D4.1: TREASURE technical architecture (1st version)

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Technical References

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EXECUTIVE SUMMARY

The present deliverable D4.1 “TREASURE technical architecture (1st version)” is the first document released within WP4 “TREASURE platform design, development & integration”, presenting the first version of the platform technical development.

The starting point on which D4.1 is based relates to the early requirements and the preliminary architecture collected from Task 1.2, which is focused on the investigation of high-level TREASURE structure. In particular, the main addressed issues refer to reference framework, users’ needs assessment, advisory model and the related software implementation, as reported into D1.2 “TREASURE tool & platform requirements and specifications”. In accordance with this analysis, the present document firstly reports the definition of the technical requirements and the architectural design of the technical solution to be implemented in subsequent tasks of WP4. These drivers represent the foundations of TREASURE component’s structure defining not only the integration process concerning each key element but also the relevance for use cases purposes.

The first chapter of the present deliverable provides an overall display of the project activities and objectives, with a particular focus on tasks related to WP4, in addition to the explanation of the document scope and its connection with other WPs.

The second chapter presents a complete list of technical requirements, that emerged during the periodic discussion carried out with the project partners, mainly constituted by the target users of the platform and the process owners. To provide a complete depiction of the platform structure, the prioritization process, based on MoSCoW Method, is depicted by assigning a specific subchapter to each requirements category.

The integration of these requirements within the TREASURE platform is outlined in the third chapter with a detailed explanation of the data driven architecture. The relevant role played by TREASURE platform is specified in connection with already existing productive processes in selected industrial scenarios. In particular, three main use cases are considered, according to demonstrators’ emerging needs and requirements, converging in the three modules, i.e. the Disassemblability module, concerning the identification of the critical and valuable parts to be disassembled and related instructions, the Recyclability module, regarding the performance and results of the recycling/recovery processes (covering the entire flowsheet from disassembly, shredding/sorting and (metallurgical) final treatment processes for material and energy recovery) of car and electronics (EoL) raw materials, elements and compounds to identify the best recycling solutions and recycling/recovery rates to be achieved; the Eco-design, providing valuable recommendations for EoL to the design phase based on KPI’s and knowledge as derived from the previous modules. Since the tools foreseen in the platform architecture are transversal to the modules, a specific chapter is assigned to an in-depth depiction of each component, displaying its features, functionalities and objectives in the project’s application with a clear reference to the requirements that have to be fulfilled. On top of the three modules, a Circular AI-based Advisory tool is developed with the aim at supporting both designers and EoL managers in optimizing products’ circularity levels. Simultaneously, a semantic social network analysis is performed to check the social impact of adopted CE practices, offering to customers a graphical index assessing of the circularity level of cars. To complete the platform design characterization, an overview of the data lake is presented, detailing the data flows derived by specific databases that have been selected on the basis of their field of application.

Finally, a detailed list of the TREASURE platform requirements and functionalities, represented in the form of sequence diagrams is provided according to the main identified users of the platform, namely Beginning of Life (BoL) (car parts designer and car makers) and End of Life (EoL) (dismantlers, shredders/sorters, recyclers) actors as well as final consumers. Two diagram categories are illustrated: use-case diagrams model aiming at identifying the synergies between users and systems in a standardized graphical format; and sequence diagrams designed to display how operations are carried out, capturing the interaction between objects in the context of a collaboration.

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1 Introduction

Deliverable D4.1 starts from the outcomes and considerations achieved from the early discussion with the TREASURE use cases, that have been reported into D1.2 "TREASURE tool & platform requirements and specifications", submitted by TXT at M8. The main goal of this deliverable is to define a concrete application of the theoretical assessment and methodology analysis partially performed in WP1 and WP2. This deliverable sets the basis for the platform design, development, and integration in its first form that will be refined in the following months in order to establish the tool final version which will be described in D4.2, due on M28.

1.1 Project Overview

TREASURE – "*leading the TRansition of the European Automotive SUpply chain towards a circulaR futurE"* wants to support the transition of the automotive sector towards Circular Economy (CE), by providing a concrete demonstration of how the industry can benefit from the adoption of Circular Economy practices and principles, both from a business and a technological perspective. One of the main encountered issues highlighted by the automotive actors, refers to the huge information gap exigent between Beginning-of-Life (BoL) and End-of-Life (EoL) actors along the whole automotive value chain up to the final consumers.

TREASURE aims at filling this gap through the development of an AI-based assessment tool able to connect and facilitate the interaction among the key involved stakeholders dedicated to car electronics: car parts suppliers, car makers, dismantlers, and shredders. On the other hand, TREASURE goal consists in assisting both BoL and EoL actors in performing their operations, best recycling options for optimal recovery), taking the most suitable decision according to up-to-date information, as well as in assessing the impact and the effect of their decision on the final customers.

To this aim, a web-based platform will be developed as a new information sharing tool among all stakeholders, both in forward and backward directions, ensuring secure access and confidentiality. The platform will indeed be developed in order to enhance the connection among the actors, making information available through specific modules that will be built and tailored according to their needs.

The platform will be tested with a set of dedicated demonstration actions within the project boundaries. However, it will be designed assuring that its potential can go beyond the project and its sustainability will be properly defined and agreed with the TREASURE consortium, guaranteeing the possibility for its scale-up and adoption by a wider group of stakeholders

1.2 Scope of the deliverable

This deliverable is the outcome of Task 4.1 "TREASURE platform design, development & integration" and it is the first document to be released concerning WP4 activities. Therefore, D4.1 has to be considered as the starting point for the actual design, development and integration of the TREASURE Platform, defining a proper roadmap mainly for the subsequent WP4 Tasks and Deliverables. A refined description of the underlying technical architecture is exposed detailing the single components that are part of the platform with a specification of the tool that will be used and the requirements that will be met.

1.3 Contribution to other WPs

Receiving as input the emerging key points from D1.2 ""TREASURE tool & platform requirements and specifications", submitted by TXT at M8, the present document firstly contributes to WP4 "TREASURE platform design, development and integration" subsequent tasks, as follows:

- Task 4.2 "TREASURE data lake development".
- Task 4.3 "Semantic social network analysis module".
- Task 4.4 "Design of the eco-design, dismantling, reuse and recycling modules".
- Task 4.5 "Circular (AI-based) advisory tool".
- Task 4.6 "Functional and non-functional evaluation".

Since D4.1 defines the platform architecture, it's evident that this deliverable lays the foundation of the technical execution of WP5 activities related to platform application, testing and validation in selected uses cases with the aim at reconfiguring the disassembly and recovery process. The TREASURE Platform will then be validated in the demonstration phase performed within WP6, evaluating the new procedure performances in terms of circularity and economic feasibility. Moreover, the present deliverable also represents the starting point for Advisory tool implementation including its functionality which will be discussed and presented extensively in D2.2.

2 Requirements and specifications

2.1 System requirements

Starting from the list of system requirements early provided in D1.2, this section provides a full list of technical requirements, that emerged during the discussion with the project partners, mainly the target users of the platform and the process owners.

ID	System Requirement	Description	Functional (F)/Non-functional (NF)
R_1	USER LOGIN	The platform must allow login for different user types (car makers, recyclers, …) based on predefined policies	F
R_2	USER ACCESS CONTROL	The platform must enable users to access only the tools allowed by the group policy assigned to them	F
R_3	USER INSERTION	The platform must allow new users to be inserted, specifying a group policy for each one of them	F
R_4	USER REMOVAL	The platform must allow existing users to be removed	F
R_5	USER DATA MODIFICATION	The platform must enable modification of the data corresponding to each user	F
R_6	USER SECURITY	The platform must follow security guidelines for the user authentication procedures	NF
R_7	CAR/ELECTRONICS SELECTION	The platform must allow disassemblers to select the car/electronics to be disassembled	F

R_8	PART SUGGESTIONS	The platform must provide suggestions to the disassembler about specific parts that can be disassembled	F
R_9	DISASSEMBLABILITY PROCEDURE SUGGESTIONS	The platform must provide disassemblers with step-by-step instructions to disassemble specific parts	F
R_10	DISASSEMBLABILITY PROCEDURE CHOICE	The platform must allow disassemblers to choose the desired procedure for disassembling a specific part, among a set of proposed procedures	F
R_11	DISASSEMBLABILITY INSTRUCTIONS VISUALIZATION	The system should provide disassemblability instructions to the user in a simple way using graphical representation	F
R_12	DISASSEMBLABILITY KPI VISUALIZATION	The platform must provide disassemblers with the proper KPI relevant to the part being disassembled,	F
R_13	DISASSEMBLABILITY FEEDBACK	The platform must allow disassemblers to provide feedback about a specific disassembly operation	F
R_14	COBOT ACTIVATION	The platform must allow disassemblers to communicate and activate pre-defined operations of the cobot	F
R_15	COBOT TRAINING	The platform must allow disassemblers to teach the cobot to perform unknown operations and save reference in the platform	F
R_16	ELEMENT/MATERIAL SELECTION	The platform must provide knowhow on specific elements/materials to be recovered by and send to most suited recycling operators/recyclers (meaning final treatment processors such as metallurgical recycling processing and refining)	F
R_17	RECYCLABILITY INSTRUCTIONS VISUALIZATION	Similar to R_11 but targeted to shredders/physical recycling operators/recyclers	F
R_18	RECYCLABILITY KPI VISUALIZATION	The platform must provide shredders/physical recycling operators/recyclers with the proper KPI's relevant to the valuable/critical materials being recycled (and all other materials/compounds included)	F
R_19	RECYCLABILITY FEEDBACK	The platform must provide feedback and insight to shredders/physical recycling operators/recyclers concerning recovery rates of specific elements/compounds or materials (within the suite of all other materials/elements/compounds recovered and lost/emitted)	F
R_20	PROCEDURES DOWNLOAD	The platform must allow disassemblers and shredders/physical recycling operators/recyclers to download procedures on the device	F

R_21	CAR/PART INFORMATION SHARING	The platform must allow car parts designers/car makers to upload information about cars and parts composition	F
R_22	CAR/PART INFORMATION UPDATE	The platform must allow car parts designers/car makers to update existing information about cars and parts composition	F
R_23	CAR/PART SEARCH	The platform must allow car parts designers/car makers to search for car/parts	F
R_24	CAR/PARTS KPI VISUALIZATION	The platform must allow the car parts designers/car makers to visualize relevant information and KPIs about a specific car/part	F
R_25	CE PRACTICES VISUALIZATION	The platform must allow car parts designers/car makers to view graphs assessing the impact of their Circular Economy practices in the market	F
R_26	SUGGESTIONS VISUALIZATION	The Platform must allow car parts designers/car makers to view eco-design suggestions regarding a specific car/part	F
R_27	CONSUMER SEARCH	The platform must allow consumers to search for a specific car	F
R_28	CONSUMER INDICATORS VISUALIZATION	The platform must allow customers to view CE indicators and graphical indexes reporting the circularity level of their cars	F
R_29	KPI COMPARISON	The platform must allow disassemblers, shredders/physical recycling operators/recyclers and car parts designers/car makers to compare KPIs relevant to them	F
R_30	DATA SECURITY	The platform must guarantee security of data	NF
R_31	OPEN INTERFACES	The platform should possibly be implemented using open interfaces to be able to communicate with other systems.	NF
R_32	DATA ENTRY PART/MODULE COMPOSITION	Availability and entry of the complete BOM and FMD, i.e., material description in terms of components, materials, elements in terms of both physical materials and corresponding chemical/molecular formulas etc. into the simulation model of each module/part	F
R_33	RECYCLING SIMULATIONS	Simulate the recycling of the modules and calculated the recycling rates of modules, materials, components etc. for different most suitable recycling flowsheet configurations	F
R_34	RECYCLING/RECOVERY RATES	Know-how on recycling/recovery rates for all elements/compounds/materials included	F

R_35	DISASSEMBLY FOR OPTIMAL RECYCLING	Instructions to disassemblers for optimal disassembly depth/intensity for optimal recycling/recovery	F
R_36	DESIGN FOR RECYCLING	Feedback to OEMs/part suppliers on DfR based on results and insights on losses/emissions and/or low recovered materials/compounds based on the range of simulations performed by the recycling simulation model	F
R_37	SURROGATE FUNCTION (AI)	Create a surrogate function (AI) that captures the recyclability of the modules that can be applied in the TREASURE platform	F
R_38	RECYCLING FLOWSHEET INSTRUCTIONS	…see above	F

Table 2.1 – Technical system requirements

2.2 Preliminary MVP

In order to delineate the MVP features of the TREASURE Platform, the MoSCoW Method has been adopted, representing a standardized way to express requirements priority, based on the RFC-2119 specification. The standard defines four prioritization categories in which each requirement must be included: must-have, should-have could-have and won't-have (or won't-have right now). In the following sections are listed all the previously indicated requirements following the MoSCoW classification and organized by category; a brief explanation of the categories is also given at the beginning of each section.

2.2.1 Must-have requirements

Requirements indicated as must-have are considered critical in the scope of the project and represent features that for sure will be present in the final product. The table below lists all the must-have requirements for the TREASURE Platform which have been selected starting from the previous requirements identification.

ID	System Requirement	Description	Functional (F)/Non-functional (NF)
R_1	USER LOGIN	The platform must allow login for different user types (car makers, recyclers, …) based on predefined policies	F
R_2	USER ACCESS CONTROL	The platform must enable users to access only the tools allowed by the group policy assigned to them	F
R_3	USER INSERTION	The platform must allow new users to be inserted, specifying a group policy for each one of them	F
R_4	USER REMOVAL	The platform must allow existing users to be removed	F
R_5	USER DATA MODIFICATION	The platform must enable modification of the data corresponding to each user	F
R_6	USER SECURITY	The platform must follow security guidelines for the user authentication procedures	NF

R_7	CAR/ELECTRONICS SELECTION	The platform must allow disassemblers to select the car/electronics to be disassembled	F
R_9	DISASSEMBLABILITY PROCEDURE SUGGESTIONS	The platform must provide disassemblers with step-by-step instructions to disassemble specific parts	F
R_11	DISASSEMBLABILITY INSTRUCTIONS VISUALIZATION	The system should provide disassemblability instructions to the user in a simple way using graphical representation	F
R_14	COBOT ACTIVATION	The platform must allow disassemblers to communicate and activate pre-defined operations of the cobot	F
R_17	RECYCLABILITY INSTRUCTIONS VISUALIZATION	Similar to R_11 but targeted to shredders/physical recycling operators/recyclers	F
R_19	RECYCLABILITY FEEDBACK	The platform must provide feedback and insight to shredders/physical recycling operators/recyclers concerning recovery rates of specific elements/compounds or materials (within the suite of all other materials/elements/compounds recovered and lost/emitted)	F
R_20	PROCEDURES DOWNLOAD	The platform must allow disassemblers and shredders/physical recycling operators/recyclers to download procedures on the device	F
R_23	CAR/PART SEARCH	The platform must allow car parts designers/car makers to search for car/parts	F
R_24	CAR/PARTS KPI VISUALIZATION	The platform must allow the car parts designers/car makers to visualize relevant information and KPIs about a specific car/part	F
R_25	CE PRACTICES VISUALIZATION	The platform must allow car parts designers/car makers to view graphs assessing the impact of their Circular Economy practices in the market	F
R_26	SUGGESTIONS VISUALIZATION	The Platform must allow car parts designers/car makers to view eco-design suggestions regarding a specific car/part	F
R_29	KPI COMPARISON	The platform must allow disassemblers, shredders/physical recycling operators/recyclers and car parts designers/car makers to compare KPIs relevant to them	F
R_30	DATA SECURITY	The platform must guarantee security of data	NF
R_32	DATA ENTRY PART/MODULE COMPOSITION	Availability and entry of the complete BOM and FMD, i.e., material description in terms of components, materials, elements in terms of both physical materials and corresponding chemical/molecular formulas etc. into	F

		the simulation model of each module/part	
R_33	RECYCLING SIMULATIONS	Simulate the recycling of the modules and calculated the recycling rates of modules, materials, components etc. for different most suitable recycling flowsheet configurations	F
R_34	RECYCLING/RECOVERY RATES	Know-how on recycling/recovery rates for all elements/compounds/materials included	F
R_35	DISASSEMBLY FOR OPTIMAL RECYCLING	Instructions to disassemblers for optimal disassembly depth/intensity for optimal recycling/recovery	F
R_36	DESIGN FOR RECYCLING	Feedback to OEMs/part suppliers on DfR based on results and insights on losses/emissions and/or low recovered materials/compounds based on the range of simulations performed by the recycling simulation model	F
R_37	SURROGATE FUNCTION (AI)	Create a surrogate function (AI) that captures the recyclability of the modules that can be applied in the TREASURE platform	F
R_38	RECYCLING FLOWSHEET INSTRUCTIONS	…see above	F

Table 2.2 - TREASURE Platform, must-have requirements

2.2.2 Should-have requirements

Requirements indicated as should-have are considered important, similar to must-have requirements, but not critical in the delivery of the final product and, therefore can be held back in favour of must-have ones in case of delays in the delivery plan.

ID	System Requirement	Description	Functional (F)/Non-functional (NF)
R_8	PART SUGGESTIONS	The platform must provide suggestions to the disassembler about specific parts that can be disassembled	F
R_10	DISASSEMBLABILITY PROCEDURE CHOICE	The platform must allow disassemblers to choose the desired procedure for disassembling a specific part, among a set of proposed procedures	F
R_13	DISASSEMBLABILITY FEEDBACK	The platform must allow disassemblers to provide feedback about a specific disassembly operation	F
R_15	COBOT TRAINING	The platform must allow disassemblers to teach the cobot to perform unknown operations and save reference in the platform	F
R_16	ELEMENT/MATERIAL SELECTION	The platform must provide knowhow on specific elements/materials to be recovered by and send to most suited recycling operators/recyclers (meaning final treatment processors such as	F

		metallurgical recycling processing and refining)	
R_21	CAR/PART INFORMATION SHARING	The platform must allow car parts designers/car makers to upload information about cars and parts composition	F
R_22	CAR/PART INFORMATION UPDATE	The platform must allow car parts designers/car makers to update existing information about cars and parts composition	F
R_31	OPEN INTERFACES	The platform should possibly be implemented using open interfaces to be able to communicate with other systems.	NF

Table 2.3 - TREASURE Platform, should-have requirements

2.2.3 Could-have requirements

Requirements indicated as could-have are considered desirable but not necessary for the filial product. These requirements may bring marginal benefit in addition to the core product and therefore may be postponed after the delivery of the final product.

ID	System Requirement	Description	Functional (F)/Non-functional (NF)
R_12	DISASSEMBLABILITY KPI VISUALIZATION	The platform must provide disassemblers with the proper KPI relevant to the part being disassembled,	F
R_18	RECYCLABILITY KPI VISUALIZATION	The platform must provide shredders/physical recycling operators/recyclers with the proper KPI's relevant to the valuable/critical materials being recycled (and all other materials/compounds included)	F
R_27	CONSUMER SEARCH	The platform must allow consumers to search for a specific car	F
R_28	CONSUMER INDICATORS VISUALIZATION	The platform must allow customers to view CE indicators and graphical indexes reporting the circularity level of their cars	F

Table 2.4 - TREASURE Platform, could-have requirements

2.2.4 Won't-have right now requirements

Requirements indicated as won't-have right now are considered least-critical or not appropriate for the time being and, as a result, those are not planned for the final delivery of the product. Usually, requirements marked as won't-have right now are either dropped or reconsidered at a later time.

ID	System Requirement	Description	Functional (F)/Non-functional (NF)
-	-	-	-

Table 2.5 - TREASURE Platform, won't-have right now requirements

Please note that, for the time being, the TREASURE Platform does not have any won't-have requirements.

3 TREASURE Platform technical architecture

3.1 Introduction

The TREASURE Platform will be a web-based multi-layered data-driven platform able to foster the communication and connect TREASURE Partners, exchange valuable information and knowledge for a proper implementation of CE practices along the automotive value chain.

The platform exchanges KPIs on recycling rate, disassembly and recycling instructions, information for identification of materials/elements/compounds with a low recycling/recovery rate or losses/emission.

In particular, **3 main modules** are foreseen to support the platform activities:

- A **Disassemblability module** providing information on critical and valuable car parts to be disassembled and useful disassembly instructions.
- A **Recyclability module** providing information on the recycling/recovery rates of car and electronics raw materials/elements/compounds (including losses and emissions) and providing advice on best recycling routes and processes for optimal recovery and disassembly intensity.
- An **Eco-design module** providing information on hardware components, valuable recommendations for the design phase based on KPI's as derived from the disassembly and recycling module.

On top of the three major modules, a **Circular AI-based advisory tool** will be developed to provide intelligence to the system.

The platform is complemented by a **service layer** providing several functionalities needed by upper modules like administration services (accounting, authorisation and authentication), AR/VR development platform and others including the **Semantic Social Network Analysis Module**, connecting the EDGEYDERS Platform, to check the social impact of adopted CE practices and offer to customers a graphical index assessing the circularity level of cars.

At bottom layer data coming from the different Lifecyle stages are stored, managed and connected with external databases.

The following sections provide a detailed technical architecture, highlighting the main technologies that will be used for the main platform components development, starting from the finding reported into D1.2.

3.2 Software Architecture

Starting from the early logical architecture of the TREASURE Platform reported in D1.2, where principles of software architecture design were highlighted, this section depicts the detailed 1st version of TREASURE Platform architecture. The TREASURE Platform will deal with several different industrial scenarios, where Artificial Intelligence will have effects on the existing processes by enhancing the implementation of Circular Economy practices along the whole automotive value chain that will be interconnected. Accordingly, a proper Reference Architecture following a data-driven approach and capable of driving the automotive sector transformation into a networked, data driven environment, empowered at the same time with the concepts of AI have been developed.

The TREASURE Platform architecture can be divided into three sub-architectures, with the aim of providing categorized building blocks that will exploit specific tasks at different levels of abstraction. The lower-level components will then be exploited by higher-level ones through a standardized interface that will allow for generality of implementation and reusability throughout a wide variety of different scenarios. The figure below shows how the individual components are grouped inside the three sub-architectures and a basic interactional model among them; this will be further expanded in the next chapters. In particular, for each specific component, a dedicated paragraph will describe its purpose in the TREASURE Platform, the requirements covered and integration with the rest of the platform architecture.

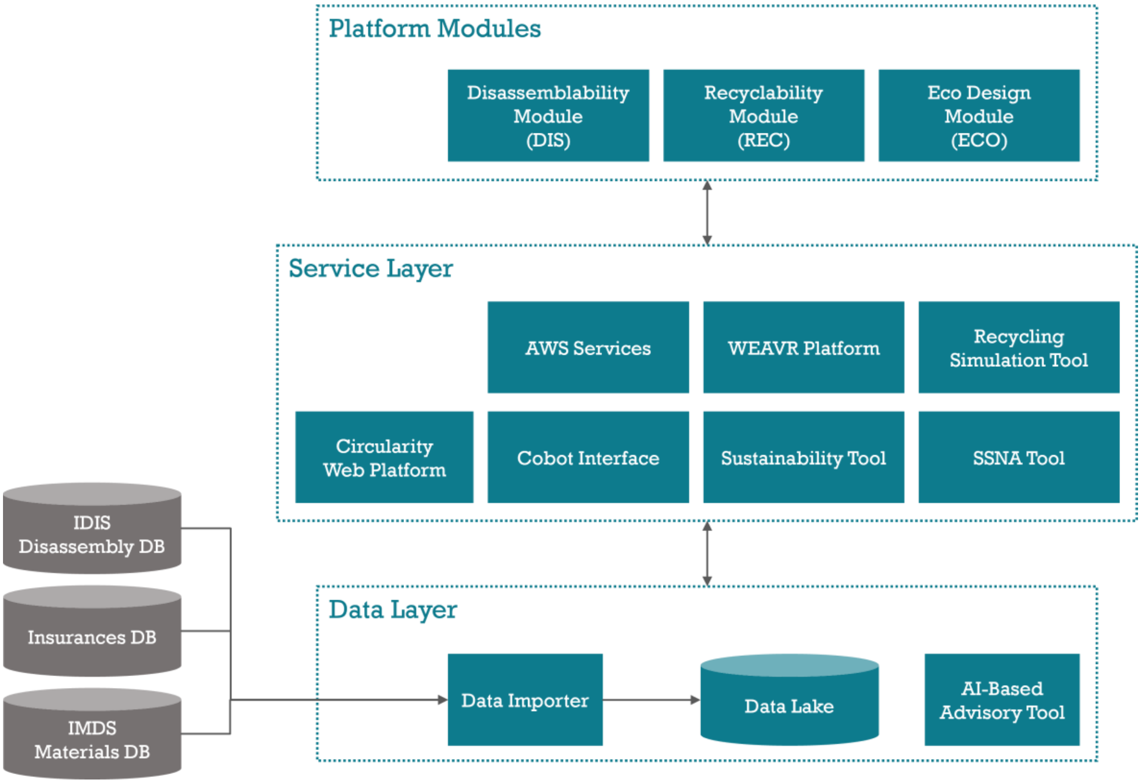


Figure 3.1 - Architecture of the TREASURE Platform

The first sub-architecture to be presented is the *Data Layer*, containing all the components that will heavily leverage data flow and manipulation. In particular, the TREASURE Data Lake constitutes the centralized storage location where all the data relevant for the TREASURE Platform will reside. Data can either be shared by the interested partners or gathered from external data sources that are publicly available and relevant in the scope of the project. For this second case specifically, the Data Importer component will be exploited to fetch external information and provide them to the Data Lake in a standardized format that is suitable for the future processing to be performed. Finally, the AI-Based Advisory Tool will perform assistive predictions and KPI forecasting starting from the raw data collected.

The Data Layer components will then be leveraged by the *Service Layer* to create the basic services contributing to the high-level platform modules. The Service Layer acts as a middleware and it is responsible for implementing the main components able to interact with multiple modules in different ways. Therefore, each individual component must be made serviceable for different purposes, depending on the upper layer it interacts with. The Recycling Simulation Tool, Sustainability Tool and SSNA Tool will provide suitable methodologies to support the decision process that will take place in the three upper modules, while the WEAVR platform will support operators in the physical procedures to be performed, in conjunction with the automated robotic arm (cobot) controlled via the Cobot Interface. The circularity Web Platform will support BoL actors in the decision-making process by providing a visual representation of critical KPIs and interactive dashboards. Finally, the Service Layer will be supported by a set of AWS Services for all the behind-the-scenes tasks, such as user management, load balancing and data storage solutions.

The last sub-architecture to be presented consists of the three main *Platform Modules*, each one focusing on an individual aspect of the TREASURE Project. The Disassemblability module will focus on the dismantling process of EoL vehicles both from a methodological and industrial point of view, the Recyclability module will be centred around recycling procedures for materials extracted from EoL components, while the Eco Design module will support decision making processes for BoL actors responsible for components and car parts manufacturing. In particular:

- The Disassemblability module will leverage the WEAVR platform and Cobot Interface for the physical dismantling procedures, suggested by the AI-Based Advisory Tool on the basis of the TREASURE Data Lake.
- The Recyclability module will focus on recycling procedures and sustainability KPIs obtained through the use of Sustainability Tool and Recycling Simulation Tool. The physical recycling procedures are once again supported by the WEAVR platform.
- The Eco-Design module will exploit the SSNA Tool and Circularity Web Platform to serve BoL actors with proper knowledge generated by the AI-Based Advisory tool on top of the platform data provided by the TREASURE Data Lake.

For all of the three above modules, technological support will be provided by the AWS Services component for backend tasks, similar to what described in the Service layer usage.

3.3 Disassemblability Module (DIS)

3.3.1 Purpose

The Disassemblability module (DIS) mainly address EoL actors, dismantlers, and shredders in particular. Car makers will also leverage on this module to understand how to improve car assembly process, both in terms of time and effectiveness, to therefore improve car repair, disassembly and following operations.

By combining all the received information from car makers, car parts suppliers and external databases, this module will be able to provide information on critical and valuable car parts to be disassembled and generate valuable disassembly instructions.

3.3.2 Covered Requirements

In the table below are listed all the requirements covered by the Disassemblability module (DIS). In the last column are listed all the components in charge to fulfil the corresponding requirement. Further details are provided in the chapter of each specific component.

Requirement ID	Requirement Name	Requirement Description	Component in charge
R_1	USER LOGIN	The platform must allow login for different user types (car makers, recyclers, …) based on predefined policies	WEAVR Platform, AWS Services
R_2	USER ACCESS CONTROL	The platform must enable users to access only the tools allowed by the group policy assigned to them	WEAVR Platform, AWS Services

R_3	USER INSERTION	The platform must allow new users to be inserted, specifying a group policy for each one of them	WEAVR Platform, AWS Services
R_4	USER REMOVAL	The platform must allow existing users to be removed	WEAVR Platform, AWS Services
R_5	USER DATA MODIFICATION	The platform must enable modification of the data corresponding to each user	WEAVR Platform, AWS Services
R_6	USER SECURITY	The platform must follow security guidelines for the user authentication procedures	WEAVR Platform, AWS Services
R_7	CAR/ELECTRONICS SELECTION	The platform must allow disassemblers to select the car/electronics to be disassembled	WEAVR Platform
R_8	PARTS SUGGESTIONS	The platform must provide suggestions to the disassembler about specific parts that can be disassembled	WEAVR Platform, AI-Based Advisory Tool
R_9	DISASSEMBLABILITY PROCEDURE SUGGESTIONS	The platform must provide disassemblers with step-by-step instructions to disassemble specific parts	WEAVR Platform
R_10	DISASSEMBLABILITY PROCEDURE CHOICE	The platform must allow disassemblers to choose the desired procedure for disassembling a specific part, among a set of proposed procedures	WEAVR Platform
R_11	DISASSEMBLABILITY INSTRUCTIONS VISUALIZATION	The system should provide disassemblability instructions to the user in a simple way using graphical representation	WEAVR Platform
R_12	DISASSEMBLABILITY KPI VISUALIZATION	The platform must provide disassemblers with the proper KPI relevant to the part being disassembled,	WEAVR Platform, Sustainability Tool
R_13	DISASSEMBLABILITY FEEDBACK	The platform must allow disassemblers to provide feedback about a specific disassembly operation	WEAVR Platform
R_14	COBOT ACTIVATION	The platform must allow disassemblers to communicate and activate pre-defined operations of the cobot	Cobot Interface
R_15	COBOT TRAINING	The platform must allow disassemblers to teach the cobot to perform unknown operations and save reference in the platform	Cobot Interface
R_21	CAR/PART INFORMATION SHARING	The platform must allow car parts designers/car makers to upload information about cars and parts composition	Data Lake
R_22	CAR/PART INFORMATION UPDATE	The platform must allow car parts designers/car makers to update existing information about cars and parts composition	Data Lake
R_29	KPI COMPARISON	The platform must allow disassemblers, shredders/physical recycling operators/recyclers and car	Sustainability Tool

		parts designers/car makers to compare KPIs relevant to them	
R_30	DATA SECURITY	The platform must guarantee security of data	Data Lake, AWS Services
R_31	OPEN INTERFACES	The platform should possibly be implemented using open interfaces to be able to communicate with other systems.	Data Lake, AWS Services
R_32	DATA ENTRY PART/MODULE COMPOSITION	Availability and entry of the complete BOM and FMD, i.e., material description in terms of components, materials, elements in terms of both physical materials and corresponding chemical/molecular formulas etc. into the simulation model of each module/part	Recycling Simulation Tool
R_33	RECYCLING SIMULATIONS	Simulate the recycling of the modules and calculated the recycling rates of modules, materials, components etc. for different most suitable recycling flowsheet configurations	Recycling Simulation Tool
R_34	RECYCLING/RECOVERY RATES	Know-how on recycling/recovery rates for all elements/compounds/materials included	Recycling Simulation Tool
R_35	DISASSEMBLY FOR OPTIMAL RECYCLING	Instructions to disassemblers for optimal disassembly depth/intensity for optimal recycling/recovery	Recycling Simulation Tool

Table 3.1 - Disassemblability module, covered requirements

3.3.3 Platform integration

The figure below represents all the components that take part in the DIS module, as well as the interactions between them; the main actors involved in this use case are also present near the component that they leverage in the context of this module.

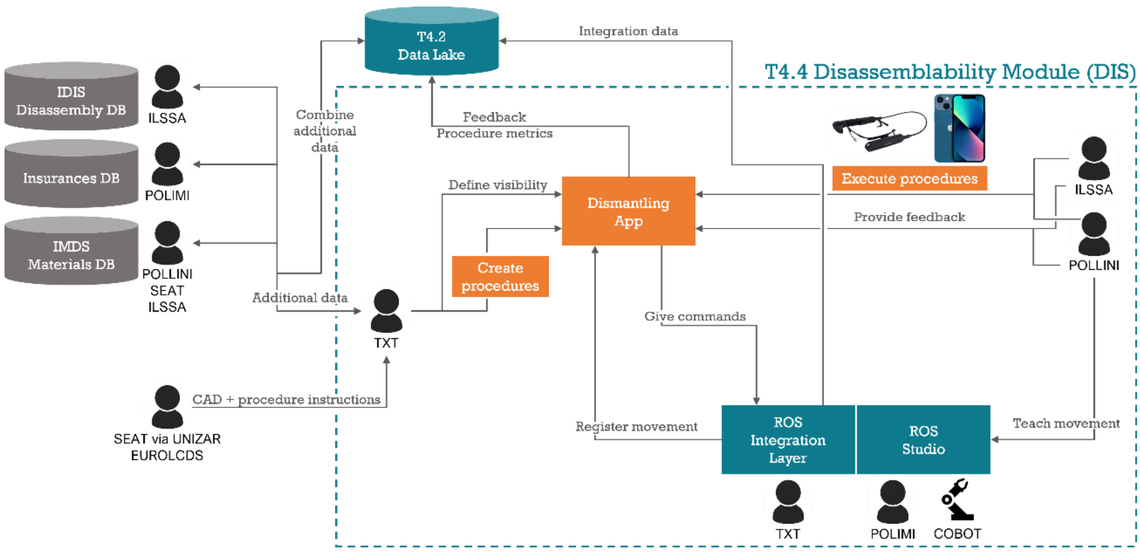


Figure 3.2 - Disassemblability module, technical architecture

The core of the disassemblability module is represented by the Dismantling App, managed by TXT. This application displays disassembly procedures to the physical operators from POLLINI and ILSSA, allowing users to perform the step-by-step procedures either via augmented reality headsets or via regular mobile devices. Through these supports the user is able to provide feedback concerning each specific step of the procedure. The feedback is then collected by the application and inserted in the Data Lake for future usage. During the execution of certain disassembly procedures, the operator is assisted by a robotic arm (the cobot). This tool is controlled by the Dismantling application that provides the appropriate instructions to execute throughout the procedure. The integration between the application and the cobot is realized from TXT in collaboration with POLIMI via the ROS Integration Layer that allows the cobot to receive commands from the application and the procedure to be notified about actions taken by the cobot. It may happen that for certain procedures, the cobot is not trained on the action to take; this could happen if it is the first time that a particular procedure is performed by the cobot, or a variant of an existing procedure needs to be put in place. In this scenario, the physical operator can manually teach the robotic arm the correct movement through the ROS Studio component. The new movement is then registered and integrated in the procedure for future executions by means of the ROS Integration Layer. This way the robot can actually learn from previous executions and extend the set of operations that it is capable of performing, the more the executions are repeated. During the entire execution of the procedure, various metrics are collected both directly from the cobot and indirectly from the application (in background). All of this information is then stored in the TREASURE Data Lake and serves as starting point for the AI-Based Advisory Tool to compute predictions and provide suggestions. Concerning the creation of the dismantling procedures, this is performed by TXT leveraging the disassembly instructions and CAD representation of the car parts/components provided by SEAT (via UNIZAR) and EUROLCDS, as well as information present in the Data Lake and additional data coming from publicly available external data sources through POLLINI, SEAT ILSSA and POLIMI. These procedures also represent the main value that the DIS module brings to the TREASURE Project, since they will be custom-built specifically to perform disassembly of car parts and components. Another portion of novelty brought to the project is the integration of the cobot with the dismantling application and, specifically, the ability to give precise commands to the cobot from any stage of the procedure, as well as receiving updates on the cobot status and current performing actions. This will be achieved by exploiting a standardized API system created with generality in mind, with the possibility to provide interaction to a wide variety of robotic arms that internally operate in completely different ways.

3.4 Recyclability Module (REC)

3.4.1 Purpose

The Recyclability module (REC) mainly addresses recyclers, ranging from shredder, disassembler and sorting plants to final treatment processing actors in the metallurgical recycling industry, in addition to car manufacturers. In fact, the three modules are strongly linked together, constantly communicating in an interconnected manner. The Recyclability module will be further refined in WP5 and the main aspects will be expanded in the corresponding deliverables.

The main outcome of the module will be (i) KPIs on recycling/recovery (rates) for whole car parts/components as well as for individual elements/materials/compounds present in the car/electronics/components under consideration (implying the full range material/element/compounds included will be assessed in the recycling module), and (ii) recycling instructions for the car parts/components under operation (i.e. implying best recycling flowsheet architecture/routes as well as feedback on disassembly depth/intensity for optimal recycling/recovery) in order to optimize the recycling process flowsheet performance and at the same time increase operators' performances and minimise losses and emissions. Shredding/recycling workers will also benefit from the module being informed about critical/dangerous components and components that embed valuable materials/elements that are worth to be focused on during recycling operations, for example components that can be disassembled and separately processed in most suitable metallurgical (recycling) processes to optimise recycling/recovery before sending the remaining car wreck to shredding and sorting in which these specific components/contained critical/minor elements/materials will go lost due to dispersion over the produced recycled fractions (i.e. sorted fractions after shredding/separation such as steel fraction, copper fraction, aluminium/light metals fraction, plastics fraction, etc).

This module will also compare bio-hydrometallurgical processing with existing metallurgical infrastructures by not only assessing recycling/recovery rates, but also taking into consideration losses and exergy created, hence providing a sound framework for selection of best available technology processing of disassembled cars parts (focusing on modular recycling). In general, the recycling module will be applied to quantitatively assess the recycling/recovery of products/parts under consideration in this project including all materials/elements/compounds applied in these. The recycling/recovery rates (and losses/emissions created) for disassembled components/parts as well as IMEs will be calculated by application of the recycling module. Most optimal balance between disassembly depth and best suited recycling flowsheet architectures will be determined. KPI's will be generated to quantitatively assess recycling and provide physics and recycling technology-based feedback to Design for Recycling (also by application of the Recycling Index and Material Recovery Flowers as developed by MARAS).

3.4.2 Covered Requirements

In the table below are listed all the requirements covered by the Recyclability module (REC). In the last column are listed all the components in charge to fulfil the corresponding requirement. Further details are provided in the chapter of each specific component.

Requirement ID	Requirement Name	Requirement Description	Component in charge
R_1	USER LOGIN	The platform must allow login for different user types (car makers, recyclers, …) based on predefined policies	WEAVR Platform, AWS Services
R_2	USER ACCESS CONTROL	The platform must enable users to access only the tools allowed by the group policy assigned to them	WEAVR Platform, AWS Services
R_3	USER INSERTION	The platform must allow new users to be inserted, specifying a group policy for each one of them	WEAVR Platform, AWS Services
R_4	USER REMOVAL	The platform must allow existing users to be removed	WEAVR Platform, AWS Services
R_5	USER DATA MODIFICATION	The platform must enable modification of the data corresponding to each user	WEAVR Platform, AWS Services

R_6	USER SECURITY	The platform must follow security guidelines for the user authentication procedures	WEAVR Platform, AWS Services
R_8	PART SUGGESTIONS	The platform must provide suggestions to the disassembler and the recycler about specific parts that can be disassembled	AI-Based Advisory Tool
R_16	ELEMENT/MATERIA L SELECTION	The platform must provide knowhow on specific elements/materials to be recovered to recycling operators/recyclers (meaning final treatment processors such as metallurgical recycling processing and refining)	WEAVR Platform
R_17	RECYCLABILITY INSTRUCTIONS VISUALIZATION	Similar to R_11 but targeted to shredders/physical recycling operators/recyclers	WEAVR Platform
R_18	RECYCLABILITY KPI VISUALIZATION	The platform must provide shredders/physical recycling operators/recyclers with the proper KPI relevant to the valuable/dangerous material being recycled	WEAVR Platform, Sustainability Tool
R_19	RECYCLABILITY FEEDBACK	The platform must provide feedback and insight to shredders/physical recycling operators/recyclers concerning recovery rates of specific elements/compounds or materials	WEAVR Platform
R_20	PROCEDURES DOWNLOAD	The platform must allow disassemblers and shredders/physical recycling operators/recyclers to download procedures on the device	WEAVR Platform
R_21	CAR/PART INFORMATION SHARING	The platform must allow car parts designers/car makers to upload information about cars and parts composition	Data Lake
R_22	CAR/PART INFORMATION UPDATE	The platform must allow car parts designers/car makers to update existing information about cars and parts composition	Data Lake
R_29	KPI COMPARISON	The platform must allow disassemblers, shredders/physical recycling operators/recyclers and car parts designers/car makers to compare KPIs relevant to them	Sustainability Tool
R_30	DATA SECURITY	The platform must guarantee security of data	Data Lake, AWS Services
R_31	OPEN INTERFACES	The platform should possibly be implemented using open interfaces to be able to communicate with other systems.	Data Lake, AWS Services
R_35	DISASSEMBLY FOR OPTIMAL RECYCLING	Instructions to disassemblers for optimal disassembly depth/intensity for optimal recycling/recovery	Recycling Simulation Tool
R_37	SURROGATE FUNCTION (AI)	Create a surrogate function (AI) that captures the recyclability of the	Recycling Simulation Tool

		modules that can be applied in the TREASURE platform	
R_38	RECYCLING FLOWSHEET INSTRUCTIONS	…see above	Recycling Simulation Tool

Table 3.2 - Disassemblability module, covered requirements

3.4.3 Platform Integration

The Recyclability module core contents will be mainly provided by advanced recycling flowsheet simulation models, supplied by the Recycling Simulation Tool from MARAS and then technically implemented through the Recycling Application provided by TXT, leveraging on custom built interactive procedures as described for the Disassembly module.

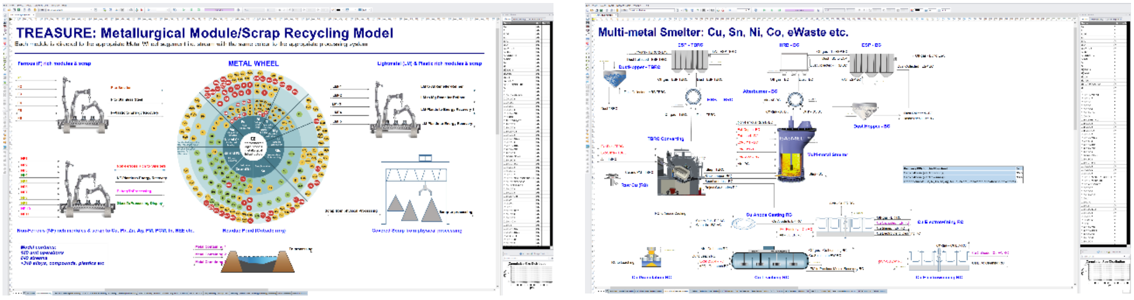


Figure 3.3 - Recyclability module, flowsheet simulations

In particular, once data will be collected into the platform, KPIs and the main recycling information (e.g., recycling/recovery rates, recycling routes to be followed for most optimal recycling,) will be determined within the recycling simulation models. The disassembled parts and other parts under consideration (IMEs) will be directed in the recycling flowsheet simulation model following the segments in the Metal Wheel (as displayed in Figure 3.3), where each module is directed to the appropriate metal wheel segment, which is covered in the simulation models by the complete metallurgical (and other final treatment) recycling processing infrastructures. Extensive combination of flowsheets into one master flowsheet in which all available technologies are present to process/recycle the parts/components and contained materials/elements/compounds is applied and simulated. A modular approach to recycling will be favoured, following a novel approach to (car) recycling, as it has been proven in many studies by MARAS that this will lead to the most optimal recycling/recovery performance. Important to emphasize is that in the recycling flowsheet simulation models all materials/elements/compounds in their full compositional analyses and combinations will be addressed and not only the metals of interest are being considered.

Then, the platform will leverage on the Recycling App to create the information and procedures to perform the recycling of components and materials. Those will be sent to the operator’s device, ready to be consulted and the appropriate feedback will be provided, contributing to increase the amount of information at disposal in the TREASURE Data Lake that will then be leveraged by the AI-based Advisory Tool. The final technical architecture for the Recyclability module is therefore depicted in the figure below.

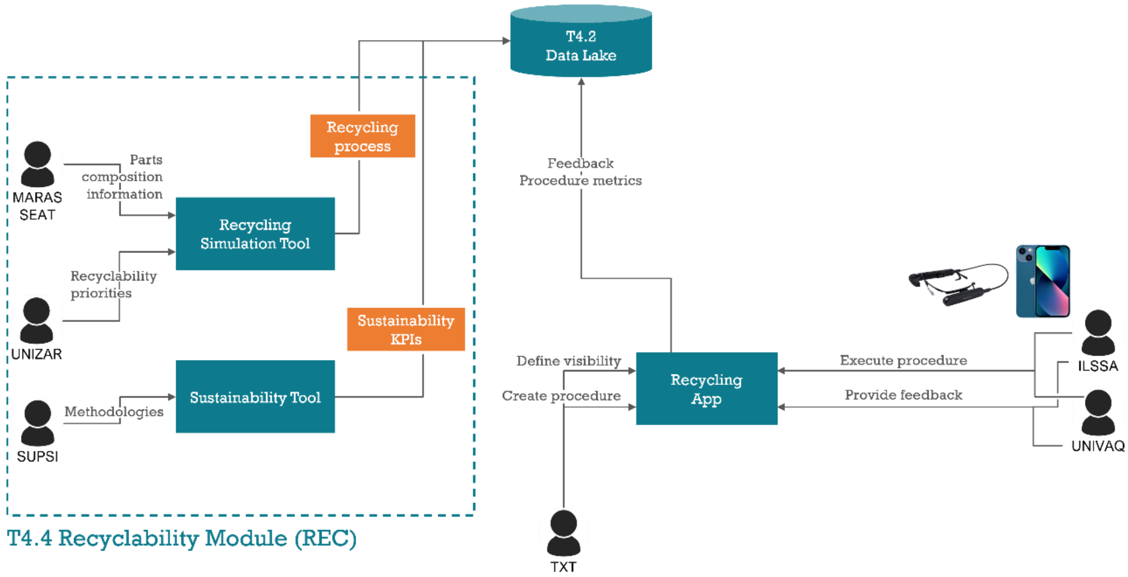


Figure 3.4 - Recyclability module, technical architecture

3.5 Eco-Design Module (ECO)

3.5.1 Purpose

The Eco-Design module (ECO) is designed for BoL actors, namely car makers, parts suppliers and component designers mainly, with the aim of supporting them in improving the design phase based on easing the disassembly process and improving the reusability and recyclability potential of the vehicles and components. This module will include a collaborative cloud platform in which each BoL actor will be able to visualize KPIs and other metrics about the circularity level of his production cycle, as well as receive suggestions on recycling routes and EoL feedback to improve the overall sustainability of the production process.

3.5.2 Covered Requirements

In the table below are listed all the requirements covered by the Recyclability module (REC). In the last column are listed all the components in charge to fulfil the corresponding requirement. Further details are provided in the chapter of each specific component.

Requirement ID	Requirement Name	Requirement Description	Component in charge
R_1	USER LOGIN	The platform must allow login for different user types (car makers, recyclers, …) based on predefined policies	Circularity Web Platform, AWS Services
R_2	USER ACCESS CONTROL	The platform must enable users to access only the tools allowed by the group policy assigned to them	Circularity Web Platform, AWS Services
R_3	USER INSERTION	The platform must allow new users to be inserted, specifying a group policy for each one of them	AWS Services
R_4	USER REMOVAL	The platform must allow existing users to be removed	AWS Services
R_5	USER DATA MODIFICATION	The platform must enable modification of the data corresponding to each user	AWS Services

R_6	USER SECURITY	The platform must follow security guidelines for the user authentication procedures	AWS Services
R_30	DATA SECURITY	The platform must guarantee security of data	AWS Services
R_31	OPEN INTERFACES	The platform should possibly be implemented using open interfaces to be able to communicate with other systems.	Circularity Web Platform, Data Lake, AWS Services
R_32	DATA ENTRY PART/MODULE COMPOSITION	Availability and entry of the complete BOM and FMD, i.e., material description in terms of components, materials, elements in terms of both physical materials and corresponding chemical/molecular formulas etc. into the simulation model of each module/part	Recycling Simulation Tool
R_33	RECYCLING SIMULATIONS	Simulate the recycling of the modules and calculated the recycling rates of modules, materials, components etc. for different most suitable recycling flowsheet configurations	Recycling Simulation Tool
R_36	DESIGN FOR RECYCLING	Feedback to OEMs/part suppliers on DfR based on results and insights on losses/emissions and/or low recovered materials/compounds based on the range of simulations performed by the recycling simulation model	Recycling Simulation Tool

Table 3.3 - Disassemblability module, covered requirements

3.5.3 Platform Integration

In case of the Eco-Design module, the platform will mainly act as a recommendation system providing feedbacks collected from the disassembly and recyclability modules. In particular, the feedbacks collected from dismantling and recyclability assessments and suggestions collected from the workers thanks to both the Dismantling and Recycling Applications will be recorded and made available in a proper collaborative space of the platform, while useful information on hardware components and sub-components, to identify critical car parts in a vehicle, and valuable recommendations for the design phase based will be provided to BoL actors. The complete architecture for the Eco-Design module is shown in the figure below.

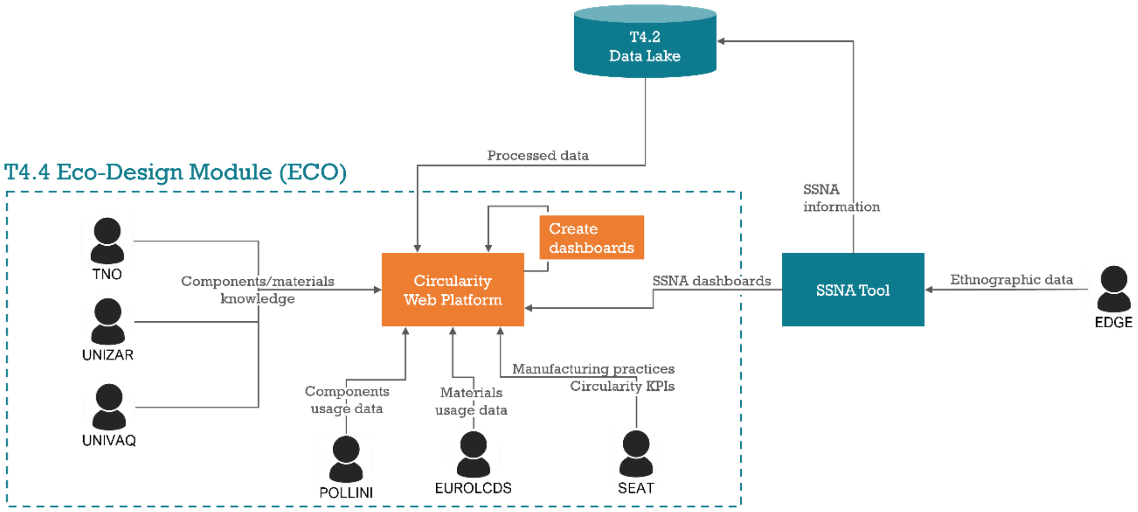


Figure 3.5 - Eco-Design module, technical architecture

At the core of the ECO module there is the Circularity Web Platform which provides BoL actors (mainly SEAT, EUROLCDS and POLLINI) with interactive dashboards and KPI specifications that will allow them to better understand the current production status and will guide them through the selection of best production routes by offering the ability to visualize EoL feedback for each car part/component provided by dismantling/recycling operators and the possibility to see and compare different KPIs in order to better understand which material/technical procedure is best suited for each use case. The Circularity Platform will also allow TNO, UNIZAR and UNIVAQ to access information about in-mold electronics to develop novel prototyping processes and further discuss IMSE (In-Mold Structural Electronics) adoption from a methodological point of view. The platform will therefore leverage the AWS Services middleware to provide each actor with the appropriate visualization tool (e.g., producers of individual components will only have access to KPIs and dashboards correlated to that specific part), ensuring security of critical assets and intellectual properties.

The contribution of this module is therefore the creation of the platform and its dashboards. This will be made possible by leveraging the AI-Based Advisory Tool for computing the appropriate KPIs based on the knowledge gathered from the TREASURE Data Lake. Concerning the integration of information about social impact of CE practices adoption, the SSNA Tool provided by EDGE will be employed to provide the semantic information gathered form end users; its contribution will be integrated as part of the displayed information to further enrich the set of tools at disposal of BoL actors, supporting even more the decision process about circularity best practices.

3.6 WEAVR Platform

3.6.1 Purpose

The objective of the WEAVR platform is to simplify the disassembly and recycling activities performed respectively in the Disassemblability module (DIS) through the Dismantling App and in the Recyclability module (REC) through the Recycling App, leveraging an innovative virtual/augmented reality platform enabling different actors to create, manage and execute augmented procedures on a wide variety of physical devices. The main advantages that the

TREASURE platform will gain throughout the usage of WEAVR boil down to a general improvement of the activity performed by the operator, that is now assisted by ad-hoc procedures during his typical working activity. Specifically, the WEAVR platform will:

- Speed up the task's execution time: by providing detailed and easy-to-follow steps that the operator will carry out in a precise order, avoiding losing time performing alternative operations in a suboptimal order.
- Reduce worker training time: by providing a virtual training environment in which the operator can receive feedback on the tasks performed, reducing the impact of errors and avoiding potential damage to real components/materials.
- Increase worker understanding of the component/material: by allowing the operator to access an interactive model of the component/part that is being disassembled/recycled, with the possibility to overimpose augmented information on top of the real component (e.g., displaying a transparent model of the part to be disassembled/recycled highlighting internal modules/materials).

The WEAVR platform will be exploited in two of the three TREASURE modules: the Disassemblability module (DIS) and the Recyclability module (REC), while leaving no usage for the Eco-Design module (ECO). In the next chapters will be presented an overview of the requirements covered by WEAVR, then a detailed description of the as-is infrastructure will be given, finally the to-be scenario will be described specifying the aspects that will compose the complete platform that will be exploited by the TREASURE project.

3.6.2 Covered requirements

In the table below are listed all the requirements covered by the WEAVR platform, along with the specific modules in which WEAVR covers each one of the assigned requirements.

Requirement ID	Requirement Name	Requirement Description	Module Covered (DIS/REC/ECO)
R_1	USER LOGIN	The platform must allow login for different user types (car makers, recyclers, …) based on predefined policies	DIS/REC
R_2	USER ACCESS CONTROL	The platform must enable users to access only the tools allowed by the group policy assigned to them	DIS/REC
R_3	USER INSERTION	The platform must allow new users to be inserted, specifying a group policy for each one of them	DIS/REC
R_4	USER REMOVAL	The platform must allow existing users to be removed	DIS/REC
R_5	USER DATA MODIFICATION	The platform must enable modification of the data corresponding to each user	DIS/REC
R_6	USER SECURITY	The platform must follow security guidelines for the user authentication procedures	DIS/REC
R_7	CAR/ELECTRONICS SELECTION	The platform must allow disassemblers to select the car/electronics to be disassembled	DIS

R_8	PARTS SUGGESTIONS	The platform must provide suggestions to the disassembler about specific parts that can be disassembled	DIS
R_9	DISASSEMBLABILITY PROCEDURE SUGGESTIONS	The platform must provide disassemblers with step-by-step instructions to disassemble specific parts	DIS
R_10	DISASSEMBLABILITY PROCEDURE CHOICE	The platform must allow disassemblers to choose the desired procedure for disassembling a specific part, among a set of proposed procedures	DIS
R_11	DISASSEMBLABILITY INSTRUCTIONS VISUALIZATION	The system should provide disassemblability instructions to the user in a simple way using graphical representation	DIS
R_12	DISASSEMBLABILITY KPI VISUALIZATION	The platform must provide disassemblers with the proper KPI relevant to the part being disassembled,	DIS
R_13	DISASSEMBLABILITY FEEDBACK	The platform must allow disassemblers to provide feedback about a specific disassembly operation	DIS
R_16	ELEMENT/MATERIAL SELECTION	The platform must provide knowhow on specific elements/materials to be recovered by and send to most suited recycling operators/recyclers (meaning final treatment processors such as metallurgical recycling processing and refining)	REC
R_17	RECYCLABILITY INSTRUCTIONS VISUALIZATION	Similar to R_11 but targeted to shredders/physical recycling operators/recyclers	REC
R_18	RECYCLABILITY KPI VISUALIZATION	The platform must provide shredders/physical recycling operators/recyclers with the proper KPI's relevant to the valuable/critical materials being recycled (and all other materials/compounds included)	REC
R_19	RECYCLABILITY FEEDBACK	The platform must provide feedback and insight to shredders/physical recycling operators/recyclers concerning recovery rates of specific elements/compounds or materials (within the suite of all other materials/elements/compounds recovered and lost/emitted)	REC
R_20	PROCEDURES DOWNLOAD	The platform must allow disassemblers and shredders/physical recycling operators/recyclers to download procedures on the device	REC

Table 3.4 - WEAVR Platform, covered requirements

The requirements listed above are covered by the WEAVR platform by exploiting its three main components: WEAVR Manager, WEAVR Creator and WEAVR Player. A detailed description of these components can be found in the next chapter "Existing Background", where their structure and operations are further explained. Here, instead, it is only described how every single requirement is met by each specific WEAVR component.

- Requirements from R_1 to R_6 specifically refer to the WEAVR Manager component that is responsible for handling users and their access policies to the appropriate augmented procedures.
- Requirements from R_7 to R_10 and requirement R_16 are leveraged by the WEAVR Player that enables operators to perform the disassembly/recycling tasks.
- Requirements R_11 and R_17 refer to both the WEAVR Creator and the WEAVR Player: the former enables non-experts to create the virtual/augmented procedures, while the latter enables the operator to actually execute the implemented procedure.
- Requirements R_12 and R_18 refer to the WEAVR Player component that will allow shredding/recycling operators to visualize relevant indicators and KPIs during the execution of a recycling/dismantling procedure on their physical devices.
- Requirements R_13 and R_19 are in charge of the WEAVR Player that will allow the disassembly/recycling operator to collect feedback through his/her physical device.
- Requirement R_20 refers to the procedure requested by the operator through the WEAVR Player on his/her physical device and performed by the WEAVR Manager.

3.6.3 Existing background

In this chapter it is presented an architectural overview of the different components of the WEAVR platform. The individual components will be individually explained first, while their interaction with the rest of the TREASURE platform components in the two different modules (DIS and REC) will be described afterwards.

WEAVR is a powerful software toolbox developed by Pacelab (a TXT company) able to streamline the design and development of virtual training systems. It provides an integrated Editor platform, which supports the entire production process from instructional design to final delivery. WEAVR enables the user to create a wide array of training systems from the same set of training data, creating a seamless and consistent learning experience from desktop procedural training to full mission practice. Its template-based, visual approach requires little to no programming or scripting skills, allowing subject matter experts to create tasks efficiently and without involving 3D Editors or software engineers. This innovative toolbox has been designed to promote a high level of reuse, seamlessly integrating existing components with simulation ones, and deploying the same training content across a variety of systems including desktop PC, mobile and VR devices. The Editor is also a verified solution in the Unity framework, the leading platform for creating and operating interactive, real-time 3D contents, and it enables the creation of more interactive content than traditional training, resulting in more realistic training scenarios and better retention of learners' acquired knowledge.

WEAVR offers a unique set of features and components, enabling companies to create, manage, and implement a wide array of training systems from the same set of training data, and to support field operations from desktop procedural training to full mission practice. The solution is designed for subject matter experts to easily create content; for students and field operators to learn and get support while carrying out operations collaboratively; for instructors and managers to monitor and support these activities. WEAVR comprises three main components:

- WEAVR Creator: built on top of Unity 3D, WEAVR Creator is a WYSIWYG (“What You See Is What You Get”) authoring tool providing wizards and libraries for the creation of procedural based content enhanced by virtual and mixed reality. The Creator is designed to require little to no programming or scripting skills. It enables the definition of behaviours and animations of 3D elements empowered by customizable assets, implementing:

- Basic tools with standard behaviour and animations, e.g., buttons and levers.
- Cameras and relative movement scripts.
- A flow-chart editor enables users to model procedures by defining steps, groups of steps, navigation flows, animations, conditional navigations, and any other useful actions.

The optional Developer Simulation Hub module is an SDK that allows integration with existing real-time simulations and related visual streams.

An example of the WEAVR Creator interface is shown below.

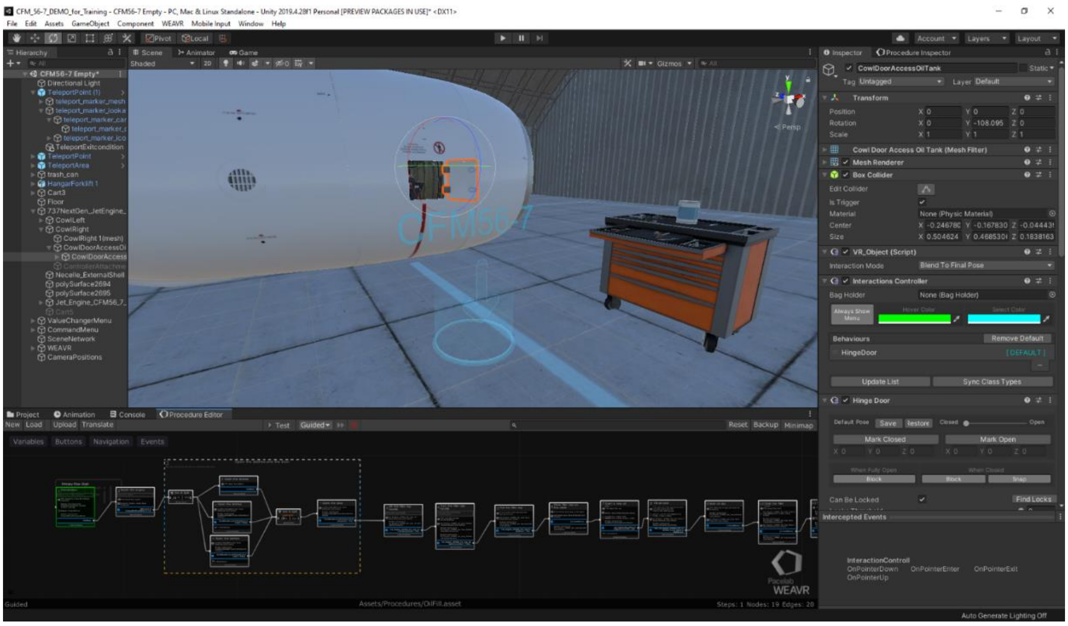


Figure 3.6 - WEAVR Creator, procedure development UI

As can be noted, the 3D scene representing the final procedure is rendered in the upper part of the screen, while in the lower part it is displayed the procedure diagram representing the sequence of action that the physical operator has to follow in order to carry out a specific task. Finally in the right part of the screen it is displayed the control section that allows the user to define parameters about the step of the procedure that is currently selected (e.g., entering and exit conditions, interactive and non-interactive objects, sounds to play and messages to show).

- WEAVR Manager: provides functionalities to manager users, procedures, and integration connectors to upload the procedure in cloud environment. Through this module managers can view and share metrics and statistics about procedures, while operators can access and download procedures that will then be executed in the Player component. The pictures below show the web interfaces that allow to manage procedures and visualize metrics related to them.

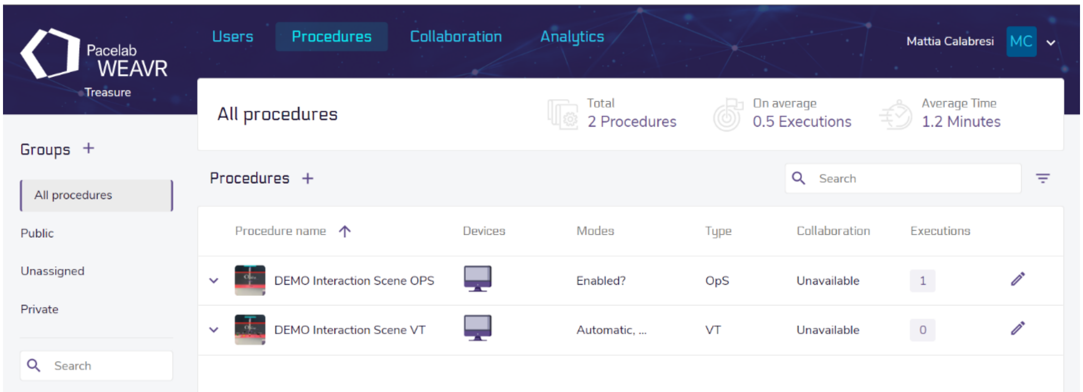


Figure 3.7 - WEAVR Manager, procedure management UI

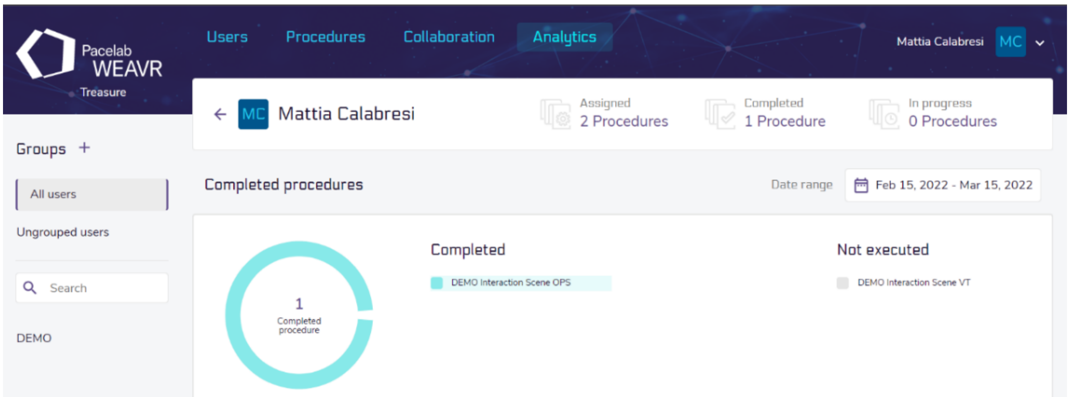


Figure 3.8 - WEAVR Manager, metrics visualization UI

- WEAVR Player: enables to access, select, and execute the available procedures in different modalities. WEAVR player is available across various systems including desktop PC, mobile devices, and VR headsets. The Player needs to connect to WEAVR Manager, through a login process, to update the state of its existing procedures and/or download new procedures. The Player also allows a procedure to be shared by multiple operators. The figure below shows a demo procedure being run through the WEAVR Player on a Virtual Reality headset.

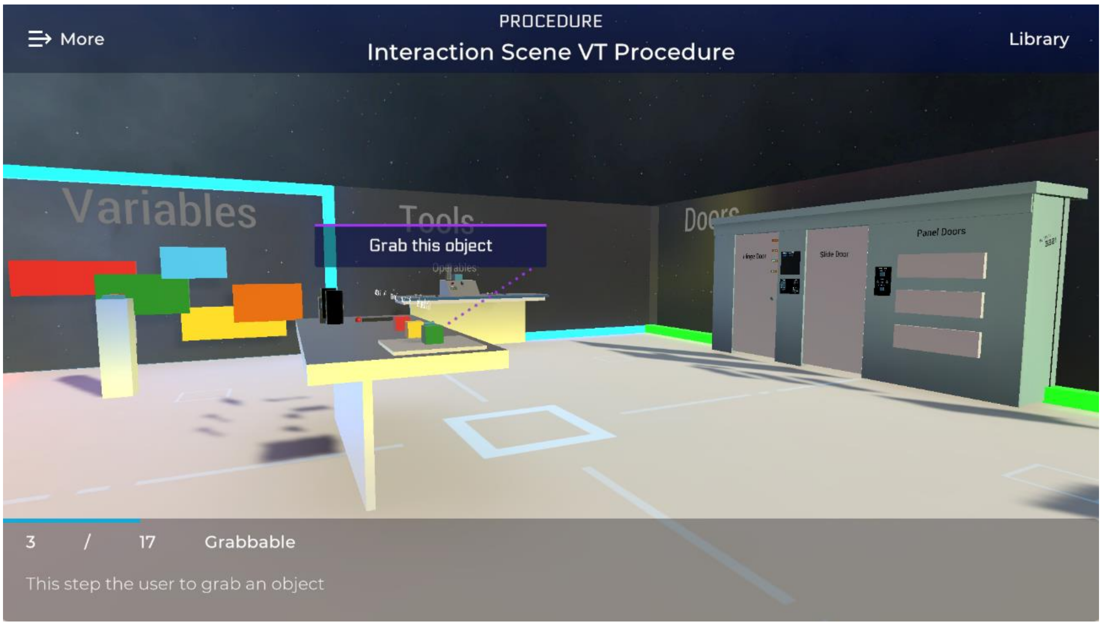


Figure 3.9 - WEAVR Player, demo procedure

3.6.4 Work to do

The future developments of the WEAVR component will mainly address three core features that will be leveraged by the TREASURE platform:

1. Collect feedbacks from operators: this feature will be exploited by both the DIS and REC use case and will allow the operators to share notes/improvements with the rest of the TREASURE platform. To do so, the user will have a dedicated portion of the UI provided by the Dismantling app/Recycling app through which the feedback could be inserted, collected and forwarded to the appropriate handler (see the next chapter "Platform integration" for a deeper explanation of this mechanism). The forwarding mechanism, as well as the handling procedures and the operator UI are yet to be implemented and will further need to be integrated with the different WEAVR components.
2. Integration between augmented procedures and the cobot: this feature will be mainly addressed to the DIS module and will allow the Disassembly app to provide commands to the robotic arm throughout each step of disassembly procedure. In order to achieve this result, directives to be sent to the cobot will be incorporated in the augmented procedure, along with the instructions for the dismantling operator; then, the Dismantling app will distinguish between users and cobot instructions sending the latter to the robotic arm via a set of standard APIs.
3. Integration between the WEAVR platform and the TREASURE data lake: this feature will allow the platform to incorporate in the data lake the feedback coming from the operators in both DIS and REC modules, as well as a series of metrics regarding the procedure execution, used for tasks monitoring. While feedback will be collected via manual insertion of the users and complete forwarding needs to be implemented from scratch, the metrics monitoring has already been implemented, allowing them to be automatically collected by the Player component and sent to the Manager. The objective with the metrics is, therefore, to forward them further to the data lake, in order to centralize the data collection.

3.6.5 Platform integration

Each one of the WEAVR components integrates seamlessly with other parts of the TREASURE platform, playing a different role depending on the TREASURE module in which it is inserted into. Described below are the detailed activities that the different WEAVR components will perform for each individual TREASURE module.

In the **Disassemblability module (DIS)**, the WEAVR platform is integrated in the form of the Dismantling App (see section "3.3 Disassemblability Module (DIS)" for an overview of the whole architecture), allowing operators to disassemble car parts/components exploiting augmented reality procedures. As can be seen by the figure below, the application takes advantage of the full set of WEAVR components (Creator, Manager and Player).

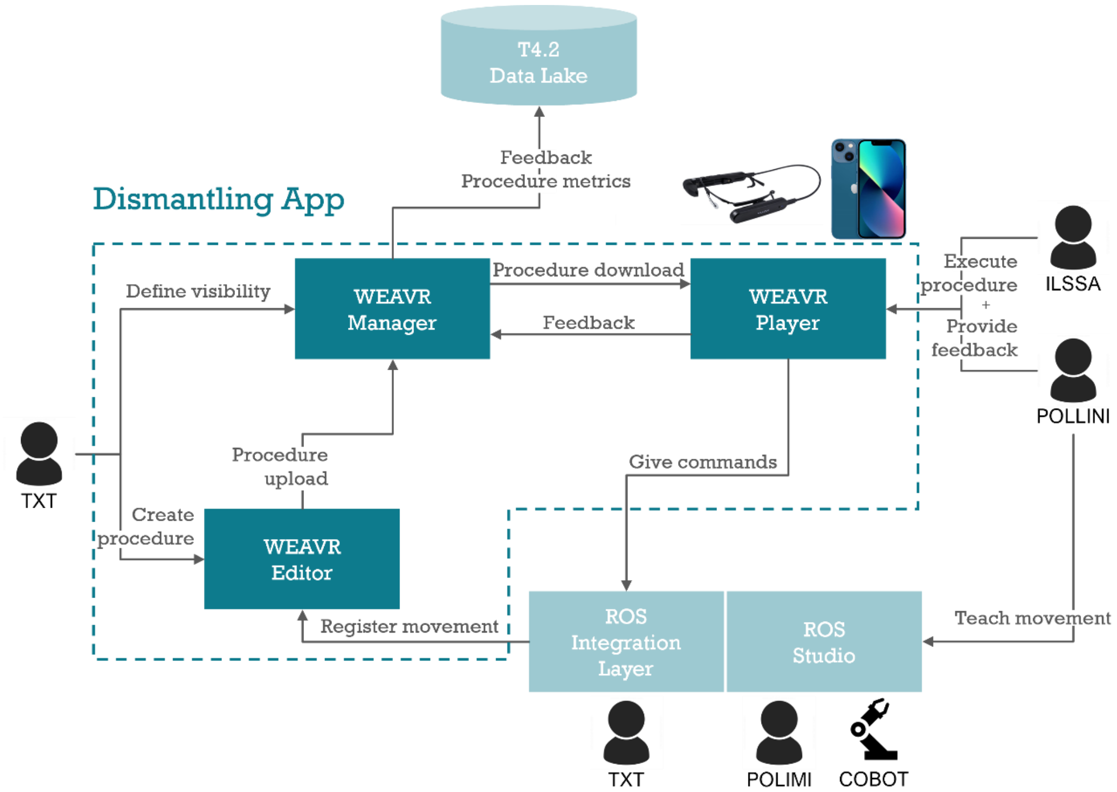


Figure 3.10 - The WEAVR platform behind the Dismantling App component

In particular, each component behaves as follows:

- The WEAVR Manager will be utilized by TXT (and by the companies involved in the dismantling activities) to define the visibility of the procedures, allowing only the right operators to access disassemblability procedures. The manager is then responsible for providing the Player with procedures to be downloaded, basing on the access policies defined previously. During the execution of a procedure, the operator may need to leave a comment concerning a specific operation concerning a dismantling step; the collected feedback is taken in charge by the Manager and stored in the TREASURE Data Lake for future analysis, along with a set of procedure metrics collected automatically by the Player component. Another important role covered by this Manager is the ability to store incoming procedures generated by the Creator component. In particular, the Manager allows to store new procedures and upload an updated version of existing ones, keeping track of the upload history and serving specific versions of the same procedure to different operators, allowing for legacy support and improved compatibility.
- The WEAVR Creator will be exploited by TXT to create, manage and update the dismantling procedures. Those are created using the appropriate Unity 3D plugin that

simplifies and streamlines the development. Once the procedure is ready, it is uploaded to the Manager component and, depending on the prior availability of the procedure, this could result in a new procedure upload or in the update of an existing one. The Creator also allows to incorporate directives targeting the cobot inside the dismantling procedures, providing instructions such as the position the robotic arm has to reach, the path to follow and the activity to accomplish, depending on the tool installed at the end of the arm (including but not limited to the duration of the action, parameters concerning the specific tool the arm is holding, …)

- The WEAVR Player will be leveraged by the dismantling operators to perform disassemblability procedures. To do so, each operator will authenticate using his/her device of choice to the Manager and will request the procedure to execute. The request will be handled by the Player that will download the procedure from the Manager component on the user's device. At any point in time during the execution of a step, the operator will be able to provide feedback exploiting the corresponding function provided by the Player UI. This will then be automatically handled and sent to the Manager for later use. Finally, the Player component will guide the cobot during each step of the procedure, enabling a seamless cooperation between the user and the robotic arm.

Concerning the **Recyclability module (REC)** the WEAVR platform will assist operators in performing recyclability tasks. This will be enabled by the Recycling App (see section "3.4 Recyclability module (REC)" for an overview of the complete architecture) that will guide the recycler (implying final (metallurgical and other) recovery processors), shredder or the physical recycling operator through the sequence of steps needed to fulfil component recycling following the best possible procedure. As for the DIS module, also REC will feature the complete WEAVR platform, including the Manager, Creator and Player component. As can be seen in the figure below, the interaction of WEAVR with the other TREASURE platform components is very similar to the DIS module; this is due to the intrinsic similarities of executing a procedure in the two mentioned modules.

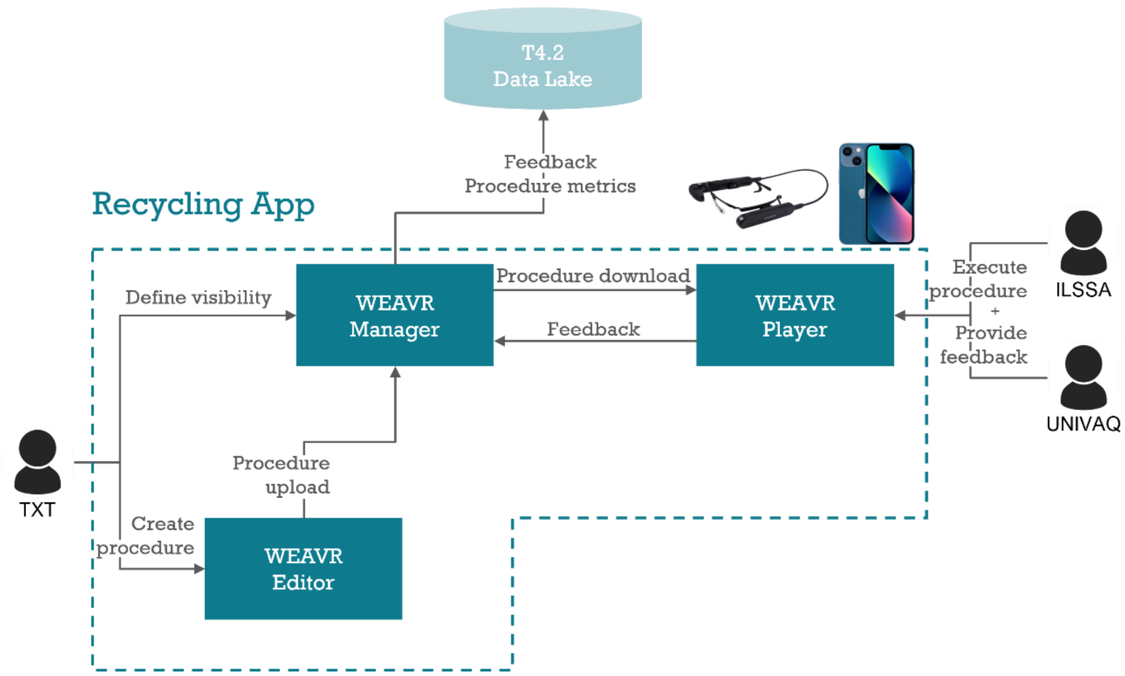


Figure 3.11 - The WEAVR platform behind the Recycling App component

It is worth emphasizing that, even if the architectural approach is very similar between DIS and REC, there are key differences between the two from a methodological point of view:

1. The targeted operators for the Player component are different with respect to the DIS use case, now focused on shredders, recyclers and physical operators (including dismantlers).
2. The actual procedures are completely different, given the also different industrial setting and users target.
3. The interaction with the cobot is no longer needed, as all REC processes are carried out by physical operators and recyclers without the need for robotic assistance.

Considering the observations made so far, the complete explanation of the WEAVR interaction with the other TREASURE platform components can be found in the description of interaction with the DIS component, above.

Finally, as briefly mentioned at the beginning of this chapter, none of the components comprising the WEAVR platform will be exploited by the **Eco-Design module (ECO)**.

3.7 Circularity Web Platform

3.7.1 Purpose

The objective of the Circularity Web Platform in the scope of the TREASURE Project it to support BoL actors in their decision-making process by providing each actor with a series of ad-hoc tools that aggregate prior knowledge gathered from EoL actors during the Disassemblability module (DIS) and the Recyclability module (REC) and served in the form of interactive dashboards. The Web Platform mainly targets users involved in the Eco-Design module (ECO) and allows different BoL actors with different roles to access visualization tools relevant to the car parts, components or materials of their competence, preserving data security on critical assets with strict access policies.

The main advantage in the adoption of the Circularity Platform for the TREASURE Project, and from involved actors in particular, is the ability to have a bird’s-eye view of the entire circularity status about their current production process in a single place on a dedicated page. The main tools ad their disposal will be interactive dashboards displaying relevant charts, graphs, indicators etc. about critical KPIs for recycling/recovery rates of applied or alternative materials/components, future technological trends as well as forecasts and recommendations about which material or component to use/avoid in future design/manufacturing processes or should be kept separated in the different modules in the design of the car or electronic components/parts. Along with such data, feedback collected from disassembly/recycling operators will be included allowing for a better understanding of the EoL requirements that will contribute in speeding up the dismantling/recycling processes and, as such, contributing to the improvement of circularity throughout the entire platform.

3.7.2 Covered requirements

In the table below are listed all the requirements covered by the Circularity Web Platform, along with the specific modules in which the Web Platform covers each one of the assigned requirements.

Requirement ID	Requirement Name	Requirement Description	Module Covered (DIS/REC/ECO)

R_1	USER LOGIN	The platform must allow login for different user types (car makers, recyclers, …) based on predefined policies	ECO
R_2	USER ACCESS CONTROL	The platform must enable users to access only the tools allowed by the group policy assigned to them	ECO
R_23	CAR/PART SEARCH	The platform must allow car parts designers/car makers to search for car/parts	ECO
R_24	CAR/PARTS KPI VISUALIZATION	The platform must allow the car parts designers/car makers to visualize relevant information and KPIs about a specific car/part	ECO
R_25	CE PRACTICES VISUALIZATION	The platform must allow car parts designers/car makers to view graphs assessing the impact of their Circular Economy practices in the market	ECO
R_26	SUGGESTIONS VISUALIZATION	The Platform must allow car parts designers/car makers to view eco-design suggestions regarding a specific car/part	ECO
R_27	CONSUMER SEARCH	The platform must allow consumers to search for a specific car	ECO
R_28	CONSUMER INDICATORS VISUALIZATION	The platform must allow customers to view CE indicators and graphical indexes reporting the circularity level of their cars	ECO
R_29	KPI COMPARISON	The platform must allow disassemblers, shredders/physical recycling operators/recyclers and car parts designers/car makers to compare KPIs relevant to them	ECO
R_30	DATA SECURITY	The platform must guarantee security of data	ECO
R_31	OPEN INTERFACES	The platform should possibly be implemented using open interfaces to be able to communicate with other systems.	ECO

Table 3.7 - Recycling Simulation Tool, covered requirements

3.7.3 Existing background

The current state of the component is represented by the presence low level services deployed through the use of the AWS Services. Those will support future works to create the actual Circularity Platform and will grant access to it using state of the art secure policies.

3.7.4 Work to do

The future steps towards the completion of the Circularity Web Platform mainly boil down to the realization of the different dashboards, taking into account the information that each actor needs, and the integration with external services that contribute to the realization of the different visualizations. In particular the steps to be taken are:

- Build the individual dashboards for each specific BoL actor, inserting the proper information gathered from the Data Lake. Data will be displayed according to user needs in the best possible form using charts, graphs and any other visual tool able to express the relevant information, as well as textual and visual feedback coming from EoL actors in the form of plain text comments that will be inserted in the page corresponding to the proper car part, component or material being visualized.

Design the integration with the TREASURE Data Lake to retrieve all the information to be included in the dashboards, such as KPIs, trends forecast and recommendations.

- Integrate the data collected from the SSNA Tool provided by EDGE with the relevant dashboards, allowing to include semantic user information to the list of tools at disposal of ECO users.
- Implement the access control system for each type of EoL actor, allowing to have a separate cloud space for every user that will be able to access only relevant information to the portion of the data relevant to him/her. This system will be a joint effort between the Circularity Web Platform component and the AWS Services one that will ensure user protection and data security.

An early proposal of the end result can be seen in the mock-ups shown below, where an example of potential dashboard has been drawn taken into account the needs of ECO actors. It is important to notice that the arrangement of the components and their format can be susceptible to changes due to further refinement of user needs and will be updated in the upcoming deliverables.

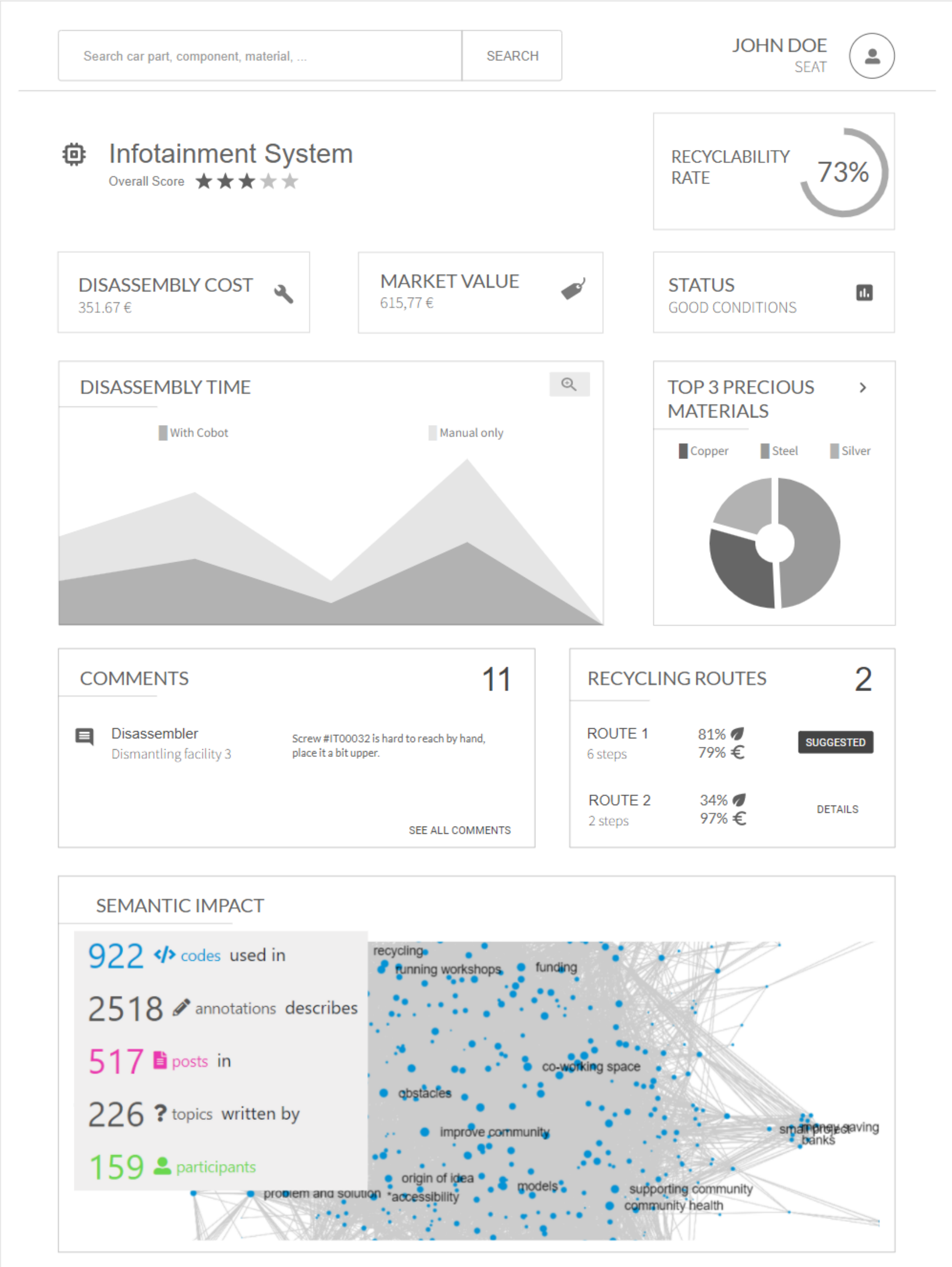


Figure 3.12 - Circularity Web Platform UI components, mock-up

3.7.5 Platform integration

The Circularity Web Platform component will mainly interact with the TREASURE Data Lake component, from which it will gather the data processed by the Ai-Based Advisory Tool that will be ready to be inserted in the dashboards. This interaction will be realized by means of open APIs that allows the two systems to communicate in a standardized way, ensuring reusability of the information sharing process and an easier and faster future improvement. Another integration to be realized is the one between the Circularity Web Platform and the SSNA Tool by including the user data gathered from EDGTE tool inside the views built by the web application. The information to be included comes in the form of interconnecting graphs representing relations between users and reaction to different topics. Those graphs will be taken as they are and mapped to the appropriate dashboards without resorting to any intermediate computation, as they come pre-processed from the EDGE dedicated platform.

3.8 Recycling Simulation Tool

3.8.1 Purpose

Simulation-based analysis of metallurgical and recycling systems linked to product design have had a long history of over 20 years' development by MARAS as documented by Van Schaik and Reuter[2,3,4,5,6,7,8,9,10]. These papers document covers the development of simulation models that link product design, physical recycling, as well as metallurgical recycling. In addition, parameterization of the simulation models with industrial data has created realistic evaluations of recycling and circular economy systems, as well as product design in terms of mass and energy and exergy balances, in addition to the normal foot-printing in terms of the usual environmental indicators directly linked to the simulation models. Using these approaches, surrogate functions in AI have been used to link product design to recycling rate calculations.

The Recycling Simulation Tool links the full composition of a product and module, as well as functional connections to metallurgical processing, in addition to the production of high-quality materials, metals, alloys etc., as has been discussed in section 3.4. and the lasted papers best summarized by Reuter[11,12]. The present prior art model will be adapted for the purpose of this project to link various product modules (e.g., car electronics, PCBs and IMEs) to recycling/recovery rates of all compounds/elements/materials as well as energy dissipation.

An example of simulation-based analysis of metallurgical and recycling systems and recycling/recovery rate calculations linked to product design and environmental assessment is provided in the following Figure 3.13.

2 A. van Schaik, M.A. Reuter (2007): The use of fuzzy rule models to link automotive design to recycling rate calculation. Minerals Engineering, 20, 875-890.

3 A. van Schaik, M.A. Reuter (2010): Dynamic modelling of E-waste recycling system performance based on product design. Minerals Engineering, 23, 192-210.

4 A. van Schaik, M.A. Reuter (2016): Recycling indices visualizing the performance of the circular economy, World of Metallurgy – ERZMETALL, 69(4), 201-216.

5 M.A. Reuter, K. Heiskanen, U. Boin, A. van Schaik, E. Verhoef, Y. Yang (2005): The Metrics of Material and Metal Ecology, Harmonizing the resource, technology and environmental cycles Elsevier BV, Amsterdam, 706p. (ISBN: 13 978-0-444-51137-9)

6 E. Worrell, M.A. Reuter (2014): Handbook of Recycling, Elsevier BV, Amsterdam, 595p.

7 M.A. Reuter, A. van Schaik (2015): Product-centric simulation-based design for recycling: Greenprinting of LED lamp recycling, Journal of Sustainable Metallurgy 1(1), 4-28.

8 M.A. Reuter, A. van Schaik, J. Gediga (2015): Simulation-based design for resource efficiency of metal production and recycling systems, Cases: Copper production and recycling, eWaste (LED Lamps), Nickel pig iron, International Journal of Life Cycle Assessment, 20(5), 671-693.

9 M.A. Reuter, A. van Schaik, M. Ballester (2018): Limits of the Circular Economy: Fairphone Modular Design Pushing the Limits, World of Metallurgy - ERZMETALL 71(2), pp. 68-79.

10 M.A. Reuter, A. van Schaik, J. Gutzmer, N. Bartie, A. Abadías Llamas (2019): Challenges of the Circular Economy - A material, metallurgical and product design perspective. Annual Review of Materials Research, 49, 253-274.

11 M.A. Reuter (2016): Digitalizing the Circular Economy - Circular Economy Engineering defined by the metallurgical Internet of Things-, 2016 TMS EPD Distinguished Lecture, USA, Metallurgical Transactions B, 47(6), 3194-3220

12 M.A. Reuter (2011): Limits of Design for Recycling and ''Sustainability'': A Review. Waste and Biomass Valorisation, 2, 183-208.

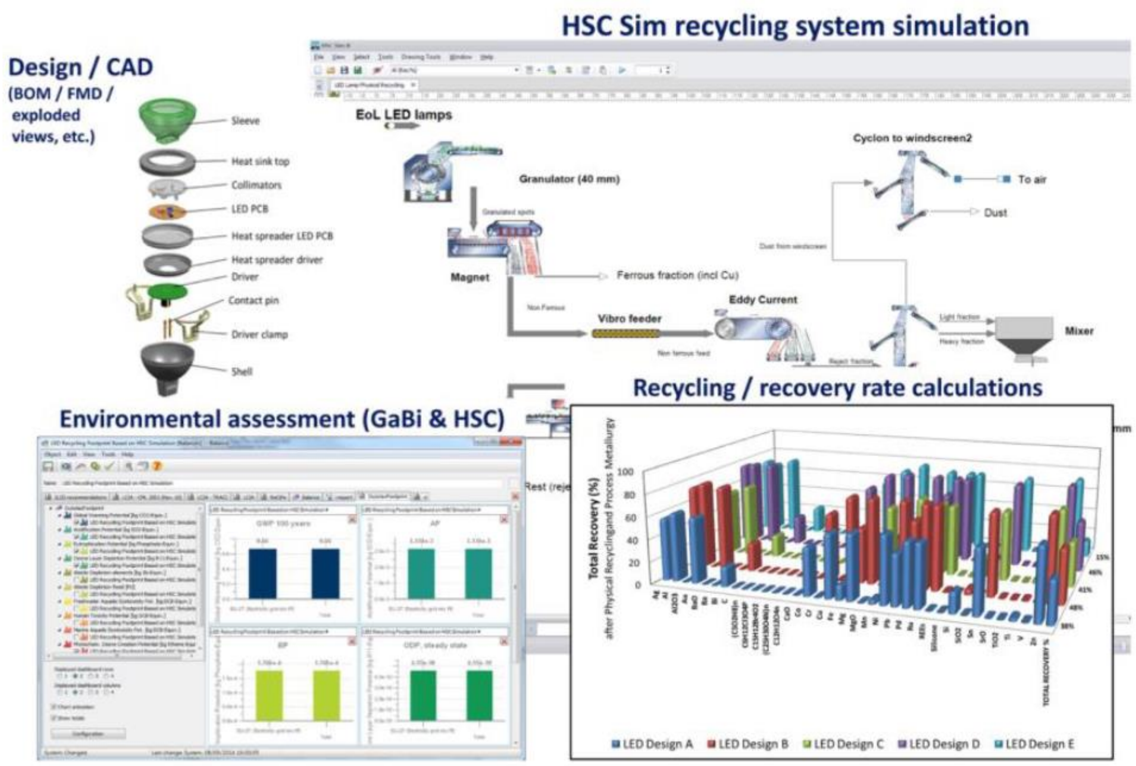


Figure 3.13 - Example of Recycling Simulation Tool analysis

3.8.2 Covered requirements

In the table below are listed all the requirements covered by the Recycling Simulation Tool, along with the specific modules in which the tool covers each one of the assigned requirements.

Requirement ID	Requirement Name	Requirement Description	Module Covered (DIS/REC/ECO)
R_32	DATA ENTRY PART/MODULE COMPOSITION	Availability and entry of the complete BOM and FMD, i.e., material description in terms of components, materials, elements in terms of both physical materials and corresponding chemical/molecular formulas etc. into the simulation model of each module/part	DIS/REC/ECO
R_33	RECYCLING SIMULATIONS	Simulate the recycling of the modules and calculated the recycling rates of modules, materials, components etc. for different most suitable recycling flowsheet configurations	DIS/REC/ECO
R_34	RECYCLING/RECOVERY RATES	Know-how on recycling/recovery rates for all elements/compounds/materials included	DIS/REC
R_35	DISASSEMBLY FOR OPTIMAL RECYCLING	Instructions to disassemblers for optimal disassembly depth/intensity for optimal recycling/recovery	DIS/REC
R_36	DESIGN FOR RECYCLING	Feedback to OEMs/part suppliers on DfR based on results and insights on losses/emissions and/or low recovered materials/compounds based on the	ECO

		range of simulations performed by the recycling simulation model	
R_37	SURROGATE FUNCTION (AI)	Create a surrogate function (AI) that captures the recyclability of the modules that can be applied in the TREASURE platform	REC
R_38	RECYCLING FLOWSHEET INSTRUCTIONS	…see above	REC

Table 3.5 - Recycling Simulation Tool, covered requirements

3.8.3 Existing background

The recycling flowsheet simulation models are being developed in the industrial software HSC Chemistry/Sim 10 ® (Metso:Outotec), providing a professional and industrial platform for process simulation tools and recycling and recovery calculations. HSC Chemistry/Sim as developed by Metso Outotec's is chemical reaction and equilibrium software (i.e., thermochemical software) with a versatile flowsheet simulation module. HSC is designed for various kinds of chemical reactions and equilibria calculations as well as process simulation. Recycling flowsheet process simulation models have been developed in this software platform. In HSC Chemistry/SIM calculation modules automatically utilize the same extensive thermochemical database, which contains enthalpy (H), entropy (S) and heat capacity (C) data. The recycling simulation models are developed containing large scale recycling flowsheets ranging from dismantling/disassembly, shredding and physical separation and extensive final treatment processing infrastructures/flowsheets and materials definitions are included (and continuously expanded) to include the required detailed description of materials in terms of needs to functionally describe recycling processing. In HSC Chemistry/Sim, recycling simulation (and other simulations) can be directly linked to different LCA assessment tools, which have been integrated in the software.

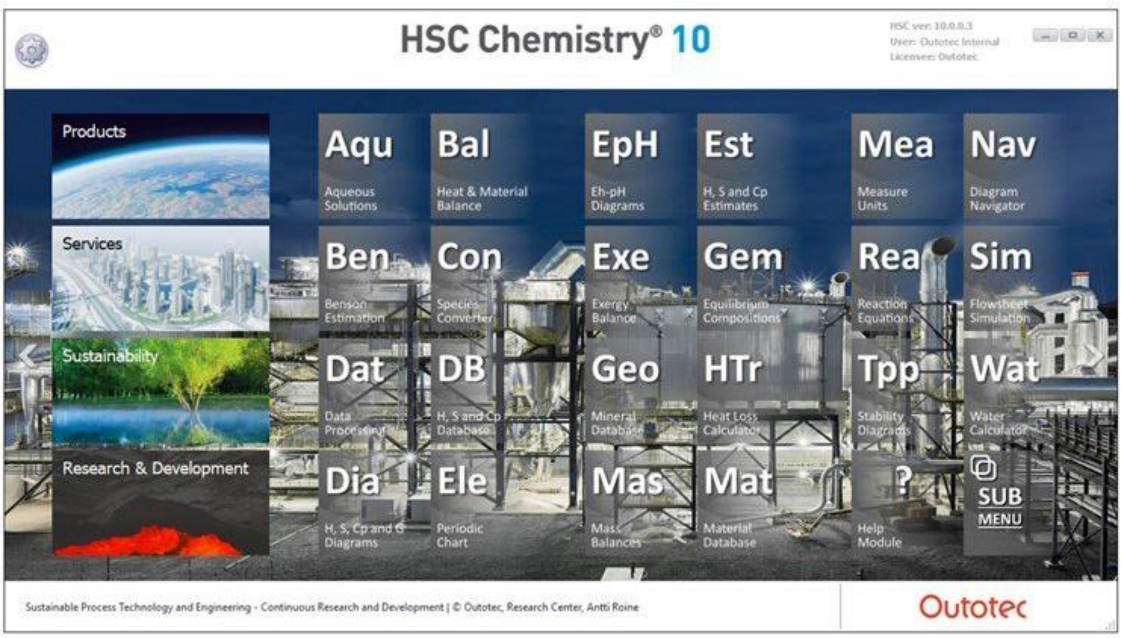


Figure 3.14 - HSC Chemistry/Sim 10

3.8.4 Work to do

The recycling simulation model will be modified for the modules (car parts and electronics/IMEs) of this project. The recycling assessment will be performed for the different disassembled cars parts and will be applied as to assess and quantify the recycling/recovery of all materials/elements/compounds included in the IMEs (and conventional parts). The most optimal recycling flowsheet architecture together with the optimal disassembly depth will be advised on based on a wide range of simulations for different disassembly levels and processing options for the disassembled modules. For the IMEs both recycling/recovery rates will be determined, as well as an assessment of the hydro-pilot by comparison with existing metallurgical recycling processing options will provide insight into the best recycling options for IMEs. Detailed focus on losses and emissions allows in the recycling simulation models for the range of simulations allows to pinpoint critical/limiting issues in recycling as a consequence of product design, hence providing feedback for Eco-design on a physics and industry-based background. Using the process module, a surrogate function will be created, which can be integrated into the digital platform of Treasure.

The following figure represents Recycling Index and Recycling Material Flower to visualize the recycling/recovery performance for the entire product/part as well as for all composing materials/elements/compounds[13]

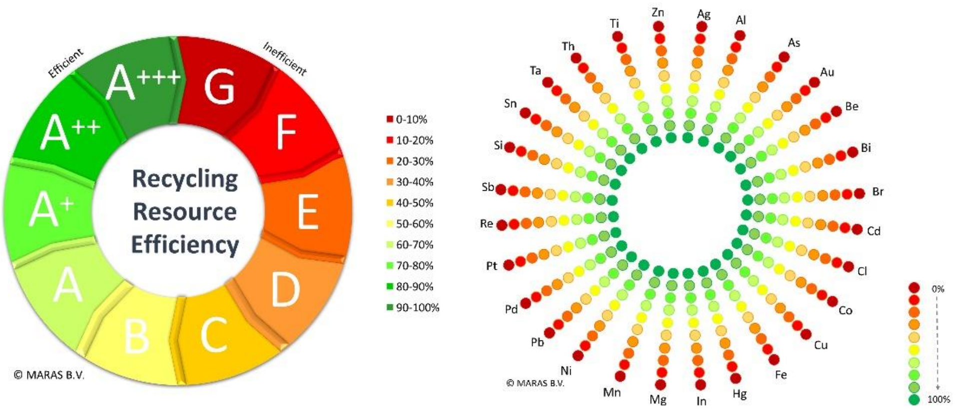


Figure 3.15 - Recycling Index and Recycling Material Flower

3.8.5 Platform integration

A surrogate function will have to be developed to capture the information of the process model and will be integrated into the platform (DIS/REC/ECO). The integration will happen at an earlier stage of the project, where the output of the sustainability tool will be used to create valuable knowledge and KPIs, allowing to obtain an innovative recycling process blueprint and quantified values that will be used both in production environments and in the research field, improving the overall understanding of circularity-based recyclability approaches.

3.9 Cobot Interface

3.9.1 Purpose

The objective of the cobot integration is to simplify the disassembly activities performed respectively in the Disassemblability module (DIS) and in the Recyclability module (REC), thanks to the adaptability of the cobot to quickly learn new disassemble procedures directly from the operator. The main advantages that the TREASURE platform will gain throughout the usage of

[13] A. van Schaik, M.A. Reuter (2016): Recycling indices visualizing the performance of the circular economy, World of Metallurgy – ERZMETALL, 69(4), 201-216.

the cobot is a general improvement of the activity performed by the operator. Specifically, the cobot integration within the WEAVR platform will

- Speed up the learning of new procedures for new parts to be disassembled: providing a user-friendly learning platform for the cobot.
- Making disassembly automatic if the part reoccurs in the future: adequately storing the information about disassembly operations learned by the cobot.
- Helping the operator in the disassembly desoldering activities: using the ad-hoc end-effector that will facilitate the operator in his work.

The cobot integration in the WEAVR platform will be used specifically to improve the Disassemblability module (DIS). While the Recyclability module (REC) and the Eco-Design module (ECO) will collect all the useful feedback the DIS, i.e., some parts may not be compatible with the disassembly operations foreseen for the cobot and this is an information to be taken into account in both REC and ECO modules. In the next chapters will be presented an overview of the requirements covered by the cobot integration, then a proposed architecture to satisfy the requirements and integrate the cobot with the WEAVR platform, finally how the said architecture will be included in the complete platform that will be exploited by the TREASURE project.

ABB Ltd will provide (?) their cobot type YuMi® - IRB 14000 which was introduced to the market in 2015. It fits the purpose of the TREASURE project perfectly since it is made for working together closely with human workers, without the need of barriers or safety-zones. It is available in two different versions, either with a single or dual arm. Both are designed for example for part-assembly and no specialized training is required to use it. In the following the features of the single arm cobot will be described.

With a weight of 9.5 kg YuMi is a lightweight cobot, which makes moving and installation on site easy and doable for all the workers. Movement of the cobot itself is being realized with 7-axis of freedom and a reach of 559 mm to move a payload up to 0.5 kg. Fully extended the cobot can reach a height up to 835 mm. The bottom part of it takes up a circle with 160 mm so it can be easily mounted on every working site. Already integrated are a gripper with servo, vacuum and also a vision being realized by a camera.

For programming on site ABB provides the Wizard program, which is a graphical programming interface using drag-and-drop options for coordinating the movement of the robot on the FlexPendant (a tablet used next to the robot by the human worker). It is also possible to navigate the robot within a simulation with a computer using RobotStudio. This is a program in which the cobot can be digitally imported and all the possible movements can be virtually tried out. Also, a 3-D environment can be implemented to symbolize a digital twin of the actual working site to optimize the process without interrupting the actual procedure.

3.9.2 Covered requirements

In the table below are listed all the requirements covered by the Cobot Interface, along with the specific modules in which the cobot covers each one of the assigned requirements.

Requirement ID	Requirement Name	Requirement Description	Module Covered (DIS/REC/ECO)
R_14	COBOT ACTIVATION	The platform must allow disassemblers to communicate and activate pre-defined operations of the cobot	DIS
R_15	COBOT TRAINING	The platform must allow disassemblers to teach the cobot to perform unknown operations and save reference in the platform	DIS

Table 3.9 – Cobot Interface, covered requirements

The requirements listed above are the ones that require not only the WEAVR platform, but also its integration with the cobot for the human-cobot collaboration that can reach the objectives described in the purposes.   by exploiting its three main components: WEAVR Manager, WEAVR Creator and WEAVR Player. A detailed description of these components can be found in the next chapter "Existing Background", where their structure and operations are further explained. Here, instead, it is only described how every single requirement is met by each specific WEAVR component.

- Requirement R_15 specifically refer to the integration of the cobot to allow the human to teach the right operations to perform to cobot, guided by the WEAVR platform.
- Requirement R_14 refers to the automatic activation once the operation – previously taught to the cobot by the operator – to perform is known and correctly stored in the WEAVR platform, or conveniently in another local application. In any case, the feedback on the task will be stored in the WEAVR platform.

3.9.3 Existing background

In this chapter the architectural overview of the cobot integration strategy is presented. In order to strengthen the genericity of the solution and avoid a link to a specific cobot, the integration will be treated generically and then applied on the POLIMI cobot chosen for the task.

For the integration of the cobot in the WEAVR platform, the main activities to be carried out are the cobot are the learning procedure and the storage of information about the learned operations. These activities require the architecture in Figure 3.13 and specifically the creation of:

- A Learning Platform, to let the operator teach the disassembly operation to the cobot, within a GUI depending on the type of learning procedure used.

- A Communication Platform, to manage all the communication between the cobot, the WEAVR platform and the other devices as a camera for future automatic recognition of the piece to be disassembled.

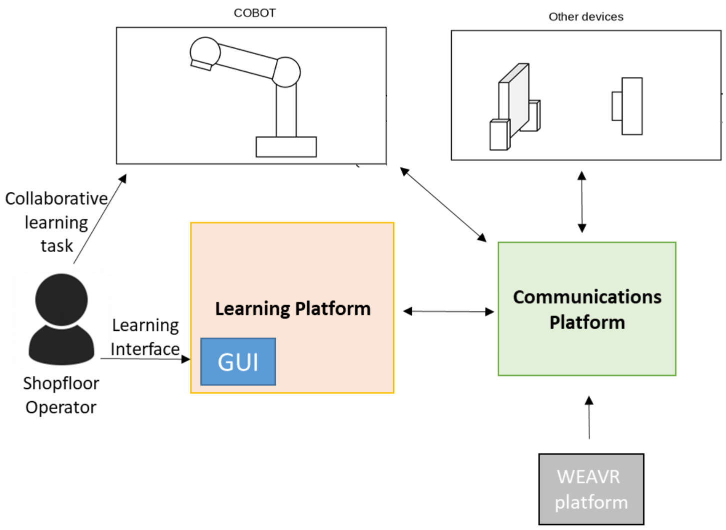


Figure 3.16 - Cobot integration with the WEAVR Platform

The information about the disassembly procedures – provided by the WEAVR platform – will be used to teach the cobot the correct operations to perform for the selected piece to be dismounted. In particular:

- If the cobot – through the use of a camera – does not recognise the piece to be dismounted, it enters in the Learning Behaviour. Within this operational status, the user will teach the cobot the right sequence of operation to be performed for the disassembly task, following the WEAVR instruction.
- On the contrary, if the cobot recognize the piece and has already stored the right procedure for the disassembly of that specific piece, the whole task will be automatically performed by the cobot.

3.9.4 Work to do

A cobot allows the ad-hoc teaching of new paths and the communication of information generically in different ways:

1. a programming language that allows the creation of apps, that can manage communications from/to the cobot within which a learning algorithm can also be programmed.
2. the possibility to build an impedance/admittance controller, which guarantees both the control of the motion of the cobot and the control of the forces at the end-effector.

The last method is safer and the most user-friendly from the user's point of view, in fact it would allow the user to move the cobot directly from the end-effector, while the other two methods would allow movements only through ad-hoc steps for each cobot (usually combinations of buttons on the wrist of the manipulator, and not directly on the end-effector). Although the implementation of an impedance/admissive controller would be the most user-friendly choice, this is rather complex implementation and not all manipulators allow to bypass the control already implemented on board. So, it may not be applicable to all the types of cobots and be genericical enough. All the above considered, as we will better explain in the next section, we will carry out the work considering both the options, in order to adopt the best one to our case study.

3.9.5 Platform integration

In the Disassemblability module (DIS), the cobot integration is still in progress. Considered the two alternatives well explained in the “Work to do section” the integration will be in the form of a ROS integration layer in the case of a controller implementation or in the form of a programming language – ad-hoc for the cobot considered – integration layer. In both the cases, this layer will communicate with the Communication Platform as per the architecture in Figure 3.13.

3.10 Sustainability Tool

3.10.1 Purpose

The objective of the Sustainability Tool in the scope of TREASURE is to allow the calculation of the environmental, social, economic and circularity indicators selected taking into account relevant existing standards and the Life Cycle Sustainability & Circularity Assessment (LCS&CA) methodology developed in TREASURE T2.1. The indicators will address not only the specific sustainability & circularity area, but they will be categorized based on the specific life cycle phase they are evaluating, namely use case dedicated indicators will be provided. The results of the indicators calculation will feed the AI-based Advisory Tool, which will be defined upon the sustainability advisory methodology developed in TREASURE T2.2.

The sustainability tool is intended to be the sustainability engine on which the Advisory will base its suggestions. The advisory suggestions will be addressed to the various use cases of the project and the related modules of the platform, respectively those of disassembly, recycling and eco-design. In other words, use case dedicated indicators selected in TREASURE T2.1 will be elaborated by an AI algorithm based on the sustainability advisory model developed in TREASURE T2.2 to provide specific/dedicated advisory functionalities for dismantlers, recyclers and designers.

3.10.2 Covered requirements

The requirements that the Sustainability Tool fulfils, with respect to section 2.1 “System Requirements”, are listed in the table below, along with the specific modules in which the Sustainability Tool covers each one of the assigned requirements.

Requirement ID	Requirement Name	Requirement Description	Module Covered (DIS/REC/ECO)
R_12	DISASSEMBLABILITY KPI VISUALIZATION	The platform must provide disassemblers with the proper KPI relevant to the part being disassembled,	DIS
R_18	RECYCLABILITY KPI VISUALIZATION	The platform must provide shredders/physical recycling operators/recyclers with the proper KPI relevant to the valuable/dangerous material being recycled	REC
R_24	CAR/PARTS KPI VISUALIZATION	The platform must allow the car parts designers/car makers to visualize relevant information and KPIs about a specific car/part	ECO
R_29	KPI COMPARISON	The platform must allow disassemblers, shredders/physical recycling operators/recyclers and car parts designers/car makers to compare KPIs relevant to them	DIS/REC/ECO

Table 3.10 - Sustainability Tool, covered requirements

3.10.3 Existing background

The Sustainability Assessment Application (SAA) is an evolution of an already existing application developed by SUPSI in previous EU projects (MANUTELLIGENCE project - proposal ID 636951- and MANUSQUARE - proposal ID 761145-2). The SAA allows to perform environmental assessments in compliance with the LCA methodology described in the ISO 14040 framework.

To better address the TREASURE requirements, the SAA is undergoing a revision that includes the following elements:

- both product and process oriented.
- focusing both on the single company and its supply chain.
- "DT compliant", thus able to work on Data from the production lines.

The SAA is designed to:

- edit Models of products and processes.
- import e-BOMs originated from CAD and stored in other companies' applications such as PLM software.
- provide LCA results visualisation (via tables and graphics) for product and process improvement.

export LCA results to be imported in external software (e.g., PLM) and the TREASURE Platform
LCA is a well-acknowledged methodology to analyse the environmental impacts of (manufacturing) processes along their entire lifecycle, but it is also often considered to be highly time and resource consuming, needing the support of experts (not always available in companies) both in the phase of the study preparation and during results interpretation. For this reason, in SAA the LCA assessment has been alleviated by exploiting the use of well-founded background data, but, at the same time, giving users the possibility to personalise their operation information in order to obtain the calculation of environmental indicators that are actually able to represent the impacts related to the specific process.

In order to guarantee the sustainability assessment execution, the SAA Process Templates (PT) create process characterisation by allowing a reliable and simplified description of their manufacturing operations from a sustainability perspective. Specifically, the PT enables the:

- LCA-oriented characterisation of the processes
- Setting up default parameter and impact values for each process
- Identification of the critical (LCA-oriented) process parameters
- Process instantiation on the company operations characteristics

As shown in Figure 3.17below, PT are meant to formalise the LCI description of the processes, where for each specific process, Inputs (I1, I2…, In) and Outputs (O1, O2…, On) are identified and quantified (Q_{I1}, Q_{I2}…Q_{O1}, Q_{O2}…). In this context, all similar processes are characterised by the same list of Inputs and Outputs, while it is possible to change their quantities (as shown hereinafter only some of these quantities) that are distinctive passing from a supplier to another one or, within the same supplier, from an equipment to a different one.

Process			
Input	Quantity	Output	Quantity
I1	Q_{I1}	O1	Q_{O1}
I2	Q_{I2}	O2	Q_{O2}
I3	Q_{I3}	O3	Q_{O3}
…	…	…	…
In	Q_{In}	On	Q_{On}

Figure 3.17 - List of Inputs and Outputs (LCI Data) for a generic process

From the input side, LCI considers resources coming from the eco-sphere (e.g., raw material, water) or from another techno-sphere (e.g., ancillary material such as lubricating oil) and energy of various types. From the output side, LCI inventories emissions (directed to the different environmental compartments), waste, products (the results of the system in analysis), and co-products. Concerning the LCA model, LCI data represents the input variables of the Model. LCI data can be retrieved directly from the production line and can be collected manually or through IoT devices. These kinds of LCI information are called foreground or primary data. Besides, LCI can also be obtained from databases (such as Ecoinvent), or alternatively literature or statistical data (called secondary or background data). Figure 3.18 reports an example of the possible LCI data concerning a generic process P_i.

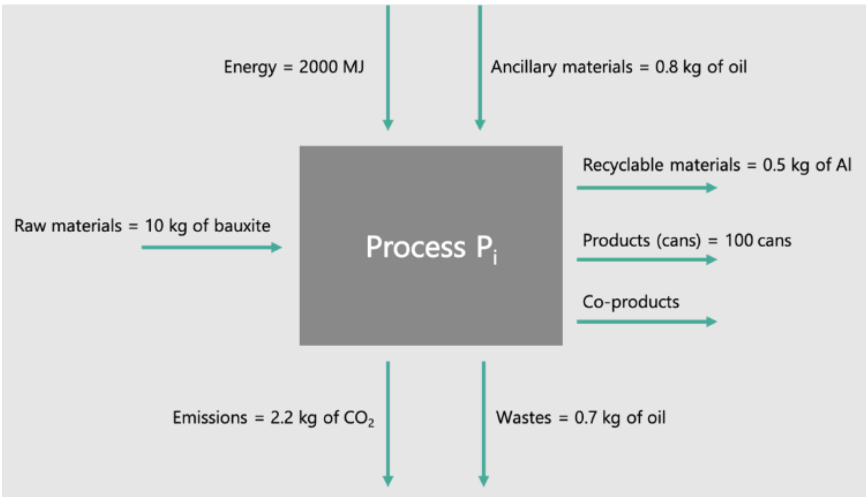


Figure 3.18 - Example of the LCI Data concerning a generic process Pi

In addition to the LCI data, the LCA methodology is based on Life Cycle Impact Assessment (LCIA) information that are the impacts related to the inventory, thus the environmental indicators calculated. Concerning analysis of a specific system, LCIA data can be retrieved from database, or calculated from the LCI data via characterisation factors (available from the databases), which are factors meant to translate the inventory into environmental impacts. LCIA data represents the LCA model outputs.

Functionality

For each PT (Process Template), default LCI Data and the related environmental impacts (LCIA Data) are obtained using the Ecoinvent[14] database. Each PT is related to a specific Functional Unit (the quantification of the function of the system analysed by LCA), that is meant to quantify the function of the process in analysis, e.g., 1 kg of removed steel for milling, 1 kg of injected plastic for injection moulding. As an example, Figure 3.19 reports the LCI Data concerning the milling operation that is removing a functional unit of 1 kg of steel (see Figure 3.20), while the related impact on Climate Change category is about 3.33 eq. kg CO2, as shown in Figure 3.21.

14 https://ecoinvent.org

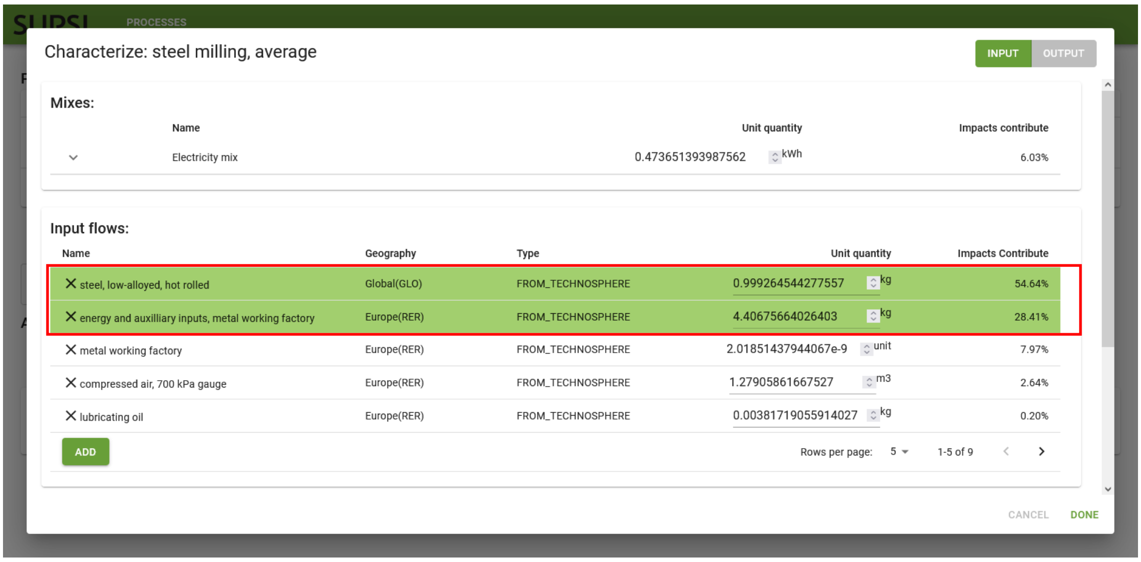


Figure 3.19 - LCI Data and LCIA Data from DB for a steel milling process – input flows

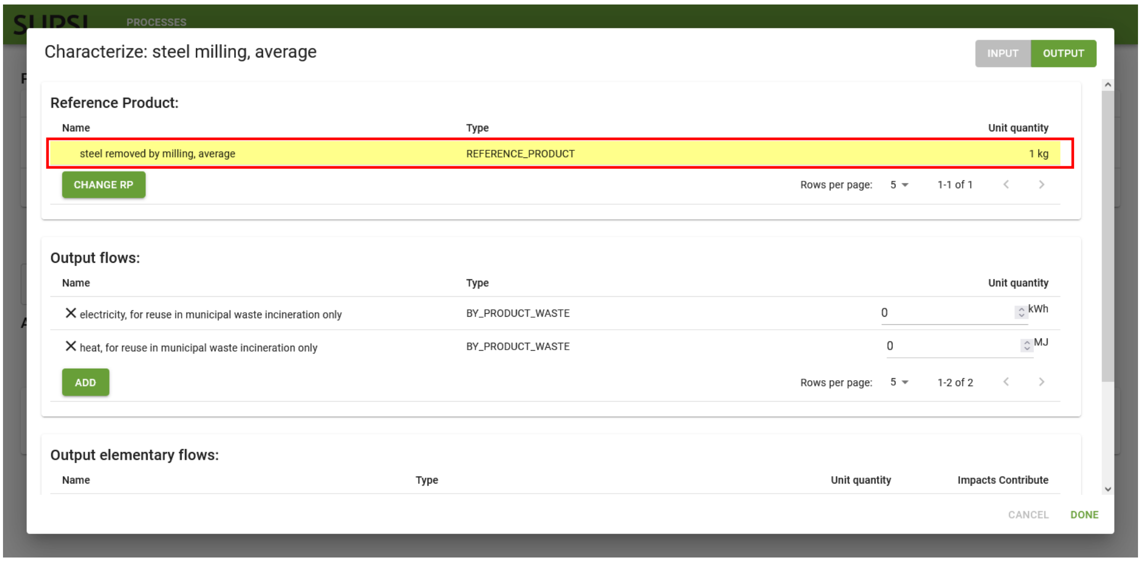
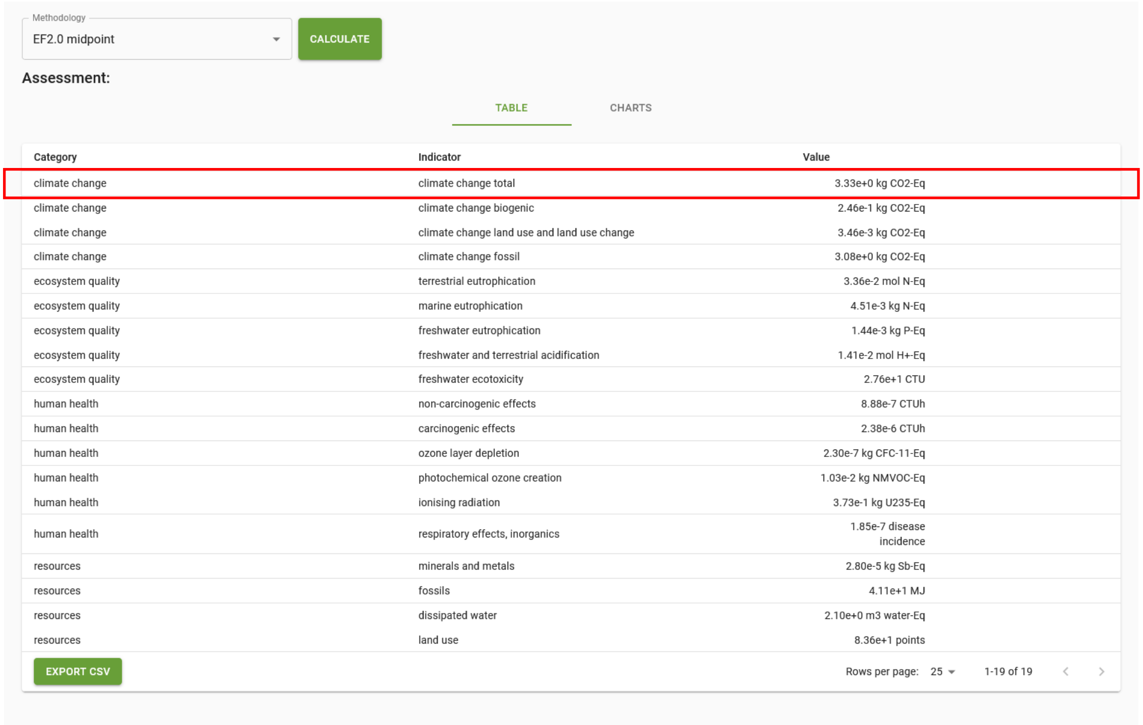


Figure 3.20 - LCI Data and LCIA Data from DB for a steel milling process – output flows

Starting from Ecoinvent data (background data) the percentage contribution of inputs and outputs to the selected environmental indicators are evaluated in order to identify process parameters critical from the LCA point of view. For instance, concerning the Climate Change indicator of the milling operation, it has been estimated that the inputs “steel, low-alloyed, hot rolled” and the “energy and auxiliary inputs, metal working factory” represent above the 80% of the indicator value (see Figure 3.21).


Methodology
EF2.0 midpoint
CALCULATE
Assessment:
TABLE
CHARTS

Category	Indicator	Value
climate change	climate change total	3.33e+0 kg CO2-Eq
climate change	climate change biogenic	2.46e-1 kg CO2-Eq
climate change	climate change land use and land use change	3.46e-3 kg CO2-Eq
climate change	climate change fossil	3.08e+0 kg CO2-Eq
ecosystem quality	terrestrial eutrophication	3.36e-2 mol N-Eq
ecosystem quality	marine eutrophication	4.51e-3 kg N-Eq
ecosystem quality	freshwater eutrophication	1.44e-3 kg P-Eq
ecosystem quality	freshwater and terrestrial acidification	1.41e-2 mol H+-Eq
ecosystem quality	freshwater ecotoxicity	2.76e+1 CTU
human health	non-carcinogenic effects	8.88e-7 CTUh
human health	carcinogenic effects	2.38e-6 CTUh
human health	ozone layer depletion	2.30e-7 kg CFC-11-Eq
human health	photochemical ozone creation	1.03e-2 kg NMVOC-Eq
human health	ionising radiation	3.73e-1 kg U235-Eq
human health	respiratory effects, inorganics	1.85e-7 disease incidence
resources	minerals and metals	2.80e-5 kg Sb-Eq
resources	fossils	4.11e+1 MJ
resources	dissipated water	2.10e+0 m3 water-Eq
resources	land use	8.36e+1 points

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Figure 3.21 - Impacts calculated through EF2.0 midpoint methodology

Through this sort of Pareto analysis, performed by LCA experts and automatized by the SSA, whenever a new operation type is introduced into the ecosystem, it is determined the LCI Data that is actually affecting most of the process environmental impacts. The identified crucial parameters are thus considered as “free” parameters that, starting from the default value proposed by SSA, can be that customised by the supplier in order to better represent its manufacturing operation, thus determining more specific indicators values. Considering again milling, the user could decide to personalise its milling operation, maintaining the inputs “steel, low-alloyed, hot rolled”, while customising the “energy and auxiliary inputs, metal working factory” quantity using the one measured from the production line. With the parameter modification proposed in Figure 3.22, reducing 50% of the “energy and auxiliary inputs, metal working factory” default value, a 16% decrease of the Climate Change indicator is measured, from 3.33 to 2.80 eq. kg of CO2 (see Figure 3.23).

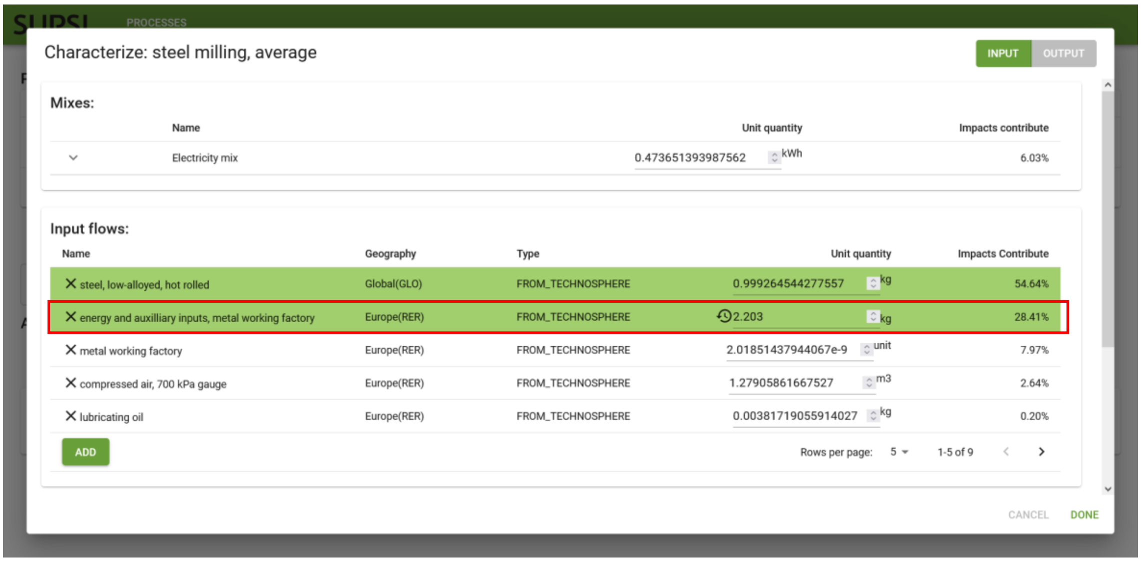

Figure 3.22 - LCI Data and LCIA Data from DB for a steel milling process – customized output flows

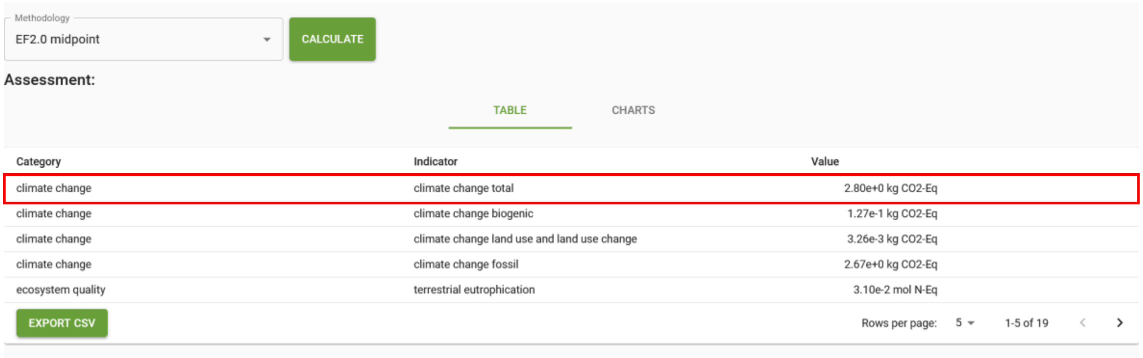

Figure 3.23 - Impacts calculated through EF2.0 midpoint methodology – customized process

<u>Results</u>

The SSA calculates a list of environmental impacts according to a selected LCA methodology. For example, choosing the "EF2.0" methodology, the LCA result is, amongst the other, constituted by the following environmental impacts (see Figure 3.23):

- ***Global Warning Potential (GWP)***: it measures the potential generation of climate change caused by the emissions of green-house gasses.
- ***Human toxicity Potential (HTP)***: it measures the potential impacts on human health related to the emission of toxic substances.
- ***Acidification Potential (AP)***: it provides an evaluation of the impact generated by the emissions of acidification substances in the air compartment.
- ***Depletion of abiotic resources***: it is meant to measure the impact on the not-living natural resource availability considering both the accessible resource quantity and its annual use rate.

The results of the environmental impact assessment can be shown also in chart format, as reported in Figure 3.24. The filtering function allows charts to display how the impacts are shared in percentage among the processes within the same Group, where Group functionality can be modelled according to user needs, or how the indicators contribute to the total impact attributable to a single process. Moreover, an additional filtering function allows the representation of how the processes in a group, or even more groups with respect to each other, behave in terms of environmental impacts in relation to each category/indicator (see Figure 3.25).

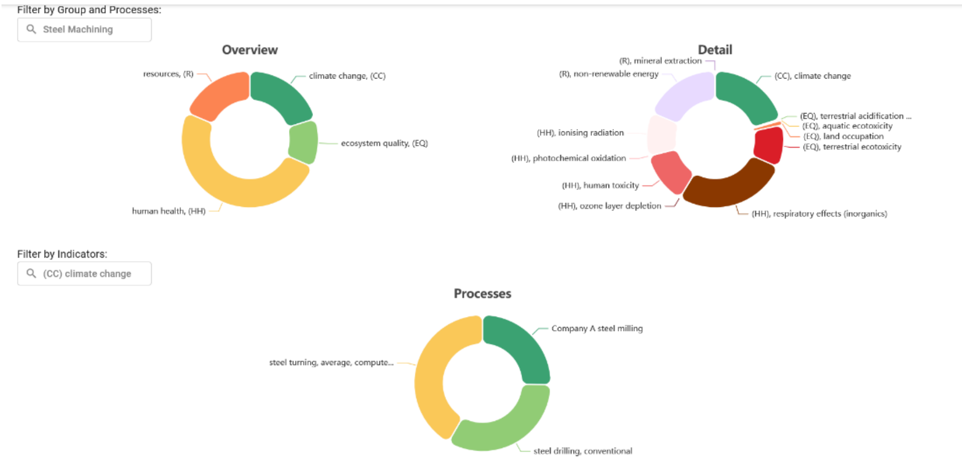

Figure 3.24 - Chart functionality – filtering by group or process

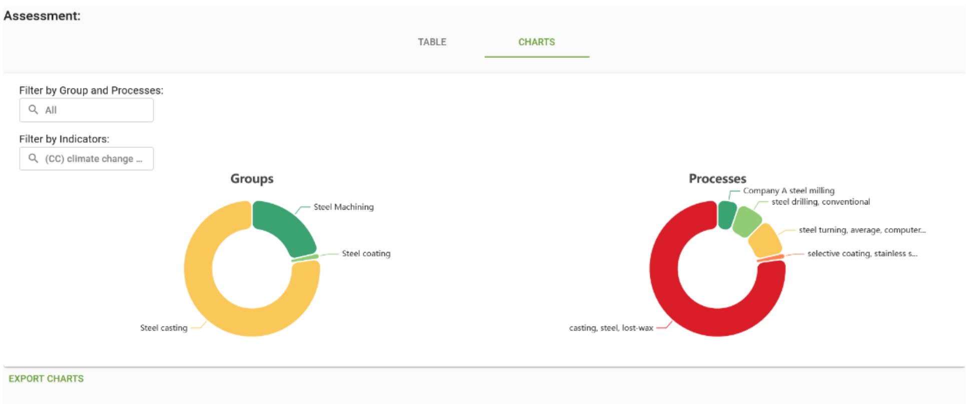

Figure 3.25 - Chart functionality – filtering by indicators

3.10.4 Work to do

The SUPSI Sustainability software solution exploited in TREASURE will be based on software developed within previous research projects and/or integrating other commercial/prototype solutions. The current version of the software is designed and developed to facilitate the preparation of evaluations but needs some adjustments. In relation to the objective of the TREASURE project, the version provided will allow to:

i) Integrate <u>existing solutions and databases</u>. By upgrading the current platform, the extension of the social and economic databases will be possible. In this way, the potential of the platform will be extended and will allow the assessment of the 3 sustainability areas in a single solution.

ii) <u>Calculate Life Cycle Sustainability & Circularity Assessment (LCS&CA) Indicators</u>. The aim of Assessment Engine is to provide the calculation of the environmental, social, economic and circularity indexes taking into account relevant existing standards and the LCS&CA methodology developed in TREASURE T2.1.

iii) <u>Integrate a semi-automatically gather data along the value chain via IoT solutions</u>. If the use of Life Cycle Inventory (LCI) primary data enhances the quality of LCS&CA results, the collection of this foreground data (e.g., the energy consumed by a production equipment) requires extraordinary effort especially when real-time assessment or traceability of a specific production lot is needed, or when the data in analysis has to be collected from suppliers. In order to address this issue, IoT devices enables real-time data gathering from the different life cycle phases of the product, thus retrieving data from suppliers and company shop floor, together with figures coming from the use phase of the product and its End of Use. In addition to that, additional sources of data for the sustainability assessment could be exploited through custom interfaces.

iv) Provide smart sustainability advise functionalities. The interpretation of LCS&CA results is currently a prerogative of sustainability experts. In this context, the software allows to elaborate via third-party AI solutions (see Figure 3.12, based on the sustainability advisory model developed in TREASURE T2.2) the data collected (both LCI and LCIA) to provide decision maker with sustainability advisory indications.

v) Allow an effective interaction with LCS&CA stakeholders. A Graphical User Interfaces (GUI) is prepared aiming at retrieving the data needed for the LCS&CA from the stakeholders involved in product lifecycle modelling, also involving suppliers and returning the LCS&CA results to the diverse decision makers.

3.10.5 Platform integration

At architectural point of view the integration of the SAA is quite simple: the SAA has the main aim to feed the TREASURE Data Lake with a, quite complex, set of sustainability and circularity KPIs (S&C KPIs) each of which will have a purpose and different use within the platform.

In the **Disassemblability module (DIS),** the SAA must provide a set of environmental KPIs relevant for supporting disassemblers in evaluating the sustainability aspects of the parts being disassembled. Those KPIs will be saved into the TREASURE Data Lake by means of set of proper APIs, provided by the Data Lake itself, and gathered by the TREASURE platform for their visualization in a suited dashboard.

Concerning the **Recyclability module (REC)** the SAA must provide a set of circularity KPIs useful for allowing the shredders/physical recycling operators/recyclers to evaluate, from the sustainability point of view, the valuable/dangerous (and all other) materials/elements/compounds being recycled. As the previous module, those KPIs will be saved into the TREASURE Data Lake by means of set of proper APIs and gathered by the TREASURE platform. Those data will be also used for feeding a knowledgebase on which the AI-based Advisory Tool is based on.

In the **Eco-design module (ECO)**, the platform is aimed to provide information on hardware components and, by levering on the AI-based Advisory Tool, valuable recommendations for the design phase. As for the REC module, the role of SAA is to feed the knowledgebase, made available by the TREASURE Data Lake, with the calculated S&C KPIs.

3.11 SSNA Tool

3.11.1 Purpose

The module to be developed in order to connect the Semantic Social Network Analysis toolset and the TREASURE Platform will be addressed both to car makers and consumers. Indeed, SSNA will be used both to check the social impact of adopted CE practices and offer to customers a graphical index assessing the circularity level of cars.

The content on the social impact assessment and the SSNA methodology will be developed within T2.3 "Participatory social impact assessment", led by EDGE.

On the other hand, this component will also enrich consumers awareness with information in the form of CE indicators and graphical indexes reporting the circularity level of their cars.

3.11.2 Covered requirements

In the table below are listed all the requirements covered by the SSNA Tool, along with the specific modules in which the tool covers each one of the assigned requirements.

Requirement ID	Requirement Name	Requirement Description	Module Covered (DIS/REC/ECO)
R_25	CE PRACTICES VISUALIZATION	The platform must allow car parts designers/car makers to view graphs assessing the impact of their Circular Economy practices in the market	ECO
R_28	CONSUMER INDICATORS VISUALIZATION	The platform must allow customers to view CE indicators and graphical indexes reporting the circularity level of their cars	ECO

Table 3.6 - SSNA Tool, covered requirements

3.11.3 Existing background

The background already available for this component consist of the SSNA cloud platform. SSNA is open source, self-hosted, GDPR compliant, open to various input methods and languages and ensures ethical consent. On a dedicated platform (https://edgeryders.eu), equipped with integrated tools for data collection, elaboration and visualisation, the interested groups are engaged in a large open conversation. Here, trained interviewers or community managers guide the data collection in the form of transcriptions, diaries, images, online forums etc.

Professional ethnographers encode the data and isolate the topics that emerge in the discussions, providing a zoomed-out perspective. The results and their connections are visualised in the form of graphs, which will flow into the platform and provided to car makers with different visualizations.

A picture of the current state of the tool cam be seen in the picture below.

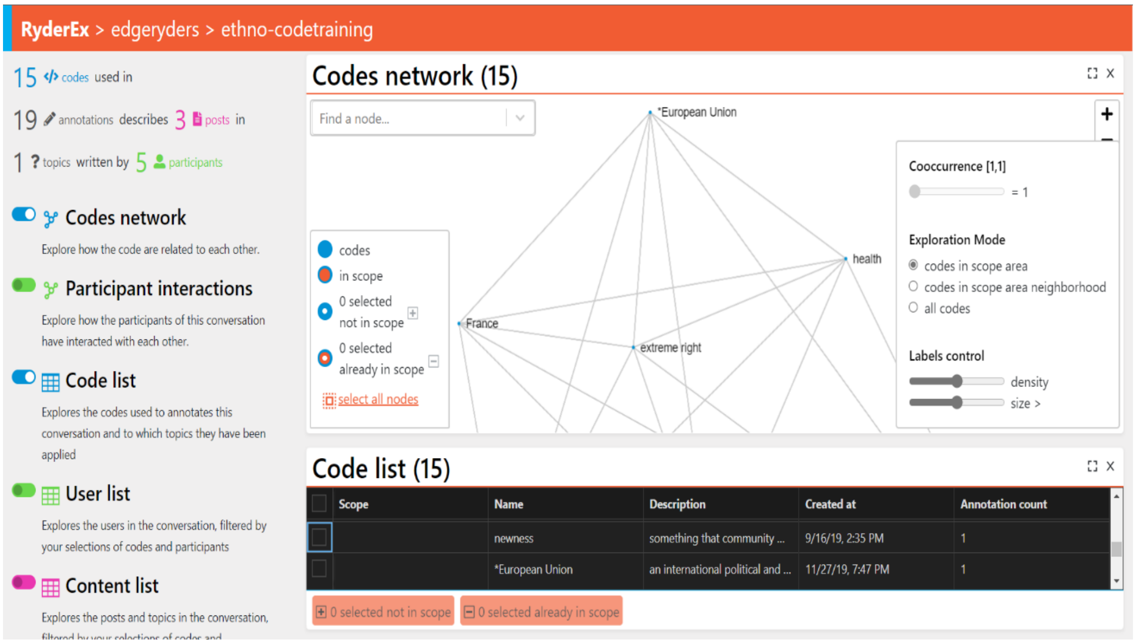

Figure 3.26 - SSNA Tool, sample interface

As can be noted, the tool offers a user-friendly interface that allows the involved actors to seek information provided in different data formats such as relationship graphs, tabular data and numerical indicator. Please note that the data included in the above figure do not refer to the TREASURE Project yet, as they will be made available once the platform will be fully operational and statistics could be gathered and processed.

3.11.4 Work to do

The next steps concerning the SSNA Tool are mainly targeted towards the integration of the already available standalone cloud tool with the TREASURE Platform. This allows a complete reuse of the already available application that will be able to analyse semantic impact in the scope of the TREASURE Project having at its disposal the complete set of data offered by the Data Lake. Further information about the integration procedures is specified in the next section.

3.11.5 Platform integration

The integration procedure to interconnect the SSNA Tool and the TREASURE Platform will happen on two main axes. The first one is represented by a backend integration that aims at ingesting already available knowledge into the TREASURE Data Lake to enlarge the amount of information at disposal of the other components of the platform by also including data coming from EDGE tool. The second axis is constituted by a frontend integration between the SSNA Tool and the Circularity Web Platform by including into the generated dashboards the semantic impact concerning the specific car part/component being retrieved. The information provided will be framed inside the appropriate dashboards by contacting a dedicated API to the appropriate semantic information in the form of charts, tables and numerical indicators.

3.12 AI-Based Advisory Tool

3.12.1 Purpose

The role of the Advisory is to provide guidelines and suggestions for various use cases.

To do this it uses AI which allows information from all use cases to be taken into account, thus considering the entire product life cycle. In other words, the advisory of each use case is not stand-alone but all interconnected, forming a global picture, from which it processes information and provides feedback.

Investigating the role of Advisory, currently designers in the product development phase focus on functionality, cost and quality of the product, not considering the end of life of the product. The Advisory will provide guidelines, suggestions, and assessments to designers to support them in creating a product designed to be disassembled and recycled in an optimized way. Based on the peculiarities of EoL actors and on future technological trends, the platform might also provide BoL with forecasts and recommendations in terms of which elements/material combinations to use or avoid in assembly and provide corresponding recycling/recovery rates by application of AI based recycling assessment. (ECO module).

Similarly, the Advisory supports disassemblers and recyclers by indicating the economic value contained in the boards in the vehicle, at the same time it proposes the recycling routes suggested by the MARAS tool in order to support them in the disassembly and recycling phases. (DIS/REC module).

A feature and, above all, a strength of the Advisory tool is its dynamism as, thanks to a feedback loop provided by each use case (each operator involved has the opportunity to provide feedback to the platform), it is possible to provide up-to-date and accurate recommendations.

The role and functionality of the Advisory will be discussed and presented extensively in D2.2.

3.12.2 Covered requirements

In the table below are listed all the requirements covered by the AI-Based Advisory Tool, along with the specific modules in which the tool covers each one of the assigned requirements.

Requirement ID	Requirement Name	Requirement Description	Module Covered (DIS/REC/ECO)
R_8	PART SUGGESTIONS	The platform must provide suggestions to the disassembler and the recycler about specific parts that can be disassembled	DIS/REC
R_26	SUGGESTIONS VISUALIZATION	The Platform must allow car parts designers/car makers to view eco-design suggestions regarding a specific car/part	ECO

Table 3.7 - AI-Based Advisory Tool, covered requirements

3.12.3 Work to do

The Advisory is a new tool that does not currently exist and will be developed within the project based on use cases. The role and functioning of the advisory have not yet been defined in its details, it will be necessary to:

- establish what suggestions it will have to give, to whom, and in what way.
- establish what feedback it will receive back, from whom, in what format and how.
- establish how the calculation of the indicators carried out by the sustainability tool will be taken up by the advisory and transformed into suggestions.

More details about the functionality provided by the Advisory will be discussed and presented extensively in D2.2.

3.13 Data Lake

3.13.1 Purpose

The objective of the Data Lake component in the scope of the TREASURE Project is to provide a centralized platform to access knowledge, provided by different actors and gathered from multiple data sources, spanning a wide variety of data types. To allow the flow of information from external data sources, a Data Importer helper tool will be exploited to convert information that may come in a format that is not compatible with the Data Lake storage, into a suitable one. The Data Lake will also allow dedicated components of the platform to utilize such information to extract value out of it. In particular, the AI-Based Advisory Tool will exploit data from the platform to provide BoL actors with the set of tools needed to improve sustainability in their production chain. The Data Lake is, therefore, meant to be a collaborative space in which knowledge is shared and utilized among different components of the TREASURE Platform.

3.13.2 Covered requirements

In the table below are listed all the requirements covered by the TREASURE Data Lake, along with the specific modules in which the Data Lake covers each one of the assigned requirements.

Requirement ID	Requirement Name	Requirement Description	Module Covered (DIS/REC/ECO)
R_21	CAR/PART INFORMATION SHARING	The platform must allow car parts designers/car makers to upload information about cars and parts composition	DIS/REC/ECO
R_22	CAR/PART INFORMATION UPDATE	The platform must allow car parts designers/car makers to update existing information about cars and parts composition	DIS/REC/ECO
R_30	DATA SECURITY	The platform must guarantee security of data	DIS/REC/ECO
R_31	OPEN INTERFACES	The platform should possibly be implemented using open interfaces to be able to communicate with other systems.	DIS/REC/ECO

Table 3.8 - Data Lake, covered requirements

3.13.3 Existing background

From an information perspective, there is still not enough data composing the Data Lake. That's because the main knowledge base has to be built during platform operations, based on the output of the three main modules (DIS, REC, ECO) and depending on the use case in question. However, some information is already present in the form of independent data sources that will be incorporated into the unified Data Lake component. Such information comprises publicly available data about disassembly, materials and insurances and will contribute to enrich the overall knowledge at disposal of the TREASURE Platform. For more information about the composition of those sources, as well as a brief description of them, please refer to section 3.13.6 External Data sources .

Furthermore, the cloud system responsible for supporting the Data Lake infrastructure is already present and the physical architecture of the centralized data store is currently available in the form of dedicated AWS services. More information about the physical infrastructure will be given in chapter 3.14 AWS Services, as well as in future software release documents.

3.13.4 Work to do

The main activities that address the development of the Data Lake component, have the objective to unify each existing knowledge base into the unified storage solution and ensuring that, while each module produces its output data, it will be possible to integrate it inside the data lake. In particular, integration has to be performed on multiple axis and comprises different data types:

- Dismantling information: provided by BoL actors such as SEAT and EUROLCDS in the form of disassembly procedures performed by physical operators.
- Recyclability/Disassemblability routes, circularity KPIs, material composition of car parts/components, provided by both the Sustainability Tool from SUPSI
- (Environmental KPIs for Life Cycle) and the Recycling Simulation Tool by MARAS (recycling/disassembly routes, recycling KPIs). Dismantling information, material properties and insurance data provided by external data sources, publicly accessible using open standards.

- Semantic information and user sentiment concerning environmental impact of CE practices provided by the SSNA Tool from EDGE.
- Procedures' metadata, execution logs and user's feedback, collected by the WEAVR platform from TXT during the execution of dismantling/recycling procedures.
- Integration data between the cobot and the WEAVR platform, from a joint effort between TXT and POLIMI.
- Advisory information, forecasts, suggestions and predictions from the AI-Based Advisory Tool as a result of the analysis of a set of all the above data.

To allow the integration of external data sources, a prior activity will be the development of the Data Importer component that will allow to gather information from a specified public data store and retrieve it in a standardized format that is suitable for storage in the Data Lake component.

3.13.5 Platform integration

The Data Lake platform will be integrated with the majority of TREASURE components in order to collect data and allow its retrieval. Also, since the main objective of the work to do already focuses on platform integration, the detailed list of data to be collected cab be found in the above chapter 3.13.4 Work to do.

Finally, in order to facilitate information flow, the Data Lake component will be also implemented with open standards in mind, in order to allow future integrations with external systems that may leverage sustainability information coming from the TREASURE Project.

3.13.6 External Data sources

In this chapter are presented all the publicly reachable data sources that the Data Lake component will leverage in order to further expand the knowledge base at disposal of the TREASURE Platform. In particular such data sources comprise:

- IDIS Disassembly Database

IDIS is the advanced and comprehensive information system for pre-treatment and dismantling information for End-of-Life Vehicles (ELV). It contains safe handling information with focus on airbag deployment instructions, handling and treatment of high voltage batteries as well as gas vehicles. Additionally, it provides user friendly navigation to an extensive database with practical information on pre-treatment, dismantling of potentially recyclable parts and other elements mentioned in ELV regulations (e.g., mercury, lead, cadmium and chromium VI). The database contains relevant data to be processed by TRASURE platform mainly with respect to disassemblability module

- IMDS Materials Database

The IMDS (International Material Data System) is the material data system for the automotive industry, in which all automotive suppliers are obliged to declare the composition and weight of the parts under their responsibility. The creation of this database is derived from the Directive of EoL Vehicles (European Commission, 2000), with the purpose of controlling declarable and/or prohibited substances within cars. SEAT brand accesses this information through an internal system of the Volkswagen Group named MISS (Material Information Sheet System). This system has basically two functionalities. On one hand, all SEAT models can be configured for analysing the content of specific materials or elements. On the other hand, specific car parts of SEAT models can be searched for material/element content. This database is of the utmost importance for TREASURE project, as it contains the feeding information for the disassemblability and recyclability assessments.

It should be noted that these databases do not provide the detail information and differentiation level as required to perform a sound and industrial relevant recycling assessment due to ignorance of the depth of recycling performance and the fact that this is determined by both material combinations, construction as well as the chemical form (compound) in which a material is present (for example: Al in its metallic form acts completely different during recycling than Al present as $Al2O3$ in capacitors). The project will contribute to a more consistent and detailed database on material composition for reliable and sound EoL assessment.

3.14 AWS Services

3.14.1 Purpose

The AWS Services component provides the appropriate infrastructure to support the other parts of the TREASURE Platform and ensure their proper functioning. This is achieved by leveraging the cloud services provided by AWS, which offer state of the art solutions to quickly and reliably deploy ad hoc infrastructures suitable for a wide range of needs. In the scope of the TREASURE Project, the functionalities that will be managed through the use of such infrastructure are listed below:

- User management solutions that allow to securely handle user-related activities (e.g., registration, login, …) and regulate access to dedicated procedures and data stores, following a set of access control policies that ensure authorization-bases content access.
- Physical nodes required for hosting the platform services, ranging from dedicated host machines to serve web content, to data store solutions such as databases and data lakes where different types and amounts of data are securely stored.
- Middlewares and load balancers, mainly used to spread user traffic among multiple instances and prevent congestion of individual nodes. Those infrastructures will be deployed in such a way that will be transparent both to end users and to physical nodes, allowing for a simpler management of the other resources involved.

3.14.2 Covered requirements

In the table below are listed all the requirements covered by the AWS Services component, along with the specific modules in which the AWS Services cover each one of the assigned requirements.

Requirement ID	Requirement Name	Requirement Description	Module Covered (DIS/REC/ECO)
R_1	USER LOGIN	The platform must allow login for different user types (car makers, recyclers, …) based on predefined policies	DIS/REC/ECO
R_2	USER ACCESS CONTROL	The platform must enable users to access only the tools allowed by the group policy assigned to them	DIS/REC/ECO
R_3	USER INSERTION	The platform must allow new users to be inserted, specifying a group policy for each one of them	DIS/REC/ECO
R_4	USER REMOVAL	The platform must allow existing users to be removed	DIS/REC/ECO
R_5	USER DATA MODIFICATION	The platform must enable modification of the data corresponding to each user	DIS/REC/ECO
R_6	USER SECURITY	The platform must follow security guidelines for the user authentication procedures	DIS/REC/ECO
R_30	DATA SECURITY	The platform must guarantee security of data	DIS/REC/ECO
R_31	OPEN INTERFACES	The platform should possibly be implemented using open interfaces to be able to communicate with other systems.	DIS/REC/ECO

Table 3.9 - AWS Services, covered requirements

3.14.3 Existing background

The services that are currently being deployed as pre-existing infrastructure consist of the backend components serving the WEAVR Platform, being this component already in use and completely functioning. These include a set of data storage solutions for procedures, assets and user data, as well as procedure metrics and logs. A set of physical nodes for hosting the cloud portion of the WEAVR has been also put in place, along with the corresponding user management and load balancing infrastructures. Those will represent the starting point from which the other AWS components will be picked to form the complete cloud platform that will support the entire TREASURE platform architecture.

3.14.4 Work to do

A set of services will be added to the existing ones that will allow the entire platform to function properly. In particular, the infrastructure around the Circularity Web Platform needs to be deployed, comprising the physical machines hosting the platform, the user and data management solutions (e.g., secure data stores) as well as the load balancing technologies that will be deployed starting from the existing ones at disposal of the WEAVR Platform component.

Another component to be deployed is the data lake infrastructure needed to support the knowledge base of the entire TREASURE Project. This will represent an expansion of the already existing data storage solution for the WEAVR component. The process will start gradually based on the amount of data to be ingested and will allocate further nodes depending on the storage requirements; this deployment technique allows to keep costs relatively low and use only the amount of storage infrastructure needed. Thanks to the load balancing components it will also be possible to access only the nodes containing the data of interest, preventing network congestion and improving concurrent access to the Data Lake.

3.14.5 Platform integration

Since the AWS Services interact with most of the other platform components, the integration needs to be performed among different axis and will involve different aspects per each component. In particular:

- The Circularity Web Platform component will be integrated by offering hosting capabilities, user management and security functionalities, and load balancing of the physical machines the platform is hosted onto.
- The WEAVR Platform will leverage different AWS services depending on the individual components it comprises:
    - For the WEAVR Manager component a dedicated machine will be deployed to host user data, procedures and their corresponding execution traces/logs, as well as load balancing capabilities to ensure robust access from a large number of users. Network requirements are also needed in order to rapidly upload/download complex procedures from/to multiple users concurrently.
    - For the WEAVR Player component, integration will be performed by providing access to the user store for authentication and management activities, as well as asset storage to retrieve the procedures to be performed on the worker physical device.
    - For the WEAVR Creator component, the integration will leverage the asset store infrastructure to allow procedures upload in the dedicated storage spaces managed by the Manager component.
- The Data Lake component will then be integrated with most of the TREASURE Platform, allowing those to retrieve, upload, edit and remove all the knowledge available through dedicated access policies that will be user specific and/or asset specific. The Data Lake integration needs to be performed through the deploy of load balancers that will be transparent to both the Data Lake and the other components accessing the stored information.

4 Use-case & sequence diagram collection

Starting from the use case analysis reported in D1.2, this section provides the use-case diagrams, along with the proper user sequence diagrams in two dedicated chapters. First a brief description of the diagrams is provided, then motivations about their usage is given, finally the proper diagrams are provided.

4.1 Use-case diagrams

Use-case diagrams model the interaction between users and systems in a standardized graphical format. Unlike sequence diagrams, the point of view of these diagrams is the use-case: the scenario in which the different actors interact with the system.

Use-case diagrams are usually leveraged to:

- Representing the goals of interactions between actors and a components of a system
- Defining and organizing functional requirements in a system
- Specifying the context and requirements of a system
- Modelling the basic flow of events in a use case

Below are presented all the use-case diagrams for the TREASURE Project. In particular, a sequence diagram is identified for each one of the three platform modules (DIS, REC, ECO).

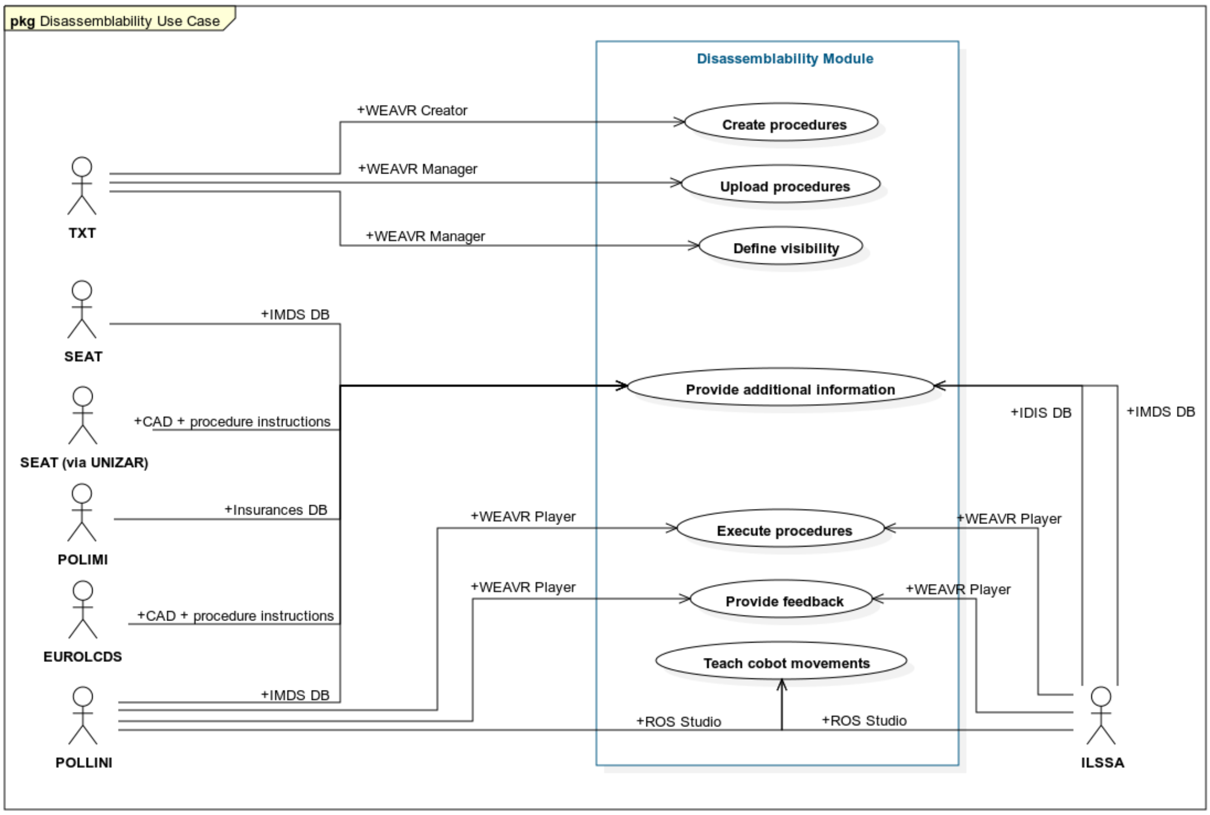

Figure 4.1 - DIS module, use case diagram

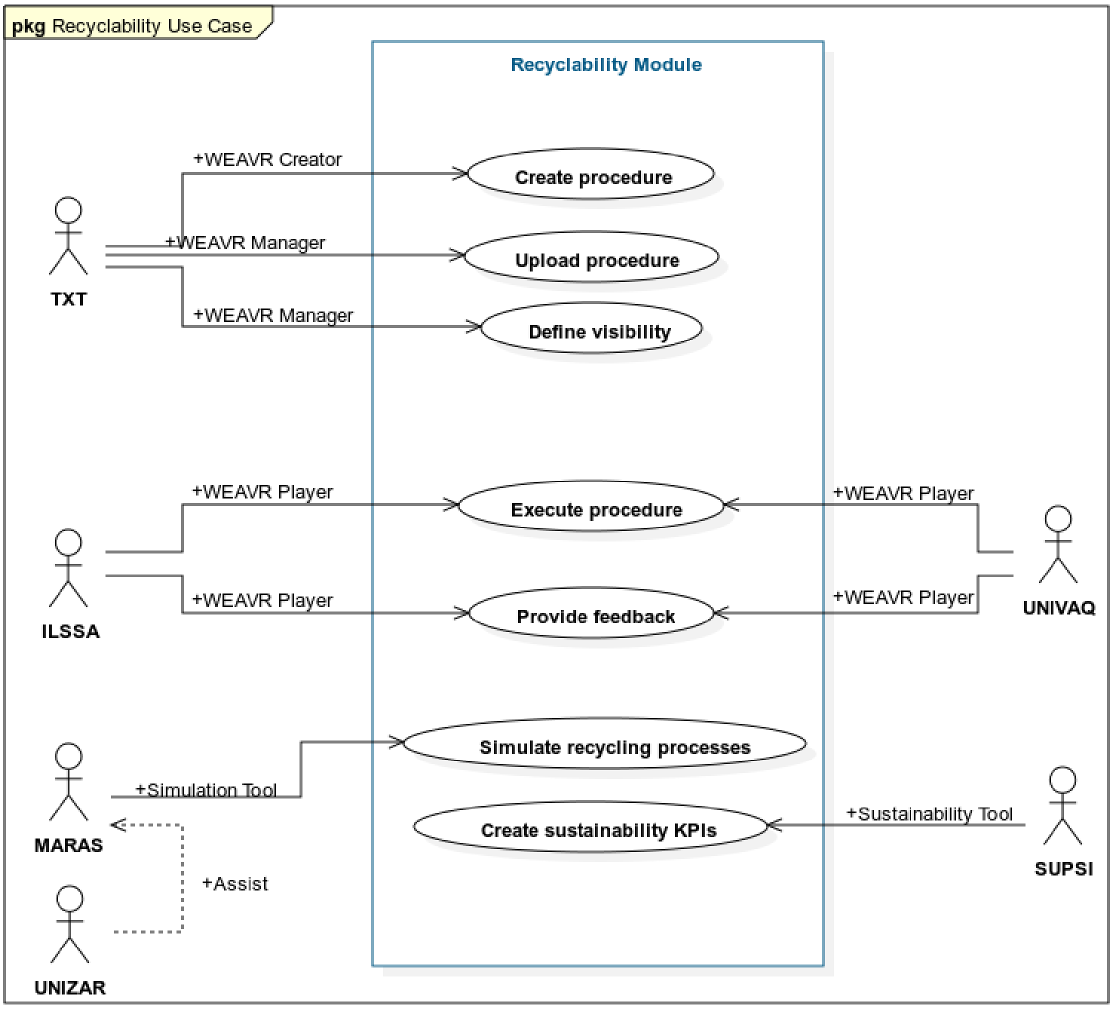

Figure 4.2 - REC module, use case diagram

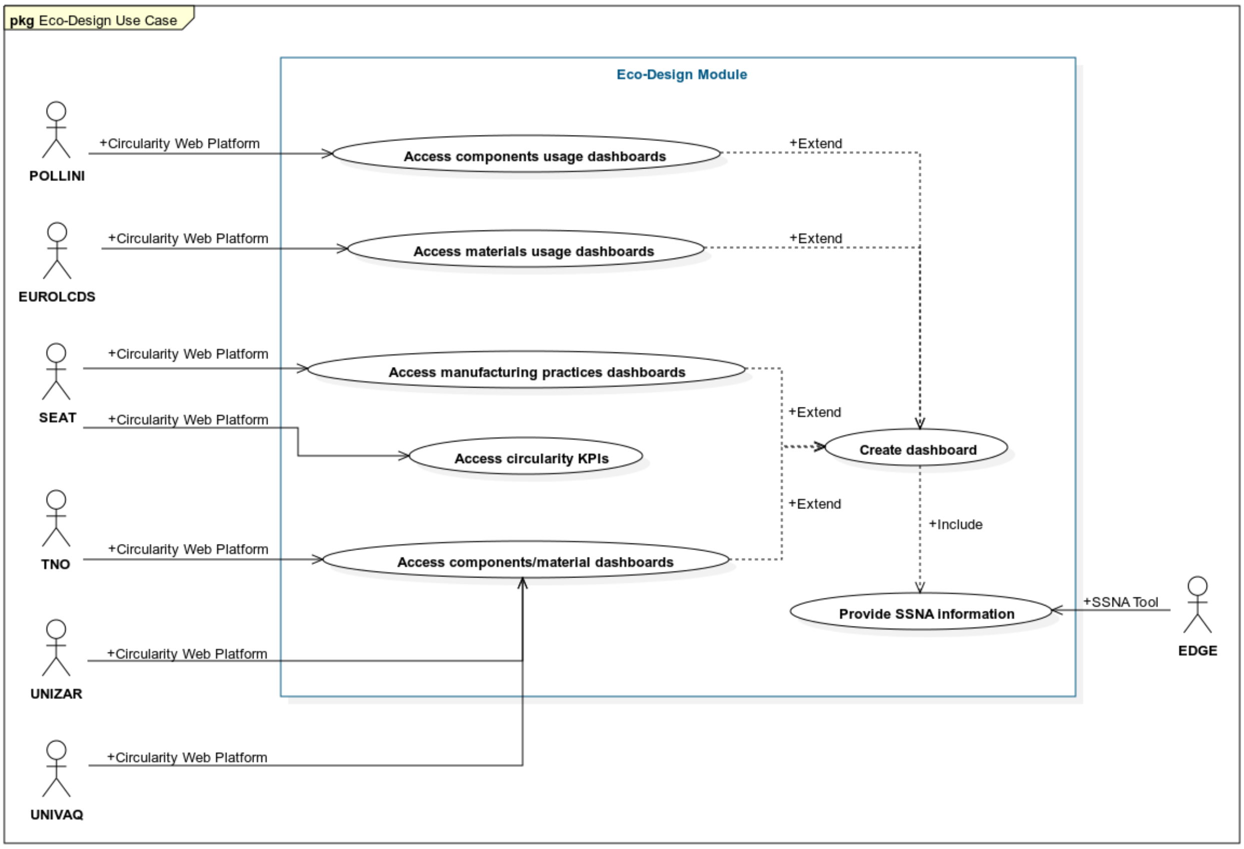

Figure 4.3 - ECO module, use case diagram

4.2 Sequence diagrams

Sequence diagrams are interaction diagrams that detail how operations are carried out, capturing the interaction between objects in the context of a collaboration.

Sequence diagrams are usually developed to:

- Model high-level interaction between active objects in a system.
- Model the interaction between object instances within a collaboration that realizes a use case.
- Model the interaction between objects within a collaboration that realizes an operation.
- Either model generic interactions (showing all possible paths through the interaction) or specific instances of an interaction (showing just one path through the interaction).

Differently from Use-case diagrams, sequence diagrams are developed with the user in mind, and in the context of the TREASURE Project, they provide the interactional model behind each one of the three main platform modules (DIS, REC, ECO) from the point of view of the different groups of actors.

Here below, sequence diagrams per target user are provided. Being the number of actors involved in the TREASURE Platform high, only diagrams for the main users are reported.

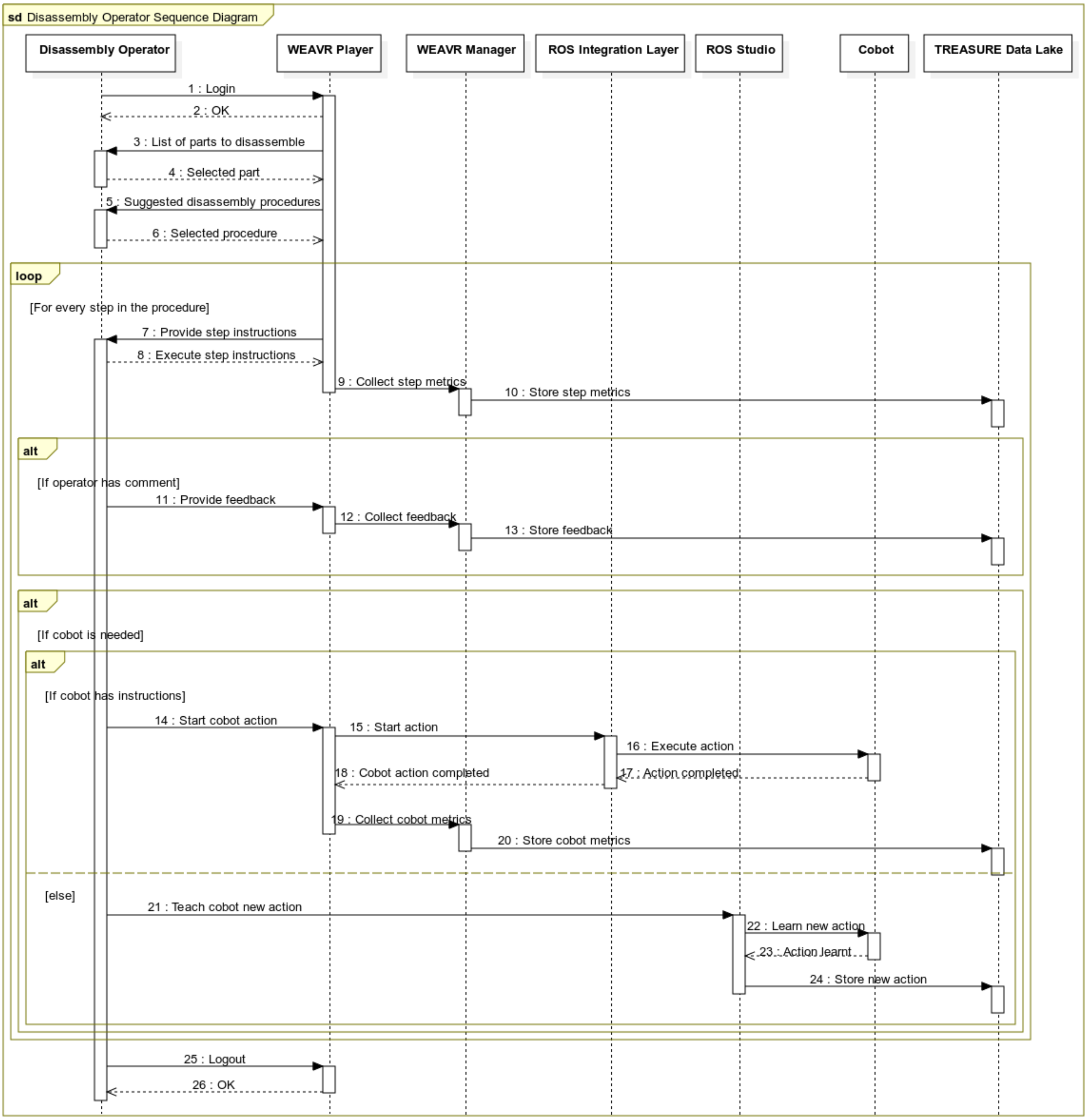

Figure 4.4 - Disassembly operator, sequence diagram

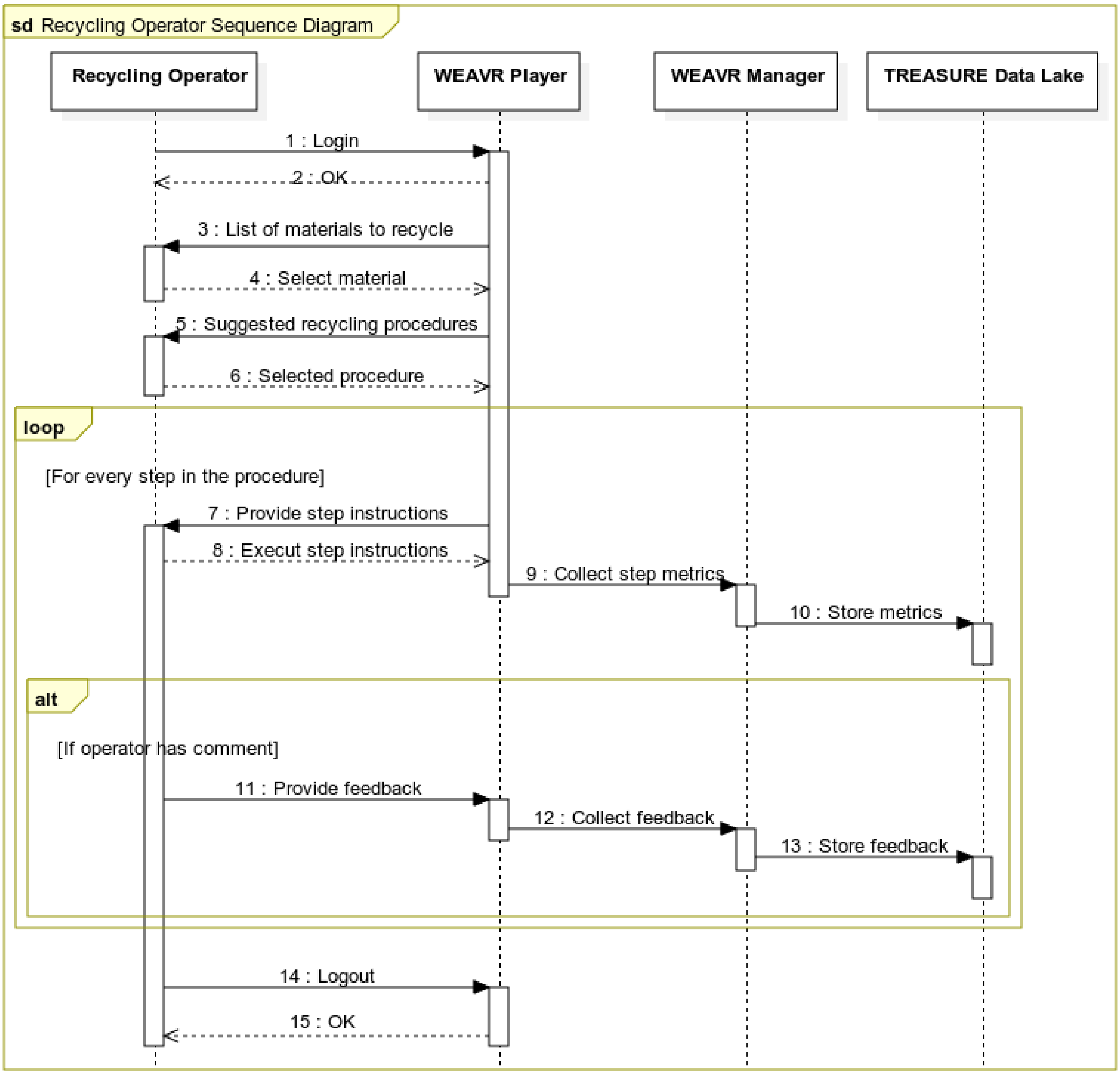

Figure 4.5 - Recycling operator, sequence diagram

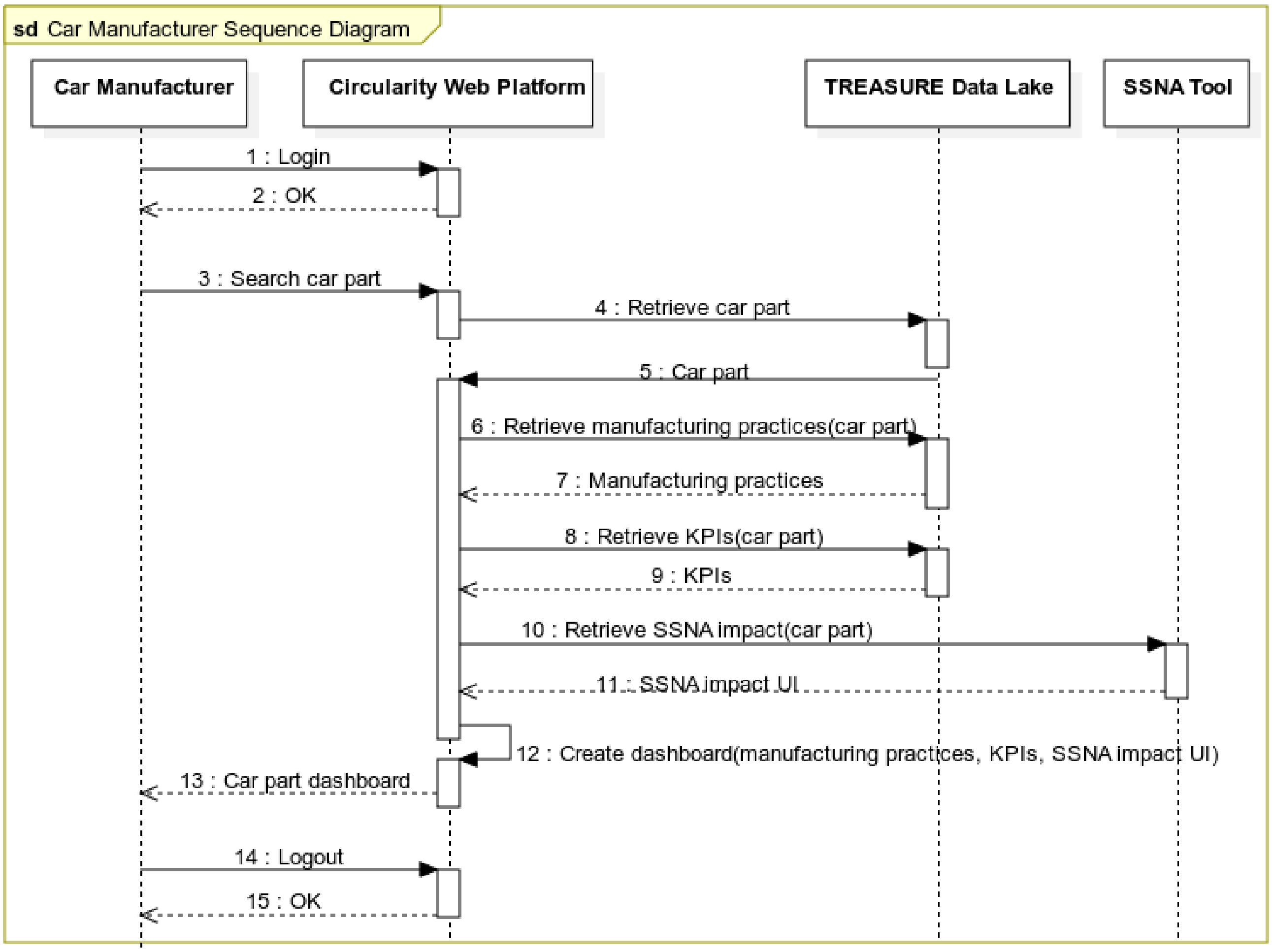

Figure 4.6 - Car Manufacturer, sequence diagram

The sequence diagrams modelling the ECO actors are all very similar to the one presented in Figure 4.6 and are therefore omitted for brevity.

5 Conclusions and Next Steps

The present deliverable documents TREASURE architecture as a result of the early outputs regarding technical requirements and specifications as pinpointed in D1.2, deriving not only from the preliminary system analysis but also from the discussion with the industrial use cases. A complete description of platform use in the three modules is presented, followed by a comprehensive depiction of each component with additional details related to features, functionalities in the selected modules, met requirements and synergy with other key elements. To outline users' interaction and operations flow, diagrams models are provided with a brief description of the diagram characterization and motivations about their usage for project purpose.

The next steps will be mainly focused on the execution of the other tasks foreseen in WP4, assigned to technical design, implementation, and integration of the modules. The activities will be carried out strongly collaborating with the other Work Packages, mainly WP3, aimed at providing the main contents of the modules; WP5, aimed at providing a testing simulation, and WP6, aimed at providing a final validation of the TREASURE platform and its technical implementation. Moreover, the present deliverable also represents the starting point for Advisory tool implementation including its functionality which will be discussed and presented extensively in D2.2.