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TREASURE

D4.2: TREASURE technical architecture (final version)

30/09/2023 (M28)

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Technical References

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EXECUTIVE SUMMARY

The present deliverable D4.2 "TREASURE technical architecture (last version)" is the last document released within T4.1 "Technical requirements and solution design", presenting the ultimate version of the platform.

The starting point on which D4.2 is based relates to the preliminary requirements and the preliminary architecture collected in the previous iteration period and reported in D4.1. In particular, the main addressed issues refer to reference framework, users' needs assessment, advisory model and the related software implementation. In accordance with this analysis, the present document reports the update and integration of the technical requirements and the refinement of the architectural design implemented in subsequent tasks of WP4. These drivers represent the foundations of the final elaboration 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 the updated 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, after the first iteration. 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 refinement of the technical features takes into consideration not only the internal actors within the consortium but also external stakeholders to generalize the identified requirements. This task has been carried out to expand platform additional users' needs and ensure an external validation from other actors in the automotive sector. A survey has been elaborated to gain feedbacks and insights of external stakeholders on the digital solution main features, understanding which are considered the most valuable and which should be improved. The survey outcomes played an important role in the integration of technical requirements giving additional inputs that have been considered in the elaboration of the final version of the architecture.

The inclusion of these requirements within the TREASURE platform is outlined in the third chapter with a detailed explanation of the data driven architecture. Starting from the first version of the platform, the updated overall architecture is presented highlighting the elements that were affected by the revision after the first iteration validation and testing. Thus, after displaying TREASURE software structure, a detailed analysis of all involved components is provided, explaining the asset purpose in the project, the covered requirements and the integration with the platform. This overview is firstly carried out starting from the application modules, Disassemblability, Recyclability and Eco-Design, that are the building blocks of the Web Circularity Platform and the Circular Advisory Tool.

Finally, the updated 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

D4.2 presents the final version of TREASURE platform describing the technical improvements implemented according to the users' testing and validation activities carried out in T4.6. The integrations made in the second iteration start from the outcomes and considerations achieved from the discussion with TREASURE use cases based on the functional and non-functional evaluation. This deliverable describes the ultimate platform design, defining the modules interdependencies in conjunction with the external tools' integration.

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 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 last document to be released concerning this task activities. Therefore, D4.2 has to be considered the arrival 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 are used and the requirements that are met.

1.3 Contribution to other WPs

Presenting the final version of platform architecture, 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”.

Moreover, since D4.1 defines the digital solution structure, 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 is also validated in the demonstration phase performed within WP6, evaluating the new procedure performances in terms of circularity and economic feasibility.

TREASURE

2 Requirements and specifications

The present deliverable reports the updated and final version of the technical specifications on which the platform ultimate design and implementation is based. The list of the refined requirements emerged during the periodic discussion carried out with the project partners, mainly constituted by the target users of the platform and the process owners, after the first iteration. The integration or/and modification of the technical features takes into consideration not only the internal actors within the consortium but also external stakeholders to generalize the identified requirements. This task has been carried out to expand the list of additional users' needs to include in the identification of the platform specifications. The final goal is to ensure both internal and external validation to improve TREASURE solution adoption in different use cases depending on the involved stakeholder.

2.1 External validation and Requirements generalization

To expand TREASURE application validation to actors outside the consortium, a survey has been elaborated to gain insights and feedbacks from a wide range of players in the automotive industry or cluster associations on the TREASURE platform. The survey outcomes have been pivotal in the integration of technical requirements giving additional inputs that have been considered in the elaboration of the final version of the architecture.

More in detail, the survey has been developed based on the following main goals:

1. Filling the data-lake of the TREASURE platform with additional contents.
2. Clarifying the type of contents to incorporate in the TREASURE platform.
3. Acquiring, importing and structuring data within the data-lake of the TREASURE platform.
4. Opening the TREASURE platform to other users than the TREASURE partners.

The survey wants to reach the following desired outcomes:

1. Measure circularity performances through quantitative KPIs.
2. Tracing and quantification of material flows, recyclability, exergy and environmental impact.
3. Improving the information exchange between manufacturers and recyclers on electronic products.
4. Improving EU standards for material-efficient recycling of electronic wastes from complex EoL products.
5. Developing a monitoring framework for the circular economy.
6. Achieving specific recycling rates and reducing impact of current ELV recycling practices.

The effort was intended to enhance a broader stakeholder involvement in solution design and technical specification activities, by initiating open discussion of topics, aiming for a limited co-validation of platform functionalities. In this direction the Advisory Board played a major role since their members actively contributed to the survey completion and sharing to their affiliates expanding the interviewer's pool.

Even though the results collected in the previous months have been used to the requirements refinement task, the questionnaire will remain open in order to collect additional feedbacks that could be useful for further improvements. Moreover, the survey is an important tool to enhance networking activities with sister initiatives and improve TREASURE visibility, mainly for clusters and associations in the automotive sector. One example of this is the collaboration that arose with Business Upper Austria, the Upper Austrian government's location agency dedicated to steer economic and research policy. Business Upper Austria is an innovation driver and the first contact partner for companies in Austria and abroad to whom they offer customised solutions for their investment and innovation projects. The contact with this association is particularly relevant for TREASURE scope since Business Upper Austria's cluster and network initiatives are competence centres for bringing companies currently more than 2,000 partner companies. Thus, their engagement in the project validation represents an interesting opportunity not only to further develop the platform main functionalities but also to disseminate TREASURE outcomes to their members. For this reason a preliminary meeting with the association representative has been organized to present more in detail the digital solution and its application for the project use case, demonstrating the functionalities in action.

The survey has been designed by TXT in collaboration with the project coordinator and SUPSI to include not only the feedbacks on TREASURE platform but also on the methodology used for the Circular Advisory Tool definition. Thus, the questionnaire is structured in three sections:

- Section 1 is dedicated to gathering general data from the interviewed actors in order to specify, clusterise and analyse their contribution and have a better perspective in terms of value chain's covering.
- Section 2 is the methodological section where the interviewed actors are asked to select those methods and KPIs that, from their personal perspective, will optimize the functionality of the overall TREASURE platform.
- Section 3 is the digital toolbox section where the interviewed partners are asked to provide useful suggestions on the selection of the most valuable functionalities to be embedded in the TREASURE platform in addition to pros and cons of the application value proposition.

A more detailed analysis of the results collected in each section and its related impact on TREASURE project is provided in the following sub-sections.

2.1.1 Survey Section 1: Respondent general information

The goal of this section is firstly to provide an overview of TREASURE project by describing its main objectives and secondly to collect general information on the participant.

Figure 1 Survey first page

This preliminary step is essential in determining the criteria for the results analysis since the questionnaire is open to a wide range of stakeholders coming from different professional backgrounds. Overall, up to the moment when this document is released, a total amount of more than 50 respondents participated in the survey with an average time to complete of approximately 70 minutes.

Figure 2 Survey n. of respondents and average time

The majority of respondents belong to the private sector, more than half with respect to the public field (the replies classified as “Other” consist in Cluster organization and Innovation Cluster).

Figure 2.3 - Survey results #2

The geographic composition shows a prevalence of European countries, especially Germany and Italy where the automotive sector plays an important role in the national economy.

Figure 4 Survey respondents' geography

Considering the professional background, the respondents mainly belong to clusters related to the automotive industry or more in general to mobility and technological innovation. This is an important element that has been taken into consideration for the analysis of the results collected in Section 2 and 3 of the questionnaire.

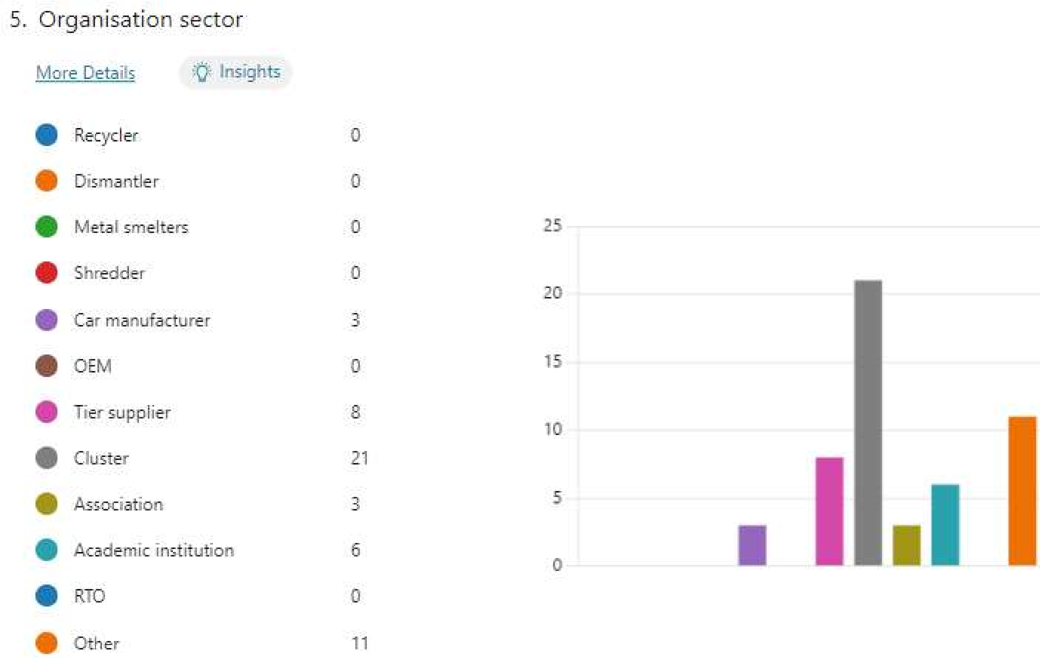

Figure 2.5 - Survey results #3

After these generic questions, the survey focuses on the methodological part which outcomes are presented in the following chapter.

2.1.2 Survey Section 2: Methodologies

The second section of the survey addressed the methodological aspects of TREASURE that constitute the theoretical structure of TREASURE platform. The sustainability and circularity assessment and advisory methodologies have been developed by SUPSI and reported in D2.1 (Assessment methodology) and D2.2 (Advisory methodology).

The survey questions were aimed at investigating the perspective of external stakeholders on the following aspects related to the methodologies:

- **Environmental assessment**. During the survey, a focus on the environmental sustainability has been proposed, while the social area has been excluded from the investigation since it would have required too much space and time in the survey (i.e. needing an AHP approach to investigate the preferred social stakeholders and indicators). Moreover, the economic area has been excluded since it already reached a good agreement on the kind of indicators to be proposed within the consortium. The choice of the environmental impact category indicators to be calculated fell on the midpoint indicators foreseen by PEF and EF3.0-related impact assessment methodology (see D2.1). The external stakeholders have been questioned to define a sub-set of indicators of major interest for the actors of the automotive value chain. When (environmental) sustainability comes into play in the decision-making process foreseen by the advisory flow of the platform, the sub-set of indicators identified by external stakeholders through the survey will be graphically shown in the platform user interface. The user will have the possibility to use the sub-set as quantified guidance to drive decisions towards a higher level of (environmental) sustainability. In any case, the user will have access to the whole set of indicators for the sake of completeness.

- **Approach for the integration of assessment results**. As discussed in D2.1, the results of the environmental, economic, social, and circular assessments are a set of different quantified indicators, which can be in contrast with each other. Without the required expertise in analyzing sustainability assessment, the platform user would not be able to handle the results to make informed decisions. Even expert users could find it difficult to extrapolate from raw indicators the support needed to orient their actions. For those reasons, the stakeholder perspective on how and whether to approach the integration has been investigated, considering the integration into overall scores of both the assessment outcomes of each individual area and of the areas together.
- **Disassembly advisory**. When dealing with the estimation of the time to disassemble a car part from a car prior to effective disassembly, a methodology has been found in the literature[2] that correlates the disassembly time to the number and type of joints. However, information related to joints is available if a CAD of the car part is provided to dismantlers. The survey recipients were asked to provide feedback on existing alternative methodologies to estimate disassembly time.
- **Eco-design advisory**. External stakeholders were asked to give feedback on existing tools for design that exploit AI to provide sustainability advice.

The results of the survey are hereafter reported and commented.

- **Environmental assessment**. The indicators resulting to be of most interest for the external stakeholder are the climate change and resource depletion, followed by land transformation, eco-toxicity, human toxicity (cancer effects), and particulate matter.

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[2] (Mandolini, Favi, et al., 2018)
Mandolini, M., Favi, C., Germani, M., & Marconi, M. (2018). Time-based disassembly method: how to assess the best disassembly sequence and time of target components in complex products. *The International Journal of Advanced Manufacturing Technology*, *95*(1–4), 409–430. https://doi.org/10.1007/s00170-017-1201-5

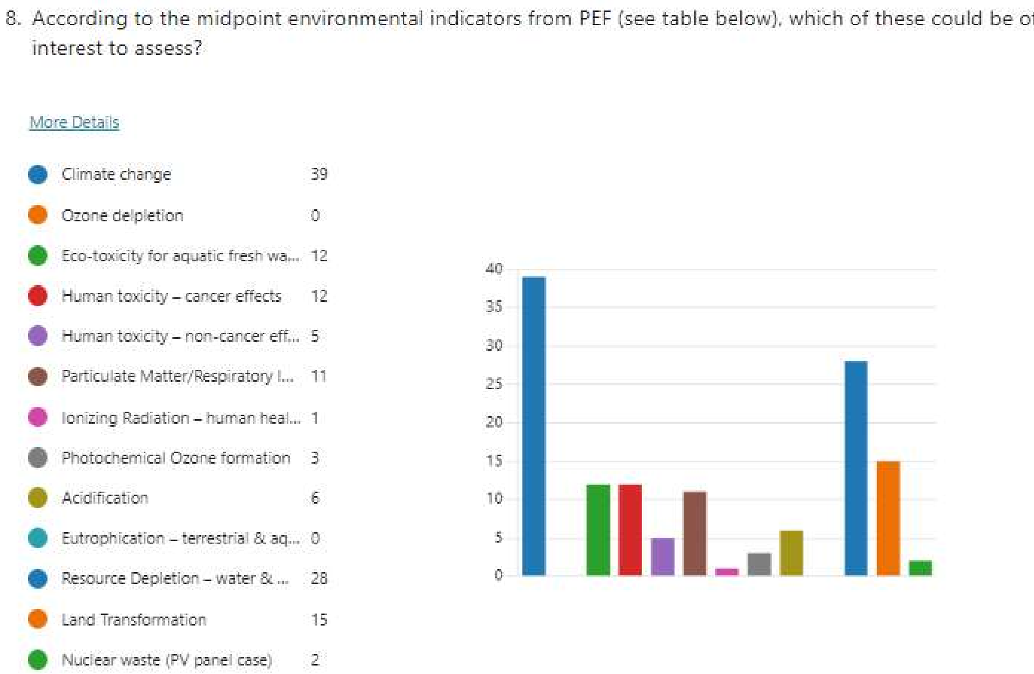

Figure 6 Survey result question n. 8

- **Approach for the integration of assessment results**. The questions and the relative received answers are reported hereafter.

1) Considering each single area of sustainability, would you prefer to see a) the value of each indicator, b) an aggregated result, or c) a combination of these options?

Figure 7 Survey results question n. 9

According to the recipients, the better way to represent the assessment results of each single area is to provide an aggregated view without losing the possibility to access the details at the indicators level. Even if there is also a considerable number of replies on the total that indicates to keep the details on the value of each indicator, it is a shared vision to avoid only an aggregate value for each area. In this sense, the survey results confirm the approach already adopted in the platform. Indeed, in the recycling module and advisory, each disassembly and recycling route is evaluated from the circularity (i.e., recycling rates from recycling simulation) and sustainability (environmental, economic, social) perspectives. Currently, the results of the assessments are displayed as aggregated values, with the possibility to access details at the level of single indicator. The results are also shown in a 3D map.

2) In addition to the aggregation options on the single sustainability area identified, are you interested to have a general aggregated indicator that summarized all the three areas of sustainability?

Figure 8 Survey results question n. 10

3) If the aggregated result is chosen, how would you manage the weighting operation needed to integrate the results?

As the reply to the previous question show a general interest towards an aggregated sustainability result as a score to drive decision-making leaving no room for interpretation, the question related to the definition of weights is crucial as they can determine whether for instance a disassembly and recycling route is more sustainable than another one. Indeed, different weights could reveal different overall scores. The results show that both the option of adopting pre-defined and validated weights and the hybrid option of giving the user the possibility to adjust the weights according to its needs and context are suitable approaches to determine weights.

Figure 9 Survey results question n. 11

4) Who may be the external stakeholders that can provide validated weights?

Correlated to the previous question, the recipients were called to identify the stakeholders that can sit at the decision table and agree on the weights to attribute to each area of sustainability for the process/product that is analysed. Excluding the out-of-scope answers, the results show that the main actors to be involved are (car/car parts) manufacturers.

Figure 10 Survey results question n. 12

- **Disassembly advisory**. Is there another mathematical methodology to define the disassembly time not based on the number of joints (e.g., given the unavailability of a CAD to support the identification of joints)?
- According to the replies of recipients, any estimation of the disassembly time based on the analysis of the design underestimates the actual time to disassembly, as it is not considering neither the human factor nor the status of the component at end of life, including the possibility of undergoing destructive disassembly actions. Thus, specific disassembly trials by the operator should be considered as the most effective estimation.

ID ↑	Name	Responses
1	anonymous	The disassembling time is essential for re-use purpose. In case of disassembly the parts for recycling some destructive actions can be taken shortening the time needed on that piece. Then ease of the access to that piece is important. In this case the "level of additional access actions" is a measurement.
2	anonymous	Number of individual PCB's could be considered.
3	anonymous	I did not find
4	anonymous	Disassembly time estimation based on the design will always be too short. Unfortunately only application specific pactical trials can provide precise answers.
5	anonymous	dismantling analysis; net time approach (with considering joints only) is not appropriate. Consider also difficulties at end-of-life, tool changes and more to get a more realistic picture.
6	anonymous	No it has to be based on practical assessment of time taken
8	anonymous	You can look at the design for disassembly methodology. In it, the designer of a vehicle defines how the product should be disassembled. It also measures a certain composition of the various components.
9	anonymous	Shortest Path Algorithms; Connectivity and Cluster Analysis
10	anonymous	this would need to be developed and needs to be transparent
11	anonymous	not to my knowledge, but several research Projects dela with similar quaestens (eg. https://www.iwu.fraunhofer.de/de/projekte/zirkel-zirkulaere-produktion-fuer-hochintegrierte-komponenten-der-elektromobilitaet.html
12	anonymous	It is difficult to demonstrate with a mathematical method, but the human factor of the disassembly capacity may still be a bottleneck.
13	anonymous	The concern of ECU component dissassembly is unsoldering where unsoldering is dependent of the size of the component. As the level of an ECU is also number of screw or fixed point such as rivet, soldering, force junction to be removed.

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1	anonymous	The disassembling time is essential for re-use purpose. In case of disassembly the parts for recycling some destructive actions can be taken shortening the time needed on that piece. Then ease of the access to that piece is important. In this case the "level of additional access actions" is a measurement.
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Figure 11 Survey results question n. 13

- **Eco-design Advisory**. Do you know any AI-based tools that can offer advice on component design to improve sustainability issues?

  The survey recipients indicated the following software tools:

  - tec4U D2050, uses partly AI.
  - Autodesk Generative Design.
  - Granta MI.
  - ExaSIM.

  However, none of these provide an advice based on sustainability assessments. This information at least could be exploited to confirm the novelty of the solutions proposed by TREASURE.

2.1.3 Survey Section 3: Platform

The last section of the survey is dedicated to TREASURE platform in order to gain useful feedback on the application main functionalities, collect suggestions for technical improvements, determine the most appreciated distinguishing elements and possible barriers to adoption. This part is split in three segments corresponding to the three modules that compose TREASURE application, Disassemblability, Recyclability and Eco-Design, each of them complemented by its own Advisory. Thus, the questions cover the whole platform to acquire a comprehensive knowledge of respondents' opinion on key functionalities of each module and related advisory part. The same structure is used for all three applications: the first questions are dedicated to the platform specifications from a technical point of view while the last two questions consider users' feedback from a perspective more focused on exploitation. Although it is possible to skip a module if not relevant for the user background, all respondents fully completed the survey answering all questions. One reason for this consists in the fact that the bulk of interviewed belong to clusters or associations, having thus a comprehensive knowledge of different actors in the automotive value chain and circular economy field.

For the first questions of this survey part, an explanation of the application goal, use and design/architecture is provided at the beginning of each segment to ensure that participants were as much informed as possible on TREASURE platform. This is made providing a short video showing key platform features with a description of each requirement, based on the table of functional and non-functional specifications related to the platform first version as presented in D4.1.

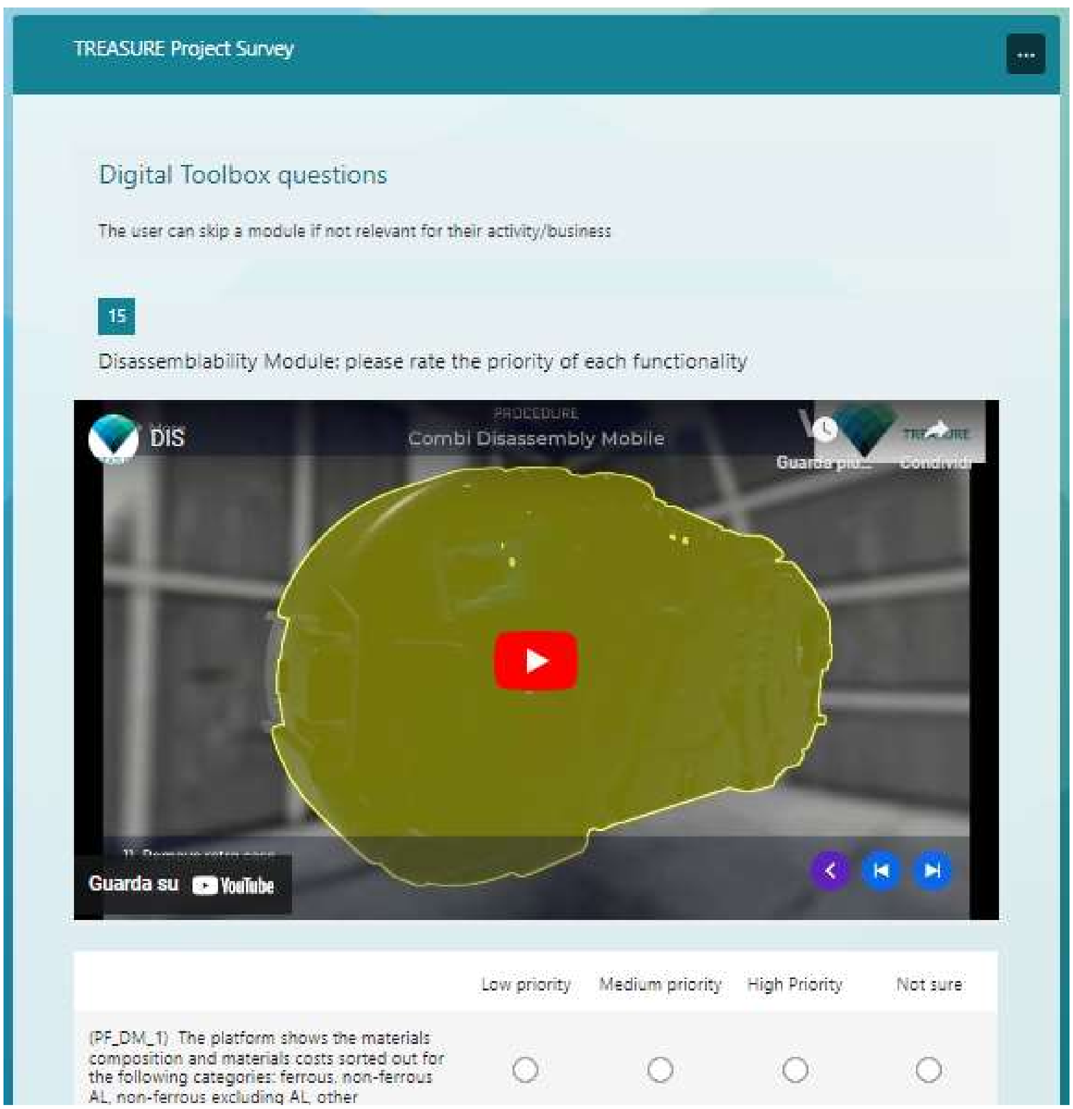

Figure 12 Example of introduction part of platform section

For the scope of the survey, only relevant requirements were selected from the full list of identified specs provided in D4.1, ignoring the basic and general ones, such as allow login from different users, perform search option smoothly, guarantee data security. Moreover, only must-have requirements were considered due to their relevance, omitting should-have and could-have functionalities. Thus, the respondent is provided with a list of key technical specifications he can rate according to the following scale:

- No priority
- Low priority
- Medium priority
- High priority
- Top priority
- Not applicable

For each requirement the interviewee can provide a comment, feedback or suggestion on the specific item assessing which features are preferable. Then, it is asked for additional features considered useful/necessary that should/could be implemented to improve platform value. The reason behind this specification is to align the additional requirements provided by the respondents to the MoSCoW Method that has been adopted for the prioritization of TREASURE platform requirements based on the RFC-2119 specification (must-have, should-have could-have and won't-have (or won't-have right now)).

If this first part of the survey section dedicated to the platform is focused on the technical matters, the second part comprises questions more related to its business perspective. More in detail, the goal is to assess the respondents' impressions about TREASURE application based on the key functionalities presented in the previous questionnaire segment. Thus, they are firstly asked if they would be willing to pay for using the platform and, if so, in the form of a pay per use solution or as a subscription fee. Secondly, the survey users have to determine the most valuable and distinguishing elements of the platform for their potential use. Some possible answers are provided based on the assumptions we made in defining the key points of the application value proposition. Similarly, the same approach is used for the last question of the survey dedicated to the identification of the main barriers that could prevent platform adoption, spanning from technical reasons to financial ones. The answers collected from this survey part play an important role in the refinement of the platform exploitation strategy contributing to the business model revision to include, where applicable, respondents' feedbacks.

In the following sub-chapters the full analysis of the survey results is provided split for platform modules, highlighting the outcomes that lead to the integration of additional requirements.

2.1.3.1 Disassemblability Module

Concerning the first question dedicated to the prioritization of requirements, the interviewee is asked to determine the degree of priority of the functionalities listed in the table below (since in the responses collection page the requirement description is not fully visible, here is provided the full list)

ID	Platform Requirements	Description

PF_DM_1	MATERIAL DATA CONFIGURATION	The platform shows the materials composition and materials costs sorted out for the following categories: - ferrous - non-ferrous AL - non-ferrous excluding AL - other
PF_DM _2	DISASSEMBLY METRICS	The platform shows the disassembly time, market value and difficulty level, providing the total disassembly cost based on hourly costs (inserted by the user)
PF_DM _3	FEEDBACKS FOR ADVISORY	The platform enables the user to write feedbacks referenced by other platform modules to perform advisory analysis
PF_DM _4	DISASSEMBLABILITY PROCEDURE EXECUTION	The platform allows the user to choose the desired procedure providing the dismantling instruction in 3D AR/VR in a clear way
PF_DM _5	DISASSEMBLABILITY INSTRUCTIONS VISUALIZATION	The system should provide disassemblability instructions to the user in a simple way using graphical representation
PF_DM _6	CAR PART PROFIT CALCULATION	The platform calculates the profit margin based on the ratio between the thermodynamic rarity indicator and the desired revenue value
PF_DM _7	DISASSEMBLY PRIORITY CALCULATION	The platform ranks the components to dismantling based on the lower value of the disassembly time

Table 2.1 - Disassemblability Module requirements list

As visible in Figure 13, the highest priority is given to the first requirement (PF_DM _1) followed by the second one (PF_DM _2) and PF_DM _6 while low interest was shown for PF_DM _3 dedicated to the possibility for platform users to provide feedbacks on the disassembly process. Although this functionality plays an essential role in the platform for the definition of the recyclability and eco-design recommendations, it’s not considered crucial. A major interest is instead perceived for the features that provide intelligence on the following aspects: component material composition with the classification according to the categories ferrous, non-ferrous AL, non-ferrous excluding AL and a generic other; disassembly time, market value and difficulty level, providing the total disassembly cost based on hourly costs; disassemblability instructions in a simple way using graphical representation; and profit margin based on the ratio between the thermodynamic rarity indicator and the desired revenue value. As for the disassembly instructions, the possibility to see the dismantling procedures in AR/VR is not considered a fundamental asset. The outcomes of this responses show a high interest in the provision of information perceived as critical for the users to drive day to day operations and business strategy.

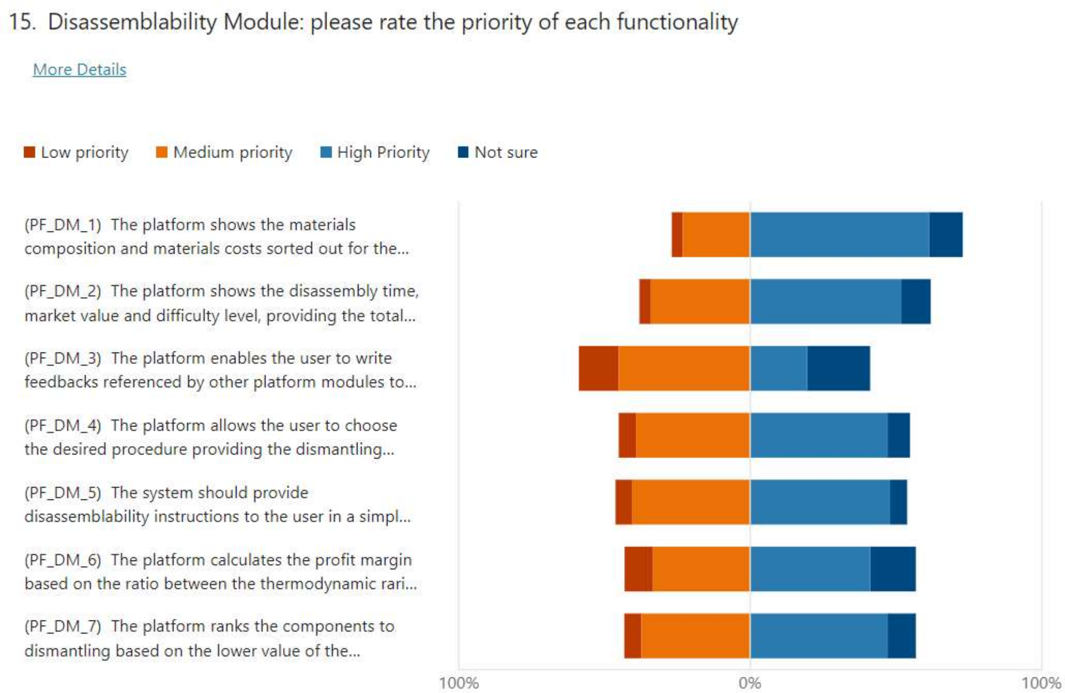

Figure 13 Responses to Disassemblability Module requirements prioritization

When asked about their preferences and additional functionalities to be implemented to improve the platform, the respondents pointed out an interest for accessing further data on specific material or part of the car component, i.e. assembly alloys or used plastics. As shown in the table below where all answers are reported, the suggestions concern also the parameters used for the disassembly analysis (see R_DM_1, R_DM_4 and R_DM_6), proposing a more detailed study for re-use components, which is not the focus of TREASURE project. Among all responses, R_DM_6 has been selected as an additional feature to implement in the platform since other suggestions belong to a wider scope of TREASURE. As for the chosen feedback, in the disassembly metrics section of the Disassemblability Module of the platform, two rows with lower and higher value of disassembly cost will be added to provide a clear indication of confidence score of the results shown in the platform. This is useful to improve user trustworthiness in the provided data while increasing accuracy.

ID Response	Response full text
R_DM_1	Quality of disassembling parts depends on the purpose: re-use requires more detailed information than recycling
R _DM _2	Identification of assembly alloys used in solder joints (Sn-Ag-Cu, Sn-Ag, Bi-Sn-Ag etc)
R _DM _3	Set more focus on different plastics and also distinguish different types of plastics for the composition.
R _DM _4	Recommendation of parts based on cost/revenue considerations
R _DM _5	Jiva's business model is to provide a way of getting a more concentrated waste stream of electronics from which value can be more easily extracted

R _DM _6	28isassembly instructions and value for re-use, material composition for recycling; for cost and profitability (which are very time-specific) a range or “confidence score” of the result would be helpful to make better informed
R _DM _7	Potential for reusable component including dismantling operating risk

Table 2.2 - Responses to Disassemblability Module functionalities

Given the collected feedbacks presented above, it’s not surprising that, when asked if they would buy the platform, users’ answer is divided in two opposite results: 55% of them is in favour of paying to use the digital solution while the remaining 45% is not interested. It’s interesting to note that, in the first case, the preferred buying option is in form of a subscription fee and not as per use. This implies that users are more interested in a long-term business relationship, not limited to a specific random use but as a continuous service to be exploited in day to day operations planning.

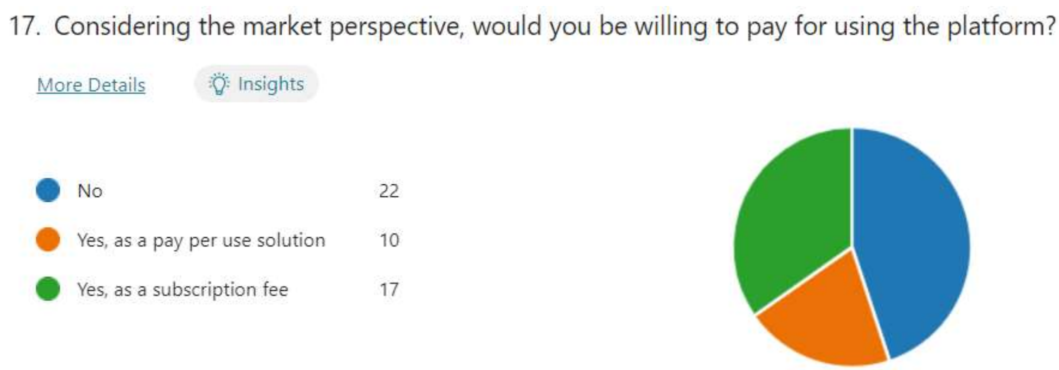

Figure 2.14 - Disassemblability Module Question n. 17

To gain more insights on the reasons behind these answers, we need to analyse the responses provided for the following question dedicated to defining the key aspects of the platform which are below reported:

- Possibility to gain access to several relevant aggregated information.
- Speed up of operators training process.
- Efficiency improvement for dismantling operation performance.
- Possibility to compare different key metrics.
- Easy to use because it is cloud based.
- Support in the decision-making process.
- Other (please specify).

As shown in Figure 15, the higher rating is assigned to the possibility to access strategic data (reinforcing the results of the first question on requirements prioritization) not only on material composition of car part but also on the disassembly procedures. The most valuable feature in fact is considered the support for the decision-making process leading to an improvement in efficiency of the dismantling operations planning. This result confirms the interest in establishing a long-lasting use of the platform as a potential additional IT application integrated in the already existing system for operation management. On the contrary the ease of use as a cloud-based solution is not considered very relevant either because it doesn't represent a major restrain for the integration with the legacy system or because this approach is not perceived as the preferred one.

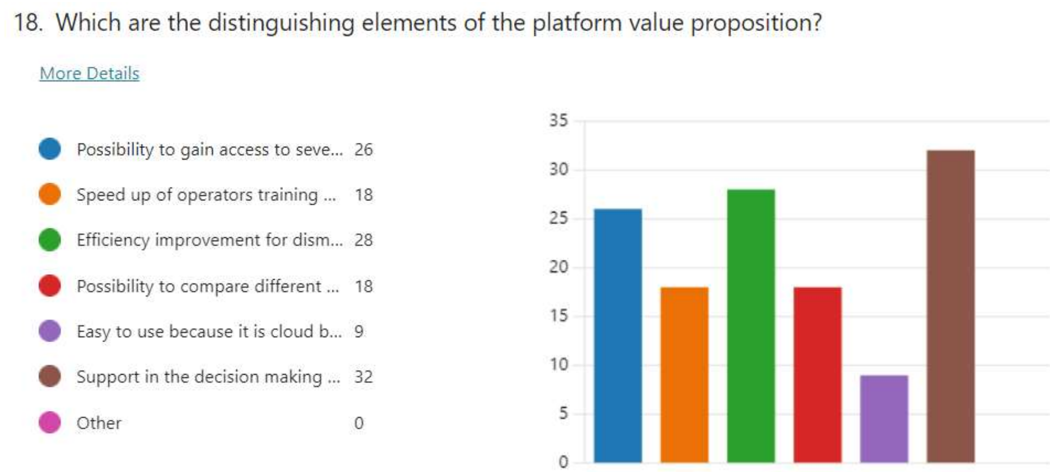

Figure 15 Disassemblability Module Question n. 18

Finally, the last question is dedicated to acquiring knowledge on the possible limits in platform purchase. The options provided to users (listed below) consider both financial and technical aspects to have a comprehensive overview of respondents' impressions.

- Additional cost/investment that is perceived as accessory or not strategic.
- The training required could take too much time.
- Not aligned/relevant with company scope/business.
- Difficulty to implement in the company IT system (the platform is cloud based).
- No additional benefits for the company business or operations management.
- Not user-friendly enough.
- Other (please specify).

As visible in Figure 16, the financial element counted the most, although no hints on the estimated price are intentionally given since the fee may consistently vary based on the use and additional services required. This is a relevant point to be considered for the platform exploitation plan since it heavily affects the business model pricing strategy. Moreover, it's interesting to note that the concern for technical integration has an impact on the adoption of TREASURE solution and it must be taken into account for further development once the project ends. Similarly, if we consider the answer "No additional benefits for the company business or operations management", an improvement in the platform value proposition is suggested. This could be achieved by expanding the commercial offering by including new services or analysis based on the different users' needs that can emerge in the future.

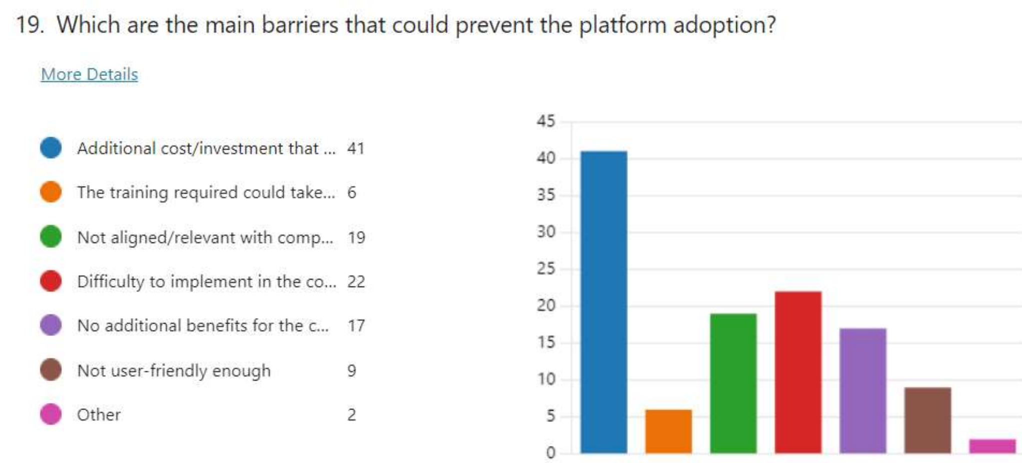

Figure 16 Disassemblability Module Question n. 19

2.1.3.2 Recyclability Module

Concerning the first question dedicated to the prioritization of requirements, the interviewee is asked to determine the degree of priority of the functionalities listed in the table below (since in the responses collection page the requirement description is not fully visible, here is provided the full list).

ID	Platform Requirements	Description
PF_RM_1	MATERIAL DATA COMPOSITION	The platform shows the materials composition sorted out for the following categories: - organics - inorganics - metals (metallic/alloys) - metals (oxides, sulfides/etc)
PF_RM _2	RECYCLING RATE OBJECTIVES	The platform shows the recycling rate according to the following objectives: - total recycling rate - ferrous metal recycling rate - CRM recycling rate - organic recovery rate
PF_RM _4	RECOVERY RATE FOR RECYCLING PROCESS CALCULATION	The platform shows the different recovery rate according to the following recycling processes: - recycling PCB parts in Copper processing route - recycling of ferrous part in steel processing - recycling of plastics/organics parts in energy recovery
PF_RM _5	ROUTES IMPACT ASSESSMENT	The platform provides a ranking of the disassembly and recycling routes according to social, economic and environmental perspective
PF_RM _6	ROUTES COMPARISON	The platform shows a graphic with the 3 dimensions (social, economic and environmental) for comparing disassembly and recycling routes

Table 2.3 - Recyclability Module list of requirements

If we study the results of the prioritization, a clear preference for PF_RM _2 is evident, demonstrating that users appreciate platform versatility in showing the recycling rate according to specific objectives. Similarly to the Disassemblability Module, also in this case the provision of data concerning materials composition is considered valuable with the possibility to sort out for categories based on organics/inorganics and metals groups. The last two requirements (PF_RM _5 and PF_RM _6) obtained a very similar ranking meaning that the environmental, social and economic dimensions don't play the same degree of relevance as the recycling rate visualization.

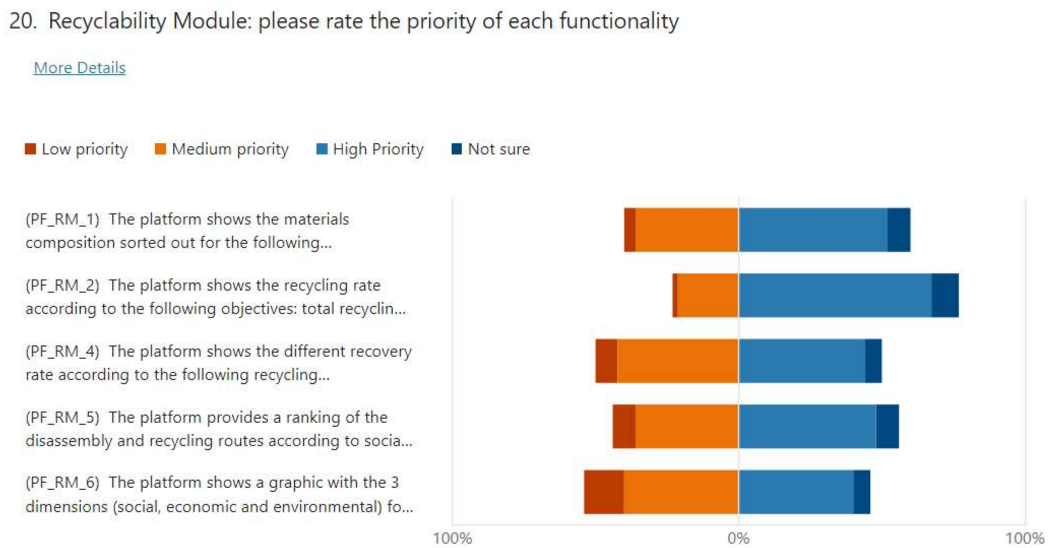

Figure 2.17 – Recyclability Module Requirements prioritization results

When asked about their preferences and additional functionalities to be implemented to improve the platform, the respondents pointed out an interest for accessing further data on specific material or more details on the energy recovery level (R_RM_2) to assist in better recyclability assessments (R_RM_1). As shown in the table below where all answers are reported, the comments concern also the parameters used for the recyclability analysis (see R_RM_5 and R_RM_7), proposing a comparison with standard recycling rate of the same product (not implementable due to the difficulty to identify a benchmark applicable for all use cases) and a confidence score, similar to the feedback already analysed in the Disassemblability Module. Given the relevance for the other modules, R_DM_4 has been selected as an additional feature to implement in the platform since the provision of feedbacks collected in the Recyclability Module affect the Eco-Design application functionality, especially for the recommendations and Advisory part. Thus, the second version of the platform will be integrated with a new section where the user can provide his comments/suggestions/notes. On the other hand, the user will also obtain recommendations on the recycling rates and processes as proposed in R_DM_3. Thus, as it is already foreseen in the Eco-Design Module, another section will be integrated in the Recyclability platform Module where instructions will be provided according to the recycling objective selected and related analysis performed.

ID Response	Response full text
R_RM_1	Provide more detailed information about the composition of car parts, including specific materials and their percentages

R _RM _2	Offer insights into energy recovery during the recycling process, helping users understand the environmental impact of recycling specific car parts
R _RM _3	Provide recommendations on the most efficient and environmentally friendly recycling routes for each car part, considering the best available technologies.
R _RM _4	Establish a feedback loop with dismantlers to inform them about the impact of additional disassembly on recyclability and guide them in optimizing the process.
R _RM _5	Introduce a confidence score for recyclability assessments, reflecting the level of certainty in recycling rate predictions, as recycling rates can vary based on conditions.
R _RM _6	Seamlessly integrate recyclability data with the Disassemblability Module to offer a holistic view of the circularity of car parts.
R _RM _7	Include a benchmarking tool that allows manufacturers to compare the recyclability of their car parts with industry standards and competitors.

Table 2.4 - Recyclability Module responses to Question n. 21

Regarding the business perspective, for the Recylability Module a lower percentage of users (53%) with respect to the Disassemblability Module would be willing to pay to exploit it. This could be due to the fact that, as it is conceived in the first version, this module mainly presents information, not providing suggestions or instructions as it is for the Disassemblability application. This was another driver for the integration of the additional requirements dedicated both to the provision of recommendations and to the collection of feedbacks. Finally, it must be noted that, similarly to the Disassemblability Module, also in the Recyclability Module case the preferred option for platform use is the subscription fee solution.

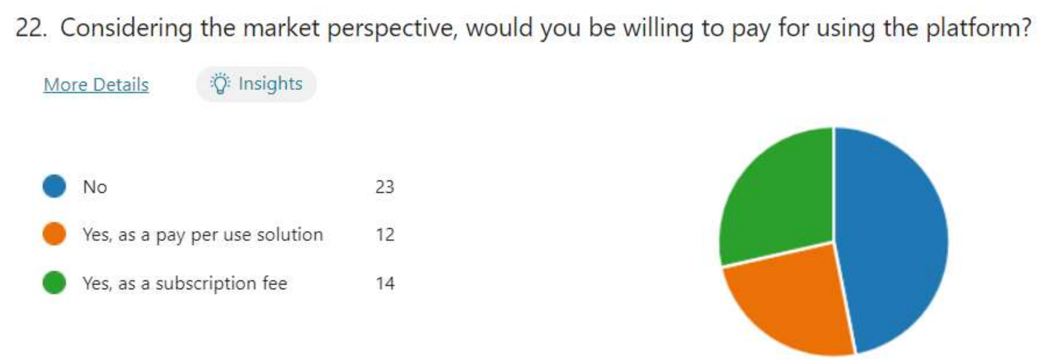

Figure 2.18 - Recyclability Module Question n. 22

To gain more insights on the reasons behind these answers, we need to analyse the responses provided for the following question dedicated to defining the key aspects of the platform which are below reported:

- Possibility to gain access to several relevant aggregated information.
- Efficiency improvement for recycling operation performance.
- Possibility to compare different key metrics.
- Easy to use because it is cloud based.
- Support in the decision-making process.
- Other (please specify).

As shown in Figure 19, the higher rating is assigned to the support for the decision-making process leading to an improvement in efficiency of the recycling operations performance. This result confirms the interest in establishing a long-term use of the platform as a potential additional application exploited for the recovery process management. In alignment with the highest priority for the requirement dedicated to the recycling objective definition, also in these answers it is evident that the opportunity to compare different metrics has a positive impact on respondents' impressions. This supports the design of the platform as an adaptable digital solution that considers the impact of the recycling goal in the LCA analysis. As already noted for the Dissassemblability Module, the ease of use as a cloud-based solution is not considered very relevant.

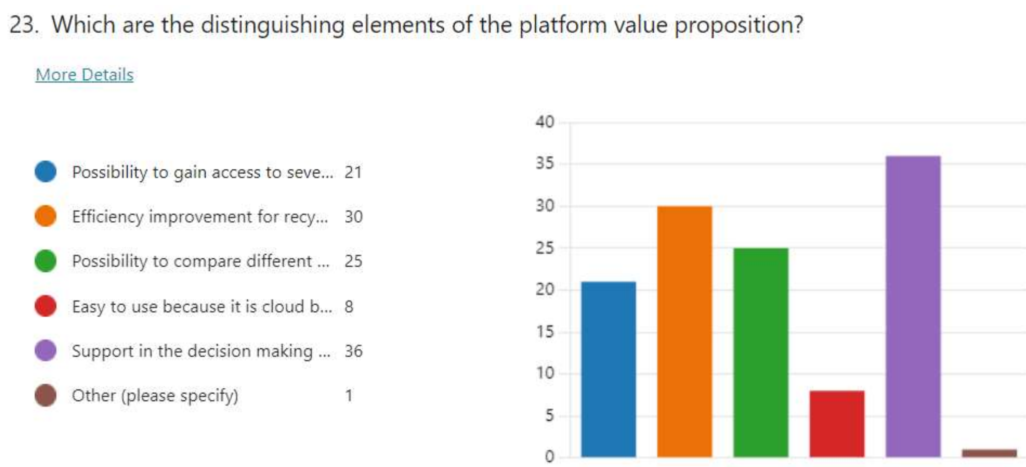

Figure 19 Recyclability Module Question n. 23

Finally, the last question is dedicated to acquiring knowledge on the possible limits in platform purchase. The options provided to users (listed below) consider both financial and technical aspects to have a comprehensive overview of respondents' impressions.

- Additional cost/investment that is perceived as accessory or not strategic.
- The training required could take too much time.
- Not aligned/relevant with company scope/business.
- Difficulty to implement in the company IT system (the platform is cloud based).
- No additional benefits for the company business or operations management.
- Not user-friendly enough.
- Other (please specify).

As visible in Figure 20, also in this case, the financial element counted the most, although no hints on the estimated price are intentionally given since the fee may consistently vary based on the use and additional services required. This is a relevant point to be considered for the platform exploitation plan since it heavily affects the business model pricing strategy. Moreover, it must be noted that the second answer "Not aligned/relevant with company scope/business "could be due to the respondents' professional background. Similarly, if we consider the answer "No additional benefits for the company business or operations management", an improvement in the platform value proposition is suggested. This could be achieved by expanding the commercial offering by including new services or analysis based on the different users' needs that can emerge in the future. As for the Other option, the comments refer to the fact that the information provided on recyclability is too general, that the data must always kept updated and the recycling isn't enough considered at the conception phase.

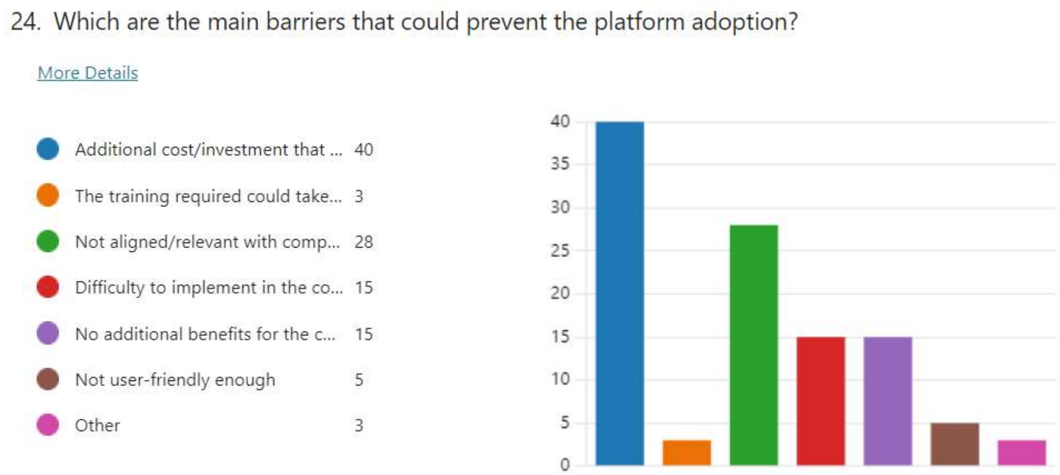

Figure 20 Recyclability Module Question n. 24

2.1.3.3 Eco-Design Module

Concerning the first question dedicated to the prioritization of requirements, the interviewee is asked to determine the degree of priority of the functionalities listed in the table below (since in the responses collection page the requirement description is not fully visible, here is provided the full list)

ID	Platform Requirements	Description
PF_EM_1	METAL RANKING	The platform ranks the top 5 metals sorted out for: - weight - thermodynamic rarity According to this classification, more details concerning market and production indicators
PF_EM _2	PLASTIC CHARACTERIZATION	The platform shows the plastic composition for the car part according to the mass
PF_EM _3	ECO DESIGN RECCOMENDATIONS	The platform provides recommendations concerning car part design improvements from a circularity perspective in a textual form
PF_EM _4	DESIGN COMPLIANCE TO GUIDELINES	The platform assesses the compliance of the car part design with specific guidelines based on the feedbacks collected in the other modules

Table 2.5 - Eco-Design Module requirements list

As visible in Figure 21, the highest priority is given to the first requirement (PF_EM _1) followed by the third one (PF_EM _3) and PF_DM _4 while low interest was shown for PF_DM _2 dedicated to the visualization of the plastic composition for the car part according to the mass. As for the previous modules, major interest is instead perceived for the features that provide intelligence, and in this case namely on the top 5 metals sorted out for weight and thermodynamic rarity presenting additional data on market and production indicators. As already noted, the functionality related to the provision of recommendations and collection of feedbacks is considered valuable especially in this module. In fact, since the Eco-Design application addresses car designer, the opportunity to access knowledge coming from EoL actors is particularly interesting from a BoL perspective.

25. Eco-Design Module: please rate the priority of each functionality

More Details

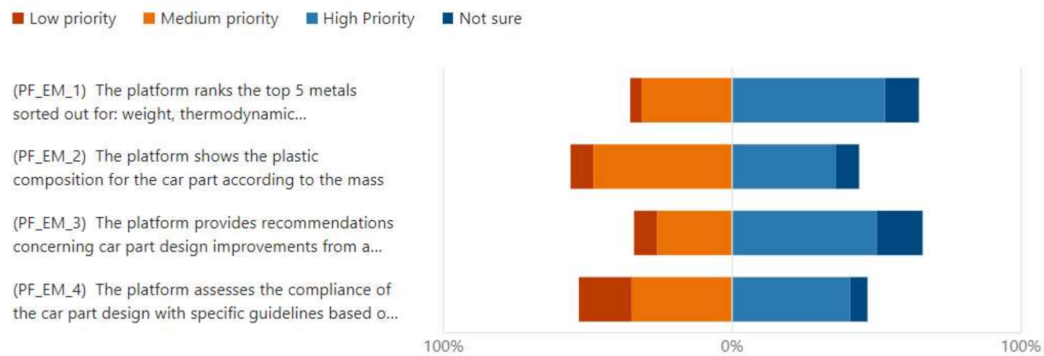

Figure 21 Responses to Eco-Design Module requirements prioritization

When asked about their preferences and additional functionalities to be implemented to improve the platform, the respondents pointed out an interest for accessing further data on specific material or part of the car component to improve the identification of possible alternative designs or facilitate comparisons. This is evident in suggestions R_EM_1, R_EM_4, R_EM_2 and R_EM_5. As for the first two comments, no actions were token since they concern information already provided in the platform while for the last two recommendations it was decided to integrate them in the already existing functionalities in the following form: for R_EM_2, a pop up with an explanation of what the thermodynamic rarity is will be included in the homepage of the Eco-design module in order to improve system explainability and transparency on the metrics used and results presented; similarly, for R_EM_5, an additional pop up will be shown to explain supply risk assessment and other relevant indicators. If we analyse the other feedbacks, R_DM_6 is implicit in the platform data management while R_DM_7 adoption presents some difficulties in terms of assessing the material substitutions that could improve overall sustainability since this depends on different variables that affects the definition of the most suitable alternative materials to use (i.e., the goal of the analysis, material availability, prioritization of indicators). Finally, for R_DM_8 a dedicated section of the platform for real-time knowledge sharing between the different users is not foreseen in TREASURE architecture nor within its scope.

ID Response	Response full text
R_EM_1	Provide insights into metallurgical incompatibilities and quantitative data on material recoveries and losses
R _EM _2	Provide manufacturers with insights into the scarcity and thermodynamic rarity of the metallic elements used in car parts, helping them make informed decisions about material selection.
R _EM _3	Highlight the use of critical raw materials in car parts to draw attention to potential supply risks and encourage the exploration of alternative materials
R _EM _4	Display the percentage of each metal's contribution to the total weight of the car part and show how the demand for specific metals in the automotive sector compares to their use in other industries
R _EM _5	Offer information on supply risk as assessed by the European Commission, allowing manufacturers to assess the vulnerability of their supply chains

R _EM _6	Implement real-time or regularly updated data feeds to keep manufacturers informed about changing material availability and supply risk assessments
R _EM _7	Provide suggestions for material substitutions that could improve overall sustainability
R _EM _8	Facilitate collaboration between manufacturers and eco-designers by offering a space for sharing insights and recommendations based on materials data

Table 2.6 - Responses to Eco-Design Module functionalities

As for the market perspective question, half the respondents said that they wouldn't be interested in purchasing the Eco-Design module. This could depend on the interviewees' professional provenience and the business field they operate in, in addition to the fact that this section of the platform is the module that mainly needs improvements in the implementation. In fact, with respect to the other two modules, the Eco-Design and more precisely the Advisory part, will be integrated in the beta version with additional features not presented in the requirements list shown in the survey since they are related to the alpha version of the platform. As previously noted, also in this case the preferred buying option is in form of a subscription fee and not as per use.

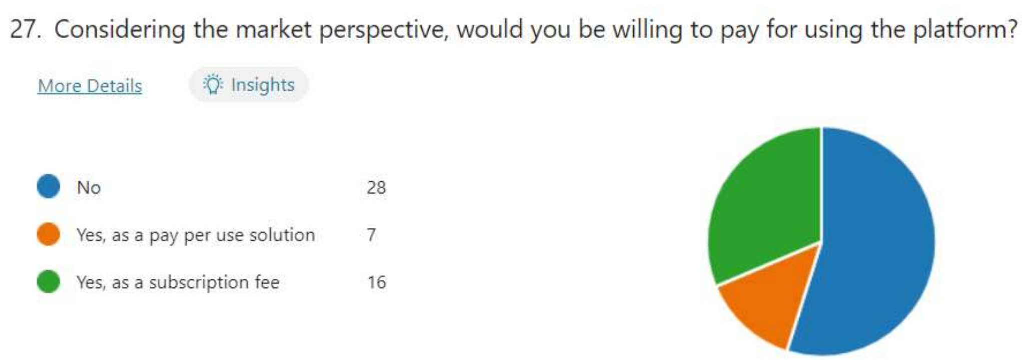

Figure 2.22 - Eco-Design Module Question n. 27

To gain more insights on the reasons behind these answers, we need to analyse the responses provided for the following question dedicated to defining the key aspects of the platform which are below reported:

- Possibility to gain access to several relevant aggregated information.
- Efficiency improvement for eco design performance.
- Possibility to compare different key metrics.
- Easy to use because it is cloud based.
- Support in the decision-making process.
- Chance to visualize different EoL actors' feedbacks on recycling and dismantling processes.
- Possibility to compare guidelines compliance of different car part designs.
- Other (please specify).

As shown in Figure 23, it's not surprising the higher rating is assigned to the support in the decision-making process since it's the main goal of the Eco-Design module. It's interesting to note that the other options receive almost the same ranking indicating that the application is versatile. On the contrary, as for the previous modules, the ease of use as a cloud-based solution is not considered very relevant.

28. Which are the distinguishing elements of the platform value proposition?

More Details

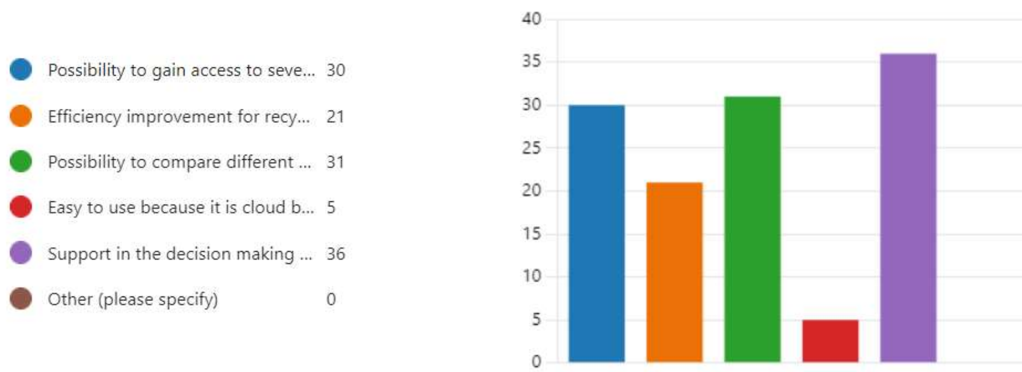

Figure 23 Eco-Design Module Question n. 28

Finally, the last question is dedicated to acquiring knowledge on the possible limits in platform purchase. The options provided to users (listed below) consider both financial and technical aspects to have a comprehensive overview of respondents' impressions.

- Additional cost/investment that is perceived as accessory or not strategic.
- The training required could take too much time.
- Not aligned/relevant with company scope/business.
- Difficulty to implement in the company IT system (the platform is cloud based).
- No additional benefits for the company business or operations management.
- Not user-friendly enough.
- Other (please specify).

As visible in Figure 24, the financial element is confirmed as the most impacting barrier as already noted for the other two modules. In alignment with the answer provided in the question n. 27, the option "No additional benefits for the company business or operations management" is a relevant input for future platform development. As pointed out in the previous paragraph, the Eco-Design module is the most impacted by the revision made for the second version of the platform. Thus, it's important to contextualise these answers to the alpha version of TREASURE system as suggestions for the beta version improvements. As for the Other option, the comments refer to the fact that from one side the textual design recommendations are too broad and, from the other, that additional information about the plastics involved is desirable.

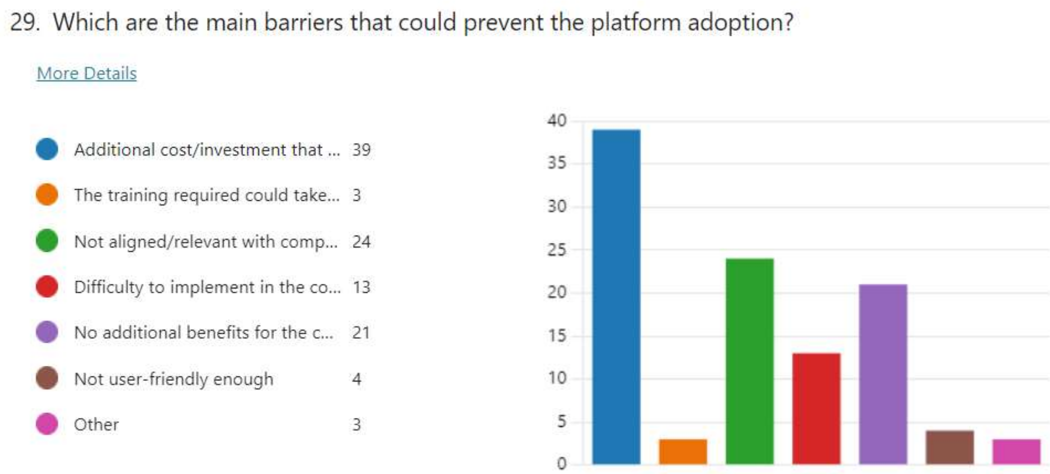

Figure 24 Eco-Design Module Question n. 29

The responses collected thanks to this survey have proven to be an interesting and valuable tool to improve technical developments for the second version of TREASURE platform. This is particularly true in the case of the functional requirements that have been updated taking into consideration not only internal validation performed within the consortium with the involvement of end-users but also considering the inputs collected through this questionnaire.

2.2 System requirements

Starting from the list preliminary system requirements provided in D4.1, this section provides an updated list of technical requirements, that were further refined during the continuous discussions with the project partners, mainly the target users of the platform and the process owners. The refinement of the technical features takes into consideration not only the internal actors within the consortium but also external stakeholders to generalize the identified requirements. This task has been carried out to expand platform additional users' needs and ensure an external validation.

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 should 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 should 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 must provide disassemblablity instructions to the user in a simple way using graphical representation	F
R_12	DISASSEMBLABILITY KPI VISUALIZATION	The platform could provide disassemblers with the proper KPI relevant to the part being disassembled,	F
R_13	DISASSEMBLABILITY FEEDBACK	The platform should allow disassemblers to provide feedback about a specific disassembly operation	F
R_16	ELEMENT/MATERIAL SELECTION	The platform should 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	The platform must provide guidelines on best suited/most optimal recycling routes (including combination between disassembly and recycling processing) as a function of the objective of recycling optimisation based on quantified and visualised KPIs	F
R_18	RECYCLABILITY KPI VISUALIZATION	The platform must provide end-of-life stakeholders as well as designers and disassemblers with recycling KPI's for the part/product assessed for both valuable/critical materials being recycled and all other materials/compounds included in the part/product	F
R_19	RECYCLABILITY FEEDBACK	The platform must provide feedback and insight to End-of-Life (EoL) operators/ stakeholders (including disassemblers) and designers concerning recovery rates of specific elements/compounds or materials (within the suite of all other materials/elements/compounds	F

		recovered and lost/emitted from the part)	
R_20	PROCEDURES DOWNLOAD	The platform must allow disassemblers and disassembly operators download procedures on their devices	F
R_21	CAR/PART INFORMATION SHARING	The platform should allow car parts designers/car makers to upload information about cars and parts composition	F
R_22	CAR/PART INFORMATION UPDATE	The platform should allow car parts designers/car makers to update existing information about cars and parts composition	F
R_23	CAR/CAR-PART 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 could allow consumers to search for a specific car	F
R_28	CONSUMER INDICATORS VISUALIZATION	The platform could 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 EoL operators/stakeholders (I.e., disassemblers, shredders/physical recycling operators and recyclers) as well as 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	The platform must allow eco-designers to insert information about 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	The platform must be able to simulate the recycling of the (car) parts and calculate the recycling performance (recycling rates, energy recovery) of parts, materials, components etc. for different most suitable recycling flowsheet configurations	F
R_34	RECYCLING/RECOVERY RATES	The platform must be able to generate know-how/KPIs on quantified recycling/recovery rates for all elements/compounds/materials included	F
R_35	DISASSEMBLY FOR OPTIMAL RECYCLING	The platform must be able to provide instructions to disassemblers for optimal disassembly depth/intensity for optimal recycling/recovery	F
R_36	DESIGN FOR RECYCLING	The platform must be able to provide 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_38	RECYCLING FLOWSHEET INSTRUCTIONS	The platform must provide guidelines on best suited/most optimal recycling routes (including combination between disassembly and recycling processing) as a function of the objective of recycling optimisation	F
R_39	COBOT DISASSEMBLY KPIS	The platform should allow dismantlers to assess disassemblability level 3 KPIs provided by the cobot interface	F

Table 2.7 - Technical system requirements

2.2.1 Changes from previous iteration

Below are highlighted the main changes in requirements with respect to the previous iteration, as reported in D4.1. In particular:

- Requirements R_17, R_23, R_32, R_33, R_34, R_35, R_36 and R_38 have been partially rewritten to better express the subject involved and the targeted platform module.
- Requirement R_18 has been moved to must-have due to its core contribution within the recyclability module.
- Requirement R_20 has been updated to reflect more in details the operators involved.
- Requirement R_39 has been added to the must-have category, as a new approach to the integration between the Circularity Web Platform and the Cobot Interface component.
- Requirements R_14 and R_15 have been removed as no longer aligned with the updated vision for the Cobot Interface tool.
- Requirement R_37 has been removed as no surrogate AI function will be provided from the platform. The platform serves as an aggregator of knowledge and recycling information have to be provided already pre-processed.

- Requirements related to the WEAVR Platform have been revised to match the updated use case scenarios for AR/VR operator training. In particular, a focus has been put on the Disassemblability module and dismantling procedures from car to parts and from parts to sub-parts.
- A general check has been performed to ensure that the rest of the requirements still matched the assigned priority. No other requirement (apart from the already mentioned R_18) have been reassigned to a different priority category. No requirement is present in the won't-have category, as per D4.1.

2.3 MVP Features

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.

2.3.1 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 platform must provide disassemblability instructions to the user	F

		in a simple way using graphical representation	
R_17	RECYCLABILITY INSTRUCTIONS VISUALIZATION	The platform must provide guidelines on best suited/most optimal recycling routes (including combination between disassembly and recycling processing) as a function of the objective of recycling optimisation based on quantified and visualised KPIs	F
R_18	RECYCLABILITY KPI VISUALIZATION	The platform must provide end-of-life stakeholders as well as designers and disassemblers with recycling KPI's for the part/product assessed for both valuable/critical materials being recycled and all other materials/compounds included in the part/product	F
R_19	RECYCLABILITY FEEDBACK	The platform must provide feedback and insight to End-of-Life (EoL) operators/ stakeholders (including disassemblers) and designers concerning recovery rates of specific elements/compounds or materials (within the suite of all other materials/elements/compounds recovered and lost/emitted from the part)	F
R_20	PROCEDURES DOWNLOAD	The platform must allow dismantlers and disassembly operators download procedures on their devices	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 EoL operators/stakeholders (I.e., disassemblers, shredders/physical recycling operators and recyclers) as well as 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	The platform must allow eco-designers to insert information about the complete BOM and FMD, i.e., material description in terms of components, materials, elements in terms of both	F

		physical materials and corresponding chemical/molecular formulas etc. into the simulation model of each module/part	
R_33	RECYCLING SIMULATIONS	The platform must be able to simulate the recycling of the (car) parts and calculate the recycling performance (recycling rates, energy recovery) of parts, materials, components etc. for different most suitable recycling flowsheet configurations	F
R_34	RECYCLING/RECOVERY RATES	The platform must be able to generate Know-how/KPIs on quantified recycling/recovery rates for all elements/compounds/materials included	F
R_35	DISASSEMBLY FOR OPTIMAL RECYCLING	The platform must be able to provide instructions to disassemblers for optimal disassembly depth/intensity for optimal recycling/recovery	F
R_36	DESIGN FOR RECYCLING	The platform must be able to provide 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_38	RECYCLING FLOWSHEET INSTRUCTIONS	The platform must provide guidelines on best suited/most optimal recycling routes (including combination between disassembly and recycling processing) as a function of the objective of recycling optimisation	F
R_39	COBOT KPIS	The platform should allow dismantlers to assess disassemblability level 3 KPIs provided by the cobot interface	F

Table 2.8 - TREASURE Platform, must-have requirements

2.3.2 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 should provide suggestions to the disassembler about specific parts that can be disassembled	F
R_10	DISASSEMBLABILITY PROCEDURE CHOICE	The platform should 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 should allow disassemblers to provide feedback about a specific disassembly operation	F

R_16	ELEMENT/MATERIAL SELECTION	The platform should provide knowhow on specific elements/materials to be recovered by and send to most suited recycling flowsheets/processes (meaning final treatment processors such as metallurgical recycling processing and refining)	F
R_21	CAR/PART INFORMATION SHARING	The platform should allow car parts designers/car makers to upload information about cars and parts composition	F
R_22	CAR/PART INFORMATION UPDATE	The platform should 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 2.9 - TREASURE Platform, should-have requirements

2.3.3 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 could provide disassemblers with the proper KPI relevant to the part being disassembled,	F
R_27	CONSUMER SEARCH	The platform could allow consumers to search for a specific car	F
R_28	CONSUMER INDICATORS VISUALIZATION	The platform could allow customers to view CE indicators and graphical indexes reporting the circularity level of their cars	F

Table 2.10 - TREASURE Platform, could-have requirements

2.3.4 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 2.11 - 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 is 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 and sustainability-oriented 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. These the three modules are strongly linked together, constantly communicating in an interconnected manner and their main functionalities are listed below.:

- A **Disassemblability module** providing information on critical and valuable car parts to be disassembled and useful disassembly instructions.
- A **Recyclability module** providing information based on quantification of the recycling performance (quantified KPIs) 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.

Complementing each module, the **Circular Advisory Tool** is 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 data sources.

The following sections provide a detailed technical architecture, highlighting the main technologies that are used for the main platform components developed, starting from the finding reported into D1.2 and based on the work provided in D4.1.

3.2 Software Architecture

Starting from the initial architecture of the TREASURE Platform reported in D4.1, where the alpha version was introduced, this section depicts the detailed 2nd (stable) version of TREASURE Platform architecture.

The TREASURE Platform architecture can be divided into three sub-architectures, with the aim of providing categorized building blocks that exploit specific tasks at different levels of abstraction. The lower-level components are exploited by higher-level ones through a standardized interface that allows 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 is further expanded in the next chapters. In particular, for each specific component, a dedicated paragraph describes its purpose in the TREASURE Platform, the requirements covered and integration with the rest of the platform architecture.

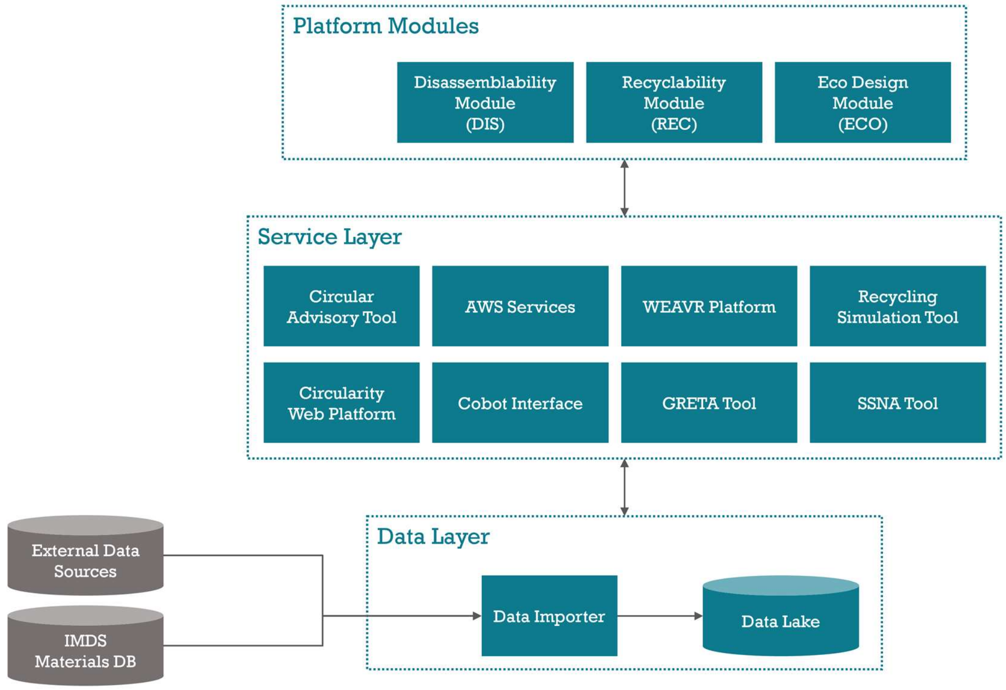

Figure 3.1 - Architecture of the TREASURE Platform

The first sub-architecture to be presented is the *Data Layer*, containing all the components that heavily leverages data flow and manipulation. In particular, the TREASURE Data Lake constitutes the centralized storage location where all the data relevant for the TREASURE Platform resides. The Data Importer component is 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 Circular Advisory Tool performs assistive predictions and KPI forecasting starting from the raw data collected.

The Data Layer components is 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, GRETA Tool and SSNA Tool provide suitable methodologies to support the decision process that takes place in the three upper modules, while the WEAVR platform supports operators in the physical procedures to be performed. The circularity Web Platform supports BoL actors in the decision-making process by providing a visual representation of critical KPIs and interactive dashboards. Finally, the Service Layer is 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. In particular:

- The Disassemblability module leverages the WEAVR platform for the physical dismantling procedures
- The Recyclability module focuses on recycling procedures and sustainability KPIs obtained through the use of GRETA Tool and Recycling Simulation Tool.
- The Eco-Design module exploits the SSNA Tool and GRETA Tool to serve BoL actors with proper knowledge generated by the Circular Advisory tool on top of the platform data provided by the TREASURE Data Lake.

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

At the current state of activities, a machine learning approach is not applicable in TREASURE given limited data availability due to confidentiality issues and fragmentation of the data sources. Since the collected intelligence isn't extensive enough to implement complex AI methods, the configuration of expert system has been selected because of its suitability and adaptability to project scope as discussed during the first project review. As stated by Russell and Norvig[3] in the overview of AI history expert systems are considered one of the first truly successful forms of artificial intelligence software because they provide knowledge more suited to making larger reasoning steps and to solve typically occurring cases in narrow areas of expertise. Thus, TREASURE platform relies on a knowledge-based expert system in the form of textual and graphic recommendations. These guidelines are provided to users depending on a specific set of KIPs defined within the WP3 and WP2 activities in accordance with the analysis performed by technical partners. This preliminary step determined the algorithm selection phase leveraging on a rule-based method leading to the design of the expert system used in TREASURE. An example of this application has been demonstrated during the first review and it is evident in the Disassemblability module: the first recommendation provided by the platform is the list of components to extract based on a prioritization scale concerning timing and cost metrics.

3.3 Disassemblability Module (DIS)

3.3.1 Purpose

The Disassemblability module (DIS) mainly address EoL actors, dismantlers, and shredders in particular. Car makers can 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 data sources, this module is 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,	WEAVR Platform, AWS Services

[3] Artificial Intelligence: A Modern Approach by Stuart Russell and Peter Norvig, c 1995 Prentice-Hall, Inc

		recyclers, …) based on predefined policies	
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 should provide suggestions to the disassembler about specific parts that can be disassembled	WEAVR Platform, Circular 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 should 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 must provide disassemblability instructions to the user in a simple way using graphical representation	WEAVR Platform
R_12	DISASSEMBLABILITY KPI VISUALIZATION	The platform could provide disassemblers with the proper KPI relevant to the part being disassembled	WEAVR Platform, GRETA Tool
R_13	DISASSEMBLABILITY FEEDBACK	The platform should allow disassemblers to provide feedback about a specific disassembly operation	WEAVR Platform
R_21	CAR/PART INFORMATION SHARING	The platform should allow car parts designers/car makers to upload information about cars and parts composition	Data Lake
R_22	CAR/PART INFORMATION UPDATE	The platform should 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 EoL operators/stakeholders (I.e., disassemblers, shredders/physical recycling operators and recyclers) as well as car parts designers/car makers to compare KPIs relevant to them	GRETA 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_32	DATA ENTRY PART/MODULE COMPOSITION	The platform must allow eco-designers to insert information about 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	The platform must be able to simulate the recycling of the (car) parts and calculate the recycling performance (recycling rates, energy recovery) of parts, materials, components etc. for different most suitable recycling flowsheet configurations	Recycling Simulation Tool
R_34	RECYCLING/RECOVERY RATES	The platform must be able to generate know-how/KPIs on recycling/recovery rates for all elements/compounds/materials included	Recycling Simulation Tool
R_35	DISASSEMBLY FOR OPTIMAL RECYCLING	The platform must be able to provide instructions to disassemblers for optimal disassembly depth/intensity for optimal recycling/recovery	Recycling Simulation Tool
R_39	COBOT DISASSEMBLY KPIS	The platform should allow dismantlers to assess disassemblability level 3 KPIs provided by the cobot interface	Cobot Interface

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.

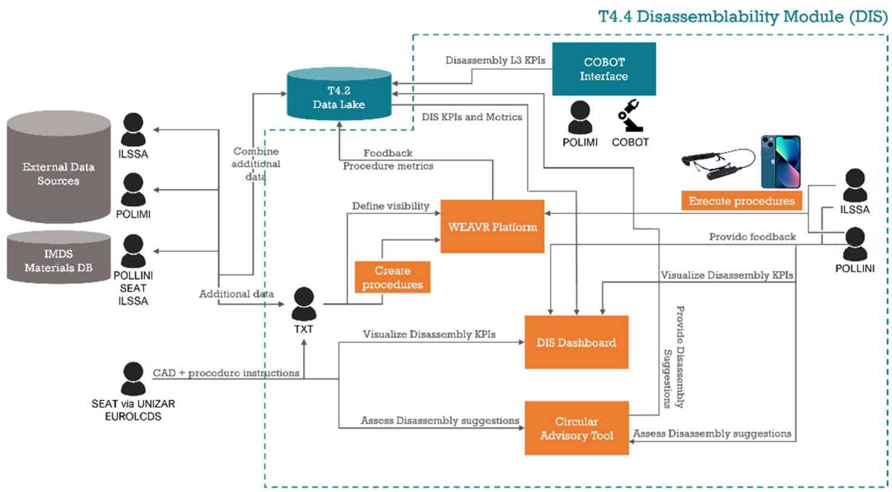

Figure 3.2 - Disassemblability module, technical architecture

The core of the disassemblability module is represented by the Disassembly Dashboard, managed by TXT. This portion of the Circularity Web Platform displays disassembly KPIs and metrics to the dismantling operators from POLLINI, ILSSA and can also be exploited by BOL actors such as SEAT. Through the dedicated form, the user is able to provide feedback concerning each specific step of the dismantling procedure. The feedback is then collected by the platform and inserted in the Data Lake for future usage. Additional information is then provided by the COBOT Interface provided by POLIMI. This component will record disassembly metrics regarding DIS Level 3 procedure (from component to sub-components) such as dismantling time and information on feasibility of extracting sub-components from the main one. Further relevant information accessible through the dedicated platform dashboard concerning the Circular Advisory Tool component (based on the advisory model provided by SUPSI in T2.2), which helps the decision-making process by offering disassembly insight regarding material composition and cost, thermodynamic rarity of car components and different disassembly routes to choose from. Dismantling operator can also take advantage of the WEAVR Platform provided by TXT, which offers the ability to execute AR/VR dismantling procedures that allows BoL operators to speed up the dismantling process, while gain precious knowledge on which material and components are worth keeping and which ones have to be discarded. During the entire execution of the procedure, various metrics are collected from the WEAVR Player. All of this information is then stored in the TREASURE Data Lake and serves as starting point for the Circular 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.

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 and designers. The Recyclability module is developed and applied within WP3 and is further refined and applied in WP5 and WP6 to compare existing processing flowsheets with the developed processes in this project for the different pilots.

The main outcome of the module are (i) KPIs on recycling/recovery (rates) (in % of mass) 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 are assessed in the recycling module),(ii) energy recovery during recycling, (iii) 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 (iv) feedback to disassembly in view of optimal disassembly depth for recycling optimisation and (v) recycling technology driven design for recycling guidelines derived on a quantitative basis from the recycling simulation models. Disassemblers/physical recyclers can also benefit from the module being informed about critical 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 also compares bio-hydrometallurgical processing with existing metallurgical infrastructures by not only assessing recycling/recovery rates, but also taking into consideration losses and exergy created, mass flows over the recycling system, required primary sources, etc hence providing a rigorous framework for selection of best available technology processing of disassembled cars parts and/or design of an optimal processing flowsheet (focusing on modular recycling).

In summary, the recycling module is 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 IMSEs are calculated by application of the recycling module. KPI's are generated to quantitatively assess recycling. Most optimal balance between disassembly depth and best suited recycling flowsheet architectures are determined and the Recycling Module i.e., underlaying simulation models provide a 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	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	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_8	PART SUGGESTIONS	The platform should provide suggestions to the disassembler and the recycler about specific parts that can be disassembled	Circular Advisory Tool
R_16	ELEMENT/MATERIAL SELECTION	The platform should provide knowhow on specific elements/materials to be recovered to recycling operators/recyclers (meaning final treatment processors such as metallurgical recycling processing and refining)	Recycling Simulation Tool
R_17	RECYCLABILITY INSTRUCTIONS VISUALIZATION	The platform must provide guidelines on best suited/most optimal recycling routes (including combination between disassembly and recycling processing) as a function of the objective of recycling optimisation based on quantified and visualised KPIs	Recycling Simulation Tool/Circularity Web Platform
R_18	RECYCLABILITY KPI VISUALIZATION	The platform must provide end-of-life stakeholders as well as designers and disassemblers with recycling KPI’s for the part/product assessed for both valuable/critical materials being recycled and all other materials/compounds included in the part/product	Recycling Simulation Tool, Circularity Web Platform
R_19	RECYCLABILITY FEEDBACK	The platform must provide feedback and insight to End-of-Life (EoL) operators/ stakeholders (including disassemblers) and designers concerning recovery rates of specific elements/compounds or materials (within the suite of all other materials/elements/compounds	Recycling Simulation Tool, Circularity Web Platform

		recovered and lost/emitted from the part)	
R_21	CAR/PART INFORMATION SHARING	The platform should allow car parts designers/car makers to upload information about cars and parts composition	Data Lake
R_22	CAR/PART INFORMATION UPDATE	The platform should 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 EoL operators/stakeholders (I.e., disassemblers, shredders/physical recycling operators and recyclers) as well as car parts designers/car makers to compare KPIs relevant to them	Recycling Simulation Tool, GRETA 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_32	DATA ENTRY PART/MODULE COMPOSITION	The platform must allow eco-designers to insert information about 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_35	DISASSEMBLY FOR OPTIMAL RECYCLING	Instructions to disassemblers for optimal disassembly depth/intensity for optimal recycling/recovery	Recycling Simulation Tool
R_38	RECYCLING FLOWSHEET INSTRUCTIONS	The platform must provide guidelines on best suited/most optimal recycling routes (including combination between disassembly and recycling processing) as a function of the objective of recycling optimisation	Recycling Simulation Tool

Table 3.2 - Recycling module, covered requirements

3.4.3 Platform Integration

The Recyclability module core contents are 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.

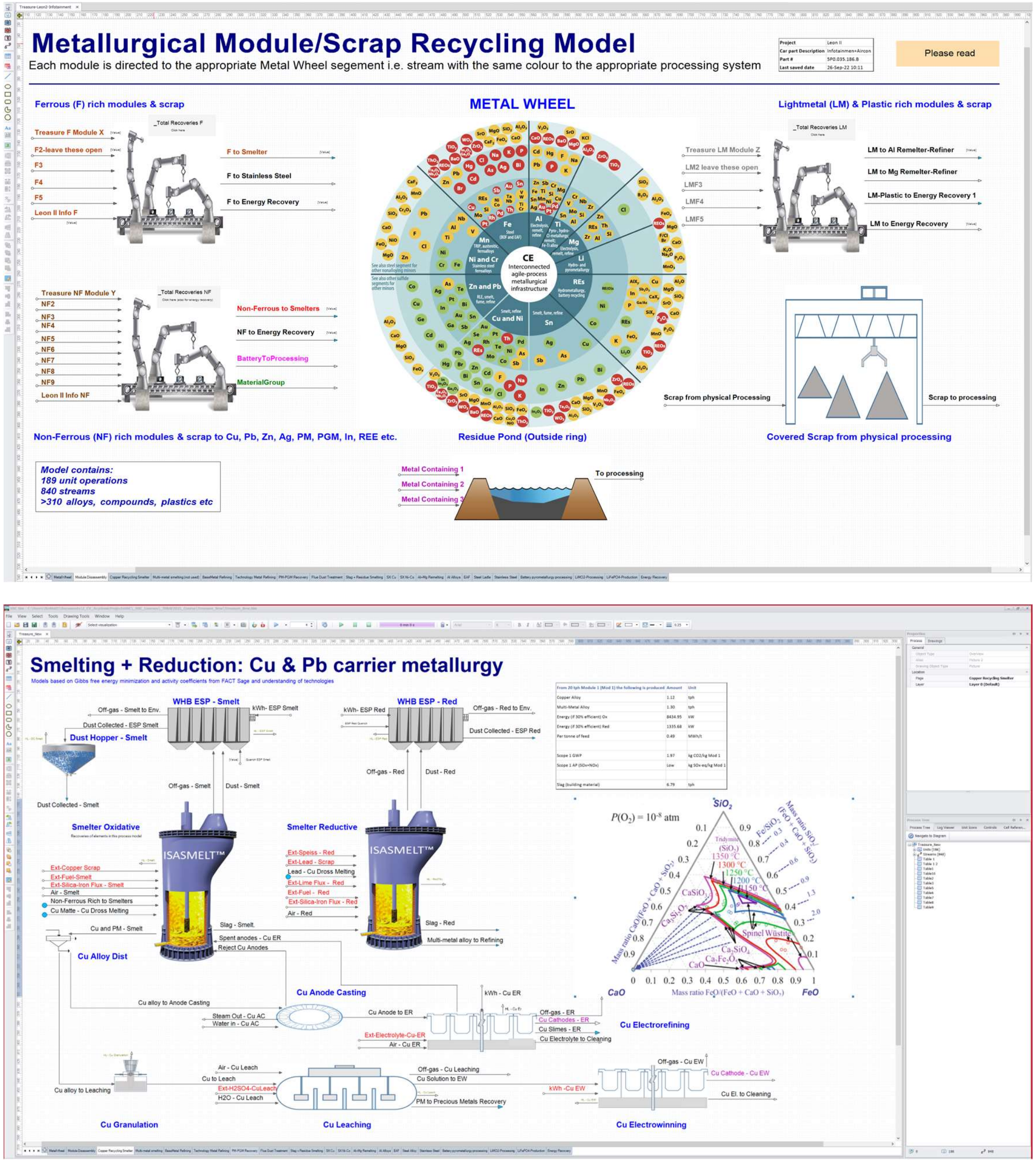

Figure 3 Recycling Simulation Tool example

In particular, once data is collected into the platform on detailed car parts compositional data (R_32), KPIs and the main recycling information (e.g., recycling/recovery rates, energy recovery, recycling routes to be followed for most optimal recycling,) is determined within the recycling simulation models.

The process simulation model has been developed in the industrial software platform HSC Chemistry Sim® 10 (www.mogroup.com), providing a professional and industrial platform for process simulation tools and recycling as well as environmental impact calculations (environmental impact calculations are not part of the Recycling Simulation Tool as explored and applied within TREASURE).

The assessment and underlying calculations as performed by the application of rigorous and physics-based process simulation model (Recycling Simulation Tool) 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. The starting point of the 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 as this quality is required to achieve true circularity.

The Figure 3.3 above is a visual summary of the simulation-based approach used to determine the recycling rate of the different car parts. It shows 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. Detailed flowsheets for each of the processing routes are underlying this approach. These flowsheets as included in the model for the recycling of car electronics cover the wide of range of industrial BAT (metallurgical) recycling infrastructures available and are based on industrial economically viable processing. The model contains almost 190 unit operations for the ca. 310 materials and compounds in the car parts and produced by the flowsheet as well as over 840 streams for all phases including metals, molten flows, aqueous, dust, slimes, slags, calcine etc.

All mass flows, recoveries and losses for all metals/materials and elements/compounds (both on physical as well as chemical level) are revealed from the Recycling Simulation Tool. This implies that the focus goes beyond only representing Critical Raw Materials (CRMs), 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 approach permits the rigorous evaluation of the recyclability of a product within the circular economy taking into account all materials/elements/compounds present in the part. Only selecting CRMs or any other metal/material under consideration, while ignoring all other materials/elements/compounds, will lead to erroneous results. In the model, all mass flows (kg or tonnes), recoveries and losses for metals/materials and elements/compounds (%) are calculated resulting in energy (kW), exergy (kW), and mass flows (tph). On this basis, KPI's on recycling/recovery for whole parts/product as well as for individual elements/materials and energy recovery are quantified. On this basis also calculation of mass and composition of all produced output flows of the recycling system, recovery and dispersion of all materials over product and other output flows, energy balances (demand and recovery), purity of produced recyclates and CE application level of all outputs is generated. The simulation-based recycling assessment therefore includes the assessment and quantification of produced by-products and their role and application in the Circular Economy.

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 select most optimal processing routes, optimise Design for Recycling and make decisions and recommendations for more in depth disassembly.

The platform leverages on the Recycling Dashboard to provide recyclers with valuable metrics for each car component, including material recycling routes for each optimization objective, material composition and individual recycling rates. The Recyclability module is therefore depicted in the figure below.

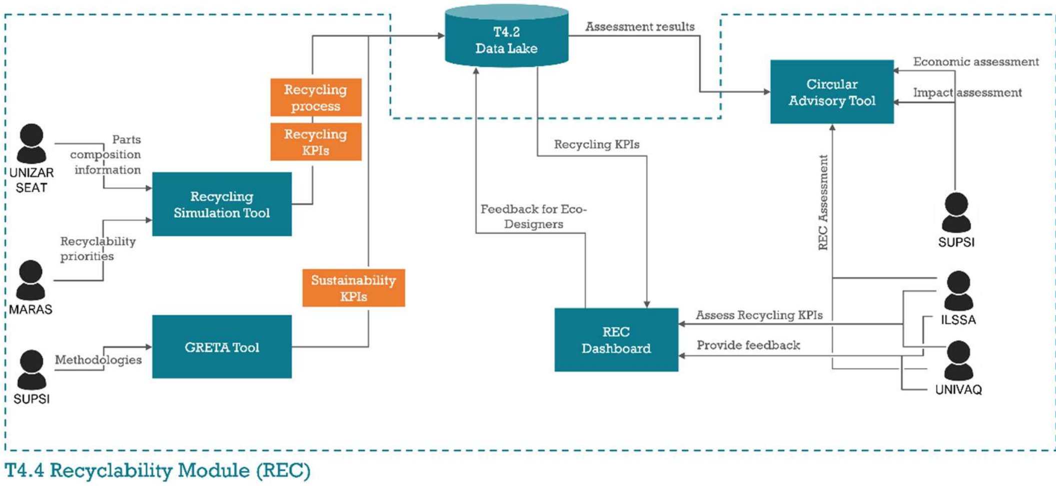

Figure 3.4 - Recyclability module, technical architecture

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 leverages dedicated sections of the Circularity Web Platform (the Eco-Design Dashboards), in which each BoL actor are 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 Eco-Design module (ECO). 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	The platform must allow eco-designers to insert information about 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	The platform must be able to simulate the recycling of the (car) parts and calculate the recycling performance (recycling rates, energy recovery) of parts, materials, components etc. for different most suitable recycling flowsheet configurations	Recycling Simulation Tool
R_36	DESIGN FOR RECYCLING	The platform must be able to provide 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 – Eco-Design module, covered requirements

3.5.3 Platform Integration

In case of the Eco-Design module, the platform mainly acts as a recommendation system providing feedbacks collected from the disassembly and recyclability modules. In particular, the suggestions collected from dismantling and recyclability assessments and feedback collected from the workers the dedicated REC and DIS dashboards of the Circularity Web Platform, are recorded and made available in a proper collaborative space of the platform, along with useful information on hardware components and sub-components, to identify critical car parts in a vehicle, and valuable recommendations for the design phase based are provided to BoL actors. The complete architecture for the Eco-Design module is shown in the figure below.

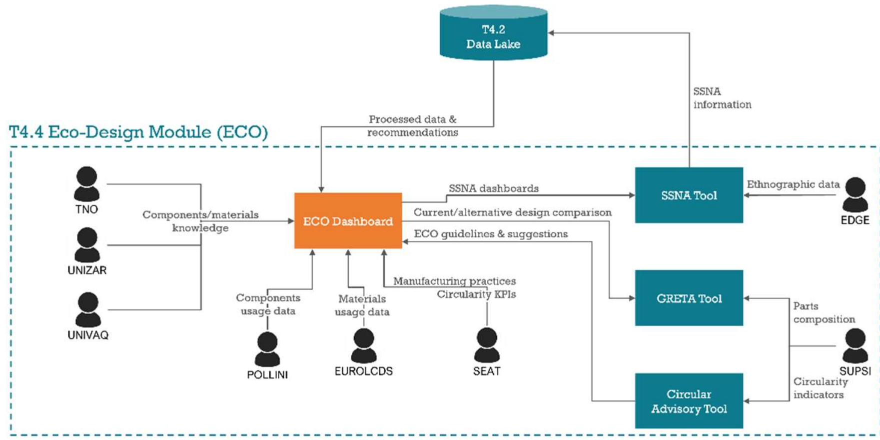

Figure 3.5 - Eco-Design module, technical architecture

At the core of the ECO module there is the Eco-Design Dashboard of Circularity Web Platform which provides BoL actors (mainly SEAT, EUROLCDS and POLLINI) with interactive analytics and KPI specifications that allow them to better understand the current production status and 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 ECO Dashboards also allows 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 therefore leverages the AWS Services middleware to provide each actor with the appropriate visualization tool (e.g., producers of individual components 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 a set of Eco-Design dashboards in the scope of the Circularity Web Platform. This is made possible by leveraging the Circular Advisory Tool for computing the appropriate KPIs based on the knowledge gathered from the TREASURE Data Lake, and in collaboration with GRETA Tool for the comparison of KPIs between the actual design and possible alternative ones. Concerning the integration of information about social impact of CE practices adoption, the SSNA Tool provided by EDGE is 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. A guidance handbook will also be provided to help eco designers understand how to perform semantic analyses and correctly interpret the results obtained.

3.6 Circularity Web Platform

3.6.1 Purpose

The objective of the Circularity Web Platform in the scope of the TREASURE Project it to support BoL and EoL actors in their decision-making process by providing each subject with a series of ad-hoc tools that aggregate prior knowledge gathered from the other modules in the platform and served in the form of interactive dashboards. The Web Platform targets users involved in all the three modules. In particular:

- Disassembly Module (DIS): allows EoL actors (car and component dismantlers) to access information about the material composition of car parts, as well as economic information, disassembly times, metrics and the ability to provide feedback for recyclers.
- Recycling Module (REC): allows BoL (OEMs/designers) and EoL actors to access or each selected component, recycling KPIs, such as total and individual material recycling rates for each optimization objective of the recycling including energy recovery rates. Recommendations on disassembly for recycling, recycling flowsheet configuration for optimal recycling (for different objectives) and DfR are part of the results of the REC module.
- Eco-Design Module (ECO): allows different BoL actors to access visualization tools relevant to material compositions (including metals and plastics) and their relevant KPIs, as well as eco design recommendations computed based on disassembly and recycling feedbacks and suggestions.

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 at their disposal are 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 are included allowing for a better understanding of the EoL requirements that contribute in speeding up the dismantling/recycling processes and, as such, contributing to the improvement of circularity throughout the entire component value chain.

3.6.2 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	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_12	DISASSEMBLABILITY KPI VISUALIZATION	The platform could provide disassemblers with the proper KPI relevant to the part being disassembled,	DIS
R_13	DISASSEMBLABILITY FEEDBACK	The platform should allow disassemblers to provide feedback about a specific disassembly operation	DIS

R_23	CAR/CAR-PART PART SEARCH	The platform must allow car parts designers/car makers to search for car parts	DIS/REC/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	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_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 could allow consumers to search for a specific car	DIS/REC/ECO
R_28	CONSUMER INDICATORS VISUALIZATION	The platform could allow customers to view CE indicators and graphical indexes reporting the circularity level of their cars	DIS/REC/ECO
R_29	KPI COMPARISON	The platform must allow EoL operators/stakeholders (I.e., disassemblers, shredders/physical recycling operators and recyclers) as well as car parts designers/car makers to compare KPIs relevant to them	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 3.7 – Circularity Web Platform, covered requirements

3.6.3 Existing background

The current status of the Circularity Web Platform is represented by the alpha release of the platform, which includes information for each of the three different modules and leveraging a set of dedicated dashboards. Each dashboard has been realized taking into account the needs of each specific actor involved. Here are presented the main parts of each module dashboard, for the combimeter component of the Seat Leon II.

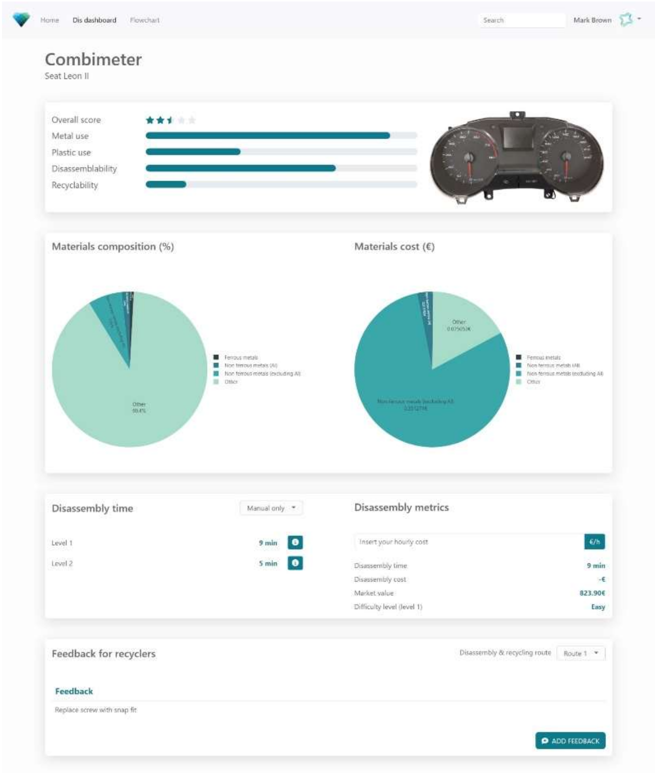

Figure 3.6 - DIS Dashboard for the combimeter component

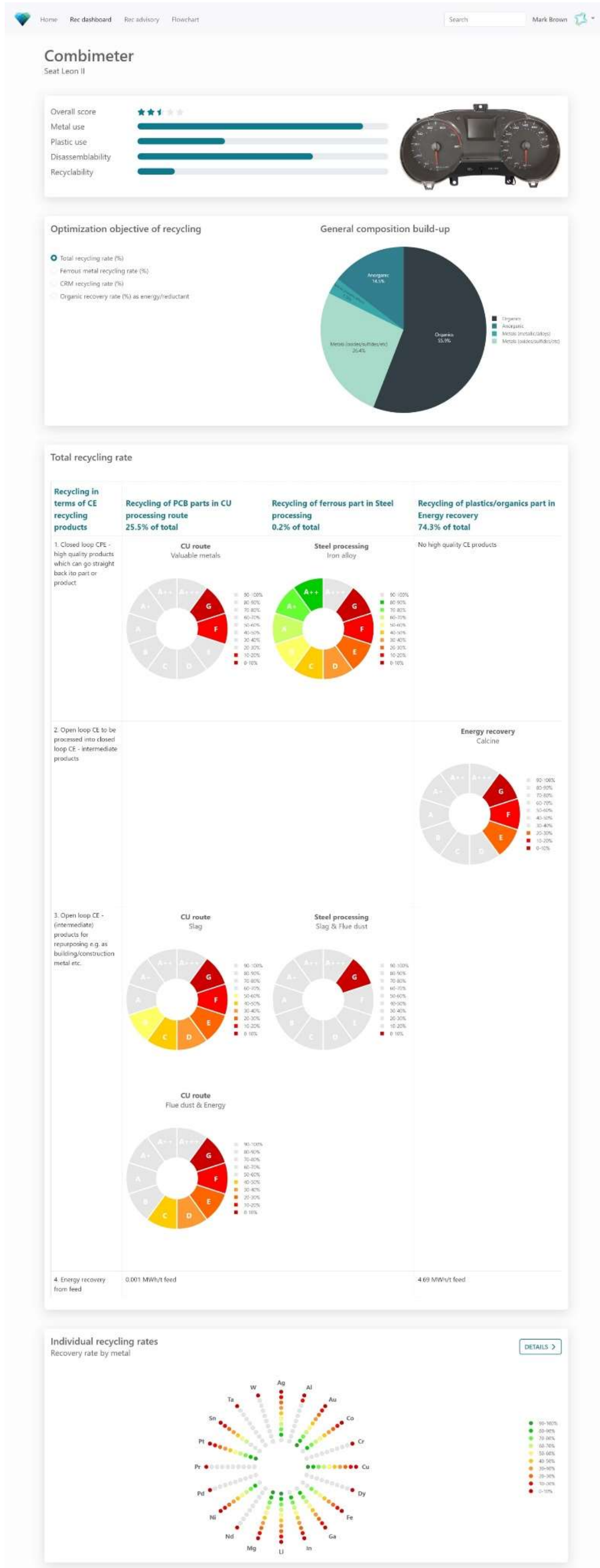

Figure 3.7 - REC dashboard for the combimeter component

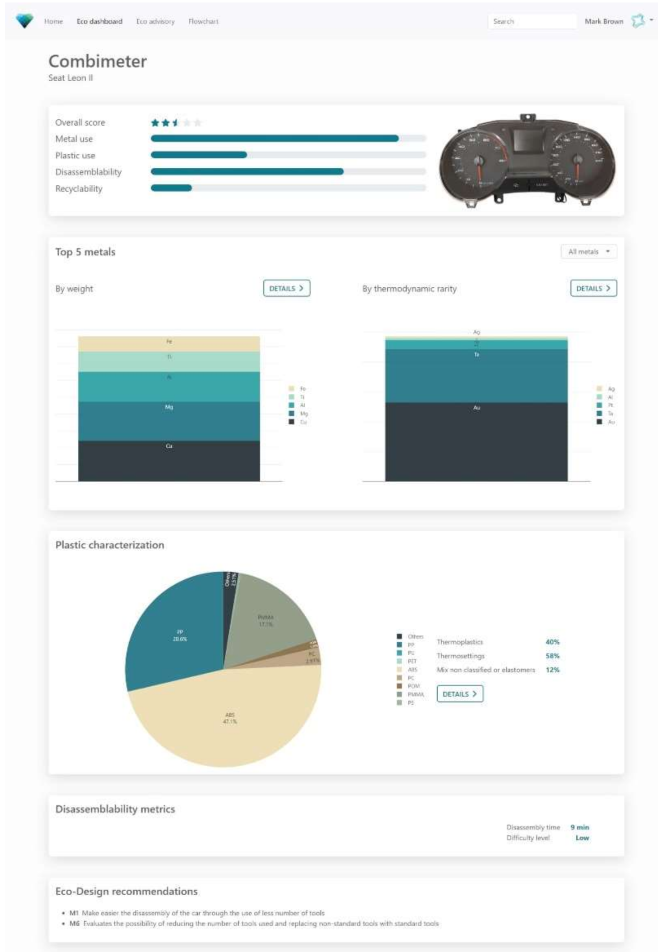

Figure 3.8 - ECO Dashboard for the combimeter component

Another objective achieved so far is the integration with the TREASURE Data Lake which allows the platform modules to ingest the relevant data from the centralized knowledge base of the project.

A significant result for the platform has been the integration activities aimed to include the Circular Advisory Tool, which now has a dedicated section in each module where the user can assess suggestions and recommendations. Below are presented the advisory dashboards for each platform module, relative to the combimeter component of the Seat Leon II:

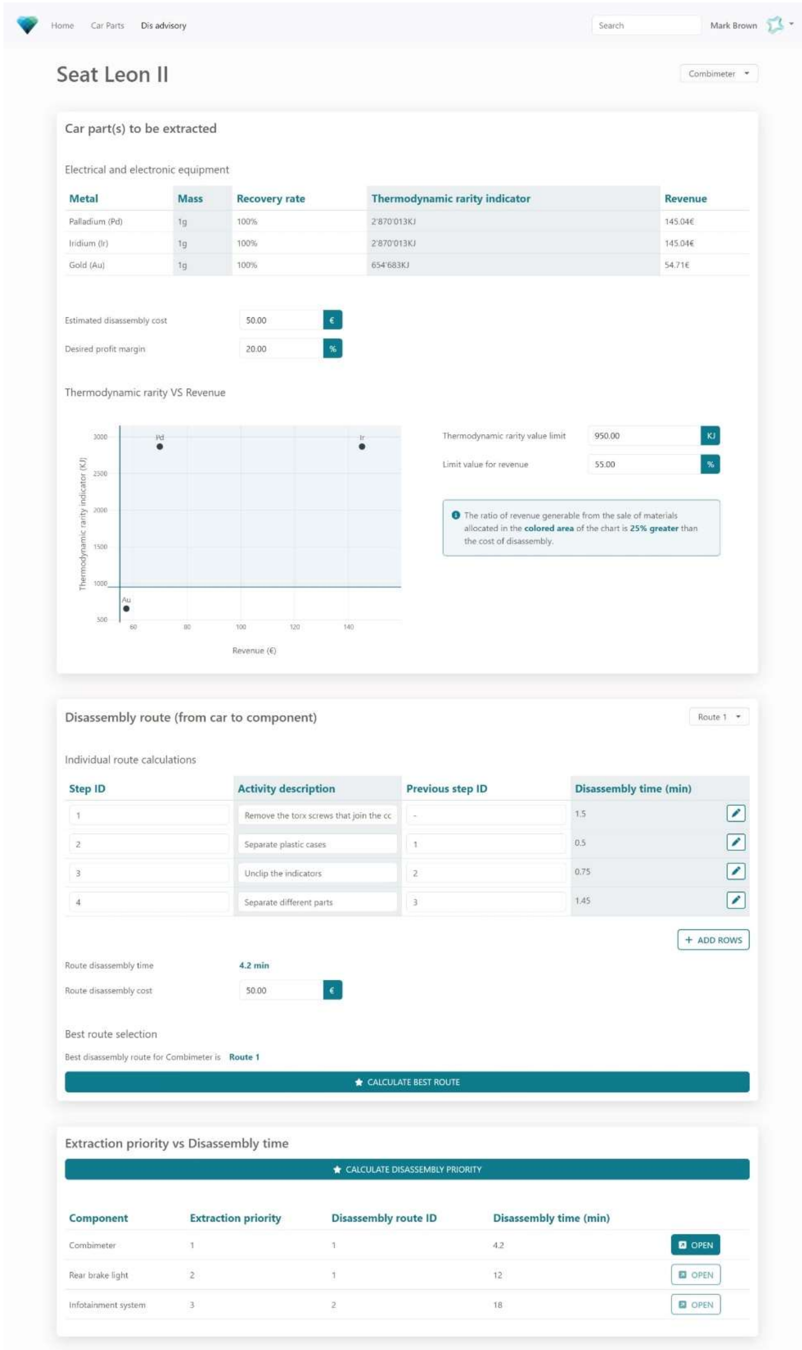

Figure 3.9 - DIS Advisory dashboard for the combimeter component

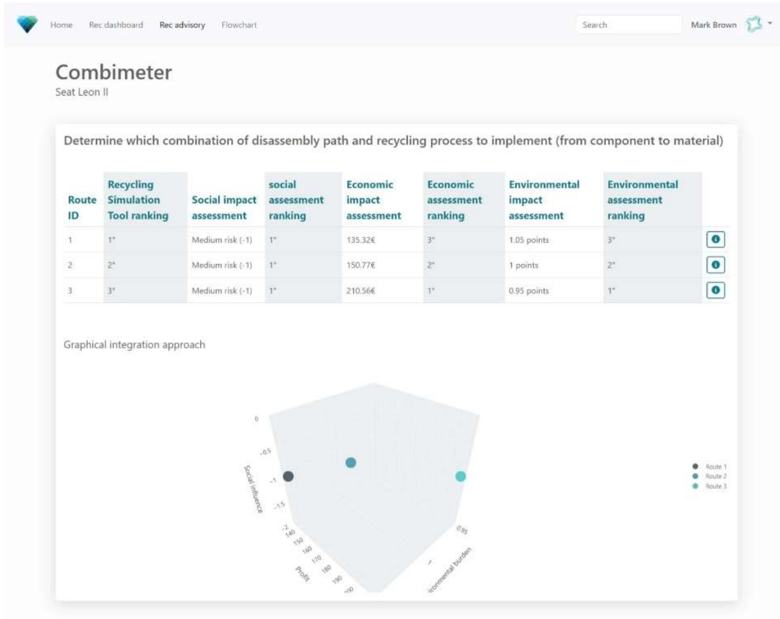

Figure 3.10 - REC Advisory dashboard for the combimeter component

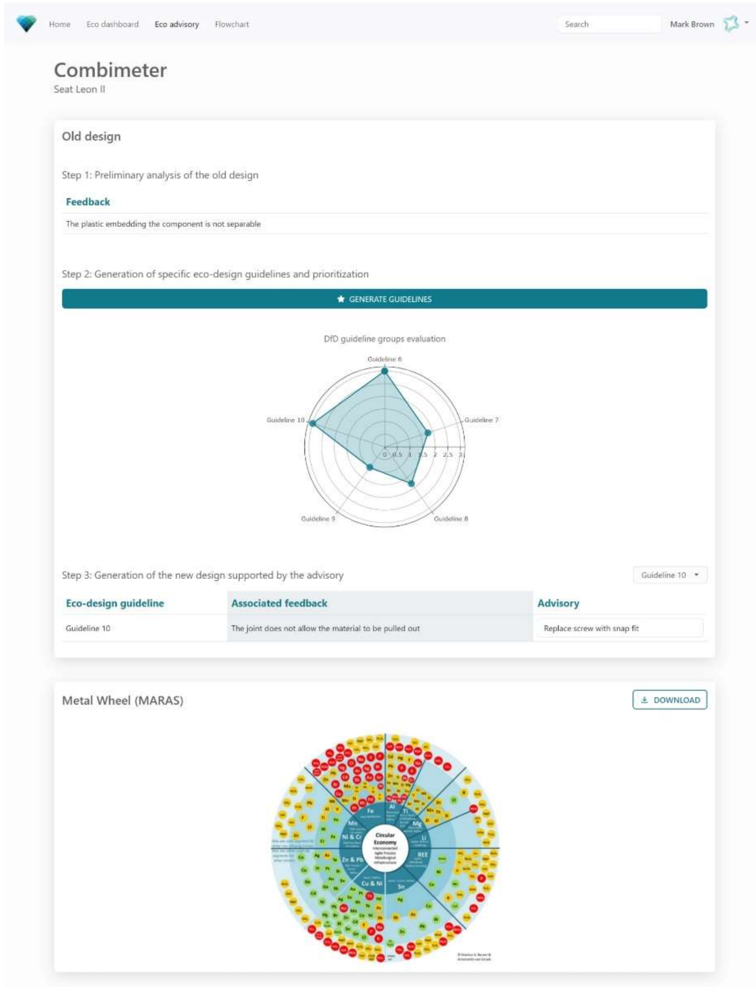

Figure 3.11 - ECO Advisory dashboard for the combimeter component

Another crucial integrations have also been realized including the one with the Recycling simulation tool, that now provides data to fill, among others, the Recyclability Dashboard with the relevant recycling objectives, KPIs and material compositions.

3.6.4 Major tasks

The future steps towards the completion of the Circularity Web Platform (in the form of the final release) are mainly focused on finalizing the open integration points with the following components (partners):

- SSNA Tool (in collaboration with EDGE): insert in the Eco-Design Dashboard the reference to the semantic analysis tool and adding the proper documentation to support eco designers.
- Cobot Tool (in collaboration with POLIMI): include level 3 disassemblability KPIs in the Disassemblability Dashboard.
- GRETA Tool (in collaboration with SUPSI): finalize the integration for the comparison between the current and alternative design in the Eco-Design Advisory dashboard.

3.6.5 Platform integration

The Circularity Web Platform component mainly interacts with the TREASURE Data Lake component, from which it will gather the data processed by the Circular Advisory Tool that is ready to be inserted in the dashboards. This interaction is 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 point occurs between the Circularity Web Platform and the SSNA Tool by including the user data gathered from EDGE 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.

3.7 Circular Advisory Tool

3.7.1 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 final version of the role and functionality of the Advisory is discussed and presented extensively in D2.2.

3.7.2 Covered requirements

In the table below are listed all the requirements covered by the Circular 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 should provide suggestions to the disassembler and	DIS/REC

		the recycler about specific parts that can be disassembled	
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 3.4 - Circular Advisory Tool, covered requirements

3.7.3 Major tasks

The Advisory is currently under development within the project based on use cases, based on the following topics:

- 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 GRETA Tool will be taken up by the advisory and transformed into suggestions.

More details about the final version of the Advisory will be discussed and presented extensively in D4.10.

3.8 WEAVR Platform

3.8.1 Purpose

The objective of the WEAVR platform is to simplify the disassembly operations performed respectively in the Disassemblability module (DIS), 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 gains 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 performs the following tasks:

- Speed up the task's execution time: by providing detailed and easy-to-follow steps that the operator carries 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 physical components/materials.
- Increase worker understanding of the component/part: by allowing the operator to access an interactive model of the component/part that is being disassembled, with the possibility to over impose augmented information on top of the real component (e.g., displaying a transparent model of the part to be disassembled highlighting internal modules/sub-parts).

The WEAVR Platform is exploited by dismantlers/disassembly operators in the Disassemblability module (DIS) and is further detailed in the following chapters. In particular, the next chapter provides an overview of the requirements covered by the WEAVR Platform, then a detailed description of the as-is infrastructure, finally the to-be scenario is presented specifying the aspects that composes the final version of the WEAVR Platform that is exploited by the TREASURE project.

3.8.2 Covered requirements

In the table below are listed all the requirements covered by the WEAVR platform, along with the specific modules in which the WEAVR 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	DIS
R_2	USER ACCESS CONTROL	The platform must enable users to access only the tools allowed by the group policy assigned to them	DIS
R_3	USER INSERTION	The platform must allow new users to be inserted, specifying a group policy for each one of them	DIS
R_4	USER REMOVAL	The platform must allow existing users to be removed	DIS
R_5	USER DATA MODIFICATION	The platform must enable modification of the data corresponding to each user	DIS
R_6	USER SECURITY	The platform must follow security guidelines for the user authentication procedures	DIS
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 should 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 should 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 must provide disassemblability instructions to the user in a simple way using graphical representation	DIS
R_20	PROCEDURES DOWNLOAD	The platform must allow dismantlers and disassembly operators to download procedures on their devices	DIS

Table 3.5 - 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_9, requirement R_12 and requirement R_13 are leveraged by the WEAVR Player in collaboration with the Circularity Web Platform, where the user can select the appropriate component to be disassembled, by looking at the available KPIs and component dismantling information.
- Requirements from R_10 to R_12 refer to the WEAVR Player, enabling the operator to select the desired dismantling procedure and execute it step-by-step in a virtual/augmented reality manner by means of a dedicated headset.
- Requirements R_13 refer to the integration between the WEAVR Player and the Circularity Web Platform, allowing the disassembler/dismantling operator to provide valuable feedback concerning the current dismantling procedure by means of the dedicated section of the Disassemblability Dashboard (DIS).
- 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.

3.8.3 Existing background

In this chapter it is presented an architectural overview of the different components of the WEAVR platform. The single components will be individually explained first, while their interaction with the rest of the TREASURE platform components in the Disassemblability Module (DIS) 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.

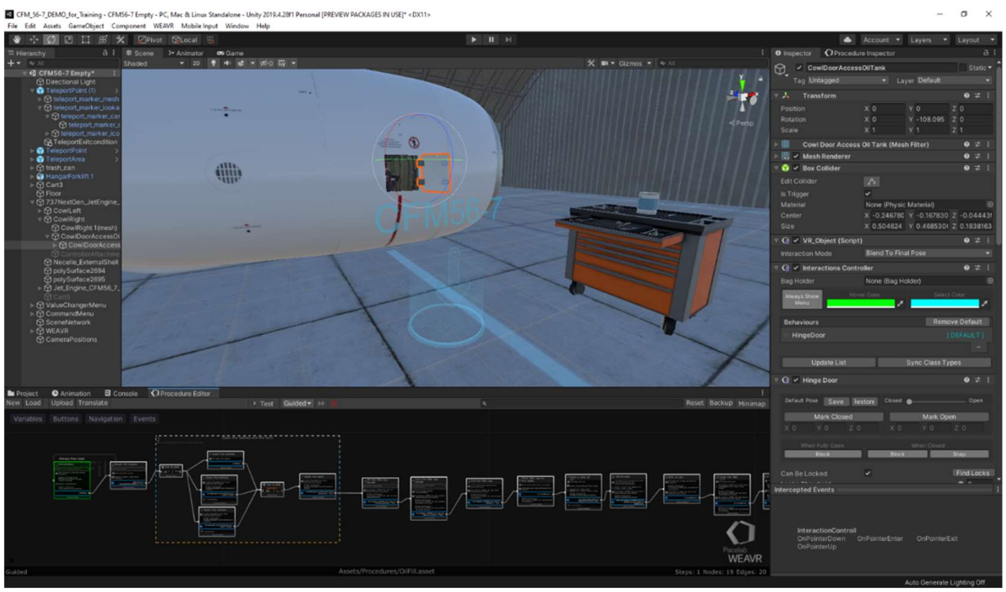

Figure 3.12 - WEAVR Creator, procedure development UI

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.

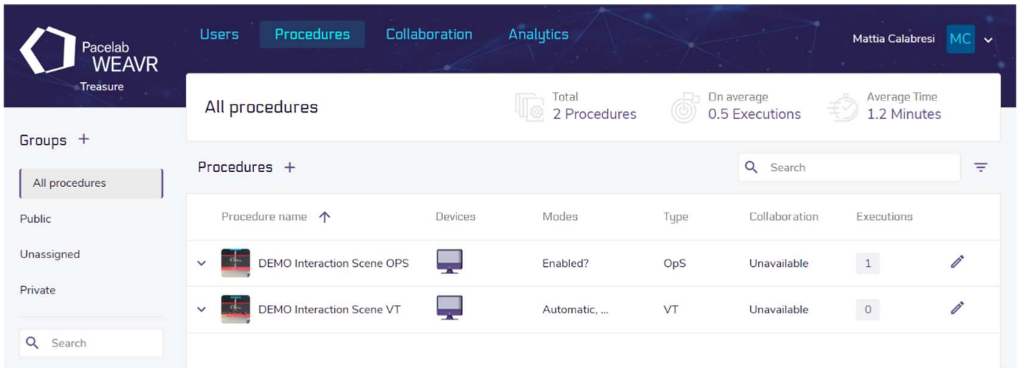

Figure 3.13 - WEAVR Manager, procedure management UI

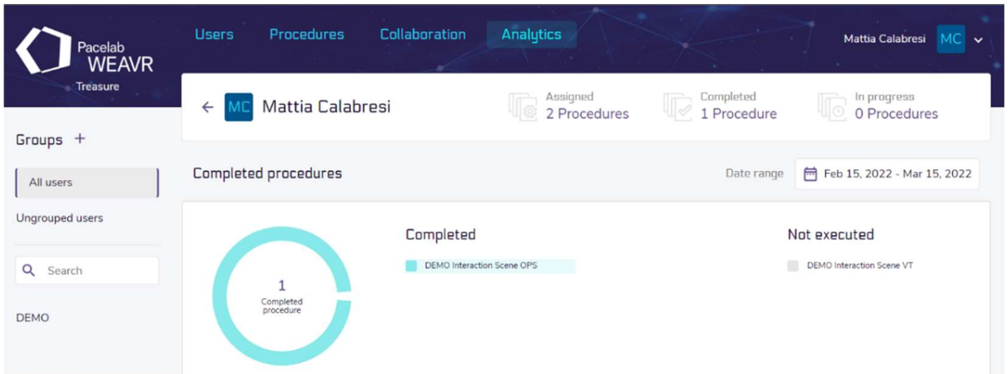

Figure 3.14 - WEAVR Manager, metrics visualization UI

- 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 3.15 - WEAVR Player, demo procedure

The activities concluded for the first iteration of the project mainly produced as a result the dismantling procedure for the combimeter component of the Seat Leon II. This procedure focuses on the disassembly of the component into sub-components (from disassembly level 1 to disassembly level 2). Below are reported a couple of extracts from the virtual procedure that the operator assesses through the AR/VR headset.

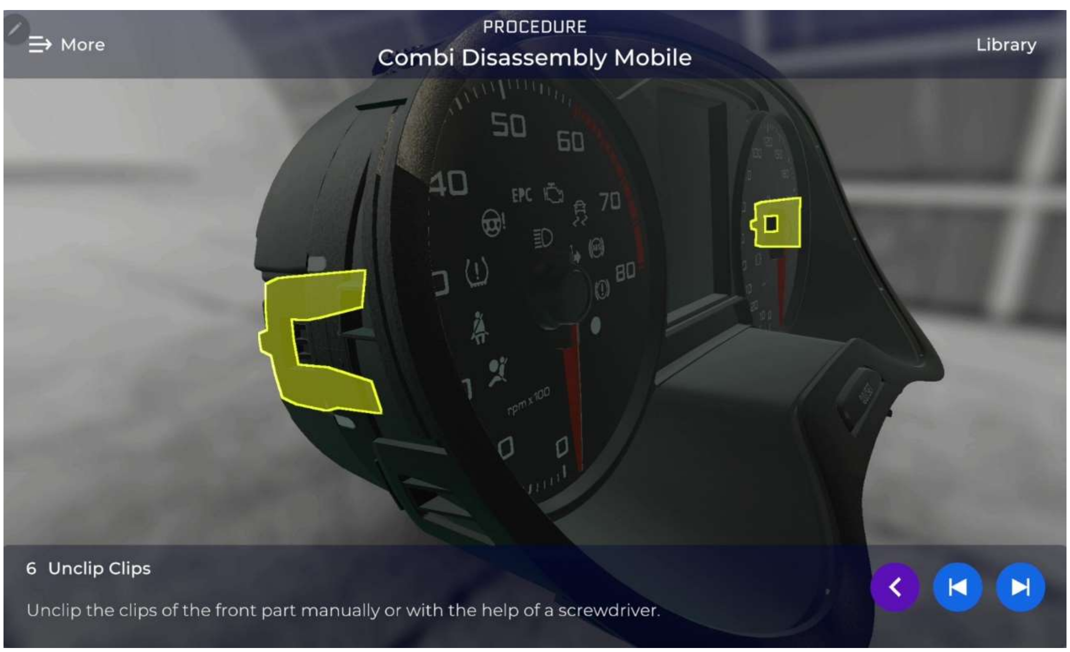

Figure 3.16 - Combimeter disassembly procedure, example step 6

Figure 3.17 - Combimeter disassembly procedure, example step 10

Another main point addressed for this first iteration has been the integration between the WEAVR Platform and the TREASURE Data Lake. This feature allows the platform to incorporate in the data lake the metrics associated to the procedures carried out by the operators. Those are being used for tasks monitoring and optimizations of the procedures.

3.8.4 Major tasks

The final steps planned for the WEAVR Platform aims to extend the pilot case of the combimeter to other car parts/components and create suitable AR/VR disassembly procedures for the rest of the involved components.

3.8.5 Platform integration

Each one of the WEAVR components integrates seamlessly with other parts of the TREASURE platform. Described below are the detailed activities that the different WEAVR components will perform in the scope of the TREASURE Project and, in particular, in the DIS module.

The WEAVR platform is integrated in the form of the Dismantling Dashboard (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).

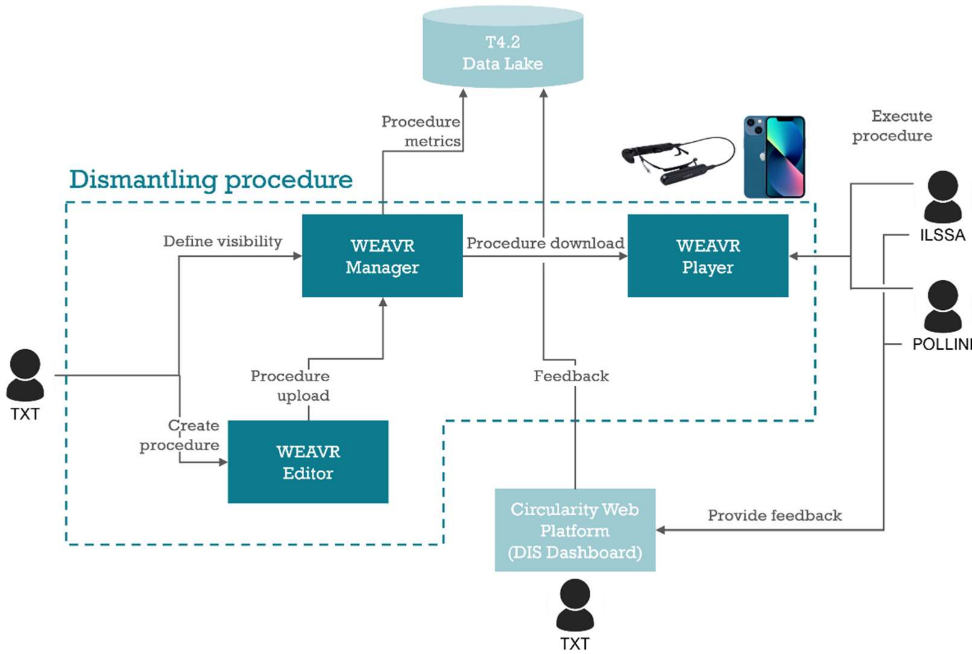

Figure 3.18 - The WEAVR Platform powering the Dismantling procedures

In particular, each component behaves as follows:

- The WEAVR Manager is 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 about a specific operation concerning a dismantling step; the collected feedback is taken in charge by the DIS Dashboard in the Circularity Web Platform 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 is 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 WEAVR Player is leveraged by the dismantling operators to perform disassemblability procedures. To do so, each operator authenticates using his/her device of choice to the Manager and will request the procedure to execute. The request is handled by the Player that downloads the procedure from the Manager component on the user's device. At any point in time during the execution of a step, the operator is able to provide feedback exploiting the corresponding function provided by the

Disassemblability Dashboard. This is then automatically handled and sent to the Manager for later use.

3.9 Recycling Simulation Tool

3.9.1 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[4,5,6,7,8,9,10,11,12]. These papers documented covers the development of simulation models that link product design, dismantling/disassembly, physical recycling, particulate quality, liberation, recyclate quality and metallurgical and other final treatment recycling processing infrastructures. The recycling process flowsheets are based on rigorous process physics and thermodynamics, integrated as functions in the model. 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.

The development and application of these Product Centric recycling process simulation tools generates the digital twins of the EoL circular economy. This permits the rigorous calculation of recycling KPIs such as Recycling Indices for the entire part (recycling rates for the total part/product), 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, 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.

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4 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.

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

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

7 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)

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

9 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.

10 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.

11 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.

12 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.

The recycling simulation models provide a rigorous and physics based back bone for true industry-based recycling assessment and forthcoming recycling system set up and DfR (Design for Recycling), design for modularity and disassembly recommendations.

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 are summarised for examples in papers by Reuter and Van Schaik[13,14].

The present prior art models have been adapted for the purpose of this project to link various product modules (e.g., car electronics, PCBs and IMSEs) 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 3.19.

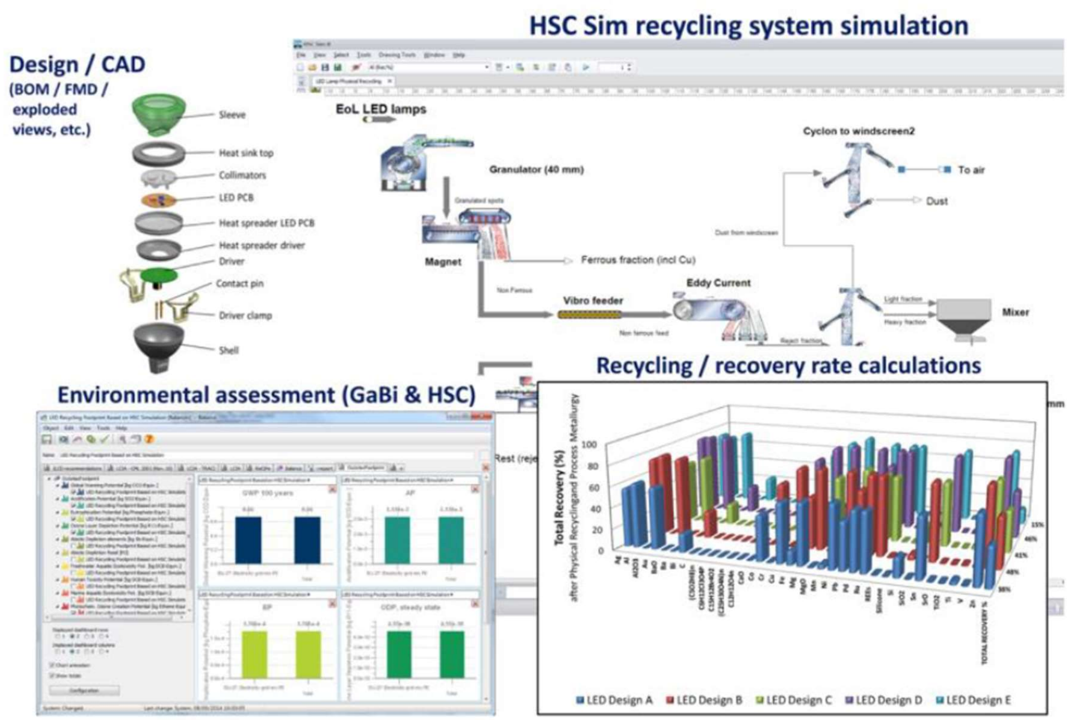


Figure 3.19 - Example of Recycling Simulation Tool analysis

3.9.2 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)

13 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

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

R_32	DATA ENTRY PART/MODULE COMPOSITION	The platform must allow eco-designers to insert information about 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	The platform must be able to simulate the recycling of the (car) parts and calculate the recycling performance (recycling rates, energy recovery) of parts, materials, components etc. for different most suitable recycling flowsheet configurations	DIS/REC/ECO
R_34	RECYCLING/RECOVERY RATES	The platform must be able to generate know-how on recycling/recovery rates for all elements/compounds/materials included	DIS/REC
R_35	DISASSEMBLY FOR OPTIMAL RECYCLING	The platform must be able to provide instructions to disassemblers for optimal disassembly depth/intensity for optimal recycling/recovery	DIS/REC
R_36	DESIGN FOR RECYCLING	The platform must be able to provide 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	ECO
R_38	RECYCLING FLOWSHEET INSTRUCTIONS	The platform must provide guidelines on best suited/most optimal recycling routes (including combination between disassembly and recycling processing) as a function of the objective of recycling optimisation	REC

Table 3.6 - Recycling Simulation Tool, covered requirements

3.9.3 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 (not done in the Recycling Simulation Models as applied in TREASURE).

Using these approaches, surrogate functions in AI have been used to link product design to recycling rate calculations for automotive recycling [2]. This approach can be followed in the TREASURE platform (see 3.9.5) (not included in the task of MARAS).

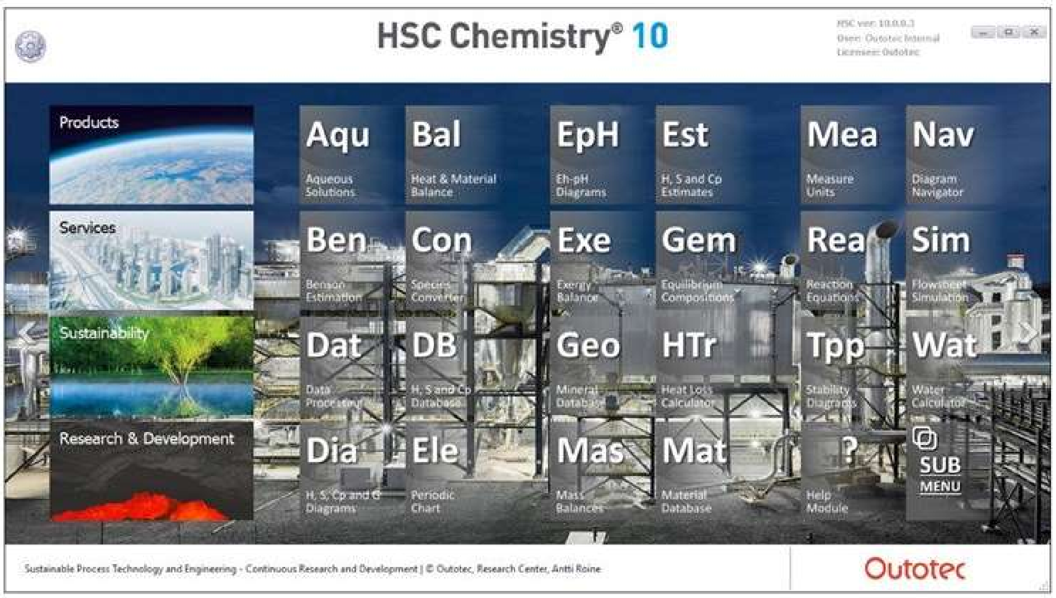


Figure 3.20 - HSC Chemistry/Sim 10

3.9.4 Major tasks

The recycling simulation model are modified, expanded and applied for the modules (car parts and electronics/IMSEs) and their compositional build-up as included in this project. The recycling assessment has been performed for the different disassembled cars parts as well as to assess and quantify the recycling/recovery of all materials/elements/compounds included in the IMSEs (and conventional parts) and PCBs. Recycling KPIs have been calculated. The most optimal recycling flowsheet architecture together with the optimal disassembly depth is advised based on a wide range of simulations for different disassembly levels and processing options for the disassembled parts and sub-parts. For the IMSEs both recycling/recovery rates have been determined, as well as the assessment of the hydro-pilot by comparison with existing metallurgical recycling processing options to provide insight into the best recycling options for IMSEs and achievable recycling/recovery rates, quality of the recovered metals/materials, use of primary resources, as well as the assessment and quantification of produced by-products and their role and application in the Circular Economy 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 KPIs for the entire product/part as well as for all composing materials/elements/compounds as developed by MARAS [15]

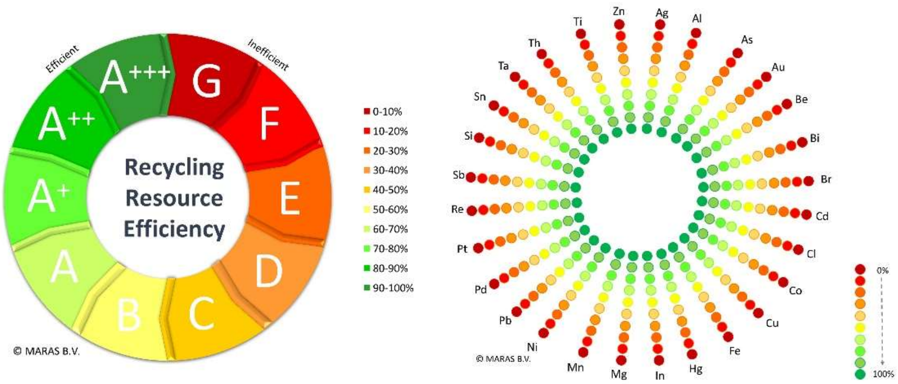


Figure 3.21 - Recycling Index and Recycling Material Flower

3.9.5 Platform integration

A backend integration has been performed, allowing the eco design processed information to be included in the Circularity Web Platform ECO Module. The output of the GRETA Tool will be used to create valuable knowledge and KPIs in addition to recycling KPIs as calculated in the Recycling Simulation models, 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.

3.10 Cobot Interface

3.10.1 Purpose

The objective of the cobot integration is to simplify the disassembly activities performed respectively in the Disassemblability module (DIS) by providing disassembly level 3 KPIs and information (from component to sub-components).

The cobot integration in the Circularity Web Platform will be used specifically to improve the Disassemblability module (DIS). While the Recyclability module (REC) and the Eco-Design module (ECO) collect all the useful feedback the DIS module, i.e., disassembly times of valuable components 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 Circularity Web Platform, finally how the said architecture is included in the complete platform that is exploited by the TREASURE project.

The cobot used will be the Universal Robot UR5e. 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 20,6 kg UR5e 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-

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

axis of freedom and a reach of 850 mm to move a payload up to 5 kg. The bottom part of it takes up a circle with 149 mm so it can be easily mounted on every working site. The cobot will be integrated with a gripper with servo, custom tool-holders and also a vision being realized by an external camera.

For programming on site Universal Robots provides the Periscope program, which is a graphical programming interface using drag-and-drop options for coordinating the movement of the robot on the TeachPendant (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 ROS. This is an ecosystem in which the cobot can be digitally imported and all the possible movements can be virtually tried out, in addition is possible to carry out research activities. 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.

3.10.2 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_39	COBOT DISASSEMBLY KPIS	The platform should allow dismantlers to assess disassemblability level 3 KPIs provided by the cobot interface	DIS

Table 3.9 - Cobot Interface, covered requirements

A detailed description of the integration plan can be found in the next chapter, 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.

- R_39 specifically refers to the ability of the cobot to register disassemblability metrics during the dismantling of a car component into sub-components (disassembly level 3) and report this metrics to the user through a dedicated section of the Circularity Web Platform.

3.10.3 Existing background

Numerous steps forward were taken during the project with regard to the application of the cobot in electronics disassembly tasks. a GUI was developed that would allow the operator to guide the cobot to the desired points in a 'teaching' action to make the cobot and human operator interact. The GUI, in Figure 3.17, provides a user-friendly way of interfacing with the operator and allows learned operations to be saved for future repetition.

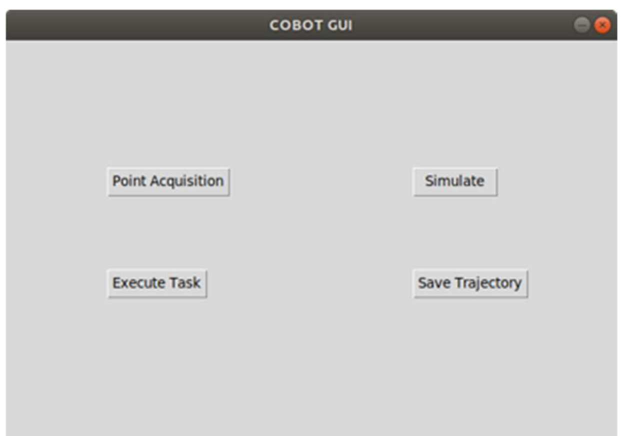


Figure 3.17 - Cobot GUI

In addition, computer vision software was developed during the project to identify the presence of SMDs on the PCB and guide the robot to their location. The software was continuously updated to make it more accurate and reliable. In Figure 3.18 are reported the first version and the last version developed. The focus of the algorithm is to isolate the components from the board and draw bounding boxes so that they can be identified. Unfortunately, however, this approach does not make it possible to identify the type of components, but only to isolate them from the board. For this reason, further solutions were developed which, once the components were isolated, would be able to provide some information on the type. Unfortunately, this, relying solely on computer vision techniques, is very complex and above all prone to errors. For this reason, it was decided to use this solution under the supervision of a human operator so that the algorithm cuts out a substantial part of the work and speeds up the identification procedures considerably.

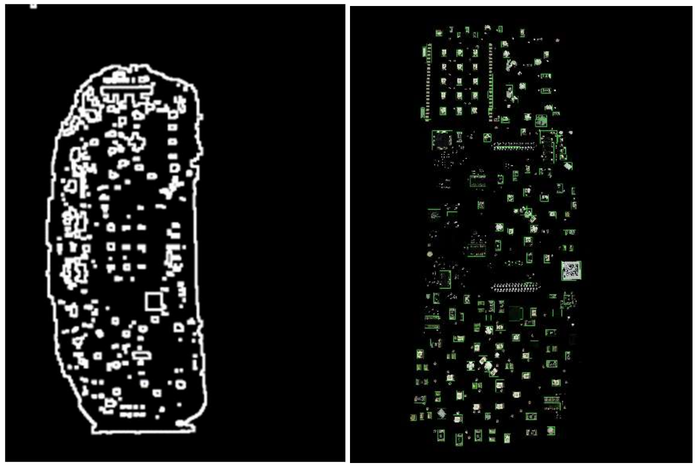


Figure 3.18 - On left side the first version of the algorithm, on the right side the last version of the algorithm

During these developments, it became clear that it was necessary to make the most of the new technologies available in order to correctly solve the problem of identifying PCB components. For this reason, AI solutions capable of providing support were explored, and an ad-hoc AI was developed which, in conjunction with a computer vision algorithm, allows certain components on the board deemed important from a recycling point of view to be correctly identified. The AI solution was designed to tag the integrated circuits on the boards so that they could be identified and then disassembled by the cobot. the well-known YOLOv5 algorithm was used for the implementation, which was trained on a public dataset of integrated circuits using the transfer learning technique. The model was then used to identify the components on the boards of the TREASURE project. Figure 3.19 shows the results of the algorithm.

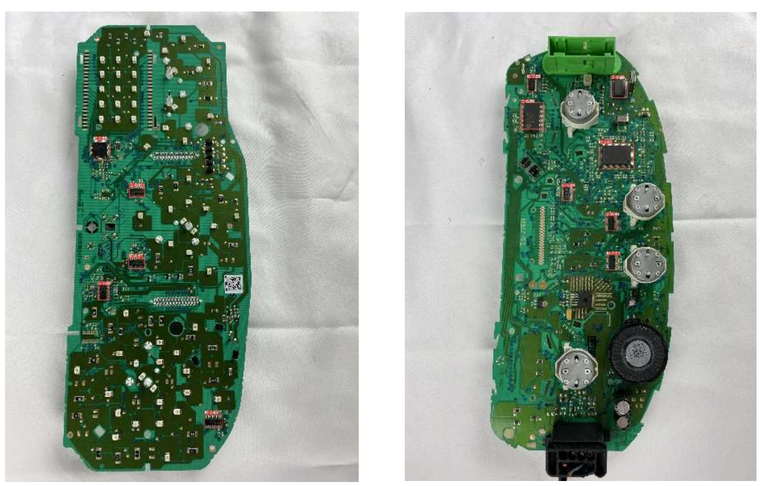


Figure 3.19 - Results of the AI model on two different combi-instrument boards

3.10.4 Major tasks

Although what was developed during the project is not the optimal solution for disassembling PCBs, it still provides excellent tools to support the operator and opens the way to new avenues of research. In the final months of the project, efforts will be made to push the limits of the project even further by attempting to obtain models capable of classifying a larger number of different components.

The developed procedures will also be tested in reality through operator training activities. During these activities the operator, after proper basic training on the subject of cobots, will test the described procedures in practice. In fact, the computer vision algorithm will be exploited to guide the cobot assisted by the operator in the removal of tantalum capacitors, a particularly relevant component in terms of raw material content. The operator will also test the model that will support him in the disassembly of integrated circuits. All these activities will be carried out with careful monitoring of the execution time, which will eventually be saved on the platform as further disassembly levels. In this way, the platform will be populated with additional information regarding the disassembly times of the boards, providing a greater level of detail.

3.10.5 Platform integration

In the Disassemblability module (DIS), the cobot integration is still in progress. Considered the two alternatives well explained in the above 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 3.19.

3.11 GRETA (GREen TArgets) Tool

3.11.1 Purpose

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

GRETA is intended to be the sustainability engine on which the Advisory bases its sustainability-related suggestions. The advisory suggestions address 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 is elaborated by an algorithm based on the sustainability advisory model developed in TREASURE T2.2 to provide specific/dedicated advisory functionalities for dismantlers, recyclers and designers.

3.11.2 Covered requirements

The requirements that GRETA fulfils, with respect to section 2.1 “System Requirements”, are listed in the table below, along with the specific modules in which GRETA 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 could provide disassemblers with the proper KPI relevant to the part being disassembled	DIS
R_18	RECYCLABILITY KPI VISUALIZATION	The platform must provide end-of-life stakeholders as well as designers and disassemblers with recycling KPI's for the part/product assessed for both valuable/critical materials being recycled, and all other materials/compounds included in the part/product	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 EoL operators/stakeholders (I.e., disassemblers, shredders/physical recycling operators and recyclers) as well as car parts designers/car makers to compare KPIs relevant to them	DIS/REC/ECO

Table 3.10 - GRETA Tool, covered requirements

3.11.3 Existing background

GRETA tool 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 3.22below, 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 3.22 - 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 3.23 reports an example of the possible LCI data concerning a generic process P_i.

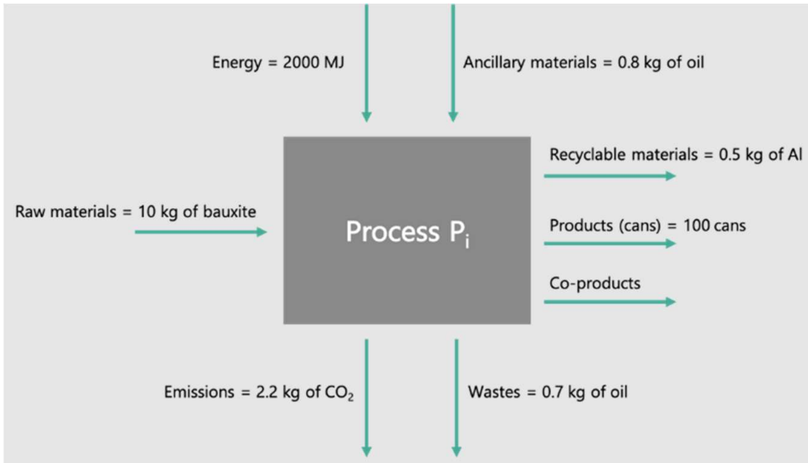


Figure 3.23 - Example of the LCI Data concerning a generic process Pi

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.

Main functionalities

For each PT (Process Template), default LCI Data and the related environmental impacts (LCIA Data) are obtained using the Ecoinvent[16] 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 3.24 reports the LCI Data concerning the milling operation that is removing a functional unit of 1 kg of steel (see Figure 3.25), while the related impact on Climate Change category is about 3.33 eq. kg CO2, as shown in Figure 3.26.

16 https://ecoinvent.org

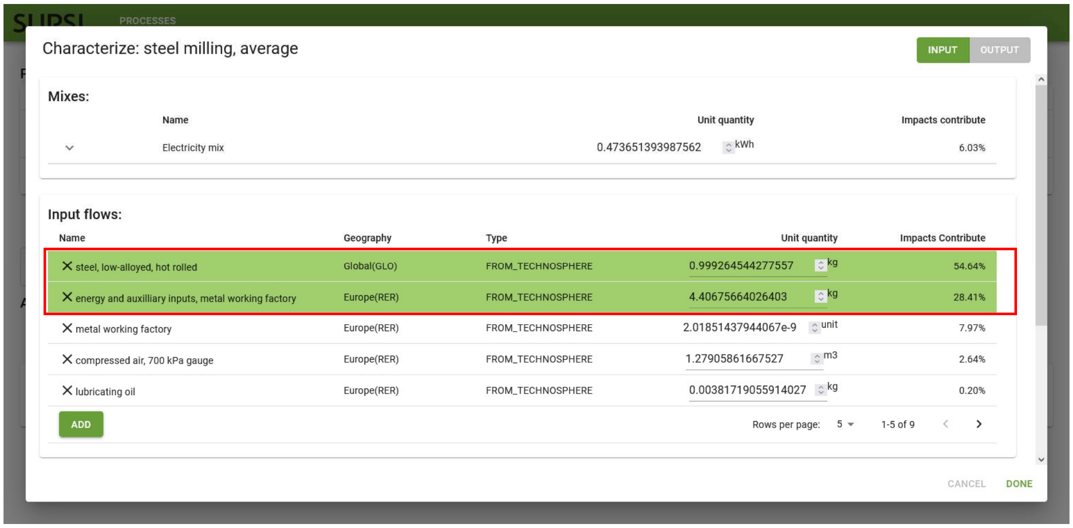


Figure 3.24 - LCI Data and LCIA Data from DB for a steel milling process – input flows

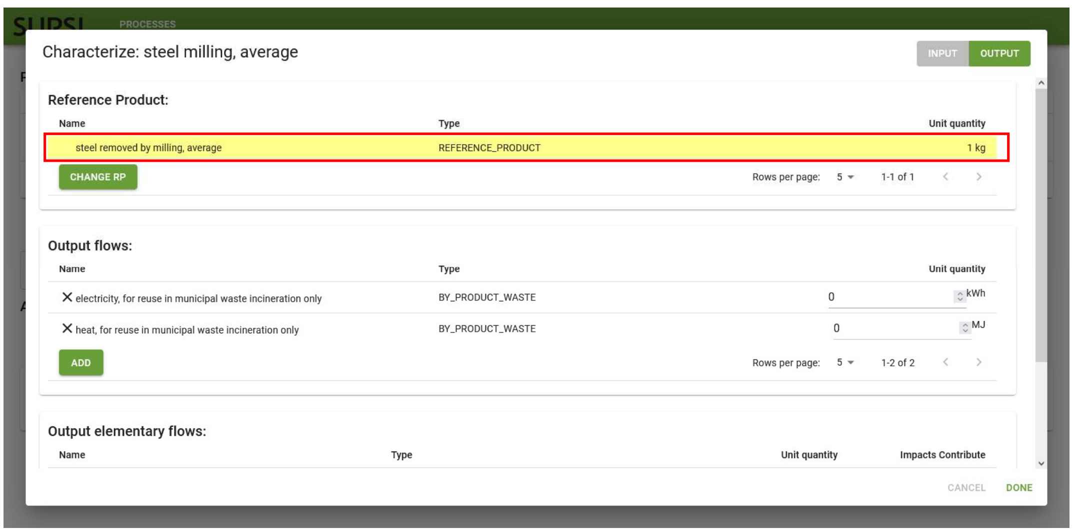
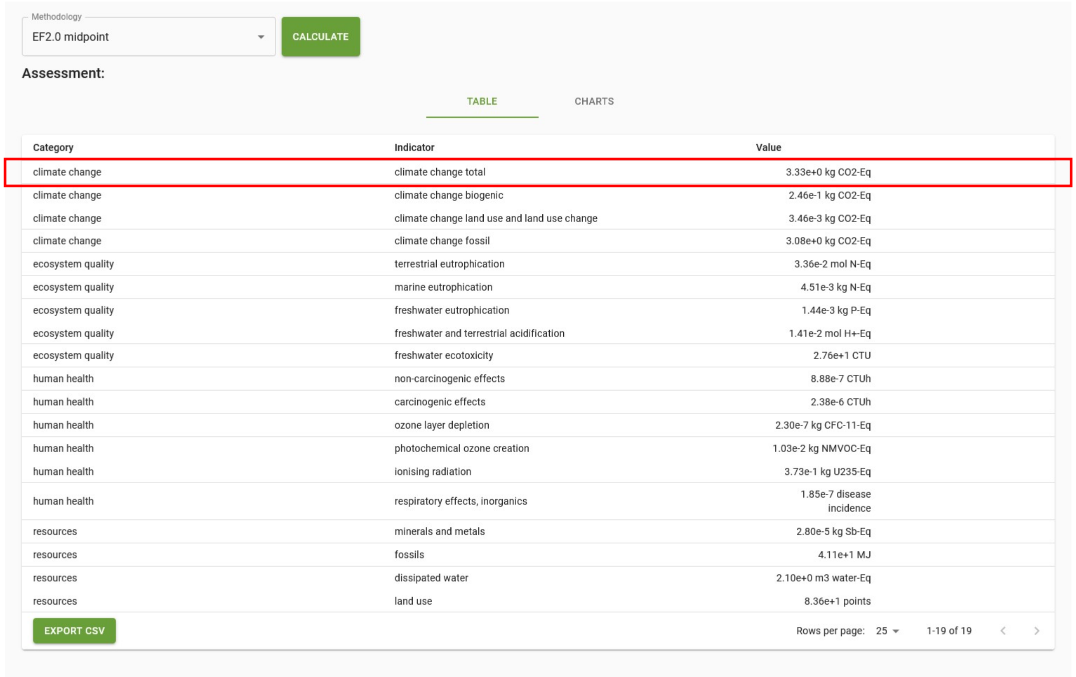


Figure 3.25 - LCI Data and LCIA Data from DB for a steel milling process – output flows

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 3.26).



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

Figure 3.26 - 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 3.27, 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 3.28).

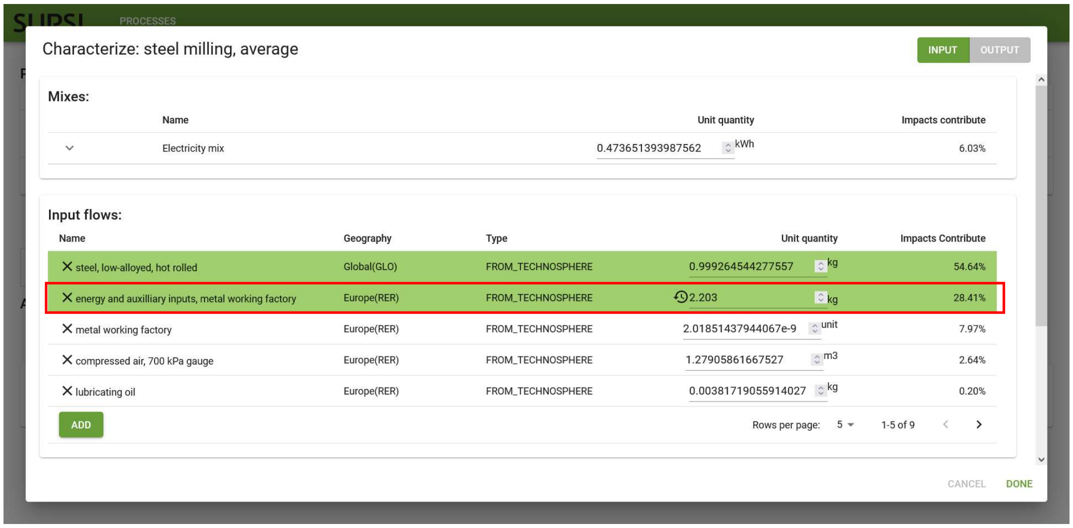


Figure 3.27 - LCI Data and LCIA Data from DB for a steel milling process – customized output flows

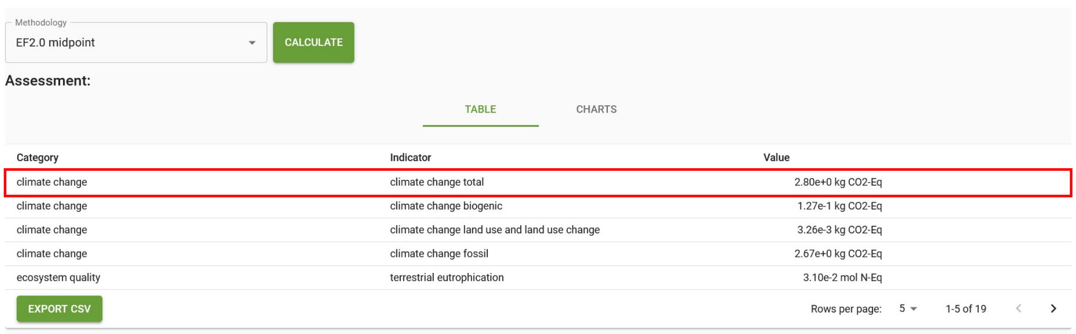


Figure 3.28 - Impacts calculated through EF2.0 midpoint methodology – customized process

<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 3.28):

- ***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 3.29. 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 3.30).

Figure 3.29 - Chart functionality – filtering by group or process

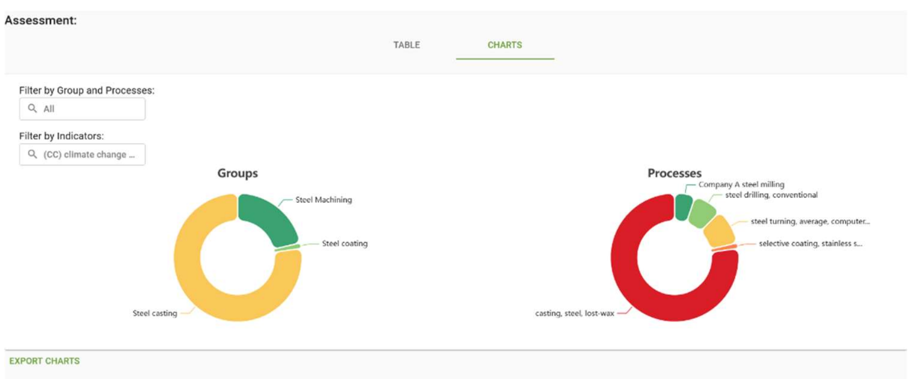


Figure 3.30 - Chart functionality – filtering by indicators

3.11.4 Major tasks

GRETA is a web, microservices-based application, developed by SUPSI during several research projects, designed for assessing the sustainability and circularity performances of products and processes in manufacturing contexts. The current version of the software is designed and developed to facilitate the preparation of evaluations but needs some adjustments and further improvements to address the TREASURE project requirements that are currently under development. In relation to the objective of the TREASURE project, the GRETA version provided will allow to:

i) Import BOM data, allowing an automated information gathering from standard format files (such as PDX).
ii) Import processes modelled by means of OpenLCA, enabling unique and faster modelling (e.g., leveraging the HSC SIM modelling tool).
iii) Execute the LCA, LCC, SLCA assessments, allowing TREASURE platform to exploit the assessment functionalities (see Figure 3.31)

iv) Compare different scenarios, exploring the potential impacts of different product design alternatives (e.g., in-mold vs PCB technology in components) and enabling decision-makers to make data-driven decisions (see Figure 3.32).

v) Provide a set of REST API, allowing the integration with TREASURE platform, as discussed in next sub-section.

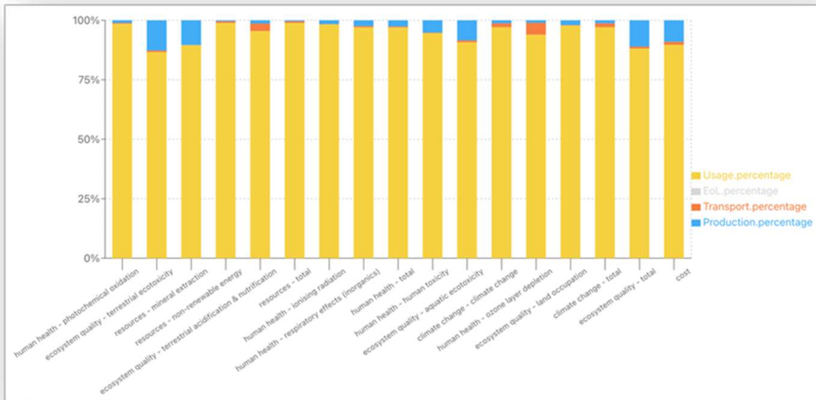


Figure 3.31 - Results examples of LCA and LCC assessments

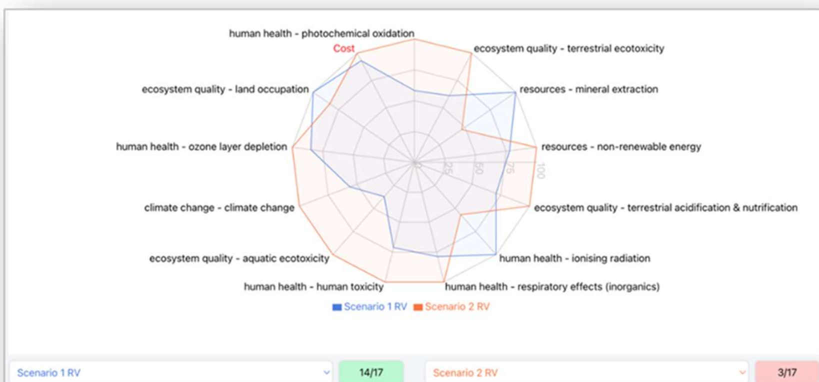


Figure 3.32 - RADAR chart for scenario comparison

3.11.5 Platform integration

At architectural point of view, the integration of GRETA is quite simple: GRETA 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 Advisory (DIS Adv)**, the user is advised on whether it is worthy to disassembly a car (electronic) part from an ELV. The criteria upon which the suggestion is made are physically and cost based. As discussed in D2.2, the car parts are ranked according to their thermodynamic rarity content and the profit margin one can theoretically earn from reselling recycled raw materials. Thus, GRETA is not exploited in this advisory module.

Concerning the **Recyclability Advisory (REC Adv)**, GRETA is adopted to perform economic and social assessments of the disassembly and recycling routes simulated by the Recycling Simulation Tool. As described in §3.9, the Recycling Simulation Tool provides the recycling rates for the analysed car part according to the objective set for the simulation and at the level of compounds.

The Recycling Simulation Tool is linked to OpenLCA to provide, besides circularity performance, also the environmental impacts of EoL phase processes. Given the set of best performing routes in terms of circularity and environmental sustainability, GRETA provides the economic and social impacts of the routes, allowing the user to have a comprehensive vision on the overall sustainability and circularity performance of the selected disassembly and recycling route. Those economic and social KPIs will be saved into the TREASURE Data Lake by means of set of proper APIs and gathered by the TREASURE platform.

In the **Eco-design Advisory (ECO Adv)**, GRETA functionalities are exploited to support the adoption of design changes able to gain sustainability and circularity margin over the current available car part design. GRETA tool indeed is adopted to perform individual and comparative assessments of the conventional (or current) design and the envisaged new potential ones (alternative) over the whole lifecycle (BoL, MoL, EoL). As for the REC module, GRETA feeds the TREASURE Data Lake with the calculated S&C KPIs.

3.12 SSNA Tool

3.12.1 Purpose

The module to be developed in order to connect the Semantic Social Network Analysis toolset and the TREASURE Platform is addressed both to car makers and consumers. Indeed, SSNA is 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 is developed within T2.3 “Participatory social impact assessment”, led by EDGE.

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

3.12.2 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 could allow customers to view CE indicators and graphical	ECO

		indexes reporting the circularity level of their cars	

Table 3.7 - SSNA Tool, covered requirements

3.12.3 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.

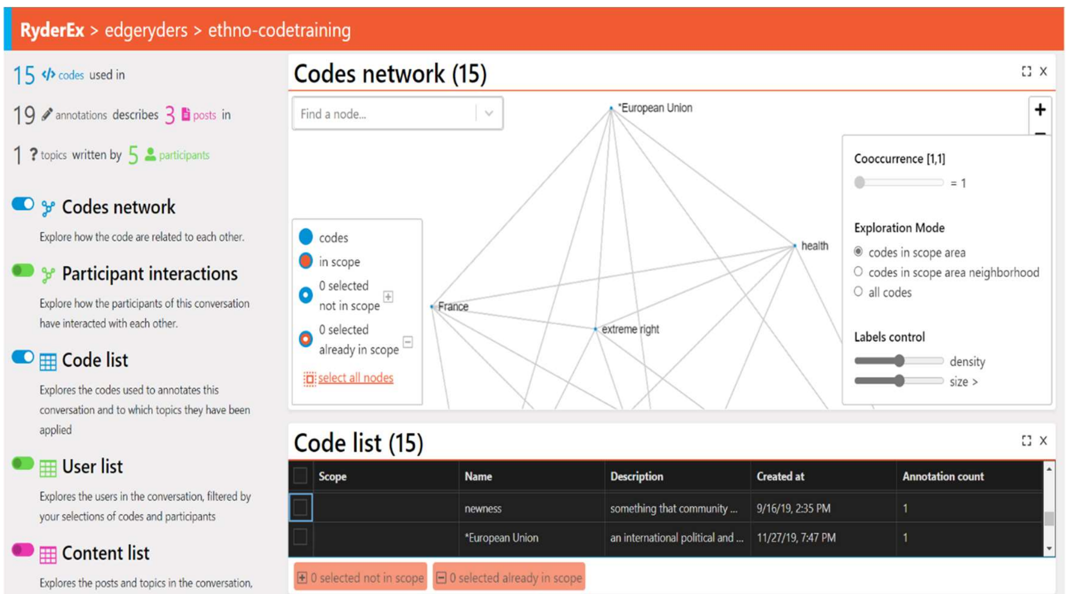


Figure 3.33 - SSNA Tool, sample interface

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.

3.12.4 Major tasks

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 is 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.

3.12.5 Platform integration

The integration procedure to interconnect the SSNA Tool and the TREASURE Platform happens 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.

3.13 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 is 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 Circular Advisory Tool exploits 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 should 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 should 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, the activities carried out related to the TREASURE Data Lake consisted in data collection operations, to ingest the relevant information coming from various data sources within the TREASURE Project. In particular, the data that has been ingested so far is the following:

- 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 and sustainability assessment scenarios and indicators (the last one provided by the GRETA Tool from SUPSI).
- 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.
- Advisory information, forecasts, suggestions and predictions from the Circular Advisory Tool as a result of the analysis of a set of all the above data.

Finally, as previously mentioned in D4.1, 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 AWS Services.

3.13.4 Major tasks

To conclude the ingestion activities related to the TREASURE Data Lake component, a couple of action points need to be addressed. In particular, the following integration activities need to be finalized:

- Incorporate environmental KPIs coming from the Recycling Simulation Tool by MARAS (recycling/disassembly routes, recycling KPIs, …).
- Include level 3 dismantling metrics collected from the sub-disassembly operations performed by the Cobot. This activity, performed as a joint effort between TXT and POLIMI, will be necessary to populate the dedicated section of the Disassemblability Dashboard in the Circularity Web Platform.

3.13.5 Platform integration

The Data Lake component has been integrated with the majority of the TREASURE components, in particular with the DIS, REC and ECO Dashboards of the Circularity Web Platform. Also, since the main objective of the major tasks already focuses on platform integration, the detailed list of collected data can be found in the chapter above. In order to facilitate information flow, the Data Lake component is 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.

3.14 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 are 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 alpha version of the TREASURE Platform is already deployed as a micro-services cloud infrastructure, in particular:

- The backend components serving the WEAVR Platform have been deployed since the beginning of the project, 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.

- The corresponding user management and load balancing infrastructures have been realized in order to support communication and access control within the different tools of the TREASURE Platform.
- An instance of the TREASURE Data Lake has been deployed together with all the data currently available. Proper connections have been put in place to ensure secure and reliable data transmission to and from the Circularity Web Platform, as well as the rest of the TREASURE Platform components.
- The Circularity Web Platform alpha version has been deployed leveraging state-of-the-art solutions to ensure strong availability and information persistence. The resulting architecture can be seen in the figure below:

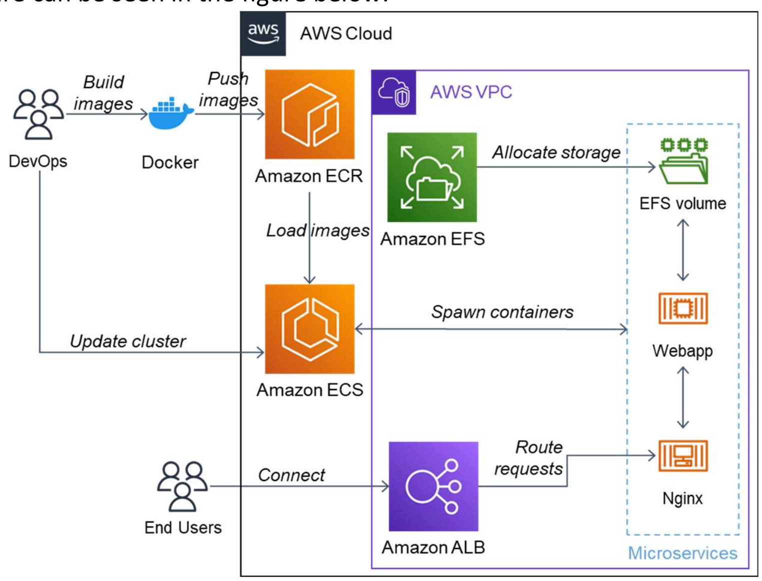


Figure 3.34 - Circularity Web Platform, micro-services architecture

3.14.4 Major tasks

After the first release of the TREASURE Platform components, the relevant infrastructure blocks have been fully deployed and, therefore, no further changes are foreseen for AWS Services as the complete architecture available in the cloud is suitable enough to accommodate the current release of the components, as well as any future release of updated versions. The infrastructure will be periodically monitored to check whether the assigned resources are still relevant, or component scaling is needed instead.

3.14.5 Platform integration

Since the AWS Services interact with most of the other platform components, the integration has been performed among different axis and involves different aspects for each component. In particular:

- The Circularity Web Platform component has been integrated by offering hosting capabilities, user management, security functionalities, and load balancing of the physical machines the platform is hosted onto.
- The WEAVR Platform leverages different AWS services depending on the individual components it comprises:

  - For the WEAVR Manager component a dedicated machine has been 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 have been also put in place in order to rapidly upload/download complex procedures from/to multiple users concurrently.
  - For the WEAVR Player component, integration has been 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 leverages the asset store infrastructure to allow procedures upload in the dedicated storage spaces managed by the Manager component.
- The Data Lake component then has been integrated with most of the TREASURE Platform, allowing those to retrieve, upload, edit and remove all the knowledge available through dedicated access policies both user specific and/or asset specific. The Data Lake integration has been realized through the deployment 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).

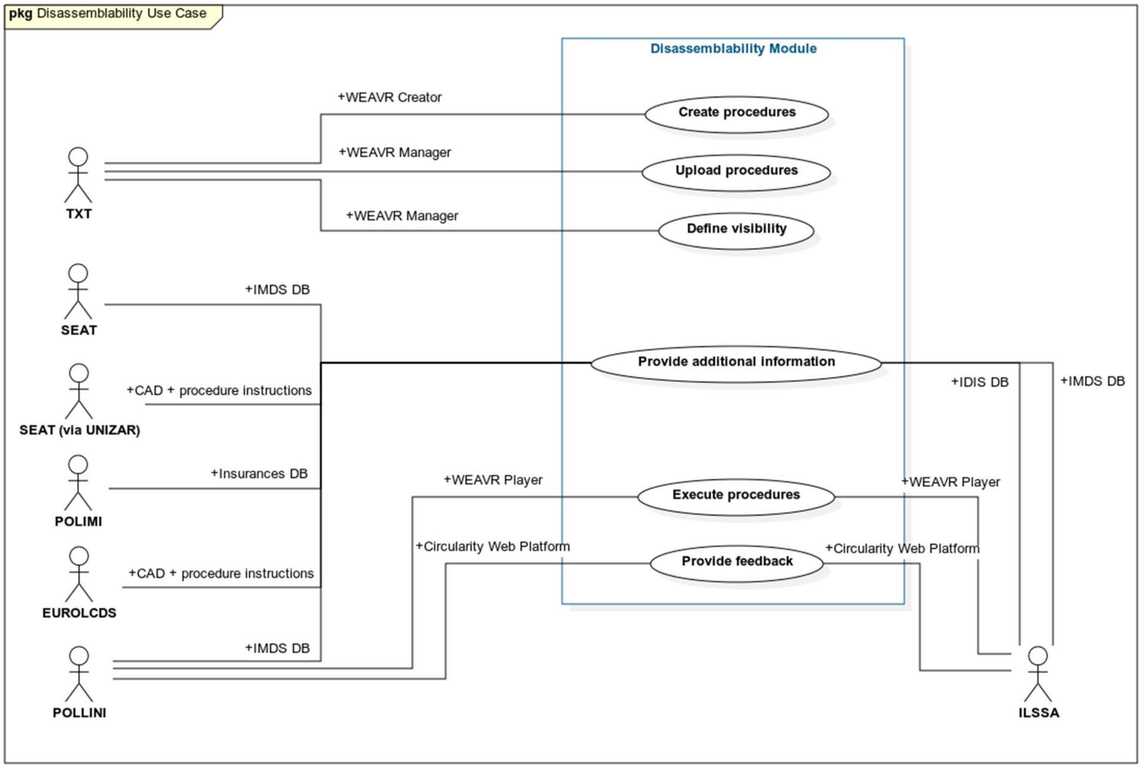


Figure 4.1 - DIS module, use case diagram

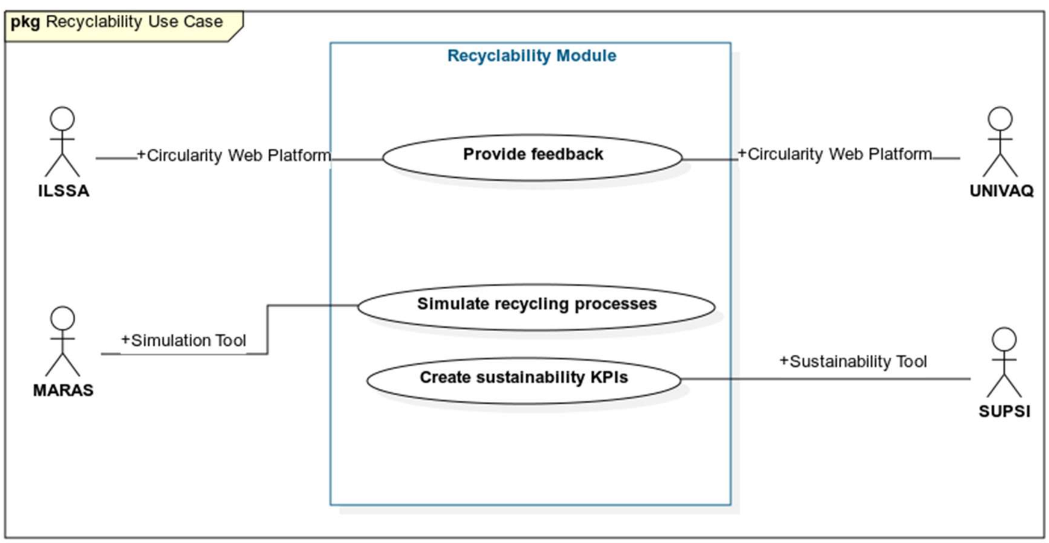


Figure 4.2 - REC module, use case diagram

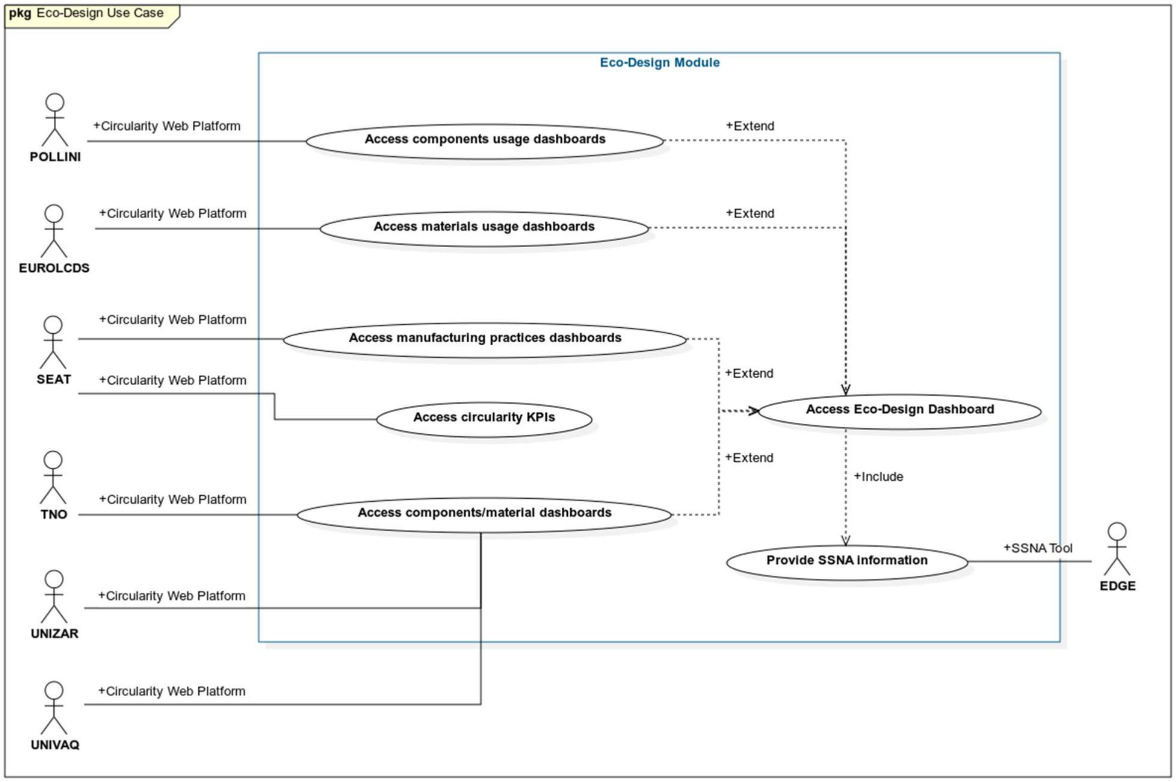


Figure 4.3 - ECO module, use case diagram

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 (i.e. Disassembly Operator, Recycling Operator and Car Manufacturer Operator)..

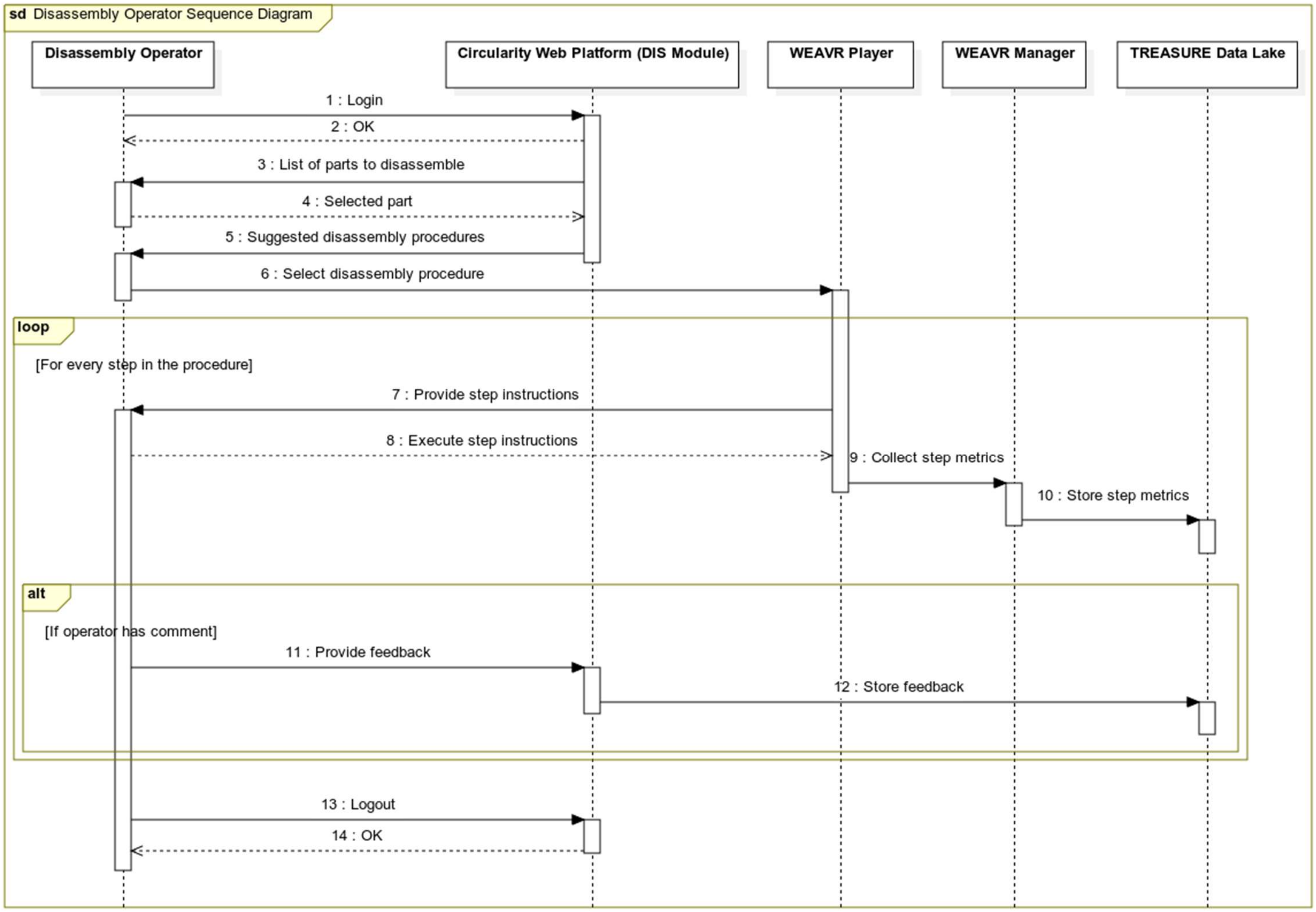


Figure 4.4 - Disassembly operator, sequence diagram

It is important to highlight that in the Disassembly Operator Sequence Diagram shown above, the Disassembly Operator lifeline represents all the EoL actors such as dismantlers and shredders which are involved in the DIS module and, therefore, can interact with the Disassembly Dashboard of the TREASURE Circularity Web Platform.

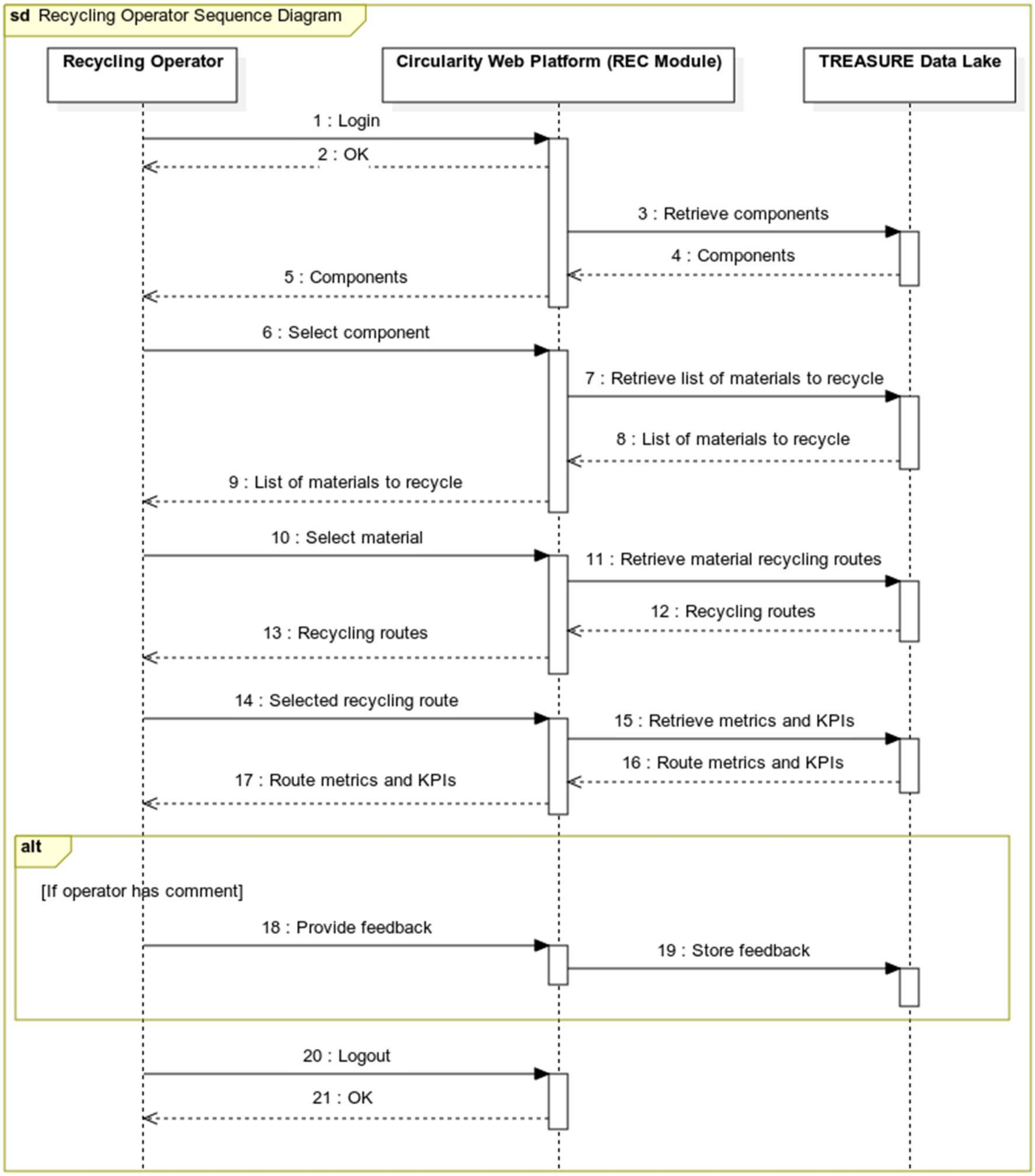


Figure 4.5 - Recycling operator, sequence diagram

It is important to highlight that in the Recycling Operator Sequence Diagram shown above, the Recycling Operator lifeline represents all the BoL actors such as car/component manufacturer and car/component designers which are involved in the REC module and, therefore, can interact with the Recycling Dashboard of the TREASURE Circularity Web Platform.

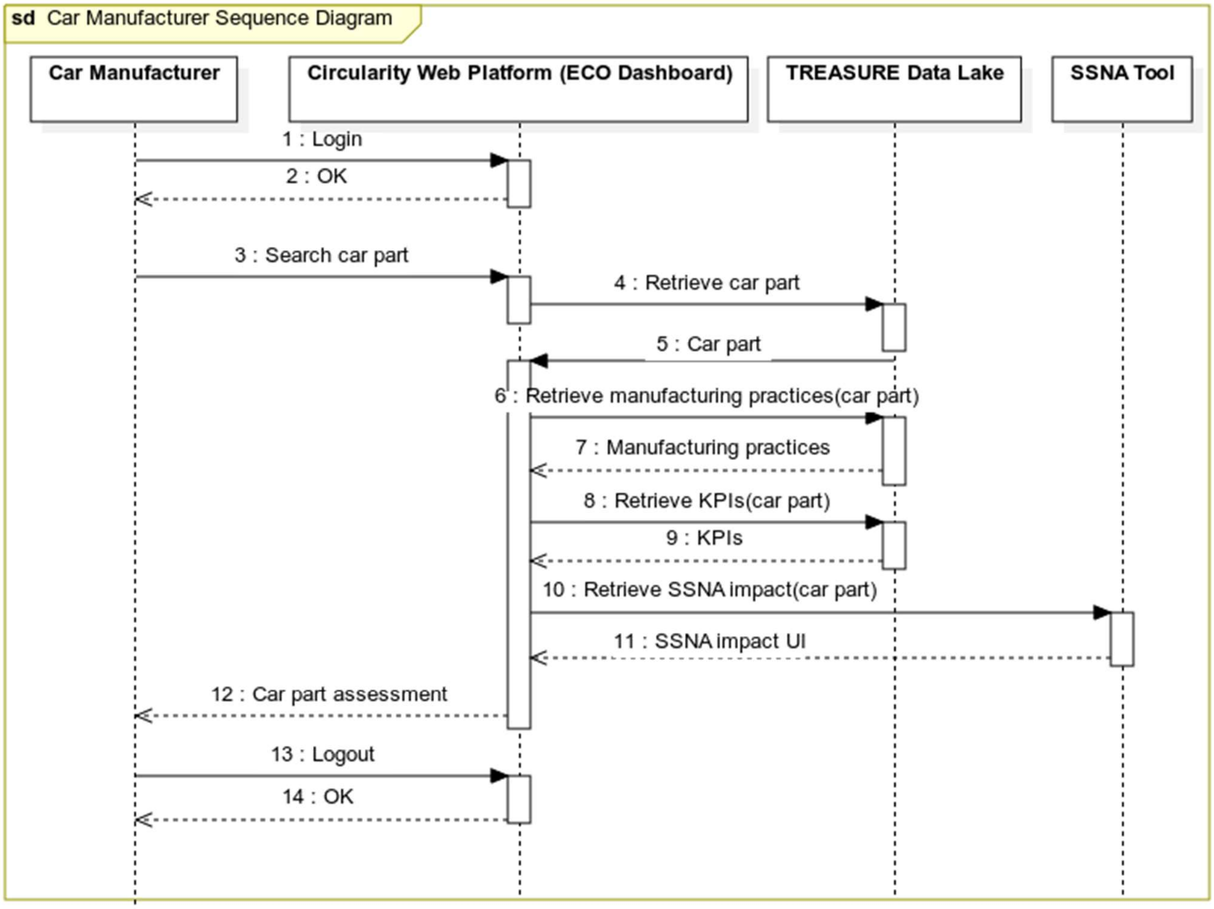


Figure 4.6 - Car Manufacturer, sequence diagram

It is important to highlight that in the Car Manufacturer Sequence Diagram shown above, the Car Manufacturer lifeline represents all the BoL actors such as car/component manufacturer and car/component designers which are involved in the ECO module and, therefore, can interact with the Eco-Design Dashboard of the TREASURE Circularity Web Platform.

5 Conclusions and Next Steps

The present deliverable documents TREASURE final architecture as a result of the outputs regarding technical requirements and specifications as pinpointed in D4.1, deriving not only from the previous period 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 main focus of the activities carried out in the second iteration of T4.1 has been the update of the results achieved in the first period based on the periodic discussion carried out with the project partners, mainly constituted by the target users of the platform and the process owners, after the first iteration. The integration or/and modification of the technical features proposed in this deliverable has taken into consideration not only the internal actors within the consortium but also external stakeholders to generalize the identified requirements. This task has been carried out to expand the list of additional users' needs to include in the identification of the platform specifications. The final goal is to ensure both internal and external validation to improve TREASURE solution adoption in different use cases depending on the involved stakeholder. To perform this activity, a survey has been elaborated to gain insights and feedbacks from a wide range of players in the automotive industry or cluster associations on the TREASURE platform. The survey outcomes played an important role in the integration of technical requirements giving additional inputs that have been considered in the elaboration of the final version of the architecture. The outcomes of this responses were useful to analyse in order to understand how the platform value proposition could be improved. In fact, the respondents showed a high interest in the provision of information perceived as critical for the users to drive day to day operations and business strategy.

The refinement of the requirements and system architecture focused mainly on the integration of additional features on the three platform modules that ensure data transparency by providing further details in forms of tables, pop-ups and recommendations. The major effort was performed in the Eco-Design Module and mainly in the Advisory part which underwent an important revision of the comparison section in order to define the metrics and indicators on which the environmental, social and economic analysis are performed. The full description of the second version of platform modules will be provided in D4.8 while the characterization of the final Circular Advisory Tool will be depicted in D4.10.

The next steps will be mainly focused on the execution of the other tasks foreseen in WP4, assigned to technical implementation of additional requirements and seamless integration of the involved components. The work completed in these tasks will lead to the execution of activities foreseen in T4.6 for the functional and non-functional validation of the platform. The process will be implemented taking into consideration not only partners involved in the project but also referring to the external stakeholders that responded to the survey. This can be achieved by sharing an overview of the final results with them in the light of an ongoing platform revision for technical improvements and new functionalities integration.