Metallic Elements Dissipation Avoided by Life cycle design for Steel

Deliverable 2.1

TrampData

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Abbreviations and acronyms

BF	Blast Furnace
BOF	Basic Oxygen Furnace
DRI	Direct Reduced Iron
EAF	Electric Arc Furnace
EV	Electric Vehicle
HM	Hot metal
HMS	Heavy Melting Steel
PMI	Positive Material Identifications
PU	Public
WP	Workpackage

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Abstract

This document is compiled to report deliverable D2.1, titled "TrampData". In collaboration with partners SID, TEC, and KOB, and led by KTH, task 2.1 involves the collection and analysis of data from over different cases. This report details the methodologies adopted for collecting pre-treatment and post-treatment data on tramp elements such as copper (Cu), lead (Pb), and tin (Sn), which significantly impact the recycling efficiency, and the quality of the steel produced. Key findings from the analysis indicate variable removal efficiencies across different plants and treatments, highlighting the need for process optimization. Economic and environmental implications of enhanced tramp element removal are also discussed, illustrating the potential benefits such as cost reductions in raw material use, decreased energy consumption, and lowered environmental impacts through reduced need for virgin material sourcing. The report served as a repository of valuable data but also as a guideline for future enhancements in scrap sorting technologies considered in MEDALS project. The recommendations provided aim to support the transition towards more sustainable practices. This aligns with broader goals of reducing industrial carbon footprints and advancing circular economy initiatives.

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1 Introduction

As global efforts to reduce carbon emissions continue, there will be increasing demand for electric vehicles and renewable energy technologies, such as wind turbines. These technologies rely heavily on steel, and electric steelmaking is a more environmentally friendly alternative to traditional steelmaking processes. Additionally, as the global population grows and economies develop, there will be greater demand for steel in general, including infrastructure projects, housing, and consumer goods. This increased demand will require more steel production, and electric steelmaking can help meet that demand while reducing the environmental impact of traditional steelmaking. When traditional steelmaking is substituted by electric steelmaking, there can be a change in the type and amount of tramp elements present in the scrap used. For example, electric steelmaking can result in higher levels of certain tramp elements, such as copper and tin, because these elements are often present in electrical wiring and other electronic components commonly recycled as scrap.

'Steel scrap' is basically a steel material that doesn't fulfil its function anymore in the application. This is a valuable resource for the steel industry since it can be melted to make new steel products. The possibility to be recycled permits resource conservation. Thus, this implies less need for new raw materials, and savings on CO_2 emissions and energy consumption to extract and process iron ores. Additionally, it prevents waste build-up and landfilling. Metal scrap is differentiated into two main categories: ferrous and non-ferrous metals. The main difference between the two stands for the presence of iron in ferrous ones, making most of them ferromagnetic, while non-ferrous ones don't contain it. Examples of ferrous metals include all forms of steel, i.e., stainless steels, alloy steels and carbon steel; nickel, chromium, titanium, and many other alloyed steels. On the other hand, among non-ferrous metals we can find copper, tin, lead, aluminum, zinc, etc. [**1, 2**]. The reason why it is of utmost importance to separate ferrous from non-ferrous metals is to prevent the mixing of all different metals from the two categories, which would create a single stream of unknown lower grade ferrous scrap, that will be inevitably downcycled.

Steel scrap comes from different streams: home/prompt scrap, industrial and obsolete scrap. **Home scrap** includes leftovers from manufacturing processes, that are then reintroduced within the production processes by the plant in which it was manufactured. Since its composition is well-known, this scrap is recycled infinite times without affecting the material's performance. **Industrial scrap** is clean and new scrap that leaves its production plant since the facility itself doesn't have the machinery to process it. Industrial scrap is high-quality and high-value material; hence it's usually sold through pre-arranged contracts. **Obsolete scrap** (or **old scrap**) refers to post-consumer products that have reached their end-of-life stage, so they're no longer useful as they are in any sort of way [**3**]. Compared to prompt and home scrap, obsolete scrap requires much more care since it's not ready as it is as secondary raw material, since it is often mixed with other materials, and it could be unclean, due to possible retained moisture, oil, food particles etc. Hence, before being classified as "ready to be recycled", it needs to be properly sorted, processed, and shredded [**3**]. According to the European steel classification old scrap classes are described as E3, E1 and E40. These classes are referred to "non-alloy carbon steels" scrap. Carbon steel is a steel alloy that covers 90 % of the total steel production, with a C content that varies from 0.04 % to 1.5 % [**1**]. It is defined as a 'non-alloy' due to the absence of alloying elements, such as manganese, chromium, molybdenum, nickel, etc.

There are some general standards to check the scrap considering:

1. **Safety conditions**: There should be no presence of dangerous, inflammable, or explosive substances that could harm the environment, the health of who's handling the scrap, or the steelmaking process.

2. **Cleanliness conditions**: Scrap should be free or have negligible quantities of non-ferrous metals and non-metallic materials (e.g., rubber, plastic, oils, chemical or organic substances etc.), except from nominal amounts of rust; it should be also exempted from larger pieces which don't conduct electricity e.g. tires, cement, or wood, and from by-products resulting from steel machining or heating processes.

3. **Residual or 'Tramp' elements**:
    - Copper (Cu) - all scrap grades should be free of visible metallic copper, or from materials with high dissolved copper content; negligible amounts of wire and brass items attached to or mixed with coating ferrous scrap are allowed.
    - Tin (Sn) - all scrap grades should be free of tin in the form of cans, including all tin-coated materials, as well as bronze elements.

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- Lead (Pb) - all scrap grades should be free of lead in any form, such as batteries, solders, etcetera.

Since Cu has the highest economic value, market demand and content in steel scrap compared to Sn and Pb, it is the only one among the three with the potential for significant economic gain in case of selling the retrieved percentage from an optimized scrap sorting. Moreover, copper ranks as one of the most detrimental contaminants in steel scrap. For these reasons, it is crucial to focus primarily on copper removal. Therefore, all the studies are solely concentrated on copper removal and recovery. Despite not including the removal of Sn and Pb, ensuring their reduction is still important, as they also contribute to increasing the impurity levels in steel scrap. **Table 1** shows the residual contents of Cu and its quantities in supplies during steelmaking. The "estimated" values shows when expected copper concentrations from current scrap handling practice can no longer be tolerated. Similarly, **Table 2** details the concentrations of copper measured from different EAF processes, providing insights into the variability of copper content depending on the scrap source and processing method used.

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Table 1. Copper residual contents and quantities in supplies for different steelmaking processes [5].

Route	Supply Source	Estimated Cu (wt%)	Quantity (Mt)	Average Cu (wt%)
BF-BOF	Iron Ore	0.01	826	~ 0.04
	Primary circulating scrap	0.02	165	
	EAF circulating Scrap	0.15	41	
	Pig Iron	0.01	45	
	DRI	0.01	66	
EAF	Primary circulating Scrap	0.02	50	~ 0.1783
	EAF circulating Scrap	0.15	12	
	Transport scrap	0.3	107	
	Machinery scrap	0.2	81	
	Construction scrap	0.1	68	
	Goods scrap	0.3	42	

Table 2. Concentration of copper measured from different EAF processes [5].

EAF with 80-85% HM		EAF with DRI		EAF with 100% scrap	
Frequency (%)	Cu content (wt%)	Frequency (%)	Cu content (wt%)	Frequency (%)	Cu content (wt%)
70	0.001	9	0.007	3	0.14
22	0.002	29	0.008	40	0.17
7	0.003	38	0.009	46	0.2
1	0.004	20	0.01	10	0.23
		4	0.01	1	0.26

The demand for steel free of tramp elements is increasing, particularly in certain industries where the quality and purity of the steel are critical. Industries such as automotive, aerospace, and electronics require high-quality steel free of tramp elements to ensure the reliability and safety of their products. Overall, driven by the growing demand for high-quality and reliable products in the already mentioned and other industries, the demand for steel free of tramp elements is expected to continue to increase in the coming years. To meet this growing need for clean scrap in electric steelmaking, there may be increased efforts to collect and process scrap more efficiently, as well as to develop new technologies for sorting and cleaning scrap. This trend may also push the development of new technologies for identifying and removing tramp elements from scrap metal (solid or liquid).

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All the types of EV require a substantial amount of copper, since it is used for batteries, windings and rotors in electric motors, wiring, busbars and charging stations. The EV demand is expected to show major growth in the next ten years, meaning a substantial increase in copper demand. An internal combustion engine car requires about 20 kg of copper, whereas plug-in hybrid electric vehicles (PHEV) require a total of 60 kg of copper and as for battery electric vehicles (BEV) 83 kg are necessary. This implies that the copper demand and waste contamination management (with end-of-life EV) is going to be extremely overwhelming. Particularly, the current copper supply would not be sufficient to cover copper demand in the long term. S&P Global Market Intelligence predicted that by 2035 copper demand would double from 25 to 50 million tons [**1**]. Subsequently, the gap between the copper supply and demand is about to widen. If the mining output continues to grow every year by 2.69%, the global copper output would reach a value of 31 tons, which is far back from the 50 tons. As already stated, copper presence in steel scrap causes detrimental metallurgical problems. However, it is pervasive in obsolete scrap and cannot currently be removed once in the melt, commercially. Dilution with primary iron sources is currently used to manage contaminated scrap to recycle it. However, this does not represent a long-term solution. The best forecast shows that arising copper quantities in scrap can be managed by the global steel system until 2050 only through a perfectly operated trade and the use of dilution.

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2. Effect of Tramp elements during EAF steelmaking process

In this section, the effects of Cu, Pb and Sn during EAF steelmaking are reported. There are two forms in which Cu can be found in steel scrap: e.g. pure metal Cu (pickable copper) and Cu dissolved in steel. Some sorting technologies can remove pure metal Cu pieces from solid steel scrap. The two technologies that are described below involve either hot temperatures or leaching processes. Improved physical and sensor separation can be an energy-efficient and effective way to remove a copper rich fraction in solid steel scrap. The residual Cu could be diverted e.g. by a ballistic separator system. Finally, the concept of the coupling of the two technologies is described as the most effective solution for overcoming the meatball problem. During the melting process in the EAF, each of these elements react differently. **Figure 1** shows that Cu remains totally in the bath, as for Sn, while Pb remains mostly in the bath, and partially in the gases. Once the scrap has been melted in the EAF, all the residual elements have entered the iron matrix. This means that it would be very challenging, almost impossible, to remove Cu and Sn once they reach the EAF process. This is due to the low potential of these elements to form an oxide on top of the melt that would be easily removed along with the slag.

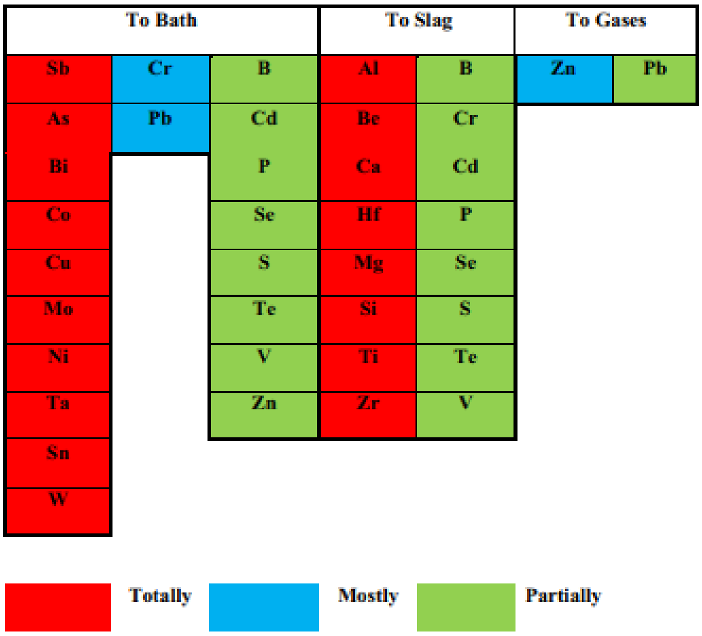

Figure 1. Residual elements behavior in EAF process [**1**].

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3. Sorting technologies for copper removal

Magnets are the simplest and most used tools to separate ferrous metals from non-ferrous metals by means of magnetic attraction. Magnets can be implemented in any sort of form: as attachments to excavator arms; as primary drums magnets for separating ferrous shred from the shredder output; as over-conveyor belts magnets that lift residual ferrous materials; as magnetic head-pullies pulling down residual ferrous from nonferrous stream [**6, 7**], which is the core concept of ballistic separators. Ballistic separators for copper sorting are currently used in shredding yards, steel mills and slag processing facilities. These separators use ballistics to segregate the copper bearing materials from the rest of the ferrous materials. The greatest manufacturers of such machineries are the American 'Eriez Manufacturing Co.' and the German 'Steinert' companies, which have expanded through multiple facilities all over the globe [**8, 9**]. Ballistic magnetic separators are often used as a low-cost alternative or as an addition to XRF sorting systems [**8**]. It is a more cost-friendly solution compared to XRF sorter and can be used also as a more effective alternative to handpicking. The ballistic separator makes it possible to create two output streams: a ferrous clean shred stream with nearly a complete removal of residual Cu and a high-copper ferrous stream.

In operation, the input material is subjected to the high-speed of a conveyor belt (its speed is about 18 km/h) and passes over a magnetic head-pulley. The technology exploits momentum to throw the ferrous shredding with substantial non-ferrous attachments to it over the splitter, while the clean ferrous stream sticks to the magnetic head pulley that drags it behind the splitter. In this case, residual non-ferrous elements (and other non-magnetic materials) because of their size, shape, and Cu content (which are in most cases weightier) are not attracted by the magnetic field and are thrown over the splitter [**1, 2**]. X-Ray Fluorescence spectrometry is used for chemical analysis for Positive Material Identifications (PMI). It works thanks to the behavior of atoms present on the surface of a piece made of a specific material when they interact with an X-radiation. This technology exploits an intense incident X-ray beam that hits the sample, and part of the energy gets scattered, in a way that differs based on sample's chemistry, while the rest is absorbed by the material. Therefore, when the X-ray beam hits the material, the latter becomes excited. Hence, it emits a fluorescent photon along the spectrum of wavelengths based on the elements that are present on the sample surface. The energy of the fluorescent photon provides information on the elements' identities. XRF can provides both qualitative and quantitative analytical information, in real-time. Handheld XRF devices are currently used in metal scrapyards for PMI, when a quick composition determination onsite is needed, but they are also commercialized as belt-type particle sorters.

EDXRF sensors, utilize the XRF technology to get identification of specific alloys, but they are also used to find meatball copper contaminants in shredded products. They have the potential to be implemented into the high copper stream of the ballistic separator, to replace the hand-picking process. Although XRF is a beneficial technology for steel sorting, it has some delimitations: XRF has continuously been improved to face its difficulty in detecting lightweight pieces and in operating in quick times. Moreover, since they emit radiations, extra safety precautions must be taken while operating these machines.

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4. Collection of data

In a previous study, mainly the elements copper, molybdenum, tin, and nickel were recognized as tramp elements. These elements dissolve in the steel matrix and as iron has a higher affinity to oxygen and a higher vapor pressure than those elements at steelmaking temperatures, they cannot be removed by oxidization or vacuum treatment. The data acquisition was mainly taken from literature studies, organizations, steelmaking, and steel recycling companies' websites, and from a field trip to Stena Recycling AB's facility in Huddinge, Stockholm. This is mainly highlighted in the master's thesis carried out by two KTH students in collaboration with MEDALS partner KOB [**1, 2**]. When data was difficult to find, reasonable assumptions had to be made, always explaining the logic behind it in the model description. On the other hand, different values about the same information from one source to another occurred. In those cases, the frequency with which a particular value was reported, the year of publication and the reliability of the source were the parameters taken into consideration. The following model refers to a made-up company to which mixed (ferrous and non-ferrous) metal scrap of unknown composition is delivered. The company is responsible to sort out the ferrous scrap stream from the non-ferrous one, providing the 'cleanest' steel scrap (with the lowest Cu residual content) to sell to steel companies, hence reducing the virgin steel required quantity for the dilution process in the secondary steel production. This entails for using as much clean steel scrap as feedstock as possible. The company is a scrap treatment plant that buys mixed metal scrap from a collection company, it executes the same steps as the ones introduced as any other company does currently. What differentiates it from the others is the adding of one additional separation step right after the conventional magnetic sorting: a ballistic separator, followed by a hand sorting station.

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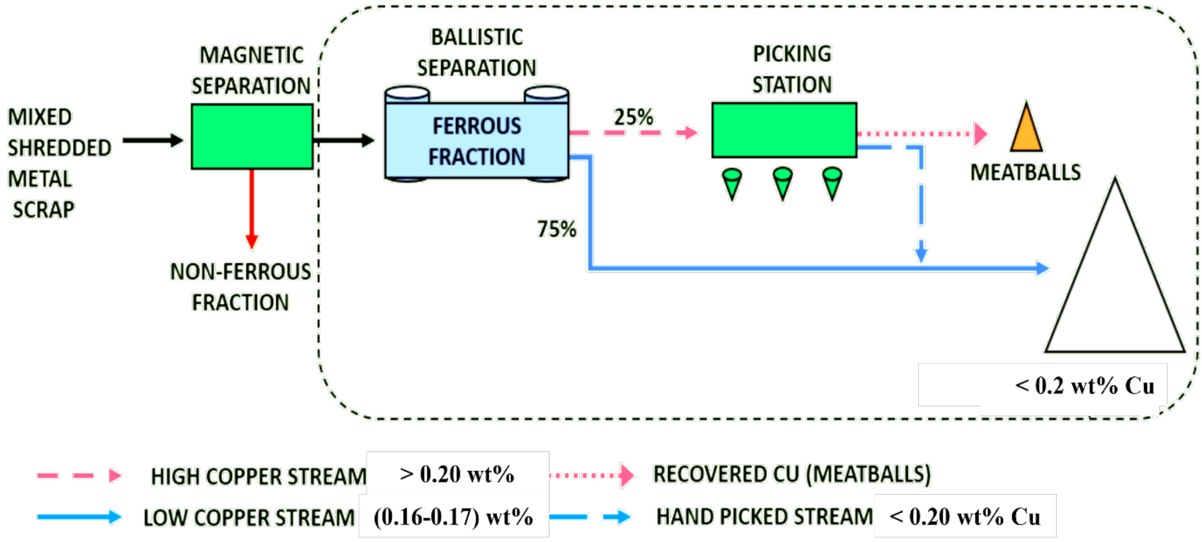

Figure 2. Schematic representation of a ballistic separator and hand-picking station system [**1**].

Figure 2 showcases how the process should be carried out: the ballistic separator technology exploits ballistics and magnetic attraction to create two different scrap streams: a low-copper ferrous shred (which represent the 75% of the total input material) and a high-copper stream (representing the 25%). The latter goes through a manual picking station, to separate the meatballs from the residual ferrous scrap. Since this model is focused on obsolete steel scrap, the scrap categories E1, E3, E40 were selected. The fictional E40* category was tailor-made to illustrate the upcoming challenge of an increasing Cu content in ferrous scrap streams. Residual Cu content aimed residual Cu content and ΔCu (in wt%) in E3, E1, E40 and E40* steel scrap is shown in **Table 3**.

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Table 3. Residual Cu content aimed residual Cu content and ΔCu (in wt%) in E3, E1, E40.

Category of scrap	Specification	Residual Cu content (wt%)	Aimed Residual Cu content (wt%)	ΔCu (wt %)
Old	**E3**	≤ 0.25	0.1	0.15
	E1	≤ 0.40	0.1	0.30
Shredded	**E40**	≤ 0.25	0.1	0.15
E40 with an expected higher EV waste content	**E40***	≤ 0.60	0.1	0.50

The residual Cu content (R_{Cu}) value refers to the output Cu contents per one ton of initial steel scrap downstream the magnetic separation sorting process, which are according to EU's current standards. The ideal and aimed residual Cu content (Aimed R_{Cu}) downstream the ballistic separator and hand-picking station is set at 0,1 wt%. The parameter ΔCu refers to the total Cu content that must be removed. For each scrap category, it has been calculated as follows:

$$\Delta Cu = R_{Cu} - Aimed\ R_{Cu} \quad \textbf{(1)}$$

where, R_{Cu} is the Residual Cu content [wt%]; $Aimed\ R_{Cu}$ is the set ideal Cu Content downstream of the process [wt%].

The residual Cu content in E40* was estimated, since the expected rising Cu content in the next few years is just a forecast, no data about it has still been released in the literature. Nevertheless, the selected value was set as a parameter (as for R_{Cu} for E3, E1 and E40).

Four steel scrap classes have been investigated: E1, E3, E40, E40*. For simplicity, material losses during the sorting process are neglected, even though in reality they inevitably occur. Moreover, the set of data is referred to the stages that occur right after the magnetic separation, so economic and environmental data of prior processes to the latter are not included within the calculations. In the same way, recycling stages consecutive to sorting i.e., all that concerns the transport to the steel mill facility and the manufacture of secondary steel, is disregarded. Only residual copper in form of pure metal bits (pickable copper) can be removed by the proposed sorting process. Copper in form of alloying element cannot be recovered in this case, so it was not considered during calculations. However, its overall content is included within the aimed 0.1 wt%.

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5. Analysis of Copper Content Trends in Steel Scrap

The copper content in steel scrap significantly influences the recycling process and the quality of the final recycled steel products. Shredded steel scrap refers to smaller pieces of metal that have been processed through shredding machines, which break down larger items of scrap into manageable sizes. This type of scrap typically originates from consumer goods, end-of-life vehicles, and industrial waste, and is characterized by its mixed composition and smaller physical form. Heavy Melting Steel (HMS), scrap steel is primarily derived from construction and demolition sites, industrial and commercial scrap, and obsolete equipment. **Figure 3** and **Figure 4** offer a detailed look at the four-month rolling average of Cu content in two different types of steel scrap, Shredded and Heavy Melting Steel (HMS) over the period from August 2022 to July 2024. This analysis aims to elucidate the trends and implications of copper content fluctuations and provide strategic insights for stakeholders in the steel recycling industry. The presence and fluctuations of copper content highlighted in the graphs are critical for steel producers as they influence the desirability and value of scrap. This data highlights the necessity for effective sorting and processing strategies to mitigate copper levels in steel scrap. Understanding the trends helps scrap processors and steelmakers to adjust their operations to maintain quality while managing costs. Insights from the trends enable better forecasting of scrap quality, facilitating strategic decisions regarding scrap purchasing and processing schedules. This can optimize operational efficiencies and cost-effectiveness in the volatile scrap market.

1. **Shredded Steel Scrap:**

Trend Analysis: The copper content in shredded steel scrap displayed notable fluctuations over the analyzed period. The mean copper content began at approximately **0.206% in August-November 2022**, peaked at **0.220% in February-May 2023**, and then significantly declined to a low of **0.136% in July-October 2023**, before a slight recovery to **0.191% in March-June 2024**.

Variability and Range: The range between the minimum and maximum copper content, along with the 25th to 75th percentile intervals, showed a contraction particularly around July 2023. This period demonstrates a notable reduction in variability, suggesting a temporary stabilization in copper content in the shredded scrap.

2. **Heavy Melting Steel (HMS) Scrap:**

Trend Analysis: Unlike shredded scrap, HMS scrap exhibited a more stable copper content trend with only minor fluctuations. Starting from **0.206% in August-November 2022**, the copper content varied modestly around an average of **0.175%**, concluding slightly higher at **0.204% in April-July 2024.**

Variability and Range: The variance in copper content for HMS scrap remained relatively consistent throughout the year, with a slight increase in variability noted towards the end of the period.

Efficient management of copper content not only impacts the economic aspects of steel recycling but also its environmental footprint. Reducing reliance on virgin materials through effective recycling of scrap metal, including the reduction of tramp elements like copper, enhances the overall sustainability of the steel industry.

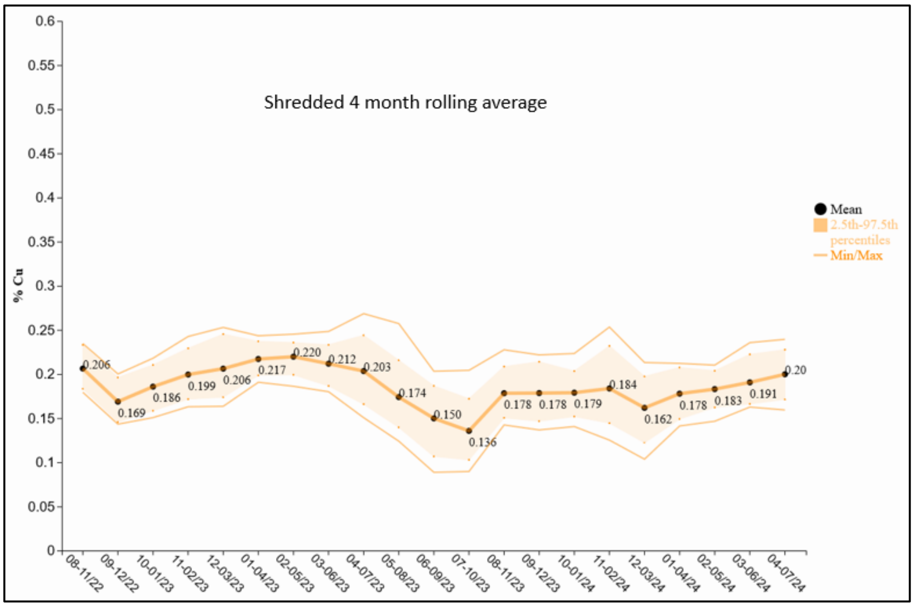

Figure 3. Four-month average of Copper Content in Shredded Steel Scrap (Aug. 2022 – July 2024).

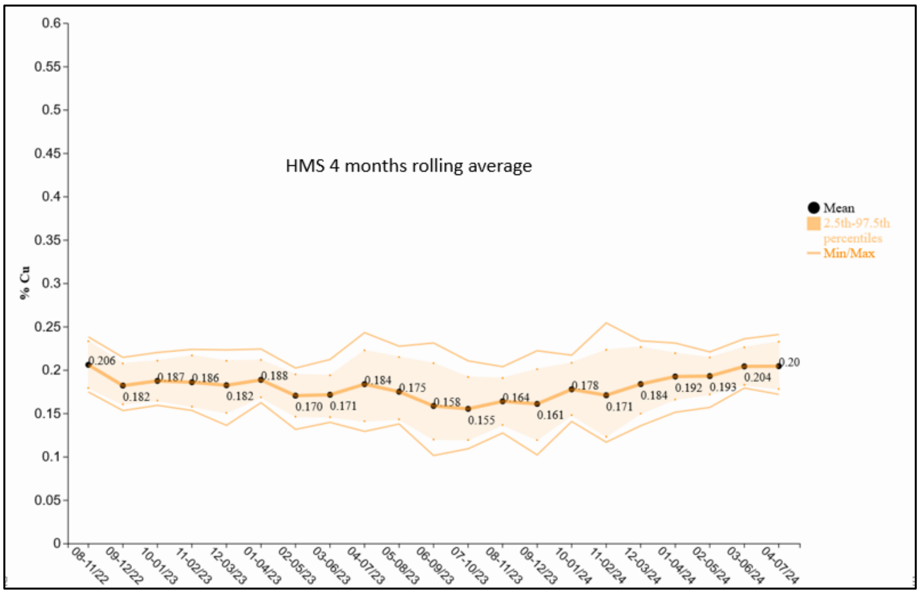

Figure 4. Four-month Rolling Average of Copper Content in Heavy Melting Scrap (August 2022 - July 2024).

The impact of revenue from the increased copper yield is relatively low due to the very small copper content in the scrap and the additional processing required for components like 'meatballs.' It is unrealistic to assume that this revenue could fully cover the costs of a ballistic separator or handpicking operations. The data from STE and Steinert indicate that only a few of these machines have been sold across Europe. Therefore, the revenue from recovered copper is only a secondary benefit of the sorting process. The economic value of the furtherly cleaned steel scrap increases, potentially resulting in higher revenues per ton of processed scrap. This increase depends on the initial residual Cu content upstream of the ballistic separator; the higher the residual Cu content, the greater the weight of Cu recovered and sold. [**1, 2**]. The cost for the ballistic separator was assumed as an average value of similar technologies prices found on various retailers and manufacturers' websites. The adoption of such technology is economically convenient considering the initial investment for acquiring the machine. The cost for a ballistic separator was assumed to be €75,000-93,000 as per the information received from MEDALS project partner, STE. Thanks to the efficiency of ballistic separation, the number of hand pickers required at the picking station is cut in half. This leads to significant savings in staff costs, which represent a major component of operational expenses. Ballistic separators are quite simple machines: they do not rely on expensive equipment, such as running specific software or robotic elements, except for exploiting the high-speed of a conveyor belt and the magnetic effect of a magnetic pulley. Thanks to the efficiency

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of ballistic separation, the number of hand pickers needed at the picking station is cut in half (this number is dependent on how much tons of scrap the machinery can handle per every working hour) in respect to the conventional number of workers needed for manually picking copper. Thus, the staff costs considered in this case would be cut in half as well, leading to a not indifferent economical saving. This innovative machinery is able to create a low-copper ferrous stream with a residual Cu level of 0.16-0.17 wt%, which doesn't require any further treatment and is ready to be packed and sold. However, with additional downstream processing or advanced configurations, such as using the ballistic separator system, the residual Cu level could be further reduced to approximately 0.1 wt%, which represents dissolved copper that cannot be removed through conventional solid scrap sorting methods. This ratio in weight refers to 75% of the total input material. Moreover, the rest of the material (25%) entails a high copper ferrous-scrap stream, which needs further care, being passed through a picking station, where residual "pickable copper" (the so called "meatballs") is finally manually removed. The costs for running the technology, linked to electricity usage and staff wages, are particularly low (they represent only the 0.3% of the total costs). In fact, most of the costs are related to the metal scrap acquisition, i.e., feedstock to process, so to speak. In **Figure 5**, the two trends of the two net gains calculated for one year depending on the number of tons processed per working hours are shown. The results below have been calculated with the assumption of an equal productivity between the clean steel sorting process versus a conventional one. However, if the efficiency of the latter process was higher than the proposed solution, its trend would be shifted towards higher values, potentially even higher than the proposed sorting process. The net gain in **Figure 5** is calculated by considering two key revenue sources: the increased value of cleaned steel scrap (due to its lower copper content) and the revenue from selling the recovered copper. From this total revenue, the costs of the ballistic separator (machine investment and operating costs) and labor are subtracted.

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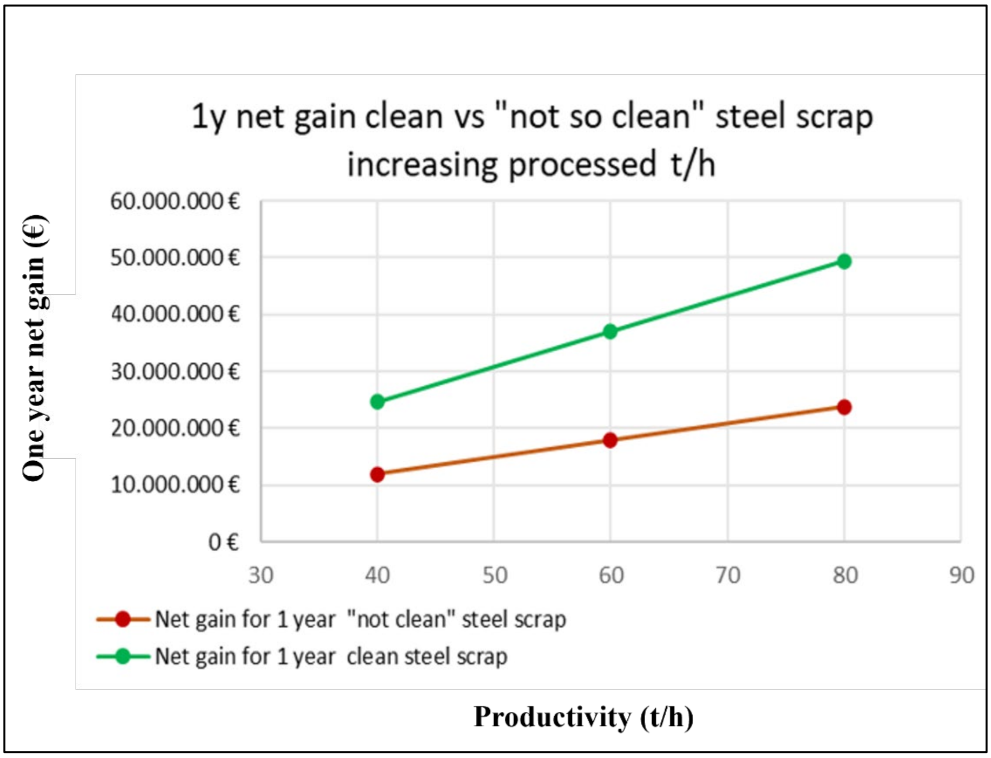

Figure 5. Clean vs "not clean" steel scrap gains varying the productivity of the proposed sorting solution (considering E40 class) [**1**].

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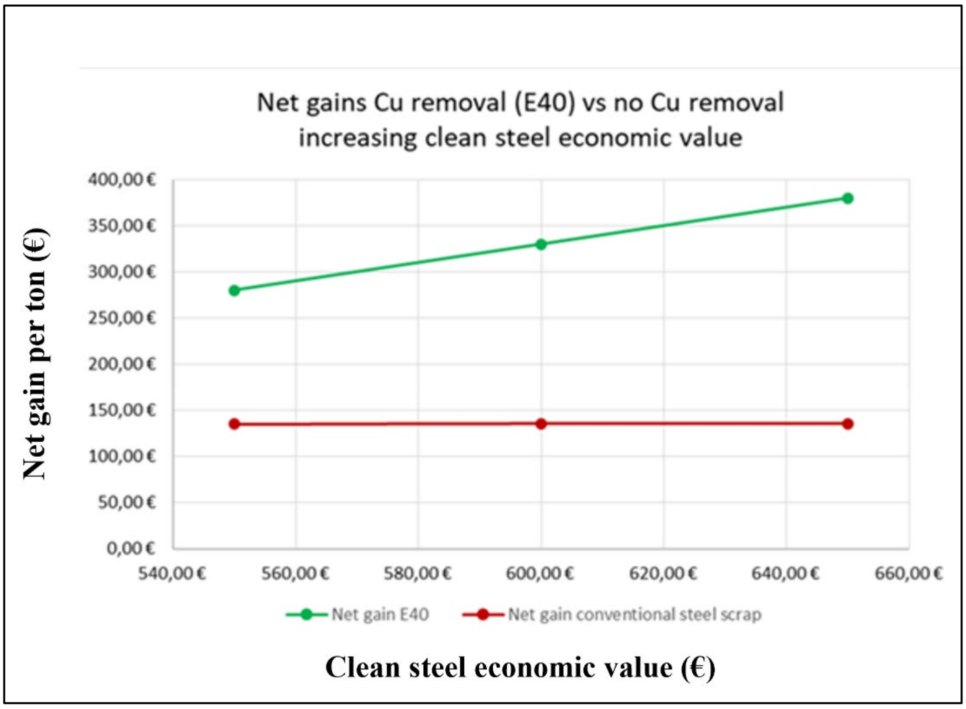

Figure 6. Net gains clean vs. "not so clean" steel increasing clean steel economic value [**1**].

Figure 6 showcases the different trends on net gains per ton of sold clean steel scrap versus "not so clean" scrap increasing the economic value of the clean steel. The choice of the price for clean steel is variable, depending on the level of output clean steel "cleanliness", which is based on the final residual Cu content. Limiting the sorting process to magnetic separation, the minimum reachable residual Cu is 0.25 wt%, so the economic value of "not so clean" steel is also limited to remain constant as this is what has been currently done in the industry. The arbitrary choice of the selling price of the clean steel scrap could represent one of the driving forces to economic gains for a hypothetical company using the proposed sorting solution. **Table 4** highlightes the difference in yearly net gains between the two processes, which is very noticeable. In **Figure 6**, the net gain is calculated by comparing the selling price of clean steel scrap versus "not clean" scrap, with the cleaner scrap having a higher market value due to its improved quality. These calculations assume equal productivity for both processes and include factors like labor savings and minimal operating costs.

Table 4. Net gains in "not clean" vs clean steel scrap depending on the tons processed per working hour (considering E40 class).

Tons processed per hour (t/h)	**40**	**60**	**80**
Net gain for 1-year not clean steel scrap	11.931.764€	17.897.647€	23.863.529€
Net gain for 1-year clean steel scrap	24.646.796€	37.011.247€	49.375.679€

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6. Conclusions

The methodologies deployed across various treatment facilities described significant variations in the removal efficiencies of tramp elements. These findings highlight the urgent need for enhancing the precision and effectiveness of current sorting technologies to ensure the production of high-quality recycled steel, which is paramount for maintaining the integrity and performance of steel products. Enhanced tramp element removal processes not only align with the strategic objectives of reducing industrial carbon footprints but also support the broader aims of the circular economy by extending the lifecycle of materials and minimizing waste. The insights garnered from this deliverable highlight the essential role of innovative technologies and robust methodologies in overcoming the challenges posed by tramp elements. As MEDALS project look towards future advancements in this field, the continuation of this research will be critical in driving forward the standards of steel recycling, ensuring that the steel industry remains both economically viable and environmentally responsible. In conclusion, "TrampData" serves not only as a repository of crucial data but also as a foundational guideline for future improvements in scrap sorting technologies. The concerted efforts of the MEDALS project will contribute significantly to the ongoing evolution of steel recycling practices, promising a future where steel production is increasingly sustainable, efficient, and aligned with global environmental targets.

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