Ref. Ares(2025)2595229 - 01/04/2025

MEDALS

Metallic Elements Dissipation Avoided by Life cycle design for Steel

Deliverable 2.3

MetricReport

Project details

Project Title	**Metallic Elements Dissipation Avoided by Life cycle design for Steel**		
Project Acronym	**MEDALS**		
Grant Agreement No.	101138516	**Duration**	48 months
Project Start Date	01-07-2024	**Project End Date**	30-06-2028

Document details

WP:	2	**WP Leader:**	KTH
WP Title:	New performance metric for tramp element removal		
Task:	**2.2**	**Task Leader:**	KTH
Task Title:	Quantification of tramp element removal		
Deliverable No.	**D2.3.**		
Deliverable Title	MetricReport		
Dissemination level	PU		
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Contributing beneficiary(ies)	KTH, KOB, SID, TEC		
Approved by	Björn Glaser		
Status	Final version		
Date	30 March 2025		

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List of Abbreviation

BF	Blast Furnace
CRM	Critical Raw Material
DDQ	Deep Drawing Quality
EAF	Electric Arc Furnace
EoL	End of Life (for products)
EoW	End of Waste
EPD	Environmental Product Declaration
GWP	Global Warming Potential
HBI	Hot Briquetted Iron
IF	Interstitial Free
ISO	International Organization for Standardization
LME	London Metal Exchange
RIR	Recycling Input Rate
USD	United States Dollar
XRF	X-Ray Fluorescence

Abstract

The present document corresponds to the deliverable D2.3 report on “MetricReport”. The goal of this deliverable is to report the parametric “Metric” which can be used as reference to analyse the removal of tramp elements, specifically for copper and tin. The report also deals with the value of assessing scrap analysis and variation in analysis as well as alloy recovery. The research in the MEDALS project will be focused on this “Metric” so that novel industrial practices can be developed. The proposed metric will be updated during the timeline of the MEDALS project.

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1 Introduction

This document presents the findings and methodologies associated with Deliverable D2.3, titled "MetricReport" under the broader scope of the MEDALS project, aimed at advancing the lifecycle design for steel through the mitigation of metallic element dissipation. Coordinated by KTH and in collaboration with partners including SIDENOR, TECNALIA, and KOBOLDE, this deliverable focuses on the development, application, and validation of a new metric designed to quantify the efficacy of tramp elements removal, specifically copper (Cu) and tin (Sn) from the scrap and recovery of alloying elements.

Furthermore, an objective is to establish the method as a robust metric for assessing the removal of tramp elements across different processes. This was motivated by the need of enhancing the purity of recycled steel, which is critical for its performance and market value. The development of this metric also aligns with the MEDALS project's goals to introduce innovations that reduce environmental impacts and promote sustainable industrial practices. Decreasing contamination of steel by tramp elements investigated in MEDALS can be done in different ways. Tramp element removal can be carried out either at the scrap processing stage by identifying and removing shrapnel with high tramp element content to enhance alloy recovery and purity or during the melting stage.

In addition to the removal of tramp elements, the assessment of scrap quality by means of measuring techniques allows the use of charging recipes without unnecessary big safety margins. This document is focussed on calculating the actual effect of implementing a technology. To assess the economic viability, the processing cost and the value generation must be calculated with similar equations. That will be done in the separate WPs.

This report has been prepared in cooperation with the projects Scrap Precision and Design Value, both funded by Sweden's Innovation Agency, Vinnova.

2 Complex products and the circular economy

Complex products contain many different metals and alloys to give them their performance. At the end of life most parts are shredded and the metals separated in a magnetic and a non-magnetic flow. Copper, though being non-magnetic, is often trapped in iron parts and goes with the magnetic flow. Ferritic alloys containing for example nickel, chromium, manganese and molybdenum go into the magnetic stream and are seldom, if ever, valorised. The smaller stream of non-magnetic shrapnel represents a higher value and is sorted in different flows like copper, brass, copper-alloyed aluminium, aluminium, stainless steel with and without molybdenum. Creating an additional special stream of stainless steel where manganese replaces nickel would also be desirable but is not always the case. For the ferritic flow, so far, the strategy has been to dilute the scrap to keep the alloys under set limits for tramp elements creating a rather big scrap flow. Trials to apply automatic sorting have so far not proven to be profitable, probably for several reasons, other than perhaps removing trapped copper. A vision of a future "Design-Deconstruction-Recycling" flow where the value of alloys is retained over the life cycles is shown in **Figure 1**. In some cases, as pure metals but most often as well sorted alloys where the components keep their value giving the alloy the intended properties. This is what is generally called closed loop recycling.

Figure 1. A vision where the value of metals is retained over consecutive product life cycles. (DesignValue project, artwork: Katarina Hamilton.)

Such a vision can only be realised by considering other values than low contamination and the scrap alloy value. Scarcity of raw materials and avoided emissions must play a role as must the willingness of product producing companies to carry part of the burden to ensure a low environmental footprint of the product. Creating a logistic system where alloys are tracked, sorted and valorised requires cooperation throughout the supply chain supported by standardisation and a legislative framework.

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This kind of development can only be realised with a well-functioning metric system where the status of operations and possible improvements can be assessed.

2.1 Alloys in the circular economy

Material flows over a complex product's life cycle from a steel alloy's perspective is shown in **Figure 2**. The steel cycle can be described in many ways and the nomenclature shifts. **In this report these process steps and these terms are used to serve the goals of the MEDALS project.** Keeping the alloying elements in the loop without contamination is the main challenge as is described below in paragraphs 2.1.1-2.1.9.

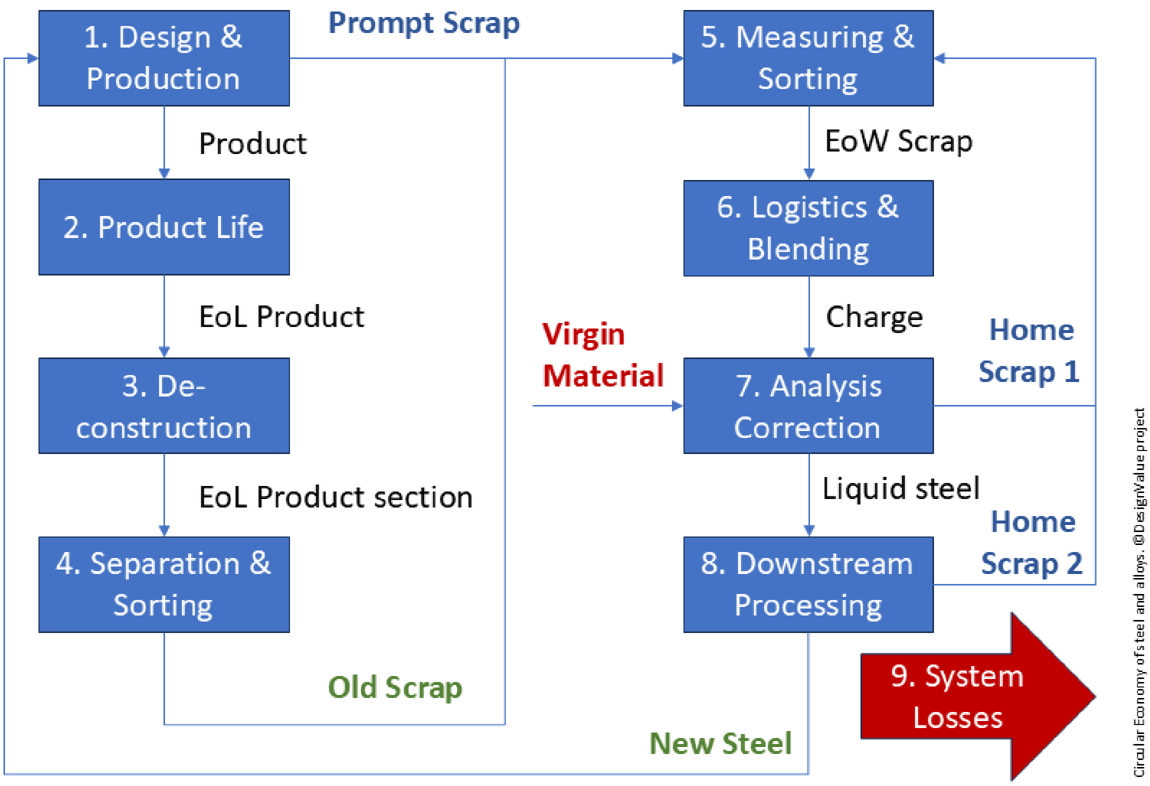

Figure 2. The product life cycle from the perspective of alloyed steel in complex products. In a static system materials are recycled and virgin materials have to be added to make up for system losses and system growth.

2.1.1 Design and production of a product

Product companies have a detailed documentation on the content of steel, stainless steel, cast iron, copper and aluminium necessary to fulfil EU-legislation.

Improvements involve:

1. Separating alloys in turnings and cuttings that become prompt scrap in different streams. Especially steel that contains copper, manganese and phosphorous.
2. Designing for deconstruction of an EoL product in sections with high amounts respective low amounts of alloys. That would make alloy valorisation more efficient.
3. Making a deconstruction instruction focussed on resource recovery.
4. Reporting the metal content of a product (per section?) in a product passport.
5. Estimating the recovery rate of the metals necessary for module D in product Environmental Product Declarations (EPDs). Module D, aims to account for net credits and environmental impacts from recyclable materials and energy recovery at the end of a product's life cycle, presents several challenges for modeling in the context of EPDs.

2.1.2 The product life

A complex product with a long life normally needs service and is refurbished during the lifetime. Replacing parts could be seen as an early deconstruction and the following processes for the part should be the same as for the same part at EoL.

2.1.3 Deconstruction

The main purpose for the deconstruction process from an alloy recovery perspective is to separate the product into sections suitable for the following separation and sorting process. Depending on the alloy content, the combination of alloys etc, a simpler and cheaper separation and sorting process may be sufficient or a more advanced and more expensive process may be necessary.

2.1.4 Separation and sorting

For complex products this means one or more shredder steps with different types of consecutive sorting steps. In the simplest version it means a single shredding step and separation in one magnetic and one non-magnetic stream where only the non-magnetic stream is sorted further. For a scrap where the magnetic part is richer in alloys, more than one shredding step may be necessary, followed by sorting with, for example, laser identification and robot sorting.

2.1.5 Measuring and sorting

This step constitutes several different activities and technologies assessing the quality for all types of scrap measuring the alloy content. This is normally the step where the scrap stops being waste and becomes a product (End of Waste - EoW). Analysing scrap can be done manually with a hand-held analyser on the scrap yard, with a fixed sensor on a conveyor belt or other arrangements.

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2.1.6 Logistics and blending

Low alloyed scrap procurement is today based on well-defined scrap classes with generous limits on tramp elements. A typical lot size is more than 100 ton.

Improvements in alloy recovery involve:

1. Sorting shredded ferritic scrap means that several new scrap classes arise that have to be handled. Furthermore, the scrap lots become smaller for the recycler and the steel company to handle. If that can be managed the alloys can be valorised.
2. Charge calculations become more precise due to better sorted scrap.

2.1.7 Analysis correction (melting step)

The steel analysis given by a scrap mix can be corrected in the melting step. For carbon steel production, the content of alloying elements with an affinity to oxygen higher than that of iron can be reduced by increasing the oxygen potential in the melt. This will oxidise, for example, phosphorous, manganese and chromium to the slag and decrease the carbon content. These elements are then lost when the slag is removed and if the operation aimed at removing phosphorus and the final steel shall contain higher levels of manganese, chromium and carbon these alloying elements must be added as virgin materials after this phosphorus refinement. Apart from being recovered in the slag, some iron and other alloying elements could leave the system and be recovered as dust in the filter

Alloying elements with less affinity to oxygen than iron like copper and nickel cannot be removed with oxidation. The normal way to deal with a copper or nickel content over the prescript limit is to:

1. Ask the customer if they can accept a higher level of the problematic element.
2. Replan the charge to another order for a steel quality with a higher limit.
3. Dilute the charge with pure material.

All three methods come with a cost where the last is the costliest.

A method to remove copper from liquid steel is suggested and will be tested in the MEDALS project. In the melting and casting steps, slag containing metal droplets or metal crusts is recovered, processed and recycled as home scrap. These batches of recovered metallics come from several charges with different analyses and consequently sorting this type of home scrap is a challenge.

2.1.8 Downstream processing

The processing after casting creates several streams of home scrap and recoverable residuals, for example:

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- Cuttings from casting, hot rolling, cold rolling, coating and formatting.
- Mill scale from heat treatment and rolling operations.
- Grinding residue from surface treatment.
- Pickling acid from surface treatment.

Whereas the first constitutes the biggest volumes, the other three are recycled as a necessity to avoid depositing and possible contamination should be avoided by choosing optimal use.

Improvements in alloy recovery involve:

- Ensuring meticulous sorting of the home scrap material.
- Strengthen efforts to use of residuals in an optimal way whatever that is.

2.1.9 System losses

The material losses accounted for in **Figure 2** are:

1. Alloying elements lost to slag, dust and other co-products and residuals.
2. Alloys becoming tramp elements

The model contains input of virgin alloys which is necessary to make up for material losses and allow for increased production volumes. **Abating losses constitute an opportunity for contributions to financing the alloy recovery and clean steel.**

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3 Existing relevant Metrics in steel production and scrap management

3.1 Metrics based on mass of steel

The most used Metric today has nothing to do with alloys or scrap quality but focuses on resource use in the society. The recycling rate as described in ISO standards like ISO 20915, is here expressed in equations 1-3 using the nomenclature from **Figure 2**. The application in the supply chain is illustrated below in **Figure 3**:

$$\textbf{Recycling rate}\ (\%) = 100 * \left(\frac{\text{mass of Prompt Scrap} + \text{mass of Old Scrap}}{\text{mass of New Steel}}\right) \quad \textbf{(1)}$$

When only looking at the end of life scrap the following equation can be used:

$$\textbf{End of life recycling rate}\ (\%) = 100 * \left(\frac{\text{mass of Old Scrap}}{\text{mass of New Steel}}\right) \quad \textbf{(2)}$$

The manufacturing yield can be expressed as:

$$\textbf{Manufacturing yield}\ (\%) = 100 * \left(\frac{\text{mass of steel in Product}}{\text{mass of New Steel Input}}\right) \quad \textbf{(3)}$$

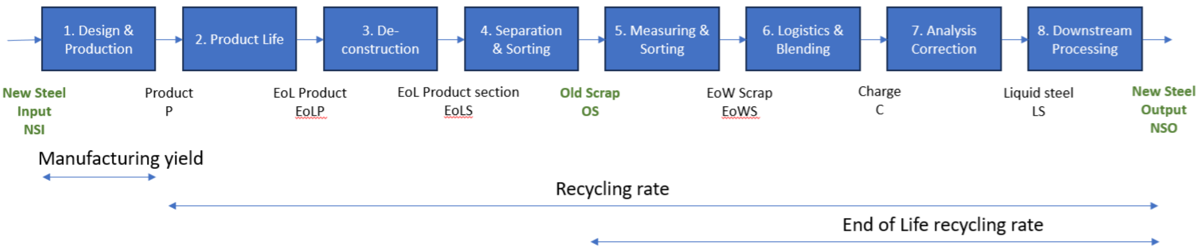

Figure 3. Processing steps used in equation 1-3.

The way these metrics are used today, the equations 1 and 2 express how much of the new steel is produced from scrap material from all types of products instead of using virgin material. Equation 2 focus on the old scrap and equation 3 on generation of prompt scrap. In a market where all scrap is used and virgin material must be added to satisfy increasing demand for steel, equation 3 is the most relevant from a sustainability point of view provided an increase in yield is not achieved decreasing the product functionality, while equation 1 and 2 are more relevant for engineering or financial studies.

3.2 Metrics based on mass of steel but used to study burdens

Standards for Environmental Product Declarations, EPDs, include a calculation of benefits and loads beyond the End of Life, called Module D. In these calculations, the end-of-life recycling rate for the initial product, the burdens making steel from scrap and possible material and quality losses are included to calculate the net benefit of recycling. This can be either positive or negative depending on the recycling rate for the initial steel, material losses and the quality loss. Although the calculation is based on mass, what is most often studied are the impact categories: Global Warming Potential (GWP), and Resource Depletion. For this type of scenario, the equation 2 can be used. See for example CEN-PREN 17662.

3.3 Metrics based on element content in scrap

As stated above low alloy scrap is traded in defined scrap classes with maximum values of certain elements like copper, nickel, molybdenum, chrome and tin. For high alloy scrap, the same alloys occur with both a minimum and maximum value. For prompt scrap, the exact steel type and alloy content may be given but that is more of an exception. Example data of average values and standard deviation can be seen in **Table 1**. An example of how the copper analysis in shredded scrap can vary over time can be seen in **Figure 4**.

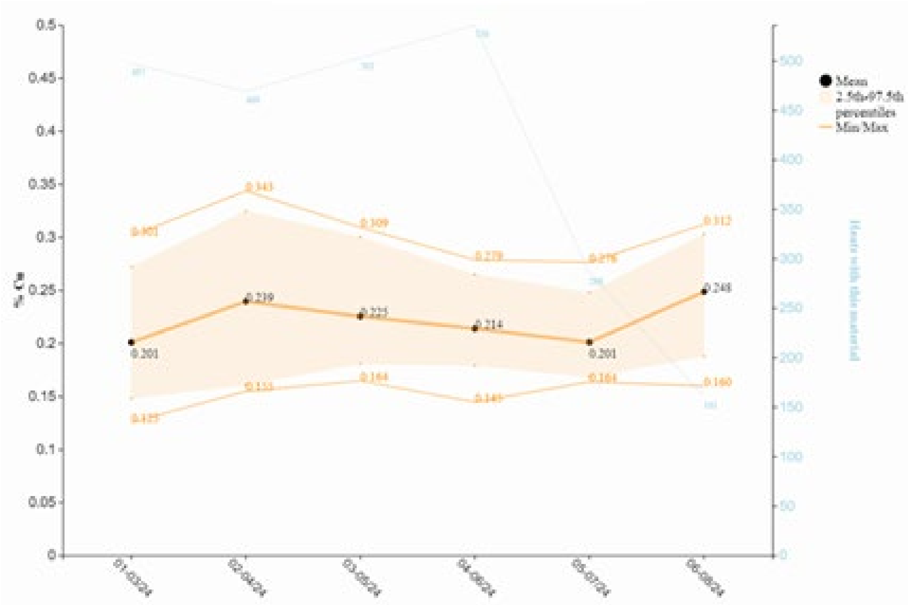

Figure 4. Copper content in shredded scrap estimated from charge data. Three month moving average with the average analysis in the middle, max and min values and a 95% confidence interval in the amber field. (Scrap precision project).

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Table 1. Post mortem analysis of charge data with calculated tramp elements in ferritic low alloyed scrap. Preliminary data from project ScrapPrecision 2024 and collected heuristic data from the USA. Hot Briquetted Iron, HBI, is added as a reference.

Scrap type	**Value**	**Cu**	**Ni**	**Mo**	**Cr**	**Mn**	**Sn**	**P**
Shredded scrap	Mean	0.230	0.064	0.011	0.271	0.245		
Old thick average	Mean	0.143	0.101	0.024	0.009	0.119		
Old thick standard deviation	Mean	0.008	0.007	0.002	0.010	0.018		
New thin average	Mean	0.034	0.070	0.009	0.107	0.195		
New thin standard deviation	Mean	0.017	0.018	0.004	0.031	0.038		
Heuristic data Steil								
Shredded scrap ex. Car bodies	Mean	0.240	0.035	0.006	0.055	0.393	0.009	0.035
Shredded scrap ex. HMS	Mean	0.190	0.042	0.005	0.211	0.273	0.004	0.016
Shredded scrap average mix	Mean	0.240	0.066	0.009	0.235	0.339	0.007	0.028
Shredded scrap XRF sorted	Mean	0.054	0.035	0.006	0.170	0.240	0.007	0.024
Heuristic data (USA)								
Shredded scrap	Mean	0.23	0.069		0.123		0.052	
Old thick	Mean	0.234	0.07		0.13		0.017	
New thin	Mean	0.027	0.020		0.031		0.002	

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HBI								

3.4 Metrics for steel quality

As stated above, an element may be a tramp element in one steel type and an alloying element in another. Even though a tramp element may not be directly harmful it represents a value that is lost. As an example, the effect of elements on some steel properties are shown in **Table 2** and examples of limits are shown in **Table 3**.

Table 2. Examples of impact on steel for seven elements that all can appear as alloying or detrimental tramp element depending on application. Adopted from Davis 2001. (+) positive impact (-) negative impact.

Steel property	**Cu**	**Ni**	**Mo**	**Cr**	**Mn**	**Sn**	**P**
Strength		+			+		+
Ductility							-
Fatigue		+					
Hardness					+		+
Abrasion resistance				+			
Hardenability		+	+	+	+		
Sharpy impact (impact resistance)							-
Fracture Toughness							-
Temper embrittlement						-	-
Hot shortness (grain boundary brittleness)	-					-	
Carbide former			+	+			
Surface quality in fabrication	-				+		

Table 3. Examples of limits to tramp elements for different types of steel. Adopted from Hellen et. Al. 2006, and Alvarez et al. 2003.

Steel type	**Cu**	**Ni**	**Mo**	**Cr**	**Sn**
IF Steel (Ultra-low carbon interstitial free)	0,03	0,03	0,008	0,03	0,008
DDQ (Deep Drawing with low carbon and residuals)	0,040	0,040	0,010	0,040	0,015
Drawing	0,060	0,060	0,015	0,060	0,015
Commercial (mild forming, low demand on surface)	0,100	0,080	0,015	0,080	0,020
Structural (Higher strength)	0,120	0,100	0,040	0,100	0,030
Fine wire	0,070	0,070	0,015	0,080	0,015
Rebar	0,400	0,350	0,080	0,150	0,080

Another way of expressing this is to consider the fraction of products with a limit under certain levels. A useful example is having one third of the production with demands under 0.15% Cu, one third under 0.20 and the rest under 0.25 with few exceptions having lower or higher limits. (Ref Sidenor)

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3.5 Value of tramp element removal and alloy recovery

3.5.1 Managing the element distribution in the melt

Possible deployment of the methods for tramp element removal depends on the value obtained by utilising new information, better scrap or having the possibility to adjust a missed threshold. **Figure 5** explains the role of copper removal from the melt. If the copper right tail is not a big problem, the charge recipe can be calculated with smaller margins cutting costs and reducing the need for primary iron. On the other hand, the figure shows that from time to time a quality limit might be exceeded and then the possibility to adjust the melt is valuable.

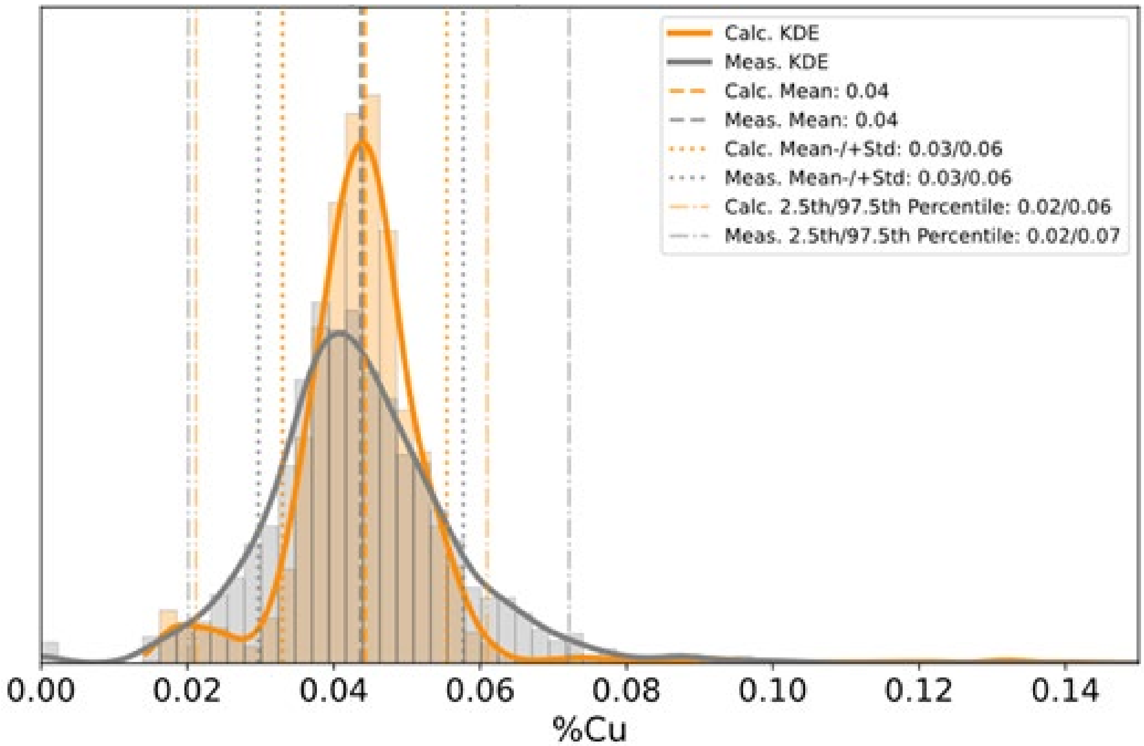

Figure 5. The variation in copper in steel. The amber field shows the distribution based on simulation with estimated raw material analyses and actual charged weights and the grey field shows the actual steel analysis for the charges. (Scrap precision project).

3.5.2 Estimating the value of improved scrap quality

The price of scrap depends on material yield and tramp element content. Price differences between different scrap classes over time can be seen in **Figure 6**.

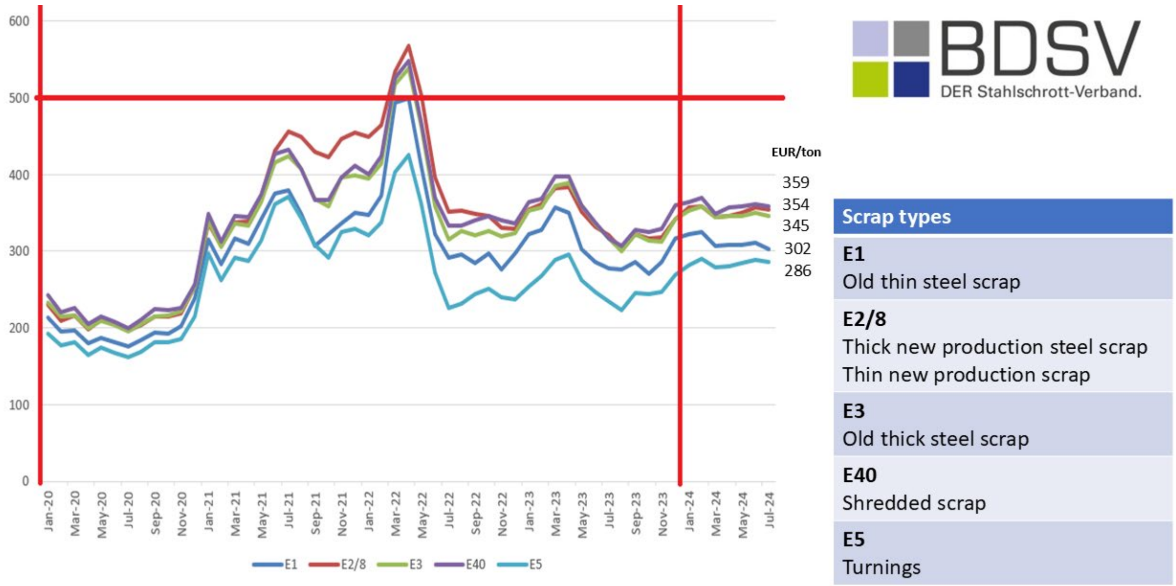

Figure 6. Price difference between different types of scrap in the European scrap market. New scrap and shredded material are the most expensive due to low tramp element content in the new scrap and charging properties. Old thick has a lower value due to impurity.

3.5.3 Valorising alloys recovery, GWP and Resource depletion impact categories

The fact that Europe imports large amounts of alloys and critical minerals is recognised by the EU. Furthermore, the higher carbon footprint of alloys makes it relevant not to waste them as tramp elements. **Table 4** summarises GWP potentials, prices and some data from the EU list of critical raw materials 2023 for some elements.

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Table 4. Price, carbon footprint and supply risk for seven elements that all can appear as alloying or detrimental tramp element depending on application.

	Cu	Ni	Mo	Cr	Mn	Sn	P
Price level USD/kg 20250212 *LME.com, **Metal.com	9*	15*	50**	7.5**	1.6**	30*	3**
Carbon footprint, Kg CO_{2eq}/kg [Torrubia et al. 2023]							
Upper	64.9	27	24		9.6		
Medium	5.5	13	12	2.4	5.2	17	
Lower	1.1	7	6		1		
EU list of critical raw materials 2020 [EU 2023]							
Supply Risk	0.1	0.5	0.8	0.7	1.2	0.9	3.3
Economic Importance (Index	4	5.7	6.7	7.2	6.9	4.5	4.7
Import Reliance % (Figure for Cr from 2020)	48	75	100	66	96	100	100
EOL Recycling % (How much of the input comes from rec)	55	16	30	21	9	31	0
Critical supply factor E: Extraction, P: Processing	E	P	E	E	E	P	P
Critical and strategic 2023	x***	x***			x		x

***Copper and nickel do not meet the CRM thresholds, but are included as Strategic Raw Materials

Critical raw materials (CRMs): Raw materials of a high importance to the economy of the EU and whose supply is associated with a high risk. The main two parameters: Economic Importance (EI) and Supply Risk (SR) are used to determine the criticality of the material for the EU. The list of CRMs is established on the basis of the raw materials which reach or exceed the thresholds for both parameters.

Economic Importance (EI): One of the two main assessment parameters (in addition to Supply Risk) of the EC methodology to measure the criticality of a raw material. In the EC methodology, the Economic Importance is calculated based on the importance of a given material in the EU for end-use applications and on the performance of available substitutes in these applications.

End-of-life Recycling Input Rate: The end-of-life recycling input rate (EOL-RIR) since the 2017 assessment refers to the ratio of recycling of old scrap in the EU to the EU supply of raw material. In other words, EOL-RIR is production of secondary material from post-consumer functional recycling (old scrap) sent to processing and manufacturing and replacing primary material input. In the previous EC criticality assessments (EC 2011, 2014), recycling rates and EOL-RIR refer only to functional recycling i.e. the portion of EOL recycling in which the material in a discarded product is separated and sorted to obtain recyclates.

Manganese, being a Strategic Raw material, used in steelmaking and batteries became critical due to Supply Risk increase at the extraction stage caused by lower domestic supply dropping from 32t to 10t (Bulgaria and Hungary production stopped) increasing import reliance and by more concentrated imports from South Africa 41% (33% in 2020) and Gabon 39% (26% in 2020). EI has always been very high.

Nickel, being a Strategic Raw material, is the only battery material which has never been on the list because of good supply diversification for the assessed period. Assessment however neither reflects the concentration of ownership of the projects and production capacities, nor private contractual arrangements, which may become an issue for the future. Main global producers of ores and concentrates are Indonesia 26%, Philippines 14%, Russia 10%, New Caledonia 9%, Canada 8%, Australia 8% and several smaller producers; and EU sources 39% from Finland, 24% from Canada, 19% from Greece, 8% from South Africa, 4% from the US. Main refiners are China 33%, Indonesia 12%, Japan 9%, Russia 7% and several smaller producers; EU sources refined nickel from 29% from Russia, 18% from Finland, 11% from Norway, 7% from Canada, 7% from Australia, 4% from Greece and several smaller importers.

Copper, being a Strategic Raw material, is used in very large quantities of 20 Mt in 2020 for electrification across all strategic technologies. Its supply is very well diversified, therefore it has not been considered critical before. However, it is challenging to substitute due to its superior performance in electrical applications.

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4 New Metrics for abating metal dissipation

Two types of metrics relevant to metal dissipation have been developed in the MEDALS project: removal for tramp elements and capture for alloying elements. Furthermore, the metrics can be applied on an individual step or on a sequence of steps. Metrics based on monetary and sustainability values are discussed later. The idea is that the metrics shall be used for case studies based on statistics, as well as for evaluating trial results leading to guidelines on efficient processing lines for different kinds of product life cycles.

Development and Deployment of the Metric

Task 2.2 involved the creation of a metric that utilizes relevant quantities, such as to remove the tramp elements from scrap, to assess removal efficiency. This metric was designed with input from multiple project partners, ensuring its relevance and applicability across diverse industrial contexts. Using detailed data from weighing, production, and energy consumption could be possible to develop metrics that can not only enhance the understanding of Cu and Sn removal efficiencies but also promote sustainable and cost-effective practices in steel scrap recycling. This approach will perhaps ensure that the proposed metrics are grounded in actual operational data, providing a robust basis for continuous process improvements.

Metric from Input Quality: The weighing data from the scrap manufactures provides detailed information on the types and quantities of scrap entering the process. The project can develop metrics that relate specific scrap types to their inherent tramp element challenges. This directly contributes to the MEDALS project's goal of improving the purity and quality of recycled steel, ensuring that the input materials are well-understood and managed appropriately for their metal content.

Production Efficiency Metrics: The production data may offer insights into the operational aspects of recycling processes, including throughput rates and downtime. Developing metrics that relate these operational parameters to the quality of output (in terms of tramp element removal) supports MEDALS' objectives to enhance the efficiency of steel recycling processes. This can lead to more consistent production quality and reduced variability in recycled steel properties.

Energy Efficiency and Sustainability Metrics: The energy consumption data may be crucial for developing metrics that measure the energy efficiency of tramp element removal processes. Optimizing these processes to consume less energy while maintaining or enhancing the quality of tramp element removal, the MEDALS project can make significant strides towards its goal of reducing the environmental impact of steel production. This aligns with global sustainability targets by

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decreasing the carbon footprint of steel recycling operations. In the Electric Arc Furnace (EAF) process, steel is primarily made from recycled scrap, where the copper content tends to be higher due to the accumulation from previous cycles of use and recycling. The decentralized nature of scrap sources can lead to variability in copper levels, posing challenges in controlling its concentration. As the EAF process relies heavily on electric energy, advancements in operational efficiency and innovations in scrap pre-treatment and post-melt treatment are crucial. Monitoring metrics such as **“Copper Removal Efficiency”** and **“Energy Consumption per Unit of Copper Removed”** are essential. These metrics help in optimizing the process to achieve lower energy use while maximizing copper removal, aligning with sustainable production goals. Conversely, the BF process primarily utilizes raw materials like iron ore, coke, and limestone, resulting in inherently lower initial copper levels. However, the integration of scrap metal to reduce cost and environmental impact has been increasing. The control of copper in the BF and EAF process is more about preventing introduction rather than removal. Therefore, monitoring the **“Copper Introduction Rate from Scrap”** and **“Copper Dilution Efficiency”** becomes important. These metrics ensure that the addition of scrap does not adversely affect the overall copper content in the produced steel. Moving forward, the evolution of copper management in steel shops will likely focus on enhancing techniques for both reducing the input copper levels and efficiently removing copper during the steelmaking process. Innovations might include more precise scrap sorting technologies, improved slagging agents that can bind copper, and advanced metallurgical processes that facilitate the separation of copper from molten steel. For both EAF and BF approaches, developing and closely monitoring specific metrics tailored to their operational realities and copper management needs is crucial. This strategic focus will not only improve the quality of steel but also its sustainability and economic viability in a competitive global market. An equation for evaluating the efficiency of removing tramp elements can be formulated as:

$$\textbf{Removal Efficiency}\ (\%) = \left(\frac{\text{Initial element content} - \text{Residual element content}}{\text{Initial element content}} * 100\right) \qquad \textbf{(4)}$$

The removed elements can either be transferred to the slag, the dust or other residuals or recovered in a way that it retains its metal value. It could be as a pure element or in the form of an alloy. Downcycling recovery such as agglomerates shall not apply unless the element properties play a valued role.

$$\textbf{Recovery Efficiency}\ (\%) = 100 * \left(\frac{\text{Mass of recovered element}}{\text{Initial mass of element}}\right) \qquad \textbf{(5)}$$

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5 Development of metric for copper removal

Rationale for Focusing on Copper

Copper presents unique challenges and opportunities within the steel recycling industry due to its high economic value, significant market demand, and prevalent content in steel scrap. As one of the most detrimental contaminants in steel scrap, copper significantly affects the quality and performance of recycled steel. Its removal is not just a quality issue but also a financial one, as the successful extraction and resale of copper can lead to substantial economic gains. Given these factors, the development of a dedicated metric for copper removal is not only beneficial but essential for optimizing recycling processes.

Definition of the Metric

The proposed metric for copper removal will quantitatively assess the efficiency and effectiveness of copper extraction processes from steel scrap. The metric will focus on the following key parameters:

- **Initial Copper Content**: The concentration of copper in the steel scrap before the recycling process begins.
- **Residual Copper Content**: The concentration of copper remaining in the steel after the recycling process.
- **Removal Efficiency**: The percentage of copper successfully removed during the recycling process, calculated as:

$$\textbf{Removal Efficiency}\ (\%) = \left(\frac{(\text{Initial Copper content} - \text{Residual Copper content})}{\text{Initial Copper content}} * 100\right) \quad \textbf{(6)}$$

Methodology for Metric Calculation

1. **Data Collection**:
   - Collect samples from various scrap grades at multiple processing stages to measure the initial and residual copper content using spectroscopic analysis or other relevant chemical analysis techniques.
2. **Metric Application**:
   - Apply the metric across different recycling facilities and processes to benchmark and compare the efficacy of various copper removal technologies.
   - Use the metric to identify best practices and technologies that maximize copper removal efficiency.

Implications for Recycling Processes

- **Standard Setting**: The metric will help set industry standards for acceptable levels of copper in recycled steel, guiding scrapyards and recyclers on the required quality benchmarks.

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- **Process Improvement**: By quantifying the removal efficiency, recyclers can adjust and improve their processing techniques, such as enhancing magnetic separation or introducing advanced sorting technologies like sensor-based sorting or flotation techniques.

Integration with Industry Practices

- **Compliance and Reporting**: Facilities can use the metric to report compliance with environmental regulations and quality standards, making it easier to track improvements and adhere to industry best practices.
- **Economic Impact**: As copper removal directly ties to economic returns due to the value of recovered copper, this metric also serves as a financial tool to evaluate the profitability of different recycling processes.

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6 Development of metric for Tin removal

While the primary focus of many recycling initiatives may be on elements like copper due to their economic impact, the removal of tin is equally important due to its influence on the quality and recyclability of steel. Tin is commonly found in steel scrap in the form of tin-plated materials and is particularly prevalent in cans and other coated materials. Its presence can lead to issues in steelmaking processes, such as contamination and difficulties in welding and painting, making its efficient removal a priority for ensuring high-quality recycled steel.

Rationale for Focusing on Tin

Tin removal is essential not only for maintaining the integrity of recycled steel but also for preventing the degradation of its properties during subsequent manufacturing processes. Given that tin can affect the surface properties and overall durability of steel, developing a metric for its removal will help in refining recycling processes and enhancing the end-product quality.

Definition of the Metric

The proposed metric for tin removal will measure the effectiveness of processes aimed at reducing tin content from steel scrap. The metric will focus on:

- **Initial Tin Content**: The concentration of tin in the scrap before processing.
- **Residual Tin Content**: The amount of tin remaining after the recycling and purification processes.
- **Removal Efficiency**: The percentage of tin successfully removed during the recycling process, calculated as:

$$\textbf{Removal Efficiency}\ (\%) = \left(\frac{\text{Initial Tin content} - \text{Residual Tin content}}{\text{Initial Tin content}} * 100\right) \quad (7)$$

Integration with Recycling Technologies

- **Enhancing Separation Technologies**: Leverage the metric to assess and improve mechanical and chemical separation processes, such as electrolytic detinning and other advanced sorting technologies.
- **Innovation and Technology Adoption**: Encourage the adoption of new technologies that show high removal efficiencies based on metric evaluations. Technologies that reduce tin content effectively can be highlighted as best practices for industry-wide adoption.

Policy and Regulatory Implications

- **Regulatory Compliance**: Use the metric to ensure compliance with international standards for steel recycling, which may dictate maximum allowable concentrations of tin in recycled products.

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- **Environmental Impact**: Highlight the environmental benefits of effective tin removal, such as reduced toxicity and lower energy consumption in subsequent steelmaking processes.

7 Developing a metric for alloying element recovery

With vast mineral resources in a global economy and high costs for manual operations, recovery of alloys from magnetic alloyed shrapnel from old scrap has not been on the agenda. As can be seen in **Table 4**, that might change in the future.

Rationale for working on alloy recovery

When removing alloyed shrapnel from pure iron shrapnel in a scrap stream, both streams increase in value. To valorise the alloyed scrap-stream, a logistic system must be created channelling the material to companies that can handle relatively diverse scrap lots and using the material without losing alloys to slag and dust.

Definition of the Metric

The proposed metric for alloy recovery will measure the effectiveness of processes aimed at recovering alloy content from steel scrap The recovery efficiency must be established for the different alloys separately depending on the ease with which they can be separated and valorised:

- **Initial Alloy Content**: The concentration of alloys in the scrap before processing.
- **Recovered Alloy Content**: The mass of alloys in scrap for valorisation.

$$\textbf{Recovery Efficiency}\ (\%) = 100 * \left(\frac{\text{Mass of recovered element}}{\text{Initial mass of element}}\right) \qquad \textbf{(8)}$$

Integration with Recycling Technologies

- **Enhancing Separation Technologies**: Leverage the metric to assess and improve mechanical and chemical separation processes, such as identification and sorting
- **Innovation and Technology Adoption**: Encourage the adoption of new technologies that show high recovery efficiencies based on metric evaluations. Technologies that recover alloy content effectively can be highlighted as best practices for industry-wide adoption.

Policy and Regulatory Implications

- **Regulatory Compliance**: Use the metric to ensure compliance with international standards for steel recycling, which may dictate maximum loss of alloys to tramp elements in recycled products.
- **Environmental Impact**: Highlight the environmental benefits of alloy recovery such as decreased use of primary raw materials and imports of strategic resources.

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8 Assessing economic viability of deploying MEDALS' technologies

To deploy a new technology, the value it generates must be higher than its cost. Furthermore, the value must be expressed in monetary terms, making an additional set of equations necessary. These equations will have to be developed within the different work packages of the MEDALS project. At least four different areas can be found:

- Net value of cleaner material
- Net value of a known analysis and distribution
- Net value of being able to correct a melt analysis
- Net value of recovered alloys from scrap

The main concerns are discussed below.

Net value of cleaner material

Diluting the melt with primary material, like HBI, is in a long-time scenario the only way to meet high quality demands as discussed in section 3.4. Price differences between different scrap types, as shown in figure 6, should give a similar result if good information on the traded scrap is provided. The way to deal with this kind of value assessment would be by considering different scenarios in which the production of different steel types using HBI and the studied scrap are studied.

Net value of a known analysis and distribution

As can be seen from figure 5, the tramp element content varies and with known average values and standard distribution a charge can be prepared with a known risk of missing the tramp element threshold. The cost for underestimating the risk, which means too many missed charges, vs. the cost for overestimating the risk, resulting in unnecessary high amount of clean and expensive scrap, must be balanced. This balance and the value of decreased variation and known average and standard deviation can also be studied with scenarios.

Net value of being able to correct a melt analysis

The optimal way to use this technology can be studied by continuing the scenario writing above. The technology can be used to save occasional melts or to use cheaper scrap. In the long run it has to do with the alternatives.

Net value of recovered alloys from scrap

Finally, the value of alloy recovery must be assessed by balancing the cost for separation, advanced logistics and possibly also processing with the economic benefits of removing tramp elements from

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the main scrap stream, lowering the primary alloy costs, resource depletion and the GWP environmental impacts. Also in this case scenario writing is the first choice.

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9 Conclusions

The metrics used today to report the efficiency in the use of scrap in steelmaking has very little to do with improving scrap upgrading, avoiding a constant increase in tramp elements in the steel or environmental burdens. The metrics developed in this report and in MEDALS project's future reports contribute to a more relevant scrap management system in Europe.

Enhancing the toolbox for assessing the efficiency of various scrap upgrading technologies is necessary to make real improvement happen. Focussing on Copper and Tin means taking care of an imminent threat to the increased use of scrap to produce advanced steels once the blast furnaces are closed in Europe. Furthermore, alloy recovery addresses the EU ambition to make Europe less dependent on imports of critical elements.

Well-established metrics are essential to facilitate research funding, investment discussions, policy making and development of working practices within steel companies.

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