TREASURE

D4.7: Platform eco-design, dismantling and recycling modules (1st version)

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EXECUTIVE SUMMARY

TREASURE platform aims at becoming a reference tool for the circularity assessment in Europe for the automotive value chain. The platform will integrate three different modules: (1) Disassemblability; (2) Recyclability, and (3) Ecodesign modules.

These modules are addressed to stakeholders from the beginning of life (designers and carmakers) to the end of life (dismantlers and recyclers), with the aim to improve circularity in the automobile sector by sharing essential information among the stakeholders of the value chain.

TREASURE platform process design has been built from the outputs of D4.1 (technical architecture) and D4.3 (platform data lake). Moreover, the circular economy algorithms are based on the main outcomes from D3.1 (critical car part analyses), D3.2 (disassemblability assessment), and D3.3 (recyclability analysis).

The Platform development is a two-stage process. This deliverable presents the initial version of the platform. However, the platform will be improved and finetuned as TREASURE project evolves and the final version is expected to be submitted in M33. The scope of this first version has been focused on developing the Circularity Web Platform and the WEAVR platform. This tool allows for the visualization of VR procedures related to dismantling operations.

The following main activities were performed in the development of the Circularity Web Platform: (1) To define the information to be presented in each module; (2) To define the visualization mock-up; (3) To create the algorithms that will be used for the platform to assess the circularity of any car part; (4) To test the platform with a pilot car part (Combi – Instrument SEAT Leon II).

The next platform version will deal with the following challenges: Automating data processing from MISS database, testing the different modules' functionality with all car parts described in D3.1 and checking the functionality of WEAVR.

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1 Introduction

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 existing between Beginning-of-Life (BoL) and End-of-Life (EoL) actors along the whole automotive value chain up to the final consumers.

TREASURE aims to fill this gap by developing an AI-based assessment tool that can connect and facilitate interaction among key stakeholders dedicated to car electronics: car parts suppliers, car makers, dismantlers, and shredders. TREASURE's goal consists of assisting BoL and EoL actors in performing their operations, making the most suitable decisions according to up-to-date information, and assessing their decision's impact and effect 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 make information available through specific modules that will be built and tailored according to each stakeholder's needs.

The platform will be tested with a set of pilot car parts that were selected in D3.1 and which disassemblability was analysed in D3.2 These car parts are: Combi Instrument; Infotainment; Rain Sensor; Speed sensor; Air quality sensor and Additional brake lighting.

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.

The Treasure Platform comprises three modules: 1) the disassemblability module, 2) the recyclability module, and 3) the eco-design module. Each module is formed by additional subcomponents, as shown in the following tables.

Table 1: components of the disassemblability module

Component	Purpose
Circularity web Disassemblability application	It supports disassemblers in their decision-making process by providing ad-hoc indicators generated through: 1) MISS database[2] 2) the information gathered and calculated in the recyclability module and 3) the information generated by other disassemblers during the disassemblability process.
WEAVR	Simulation in AR/VR of dismantling procedures
Data Lake	Storage of all data provided by WEAVR application and the Circularity Web disassemblability platform
AI-based Advisory Tool	It provides additional information to designers/consultants concerning the best disassembly routes in terms of sustainability and circularity

[2] This information is aggregated in a level in which there is no confidentiality problems.

Table 2: components of the recyclability module

Component	Purpose
Circularity Web Recyclability application	It supports recyclers, both sorters like metallurgists and disassemblers in their decision-making by providing a recycling assessment of selected car parts. Among others, it delivers: Calculation of total recycling rates of the entire part as well as of all individual materials/elements/compounds. Definition of most suitable recycling processing routes. It additionally provides disassembly recommendations and Design for Recycling input as part of the Eco-Design circularity web platforms.
Data Lake	Storage of knowledge/data generated by the Circularity Web platform
AI-based Advisory Tool	It provides a ranking of most suitable/optimal industrial recycling routes based on the analysis performed by the Recycling Simulation Tool. It delivers physics-based recycling KPIs to support recyclers in disassembly and further treatment decisions, it provides feedback to OEMs on recyclability and EoL circularity of designs and both qualitative and quantitative feedback to improve Design for Recycling

Table 3: components of the eco-design module

Component	Purpose
Circularity Web Eco-design application	It supports BoL actors in their decision-making process by providing indicators generated through: 1) MISS database 2) the information gathered in the disassemblability module and 3) recycling assessment (quantification of recoveries and losses and pinpointing of consequences of design considerations) in the recyclability module.
AI-Based Advisory Tool	It provides guidelines, suggestions, and recommendations to designers to support them in creating a product designed to be disassembled and recycled in an optimized way
Data Lake	Storage of knowledge/data generated by the Circularity Web application
SSNA Tool	It checks the social impact of adopted CE practices and offers customers a graphical index assessing the circularity level of cars.

This deliverable mainly focuses on the Circularity Web application for each module and the WEAVR tool, starting from the outcomes and considerations achieved from the discussion with the use cases that lead to the architecture design reported into D4.1 submitted at M10**.**

Beginning of Life (BoL) and End of Life (EoL) actors access the Circularity Web application to visualize relevant KPIs and metrics about the circularity level of the production cycle of car subparts with the aim of improving the overall sustainability of the recycling and manufacturing process. Since the application provides suggestions on recycling routes and EoL operators feedback, it also supports car/component manufacturers in enhancing the design phase based on easing the disassembly process and improving the reusability and recyclability potential of the vehicles and components. The recycling assessment, incorporating the full compositional detail of the car parts, recovered through metallurgical processing and energy recovery flowsheets and calculated recycling rates for the total car parts as well as all individual materials/elements provide the physics-based quantification to optimise Design for Recycling and make decisions and recommendations for more in depth disassembly. As not only recycling/recovery is considered in the Recycling Assessment, but at the same time losses and emissions are pinpointed based on a full mass balance flowsheet for all materials/compounds/elements in the car parts and their interaction (either positive or negative) is addressed, problems in design can be pinpointed and quantified, on the basis whereof recommendations to improve design for recycling can be made.

The collaborative cloud platform displays specific data depending on company policies and user's role, ensuring data protection and authorization protocols. This information is retrieved from the Data Lake starting from the data generated from the activities executed and analysis performed in the previous modules.

In addition to the Circularity Web application implementation, the information stored in the Data Lake is processed by the AI-Based Advisory tool that will provide user information.

This data includes the environmental and economic aspects and the human impact thanks to SSNA tool integration that provides ethnographic analytics. This information is especially relevant for the BoL study on design phase improvements to be made in order to enhance recyclability in the manufacturing process.

This deliverable shows the input data for the Circularity Web application, a first proposal of the outcomes provided by each module and the related internal algorithms. Note that **the final indicators used in the three modules will be addressed in Task 3.4** (ongoing), with the additional input from Task 2.1 and will be implemented in the second version of the platform. Task 2.1 is devoted to the calculation of the environmental, social, economic and circularity indicators selected according to relevant existing standards and the Life Cycle Sustainability & Circularity Assessment (LCS&CA).

An overview of the underlying technical components and main actors involved is described in section 1, following the overall architecture description, which is presented to illustrate how the three modules are connected and exploited by the different type of target users.

Section 2 presents the main characteristics of the Circularity Web application, including the main input information used, the material composition of car parts that comes from an IT system used by SEAT (MISS database). By means of processing this information, the platform can present results in Disassemblability, Recyclability and Eco-design modules, which are also presented in this section. The module's graphic information, the data sources used, the information presented to users and how the platform processes the information internally are shown for each of the modules.

Section 3 presents information about the WEAVR tool employed by dismantlers. Finally, the conclusions and next steps are shown in section 4.

In this first version, the combi instrument of SEAT Leon II is included as a pilot case.

1.1 Scope of the deliverable

This deliverable is the outcome of D4.1 "TREASURE technical architecture (1st version)," and it is the first document to be released concerning Task 4.4 activities. Therefore, D4.7 is to be considered the first description of project platform implementation, starting from the requirements defined in D4.1 and including the data lake infrastructure described in D4.3.

Since the platform development is a living activity along project lifetime, the document will be updated in the following months to establish the final version described in D4.8, due on M33. Moreover, the present deliverable is also strictly correlated to the AI-Based Advisory Tool implementation, including its functionality which is discussed and presented extensively in D4.9.

1.2 Relation with other WPs

Starting from the architecture design displayed in D4.1 and the technical requirements defined in D1.2, the document first contributes to all WP4 "TREASURE platform design, development and integration" tasks. Since this deliverable describes the implementation of TREASURE tool, it is evident that it lays the foundation for the technical execution of WP5 activities related to platform application to support the simulation of PCB 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 outcomes emerging from using the TREASURE platform are the pillars for evaluating exploitation routes and the business model definition as part of WP8 activities.

From the information presented in the different modules, it must be underlined the vital contribution of WP3 (Automotive value chain digitalization) with the following deliverables:

- D3.2: Report on disassemblability analysis (submitted) → It provides information about the main relevant variables to be considered in the disassemblability module.
- D3.3: Report on recyclability analysis (submitted M18) → It provides information about the recyclability approach and the KPI's and information calculated and generated by the recycling simulation models.
- D3.4: Report on KPIs to be embedded in the TREASURE platform (submitted M18) → It presents the indicators that must be considered in the different modules.

1.3 TREASURE Platform Process Overview

The present section portrays an overview of the processes executed using TREASURE platform with a description of the data flow between all actors involved in project activities highlighting the dependencies among each single operation and step of the procedure. The picture below eases the comprehension of platform functionalities that vary according to the user scope: different users access different types of data that are considered relevant for their goals with respect to the analysis to be performed. The same picture can be seen at the following link: Data flow, Online Whiteboard for Visual Collaboration (miro.com)

The integration between components is described in detail in the following chapters to specify the implementation of the TREASURE platform for the three modules on which the project is based: Disassemblability; Recyclability and Eco-design.

The assets involved in creating the TREASURE tool are inserted concerning their role in the process. A detailed description of every single component is reported in D4.3, detailing functionalities exploited in the project scope and technical information, such as internal architecture, technological stack, and data sources.

1.4 Overall Process Description

Starting from the platform architecture presented in D1.2 and the data sources described in D4.3, the procedural sequence of project activities has been refined to explore the whole set of operations carried out by affected actors. Since the overall process includes the participation of different users and technological components, the flow chart in Figure 1 shows how the process is structured, underlying the different perspectives of players involved in project activities that are horizontally represented.

Actors are presented in the first column, while the boxes represent step-by-step operations in the three modules. Although graphically displayed in sequence for convenience, the activities can be carried out simultaneously due to the lack of interdependency in each module. Moreover, some operations are not restricted to a specific module concerning activities that can be performed within different scopes.

Based on the user role, different authorization protocols are foreseen to avoid strategic and confidential information sharing with users without authorization to ensure privacy policy compliance. This applies especially to data related to car manufacturers that cannot be open access data. For example, this is the case of the WEAVR platform that is exploited in operations related to both the Disassemblability module

The description presented in this document does not address the AI application 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 and EoI processing phase within the Disassemblability module (DIS) and the Recyclability module (REC). Since the AI-Based Advisory Tool is not part of this deliverable scope, its implementation is further described in “D4.9: Platform Circular (AI-based) advisory module (1st version)” due on M15.

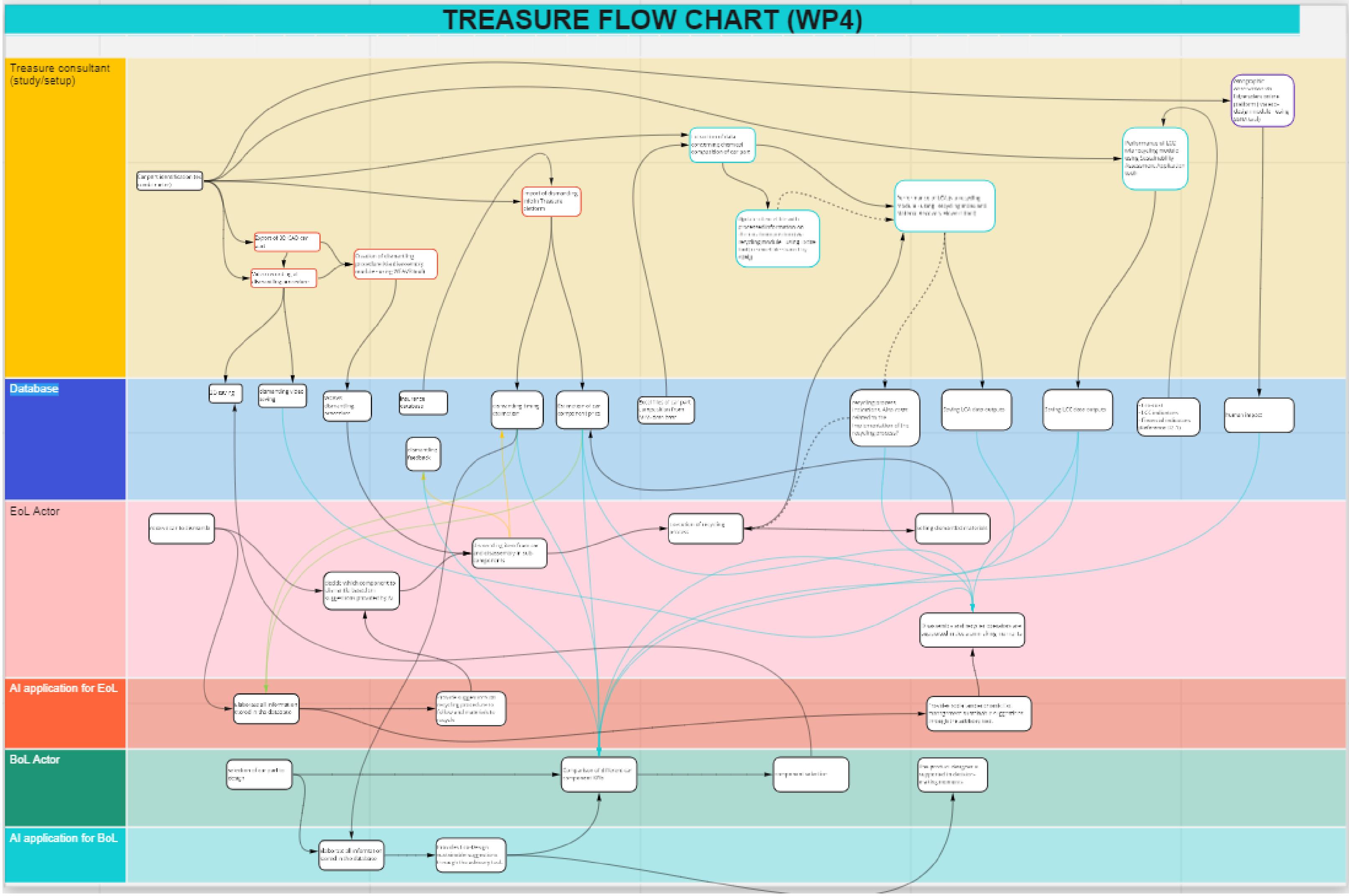

Figure 1: Overview about TREASURE platform process of creation. This picture can be downloaded from: [Data flow, Online Whiteboard for Visual Collaboration (miro.com)]

The following sub-section depicts each actor's specific procedure, focusing on the actor’s point of view to provide a background of why the platform has been structured and how the tools are integrated. The technological integration and dependency between platform components are presented in the section dedicated to each module.

1.5 TREASURE platform main stakeholders

1.5.1 Facilitator

The TREASURE platform can retrieve information useful for different types of assessment related to resource use optimization. This type of user has full access to all tool functionalities to perform consultancy services for not only BoL and EoL actors but also interested stakeholders. For this reason, the project facilitator can log in to the specific tool integrated in the platform to collect specialized knowledge and technical data required for identifying the most suitable recycling or dismantling routes to improve existing processes. Starting from user needs, TREASURE expert determines the KPIs and financial/environmental indicators to be considered in elaborating the operation reconfiguration.

According to the analysis to perform, the facilitator elects the platform functionalities in terms of visualization of information collected by the Data Lake and/or access to subcomponents, such as the Circularity Web application. Her/his role is transversal to all modules and has a bird’s-eye view of recycling and dismantling process that allows extensive know-how on the optimization of existing procedures.

1.5.2 End of Life Actor

The End-of-Life actors, namely dismantlers, shredders, recyclers and physical operators, use TREASURE platform to access data related to material composition to dismantle for reuse or recycling. Thus, their role is connected to the Disassemblability Module and Recyclability Module. The user selects the car part/s to remove according to suggestions provided by AI based TREASURE application that displays data related to all compounds, including valuable and/or critical materials present in car elements.

This information is stored in the Data Lake that collects a wide range of data concerning knowledge provided by involved technical partners, performed calculations and additional information coming from industry-standard external data sources.

In the dismantler actor's case, the information provided includes mainly technical and economic aspects from a circularity perspective. Thus, the user proceeds with the dismantling operations with the assistance of VR/AR application that shows each step of the disassembly procedure with a user-friendly approach. While using the AR/VR application as a guideline, the operator provides relevant feedback during dismantling activities, including disassembly timing, execution logs and user comments. This information set is integrated into the TREASURE database, complementing already existing data to constantly improve the centralized knowledge base and perform better analysis while providing enhanced suggestions via AI based application.

During the execution phase of the dismantling procedure, the operator can be partially assisted by cobot application in seamless cooperation between the user and the robotic arm. Thanks to WEAVR integration, the user provides instructions to the cobot such as the position the robotic arm must reach, the path to follow, and the activity to accomplish. In case the operator intends to execute a procedure that is not present in the set of operations known to the cobot, a manual training process can be performed, in which the operator teaches the movements and actions to be replicated by the robotic arm. Once the procedure is completed, the new set of instructions is recorded and ready to be exploited in the future.

During the dismantling process, the operator can provide useful feedback and relevant comments. This feedback will then flow through the platform to be exploited by the BoL actors to improve the design process of car parts and components. EoL actors will have the opportunity to give eco-designers feedback about the disassembly process and improvement areas by completing a simple questionnaire.

The last step of the dismantler's procedure consists of either selling the dismantled component as a second-hand car part, or sending it to a specialized recycler, as the content materials have proven to be financially valuable.

Recyclers in turn have also a dedicated module in the platform providing information about best recycling routes for the car components and recovery yields for the entire car parts as well as all individual materials/compound included. The recycling module gives also feedback to manufacturers to improve design for recycling and on recycling rates to be achieved for their product/parts. It also gives input and feedback to disassemblers on advice on disassembly depth in order to optimize recycling/recovery, i.e. production of modules/segments/parts (i.e. mineral fractions) based on their material build-up as derived from the MISS data, to match best with exiting industrial recycling processing infrastructures and hence best recycling technology to be applied to process these modules/segments/parts

Such information and a set of dedicated KPIs relevant to the dismantling and recycling processes can be accessed by the EoL actors through the Circularity Web application. EoL recycling performance KPIs can also be assessed by BoL actors, including recycling technology-based recommendations for DfR.

1.5.3 Beginning of Life Actor

The Beginning-of-Life Actor, namely car parts designer and car/component manufacturers, uses TREASURE Circularity Web application to access information related to valuable recommendations for the design phase based on KPI's as derived from 1) the MISS database, 2) the disassemblability module and 3) the recycling module. EoL stakeholders are mainly involved in the Eco-Design module because the collected information is exploited to improve the design phase to ease the disassembly process and enhance the reusability and recyclability potential of the vehicles and components.

The first step consists of selecting the car part to be assessed. Suppose the platform already contains information on that specific car part. In that case, it will show the relevant KPIs generated through the already introduced material composition information and the data generated from the disassemblability and recyclability modules. If, by way of contrast, the specific car part is not yet included in the platform, then the eco-designer needs to incorporate the Material Information System Sheet (MISS) into the platform, which includes the specific composition of that given car part. Based on it, the platform generates the relevant KPIs considering the materials' criticality. When this information arrives to EoL actors, the platform will gather all required information regarding disassemblability and recyclability aspects and calculated KPIs (based on AI representation of the complex recycling simulation model) that will be sent back to the designer for a complete circularity assessment of the given car part and will provide design for dismantling and recycling recommendations. It should be mentioned that the platform can only assess already designed parts. These parts have material composition data from MISS. That said, the manufacturer can learn from older car parts to improve design for recycling for the new car parts.

2 Circularity web application

The Circularity web application is a tailor-made interface devoted to dismantlers, recyclers and manufacturers. The aim is to provide helpful information and KPIs in a secure way to each stakeholder to improve circularity along the vehicle's value chain. Manufacturers, dismantlers and recyclers share key information that will help each of them in the decision-making process to optimize resource efficiency in their respective processes (see Fig. 2). Accordingly, manufacturers share information with dismantlers and recyclers regarding the material composition of already-designed car parts. Dismantlers generate information regarding times, required tools, costs and procedures needed to dismantle that specific car part. Dismantlers also share information with manufacturers about recommendations to improve design for disassemblability and with recyclers about dismantling levels that can be achieved and related costs. In turn, recyclers[3] share with manufacturers the material recovery potential of that specific car part and recommendations to improve design for recycling. The Recycling module will provide recycling rates/materials recovery rates with dismantlers depending on the disassemblability level achieved. In addition, the system generates with all such information a set of key indicators differentiated by the type of user.

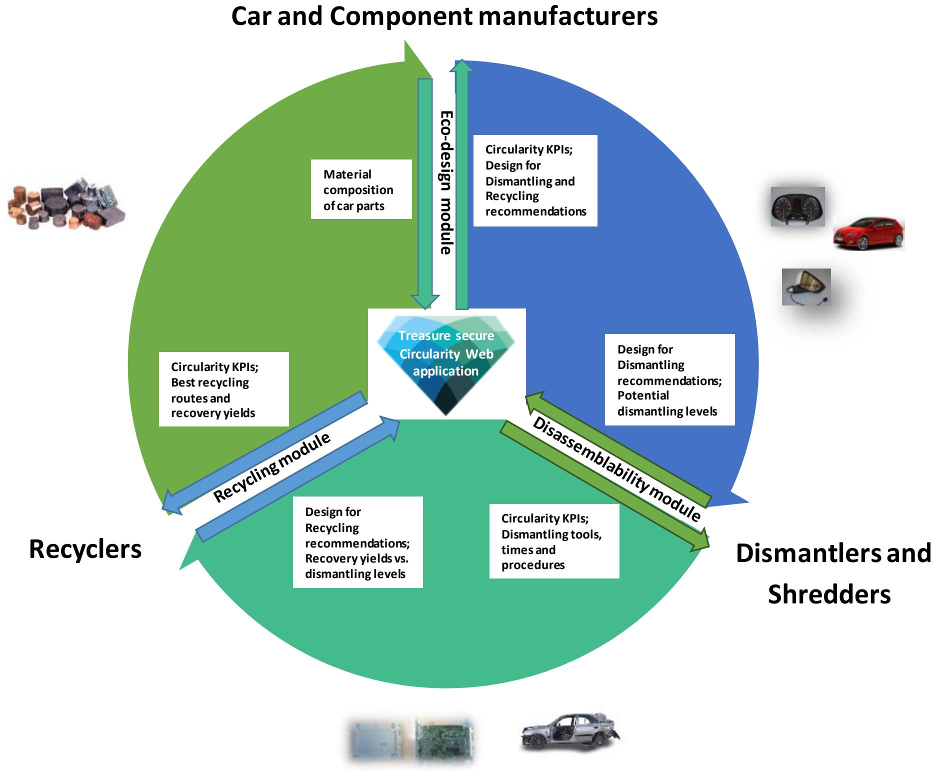

Figure 2: Overview about the Circularity Web application within TREASURE platform

[3] Those that applies metallurgical operations.

2.1 Input information about material composition

The Circularity web application's starting data for the three modules is the Material Information System Sheet (MISS) obtained from SEAT IT systems. These data are given in pdf format, so several operations about data format conversion must be done to be processed by the platform.

It should be mentioned that MISS was developed for the Volkswagen group to satisfy the requirements set in the End-of-Life Directive, mainly to ensure that the car does not include any non-permitted substances and that at least 95% of the materials in the car can be potentially recycled or valorised. Hence, even if MISS is an excellent starting point for the platform's development, several information gaps have been identified in D3.3 to be fully operational. Such gaps had to be processed manually in D3.3 to render the data in a consistent and detailed enough format suitable as input as used for thermodynamic simulators such as the recycling simulation model of D3.3. D3.3. lists guidelines for the processing of the data and possible automation thereof in view of the platform development.

Table 2: Example of data from MISS – The table only contains a short selection (rows) of the car part information.

Baum-Ebene	Typ	Name	Teilnummer/ Sachnummer/ Werkstoffnummer/ CAS-Nummer	Menge	Gewicht [g]	Mengenanteil [%]	Mengenanteil [%] (von - bis)	VDA-Kategorie/ Reinstoff-Eigenschaften	Polymer-Kennzeichnung/ Rezyklat (Prod.-Abfall/Altmetall)/ Anwendung
1		Kombiinstrument		1	738,00				
|—2		Linsenschraube / oval head screw		7	4,90				
|—3		Material for Fasteners Property Class <=12.9 (Flat Bill)	-		0,70			1.1.1	Rezyklat enthalten: Nein
|—4		Kohlenstoff	7440-44-0			0,275	0.0 - 0.55		
|—4		Phosphor	7723-14-0			0,0175	0.0 - 0.035		
|—4		Schwefel	7704-34-9			0,0175	0.0 - 0.035		
|—4		Silicium	7440-21-3			0,175	0.0 - 0.35		
|—4		Mangan	7439-96-5			0,65	0.0 - 1.3		
|—4		Chrom	7440-47-3			0,85	0.0 - 1.7		
|—4		Molybdän	7439-98-7			0,40	0.0 - 0.8		

Table 2 presents a short example of data based on the Combi Instrument of Leon III model. Each car part is disaggregated into smaller levels providing the material composition (the levels are represented in the first column of Table 1). Level #1 names the car part and shows information about the total mass. In the example, this value is 738 g.

Level #2 names the subparts, in this case the oval head screws, which are 7 units with a total weight of 4,9 g. Each car part (Level #1) has a different number of subparts (Level #2) according to the complexity of the car part (i.e.: Level #1 Combi Instrument and Level #2 PCB). For example, in the Combi Instrument case, there are 20 subparts (Level #2), some of which are: PCB; Loudspeaker; Stepper motors or lightguide.

As seen in Table 2, from Level #2 the information is disaggregated until it reaches the level of the substance (represented by 2 green circles in the second column) or of the materials (represented with a blue triangle in the second column). However, some car parts need to be divided into 9 levels until the material composition is reached.

Input data processing has been a challenging task. As detailed in D3.3 this process has proved to be very complex. The recyclability assessment requires that the full composition of all substances in the car parts and subparts as well as their masses are available in a consistent format. For example, those car parts analysed in D3.3 contain more than 320 different compounds (metals, alloys, oxides/sulphides, inorganics and organics), of which around 220 are organics (i.e: see Table 3 with a sample of compounds contained in the combi-instrument of SEAT Leon). It must be noted that this list contains only a small selection of the components of this car part.

Table 3: Input definition of car parts derived through data processing from MISS data file (source D3.3)

Infotainment-Combi Instrument - Air conditioning unit			
Compounds (chemical formulas)	**Mass % in car part**	**Compounds (chemical formulas)**	**Mass % in car part**
*2CoO*TiO2		Si	0.038089945
*3MgO*4SiO2*H2O		Si(CH3)2O(g)	0.081145506
Ag	0.050879254	Si(OC2H5)4(l)	8.91422E-05
Al	3.324194317	SiN(g)	
Al(OH)3	0.000221513	SiO	0.017611932
Al2O3	0.010980374	SiO2	6.120841659
Al2O3*2SiO2	0.000735423	Sn	0.330726024
……	……	……	……
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……	……	……	……
……	……	……	……
B	0.011693839	Tb	
B(OH)3		Te	
B2O3	0.000159093	Ti	0.000190354
Ba	0.026569005	TiO2	0.05595244
BaO	0.004543896	Ti(OC3H7)4(TTIPg)	0.003168093

In the scope of this first version, MISS data are not processed automatically, so the Combi Instrument input data were analyses and processed manually. Nevertheless, with the lessons learned, this process has to be automatized for the following platform version. Moreover, a list of recommendations regarding how to improve the data compilation process in the system was given in D3.3.

Some points which should be accounted for the automation of the data:

- Data should be provided in xlsx or similar.
- All material data/descriptions should be completely defined without uncertainty (e.g. abbreviations should be written in full) and for all material names the corresponding CAS numbers should be included in the MISS file, as this would allow for an easy lookup of stoichiometric/chemical formula.
- A database containing all CAS numbers of applied materials/substances in the car parts and their corresponding full chemical/stoichiometric formulas should be set up.
- All masses/weight percentages should be given in point separated format (for decimal definition)
- Masses of individual materials/parts should add up to full mass of component/100%, the same applies for all masses within the subparts/components
- The structure of the data file should be defined in such manner that an easy calculation of mass per material/compound/substance is possible in an automated manner from the data file.
- The number of times a part occurs (defined under 'Menge') should be defined in an equal manner for all sub-parts. This is required for a proper calculation of the mass per compound within a sub-part or component.

2.2 Disassemblability Module

This section thoroughly describes the process foreseen in the Circularity Web application of the Disassemblability Module. As can be seen in Figure 3, the disassemblability module is formed by different components in addition to the Circularity Web application, including the AI advisory tool and WEAVER tool (see section 4), which complement each other to provide dismantlers with the best user experience.

The information provided for dismantlers in the Circularity Web application is given for a specific car part and is generated from three sources: 1) the MISS database introduced by manufacturers (in this preliminary case SEAT), 2) dismantling times and tools (in this preliminary case, with the activities that were carried out in Task 3.2, but they will be generated in the future directly by dismantlers) and 3) the recyclability assessment (which was carried out in task 3.3, but it will be automatized in the future with the lessons learned from that task and MISS information). In a later stage, Artificial Intelligence (AI) will also be added to improve the decision-making process.

Dismantlers obtain feedback from the platform and are also key players in feeding the platform with valuable information for other dismantlers, eco-designers and recyclers.

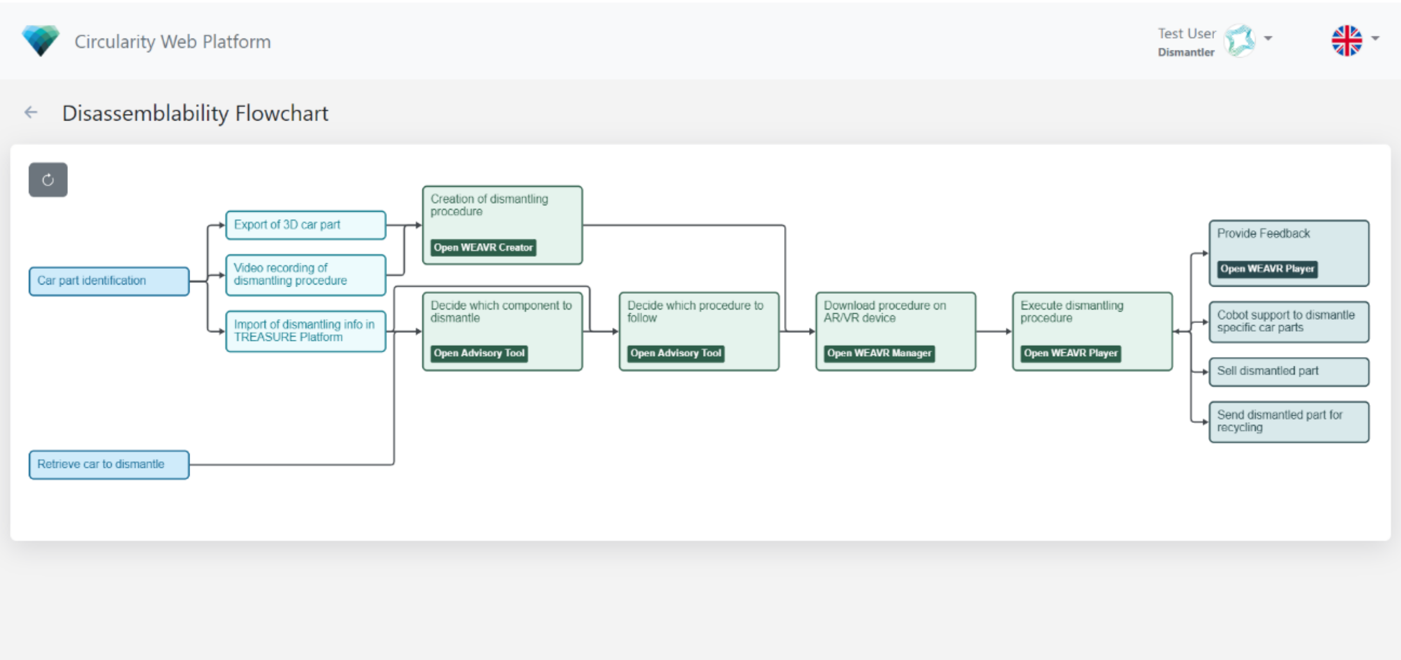

Figure 3: Preliminary Disassemblability app user process

2.2.1 Outcomes of the Disassemblability module

The Circularity Web application devoted to dismantlers will preliminarily contain the following information:

- Overall score of the car part, divided into specific scores regarding: 1) Metal use; 2) Plastic use; 3) Disassemblability and 4) Recyclability.
- Description of the car part and the location in the car.
- Level 1 disassembly time (extraction of the whole part from the car), with and without a cobot.
- Level 2 disassembly time (car part sub disassembled into subcomponents), with and without a cobot.

- Materials classification in the following categories: Ferrous metal, Non-ferrous metal excluding Al, Aluminium and Plastics.
- Materials economic value in the following categories: Ferrous metal, Non-ferrous metal excluding Al, Aluminium and Plastics.
- The market value of the car part if it were new.
- Disassembly difficulty of Levels 1 and 2 as High / Medium /Low. According to these criteria:
    - *Level 1* → Extraction of the car part from the vehicle.

Table 4: Difficulty level calculation process in Level 1

Difficulty Level	Number of tools		Type of tools		Number of parts to be disassembled before		More than 1 dismantler needed?
High	>5	OR	nonstandard	OR	>3	OR	YES
Medium	(1-5)	AND	standard	AND	(1-3)	AND	NO
Low	1	AND	standard	AND	0	AND	NO

    - *Level 2* → Car part sub-dissassembly into smaller subparts.

Table 5: Difficulty level calculation process in Level 2

Difficulty Level	Number of tools		Type of tools
High	>5	OR	nonstandard
Medium	(1-5)	AND	standard
Low	1	AND	standard

In the case of Level 2 only the number and type of tools are considered because this activity is performed over a car part already disassembled from the car.

- Process description: Narrative information about the disassemblability process.
- Dismantling costs vs. recyclability yields: to determine the level at which dismantling can be cost-effective from a recyclability point of view. This information will combine outputs from recycling module (recyclability yields) with outputs from dismantling (labor costs).

2.2.2 Feedback from dismantlers to other dismantlers, recyclers and manufacturers about disassembling and sub disassembling

This module will have two types of users: (1) users who retrieve information from the Circularity Web application (2) users who populate the platform with new disassemblability information about new car parts. The second will also contribute to give feedback to eco-designers about future recommendations of car parts concerning disassemblability and to recyclers information about potential dismantling **le**vels, so a recyclability assessment can be performed on each level and material recovery yields vs. dismantling costs can be provided.

To that end, dismantlers are asked to provide answers to the following preliminary questionnaire:

Q1: Number and types of tools needed?

Q2: Number of parts to be disassembled before?

Q3: Is more than one person needed to disassemble this car part?

Q4: Is it possible to replace the type of joint method between the subparts? / Are there any types of joining systems that avoid the disassembly process (i.e. glues, weldings, or thermal riveting)?

Q5: Are the fractions obtained in the sub-disassembly process easily identified with any recycling fraction (ferrous, aluminum, non-ferrous ex Al, plastics, PCBs)?

Q6: Can the disassembly time be reduced?

Q7: Is the lifetime of this car part regularly longer or shorter than the vehicle itself?

Q8: In the case of damage, do you consider that this part is repairable?

Q9: Disassembly difficulty (level 1) is high?

Q10: Subassembly difficulty (level 2) is high?

According to the answers, the platform will be populated so that future dismantlers can easily retrieve the information through the Circularity Web application. Additionally, the following preliminary messages (M) will be given to manufacturers through a specific area placed in the eco-design module:

M1: "*Facilitate the disassembly process of the car by using a smaller number of tools"*

M2: "*Consider the possibility of avoiding disassembling previous car parts to access the interest car part"*

M3: "*Disassembly requires more than one worker. Facilitate dismantling"*

M4: "*Consider using bolted or demountable joints instead of thermal riveting or glues"*

M5: "*Evaluate improving sub-disassembly to provide recyclable fractions rich in different recycling fractions (ferrous, non-ferrous excluding Al, non-ferrous Al and plastics)*"

M6: "*Evaluate the possibility of reducing the number of tools used and ensure that standard tools can be used"*

M7: "*Increase the durability of the car parts"*

M8: "*Consider the possibility of making the car part repairable"*

M9: "*Facilitate the disassembly of the car through use of standard tools, use less tools or less people needed"*

Conditions to show the different messages are the following:

If Q1 is >5 OR 1-5 show M1.

If Q2 is >3 OR 1-3 show M2.

If Q3 is YES show M3.

If Q4 is YES show M4.

If Q5 is NO show M5.

If Q6 is NO show M6.

If Q7 is "is shorter" show M7.

If Q8 is NO show M8.

If Q9 is YES show M9

If Q10 is YES show M9.

2.2.3 Platform implementation

Given user requirements and technical components dependencies, the Disassemblability application is created to display relevant information for the end user. For this module, three type of users are foreseen based on the granted authoring rights:

- The visualization only mode: the user can only see the platform content with no authorization to edit
- The editor mode enables the user not only to visualize the information but also to add new content on specific platform sections by clicking on the “Edit” button
- The moderator mode: the user can approve or reject the data provided by the editor, leaving feedback in case of non-approval

The figure below shows, as an example, the case study of the Combi meter with the Editor mode. The dashboard in case of visualization only and editor mode is the same except for the “Edit” button that enables the user to add data of a new car part.

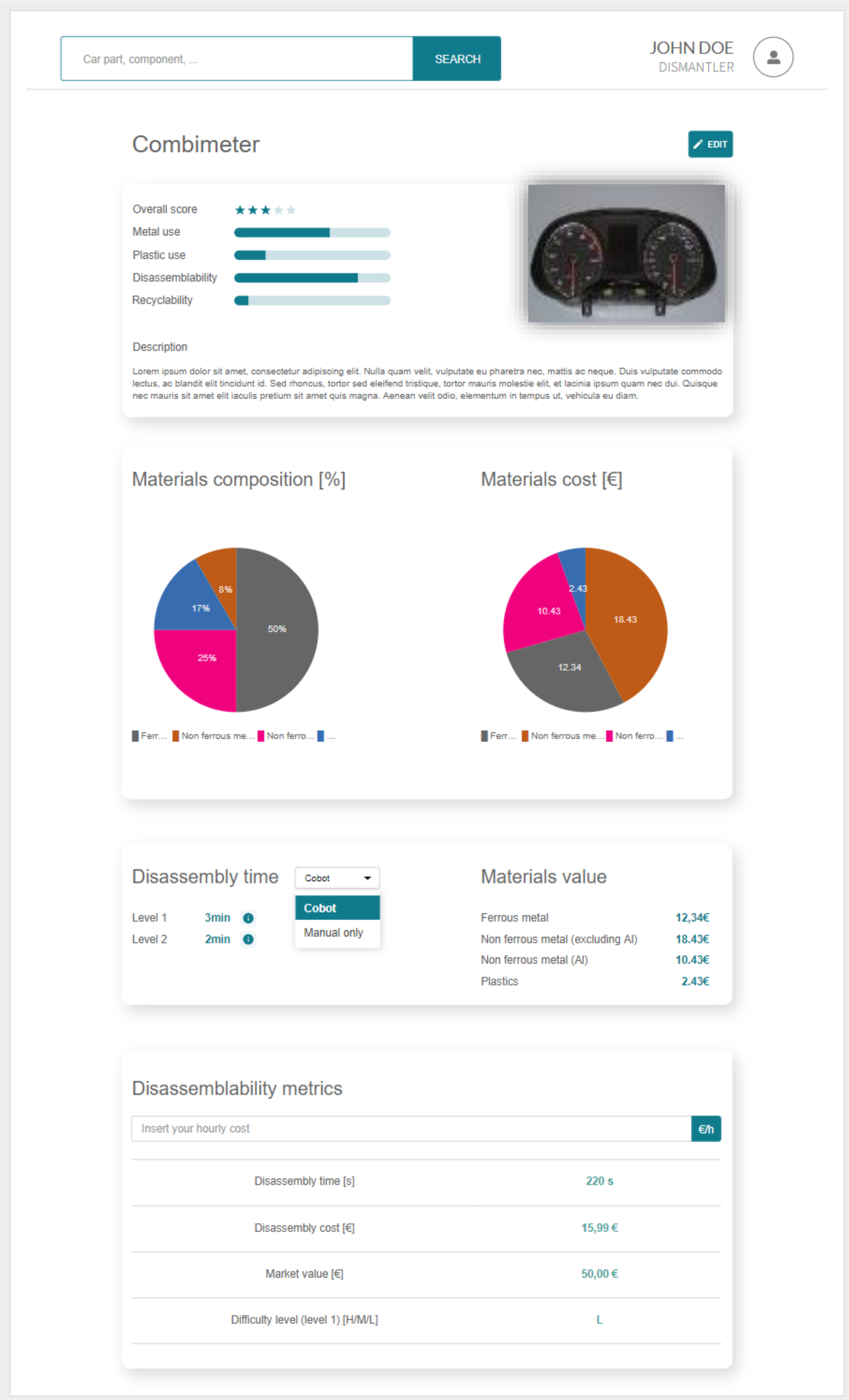

Figure 4: Preliminary Mockup of the Disassemblability module (Facilitator mode)

When the user clicks on the “Edit” button, the table with all metrics is displayed and can be filled in with the necessary data. The information provided is sent to the moderator for approval to verify the data source and ensure its accuracy. The editor user can see all submitted requests in a specific section of the platform with the date, status and eventual comment shared by the moderator.

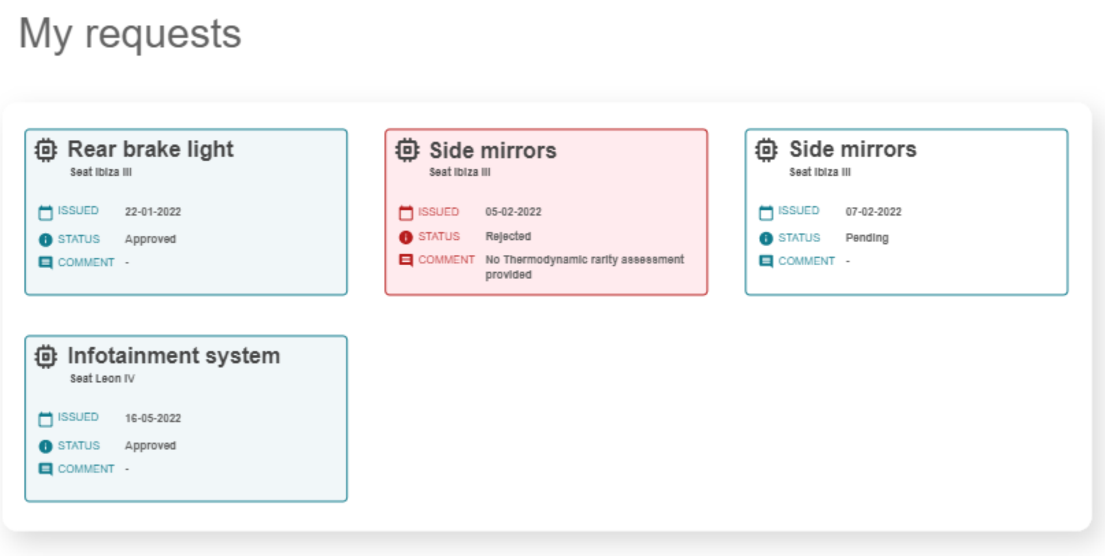

Figure 5: Facilitator mode: Request history page

The moderator dashboard displays all submitted request with the same data as the editor, except for the presence of the “Inspect” button.

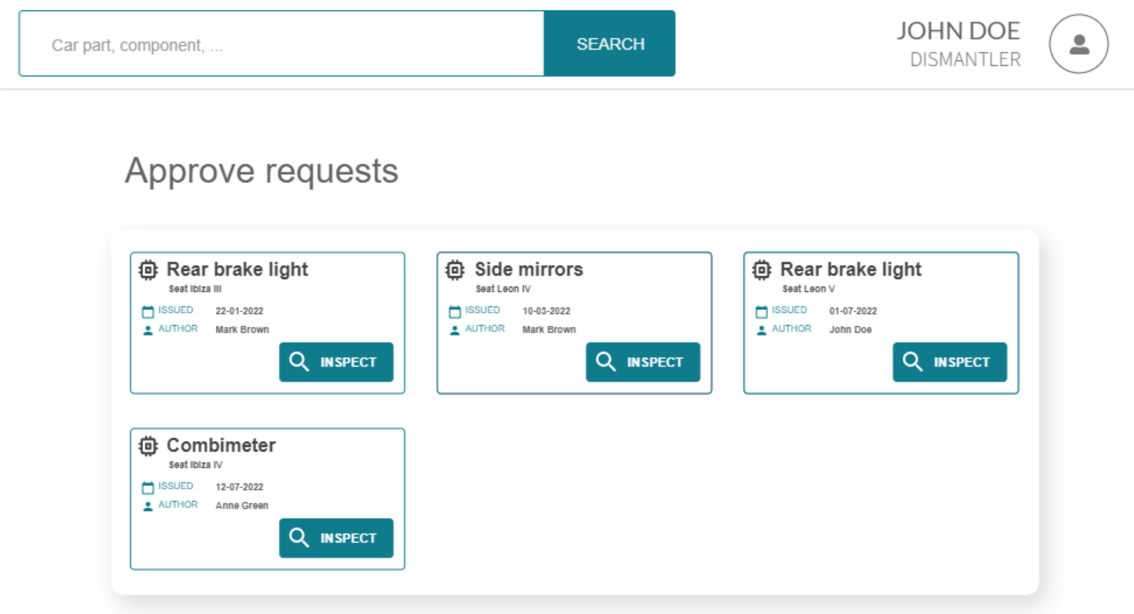

Figure 6: Facilitator mode: Dashboard

By clicking on it, the moderator can see all the information provided by the editor in a specific table and decide to approve or reject the new data.

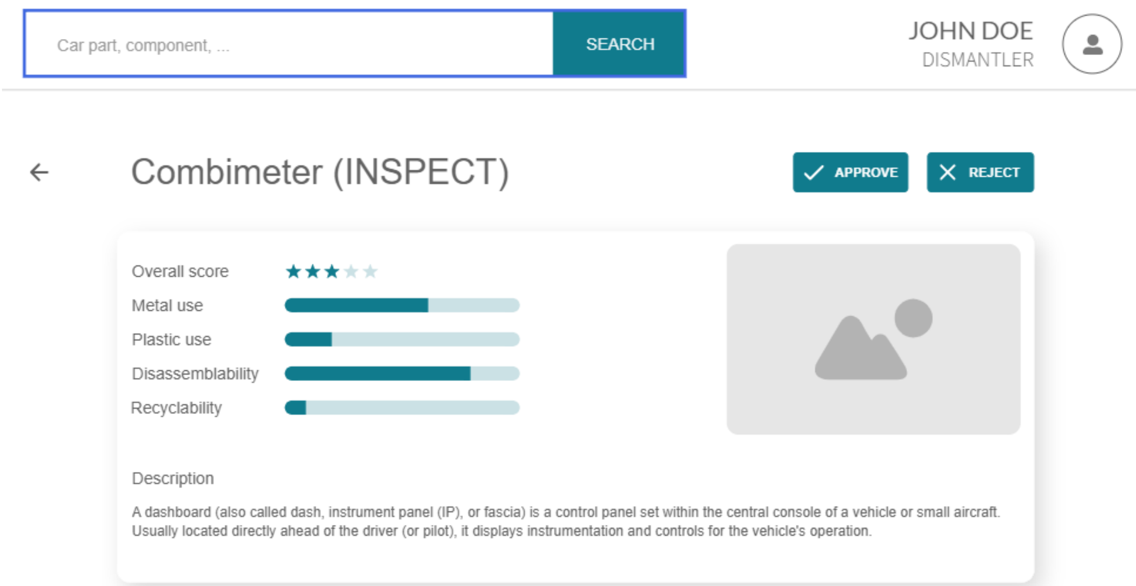

Figure 7: Facilitator mode: Inspect for new data

If the moderator accepts the new information, a pop up is shown with the possibility to provide feedback that will be seen by the editor.

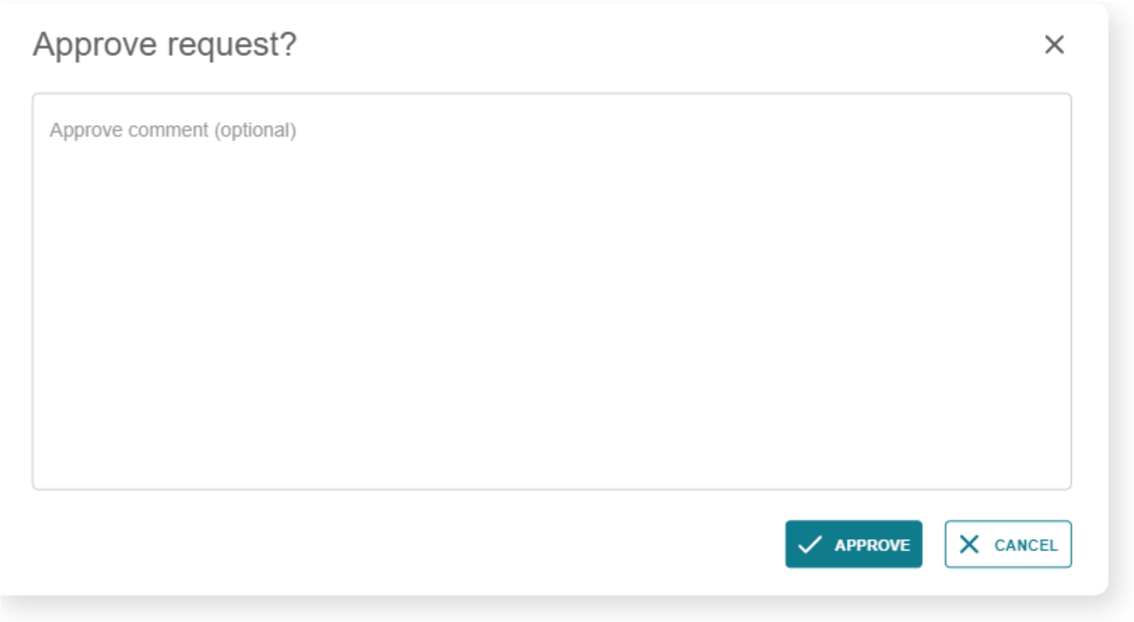

Figure 8: Facilitator mode: Approval page

If the request is rejected, the feedback provision is mandatory.

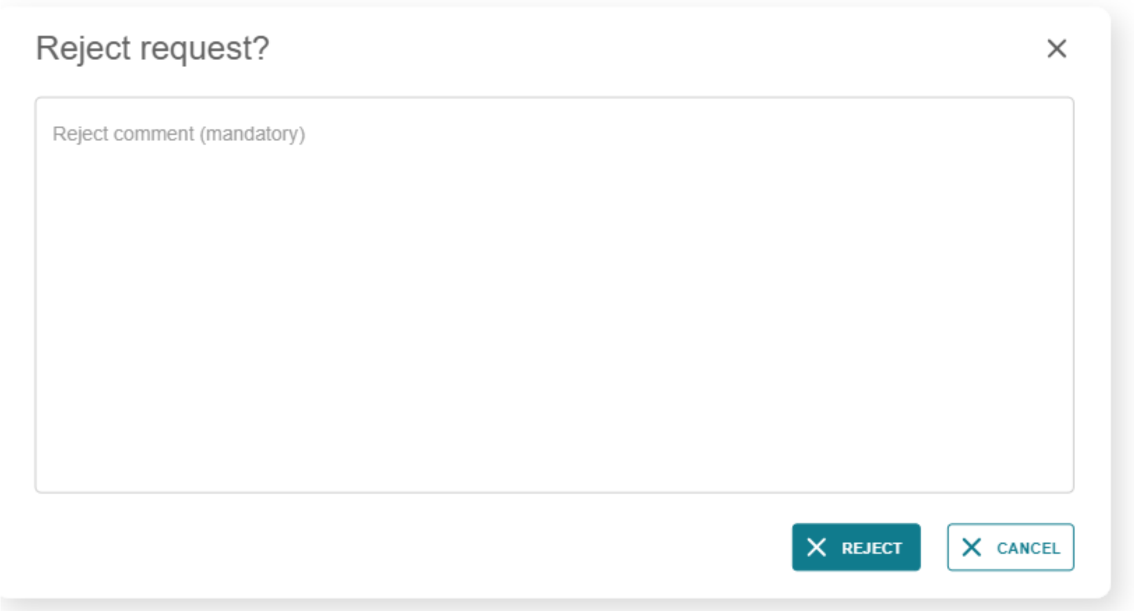

Figure 9: Facilitator mode: Reject page

2.2.4 Algorithms

With the aim to implement in the platform the knowledge described above, several algorithms have been defined. These algorithms will be implemented in the next platform version. Information about disassemblability algorithms can be checked in attached file: Algoritms.xlsx.

2.3 Recyclability Module

This section describes the process foreseen in the Circularity Web application of the Recyclability Module, which will provide manufacturers with recycling rates which can be achieved for the car parts under consideration and recommendations for Design for Recycling. At the same time, it provides recyclers with useful information to maximize material recycling/recovery rates from the car part under analysis e.g. by defining recommendations for additional disassembly to optimise the material recycling/recovery from the car parts, as well as by defining most suitable recycling processing routes to optimise recyclability. It is important to underline that recycling in the context of the circular economy is understood as producing the same quality of materials so that they can function at the same quality in the same product again.

As can be seen in Figure 10, the recyclability module is formed by different components in addition to the Circularity Web application, which complement each other to provide dismantlers, manufacturers and recyclers with the best user experience.

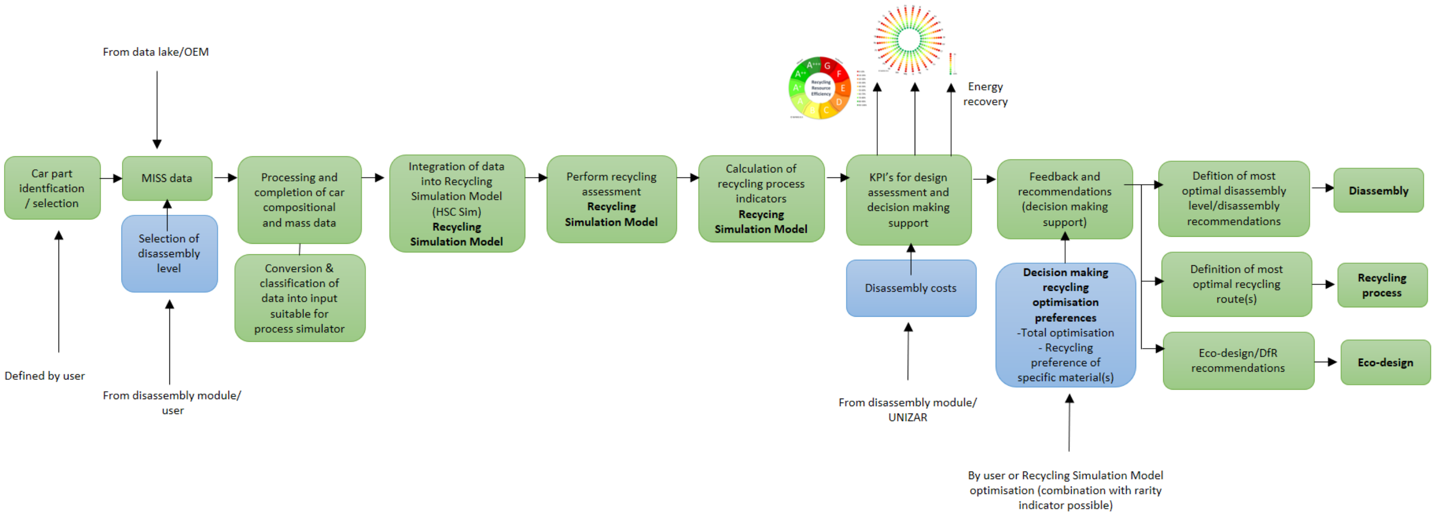

Figure 10: Preliminary Recycling app user process

The information provided for manufacturers, designers, dismantlers and/or recyclers in the Circularity Web application is generated for a specific car part. The user of the platform can select the part to be assessed. By selecting the car part to be analyzed, the information on the full compositional detail of the car part, is generated in the platform from the car compositional data from the MISS database, which is introduced by manufacturers (in this preliminary case SEAT). By application of the Recycling simulation model, i.e. a AI representative thereof, the recycling simulation models generate and calculate the feedback and KPIs for the car part under consideration.

The assessment of the recyclability of car parts under consideration and the underlying calculations are performed by the application of rigorous and physics-based recycling process simulation model. The process simulation model has been developed in the industrial software platform[4] providing a professional and industrial platform for process simulation tools and recycling as well as environmental impact calculations.

[4] HSC Chemistry Sim® 10, www.mogroup.com

The models include the complex interlinkages of functional materials in the car parts as well as all chemical transformation processes in the reactors in the system model in versatile flowsheet simulation modules. This approach permits the rigorous evaluation of the recyclability of a product within the circular economy

All mass flows, recoveries and losses for all metals/materials and elements/compounds (both on physical as well as chemical level) are included and revealed in the models as the combination of all materials/compounds/elements present interact during chemical and physical recycling and determine the recyclability and are crucial to quantify Circular Economy in the EoL stage of a product. This is following a Product Centric approach towards recycling as defined by MARAS (see Reuter and Van Schaik, 2013).

The recycling flowsheet simulation models are applied to assess and calculate the recycling/recovery rate of the car parts. This is done by linking car part compositional and structural data (from MISS data) to the HSC Sim models. The recycling simulation models cover the entire recycling processing flowsheet for the optimal recycling of car parts. These flowsheets are industrially realistic and economically viable for different processing routes.

2.3.1 Recycling simulation model development

The recycling processing flowsheet, including all (industrial) available processing routes for the recycling of car parts, provides the basis for calculating the recycling rates. This processing flowsheet has been developed, extensively updated, and expanded within the TREASURE project. These flowsheets are industrially realistic and economically viable for different processing routes. The model includes the best suitable technologies for processing car parts (car parts described in D3.1 and D3.2) to adopt and process all materials/compounds/elements. The model has been built based on the existing background within MARAS (as described in D3.3) (Ballester et al, 2017; Reuter et al, 2015, Van Schaik and Reuter, 2014, Van Schaik and Reuter, 2010). Recycling/recovery rates are calculated, different recycling processing options have been evaluated, including the energy flows within the recycling system. The work provides recycling KPI's, disassembly recommendations and BAT flowsheet architecture for recycling of each of the parts.

To be able to address and understand the balance between disassembly and metallurgical and plastics processing as well as energy recovery, a complete particle, and thermochemistry-based flowsheet simulation model was developed as depicted by Figure 11 for the ELV parts and expanded into further flowsheets as depicted for instance in Figure 12 for the copper route. All flowsheets underlying the flowsheet of Figure 11 are included in the models and are connected appropriately.

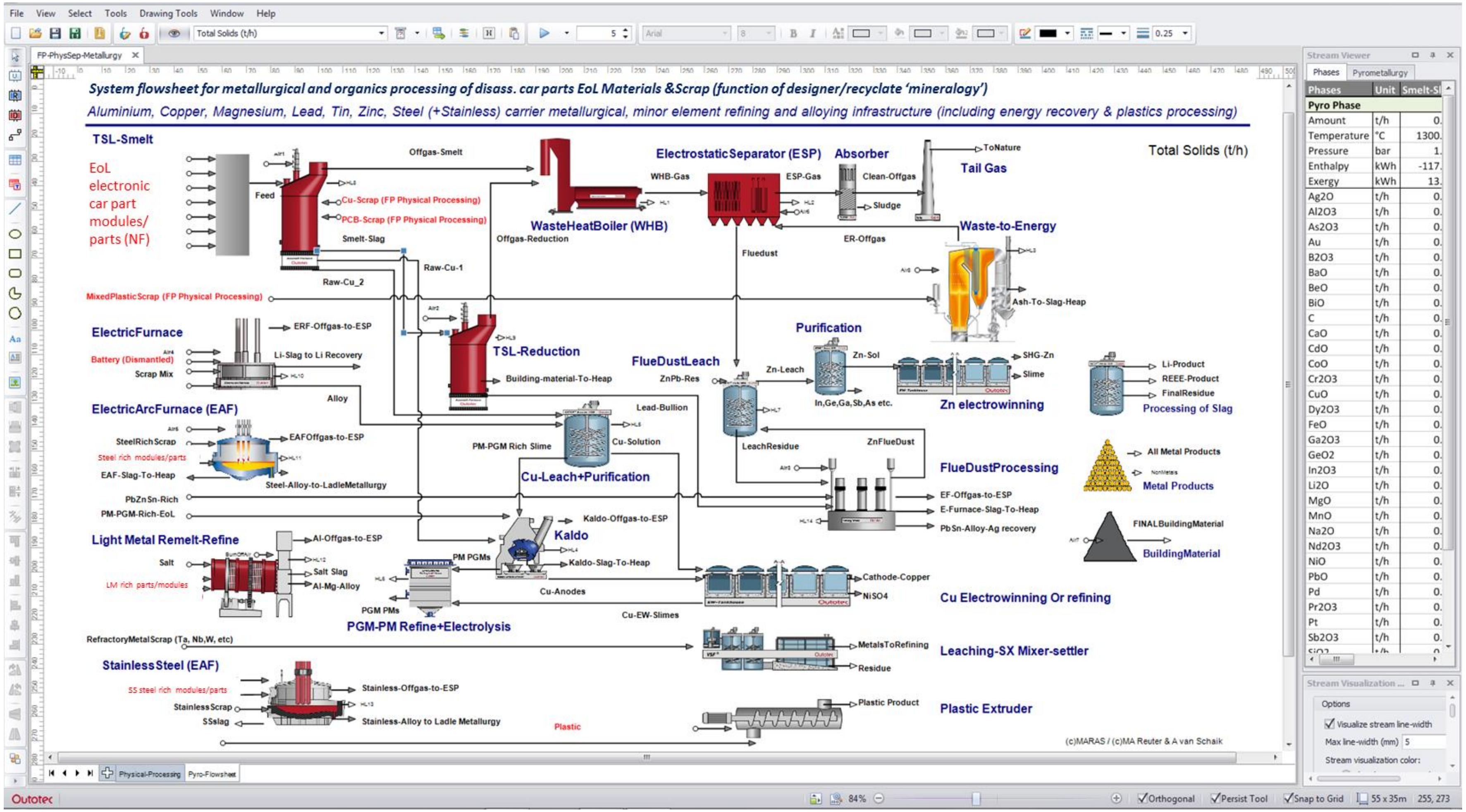

Figure 11: The metallurgical, energy and plastics processing flowsheet for (electronic) car parts and complex EoL products.

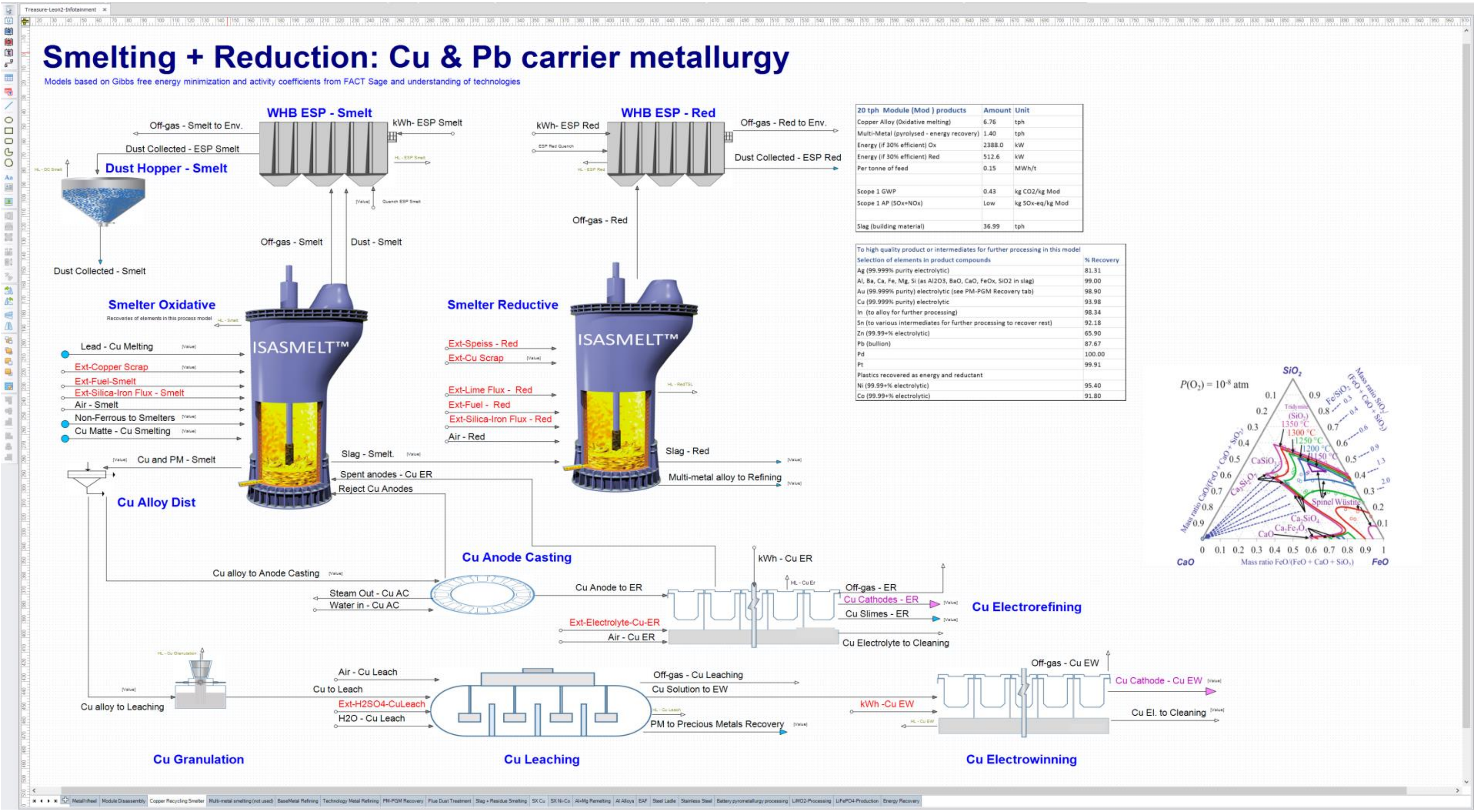

Figure 12: Cu processing route' – Oxidative smelter (Cu Isasmelt™)), reduction of Pb bullion (Pb Isasmelt™ Reductive smelter) and Cu refining.

2.3.2 Selection of most suitable processing routes

The Metal Wheel (Figure 13) depicts the basic metallurgical infrastructure in the centre band, which makes the recovery of elements in each segment possible due to the refining and alloying infrastructure and compatible chemistry and material physics. It depicts qualitatively the (in)compatibility (and hence recovery or losses) of different materials in the various base metal processing routes, based on process thermodynamics and physics.

The flowsheets cover the complete metallurgical (and other final treatment) recycling processing infrastructures as reflected by the Metal Wheel and as present in industry for the processing and recovery of all materials and compounds of the ELV car parts.

Figure 13 is a visual summary of the simulation-based approach used to determine the recycling rate of the different car parts. It shows the 'feed' sheet and reveals that each car part is processed in a segment of the Metal Wheel for optimal recovery of materials and energy, where each segment in the Metal Wheel is representing a full metallurgical recycling infrastructure for the processing of the different (base and associated) metals as depicted in Figure 6 and captured in the model. Detailed flowsheets for each of the processing routes are underlying this approach.

The 'feed' sheet is the cover disassembly sheet in the model that directs the modules/car parts into the different sections of the complete flowsheet to maximize recovery into the highest quality products. This allows to direct the car parts into the most suitable recycling processing route, as well as to assess the performance of different recycling routes to process the car part and/or disassembled components from it most optimally. Due to the complex mixture of materials in the car parts, for each car part, based on its composing material composition, the two or three best options are selected based on the full metallurgical recycling infrastructures based on the expert knowledge within MARAS. On this basis, the effect of the different recycling processing routes on recyclability can be assessed, and the most optimal/suitable recycling processing flowsheet for the part under consideration can be determined. Most suitable routes imply the recycling processing infrastructure in which the compounds of the module are most optimally recycled with a minimum of losses and emissions. It is important to be aware, that due to the complex combination of materials in the car parts, the best option to process these different parts is different depending on the focus which materials to recover, as each processing route will lead to recovery of certain elements, and losses of other, as depicted qualitatively by the Metal Wheel. This information will be provided by the Recycling Module in the platform, in addition to the recycling rates and energy recovery as can be obtained through the different recycling routes.

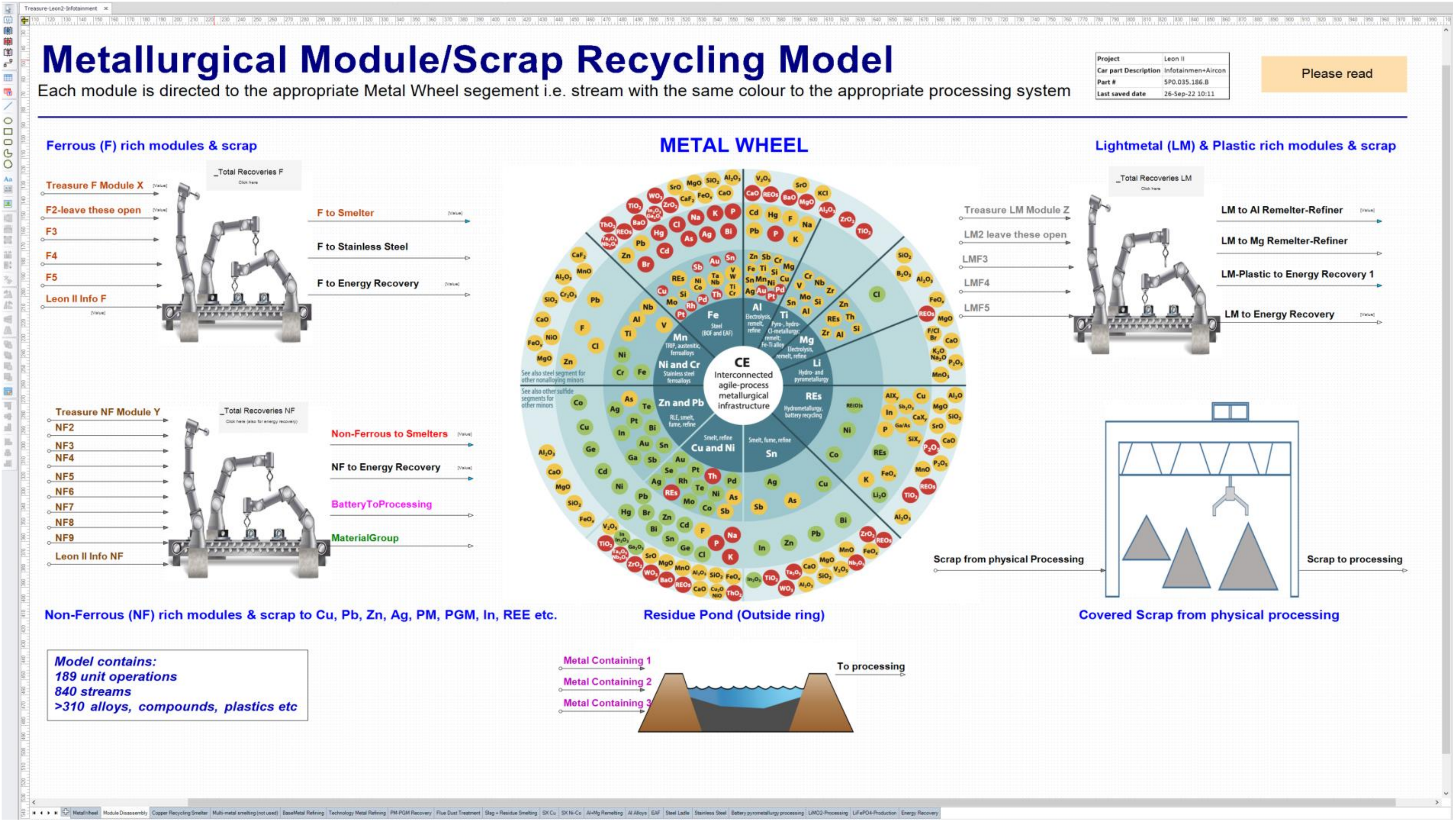

Figure 13: In the process model, the "Feeds" sheet is of importance as it shows in which metallurgical processing infrastructure (according to the segments of the Metal Wheel in the middle) the car parts and possible disassembled sub-parts are processed

2.3.3 Recycling KPI's

The starting point of recycling (and simulations) is to create material and metal products, alloys, compounds etc. of a functional quality so that these can be used in the same product these have originated from. This would be true circularity. Three different levels of circularity have hence been defined to assess the recycling results (i.e. (1) closed loop CE recycling, (2) open loop CE to be processed into closed loop CE and (3) open loop CE recycling (see D3.3 for further details).

The recycling simulation model permits the rigorous calculation of Recycling Indices for the entire part, as well as calculation of the individual recycling rates of all materials in a product, car part, sub-part or component as presented in the Material Recycling Flowers (Van Schaik and Reuter, 2016), hence providing physics based KPIs for CE and Eco-design. Whereas the overall recycling rates provide information on the recyclability of the entire part or product, the individual recycling rates/KPIs are the basis for true CE assessment. Recycling of complex products is a trade-off between bulk and minor element recycling, where often the one material will (to a more or lesser extent) be 'sacrificed' for the recovery of the other. This is not always reflected by the overall recycling rates due to the lower weight of precious (scarce, critical) elements present). Therefore, the Material Flowers as developed by MARAS serve very well as a tool in this discussion and help to make the choice for a certain recycling route, not only driven by weight-based considerations, but addressing the recycling of materials and elements, which are of interest to recycle or defined as critical and therefore require focus in selecting the most optimal recycling options. These KPIs are generated as output of the Platform of the Recycling Module. Recycling KPI's are calculated based on all mass flows, recoveries and losses for all metals/materials and elements/compounds (both on physical as well as chemical level) as addressed in the model.

2.3.4 Outcomes of the Recyclability module

On the basis of the recycling simulation models as developed in D3.3 the recyclability of the car parts are calculated, recommendations on best suitable recycling route for processing of the car part, the effect of further disassembling these parts on recycling behaviour as well as recommendations for more in depth disassembly to improve recyclability are provided. Also, Eco-design recommendations are made based on the finding of the recycling simulations and derived insights into recoveries and losses of materials/elements/compounds of these car parts.

The recyclability module will hence provide the following preliminary information regarding the car part under analysis:

- KPI's on recycling/recovery for whole parts/product as well as for individual elements/materials
    - Total recycling rate (%) visualized by the Recycling index of the car part as a whole (%)
    - Individual material recycling rate of all materials/elements/compounds included in the car part (e.g. Fe, Cu, Au, Ag, CRM recycling rate, etc.) in % (also available in mass) – visualized by the Material Recycling Flower (%)
    - Energy recovery in MWh/t of feed or per car part
- Recommendation on most optimal recycling flowsheet architecture (based on the best available technologies at industrial level) – this will differ per car part and disassembly level
- Feedback to dismantlers on additional disassembly or the effect thereof to optimize recycling

- Feedback to eco-designers based on metallurgical incompatibilities (qualitative from the Metal Wheel) and quantitatively based on the findings of the recycling simulations and derived insights into recoveries and losses of materials/elements/compounds of these car parts (shown in the eco-design and disassemblability modules, respectively).

2.3.5 Platform implementation

Given user requirements and technical components dependencies, the Recyclability application is created to display relevant information for the end user. The figure below shows, as an example, the case study of the Combi meter.

Figure 14 Preliminary Mock Up of the Recyclability module

2.3.6 Algorithms

With the aim to implement in the platform the knowledge described above, several algorithms have been defined. These algorithms will be implemented in the next platform version.

Classification of input composition is part of this process in view of preparation of data sets from the detailed simulation model to create surrogate functions that twin the simulation model. These neural net – AI based tools can then be trained and easily integrated into design tools and the TREASURE platform, i.e. implying that the Recycling Module will be an AI tool, that twins the HSC Sim recycling simulation model, as the latter will not be integrated into the platform. This has been done similarly in the past by within the EU 6th framework project SuperLightCar (Krinke et al, 2009). The figure below (Figure 15) (Bartie et al., 2021) shows this also clearly, i.e. a simulation model calculates all flows, can estimate exergy dissipation but also environmental footprint information. All these data can be integrated into surrogate functions for use in for example design tools for rapid calculations (see D3.3).

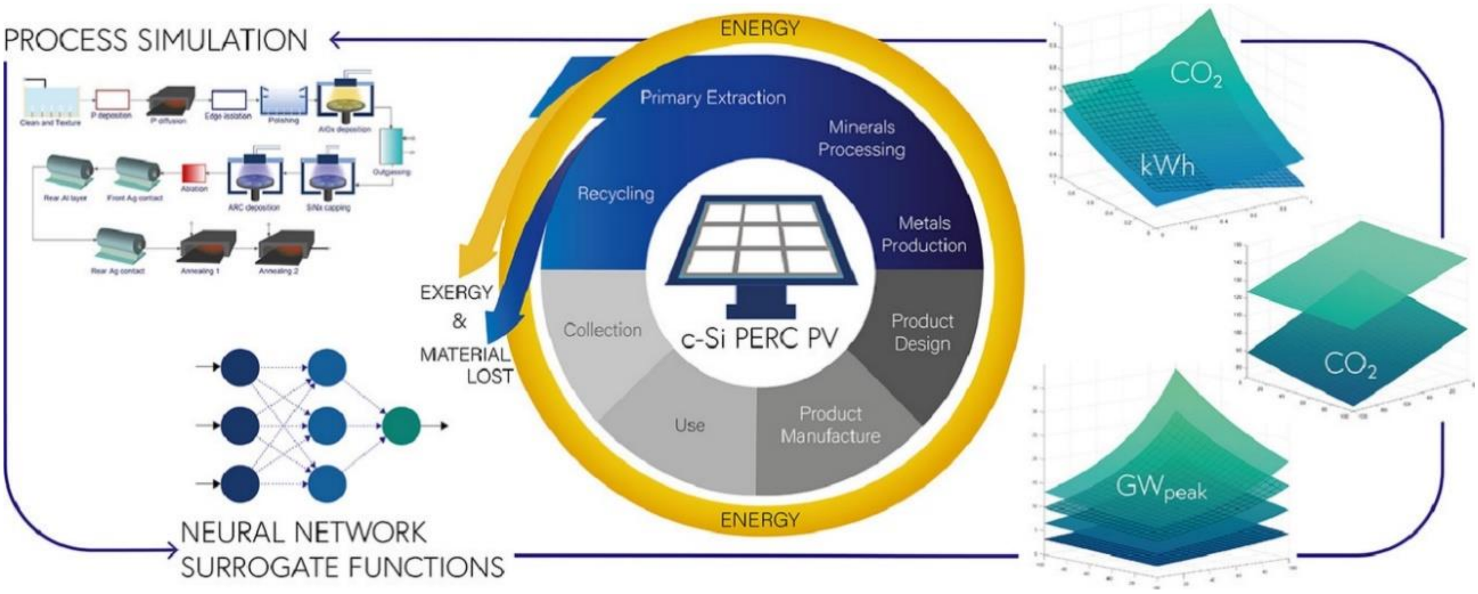

Figure 15 Process simulation and the link to neural network surrogate functions for use in AI for rapid calculations (Bartie et al. 2021)

2.4 Eco-design Module

The eco-design module aims to provide car manufacturers and car part designers with decision-making tools to improve the circularity of future car part designs. To that end, designers will receive feedback from EoL stakeholders through the other Disassemblability and Recyclability modules. Additionally, a set of recommendations regarding the eco-design of the car part in terms of 1) use of critical raw materials, 2) disassemblability potential and 3) recyclability potential are given. As can be seen in Figure 16, the eco-design module is formed by different components in addition to the Circularity Web application, which complement each other to provide dismantlers with the best user experience.

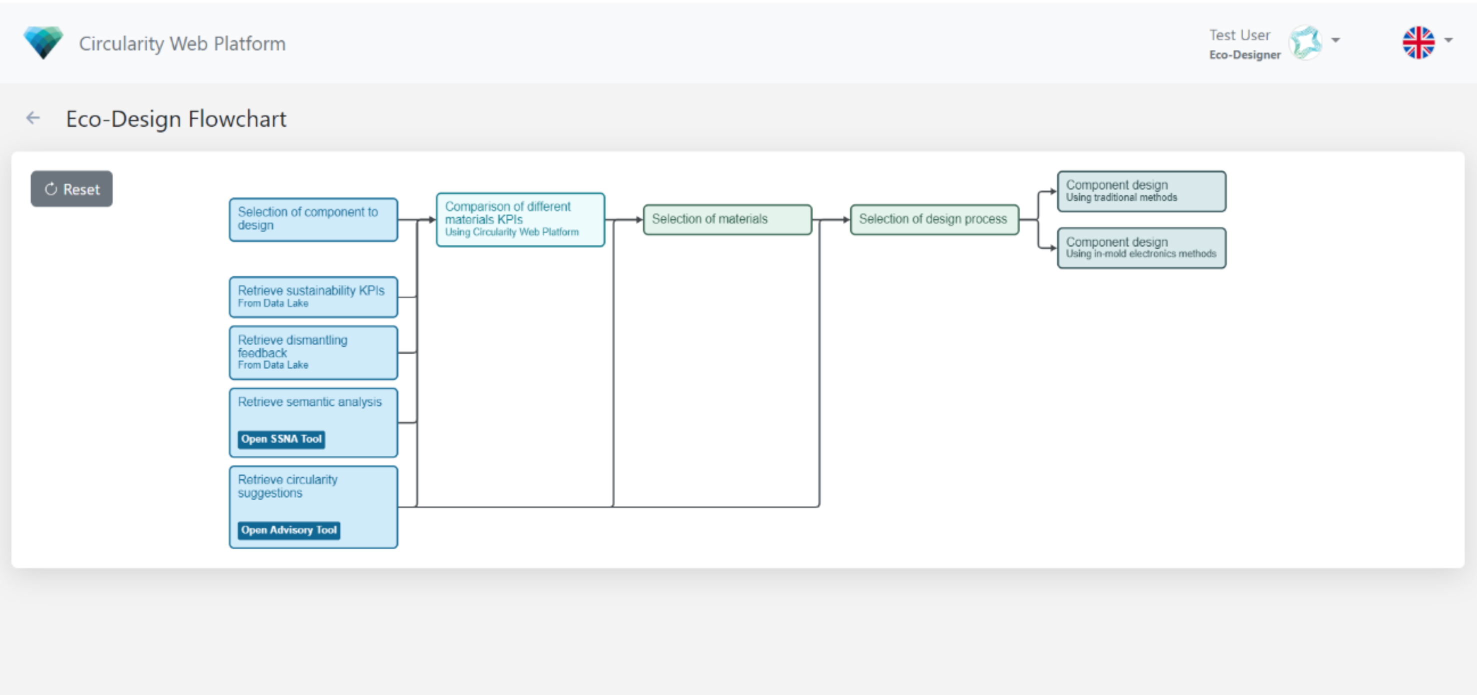

Figure 16 Preliminary Eco-design app user process

2.4.1 Outcomes of the Eco-design module

As explained above, the eco-design module gives feedback to manufacturers by providing relevant information to 1) optimize the use of critical raw materials, 2) facilitate dismantling and 3) facilitate recycling. EoL information is directly retrieved from the disassemblability and recycling modules, as explained in the previous sections.

Below, we show how the information regarding the use of critical raw materials is processed and shown. It should be mentioned that only the composition in terms of metallic elements and plastic types is shown for this case. This type of information allows manufacturers to get an idea of potential raw material supply risks associated to the car part due to the use of critical and strategic raw materials. That said, the specific recycling operations depend on the exact composition of the car part. Therefore, the design for recycling recommendations are based on the composition in terms of compounds and not elements.

The Circularity Web application provides a dedicated space where information about metal and plastic use is shown. The metallic composition by weight can be filtered by either selecting all metals or just critical raw materials[5]. This latter filtering also allows to highlight the relative weight of minor metals, which usually are hidden by major ones such as iron or aluminium when all metals are displayed. After the filtering, the following information is shown:

- Top 5 metals with the highest contribution to the car part by weight.
- Top 5 metals with the highest contribution to the thermodynamic rarity. Classification of thermodynamic rarity will use weight data and thermodynamic rarity values of each commodity. The aim is to show the quality of the elements used regarding their scarcity in the crust and the energy used to mine and refine the source ore.

Once the metals have been filtered as all or only CRMs the following information will be represented for each metal:

- Share over the total weight (%). It is calculated by dividing the metal weight with respect to the car part weight.
- WRR - World recycling rates (%) – Using data published by UNEP in the report "Recycling rates of metals: A status report" of 2011. This information is helpful to know in what cases it is not probable to get metals from secondary sources. This information should not be confused with actual recovery rates of the car part as generated in the recyclability module.
- Automobile demand with respect to the annual production (A): This will help to know the competition for the given metal with other sectors.
- Total cumulative demand up to 2050 with respect to known reserves (B): This will inform about possible future bottlenecks of that given element.
- Supply Risk according to the information published by the European Commission[6].
- Strategic Metal Index (SMI). It presents a value about how important and strategic a metal is, knowing future demand, known reserves and supply risks.
- Most important world producer and production quote of this country (According USGS data).

A, B and SMI values will come from the paper: "Assessment of strategic raw materials in the automobile sector," published by A. Ortego, G. Calvo, A. Valero, M. Iglesias-Émbil, A. Valero, and M. Villacampa in the Journal *Resources, Conservation and Recycling in 2020.*

In the following table the values of the previous variables for each metal are presented:

[5] The CRMs will be identified according to the latest EU list that includes Sb, Be, Bi, B, Co, Ga, Ge, Hf, HREEs, In, Li, LREEs, Mg, Nb, PGMs, Sc, Si, Ta, Ti, Va, W, Sr.
[6] https://rmis.jrc.ec.europa.eu/?page=crm-list-2020-e294f6

Table 6: Information used to show relevant information for Manufacturers in the Eco-design module

	Rarity - kJ/g	WRR	Is a CRM?	SR	A	B	SMI	Most important producer	Production quote
Ag	8.937,00	>50%	no	0,7	6,41	77,58	63,67%	Mexico	22%
Al	661,00	>50%	no	0,6	3,05	13,25	11,99%	Australia	28%
As	427,84	<1%	no	1,2	0,11	14,05	14,67%	China	75%
Au	654.683,00	>50%	no	0,2	6,01	70,77	66,41%	China	12%
Ba	39,34	<1%	yes	1,3	0,41	14,76	15,67%	China	38%
Be	709,93	<1%	yes	2,3	0,32	2,54	13,04%	U.S.	88%
Bi	545,62	<1%	yes	2,2	5,68	65,47	63,62%	China	80%
Cd	6.440,40	>10-25%	no	0,3	0,02	24,55	25,30%	China	36%
Ce	620,00	<1%	yes	6	3,38	8,09	37,26%	China	86%
Co	11.010,00	>50%	yes	2,5	64,64	7,18	33,82%	Congo	59%
Cr	40,90	>50%	no	0,9	1,71	9,05	8,05%	S.Africa	40%
Cu	348,40	>50%	no	0,3	19,09	12,12	12,68%	Chile	29%
Dy	732,00	<1%	yes	5,6	82,21	1,29	56,14%	China	86%
Eu	732,00	<1%	yes	5,6	5,42	3,94	19,39%	China	86%
Fe	32,00	>50%	no	0,5	1,61	11,01	10,63%	China	69%
Ga	754.828,00	<1%	yes	1,3	12,90	1,42	9,59%	China	80%
Gd	4.085,00	<1%	yes	5,6	0,76	1,35	31,24%	China	86%
Ge	24.247,00	<1%	yes	3,9	1,37	1,47	10,25%	China	80%
Hg	28.707,00	>1-10%	no		0,01	23,35	24,35%	China	92%
In	363.918,00	<1%	yes	1,8	2,12	75,75	57,34%	China	48%
Ir	2.870.013,00	>25-50%	yes	2,4	1,19	16,64	21,72%	S.Africa	92%
La	336,00	<1%	yes	6	1,38	5,34	34,36%	China	86%
Li	978,00	<1%	yes	1,6	94,03	21,52	48,38%	Chile	44%
Mg	145,73	>25-50%	yes	3,9	1,65	2,78	25,16%	China	89%
Mn	73,00	>50%	no	0,9	2,07	59,14	57,29%	S.Africa	28%
Mo	1.056,00	>25-50%	no	0,9	7,62	40,85	40,01%	China	40%
Nb	4.782,00	>50%	yes	3,9	20,82	20,20	24,87%	Brazil	92%
Nd	670,00	<1%	yes	6	61,81	12,94	41,89%	China	86%
Ni	758,00	>50%	no	0,5	36,07	95,42	67,36%	Indonesia	30%
Pb	41,00	>50%	no	0,1	12,09	8,21	7,36%	China	43%

Pd	2.870.013,00	>50%	yes	2,4	27,64	17,84	20,59%	Russia	40%
Pr	873,00	<1%	yes	6	32,14	8,85	31,45%	China	86%
Pt	2.870.013,00	>50%	yes	2,4	46,61	23,05	29,94%	S.Africa	71%
Rh	103.087,00	>50%	yes	2,4	13,05	16,36	19,38%	S.Africa	80%
Ru	2.870.013,00	>10-25%	yes	2,4	0,91	16,99	24,31%	S.Africa	93%
Sb	487,89	>1-10%	yes	2	1,04	92,27	80,25%	China	74%
Sm	732,00	<1%	yes	6	8,42	2,54	29,98%	China	86%
Sn	452,95	>50%	no	0,9	2,94	12,48	11,57%	China	30%
Ta	485.911,00	<1%	yes	1,4	49,80	18,01	26,15%	Congo	33%
Tb	732,00	<1%	yes	5,6	96	7,03	61,91%	China	86%
Te	2.825.104,00	<1%	no	0,5	0,79	100	95,11%	China	61%
Ti	203,12	>50%	yes	1,3	0,15	13,07	10,99%	China	45%
V	1.572,00	<1%	yes	1,7	46,37	7	24,71%	China	39%
W	8.023,00	>10-25%	yes	1,6	0,16	31,34	30,60%	China	69%
Yb	732,00	<1%	yes	5,6	18,23	0,07	31,29%	China	86%
Zn	196,93	>50%	no	0,3	1,73	23,89	19,60%	China	35%
Zr	2.025,93	<1%	no	0,8	0,19	22,01	22,97%	Australia	34%

In addition to metal composition, the Circularity web application for manufacturers will also offer information about plastic composition. This information will show the plastic's mixology and is helpful to provide recommendations related to avoiding thermosetting and thermoplastic mixtures which hinder their proper recovery.

Finally, there will be two sections where feedback from dismantlers and recyclers will be included.

2.4.2 Platform implementation

Given user requirements and technical components dependencies, the Eco-design application is created to display relevant information for the end user. The figure below shows, as an example, the case study of the Combi meter.

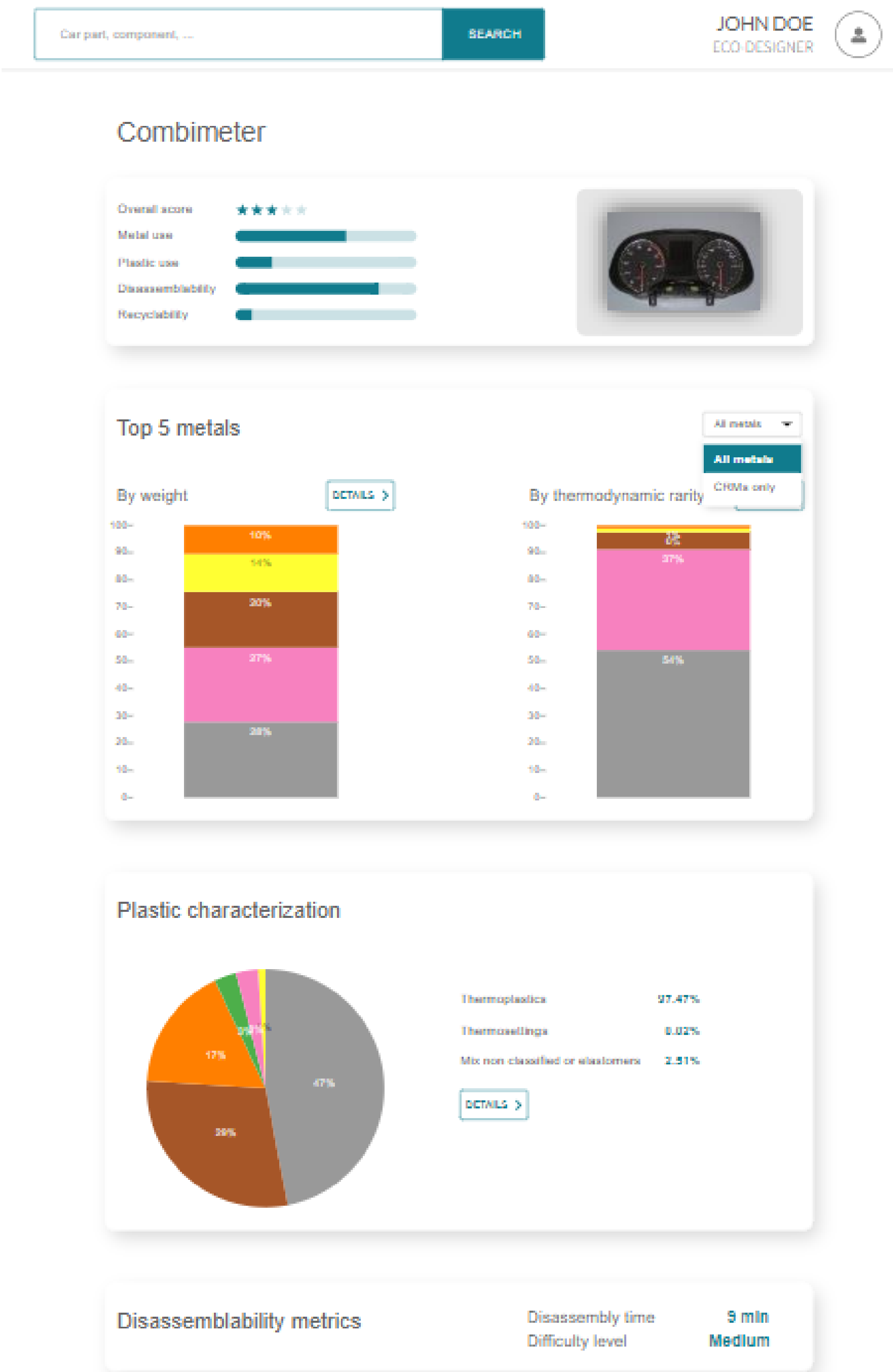

Figure 17 Preliminary Mock Up of the Eco-design module

2.4.3 Algorithms

With the aim to implement in the platform the knowledge described above, several algorithms have been defined. These algorithms will be implemented in the next platform version.

Information about disassemblability algorithms can be checked in attached file: Algoritms.xlsx.

3 WEAVR tool

The WEAVR tool is a component of the disassemblability module and complements the Circularity Web application designed for dismantlers. The first step of the disassemblability module is to present the results obtained from the Circularity Web application, which, as shown in section 3.2, provides information regarding the value of the materials contained in the specific car part under analysis, disassembly times, and recyclability values vs. disassembly costs. With this information, the dismantler can decide whether to extract the part from the car for its reuse or recycling. In this respect, TREASURE platform offers dismantlers a virtual reality tool aiding dismantlers in the disassemblability process.

From the Disassembly Module of the Platform, the dismantling operator can access the WEAVR Manager, where he or she can visualize the procedures assigned to him/her, as well as some related metrics (such as duration of the procedure, number of steps, comments provided, etc.). The operator can then proceed to download on the device of choice the procedure to be executed through the WEAVR Player app, previously installed on his/her device.

The car parts/component in TREASURE platform provides the EoL actor the information related to dismantling KPIs previously defined concerning user needs related not only to the economic aspect but also to the environmental impact. Finally, the information is complemented by feedback from the EoL operator during the dismantling process that is collected by WEAVR tool use, such as metrics, logs and operator’s notes, and suggestions. The whole data set is stored in the Data Lake where all data from different tools, actors, and external and internal sources is hosted, making this knowledge accessible to all platform components and final users. This whole set of information helps the worker understand which dismantling procedure best suits each use case, thanks to the suggestions provided by the AI-Based Advisory Tool. As a result, the operator can select the appropriate procedure to be executed for each scenario.

In performing the procedures, the worker could be supported by a cobot favouring a human-machine collaboration to optimize car electronics disassembly procedures and improve efficiency of materials recovery processes. WEAVR application provides commands to the robotic arm throughout each step of the disassembly procedure, synchronizing machine actions to operator’s activity. More in detail, activation or deactivation orders are given via dedicated controls on the WEAVR player, granting the operator the control needed over the cobot. The machine, in turn, provides feedback about the activity execution to inform the human supervisor about the successful completion of the required task or, if any problem is experienced, notification and explanation of the incurred error. In this case, the impossibility of finalizing the operation is most frequently caused by the fact that the action to perform is unknown or lacking in the knowledge database of the cobot. Thus, human intervention is foreseen in the form of manual training performed by the operator giving specific instructions that integrate the list of actions known by the cobot.

3.1 Data stream/process description

The first step of the disassemblability process consists of the visualization of VR procedures related to dismantling operations. To that end, the user can see using either augmented reality headsets or regular mobile devices. The procedure, simulated using VR application, is generated starting from data retrieved from two sources:

- CAD files related to overall car structure and specific subparts to be dismantled. The data is provided by car manufacturer (SEAT) to replicate in a digital environment the object to disassembly.
- Step by step description of disassembly process shared by EoL actor (ILLSA) that reports each action the operator performs to extract specific car components. This information is linked with the results of Deliverable 3.2.

This preliminary step is an essential part of the VR simulation procedure that is created via the WEAVR platform, particularly with the help of the WEAVR Creator component. The process starts by replicating the car and subparts structure in transparency for clarity reasons, starting from the corresponding CAD model. After optimizing the 3D model, the AR/VR procedure is created starting from the instructions provided by the dismantler operator, ILSSA.

In detail, for the CAD conversion we used PiXYZ Studio, which allows us to convert the CAD surface into a polygon mesh that can be used within Unity 3D. The optimization of the surface in this case is fundamental because it gives us the possibility to reduce the quantity of polygons of the object; for all objects in procedure that require a high level of detail, the optimization is performed by hand, automatic reduction is used for the objects not in procedure.

Before applying the materials, we will later see in the procedure, UV mapping (3D modeling process of projecting a 2D image to a 3D model's surface) is mandatory. Without this step it is almost impossible to visualize the materials in the scene correctly.

Lastly, the texturing is done using the PBR (*Physically based rendering*) technique on Substance 3D painter, which is the tool used to texturize 3D models considering the Unity URP pipeline (*Universal Render Pipeline – for high quality visualization models)*.

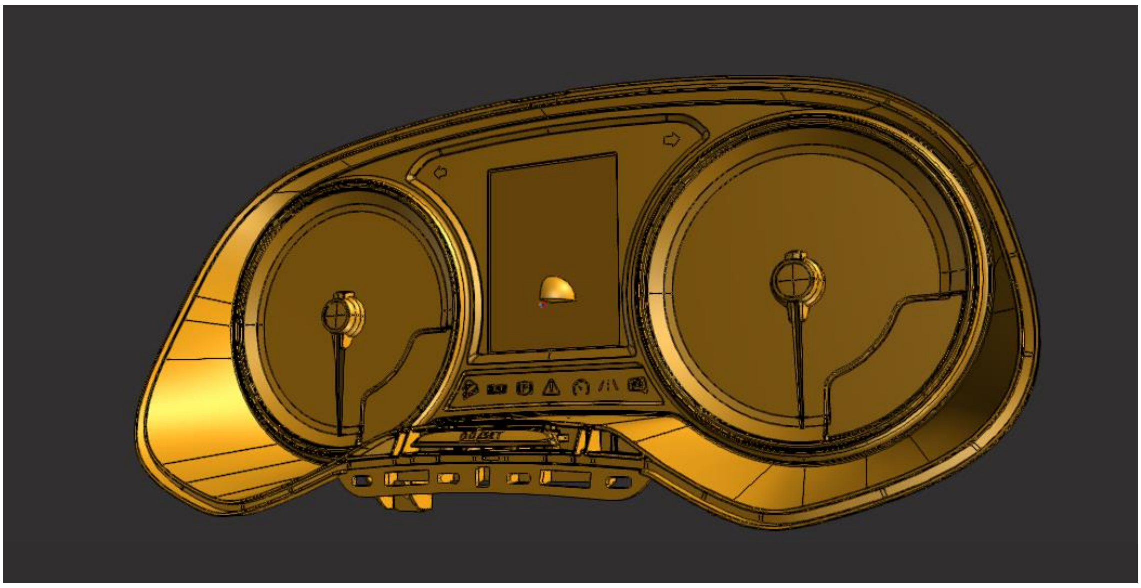

Figure 18: Optimized CAD of Combi Meter

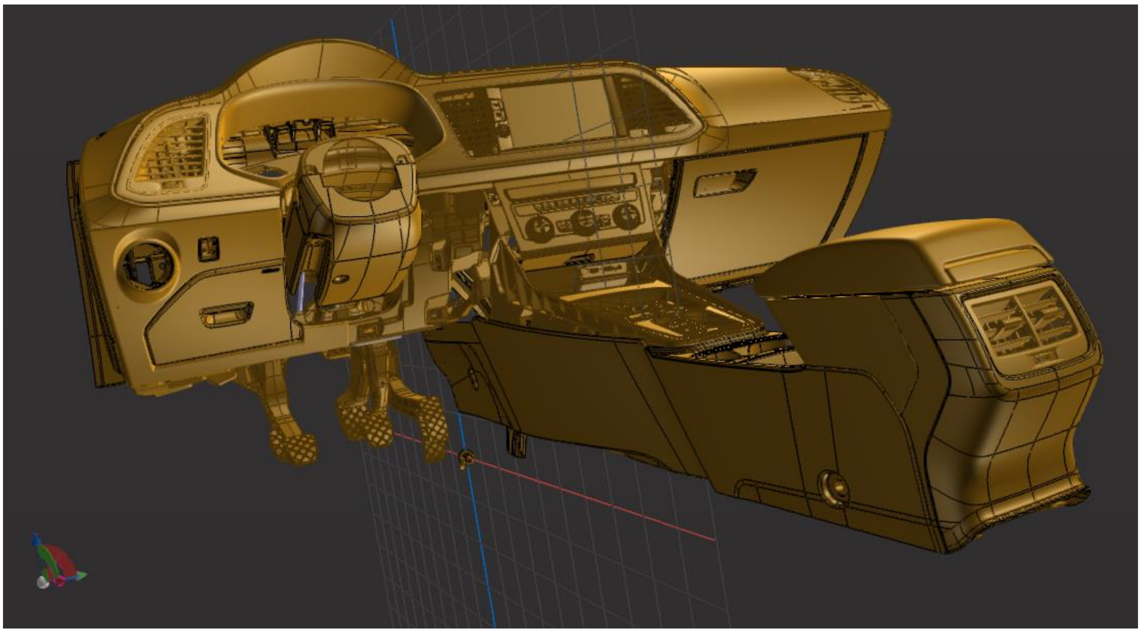

Figure 19: Optimized CAD of car interior – Dashboard

Then, the digital procedure is composed by the sequence of steps received as input, following instructions provided including all the detailed information and visual details in such a way that the virtual procedure is an exact copy of the real one.

The creation of the virtual procedure with WEAVR tool starts with the analysis of the standard procedure documentation. After this analysis, the procedure developer can understand the steps and interactions the user will have with the 3D model. WEAVR Creator is a procedure creator tool for Unity that permits executing the procedures on several platforms like PC, tablet, VR headset etc. The procedure developer replicates the procedure steps described in official documentation to build step by step the procedure. Each step has an action part and a condition part. The action part is the section where the procedure prepares the 3D scene for the current procedure step, and the procedure developer can add any hints to help the user better understand what to do during the step. For example, if the user must check a component during the procedure, a billboard action with the name and the position of the object appears to help the user execution. The condition part permits checking if the user has done all the required actions for the step to go to the next steps. For example, if a user to complete a step must unscrew 4 screws, the WEAVR procedure step is able to wait until the user never unscrews all the components. The WEAVR Creator has a Procedure Editor window in Unity that allows one to see the procedure as a flow chart composed of steps, conditions and edges which connect the steps to create an execution flow. To help the user to understand the procedure better, the developer can use different execution mode: Automatic, like a virtual instructor that executes the procedure; Guided, where the user can complete the procedure with several hints; Feedback, the user can test his capability completing the procedure without hints. Finally, the procedure is exported and uploaded on the WEAVR Manager component, where it gets shared with the relevant actors (e.g., dismantling operators) for their view and execution.

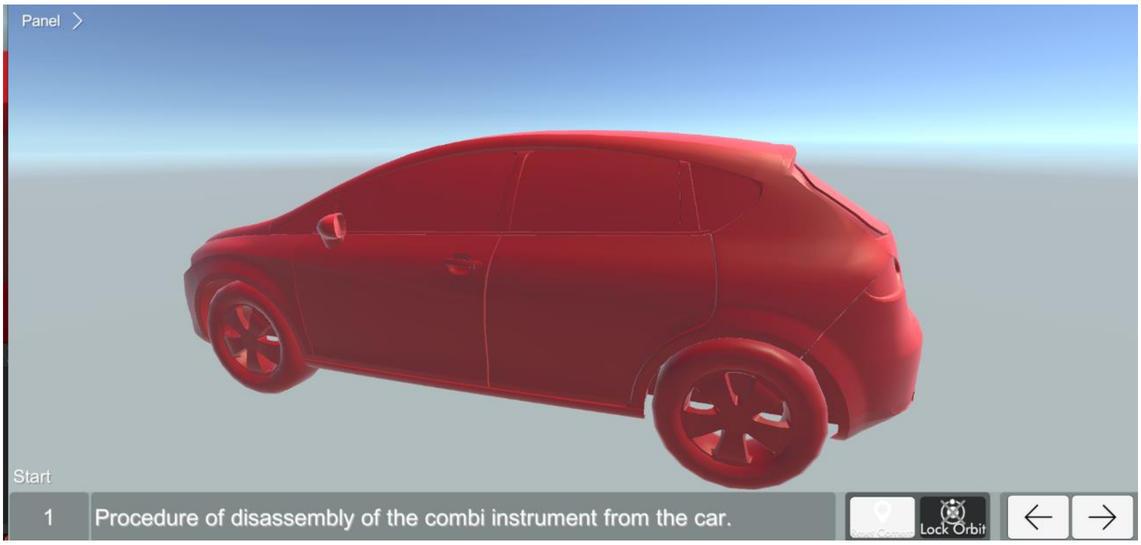

Figure 20: Disassembly procedure in VR - Step I

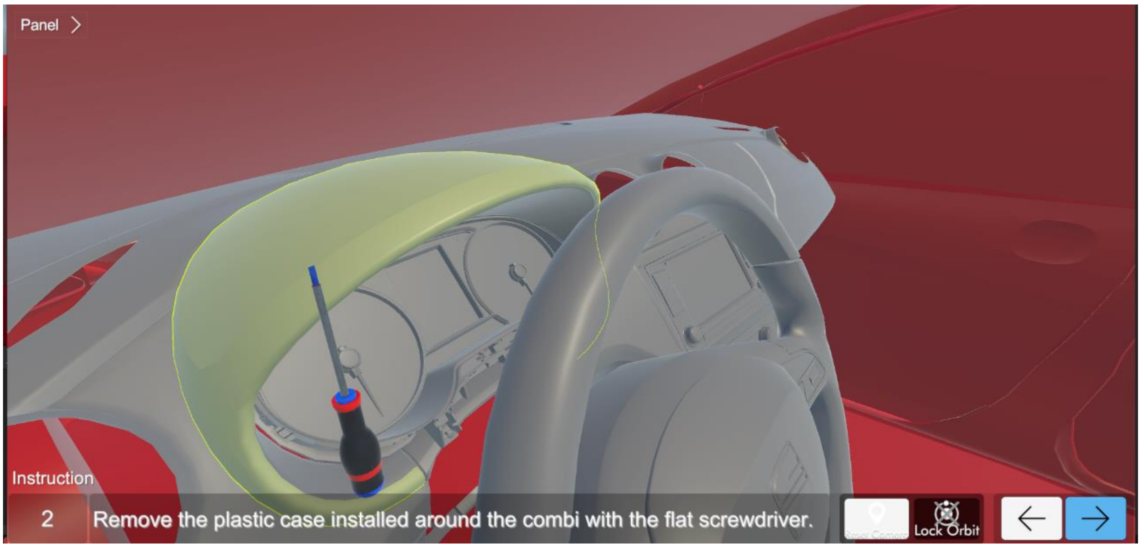

Figure 21: Disassembly procedure in VR - Step II

Figure 22: Disassembly procedure in VR - Step III

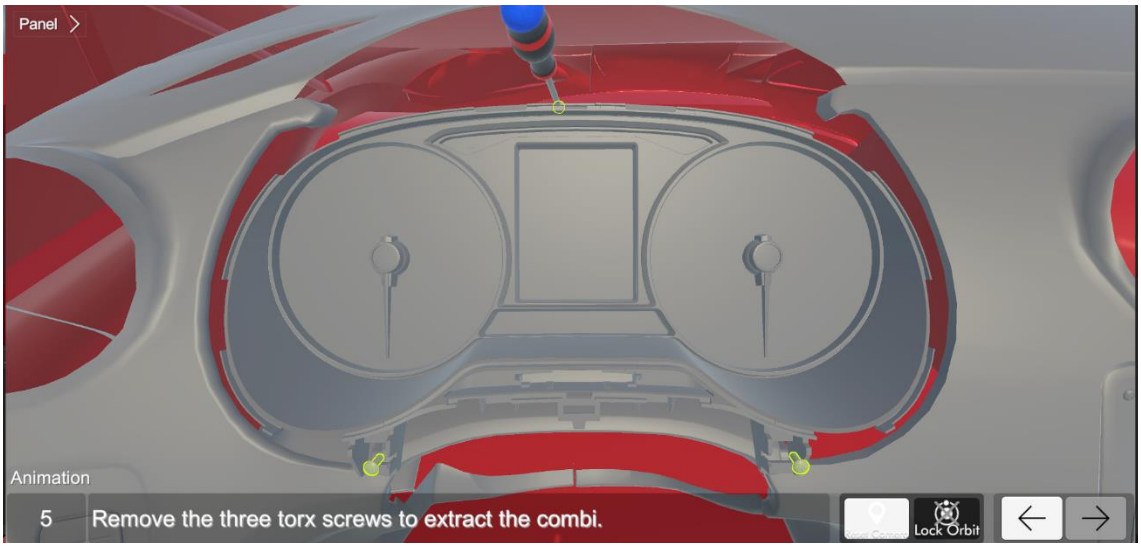

Figure 23: Disassembly procedure in VR - Step IV

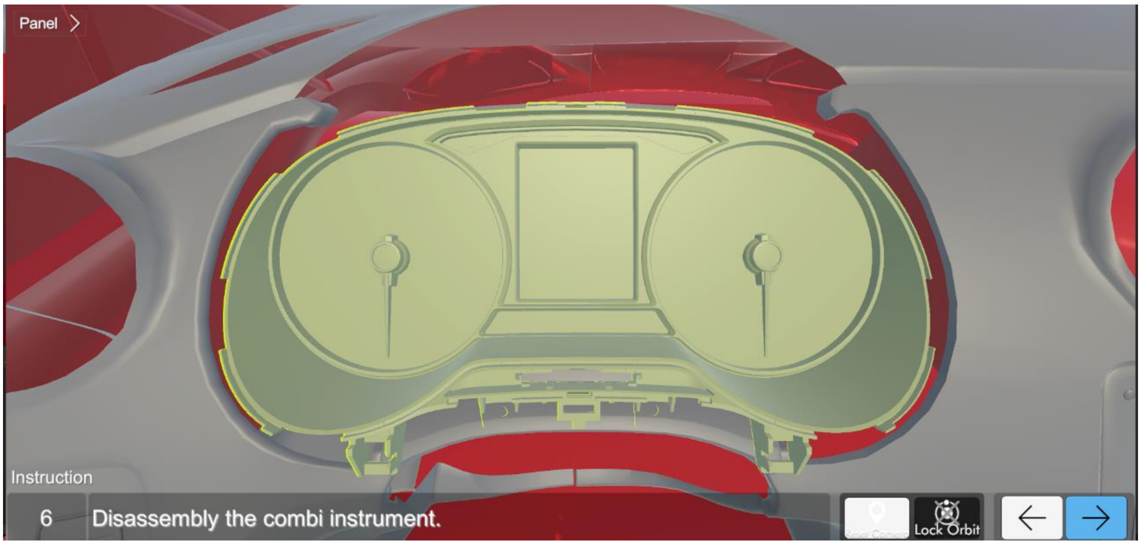

Figure 24: Disassembly procedure in VR - Step V

4 Conclusions and Next Steps

The present deliverable documents TREASURE data lake as a result of the outputs regarding technical requirements and specifications as pinpointed in D4.1, deriving not only from the preliminary system analysis but also from the discussion with the industrial use cases.

A complete description of the Circularity Web application 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. The WEAVR tool has also been presented.

The main challenges that must be addressed throughout the next months are the following:

- To develop a method that can process the MISS input data to be used automatically by the platform.
- To automatize the recycling module for the Circularity Web application.
- To complement the Circularity Web application with the indicators selected in Deliverable 3.4.
- To test the different modules with the car parts described in D3.1.
- To check the functionality of all modules and applications such as WEAVR.
- To populate the platform with the information of all car parts listed in D3.1.

Once these activities have been carried out, the final version of the platform will be submitted on M33 under the Deliverable 4.8.

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