil and gas facility might consist of a circulation system for the cooling medium and a heat exchanger with seawater supply. The circulation system can be drilled down into a set of circulation pumps, distribution headers and cooling medium expansion tank. All these system elements in the circulation system can be further drilled down in new system breakdowns (e.g., cooling medium expansion tank system consists of valves and instruments).

The desired granularity of breakdown might vary between the different parties involved in the engineering of a facility asset. For instance, the engineering contractor may take the pump as an artefact that serves as a system element, while the pump supplier needs to view the pump as a system and perform a further system breakdown. Note that since the system elements of a system comprise a group, a breakdown is also a way of grouping. The notion of granularity will be extended in future versions of the IMF manual.

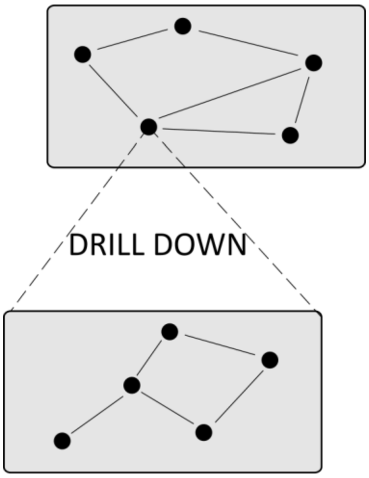


Figure 44: Illustration of a system breakdown

Topology

A systems *topology* describes how system elements are interconnected and, hence, how they interact. In IMF it is assumed that system elements interact through media, i.e., material flow, energy, force, or signal.

Different disciplines will typically address different media. Process engineers may, for example, be interested in how the liquid and gas flow between system elements. The topology within a process system may, hence, be focused on these types of media. An electrical engineer will be interested in how the electricity flows between the system elements and design the topology of an electrical system accordingly.

A complex system typically involves interaction from different disciplines. This system can be broken down into sub-systems where, in each system, elements interact through only one single media type. This situation is illustrated in Figure 45 The interface between the systems specifies how the systems interact.

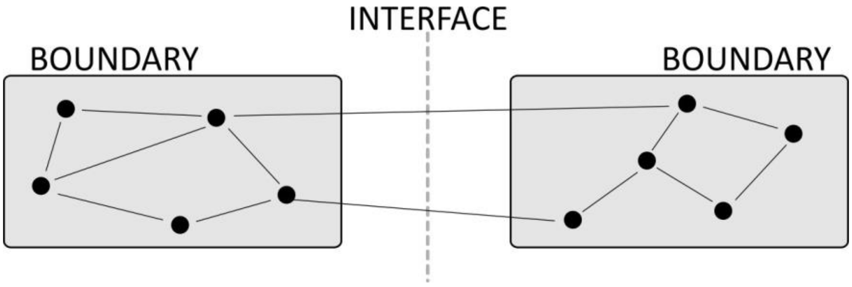


Figure 45: Illustration of the interaction of system elements inside and outside of system boundaries.

In the cooling system example, the pump and the heat exchanger interact by means of the cooling medium that the pump pumps to the heat exchanger. The circulation pump is connected to an electric supply; thus, the cooling system interacts with the electrical supply system of the facility.

Combining Breakdown and Topology

A repeated use of the principles of system breakdown and interaction gives rise to similar patterns recurring at progressively smaller scales both vertically (system breakdown) and horizontally (system interactions). The pattern is illustrated in Figure 46.

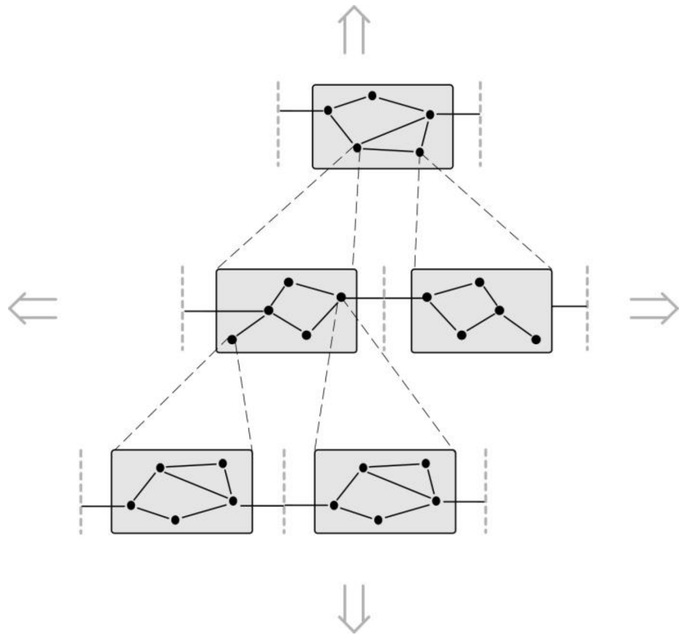


Figure 46: Illustration of system breakdown and topology.

Describing Systems through aspects

In engineering practice, it is natural to describe systems from different points of view, typically from the views of physical artefacts, activity, and location. IMF is a language designed for describing systems from such different points of view, which we refer to as "aspects". The notion of aspects is essentially the context of modelling that needs to be clarified before modelling, e.g., whether it is about the physical artefact or about the activity, what the purpose of modelling is, and who the users are. Note that the aim of IMF language is to describe systems, not to define systems.

Definition: In IMF, an Aspect is defined by specifying the following triple: ‹Perspective, Interest, Modality›.

Perspective

A *perspective* refers to a particular view of a system or system element. The IMF manual mainly addresses the following perspectives (Figure 47)and allows extension by users:

- *Activity* is to view the system from the perspective of the activity that a system performs or is designed to bring about.
- *Artefact* is to view the system from the perspective of physical objects or software.

- *Location* is to view the system from the perspective of the geometry, or position (geographical position).

Closely related to the activity perspective is the perspective of system Function, referring to the capability of a system to bring about an activity. This concept is fundamental in systems design. The concept of *function as activity* is a dualism of intended versus actual, and frequently discussed together. The names for perspective reflect class naming in the Industrial Data Ontology (IDO).

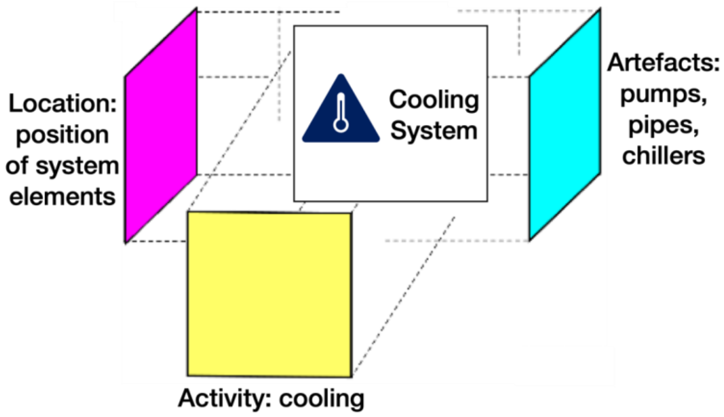


Figure 47: The same system is viewed from different perspectives

For example, from the perspective of artefact, a cooling system is a set of physical objects, such as pumps, pipes, and chillers. From the perspective of activity (function), the function of the cooling system is to realize a cooling activity. From the perspective of location, each artefact system element has a position and a geometric extension.

Interest

The *interest* is the modelling purpose; it points to the intended usage of the information, the users of the information and their preferences and working habits. The categorization of interests points to the different stages of the lifecycle of engineering systems, such as system design, detailed engineering, requirement engineering, manufacturing, procurement, commissioning, building, operation, maintenance, disposing, etc. Since the interest contains the information of purpose, usage, and users, it also provides principles of system modelling with breakdown and interaction, and hence how the system elements will be hierarchically grouped and broken down, and how the interactions shall be understood.

Each interest will be further elaborated in future versions of the IMF manual and aligned to a system lifecycle ontology introduced in the future.

Modality

The *modality* tells if a set of information about engineering systems is a *requirement* or an *intended solution* of the requirement, or it is an *actual solution*. The modality deals with two dualisms, the *intended* versus *actual* and *requirement* versus *solution*, where a requirement is always intended, thus resulting in three modalities:

- *Requirement* is to specify the intended system requirements, e.g., the functional requirements from the clients.
- *Intended Solution* is to describe the intended solution for a set of requirements, e.g., the product plan from the supplier.
- *Actual Solution* is the actual solution for the requirements, e.g., the actual installed artefacts in a factory.

Important to note is that the same set of information can be a requirement for some group of information user, and at the same time the intended solution for another group of information users. For example, if the interest is procurement, the client A provides the datasheet about some product to specify the required product (requirement). Then the supplier B provides the datasheet about some product based on some product catalogue that the supplier B can deliver (intended solution). The datasheet with the modality requirement will be verified against the datasheet provided with the modality intended solution. The later one then can serve as the requirement for the internal units of the supplier B, or the supplier C of the supplier B.

The evolving of information of the three modalities typically follows that in Figure 48: for the initial requirement an intended solution is proposed; then both of them are evolved to the revised requirement in the next stage, for which again an intended solution is proposed; this revision repeats until at the end an actual solution is installed.

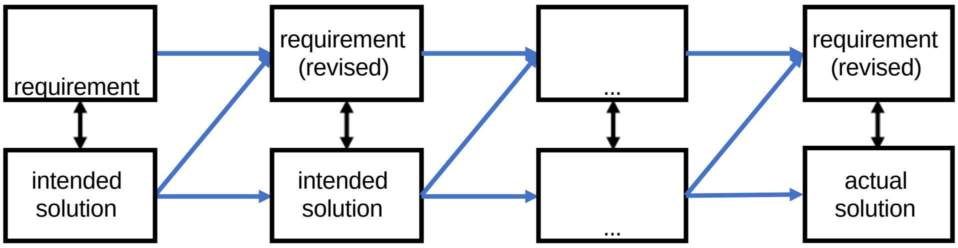


Figure 48: The three modalities and a typical evolving flow

Reserved Aspects

The IMF manual uses reserved names for the following four aspect definitions:

- Function Aspect = <Activity, System Design, Requirement>
- Product Aspect = <Artefact, Built, Intended Solution>
- Location Aspect = <Location, Geometry and Position, Intended Solution>
- Installed Aspect = <Artefact, Built, Actual Solution>

Each aspect has a colour assigned. The colours are included in Table 6 and are used in later figures to indicate the belonging aspect. Figure 49 illustrates these aspects as being different perspectives on the information about an intended pumping activity.

- The *Function Aspect* (yellow) ❶ is to specify the intended activity, e.g., the information about activity, performance, and function about a pump.

- The *Product Aspect* (cyan) ❷ is to specify the intended solution of a set of physical artefacts to perform the activity, e.g., the information about the physical artefacts of the pump.
- The *Location Aspect* (magenta) ❸ is to specify the geometrical and positional information of the intended solution, e.g., the size and shape of the specified pump.
- The *Installed Aspect* (dark blue) ❹ is to describe information about the actual solution, e.g., the serial number, run hours, and status of an actual pump installed in a plant.

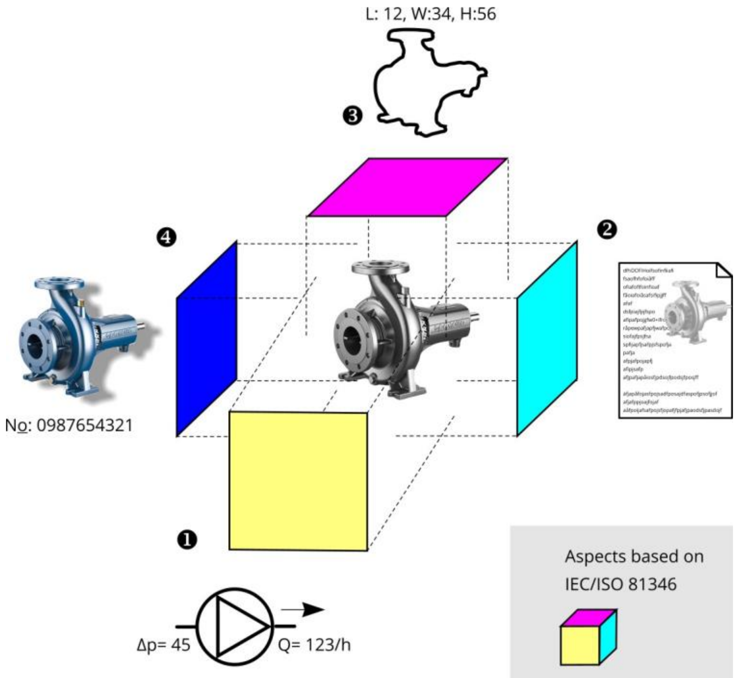


Figure 49: Illustration of the four reserved aspects

Table 6: Definition of the four aspects and their prefixes and colours

Aspect	Definition	Prefix	Color
Function Aspect (F)	The functional requirements to the intended activity	=	yellow
Product Aspect (P)	The intended solution of physical artefacts	-	cyan
Location Aspect (L)	The geometrical and positional information of the intended solution	+	magenta
Installed Aspect (I)	The description of the actual artefacts installed in industrial facilities	::	dark blue

A core concept of ISO/IEC 81346 is the notion of an aspect. IMF borrows this concept, but both widens it and makes it more specific. The IMF concept is wider than the aspect concept in ISO/IEC 81346 because it also addresses the individuals of a facility. ISO/IEC 81346 explicitly states that the standard only addresses so-called occurrences, which can be viewed as tag objects that are distinct from individuals. Also, IMF makes the topology more explicit than it is in ISO/IEC 81346. The IMF concept is narrower in the sense that an aspect is a specific information structure. Also, in contrast to ISO/IEC 81346, IMF does not treat a type as a distinct aspect.

Syntax and Interpretation

IMF is a framework that consists of a family of languages. In IMF, a language specification consists of:

- A syntax that prescribes what counts as admissible expressions in the language. The syntax can be specified formally so that it can be parsed by computer programs, or informally so that humans can understand how to write expressions in the language, possibly allowing some degree of freedom in exact ways of how to write them; such syntactical freedom is unproblematic as long as it does not compromise clarity.
- An intuitive interpretation (typically informal) aimed at users of the language. This interpretation should contain sufficient explanation so that the users understand how to express their use cases in the language and how to understand use cases that others have expressed in the language.
- A formal interpretation that captures the meaning of the language in terms of mathematically precise structures. Formal interpretations of IMF will be specified by translation into logical languages that have a precise formal (i.e., set theoretic) semantics, such as OWL.
- In order to be useful in practice, the IMF languages will need translations to other languages (typically formal languages) that preserve syntactical structures. We refer such translations as structure preserving translations. If the source language and the target language have different structures, such translations are difficult to specify.

All languages in the IMF family are object languages. Hence, this section briefly reviews the terminologies of object languages.

Object Language and Object Model

An object language consists of

- Mechanisms for creating *objects*, including mechanisms for giving the objects a unique identifier.
- Mechanisms for attaching *attributes* to objects.
- *Relations* that connect objects. Typically, we discuss *binary relations* where a relation exactly connects two objects.
- Mechanisms for creating *relationships*, which are instances of relations.

An object model is an instance of an object language, consisting of a set of expressions that specify objects, attributes or relations. For example, the following is an object model:

- A set of objects attached with tag numbers (i.e. identifiers) created by a tag master process that ensures unique tag numbers.
- Instances of the relation mountedOn. If t1 and t2 are tag numbers, mountedOn(t1,t2) is a relationship in the model.

A model with only binary relations can be naturally transformed to a directed graph, where objects are nodes, and relationships are edges between the objects.

IMF as Object Languages

In IMF, objects are called elements. Elements are created from types in analogy with the way that objects in object-oriented programming language are created for execution of a computer program.

It is useful to enrich an object language with classes ordered in a classification hierarchy. IMF also has hierarchies of types similar to classification hierarchy, but a type in IMF is not the same as a class as typically used in formal languages such as OWL: IMF types are constructive and used to reuse patterns and create elements. Classes are essentially constraints used to classify elements.

Visual Syntax

IMF models are meant to be developed by engineers by manipulation graphical forms using applications. For this reason, IMF has a visual syntax. While the precise syntax supported by an application is left for the specification of that application, the visual syntax used in this manual exemplifies how this can be done.

Displayed elements of an IMF model are blocks and terminals, while relationships between them are displayed using lines just as one would display binary relationships as edges in a graph.

This syntax will be extended so that the lines can hide an object, called an association point. In this way we can associate attributes to a relationship, and also relations to other elements.

Formal Syntax

The formal syntax of IMF is expressed in the ontology languages OWL and SHACL, both standardized as W3C recommendations.

Formal Interpretation

The formal interpretation of IMF is defined by a translation that maps IMF models into models in the language of the Industrial Data Ontology, IDO. In this translation, an element (i.e., a block or terminal) in an IMF model is mapped to

- An OWL class restriction if the modality of the aspect of the element is Requirement or Intended solution.
- An OWL individual if the modality is Actual solution.

The interpretation will map information about the same system that is spread over several elements into one system object and adjust domain and range of relations. Note that the notion of a system is a concept in IDO, but not in IMF.

The formal interpretation is essential for the integrity checking of an IMF model. This can in many cases be efficiently implemented using reasoning over the IDO interpretation of the IMF model at hand.

Language Elements Overview

The IMF language consists of

- Aspect elements
- Binary relations between aspect elements

Aspect elements in an IMF model have been created as instantiations of types and relationships between aspect elements inserted as instances of relations. Figure 50 gives an overview of terms and symbols in the IMF language. Note that the lists Association Point as an element.

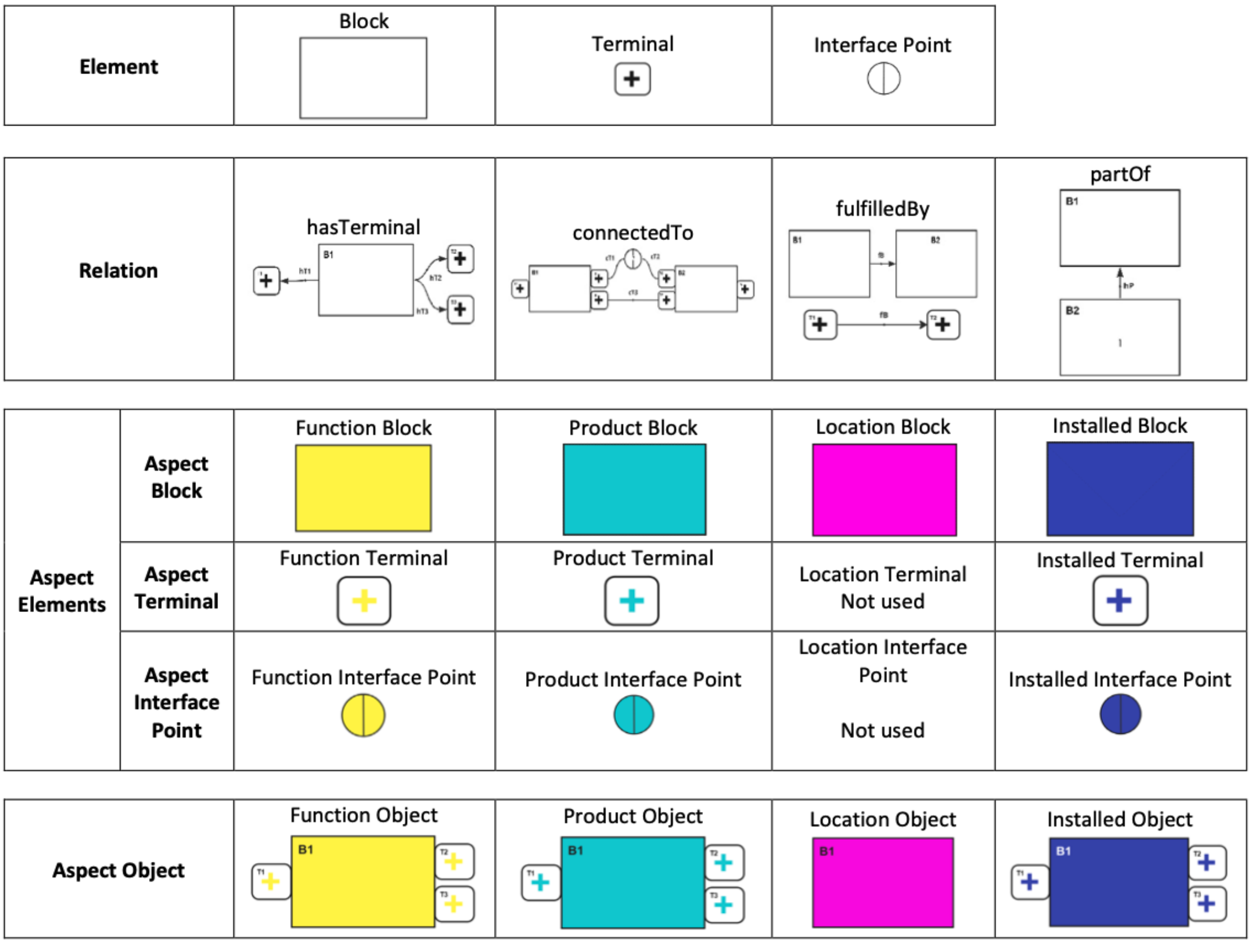


Figure 50: An overview of terms and Symbols in IMF language

Aspect Elements

Aspect Elements are blocks and terminals with exactly one aspect, as listed in Table 7.

Table 7: The different Aspect Elements

	Element	Block (B)	Terminal (T)
Function (F)	Function Element	Function Block (FB)	Function Terminal (FT)
Product (P)	Product Element	Product Block (PB)	Product Terminal (PT)
Location (L)	Location Element	Location Block (LB)	Location Terminal (LT)
Installed (I)	Installed Element	Installed Block (IB)	Installed Terminal (IT)

Relations

Relations in IMF are binary: they connect two aspect elements. Table 8 and Table 9 list all relations with their domain, range and cardinality.

Table 8: Summary of partOf and connectTo relations

Relation	Domain	Range	Cardinality
partOf	Block/Terminal	Block/Terminal	Many – 1
connectedTo	Terminal	Terminal	1 – 1

Table 9: Inter-aspect relations, their domain, range, and cardinality

Relation	Domain	Range	Cardinality
asProduct	FunctionElement	ProductElement	1 – many
asProduct	InstalledElement	ProductElement	1 – 1
asFunction	ProductElement	FunctionElement	1 – many
asLocation	ProductElement	LocationElement	1 – 1
asInstalled	ProductElement	InstalledElement	1 – many

Visualization

A Block is visualized as a box, possibly with a collection of attributes written inside. A Terminal is visualized as a small box with a plus (+) sign, as shown in Figure 51.

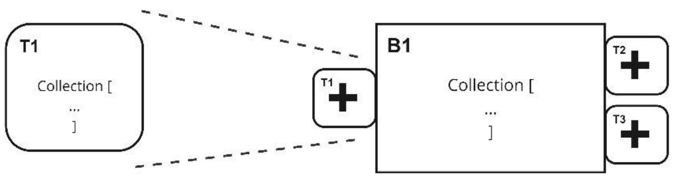


Figure 51: A Terminal

A partOf relationship partOf(B2, B1) is illustrated with an arrow pointing from the top of B2 to the bottom of B1, see Figure 52.

A connectedTo relationship is visualized as line between the Terminals it connects, as illustrated in Figure 53 which also illustrates a connectedTo relationship with an associated Association Point as a split circle placed in the middle of the line between the connected Terminals. This is not further used in the current version of this manual.

In an IMF model, the connectedTo and partOf relation are constrained so that they only relate blocks associated with the same aspect.

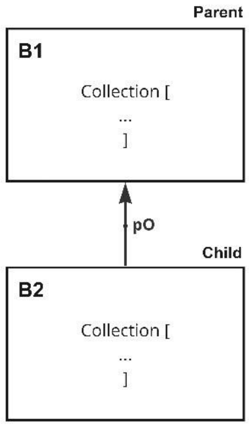


Figure 52: A partOf relationship between Blocks

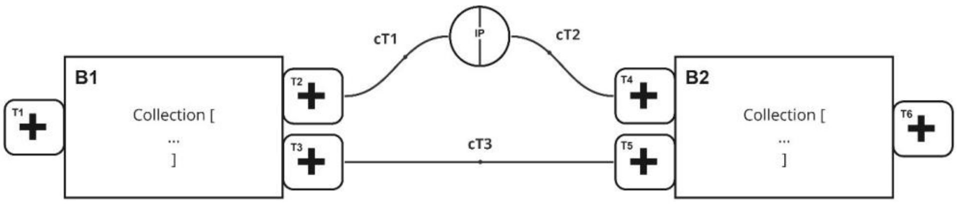


Figure 53: Two connectedTo relationships

Block

Block is the basic building block of the IMF language. A Block represents something of interest to the SME by setting the boundaries of anything which is convenient to treat as an entity. This could be a whole industry plant, a pump system, or a small location of interest.

Table 10 Summarizes the informal interpretation of blocks in each of the reserved aspects.

Table 10: Aspect Blocks and their intuition.

Name	Intuition
Function Block (**FB**)	A Function Block holds the requirements to an intended activity. Product Block (**PB**)
Location Block (**LB**)	A Location Block holds the specification of the spatial extension of an intended artefact.
Installed Block (IB)	An Installed Block holds the documentation of an actually installed artefact.

Terminal

A Terminal represents a channel of communication for a Block; hence, a Terminal cannot exist without a Block. A Block may have any number of Terminals that each represents a different communication channel or port with which the Block may receive input and/or give output. A Terminal that is specified to only receive input is called an *input* Terminal. A Terminal that is specified to only give output is called an *output* Terminal. A Terminal that may both receive input and give output is called a *bidirectional* Terminal, or, simply, a Terminal. The informal interpretation of terminals in each of the reserved aspects are summarized in Table 11.

Table 11: Aspect Terminals and their intuition.

Name	Intuition
Function Terminal (**FT**)	Requirements to one input/output stream state of an intended activity Product Terminal (**PT**)
artefact Location Terminal (**LT**)	Not used
Installed Terminal (**IT**)	Documentation of an actually installed artefact terminal.
Function Terminal (**FT**)	Requirements to one input/output stream state of an intended activity Product Terminal (**PT**)

hasTerminal

Table 12 Summarizes the informal interpretation of hasTerminal relationships in each of the reserved aspects.

Table 12: hasTerminal relations and their intuition

Name	Intuition
hasTerminal(**FB**,**FT**)	The media state of Function Terminal **FT** is the input/output of the intended activity in Function Block **FB**
hasTerminal(**PB**,**PT**)	The Product Terminal **PT** is a specification of one input/output terminal of the intended artefact of Product Block **PB**
hasTerminal(**LB**,**LT**)	Not used
hasTerminal(**IB**,**IT**)	The actually installed terminal **IT** holds documentation of an actually installed artefact terminal **IB**

partOf

The partOf relation promotes a System-Of-Systems way of thinking. The informal interpretation of partOf relationships in each of the reserved aspects is summarized in Table 13.

Table 13: partOf relations and their intuition.

Name	Intuition
partOf(**FB1**,**FB2**)	The intended activity of Function Block **FB1** is a sub-activity of that of Function Block **FB2**
partOf(**PB1**,**PB2**)	The intended artefact of Product Block **PB1** is a sub-assembly of the intended artefac Product Block **PB2**
partOf(**LB1**,**LB2**)	The intended location of Location Block **LB1** is located in the intended location of Locat

	Block **LB2**
partOf(**IB1**,**IB2**)	The actually installed artefact of Installed Block **IB1** is sub-assembly of the actually installed artefact of Installed Block **IB2**

connectedTo

The informal interpretation of connectedTo relationships in each of the reserved aspects is summarized in Table 14.

Table 14: connectedTo relations and their intuition.

Name	Intuition
connectedTo(**FT1**,**FT2**)	The media state of Function Terminal **FT1** is equal to that of Function Terminal **FT2**.
connectedTo(**PT1**,**PT2**)	The Product Terminal **PT1** is physically connected to the Product Terminal **PT2** via some media.
connectedTo(**LT1**,**LT2**)	Not used
connectedTo(**IT1**,**IT2**)	The Installed Terminal **IT1** is physically connected to the Installed Terminal

Appendix B: DPP data structure for the three pilots

Italian Pilot

Raw Materials		Re-qualification procedure	Production procedure
Expired prepreg in form of rolls	Prepreg waste pieces (arise from the cutting phase)	Properties: - Thermal properties (T_g) - Rheological properties (Viscosity vs temperature) ** To be modified after the tests in the pilot. Maybe more properties will be added.	Component production date
Dimension of the roll	Geometry of prepreg pieces	New process window for the material: - Temperature - Pressure of polymerization - Time	Production method: - Times - Temperatures - Pressure
Supplier of raw materials		Re-qualification date	Quality inspection results: - Visual inspection - Void content - Thickness measurements
Quantity		New expiry date (for the production procedure)	
Technical Datasheet (regarding the prepreg) - Technical properties			
History of source materials: - Production date of the source material - Expiry date of the source material - Storage conditions			

Greek Pilot

Molasses Product Passport

A QR code will be placed in the product packaging bag, which when scanned will redirect the consumer to a website. The website will look like Figure below.

The user will be able to select any of the four different components and will be redirected to the specific topic. The content of each topic is displayed below. Moreover, the user may select the ASPIS logo and be redirected to the official site of the company.

Product description:

ASPIS SA, with many years of experience in food production and guided by the utilization of high-quality raw materials of Greek origin, sustainability and the circular economy, has proceeded to the production of feed products.

Our feed is produced from the processing of citrus peels and pulp with different processes, covering the needs of our customers.

Recognizing the importance and linking the production of safe feed with the production of safe food, we provide feed products of high energy and nutritional value.

Derived from the citrus processing by-products, feed grade molasses is among the most popular molasses-based animal feed sold worldwide. Easy handling and high palatability make it an ideal animal-feed solution.

Molasses is to be stored in original containers or in on-site molasses specific tanks. Molasses should be stored out of direct sunlight, at less than 20°C and avoid contact with water. If stored in the correct manner, molasses will have a shelf life of 12 months from manufacture date, unless otherwise stated.

Molasses production adopts all the relevant standard procedures and undergoes a process of Quality Assurance to render the product fit for animal-feed production.

Lot No.:

Nutritional Analysis:

Component	Concentration (g/kg molasses)	Dry Matter Basis
Calcium		
Nitrogen		
Magnesium		
Phosphorous		
Potassium		
Sodium		
Soluble Sugars (NSC)		
Sulphur		
Dry Matter		
	Concentration (mg/kg molasses)	
Cobalt		
Copper		
Iron		
Manganese		
Zinc		
pH		

Specifications

Physical & Chemical Specifications	
Polarization value (% Sucrose)	
Ash (%)	
Colour (IU)	
Moisture (%)	
Particles size	
Viscosity	
Brix	

Microbiological Specifications	
Aerobic Plate Count	Absent

Environmental Impact (LCA):

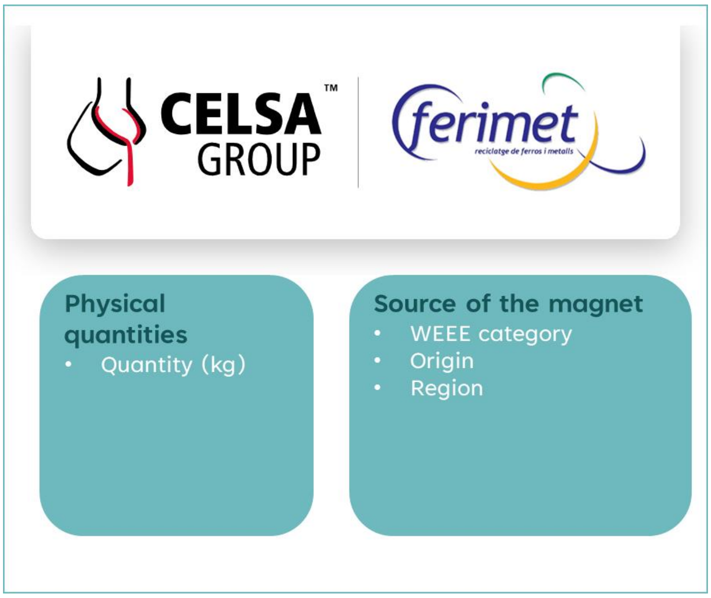
LCA analysis was carried out in accordance with the Standard ISO 14001.

Studied Category	Value (per kg of molasses)
Climate change, default, excl biogenic carbon [kg CO_2 eq.]	

Spanish pilot

Ferimet DPP

DPP per batch of magnets.



PARAMETERS	Information/ units (S.I.)
WEEE category	From the 6 general categories defined by the EU. Currently: • Large equipment, small equipment and/or Small IT telecommunications equipment.
Origin of the magnet	Original device from which the magnet was extracted (home appliance, washing machine, microwave, electronics or other type of WEEE)
Region of the WEEE	Code of the region where the WEEE waste comes from (ES, IT, FR, …)

IMDEA DPP

Where: Physical quantities and source of the magnet come from Ferimet, the other blocks contain information generated by IMDEA, which are detailed in the following tables.

Material Safety Data Sheet	
PARAMETERS	UNITS (S.I.)/ Text
Material Name	
Polymer Base	%wt
Magnetic Powder	%wt
Magnetic Properties	
• Br	T
• Hc	kA/m
• BHmax	kJ/m³
Material density	kg/m³
Maximum Temperature	ºC
Personal Protective Equipment	EPIs (Safety needs)
Temperature to Decompose	ºC

Data Sheet	
PARAMETERS	UNITS (S.I.)
Required drying time	s
Pre-drying Temperature	ºC
Maximum Temperature	ºC
Temperature to Decompose	ºC
Temperatures for each injection zones	ºC
Temperatures nozzle	ºC

Required time for each injection zone	s
Required time wait before open the mold	s

IMDEA sustainability data - other data	
PARAMETERS	UNITS (S.I.)/ text
% wt of recycled material	%wt
Quantity	Kg

IMA DPP

Sustainability data	
PARAMETERS	UNITS (S.I.)/ text
Informative message	"In order to improve the sustainability of the magnets, IMA is using magnetic material recovered from different EOL WEE. In this magnet contains magnetic materials from different recycled sources."
% wt of recycled material	%wt
Source of the magnet	*from Ferimet's DPP*
Information to recycle If possible	

Material certificate	
PARAMETERS	UNITS (S.I.) or text
Dimensional values	Mm/º/ .. drawing specifications
weight	g
Magnetic properties	
• Gauss	kG
• Flux	(µVs·cm)
• Sample Volume	Mm^3
• Magnetic properties with temperature loss	Comparing flux or Gauss values. Tmax (ºC) and %loss
Material control	
• Br - remanence	T
• HcB - coercitivity	kA/m
• BJmax – maximum energy product	kJ/m^3
Magnetic Force	N
Coating thickness	µm

Coating composition	Data values from equipment (%wt stimated)

Appendix C: IMF models for the Spanish pilot

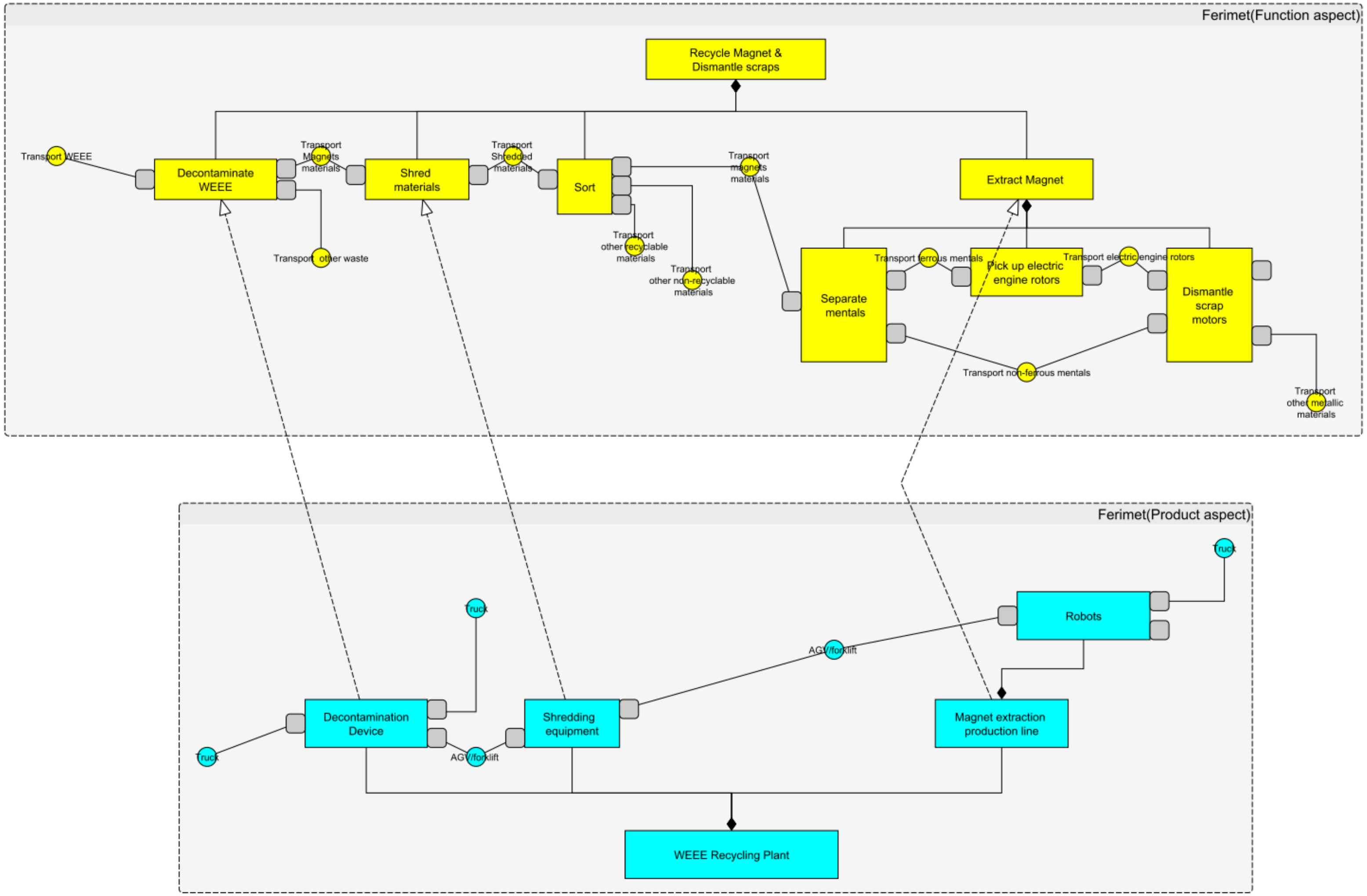


Figure 54: IMF Model Spanish pilot - FERIMET

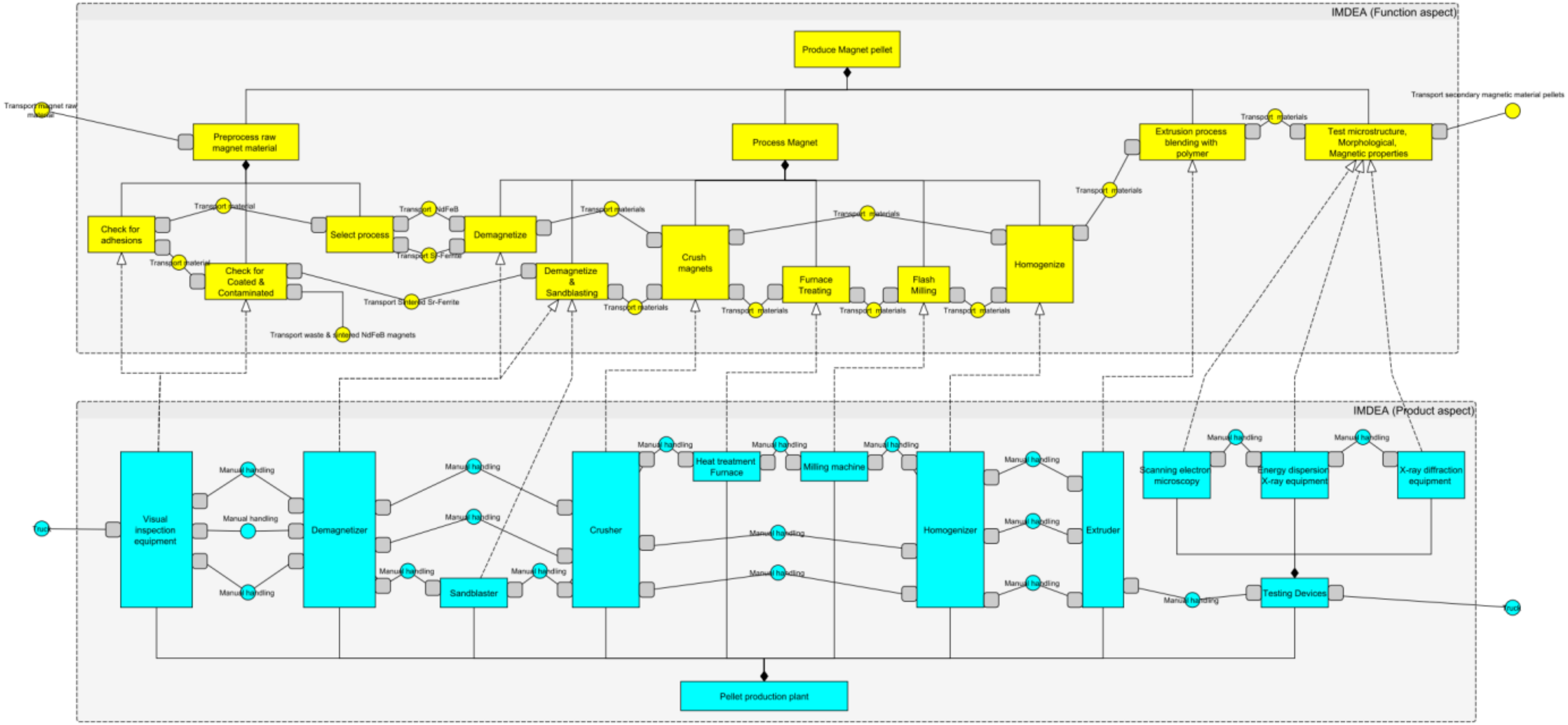


Figure 55: IMF Model Spanish pilot - IMDEA

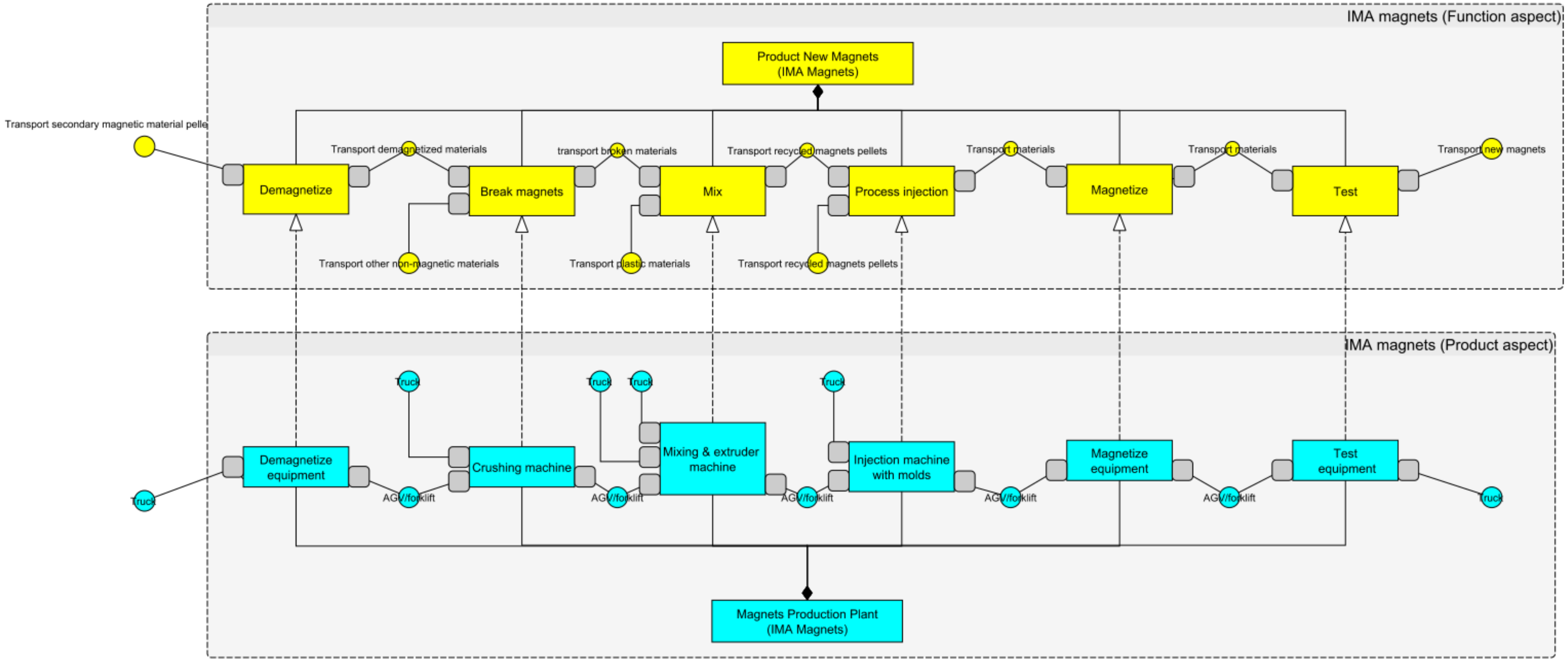


Figure 56: IMF Model Spanish pilot - IMA

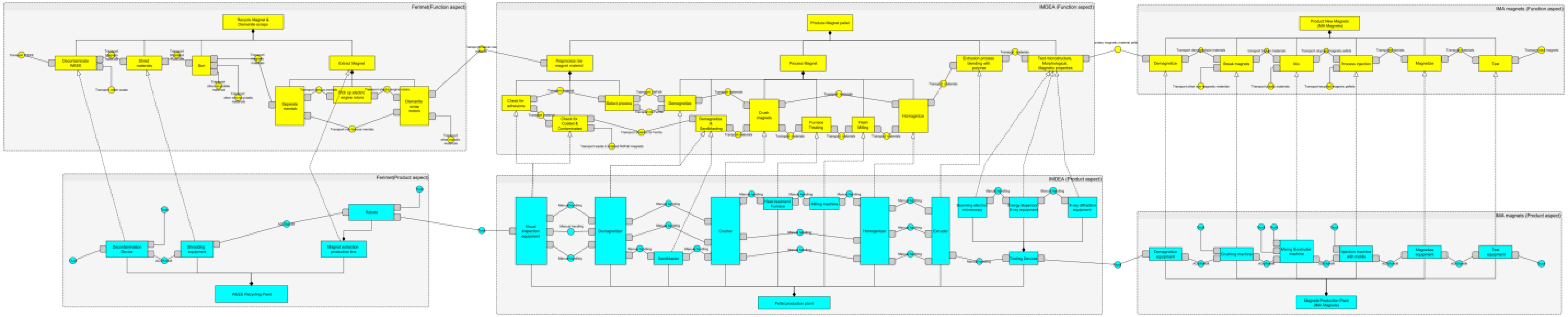


Figure 57: IMF Model Spanish pilot - whole value network

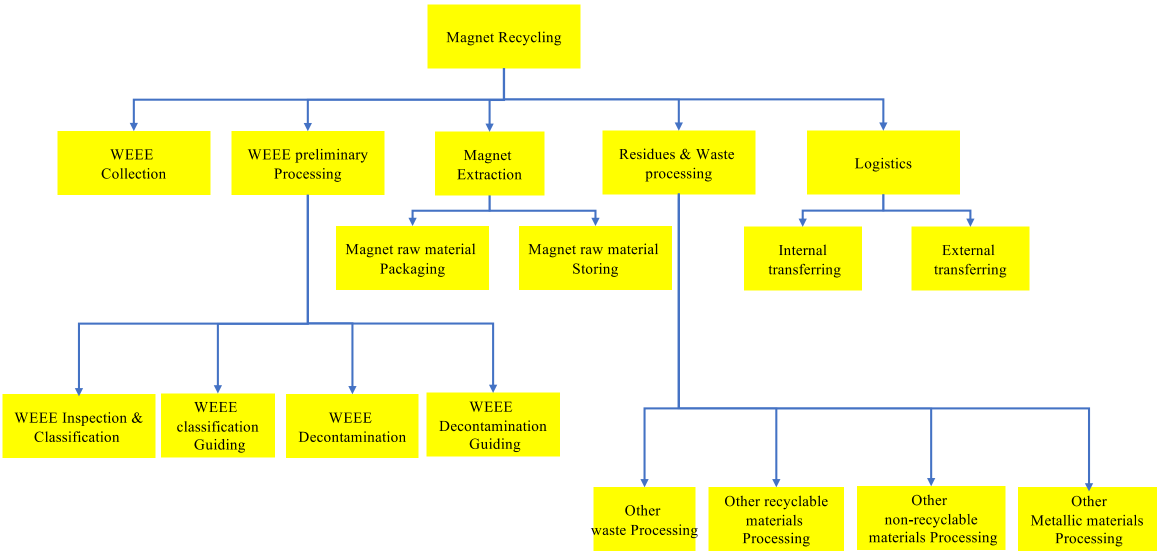


Figure 58: Functional aspects, Ferimet

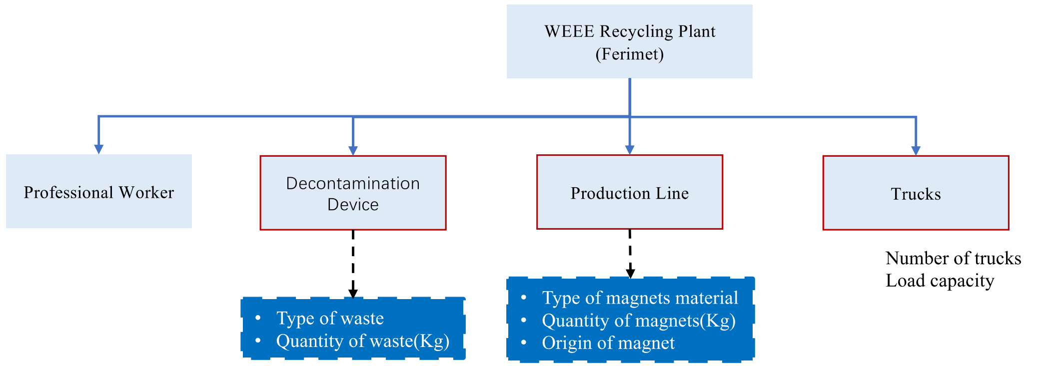


Figure 59: Production aspects, Ferimet

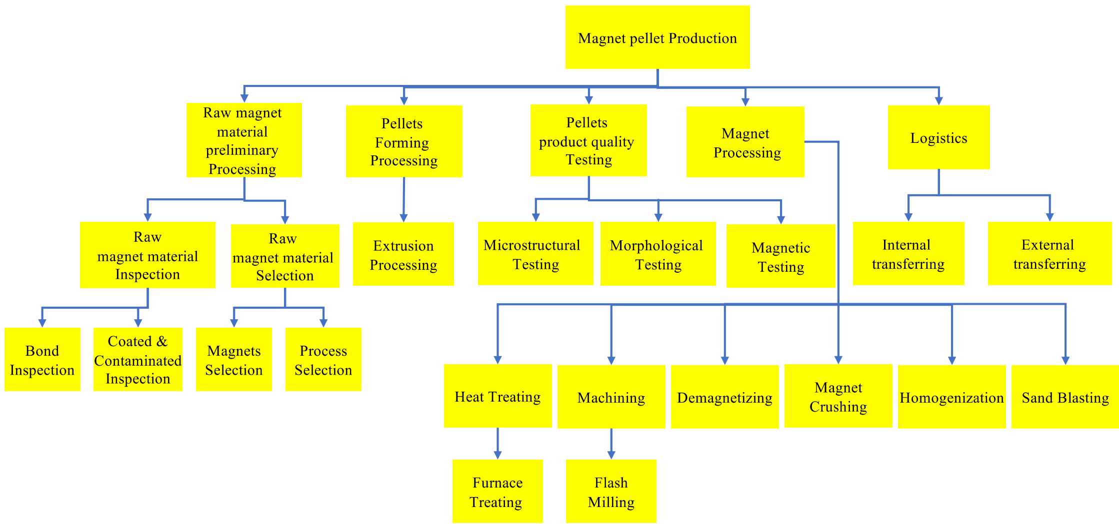


Figure 60: Functional aspects, IMDEA

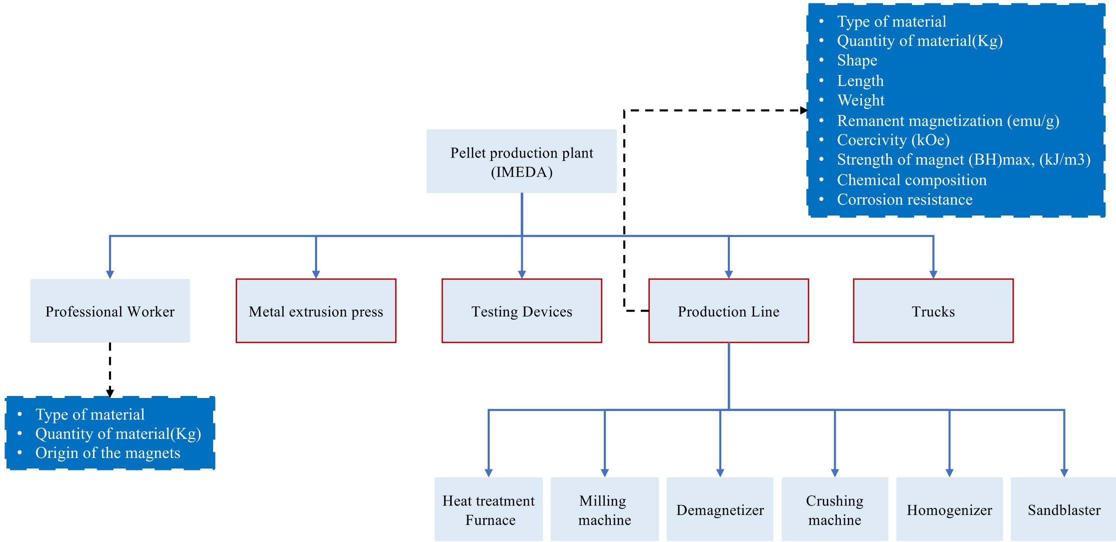


Figure 61: Production aspects, IMDEA

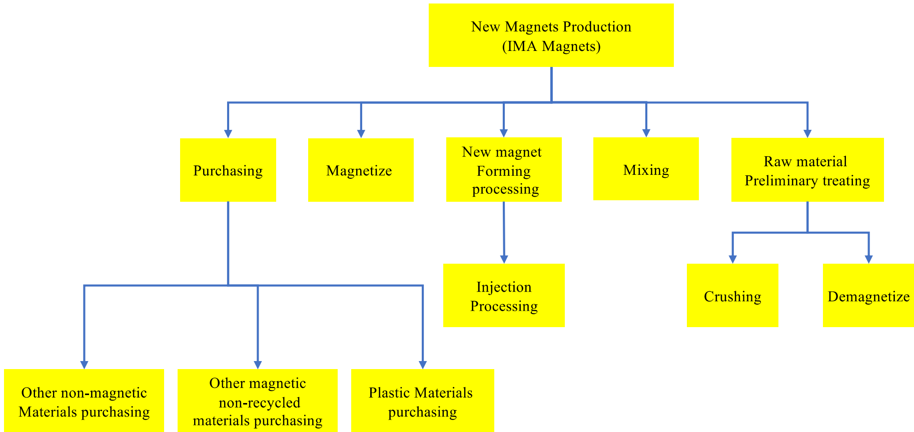


Figure 62: Functional aspects, IMA

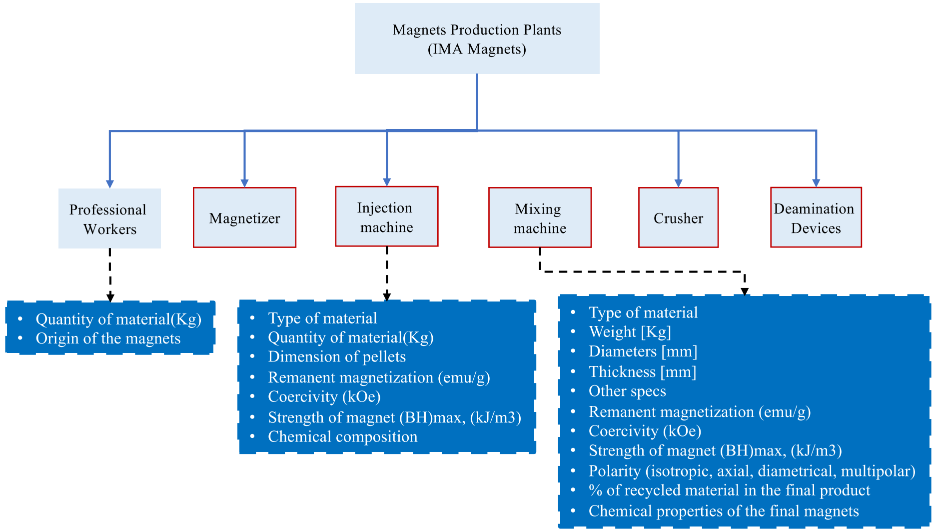


Figure 63: Production aspects, IMA

Appendix D: IMF models for the Italian pilot

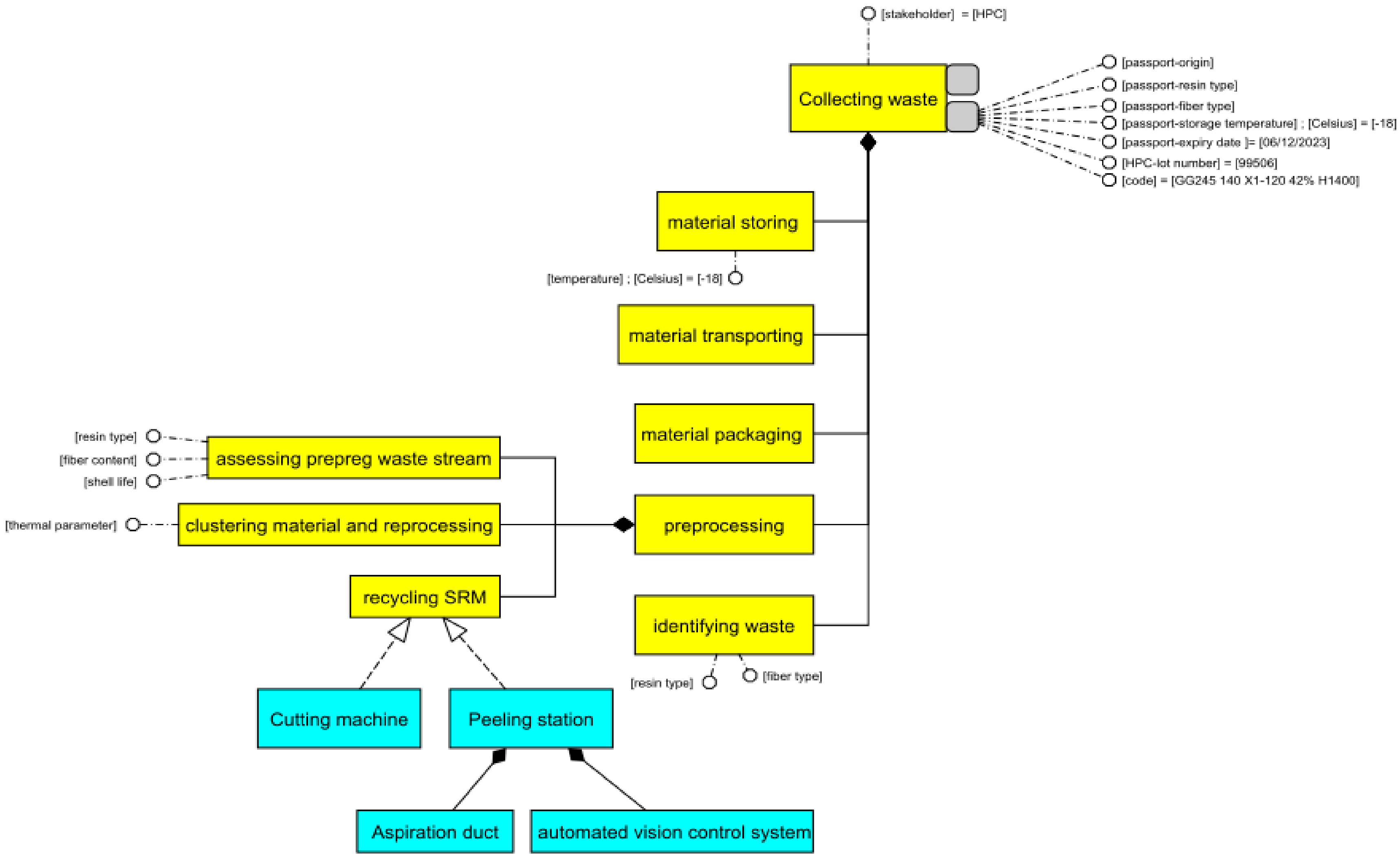


Figure 64: IMF model HPC

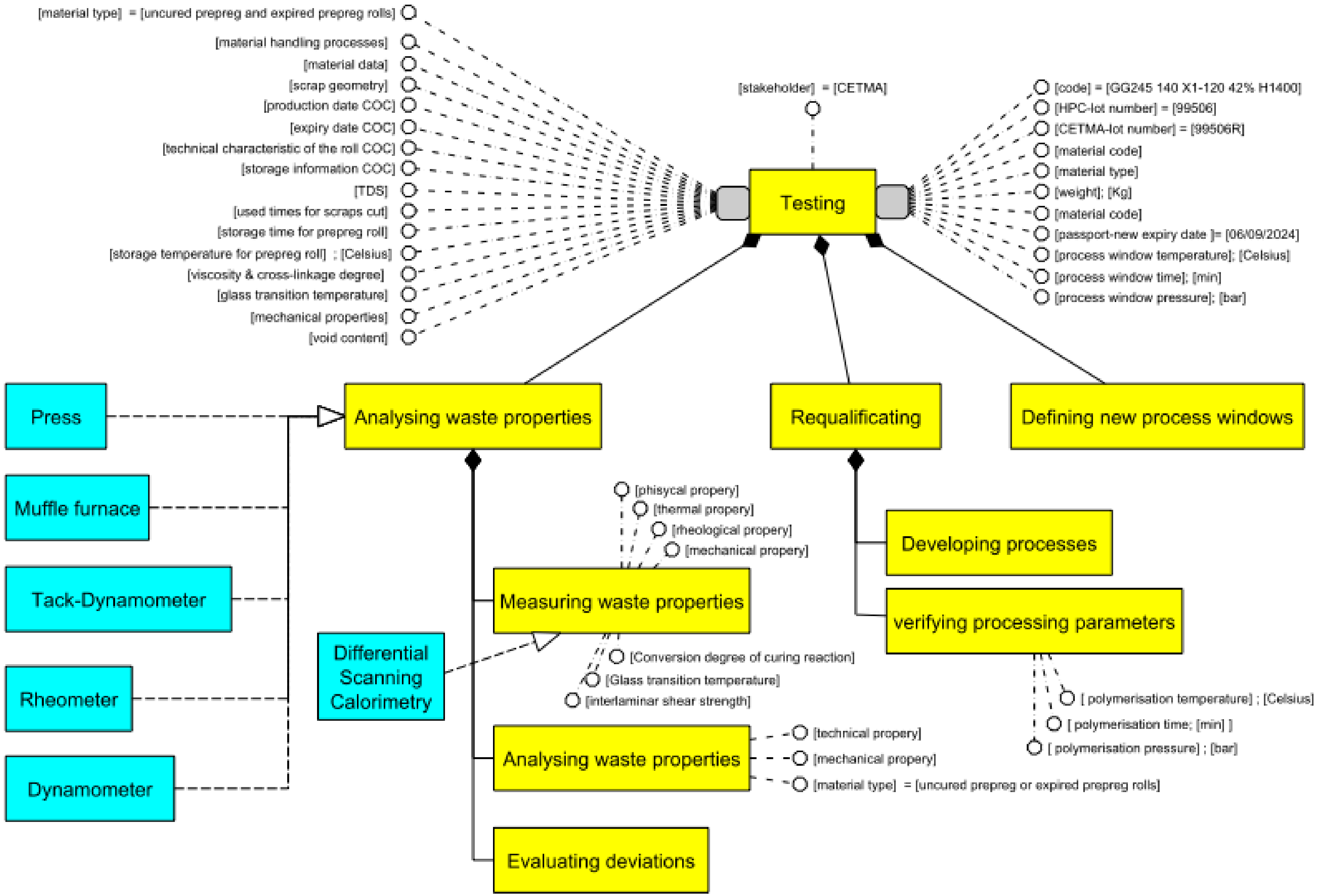


Figure 65: IMF model CETMA

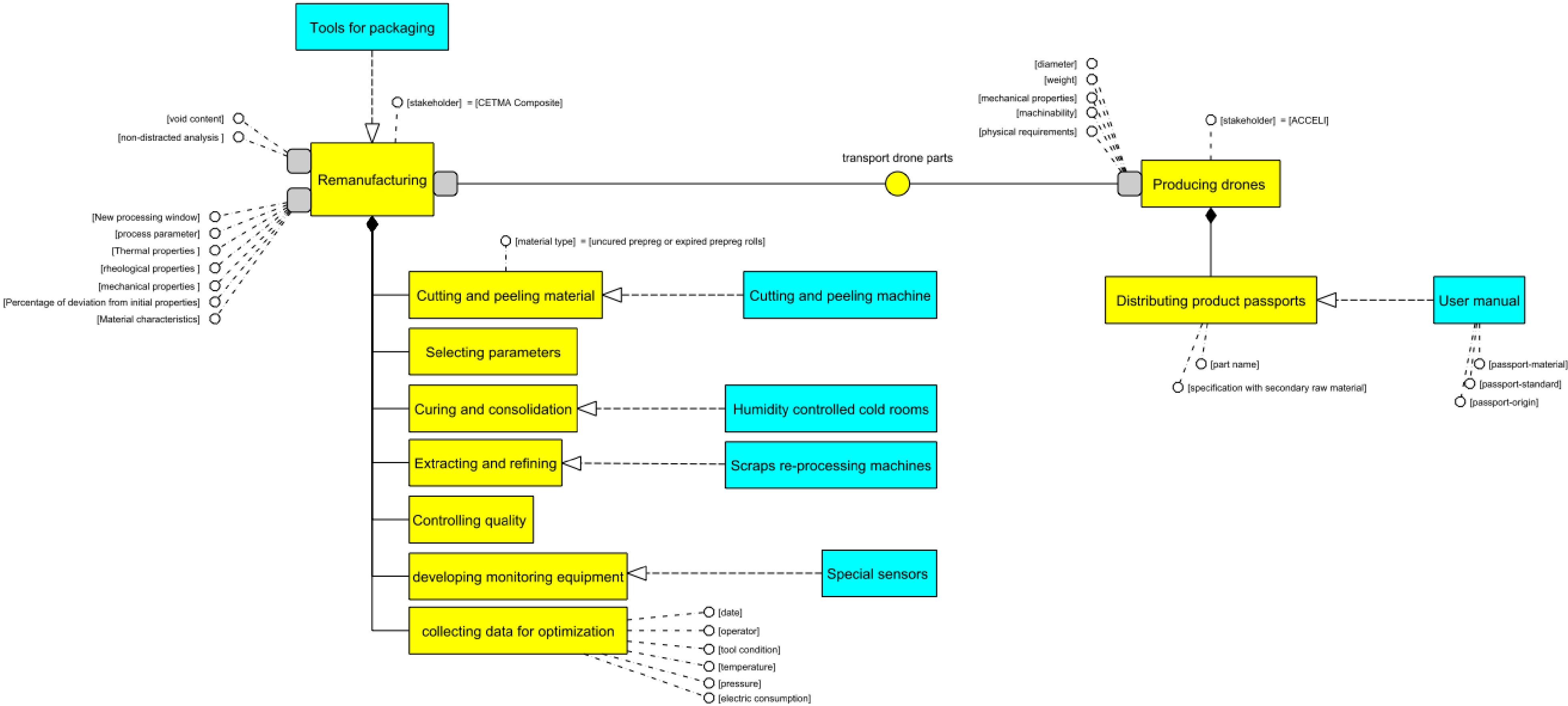


Figure 66: IMF model Cetma Composites

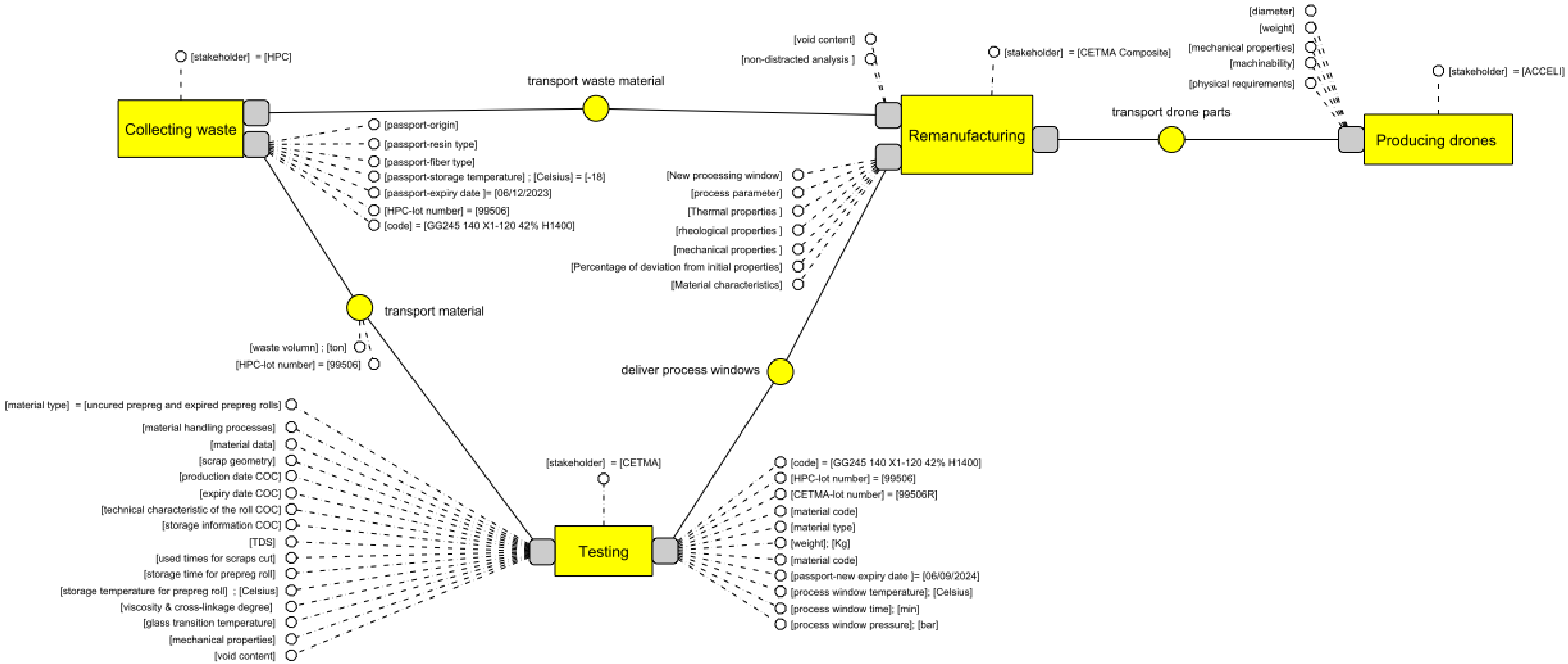


Figure 67: Italian Value network IMF model

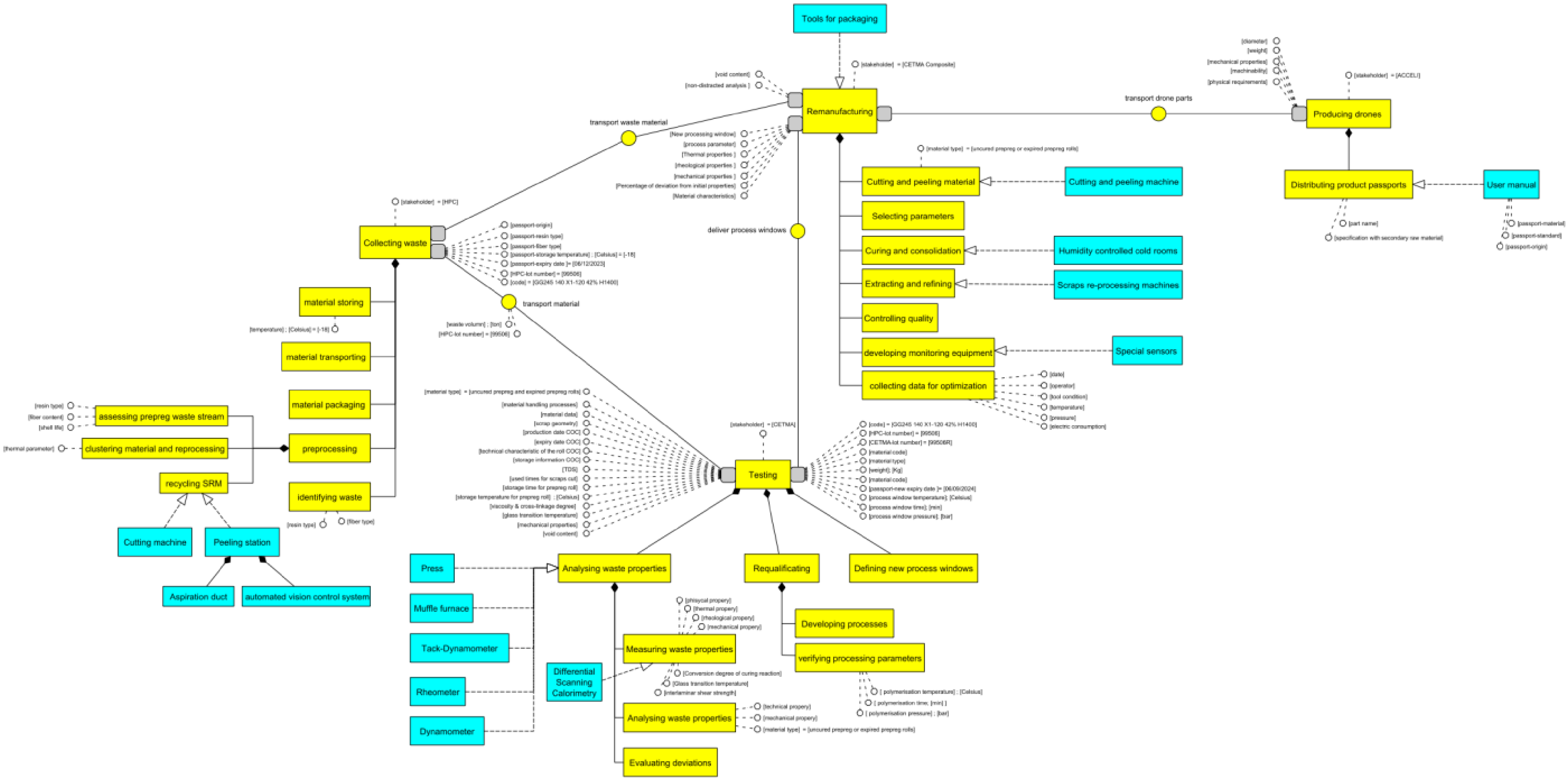


Figure 68: Detailed IMF model Italian pilot

Appendix E: IMF models for the Greek pilot

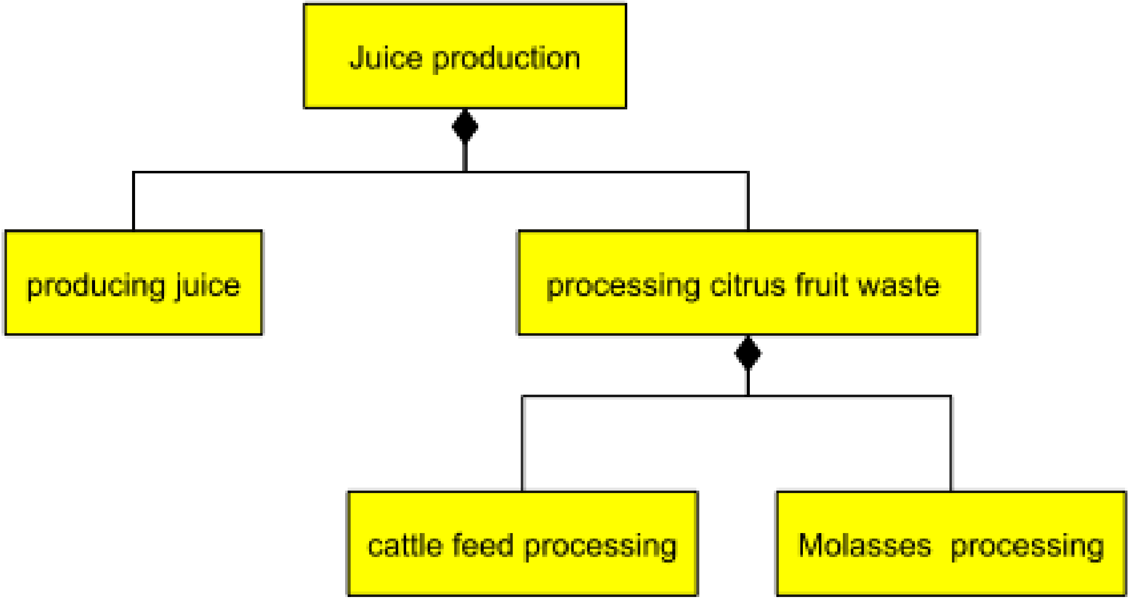


Figure 69: Greek pilot - process breakdown

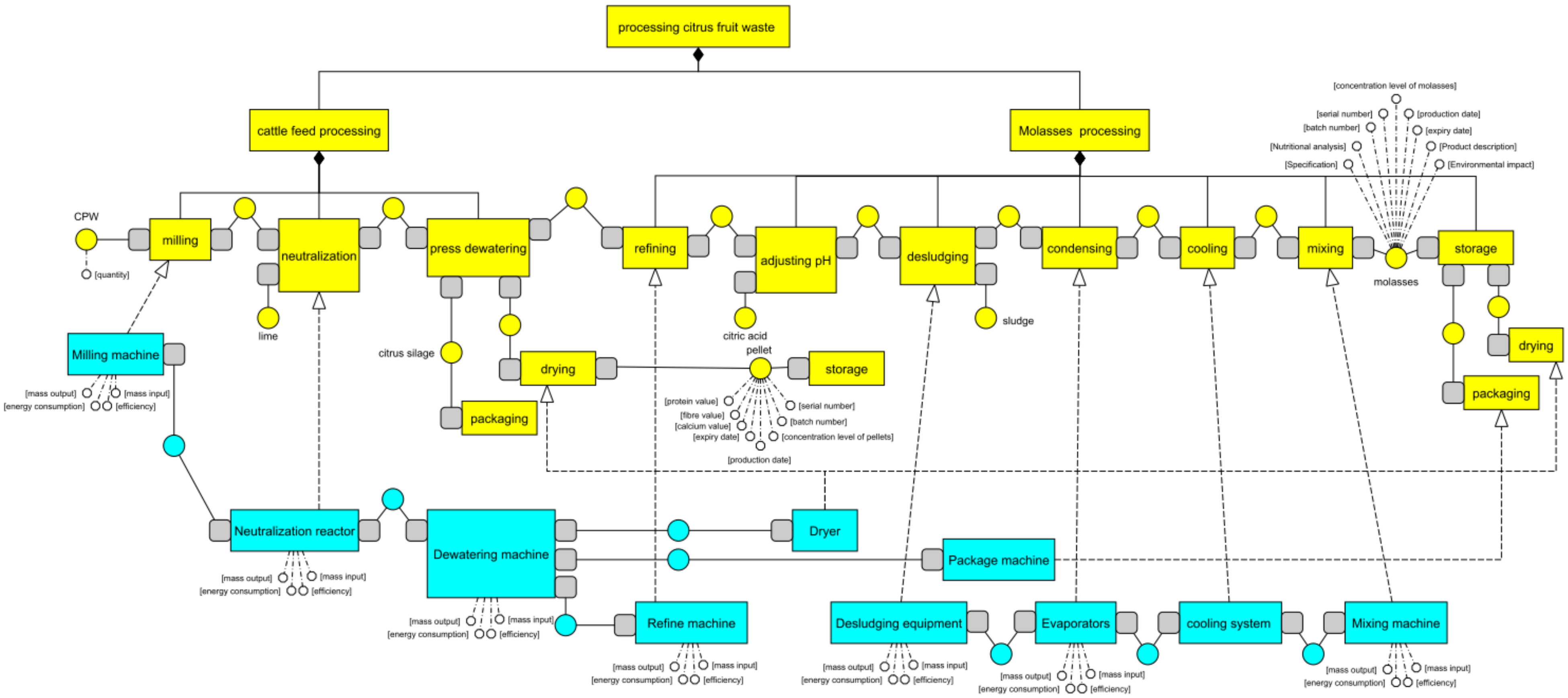


Figure 70: IMF model - Detailed view of by product process

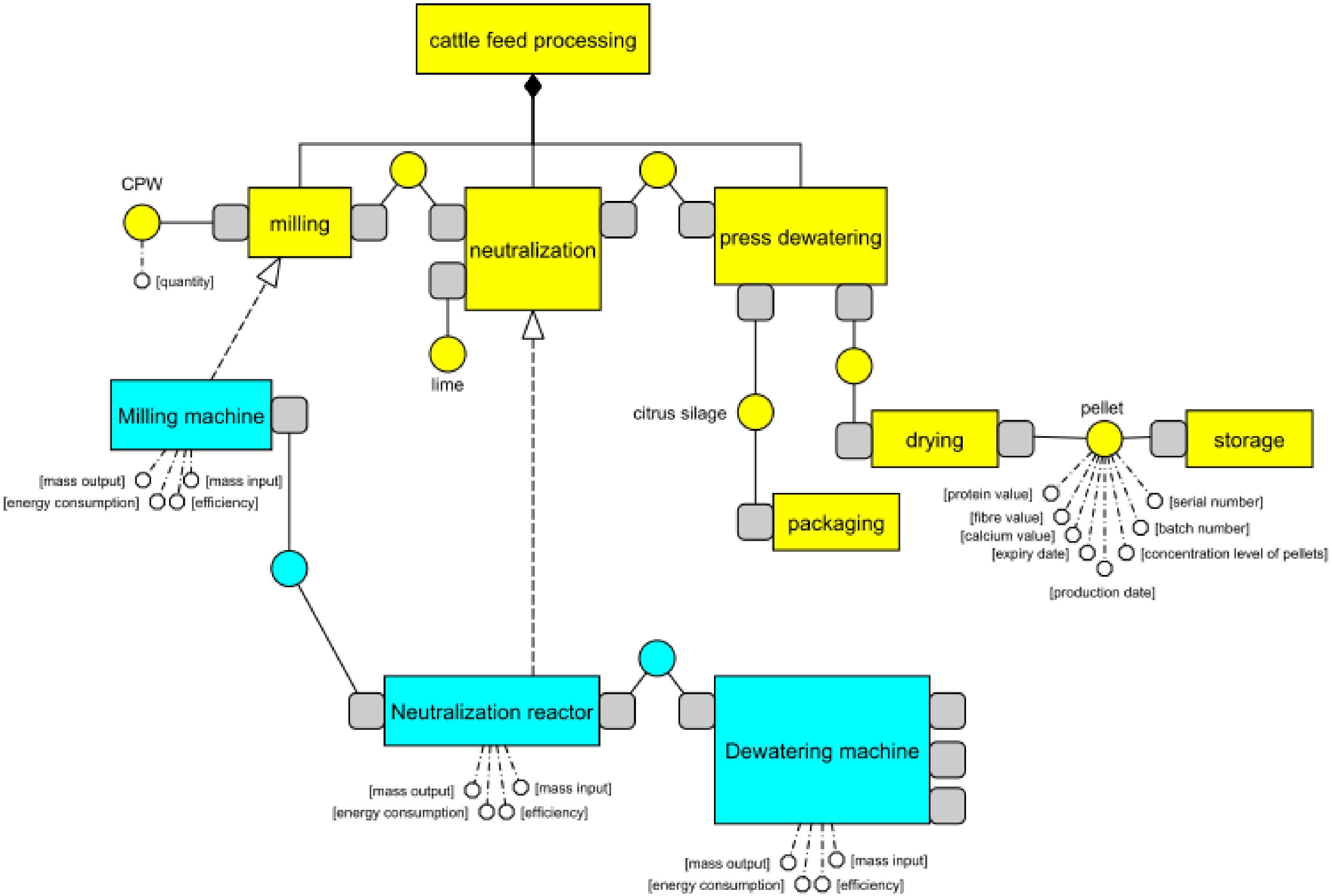


Figure 71: IMF model - Detailed view of CWP group

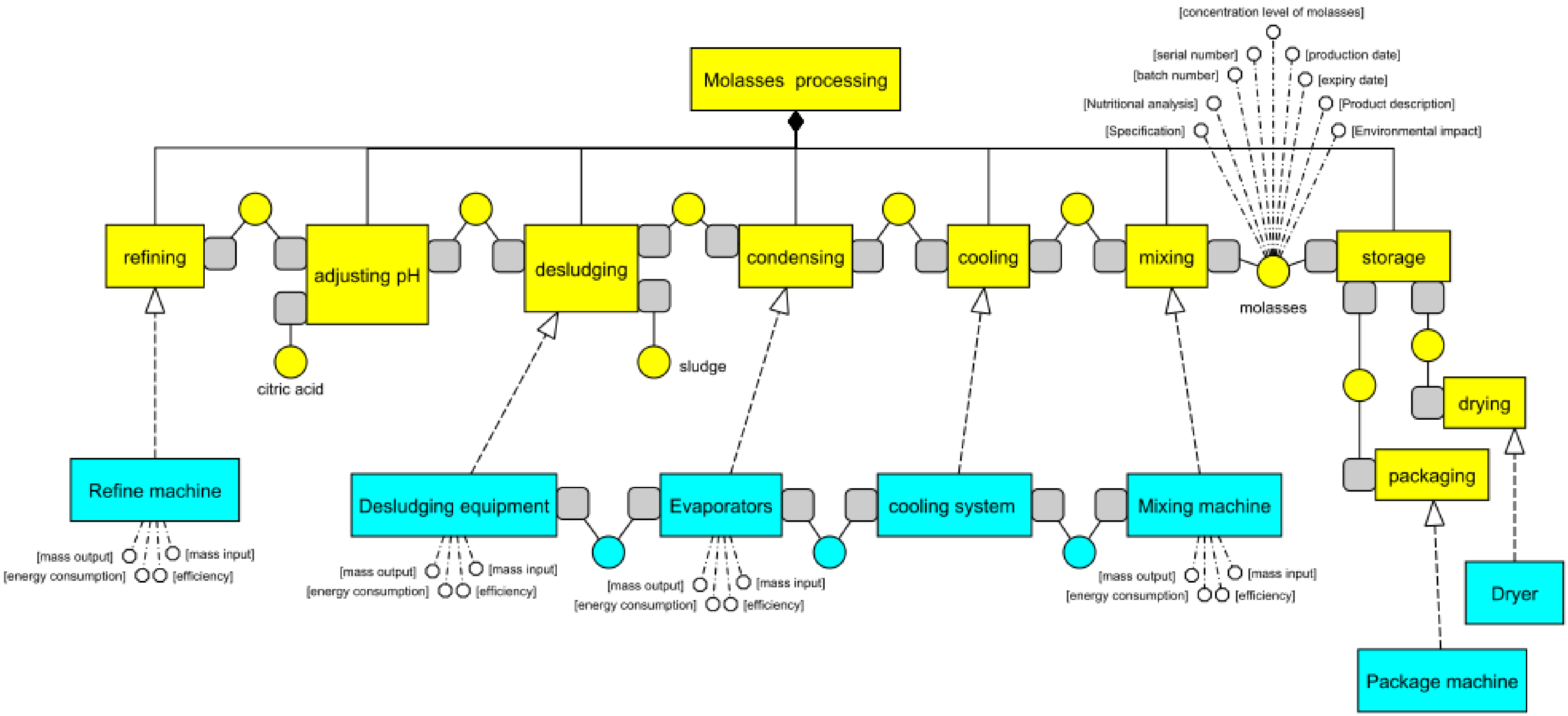


Figure 72: IMF model – detailed view of molasses group

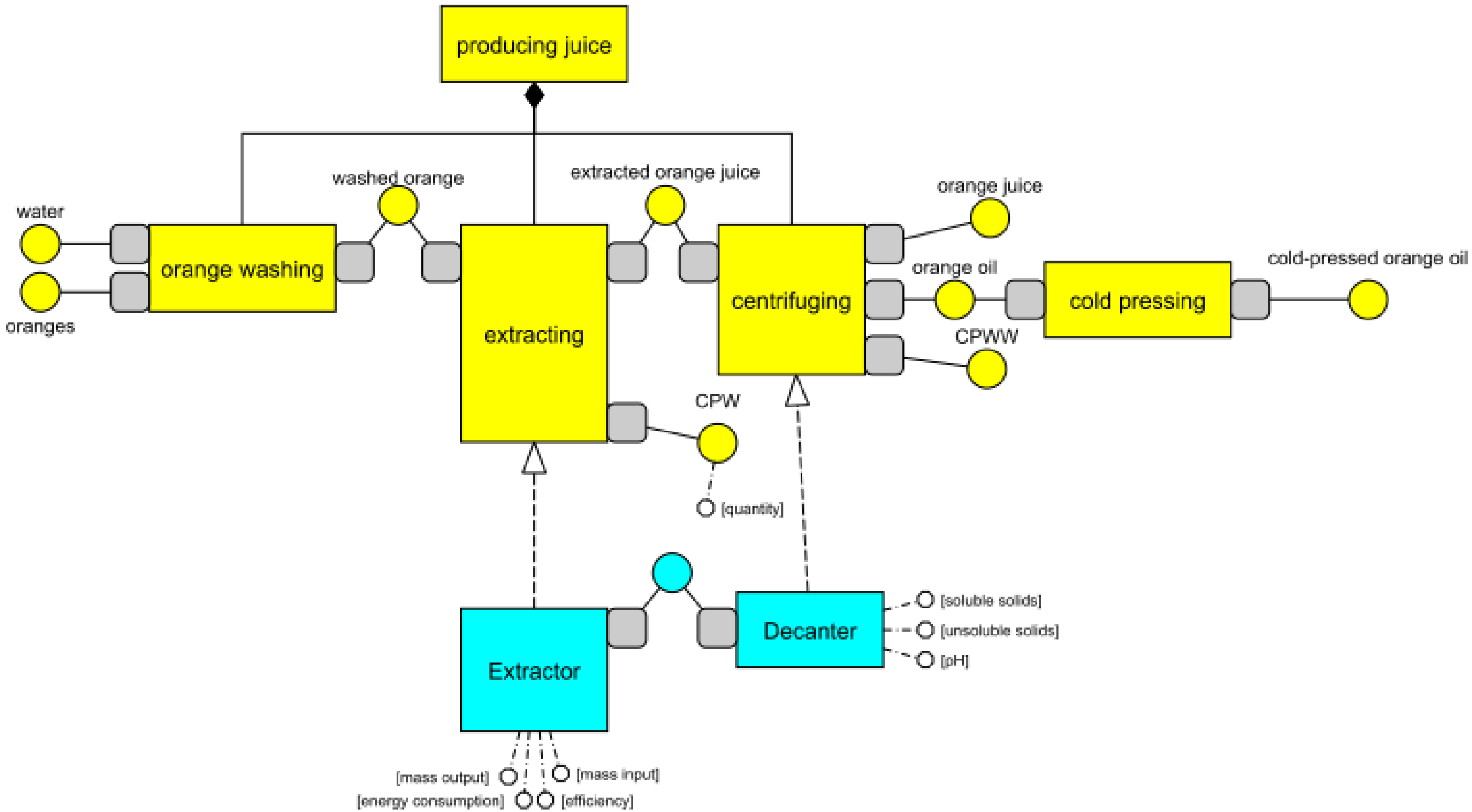


Figure 73: IMF model - detailed view of the juice production

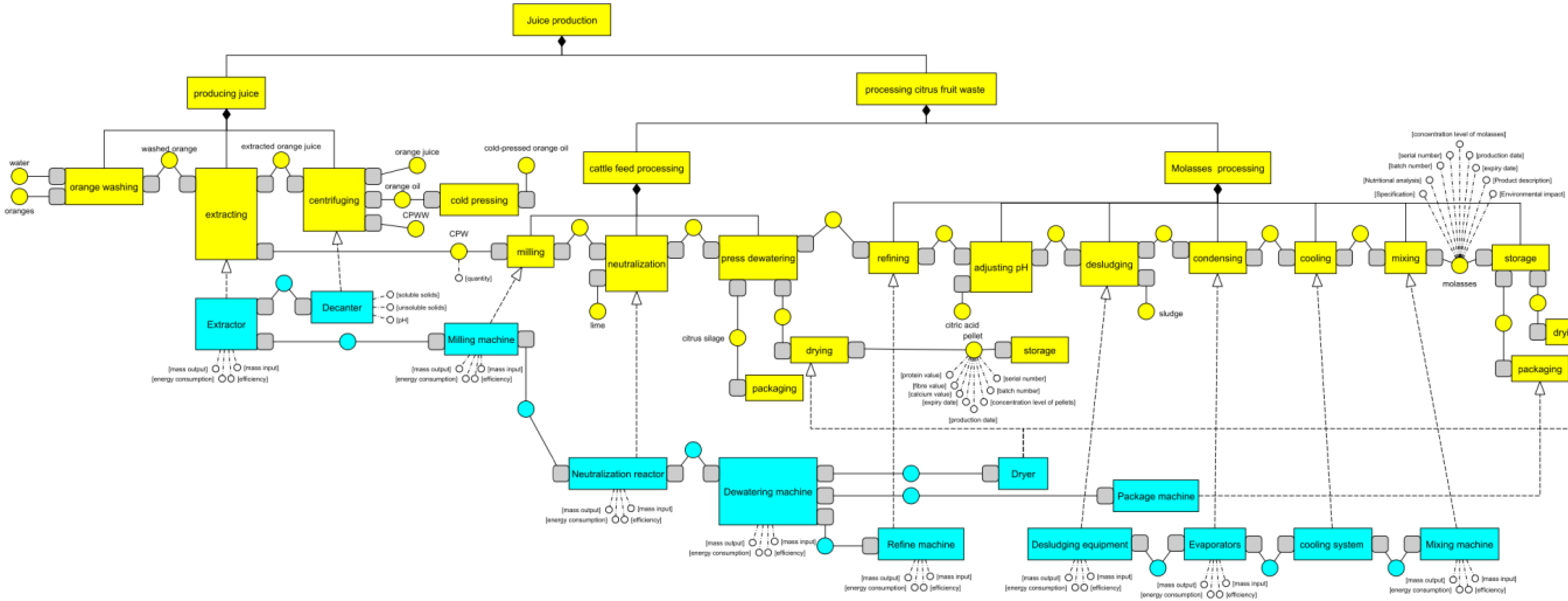


Figure 74: IMF model - Whole production process Greek pilot