Supporting the development of circular value chains in the automotive sector through an information sharing system: the TREASURE project

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Abstract. Circular Economy (CE) and Circular Value Chains (CVCs) are two topics commonly addressed in literature. However, there is a big research gap in terms of how to practically transform linear value chains into circular ones and very few application cases. The intent of this paper is to propose a way to support the creation of circular value chains through the implementation of an information sharing system in the automotive sector. To this aim, the TREASURE project will be taken into account as a reference example. A preliminary analysis of the context shows a high innovation potential related to the introduction of a similar technology linking car parts suppliers and carmakers with End-of-Life (EoL) actors.

Keywords: Circular Value Chain, Circular Economy, Product Lifecycle Management, Information Sharing, Automotive Sector.

1 Introduction

Car electronics is one of the most valuable sources of Critical Raw Materials (CRMs) in cars (Andersson et al. 2019; Restrepo et al. 2017). A modern medium-sized car can embed up to 15 electronic systems on average and luxury cars can reach up to 50 among microcomputers and electronic components (Wang and Chen 2011). A statistic of the BMW® Corporation has shown that these systems can account for more than 30% of total vehicle cost (and more than 50% in luxury cars) (Wang and Chen 2013). From 2000 onwards, electronics saw an increased penetration in the automotive sector (Restrepo et al. 2019). A recent report (MarketsandMarkets 2021) quantified the automotive microcontrollers market in about $989.2 Million in 2017, with a projection to $1,886.4 Million by 2022, at a CAGR of 13.78%. That said, remarkable is the historical lack of interest of car manufacturers (and the whole automotive sector) towards the recovery of these valuable components from End-of-Life Vehicles (ELVs). Arguably, the complex set of barriers (e.g. regulatory, governance-based, market, technological, cultural, societal, gender, etc.) result in difficulties for companies to implement Circular Economy (CE) by limiting its potential benefits. All these data show as the sectorial transition towards CE seems to be far from its completion, even if car manufacturers are investing big capitals trying to shift their business towards more sustainable mobility concepts. Especially at End-of-Life (EoL) stage, there are still many issues to be solved to functionally recover materials from cars (e.g. reuse recovered materials for the same purpose they were exploited originally) and the dependency from natural resources when producing new cars (e.g. electric/hybrid/fuel cell -powered) is still too high. This mandatory systemic transformation requires all companies/sectors to redefine products lifecycles since the beginning, by adopting CE principles already before designing them. Considering together the wide number of barriers impacting on the automotive sector and the limited collaboration among actors involved in traditional automotive value chains, the transition towards CE cannot be reached so easily. This issue is related (especially) to two elements. From one side, Beginning-of-Life (BoL) and EoL stages are still unconnected from an information sharing perspective. Data about materials embedded in cars are spread on a plethora of strictly protected databases accessible only by authorized actors. This way, even if data on materials embedded in cars are known since many years, no one can exploit them (e.g. to optimize ELV management processes). From another side, even if ELV management processes are active in Europe since the sixties, none of the actors involved in these processes is available to share their knowledge with car makers or car part suppliers, given their unavailability to collaborate. So, both car makers and car part suppliers cannot improve their design practices to make cars easier to disassemble and recycle. Considering all these issues, this paper wants to propose a way to support the creation of Circular Value Chains (CVCs) through the implementation of an information sharing system in the automotive sector. To this aim, the TREASURE project will be taken into account as a reference example. The paper is organized as follows. In Section 2, the theoretical background is presented. In Section 3, the research methodology is described. In Section 4, the expected findings are evidenced. In Section 5, concluding remarks and future research avenues are offered.

2 Theoretical background

2.1 Current automotive material loop

Current ELV recycling of steel and Al from vehicles unavoidably mix an increasing set of alloys which, in turn, leads to degradation of materials quality and forces a downgrading of recycled materials only in low-value applications (e.g. reuse recycled Al in engine basements), sometime outside the automotive sector (e.g. reuse recycled steel in buildings). Predictable technological changes (e.g. widespread adoption of electric vehicles) may lead to even worst performances. Therefore, a separation of different alloys (e.g. through the dismantling of some components) can become unavoidable in the next future to ensure an adequate recycling of these metals (Løvik et al. 2014; Ohno et al. 2017). In addition, the issues of environmental impacts and risks related to primary supply are not restricted to precious metals only. Often, critical/scarce metals have (in relation to the total vehicle's mass), disproportionally large environmental impacts and potential risks associated with their primary supply. Considering some studies on the lifecycle energy impacts of car electronics (Cassorla et al. 2017), total life cycle impacts of vehicle's Electronic Control Units (ECUs) are estimated to be 22.7 GJ of embodied energy and 654 kgCO2eq GHG emissions. That said, an average of 50 ECUs per vehicle represents 5% (or 8.5 GJ/vehicle) of the total vehicle manufacturing embodied energy. In case of an increase in the electronics content (i.e. 76 ECUs per vehicle), the embodied energy can increase by ~1.6 times. From a vehicle's lifecycle energy perspective, the ECU use phase contributes to ~63 % of total lifecycle impacts. This way, the energy impacts of new automotive electronics recycling can be comparable to that of the automotive steel recycling and materials recycling together. However, the current ELV directive does not stimulate the recovery of these metals since the recycling targets are defined by the total mass. An interesting option can be focusing on thermodynamic rarity, an indicator measuring the downcycling of materials. This way, not only quantity, but also quality of metals becoming functionally lost in ELV recycling processes can be monitored (Ortego et al. 2018).Considering that the ELV directive (European Union 2000) aims to improve the "environmental performance of all of the economic operators involved in the lifecycle of vehicles", the recovery of critical/scarce metals should be motivated.

2.2 Current EU knowledge base on automotive critical/valuable raw materials

Vehicle manufacturers do hold large amounts of data, specifically in the International Material Data System (IMDS), but these data are generally not accessible to others. The importance of vehicles and data from manufacturers was also highlighted in a past recommendation from the H2020 ProSUM (Downes et al. 2017) and ORAMA (Bide et al. 2017) projects. Again, the ELV directive states that: "In order to facilitate the dismantling and recovery, in particular recycling of ELVs, vehicle manufacturers should provide authorized treatment facilities with all requisite dismantling information, in particular for hazardous materials". This is currently ensured through the International Dismantling Information System (IDIS). However, similar provision of information from vehicle manufacturers (e.g. drawing on the IMDS data), can enable an obligation to dismantle certain parts based on their content of critical/scarce metals. The necessary data systems seem, to a large extent, to already be in place. Obviously, it's important to carefully consider a financing model and potential unintended consequences related with a mandatory dismantling of components, firstly the additional costs for dismantlers. Studies have been already made to investigate the magnitude of these costs (IEEP et al. 2010). Results state that these costs can probably not be fully compensated by increased incomes from material recycling, mainly because of current low economic value of recovered critical/scarce metals. In addition, there is a risk of disrupting the existing market for used spare parts. Setting material-specific recovery yield targets should be another option, particularly for those critical/scarce metals not mentioned in the current ELV directive. However, the compliance with such targets would need to be constantly monitored (e.g. by measuring the concentrations of some metals in various output fractions) and compared with data about ELV materials composition provided by manufacturers (e.g. by exploiting information from the IMDS).

3 Research methodology

3.1 Digitalizing the automotive value chain

One of the most important activities in TREASURE will be the physical and virtual data compilation for acquiring the initial knowledge and establishing recommendations in terms of: 1) eco-design; 2) dismantling, 3) recycling and 4) consumers involvement. In addition, this information will be the starting data of the platform, furtherly populated in the future by users themselves. The following Figure 1 shows the logic followed within the TREASURE project. For each selected car component: i) it will be identified a disassembly procedure, ii) it will be assessed its recyclability in terms of material contents (and related metallurgical procedures) and iii) it will be identified a set of KPI to measure/monitor circularity performances.

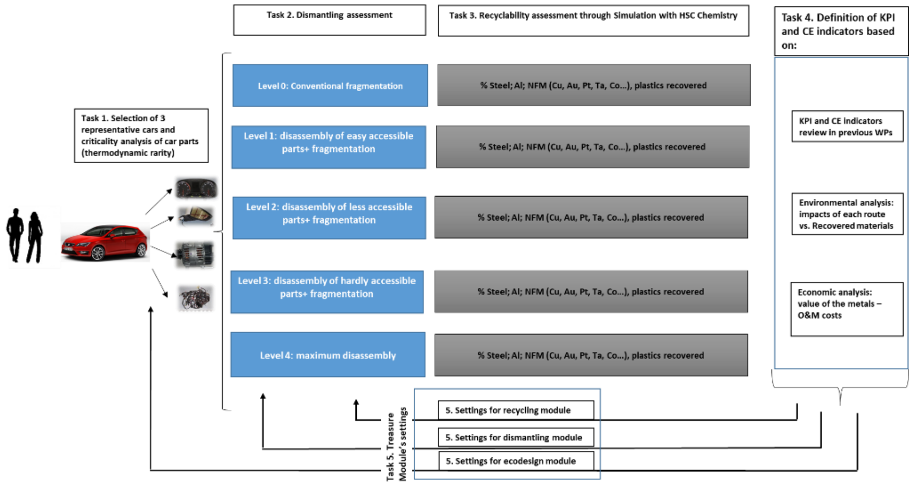

Fig. 1. Identification and selection of representative vehicles

Firstly, an identification and selection of three representative vehicles will be implemented. Such vehicles should represent different generations of cars covering as many different car parts and configurations as possible. Moreover, such car parts should be shared among as many vehicles from the same car maker as possible. Secondly, a thermodynamic criticality analysis will be undertaken. This analysis will allow to assess which car parts contain the most valuable metals from a physical point of view and classify them according to their scarcity in the earth's crust and the energy required to mine and refine them. To this aim, a specific database will be exploited. Such database includes material specifications of all car parts stemming from IMDS, a global data repository containing information on materials used by the automotive industry. Thirdly, disassembly levels will be established according to criticality of car parts and information from the specific database. The following Figure 2 shows the different disassembly levels considered within the TREASURE project.

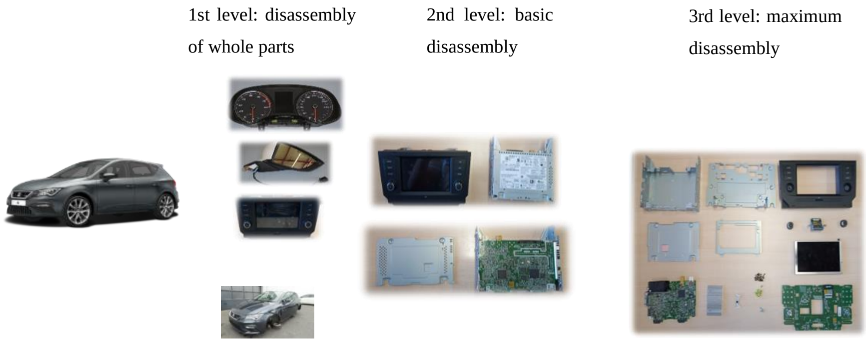

Fig. 2. Definition of the disassembly level of representative car parts (see Annex)

This way, three disassembly levels will be defined (see Figure 2), together with a set of general recommendations (e.g. disassembly times and tools). Disassembled parts (for each level and for each vehicle), will be furtherly classified into different flows depending on their prevalent material composition. Fourthly , specific recycling routes consisting of physical processing/sorting and carrier metallurgical recycling infrastructures (e.g. pyro- and hydrometallurgical smelting and refining) will be assessed through simulation models (e.g. HSC Sim10®) based on a mass (but also energy/exergy) balance for all materials/metals/elements and compounds. Recycling/recovery rates will be available for whole parts/product as well as for individual elements/materials. This way, designers could link their decision to EoL stages. To that end, a detailed flowchart will be created, defining process inputs (e.g. composition, mass flow, temperature and pressure of subparts). Subsequently, the properties of each flow will be calculated by software. Fifthly, outflows of each unit will be specified, so closing the mass balance. This way, the behavior of all metals throughout the recycling process will be analyzed (together with the total quantity of recovered/lost metals) and translated in a set of recommendations about recyclability of car parts. These recommendations will also influence disassembly levels, disassembly activities and data generation/availability for disassembled parts. Different disassembly levels and approaches will be tested on optimized results from recycling and circularity (e.g. primaries required for dilution to produce alloys from recyclates). Finally, the so-constituted technological indicators will be integrated (together with CE assessment tools) in the TREASURE platform, so obtaining a complete circularity picture in the vehicle value chain. To this aim, different labels will be created depending on end users.

3.2 Designing, developing and integrating the TREASURE platform

CE, by definition, involves all actors of a value chain, including BoL, MoL and EoL actors, processes and generating data. The TREASURE platform has the goal to provide the technical level of the project supporting data storage on which the different recommendation algorithms of the project run. Technically, the TREASURE platform relies on an open architecture in which the CE data about automotive electronics coming from different sources is stored in the TREASURE data lake and is combined with external data sources like public database (e.g. the Raw Materials Information System - RMIS). Data engineers will collaborate with end users to set up the correct data ingestion and data polishing and quality checks mechanism. Starting from initial findings, data scientists will be able to train algorithms and develop specific recommendation algorithm on top of the data lake. These recommendation algorithms are currently represented by an eco-design and circular (AI-based) advisory tool. However, they could be extended during and after the project depending on the TREASURE needs. The eco-design tool is aimed at helping car makers and car part manufacturers to identify the most critical (in terms of critical raw material contents) car parts in a vehicle, according to materials criticality levels and provide valuable recommendations based on improving the disassemblability and recyclability potential. The circular (AI-based) advisory tool is aimed at providing dismantlers and shredders with information regarding: i) critical and valuable car parts to be disassembled and ii) best recycling routes according to materials contained in car parts. In addition to these tools, a consumer involvement tool (based on a dedicated web platform) will provide a resource efficiency/CE label for awareness raising. The eco-design and circular (AI-based) tools will be fed through a specific database and will classify the different car parts of a vehicle according to their physical criticality (based on thermodynamic rarity). Based on composition and the recyclability insights, a set of recommendations (different for each end user) and a list of KPIs will be established for each car part in an automatic way. Information included in the algorithms will initially stem from the physical and virtual assessment carried out during initial activities, but it will be furtherly completed with feedbacks obtained from use cases. Even if this tool will be initially designed to work with a specific database, it could be adapted also to other automotive companies. The tool will be independent from internal systems, even if it will be fed with information from manufacturers. Confidentiality will be guaranteed by a security access and by delivering only results with aggregated non-confidential data (see the previous figure).

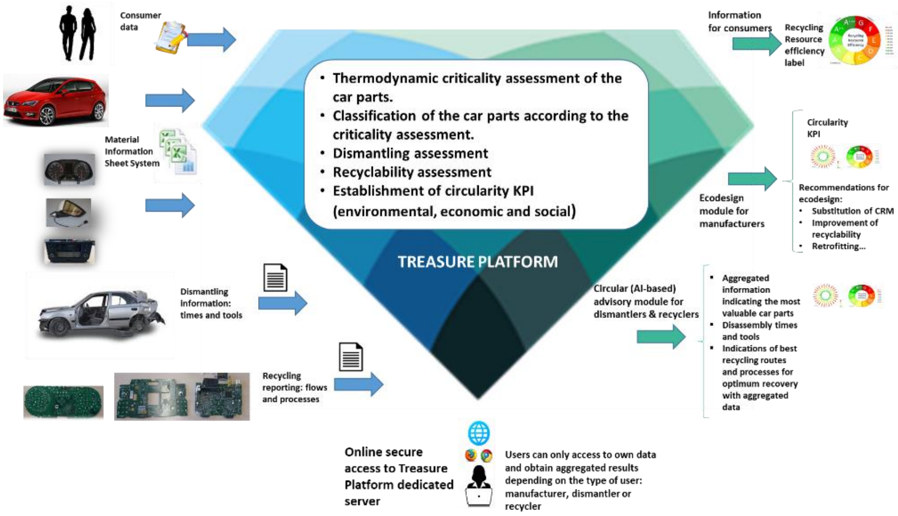

Fig. 3. Initial concept of the TREASURE solution (see Annex)

4 Expected findings

TREASURE wants to support the transition of the automotive sector towards CE trying to fill in the existing information gap among automotive actors, both at design and EoL stage, by both modifying the existing exploitation logics of international data spaces and trying to apply the concept of "cascade use" of resources (Kalverkamp et al. 2017). To this aim, a scenario analysis simulation tool dedicated to car electronics will be developed and tested with a set of dedicated demonstration actions. The, so implemented, scenario analysis simulation tool will have a multiple perspective. From one side, the TREASURE solution can assist both car parts suppliers and carmakers in assessing their design decisions in terms of circularity level, also considering the effects of their decisions on EoL processes (e.g. on car dismantlers and shredders operational performances and advanced metallurgical recycling processes). Vice versa, car dismantlers and shredders could benefit from the TREASURE solution by knowing about new design features of cars to be recycled in order to optimize their processes. Here, the TREASURE solution will exploit an already existing CE performance assessment methodology to measure and quantify CE-related performances through a set of dedicated KPIs. Specifically, economic KPIs will be identified through a Life Cycle Cost (LCC) analysis. Environmental KPIs will be identified through a Life Cycle Assessment (LCA), Material Flow Analysis (MFA) and Thermodynamic Rarity Assessment (an exergy-based analysis). Finally, social KPIs will be identified through a large-scale online ethnography of the CE movement in the automotive sector. From another side, the TREASURE project can act as an information hub, by exploiting data stored in the EU RMIS database. These data will be directly exploited by TREASURE to continuously monitor CE performances through a dedicated Circular Economy Performance Assessment (CEPA) methodology. About the EU RMIS database exploitation, an implicit hypothesis is that it will be updated with data both currently accessible by only re-known automotive actors (e.g. IDIS and IMDS) and stored in open generic databases (e.g. Eurostat, SCIP – Substances of Concern In Products). This way, data can be easily exploited also by Small and Medium Enterprises (SMEs) operating in other sectors in order to develop new businesses and value chains exploiting these data. The access to privately-owned DBs (e.g. IDIS and IMDS) will be processed according to the EU GDPR legislation.

4.1 Information sharing system logic

The TREASURE solution can be described as the sum of four main building blocks: 1) an eco-design tool, 2) a circular (AI-based) advisory tool, 3) a consumer involvement tool and 4) a web-based platform interacting with the previous tools and gathering information about valuable and critical raw materials embedded in cars by interconnecting with the RMIS. Even if all stakeholders will be interconnected through the platform, the information will be treated confidentially and that access to the platform by each stakeholder will be secure.

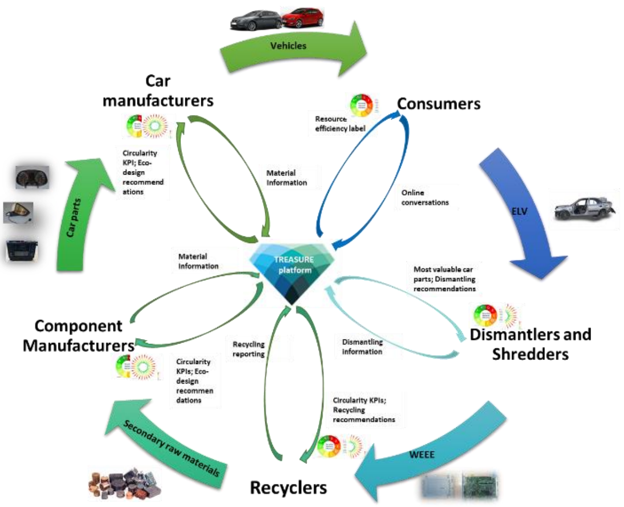

Fig. 4. Overall interaction of the TREASURE solution with different automotive value chain actors (see Annex)

When a new car electronic part must be designed, the eco-design tool will assist car parts suppliers and carmakers in selecting the most circular strategy basing on both general sustainability targets (e.g. substitute/reduce CRMs and/or plastics use) and a set of KPIs elaborated by the TREASURE platform quantifying positive and negative implications of CE on the whole automotive value chain. In order to calculate KPIs, an aggregation of data coming from both EoL actors (e.g. disassembly procedures, shredding issues, materials recovery strategies, etc.) and gathered from several databases (both private and public ones) will be executed by the platform. These KPIs will also ease the definition of design standards to facilitate disassembly and/or recyclability of cars/car parts. Vice versa, when a new car electronic model will enter the EoL stage, the AI-based advisory tool will assist car dismantler and car shredders in optimizing their processes from a CE perspective, by gathering information from the TREASURE platform. From one side, car dismantlers could gather information about 1) new disassembly procedures of specific vehicles/components (feeding from existing IMDS and IDIS platform, for instance), 2) critical car parts in a vehicle to be removed according to different perspectives (e.g. materials criticality, requirements from other EoL actors), 3) car parts circularity level (e.g. recyclability of materials, accessibility, disassemblability, hazardousness, etc.) and 4) new processes/equipments needed to recover valuable/critical raw materials from disassembled car parts. From another side, car shredders could be informed about 1) valuable materials to be separated and/or recovered before shipping materials to foundries, 2) new material separation/recovery techniques needed to recover valuable/critical raw materials from shredded cars. Finally, a consumer involvement tool will allow a bi-directional indirect interaction between automotive actors and final customers. From one side automotive actors could gather information from final customers about the impact of CE strategies on the market. From the other side, customers could increase their awareness about CE strategies adopted by automotive actors through a set of graphical indexes reporting the circularity level of their cars.

5 Conclusion

The ambition of TREASURE is offering to the European automotive sector interconnection among stakeholders of the value chain through an AI-based (secured-access) platform to foster communication for the proper implementation of CE practices and a set of new perspectives about innovative automotive components disassembly processes, materials recovery processes and secondary materials applications. This way, TREASURE wants to: i) guarantee a sustainable use of raw materials in the automotive sector, by reducing supply risks, ii) put in place CE practices in the automobile sector, acting as a showcase for the manufacturing industry, iii) offer a better environmental, economic and social performance of vehicles for users and stakeholders and iv) create new supply chains around ELV management, by focusing on the circular use of raw materials.

5.1 Contribution to theory

- Define new information sharing channels in the automotive sector (both in onward and backward directions) through a secure access and ensuring confidentiality issues among stakeholders.
- Quantify positive and negative implications of CE in the automotive sector.
- Represent a set of success stories in three key value chains of the automotive industry (focusing on SMEs): 1) dismantlers/shredders, 2) recyclers and 3) manufacturers, practically demonstrating the benefits coming from the adoption of CE principles in the automotive sector.
- Integrate Key Enabling Technologies (KETs) for the efficient design of car electronics and subsequent disassembly and materials recovery.

5.2 Contribution to practice

- Develop an information sharing system supporting the development of circular supply chains in the automotive sector.
- Close the material loop and reduce the dependency of the European automotive sector from raw materials supply.
- Perform a set of standardization and policy-related activities to make both industrial and politician actors aware about the current issues of the ELV management system.
- Increase the EU knowledge base on secondary raw materials.

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