TREASURE

D3.1: Criticality analysis of selected vehicles

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EXECUTIVE SUMMARY

This deliverable is part of Task 3.1 in Treasure Project, related to the criticality assessment of selected vehicles. Initially, three SEAT models of cars were selected: Ibiza IV generation, Seat León II generation and Seat León III generation. The selection was done, among others, ensuring that as many different car parts and configurations as possible are covered and that there is sufficient volume (or will be in the future) of such cars arriving at Authorised Treatment Centres. We then perform a comprehensive metal assessment of the three passenger cars selected in terms of mass and thermodynamic rarity. The mass composition of all car parts in the cars originates from MISS database, owned by SEAT. Once all car parts with their corresponding compositions in terms of elements is obtained, a thermodynamic rarity assessment is carried out. Thermodynamic rarity is based on the property of exergy and is defined as “the amount of exergy resources needed to obtain a mineral commodity from average crustal concentration using the best available technology” (measured in kJ). Thus, the thermodynamic rarity approach assigns a greater exergetic value to scarce (understood as having a relative low average crustal concentration) and difficult-to-extract minerals. This method, which will be automatized and implemented in the Treasure Platform within WP4, allows to identify the most critical components in a vehicle. This information is essential for targeting the right recovery strategy and hence, fostering circular economy practices in Authorised Treatment Centres and Recycling facilities. It is also very valuable for manufacturers, so as to promote ecodesign practices.
As a result of the task, between 19 and 24 parts have been identified as critical for each selected vehicle. Many of them correspond to vehicle electronics. These car parts will be the object of study of Task 3.2 (disassemblability assessment) and Task 3.3 (recyclability assessment).

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1. Introduction

This report is part of work package 3 (WP 3: Automotive value chain digitalization) belonging to the European project TREASURE and presented as deliverable 3.1, according to the activities carried out within Task 3.1 (Vehicles' selection and critical analysis).
Task 3.1 has focused on the identification and selection of three representative vehicles from SEAT fleet as objects of study. Once the cars have been selected, a criticality assessment of the analysed cars has been carried out through the "thermodynamic rarity" indicator and so identify the most critical parts of each car.

2. Objectives

The main goals of this deliverable are:

1. Selection of vehicles as object of study for compiling all information required for the automotive value chain digitalization.
2. Carry out a criticality analysis in terms of the indicator "thermodynamic rarity", to identify the most valuable car parts of the selected vehicles in terms of the materials they contain.

Additional goals

- To elaborate an easily digitizable methodology to identify critical parts from SEAT vehicles through the Material Information Sheet System (MISS).
- To gather information for the future database of the platform to be developed in WP4.

3. Selection of vehicles

The identification of vehicles has been carried out by SEAT, with the support of ILSSA and UNIZAR. SEAT Ibiza and SEAT Leon models have been selected, given that they are the most representative models in terms of sales of SEAT brand. From 2005 to 2019, more than 2 million cars of these models have been sold worldwide. In addition, both models Ibiza and Leon are hatchback compact cars, based on Volkswagen (VW) Group platforms (A0 and A respectively). Therefore, most of the contained car parts are shared among many vehicles from the Volkswagen Group. That is, Ibiza shares VW Group platform with VW Polo, Audi A1 and Skôda Fabia, whereas Leon with VW Golf, Audi A3 and Skôda Octavia. Overall, such vehicles represent different generations of cars covering as many different car parts and configurations as possible. Further, the high trimmed version has been selected, due to the higher proportion of electronic car parts. In addition, considering that more than 2 million cars have been sold in the last years, it becomes clear that enough volume of such cars will be arriving at Authorised Treatment Centres (information from ILSSA).

- SEAT Ibiza Generation (Gen.) IV (Diesel and High-trimmed)
- SEAT León Generation (Gen.) II (Diesel and High-trimmed)
- SEAT León Generation (Gen.) III (Diesel and High-trimmed)

4. Criticality assessment of vehicles

The criticality assessment of the selected vehicles in terms of the materials they contain, is carried out through the so-called thermodynamic rarity indicator. As demonstrated by Ortego et al. [1], a mass-based assessment of metal content in a vehicle does not incentivize the recovery of minor, but extremely valuable elements, such as rare earths (REE), precious metals and other essential raw materials required to manufacture electric and electronic equipment.

This could be solved by using as a weighting factor an alternative indicator based on the second law of thermodynamics and particularly the exergy analysis.

Exergy is a thermodynamic property that accounts not only for the quantity, but also for the quality of any resource.

The analysis is based on an exergy-based indicator called thermodynamic rarity [2], which allows us to assess which specific car parts contain the most valuable metals from a physical point of view. This is based on the recognition that the physical value of minerals is mainly due to their chemical properties and their availability on the Earth's crust. Therefore, the scarcer a resource, the greater its extraction costs. The aim of this indicator, called thermodynamic rarity (or simply rarity), is to allocate a physical value to raw materials according to the following parameters: (1) their scarcity in Nature and (2) the net energy required to extract and refine them to obtain the commodity. Scarce and difficult to obtain commodities such as cobalt are several orders of magnitude have a greater rarity than common ones such as iron (as shown in Table 2). Thermodynamic rarity has the advantage of mass- and economic-based approaches. As the mass approach, it is an indicator strictly based on physical aspects of the commodity and hence is universal, objective, and more stable than monetary approaches. Moreover, although alien to the volatility of the commodity markets, with frequent up and downs of prices, it is also closer to societal perception of value and in this sense, it shares the advantage of the economic approach [3].

It is important to state that thermodynamic rarity does not take into account how materials are found in a specific vehicle component. Indeed, materials can be homogenously spread throughout the whole vehicle, be combined with other materials/elements into chemical compounds or found almost pure in certain components. This fact would obviously very much affect the recyclability of the vehicle [4] but the rarity would remain the same. Thus, rarity only measures in energy terms, the impact of using those raw materials in a vehicle or any other application, considering the state of mineral ores in the earth and mining and beneficiation energies. It is a first step to identify car parts containing valuable metals. However, whether such metals can be practically recovered can only be analysed through a proper recyclability assessment, which will be carried out under Task 3.3 in a later phase.

Thermodynamic rarity values for the 50 metals analysed in this study are included in Table 1 [5]. Such values are the weighting factors for each metal used in a car to identify the most critical components in the vehicle. From there, eco-design recommendations can be easily derived.

Table 1. Thermodynamic rarity values [kJ/g].[5].

Ag	8.937	Ge	24.247	Ru	2.870.013
Al	661	Hf	32.364	Sb	487
As	427	Hg	28.707	Sm	732
Au	654.683	In	363.918	Sn	452
Ba	39	Ir	2.870.013	Sr	76
Be	709	La	336	Ta	485.911
Bi	545	Li	978	Tb	732

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Cd	6.440	Mg	145	Te	2.825.104
Ce	620	Mn	73	Ti	203
Co	11.010	Mo	1.056	U	1.090
Cr	40	Nb	4.782	V	1.572
Cu	348	Nd	670	W	8.023
Dy	732	Ni	758	Y	1.357
Er	732	Pb	41	Yb	732
Eu	732	Pd	2.870.013	Zn	196
Fe	32	Pr	873	Zr	2.025
Ga	754.828	Pt	2.870.013		
Gd	4.085	Rh	103.087		

4.1. Data Sources

For the criticality assessment of each vehicle, first, the models must be configured in the internal IT system MISS (Material Information Sheet System). This system belongs to the Volkswagen Group and is the interface with IMDS (International Material Data System), in which all automotive suppliers are obliged to declare the composition and weight of the parts under their responsibility. The creation of this database is derived from the Directive of EoL Vehicles [6], with the purpose of controlling declarable and/or prohibited substances within cars. In MISS, there is the possibility of selecting different versions of a given model. Once a certain version is chosen, the configuration of the car is generated as a tree structure of the part numbers, in which the car is hierarchically displayed in constructive groups, component groups, components and parts. Then, by means of a specific system's functionality, the part numbers are associated with their respective Material Data Sheets (MDSs), and thus, the quantity and quality of the MDSs can be easily visualized. In this way, the part numbers' list can be reworked in case the absence of any MDS is detected or the origin of the MDS is not adequate (e.g., the MDS comes from the company's development area and not from the supplier).

The quality of the MDSs may be an issue, considering that you entirely rely on the information provided by the supplier. However, the quality of the information in the MDSs is automatically checked by several quality rules of the system once the Material Data Sheet is uploaded in the system by the supplier. That said, once the part numbers' list is generated and checked, the mass analysis of each metal can be performed in MISS. To this end, the analysis must be specifically carried out for each metal to obtain the results in a file per metal. It is important to say that the overall metal content of a car cannot be analysed at once due to the capacity of the IT system.

In the generated files per metal, the part numbers containing the results of the analysis are provided in terms of metal (element) or substance (metal in combination with other elements). A calculation for obtaining the amount of metal (element) of each part is required so as to calculate the corresponding rarity of each car part (Thermodynamic rarity is given in kJ/g of element); the substance quantity is multiplied by the respective molecular weight. Moreover, the number of parts containing the substance within the part must also be taken into account (e.g., an electric engine is composed of "X" permanent magnets). By combining the part numbers' list of the car (one file) and the mass assessment of each metal, a macro file is developed, in which the part numbers are in rows and the metals are listed in columns (alphabetically ordered, from Ag to Zr) – see Table 2 and Figure 1. Thereby, a detailed description of the metals and their corresponding masses for each part is elaborated.

This process has been carried out for every selected vehicle.

Table 2. Matrix of the data obtained for each car part by metal.

Car part	Element 1	Element 2	……	Element 61
Car part 1	Mass	Mass	……	Mass
Car part 2	Mass	Mass	……	Mass
……	……	……	……	……

	A	F	V	W	X	Y	Z	AA	AB	AC	AD	AE	AF	AG	AH
1															
2			163,840334	2.436,424228	0,043679	0,043679	9,776950	9,825626	0,181566	0,186750	0,024194	0,024194	15,230738	31,179213	3.951,311747
3			148	148	21	21	112	112	112	112	4	4	207	207	428
4		Designación	Ba	Ba total	Be	Be tota	Bi	Bi total	Cd	Cd total	Ce	Ce total	Co	Co total	Cr
5	1	KANTENSCHUTZ	0	0	0	0	0	0	0	0	0	0	0	0	0
6	2	TANKKLAPPE	0	0	0	0	0	0	0	0	0	0	0	0	0,2822
7	3	BASISLACK WASSERVE	0	0	0	0	0	0	0	0	0	0	0	0	0
8	4	HYDRO-BASISLACK, L	0	0	0	0	0	0	0	0	0	0	0	0	0
9	5	WASSERBASISLACK ME	0	0	0	0	0	0	0	0	0	0	0	0	0
10	6	EURO-PVC-UNTERBODE	0	0	0	0	0	0	0	0	0	0	0	0	0
11	7	PVC-FEINABDICHTUNG	0	0	0	0	0	0	0	0	0	0	0	0	0
12	8	HYDRO-FUELLER, ALT	0,198434903	521,8837936	0	0	0	0	0	0	0	0	0	0	0
13	9	HT-WASSERFUELLER D	0,17063494	448,7698931	0	0	0	0	0	0	0	0	0	0	0
14	10	HT-WASSERFUELLER A	0,276143231	726,2566979	0	0	0	0	0	0	0	0	0	0	0
15	11	NT EINBRENNFUELLER	0,047464168	124,830762	0	0	0	0	0	0	0	0	0	0	0
16	12	NT EINBRENNFUELLER	0	0	0	0	0	0	0	0	0	0	0	0	0
17	13	LOWBAKE-FUELLER, A	0,167692959	441,0324812	0	0	0	0	0	0	0	0	0	0	0
18	14	2K-KAROSSERIE-KLAR	0	0	0	0	0	0	0	0	0	0	0	0	0
19	15	HAERTER FUER 2K-KA	0	0	0	0	0	0	0	0	0	0	0	0	0
20	16	HEISSFLUTWACHS	0	0	0	0	0	0	0	0	0	0	0	0	0
21	17	HOHLRAUMKONSERVIER	0	0	0	0	0	0	0	0	0	0	0	0	0
22	18	ENTDROEHNUNG	0	0	0	0	0	0	0	0	0	0	0	0	0
23	19	AUSKLD.KOFFERR.SEI	0	0	0	0	0	0	0	0	0	0	0	0	0
24	20	REAKTIVER HOTMELT	0	0	0	0	0	0	0	0	0	0	0	0	0
25	21	METALLVERBUNDKLEBS	0	0	0	0	0	0	0	0	0	0	0	0	0
26	22	UNTERBAU	0	0	0	0	0	0	0,004323	0,004323	0	0	0,182805	0,182805	3,790311
27	23	SEITENTEIL	0	0	0	0	0	0	0,001183	0,001183	0	0	0,000146	0,000146	24,787781
28	24	SEITENTEIL	0	0	0	0	0	0	0,001444	0,001444	0	0	0,000046	0,000046	24,773121
29	25	DACH	0	0	0	0	0	0	0	0	0	0	0	0	0
30	26	DACHQUERTRAEGER,VO	0	0	0	0	0	0	0	0	0	0	0	0	0
31	27	DACHQUERTRAEGER,HI	0	0	0	0	0	0	0,000225	0,000225	0	0	0	0	0
32	28	SCHLOSSTRAEGER,HI.	0	0	0	0	0	0	0,000144	0,000144	0	0	0	0	0
33	29	KOTFLUEGEL	0	0	0	0	0	0	0,000159	0,000159	0	0	0	0	0
34	30	BEFESTIGUNGSCLIP	0	0	0	0	0	0	0	0	0	0	0	0	0
35	31	VERSTAERKUNG	0	0	0	0	0	0	0	0	0	0	0	0	0
36	32	KOTFLUEGEL	0	0	0	0	0	0	0,000159	0,000159	0	0	0	0	0
37	33	VERSTAERKUNG	0	0	0	0	0	0	0	0	0	0	0	0	0
38	34	6KT-FLANSCHSHR	0	0	0	0	0	0	0	0	0	0	0,000001	0,00001	0,05899
39	35	BLINDNIETMUTTER	0	0	0	0	0	0	0	0	0	0	0,000011	0,000066	0
40	36	DUO-6KT-FLANSCHSHR	0	0	0	0	0	0	0	0	0	0	0	0	0
41	37	FRONTKLAPPE	0	0	0	0	0	0	0,001162	0,001162	0	0	0,008002	0,008002	0
42	38	HECKKLAPPE	0	0	0	0	0	0	0,001041	0,001041	0	0	0,000152	0,000152	0,214984

Figure 1. Example of the car parts with the number of different weights of metals [g].

4.2. Thermodynamic rarity assessment

Once the elemental composition of every vehicle is provided, as seen in Figure 1, the thermodynamic rarity of each car part can be obtained by applying Equation 1:

$$R(A) = \sum_{i=1}^{n} m_i \, R_i \quad [\text{kJ/car part}] \qquad \text{(Equation 1)}$$

Where m_i is the mass content of a given element expressed in grams of the selected component i and R_i is the thermodynamic rarity of that specific element (in kJ/g), as shown in Table 1.

It should be noted, however, that the quantity of iron and aluminium contained in the vehicle has been initially removed. This significant mass contribution does not allow to see clearly the criticality of other used metals because their weights are several orders of magnitude lower. Moreover, such minor metals are often not functionally recycled but become downcycled with

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iron and aluminium (i.e., incorporated in minor quantities in the matrix of iron or aluminium blocks with no functional use).

Not only is it essential to obtain the thermodynamic rarity of each car part, but also what we call, "the rarity intensity". This indicator makes it possible to identify car parts that contain valuable metals but with a small relative weight. To calculate this indicator, Equation 2 is applied:

$$Rarity\ intensity\ (A) = \frac{R(A)}{\sum_{i=1}^{n} mi}\ [\frac{kJ}{g}] \qquad \text{(Equation 2)}$$

Where R(A) is the rarity measured in kJ/g of the car part "*A*" and m_i, the specific mass of element *i* in car part A. These values have been calculated for each car part of every vehicle, obtaining a spreadsheet similar to Table 3 and Figure 2. For each car part, the total rarity, the rarity intensity, as well as the rarity of each metal in every car part is provided. It must be also mentioned that the rarity per unit is calculated per piece of the car part. Some car parts have more than one piece, so it is convenient to calculate this value per unit to proceed with the rest of the analysis.

Table 3. Matrix of the thermodynamic rarity calculated for each vehicle.

Car part	Name	Total Rarity	Rarity per unit	Rarity intensity	Element 1	……	Element 61
Car part 1	Name	X [kJ]	X [kJ]	X [kJ/g]	X [kJ]	……	X [kJ]

	A	F	G	H	I	J	K	Q	R	S	T	U
1												
2								95.848,929125	31,009032	5.361,057811	1.202,744700	15,000543
3								148	21	112	112	4
4		Designación	Peso unitario	Piezas	Rarity total (kJ)	Rarity unitaria (kJ)	Densidad de Rarity (kJ/g	Ba	Be	Bi	Cd	Ce
5	1	KANTENSCHUTZ	4,20	1	0,0000	0,0000	0,00%	0,0000	0,0000	0,0000	0,0000	0,0000
6	2	TANKKLAPPE	239,06	1	148,8186	148,8186	62,25%	0,0000	0,0000	0,0000	0,0000	0,0000
7	3	BASISLACK WASSERVE	1,00	2700	4.108,5125	1,5217	152,17%	0,0000	0,0000	0,0000	0,0000	0,0000
8	4	HYDRO-BASISLACK, L	1,00	5000	42.606,7963	8,5214	852,14%	0,0000	0,0000	0,0000	0,0000	0,0000
9	5	WASSERBASISLACK ME	1,00	7600	44.871,0431	5,9041	590,41%	0,0000	0,0000	0,0000	0,0000	0,0000
10	6	EURO-PVC-UNTERBODE	1,00	942	0,0000	0,0000	0,00%	0,0000	0,0000	0,0000	0,0000	0,0000
11	7	PVC-FEINABDICHTUNG	1,00	25	34,9932	1,3997	139,97%	0,0000	0,0000	0,0000	0,0000	0,0000
12	8	HYDRO-FUELLER, ALT	1,00	2630	106.919,9044	40,6540	4065,40%	20.530,9084	0,0000	0,0000	0,0000	0,0000
13	9	HT-WASSERFUELLER D	1,00	2630	105.698,5087	40,1895	4018,95%	17.654,6076	0,0000	0,0000	0,0000	0,0000
14	10	HT-WASSERFUELLER A	1,00	2630	30.917,3885	11,7557	1175,57%	28.570,9385	0,0000	0,0000	0,0000	0,0000
15	11	NT EINBRENNFUELLER	1,00	2630	88.792,6680	33,7615	3376,15%	4.910,8422	0,0000	0,0000	0,0000	0,0000
16	12	NT EINBRENNFUELLER	1,00	2630	1.024.510,8495	389,5479	38954,79%	0,0000	0,0000	0,0000	0,0000	0,0000
17	13	LOWBAKE-FUELLER, A	1,00	2630	17.350,2178	6,5970	659,70%	17.350,2178	0,0000	0,0000	0,0000	0,0000
18	14	2K-KAROSSERIE-KLAR	1,00	1630	0,0000	0,0000	0,00%	0,0000	0,0000	0,0000	0,0000	0,0000
19	15	HAERTER FUER 2K-KA	1,00	440	0,0000	0,0000	0,00%	0,0000	0,0000	0,0000	0,0000	0,0000
20	16	HEISSFLUTWACHS	1,00	1430	0,0000	0,0000	0,00%	0,0000	0,0000	0,0000	0,0000	0,0000
21	17	HOHLRAUMKONSERVIER	1,00	50	0,0000	0,0000	0,00%	0,0000	0,0000	0,0000	0,0000	0,0000
22	18	ENTDROEHNUNG	102,00	2	639,7304	319,8652	313,59%	0,0000	0,0000	0,0000	0,0000	0,0000
23	19	AUSKLD.KOFFERR.SEI	242,00	2	2.013,7368	1.006,8684	416,06%	0,0000	0,0000	0,0000	0,0000	0,0000
24	20	REAKTIVER HOTMELT	1,00	18	0,0000	0,0000	0,00%	0,0000	0,0000	0,0000	0,0000	0,0000
25	21	METALLVERBUNDKLEBS	1,00	48	151,8834	3,1642	316,42%	0,0000	0,0000	0,0000	0,0000	0,0000
26	22	UNTERBAU	135.507,46	1	375.483,3941	375.483,3941	277,09%	0,0000	0,0000	0,0000	27,8418	0,0000
27	23	SEITENTEIL	40.713,46	1	173.190,6664	173.190,6664	425,39%	0,0000	0,0000	0,0000	7,6190	0,0000
28	24	SEITENTEIL	45.355,34	1	194.103,2220	194.103,2220	427,96%	0,0000	0,0000	0,0000	9,2999	0,0000
29	25	DACH	9.609,00	1	42.775,4448	42.775,4448	445,16%	0,0000	0,0000	0,0000	0,0000	0,0000
30	26	DACHQUERTRAEGER,VO	1.309,00	1	0,0000	0,0000	0,00%	0,0000	0,0000	0,0000	0,0000	0,0000
31	27	DACHQUERTRAEGER,HI	2.259,00	1	9.937,5849	9.937,5849	439,91%	0,0000	0,0000	0,0000	1,4491	0,0000
32	28	SCHLOSSTRAEGER,HI.	1.444,00	1	5.992,7021	5.992,7021	415,01%	0,0000	0,0000	0,0000	0,9274	0,0000
33	29	KOTFLUEGEL	1.644,00	1	6.608,2411	6.608,2411	401,96%	0,0000	0,0000	0,0000	1,0240	0,0000
34	30	BEFESTIGUNGSCLIP	1,97	1	0,0000	0,0000	0,00%	0,0000	0,0000	0,0000	0,0000	0,0000
35	31	VERSTAERKUNG	7,29	1	0,0000	0,0000	0,00%	0,0000	0,0000	0,0000	0,0000	0,0000
36	32	KOTFLUEGEL	1.644,00	1	6.608,2411	6.608,2411	401,96%	0,0000	0,0000	0,0000	1,0240	0,0000
37	33	VERSTAERKUNG	7,24	1	0,0000	0,0000	0,00%	0,0000	0,0000	0,0000	0,0000	0,0000
38	34	6KT-FLANSCHSHR	7,00	10	1.182,7033	118,2703	1690,30%	0,0000	0,0000	0,0000	0,0000	0,0000
39	35	BLINDNIETMUTTER	7,31	6	185,3852	30,8975	422,67%	0,0000	0,0000	0,0000	0,0000	0,0000
40	36	DUO-6KT-FLANSCHSHR	13,83	4	137,3790	34,3448	248,30%	0,0000	0,0000	0,0000	0,0000	0,0000
41	37	FRONTKLAPPE	14.137,44	1	78.167,0268	78.167,0268	552,91%	0,0000	0,0000	0,0000	7,4837	0,0000
42	38	HECKKLAPPE	10.599,34	1	47.680,3145	47.680,3145	449,84%	0,0000	0,0000	0,0000	6,7045	0,0000

Figure 2. Example of the thermodynamic rarity for each car part.

Once the thermodynamic assessment has been carried out, all the car parts for every vehicle are classified into ten main groups, considering the rarity and the rarity intensity. The classification is as follows: one category for car parts with a rarity higher than 1 GJ, and nine additional groups (from A to I) according to the values obtained for the rarity and rarity intensity, as reflected for the SEAT Leon Gen. II Diesel High-trimmed example in Figure 3. The reason to make one category called rarity higher than 1 GJ and to exclude it from the rest of the categories (from A to I) is because there are three vehicle components (the engine, gearbox, and front axle) which are included without a disaggregation level in smallest components (i.e., crankshaft, engine head,

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clutch, servo steering, or fuel pump). As a result, these parts have a very high rarity value compared with the rest and must be studied individually.

The final selection of "critical" car parts is then carried out considering the distribution shown in Figure 3, with five columns and five rows, so as to allow for a fast but comprehensive identification of parts. Then, the mesh created is named from A to I, being the most critical car parts those which are close to A. Therefore, to proceed with the selection of critical car parts, it has been decided to choose those car parts which are found in the groups "A to G", while H and I are not considered due to their lower impact in the total rarity of the vehicle.

5. Results

5.1. Case study: SEAT Leon Gen. II Diesel High-trimmed

These results refer to the model SEAT Leon Gen. II Diesel High-trimmed. The results for the other selected analysed models are presented in the Annexes.

The list of car parts provided by SEAT is composed of 1153 car parts. Figure 3 shows the matrix of rarity intensity vs rarity as explained in the methodology section for the analysed model. This figure represents the categories' zones on the left and on the right side, the position for each of the assessed car parts.

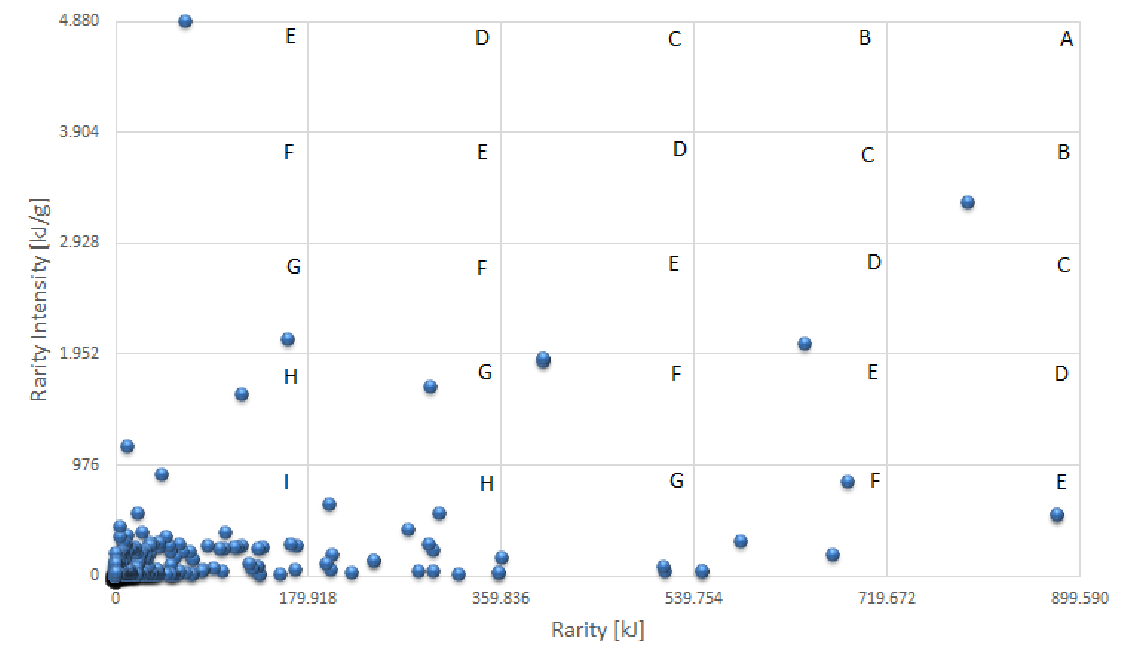

Figure 3. Car parts distribution according to the Rarity intensity vs Rarity indicators for the SEAT Leon Gen. 2 model. Criticality degree of car parts ranges from A to I in descendent order.

Most car parts are categorized in group I (low to medium rarity and rarity intensity values). However, 19 selected car parts fall within the other categories and therefore become critical following the methodology previously described.

Table 4 summarizes the number of vehicle parts for each criticality category.

Table 4. Number of vehicle parts, parts classification and selected critical car parts of the SEAT Leon Gen. II

Total car parts	1.153

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Critical car parts		21	
Car parts in cat. >1GJ	2	Car parts in cat. E	4
Car parts in cat. A	0	Car parts in cat. F	8
Car parts in cat. B	1	Car parts in cat. G	5
Car parts in cat. C	0	Car parts in cat. H	18
Car parts in cat. D	1	Car parts in cat. I	1.114

The identified critical car parts have a total rarity of more than 14 GJ, representing more than 55% above the total vehicle rarity. This means that 21 car parts, which represents less than 2% of the total car parts of the vehicle, contain a high value in terms of exergy due to their metal composition. The list of critical car parts identified can be found in Table 5. As can be seen, except for the engine, gearbox and generator most of them are electronic components. For instance, the door lock is one of the most critical car parts identified because it contains an important amount of elements (Ag, Al, Au, Co, Cr, Cu, Fe, Mo, Ni, Pd, Sn, Sr, Ti, V, Zn), many of them critical; specifically for Pd, which is thermodynamically very critical, its concentration in the door lock is relatively high (close to 0.3 grams).

Table 5. Most critical car parts based on rarity the SEAT León Generation II

Designation	Rarity (kJ)	Rarity intensity (kJ/g)	Group
Transmission	2.163.404	40,0	>1GJ
Engine	1.866.494	12,2	>1GJ
Door lock	795.224	3278,5	B
Central Electric Control Unit	644.017	2032,9	D
Front Axle	899.598	22,5	E
Window Regulator	879.210	528,7	E
Window Regulator	879.210	528,7	E
Control light Airbag	65.798	4881,5	E
Dashboard	683.932	824,1	F
Cable Harness	669.440	177,0	F
Radio	583.423	295,5	F
Wheel Drive	547.563	32,5	F
Wheel Drive	547.534	32,5	F
Door Lock	399.660	1882,5	F
Door Lock	399.525	1899,0	F
Door Lock	399.525	1899,0	F
Battery	513.749	26,5	G
Three phase Generator	512.000	71,8	G
ESP-Unit	359.861,6	154,3	G
MDI-Box	294.324,3	1660,8	G
GATEWAY control unit	160.972,1	2079,9	G

5.2. General overview of results for the selected car models

Table 6 compiles the main results obtained from the analysis.

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Table 6. Overview of the criticality assessment of the selected vehicles

	SEAT Ibiza Gen IV	SEAT León Gen II	SEAT León Gen III
Total mass of the vehicle [kg]	1.216,82	1.386,91	1.282,53
No. of car parts	951	1153	1053
No. of car parts with metals	671	836	754
Total mass of metals [kg]	867,37	996,06	904,08
Total rarity [GJ]	108,77	120,61	133,86
Rarity without Al and Fe [GJ]	22,88	25,35	50,06
No. of critical car parts identified (without considering the ">1GJ group")	15	19	22

Some of the conclusions drawn from the analysis are the following:

- The weight percentage of metals in the analysed cars is between 71 and 74%.
- For all vehicles, between 19 and 24 parts have been identified as critical. Many of them correspond to vehicle electronics.
- Comparing two generations of the same model (Seat Leon II and III), it can be observed that the new generation has in absolute terms a higher content of thermodynamically critical materials than the previous versions, despite the reduction in weight. This difference is even greater if aluminium and iron are excluded from the analysis. This is mainly due to the higher electronics content in the new generation of vehicles, what arguably will become more enhanced with the penetration of hybrid and electric vehicles.
- It is possible to compare Seat Ibiza Gen. IV and Seat León Gen. III since they were manufactured at the same time. It is noticed that the weight of the car for the second is 5% heavier than Seat Ibiza. However, when thermodynamic analysis is applied, this difference in value increases more than 50% (without Al and Fe), explaining in this way the amount of use of critical raw materials (i.e. raw materials with a high thermodynamic rarity) in the Seat León Gen. III.

Further work:

- The identification of critical parts is now an essential step for task 3.2, where most of them will be dismantled to gain insights about the disassemblability process of valuable car components. Moreover, a recyclability assessment of such car parts will be carried out in task 3.3 to assess the potential metal recovery yields that can be attained.

6. References

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7. Annex

7.1. Data output obtained for the model SEAT Ibiza Generation IV

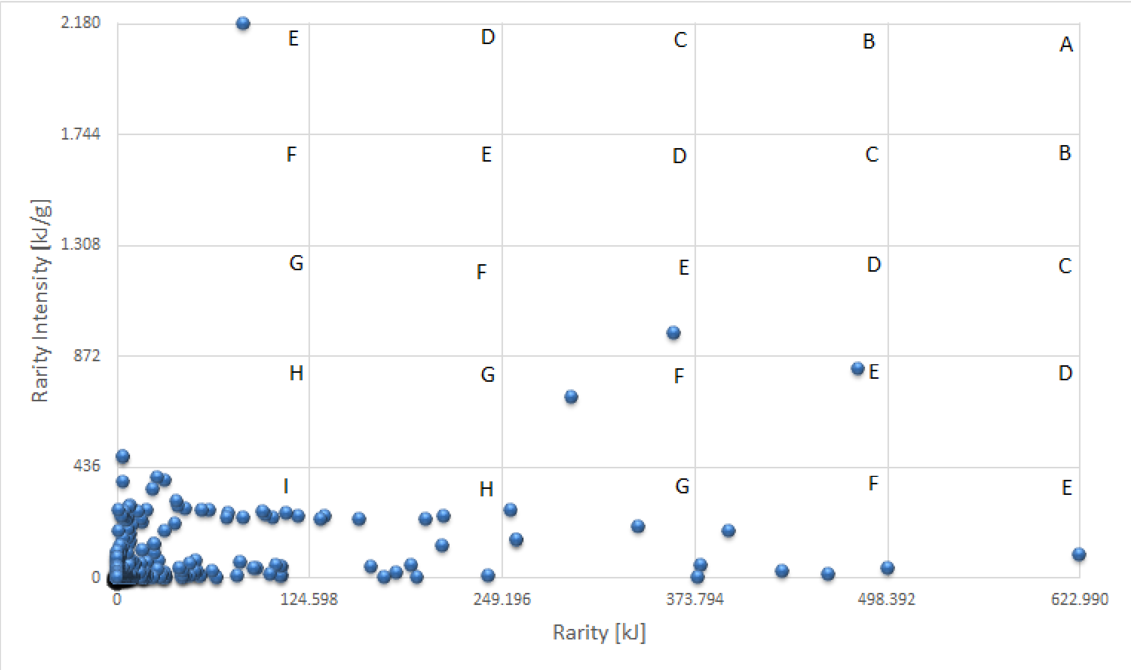

Figure 4. Car parts distribution according to the thermodynamic indicators proposed.

Table 7. Number of vehicle parts, parts classification and selected critical car parts.

Total car parts		951	
Critical car parts		19	
Car parts in cat. >1GJ	4	Car parts in cat. E	5
Car parts in cat. A	0	Car parts in cat. F	6
Car parts in cat. B	0	Car parts in cat. G	4
Car parts in cat. C	0	Car parts in cat. H	14
Car parts in cat. D	0	Car parts in cat. I	918

Table 8. Most critical car parts based on rarity.

Designation	Rarity [kJ]	Rarity Intensity [kJ]	Group
Exhaust system Front	4.648.351,76	491,43	>1GJ
Engine	3.248.099,07	20,30	>1GJ
Control Unit Engine	1.713.900,60	1.531,30	>1GJ
Burning Filler	1.024.510,85	389,55	>1GJ
Three Phase Generator	622.988,42	89,69	E
Steering system	498.376,41	37,64	F
Dashboard	479.711,99	819,24	E
Control Unit light	81.985,55	2.181,05	E

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Transmission	460.062,67	11,21	F
Battery	430.308,48	26,12	F
Basic Module harness	396.488,35	180,80	F
Air conditioner	378.137,91	46,82	F
Substructure	375.483,39	2,77	F
Lock	360.173,54	961,15	E
Engine harness	337.454,76	199,05	G
Central Electric control unit	294.403,89	707,70	F
Brake Unit	258.883,32	147,09	G
Brake Unit	258.865,59	147,08	G
Rear light harness	254.709,46	263,14	G

7.2. Data output obtained for the model SEAT León Generation III

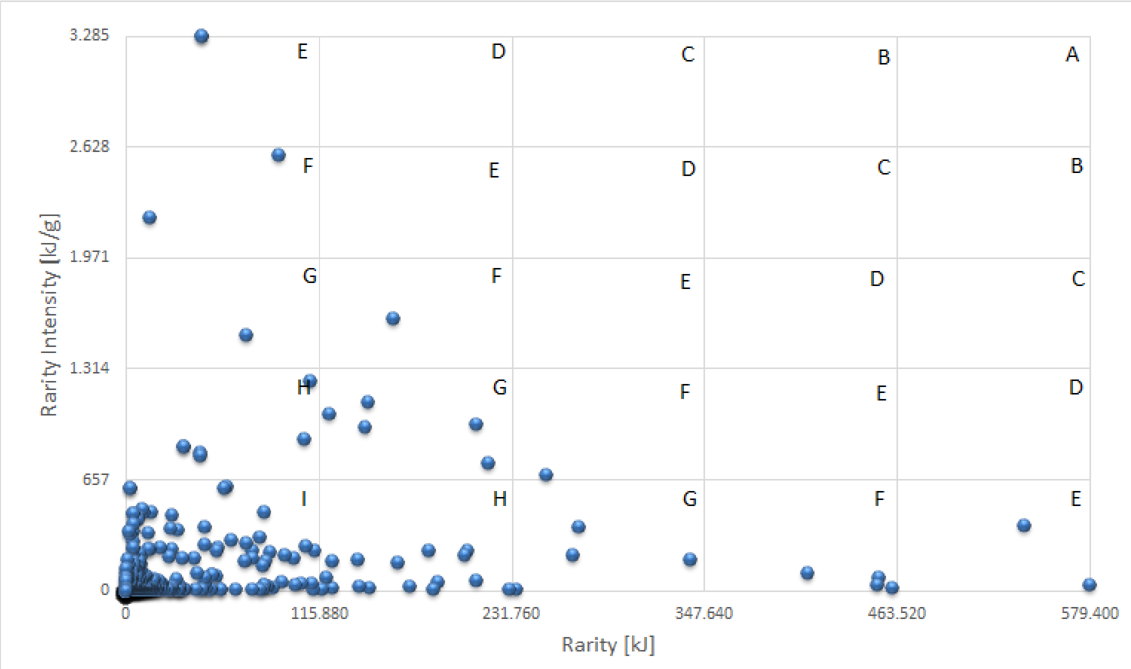

Figure 5. Car parts distribution according to the thermodynamic indicators proposed for the model SEAT Leon Gen. III.

Table 9. Number of vehicle parts, parts classification and selected critical car parts proposed for the model SEAT Leon Gen. III

Total car parts		1.053	
Critical car parts		24	
Car parts in cat. >1GJ	2	Car parts in cat. E	4
Car parts in cat. A	0	Car parts in cat. F	8
Car parts in cat. B	0	Car parts in cat. G	10

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Car parts in cat. C	0	Car parts in cat. H	22
Car parts in cat. D	0	Car parts in cat. I	1.007

Table 10. Most critical car parts based on rarity proposed for the model SEAT Leon Gen. III

Designation	Rarity [kJ]	Rarity Intensity [kJ]	Group
Engine	34.031.181	203,0	>1GJ
Transmission	1.750.486	33,5	>1GJ
Battery	579.400	28,1	E
Central computer	539.949	387,1	E
Front Axle	460.442	14,5	F
Three Phase Generator	452.757	71,5	F
Reflection DAE	452.180	32,6	F
Starter	409.572	98,4	F
Cable Harness	339.722	179,8	G
Dashboard	272.043	370,9	G
Rear light harness	269.042	205,1	G
Central Electrical control unit	252.293	683,7	F
Side panel	234.459	5,7	G
Speaker	217.879	756,4	G
Airbag	210.904	983,3	G
Belt Warning	160.656	1610,5	F
Radio Entry harness	145.352	1112,1	G
Motor light	144.117	960,8	G
Horn	122.635	1045,6	G
Transmission	91.611	2579,2	F
Make up mirror harness	72.432	1507,3	G
START/STOP	45.942	3283,5	E
Shock Absorber	45.942	3283,4	E
Controller	14.450	2210,2	F

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