Boosting the use of recycled steel in the EU automotive industry under the ELV Regulation

Quantitative Impact Study

Darmstadt,
12 February 2025

Authors

Jürgen Sutter, Frederick Adjei, Yifaat Baron, Izabela Kosińska-Terrade

Oeko-Institut e.V.

Contact
info@oeko.de
www.oeko.de

Head Office Freiburg
P. O. Box 17 71
79017 Freiburg

Street address
Merzhauser Straße 173
79100 Freiburg
Phone +49 761 45295-0

Office Berlin
Borkumstraße 2
13189 Berlin
Phone +49 30 405085-0

Office Darmstadt
Rheinstraße 95
64295 Darmstadt
Phone +49 6151 8191-0

Executive Summary

This executive summary provides a comprehensive overview of the key findings and recommendations of the study, highlighting the potential for increasing the use of recycled steel in the EU automotive industry under the revised ELV Regulation.

Introduction

On July 13, 2023, the European Commission published a legislative proposal revising Directive 2000/53/EC on end-of-life vehicles (ELVs) and Directive 2005/64/EC on the type-approval of motor vehicles. The proposal aims to enhance the use of recycled materials, particularly steel, in the automotive industry. This study, conducted by Oeko-Institut e.V., assesses the potential impact of these revisions, focusing on the use of recycled steel.

Market Overview

The EU ELV treatment sector is crucial for environmental sustainability, involving vehicle dismantling, shredding, and recycling. Key players include Authorized Treatment Facilities (ATFs) and shredder operators. The sector supports resource recycling, job creation, and technological advancements. In 2022, approximately 4.7 million ELVs incurred in the EU, corresponding to about 5.5 million tonnes. The sector achieved significant material recovery, including 4.3 million tonnes for recycling.

Steel Scrap Use and Copper Contamination

To reduce the material intensiveness of vehicles and move towards a more circular economy, an uptake of steel scrap in the automotive industry is key, but copper contamination poses challenges. Copper can cause defects in steel products, such as hot shortness, leading to surface cracking during hot rolling and forming. Effective removal of copper is essential for high-quality recycled steel. The study highlights various methods to reduce copper content, including dismantling copper-rich components before shredding and advanced sorting technologies. Investments in advanced shredder technology, are crucial for producing high-quality steel scrap suitable for flat steel production. The TSR40 plant, for example, can process up to 450,000 tonnes of input materials annually, achieving high purity levels suitable for primary steel production.

Scrap Usage in the Automotive Industry

The study provides an overview of the current and projected use of steel scrap in the EU automotive industry. In 2023, the automotive sector was the second-largest consumer of steel in Europe, using 19.1% of the total steel produced. The industry relies heavily on high-quality steel, primarily produced through the blast furnace-basic oxygen furnace (BF-BOF) route. However, the use of electric arc furnace (EAF) steel, which can utilize up to 100% scrap, is increasing. The study emphasizes the need for high-quality scrap to meet the industry's demands, particularly for flat steel products.

Green Steel

The transition to green steel involves replacing the BF-BOF route with direct reduced iron (DRI) installations and EAFs. This transition aims to reduce carbon emissions in steel production. The costs of green steel production is likely to be significantly higher than the cost of better processing of steel scrap, so that the transformation of primary steel production will probably motivate some shredding plants to invest in new scrap processing technologies.

Techno-Economic Impact Study

The study models the environmental and economic impacts of various policy options, including:

- Mandatory recycled content targets for steel: Four scenarios were examined, with targets ranging from 25% to 50% recycled content by 2035. The study found that achieving these targets would require significant improvements in scrap quality and increased collection rates of ELVs. A mandatory recycling target of 25 % by 2030 and 30% by 2035 would be feasible with closed loop recycling, a target of 50% by 2035 does not appear achievable under the foreseeable conditions as the quantities of recycled steel from closed loop recycling could just cover 84% of the required recycled content. With open loop recycling, there would at least be sufficient quantities of recycled steel available for a 50% target. However, further research is needed to investigate how much flat steel in new passenger cars can really be replaced by flat steel from high-quality recycled steel. However, in order to achieve the recommended targets, the corresponding capacities for post shredding treatment for high-quality recycling steel must also be built up.
- Copper removal from steel scrap: Three measures were analysed: dismantling the main wire harness before shredding, reducing copper content from 0.4% to 0.1%, and reducing copper content from 0.4% to 0.06%. The study found that these measures could significantly improve the quality of recycled steel. The comparison of the additional costs with the possible additional revenues shows that a separation of the copper could already be economically feasible today, for ATFs and for prost shredding sorting plants. Mandatory dismantling of 50 % of the main wire harness and reduction of Cu content to 0.1 % appears to be both technically and economically feasible. These two measures should be combined.
- Compared to the investment and operating costs of a DRI-H_2 plant, which will dominate primary steel production in the future, the investment costs for an advanced shredder technology aimed at separating post-consumer flat steel are significantly lower.
- Separate recycling of ELVs and white goods: The study explores the potential benefits of treating ELVs and white goods separately to improve the quality of recycled steel. However, it finds that joint shredding does not significantly impact steel quality, as the copper content in white goods is generally lower than in ELVs.
- Tax incentives for using recycled materials: The study highlights the potential of tax incentives to promote the use of recycled materials, drawing on examples from the US and other regions.

Case Study: US Automotive Industry

There is a trend towards using electric arc furnaces for the recycling of steel scrap in the US steel industry, driven by firms like Nucor. The question arose whether the US automotive industry uses more scrap-based steel in the manufacture of vehicles. The study found that the US automotive sector used approximately 5 million tonnes of secondary EAF steel in 2022, representing 9% of the count'y's secondary steel production. This represents a similar level of use to that common in the EU. Nonetheless, it seems that the US market is gearing up towards increasing the use of scrap-based steel and that this will also affect the automotive sector. Key factors contributing to this practice include the generation of high-quality scrap, advanced sorting technologies, and supportive policies. Lessons learned from the US include the importance of high-quality scrap and the need for advanced sorting technologies to reduce impurities.

Recommendations

To boost recycled steel use in the EU automotive industry, the study recommends:

- Setting mandatory recycled content targets for all steel products in new vehicles sold from post-consumer scrap: Establish targets for recycled steel content in new vehicles, starting with 25% by 2030 and increasing to 30% by 2035. This will drive demand for high-quality recycled steel.
- Reducing copper content in steel scrap: Implement measures to reduce copper content in steel scrap to below 0.1%. This can be achieved through a combination of mandatory dismantling of copper-rich components and advanced sorting technologies.
- Increasing the collection rate of ELVs: Enhance the collection rate of ELVs by improving tracking and reporting mechanisms, and by implementing stricter regulations on the export of used vehicles.
- Providing financial incentives: Introducing tax deductions and CO_2-related incentives to support investments in recycling technologies. This includes incentives for investments in equipment and processes that improve the quality of recycled steel.
- Promoting Research and Development: Investing in the development of new technologies for sorting and processing steel scrap to improve its quality. This includes supporting research into advanced sorting technologies and methods for reducing copper content in steel scrap.
- Enhancing regulatory frameworks: Strengthening regulations to ensure the effective implementation of recycling measures and the achievement of recycled content targets. This includes setting clear obligations for dismantlers and recyclers and ensuring compliance with recycling standards.

Table of Contents

Table of Contents 6

List of Figures 8

List of Tables 9

List of Abbreviations 10

1 Introduction 12

2 Market overview on End-of-Life vehicle treatment sector in the EU & Germany 13

2.1 Treatment of End-of-life vehicles in the EU 14

2.2 State of art in Germany 16

3 Steel scrap use and the problem of copper contamination 17

3.1 Usage of steel scrap 17

3.2 The problem with copper contamination 19

3.3 Residual copper removal from steel scrap 20

4 Overview on scrap usage in the automotive industry in EU & Germany 26

5 Green steel 28

6 In-depth techno-economic impact study 30

6.1 Model description 31

6.2 Analysis of additional policies 37

6.2.1 Mandatory recycled content targets for steel 37

6.2.2 Mandatory targets for copper removal from steel scrap 41

6.2.3 Mandatory obligation to recycle ELVs and white goods separately 46

6.2.4 Tax deductions or CO_2-related incentives for the usage of recycled copper and high-quality scrap 46

6.2.5 Assess the uncertainties identified by the EU COM which led to not propose steel recycled content targets 47

6.2.6 Implications for the scrap trade with Turkey, UK, US & India in 2030 / 2035 49

6.2.7 Implications for scrap prices in the EU 50

7 Case Study on scrap usage in the US automotive industry 52

7.1 Use of scrap-based steel components in the American Automotive Industry 53

7.2 Who are the leading firms in secondary EAF production and use in the automotive sector? 55

7.3 Are there any lessons learned from the US vehicle dismantling & recycling industry for the EU ELV revision process? 57

8 Recommendations 58

List of References 60

Annex 64

Annex I. Steel making 64

Annex II. Transformation to Green steel 64

Annex III. An overview of EAF steel production in the USA 65

Annex IV. Electric Arc Furnaces and the use of scrap in steel production 67

Annex V. Steel and copper components with potential for dismantling 68

Annex VI. Data for calculation of revenues 72

Annex VII. Results of screening on tax deductions and CO_2 related incentives for the usage of recycled copper and high-quality scrap 73

List of Figures

Figure 2-1: Stages of the ELV waste management and treatment processes performed on outputs of each stage 15

Figure 3-1: Steel production by Member States in 2020 18

Figure 3-2: Copper tolerances in different steel products 19

Figure 3-3: The copper concentration reduction from 0.4wt% and estimated specific energy consumption for the various processes analysed in Daehn (2019) 25

Figure 5-1: Governmental aid for green steel transition for steelmakers in Europe as published in the period January 2023 to March 2024 29

Figure 6-1: Number of passenger cars PoM in the EU by engine type 32

Figure 6-2: Number of decommissioned ELVs to be processed in ATFs in the EU 34

Figure 6-3: Total amounts of flat steel, long steel and cast iron used in passenger cars PoM in the EU 35

Figure 6-4: Total amounts of flat steel, long steel and cast iron contained in ELVs treated in the EU 36

Figure 6-5: Export of ferrous recycling products from EU-27 49

Figure 6-6: Import of ferrous recycling products to EU-27 50

Figure 7-1: Share of the automotive sector in primary, secondary, and total steel consumption, excluding imports, 2022 54

Figure 7-2: Share of the automakers' global steel demand for passenger vehicle production to be fossil-free or reduced GHG emissions intensity in 2030, based on automakers' public commitments. 56

List of Tables

Table 3-1 Quality of steel scrap: advantages and disadvantages of ELV treatment technologies 22

Table 4-1 Share of scrap usage in production of flat and long steel and cast iron 27

Table 4-2 Share of steel scrap usage in production of passenger cars by engine type 27

Table 6-1 Average weights of passenger cars PoM and ELVs in the EU for the years 2025, 2030 and 2035 33

Table 6-2 Share of steel and iron products in passenger cars PoM in the EU [% of total weight] 35

Table 6-3 End-of-life scenarios for ELVs treated in the EU 36

Table 6-4 Amounts of steel reused/remanufactured and recycled steel from ELVs treated in the EU [in t] 37

Table 6-5 Combination of calculation method and level of ambition for RC targets to different RC scenarios 38

Table 6-6 RC targets for steel and iron products in passenger cars PoM in the EU 38

Table 6-7 Demand for recycled flat steel, long steel and cast iron in passenger cars PoM in order to meet the RC targets examined 39

Table 6-8 Comparison of total demand for recycled steel/iron in cars PoM in the case of RC targets and total amounts of steel reused/remanufactured and recycled steel from ELVs in the EU 40

Table 6-9 Copper recovered from dismantling of main wire harness 42

Table 6-10 Copper content in steel scrap from ELVs after shredding without further treatments 42

Table 6-11 Quantities for copper removed from steel scrap from ELVs in different copper removal measures 43

Table 6-12 Additional costs for copper removal (dismantling or PST) in the various scenarios 44

Table 6-13 Additional revenues for copper removal (dismantling or PST) in the various scenarios 44

Table 7-1 Components of a typical vehicle based on flat and long steel utilization 55

List of Abbreviations

AHSS	advanced high strength steel
ATF	Authorised treatment facility
BDE	Branchenverband der deutschen Entsorgungs-, Wasser- und Kreislaufwirtschaft
BEV	Battery electric vehicle
BF-BOF	blast furnace-basic oxygen furnace
CAPEX	Capital expenditures;
CBAM	Carbon Border Adjustment Mechanism
CCS	Carbon capture and storage
CCU	Carbon capture and utilization
CRM	Critical raw material
DRI	direct reduced iron
EAF	electric arc furnace
EC, EU COM	European Commission
EGARA	The European Group of Automotive Recycling Associations
ELV	End-of-life vehicle
EoL	End of life
EPR	Extended Producer Responsibility
ETS	Emissions Trading Scheme
EU	European Union
EURiC	The European Recycling Industries‘ Confederation
EV	Electric vehicle
GHG	Green House Gas
HEV	Hybrid electric vehicle

HSS	high strength steel
iCCT	International Council on Clean Transportation
ICE	Internal combustion engine
MOE	Molten oxide electrolysis
OPEX	Operational Expenditures
PHEV	Plug-in-Hybrid electric vehicles
PoCSr	post-consumer scrap recovered
PoM	Placed on the market
PST	Post Shredder Treatment
RC	recycled content
SAF	Submerged Arc Furnaces
SHF	Shredder Heavy Fraction
SLF	Shredder Light Fraction
TRL	Technology readiness level
UBA	Umweltbundesamt
UHSS	ultra-high strength steel

1 Introduction

On 13 July 2023, the European Commission published a legislative proposal[1] revising the current Directive 2000/53/EC on end-of-life vehicles (ELVs)[2], and its corresponding Directive 2005/64/EC on the type-approval of motor vehicles with regard to their reusability, recyclability and recoverability (3R type-approval)[3].For the collection and treatment of end-of-life vehicles, in addition to specifications on the recycled content of various materials, stipulations on dismantling, on the overall rates of reuse, recycling and recovery and additional information obligations are proposed. According to the draft, vehicle manufacturers should bear the costs of collection and recovery, minus the proceeds.

The proposal includes the following measures:

- In the short term, vehicle manufacturers should be obliged to provide more detailed and user-friendly dismantling and recycling information, including on the use and fate of critical raw materials in vehicles and the proportion of recycled materials in new vehicles.
- A stricter definition of "recycling" should be established to ensure more efficient treatment. The landfilling of shredder residues from motor vehicles is to be prohibited. Furthermore, the list of components to be removed during dismantling is to be expanded, e.g. the e-drive motor, the wire harness and electrical and electronic components like inverters or printed circuit boards with a surface area, larger than 10 cm^2.In order to collect more ELVs, a clearer allocation of responsibilities for recovery certificates, binding criteria for distinguishing between used vehicles and end-of-life vehicles and new enforcement provisions are to be introduced. The export of used vehicles that are no longer roadworthy under EU law is to be prohibited.
- Financial and organisational incentives through the definition of extended producer responsibility obligations should help to increase the collection rate for end-of-life vehicles and offset the costs of improved treatment quality.

Some of the provisions of the regulation are to be gradually extended to other vehicle types. To this end, manufacturers of vehicles in the classes L3e to L7e (two- and three-wheeled vehicles) as well as lorries, buses and trailers will be obliged to provide information on the composition of their vehicles. Furthermore, minimum requirements for the disposal of these end-of-life vehicles are to be introduced12egulationlation will repeal and replace both the 3R type-approval and ELV Directives. The proposal is currently considered by the European Parliament and the Council in the ordinary legislative procedure.

As part of the European Commission's Impact Assessment Report (based on a study by the Oeko-Institut[4]), environmental, economic, and social impacts of recycled content requirements were examined. The European Commission has decided not to set any targets for the proportion of

[1] Proposal for a Regulation of the European Parliament and of the Council on requirements for the circular design of vehicles and for the disposal of end-of-life vehicles, amending Regulations (EU) 2018/858 and (EU) 2019/1020 and repealing Directives 2000/53/EC and 2005/64/EC, see https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=celex%3A52023PC0451

[2] Directive 2000/53/EC of the European Parliament and of the Council of 18 September 2000 on end-of life vehicles, see https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:32000L0053

[3] Directive 2005/64/EC of the European Parliament and of the Council of 26 October 2005 on the type-approval of motor vehicles with regard to their reusability, recyclability and recoverability and amending Council Directive 70/156/EEC, see https://eur-lex.europa.eu/legal-content/DE/TXT/PDF/?uri=CELEX:32005L0064

[4] Study to support the impact assessment for the review of Directive 2000/53/EC on end-of-life vehicles, see https://op.europa.eu/en/publication-detail/-/publication/2fa7e161-2083-11ee-94cb-01aa75ed71a1/language-en

recycled steel used in new vehicles in the current proposal for the ELV Regulation, as the impact assessment indicates that there are still too many uncertainties to allow targets to be set at this time.

Instead, according to Article 6 of the proposal the Commission is empowered to adopt delegated acts to supplement this Regulation by establishing a minimum share of steel recycled from post-consumer steel waste to be present and incorporated into vehicle types to be type-approved in accordance with this Regulation and Regulation (EU) 2018/858. The minimum share of recycled steel shall be based on a feasibility study, to be carried out by the Commission.

According to the proposal the Commission may also adopt an implementing act establishing the methodology for the calculation and verification of the share of steel recycled from post-consumer steel waste present in and incorporated into vehicle types.

The aim of this study is to collect additional quantitative and qualitative evidence by assessing which policy options would be best suited to incentivize the uptake of high-quality scrap in the automotive industry.

2 Market overview on End-of-Life vehicle treatment sector in the EU & Germany

The EU ELV treatment sector specializes in environmentally responsible treatment of end-of-life vehicles in order to minimise waste generation and maximise resource recovery. Its key activities are vehicle dismantling and treatment to gain vehicle's spare parts for reuse and materials from ELVs for further recycling and recovery. This sector deals also with proper disposal of hazardous materials.

Key players in the ELV treatment sectors are:

- Authorized Treatment Facilities (ATFs), which are facilities licensed to dismantle ELVs in compliance with EU regulations.
- Shredder and post-shredder operators: specialize in the shredding and sorting of the dismantled ELVs and the post shredder treatment (PST) of obtained residues to be sent to further recycling (e.g. smelters), recovery (e.g. co-incineration) or disposal. An example of such facilities within the EU are Galloo with its branches in Belgium, France and Zeeland Flanders.

Individual ATFs and shredder operators are often members of national and international organisations, on the European level these are for instance:

- The European Recycling Industries' Confederation (EuRIC) represents most end-of-life (ELV) recycling facilities, including shredders, post-shredders, and producers of recycled materials used in new vehicles. It also represents Authorised Treatment Facilities (ATFs) that dismantle ELVs for recycling or reuse.
- The European Group of Automotive Recycling Associations (EGARA) is the European association of national independent vehicle dismantler organizations, representing the interests of vehicle dismantlers across Europe.

Example of representative association at the German level is Industry association for the German waste disposal, water and circular economy (in German: BDE – Branchenverband der deutschen Entsorgungs-, Wasser- und Kreislaufwirtschaft).

The EU ELV treatment sector is a key economic driver, supporting both environmental sustainability and growth. Although exact figures are hard to pinpoint, the sector creates significant value in multiple ways: resource recycling (including metal and plastic recycling), job creation, innovation and technological advancements, environmental benefits and cost savings (e.g. through reuse of spare parts which also avoids production of new vehicle components).

This chapter provides a short market overview on the state of the art of vehicle dismantling and shredding in the European Union and Germany. The scope of this study is steel scrap recycling, thus the technological description covers the dismantling of vehicle scrap parts relevant from a scrap steel recycling perspective. The same approach is applied for ELV treatment in the shredder. The problem of efficient steel scrap recycling is outlined in chapter 3. This includes the challenge of steel scrap recycling with high-copper content. There are various ways to obtain steel scrap of lower copper-content to increase its use in the production of various steel products. Thus, in overall, the goal is to outline the methods (including technologies) that support this.

2.1 Treatment of End-of-life vehicles in the EU

The treatment of End-of-Life Vehicles (ELVs) in EU countries follows, in general, these steps:

- Depollution that involves e.g. removing hazardous materials like batteries and components identified as containing mercury (according to Annex I of ELV Directive (2000/53/EC).
- Removal of parts to promote their separate recycling, e.g. catalysts, tyres, metal components containing copper, aluminium and magnesium if these metals are not segregated in the shredding process, glass (according to the Annex I of ELV Directive (2000/53/EC).
- Dismantling of additional parts for reuse, depending on market demand and the potential revenue from selling the components. As such operations are currently voluntary, ATFs will only dismantle such parts if they expect the revenue from dismantling to cover the costs, which can vary by region. Dismantling aims to recover parts for reuse[5] or remanufacturing[6]. If there is no demand for a part or if it is damaged during the process, it may be sent directly to recycling rather than being shredded. In some cases, certain parts like engines are removed for direct recycling if the revenue from selling them is higher than the amount the dismantler would get from sending them to the shredder. The motivation behind the practice of dismantling for reuse is for the ATF to increase their revenues per treated ELV. Not all ATFs engage in this practice.

During the dismantling process, depolluted parts, fluids, and components must be stored carefully to avoid damage. Removing materials before the shredding stage enhances their recovery, prevents mixing, and maintains their recyclability and reusability. This process helps optimize material recovery from ELVs and ensures the maximum value of the recycling efforts.

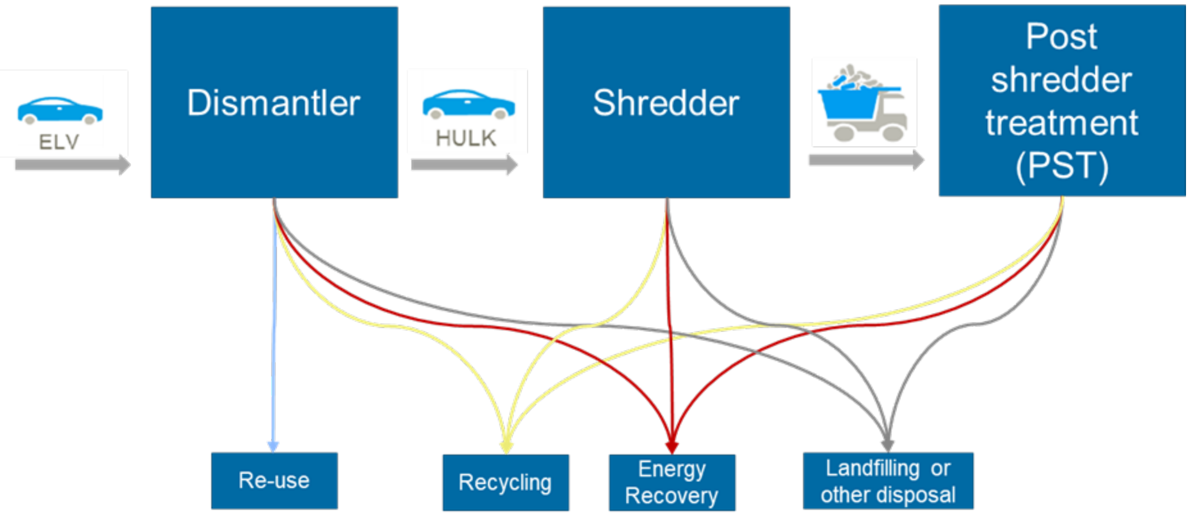
Nevertheless, currently, most vehicle dismantlers do not perform pre-shredder removal of materials like glass, large plastic parts, wire harnesses, and electronic components. This is because the value of these materials relative to the cost of removal makes it economically unfeasible. Additionally, the current ELV Directive does not provide a clear obligation to remove these parts prior to shredding.

[5] Reuse of waste means any operation by which products or components are used again for the same purpose for which they were conceived.

[6] Remanufacturing is an industrial process by which a previously sold, worn, or non-functional product can be rebuilt and recovered. Through the disassembly, cleaning, repair and replacement of worn out and obsolete components, the piece can be returned to a 'like-new' or 'better-than-new' condition and will be just as reliable as the original product.

Figure 2-1 illustrates the typical stages of ELV waste management and treatment, showcasing the output of each stage in the process.

Figure 2-1: Stages of the ELV waste management and treatment processes performed on outputs of each stage



Source: own illustration, Oeko-Institut

The next step after dismantling, is the shredding process that breaks the vehicle into smaller parts, which are then sorted into different material fractions. The primary output from shredding is quality steel scrap, which is separated using a magnetic separator. This steel is dense, pure, and homogeneous in size, although it may still contain impurities like aluminium or copper wire from electric motors, which can be manually removed to enhance the steel's quality. The resulting steel scrap can be used in metal works to produce new steel.

The products of shredding are Shredder Heavy Fraction (SHF), and Shredder Light Fraction (SLF). These can be treated further in post shredder treatment (PST) plants for further material recovery. The outputs of PST include ferrous and non-ferrous fractions, as well as materials that may undergo further treatment in recycling processes or be sent for final disposal, such as incineration (Mehlhart et al., 2018).

According to Sander et al. (2020), the typical distribution of input material in the shredding process is as follows: 70% of total materials in ELVs goes to the ferrous fraction with Cu contamination, 11% to the shredder heavy fraction (SHF), 18.5% to the shredder light fraction (SLF), and less than 0.5% are losses. The ferrous fraction consists of iron and steel, the shredder heavy fraction contains glass and non-ferrous metals including aluminum, copper and stainless steel and the shredder light fraction is a partially contaminated mixture of plastics, rubber, textiles, residual metals and other materials.

The composition and purity of the resulting ferrous products are largely influenced by the types of materials processed. In practice, end-of-life vehicles (ELVs) are often mixed with other materials. For example, in a survey of eight shredding companies, the shredded input material at these companies consisted of 45-80% automotive parts, 15-80% appliances, and 5-15% other items (Brahmst, 2006).

In 2022, in total about 4,668,000 ELVs were generated in the EU (Eurostat, 2024). This number corresponds to about 5,465,000 tonnes (EU-27 estimation). On average, in the EU about 11.5% of ELV mass is removed before the vehicle is sent to the shredder (Eurostat, 2024).

In total in the EU, the ELV treatment sector (excluding Lithuania and Slovenia) obtained 613,500 tonnes of spare parts dismantled for reuse, 4,300,000 tonnes of materials for recycling, 267,000 tonnes for energy recovery, and 330,000 for disposal in 2022.

Currently, most vehicle dismantlers do not perform pre-shredder removal of materials like glass, large plastic parts, wire harnesses, and electronic components. This is because the value of these materials relative to the cost of removal makes it economically unfeasible.

Additionally, the ELV Directive (2000/53/EC) does not provide a clear obligation to remove these parts before shredding.

By removing the parts before the shredder, the component can be sent directly for recycling while maintaining the high quality of the material from which it is made.

Removing copper-rich parts before shredding reduces shredders' residues contamination.

2.2 State of art in Germany

Each year, Member States report to Eurostat on the amount of end-of-life vehicles produced each year (number and amount in tonnes) and on the amount of material processed from end-of-life vehicles, e.g. for reuse[7], recycling[8], energy recovery[9] or disposal. The current ELV Directive sets a reuse/recovery target of 95% and a reuse/recycling target of 85%. The reuse/recovery and reuse/recycling rates achieved in 2022 for Germany are 93.7% and 86.4%, the estimates for EU are 94.4% and 89.1%, accordingly[10]. According to the German Federal Motor Transport Authority (KBA)[11], Germany recorded 2,873,831 new M1[12] and N1[13] vehicle registrations in 2022, and 311,777 used vehicles were imported, totalling 3,185,608 vehicles. There were 7,119,572 de-registrations (final and temporary), with assumed 2,872,468 M1 and N1 vehicles being permanently removed from the national register.

7 See footnote 5 for definition of reuse.

8 Recycling of waste means any recovery operation by which waste materials are reprocessed into products, materials or substances whether for the original or other purposes.

9 Recovery of waste means any operation the principal result of which is waste serving a useful purpose by replacing other materials which would otherwise have been used to fulfil a particular function, or waste being prepared to fulfil that function, in the plant or in the wider economy.

10 https://ec.europa.eu/eurostat/databrowser/view/env_waselvt/default/table?lang=en&category=env.env_was.env_wasst

11 https://www.kba.de/DE/Statistik/statistik_node.html

12 M1: Vehicles used for the carriage of passengers and comprising not more than eight seats in addition to the driver's seat.

13 N1: Vehicles used for the carriage of goods and having a maximum mass not exceeding 3.5 tonnes.

The KBA and foreign trade statistics show 2,099,456[14] used vehicles were exported to EU countries. Exports to non-EU countries were smaller, with 214,669 used vehicles exported, although this figure may underestimate the true volume due to reporting gaps. This data has a high uncertainty with regard to the volume of exports to third countries that are not systematically recorded in German foreign trade statistics because they either fall below the reporting threshold (1000 euros or 1000 kg), are exported by private individuals or because they involve the transit of used vehicles from Germany via another EU country (customs office of exit) to a non-EU country in a single-stage procedure or through customs agents. Estimates suggest an additional 120,000 used vehicles were exported to non-EU countries. Overall, Germany exported 2,430,905 used vehicles in 2022.

Undertaking the calculations using these methods yields a similar result, which in 2022 assumes there were approximately 150,000 vehicles with unknown whereabouts.

Since the statistical gap of unknown vehicle whereabouts can be partly associated with the risk of unrecognized dismantling of end-of-life vehicles, it is important to know this gap as precisely as possible in order to identify its causes and take any necessary measures against unknown whereabouts.

As the UBA/BMUV (2024) indicates: "Against this background, it would be very helpful to have precise statistical data on final decommissioning in Germany. It would be helpful to create a central database of all certificates of destruction issued, which could then be linked to the data on vehicle registrations."

Regarding unknown whereabouts / missing vehicles in Germany, UBA stated that "[…] it would be very helpful to have precise statistical data on final decommissioning in Germany. It would be helpful to create a central database of all certificates of destruction issued, which could then be linked to the data on vehicle registrations."

3 Steel scrap use and the problem of copper contamination

3.1 Usage of steel scrap

Steel is typically produced by one of two routes: Either via the blast furnace – basic oxygen furnace (BF-BOF) route, or via the electric arc furnace (EAF) route.

The steel industry in the EU produced more than 126 million tonnes of steel in 2023. This was produced by 500 production sites spread over 20 EU Member States.

More than 28% of it was produced in Germany (about 35 million tonnes), making Germany Europe's largest steel producer and the world's 7th largest producer of crude steel.[13] According to World Steel, the apparent steel use of finished steel products in Germany was about 28 million tonnes in 2023[15] making Germany a net exporter of steel.

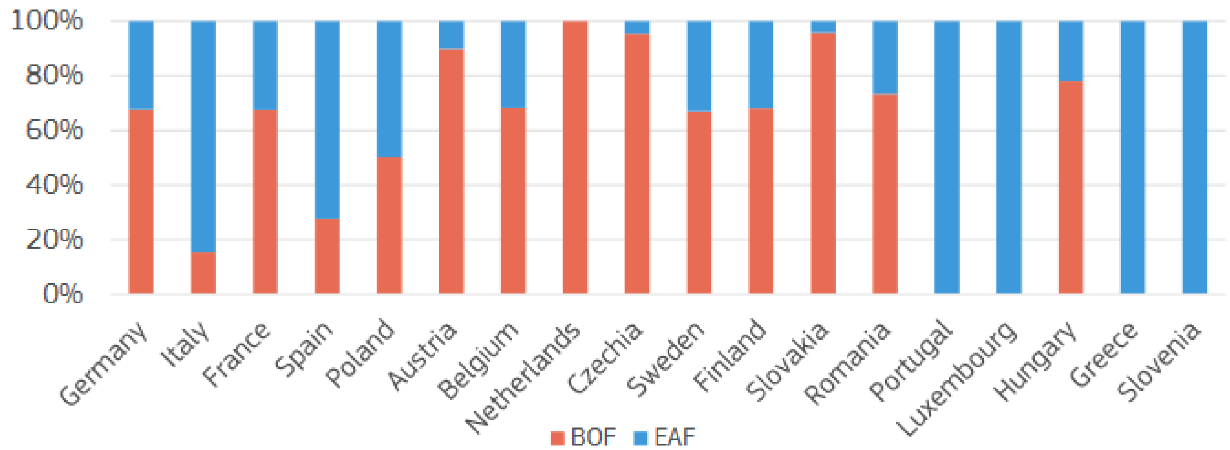
[14] This value includes additional estimates for other statistically unrecorded exports of used vehicles to other EU states with re-registration.

[15] https://worldsteel.org/data/world-steel-in-figures-2024/#steel-production-and-use-geographical-distribution-2023

Fourteen EU countries have primary steel making capacities, with plants often consisting of multiple blast furnaces and other processing facilities (coke, sinter, BOF, rolling, etc.). The smallest plants produce just over 1 million tonnes of crude steel per year, while the largest, such as in Taranto, Italy, and Duisburg, Germany, have capacities around 10 Mt/year. There are 25 integrated steelmaking sites[16] in the EU, mainly concentrated in the Rhine-Ruhr and Benelux regions, with a smaller cluster in Eastern Europe (Poland, Czechia, Slovakia). In contrast, electric arc furnace (EAF) sites, or mini-mills, are smaller, with capacities ranging from 100,000 tonnes to 2.5 Mt/year at the largest site in Germany. There are about 120 EAF sites across 18 EU countries (Somers J., 2022).

Figure 3-1 illustrates the split between BOF and EAF production in the various Member States. In Germany, two thirds of steel (68%) is made in blast furnaces, whereas in Italy the vast majority (85%) is made in electric-arc furnace mini mills (Somers J., 2022).

Figure 3-1: Steel production by Member States in 2020



Source: Somers J. (2022) based on World Steel Association from 2021 source

According to Eurofer, in 2023, the automotive sector was the second-largest consumer of steel in Europe (19.1%), after the construction sector (35.5%).[17]

The highest demand for the strip mill products (which are flat products) exists in the automotive industry. It corresponded to about 39.2% of overall production of strip mill products in 2023 (within EU it is 48.8 million tonnes in total). However, it is unclear what percentage of post-consumer scrap in the automotive sector is included in the calculation.[18]

Post-consumer steel scrap is typically used in the construction sector for producing reinforcing bars, a lower-value application for steel (Allwood, 2016). As a result, a closed-loop recycling process has not yet been established in the automotive industry, which still relies on high-quality steel from the blast furnace-basic oxygen furnace (BF-BOF) route or new scrap (Nakamura et al., 2012; Hatayama et al., 2014).

[16] An integrated steel plant has all the functions for primary steel production: coking, blast furnace, converting, casting, rolling.

[17] https://www.eurofer.eu/assets/publications/brochures-booklets-and-factsheets/european-steel-in-figures-2024/EUROFER-2024-Version-June14.pdf

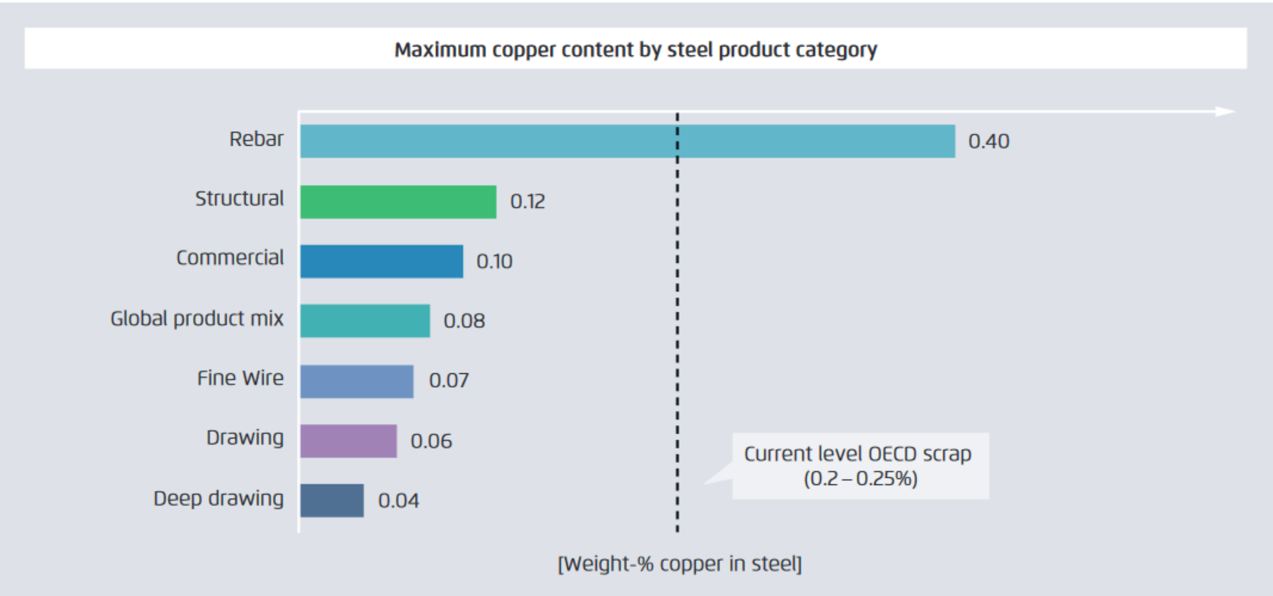
[18] Eurofer 2024, see footnote 14

A current iCCT (International Council on Clean Transportation) study (Bui et. Al, 2024) indicates that, according to a variety of sources, at least 75% of steel used in vehicle manufacturing is primary steel. It would mean that in 2023 about 18 Mt of total EU steel production used for the automotive sector was primary steel and 6 Mt was secondary steel. Another current iCCT study (Negri et al, 2024) stated: “For the European companies identified as supplying steel to automakers, 97% of the installed steelmaking capacity is based on the BF-BOF pathway compared to the European average of 56%, with the remainder being EAFs. This results in a GHG emissions intensity equal to or above 2.1 t CO_2e/t steel). In North America, steel producers supplying the automakers, on average, have a BF-BOF share of 31%, in line with the North American steel industry average.” For the US primary steel production, Negri et al (2024) gives a value of 2.3 t CO_2e/t steel.

3.2 The problem with copper contamination

Most steel scrap contains other metals, which, if not removed during the Electric Arc Furnace (EAF) melting process, are referred to as "tramp elements". These include metals such as copper (Cu), nickel (Ni), tin (Sn), arsenic (As), chromium (Cr), molybdenum (Mo), lead (Pb), and others. According to Nakajima et al. (2011), the most significant tramp elements in steel recycling are copper and tin, as both can cause hot shortness— a phenomenon that leads to surface cracking during hot rolling and forming. For copper, this occurs when its concentration exceeds 0.1 wt %, while tin can cause similar issues at concentrations as low as 0.04 wt % (Daehn et al., 2017a). Tin is in packaging tinplate and makes up a much smaller portion of the scrap stream (less than 1 %). In contrast to tin, which can be isolated and treated more readily prior to melting, copper is currently the main barrier to producing high quality steel from end-of-life scrap. Figure 3-2 indicates the tolerance level for copper in various steel products and current levels prevalent in OECD scrap.

Figure 3-2: Copper tolerances in different steel products



Source: Sartor et. al (2022)

The nominal tolerance for copper concentration in steel determines the suitability of recycled steel for various applications. For reinforcing bars, the tolerance is set at 0.4 wt % copper, while flat products (such as steel sheets) have stricter limits, typically less than 0.06 wt % copper for drawing steel (a specific flat steel product). Copper concentration in shredded end-of-life vehicle (ELV) scrap can range from 0.23% to 0.7% (Daehn et al., 2017b). A shredded scrap sorting trial conducted by ArcelorMittal showed a copper content of 0.6% (Russo et al., 2011).

In steel recycling, a common method to reduce the concentration of tramp elements, including copper, in the steel melt is to dilute it with primary iron or less contaminated scrap sources (Björkman and Samuelsson, 2013). Additionally, steelmakers may adjust their processing techniques to further control impurity levels.

Minimizing copper contamination in recycled steel is crucial for ensuring that steel derived from post-consumer scrap, particularly from end-of-life vehicles (ELVs), meets the high-quality standards required to increase recycled content in vehicle production. Therefore, removing electronic components and cables (such as the main wire harness) prior to shredding seems to be a key strategy to reduce such impurities and plays an important role in this process. Copper is found in vehicles both as an alloy in the aluminium of engine blocks or transmission housings and as cathode in cables, batteries, windings, copper rotors, electric motors, wiring, busbars and radiators. About 60% of the copper in a vehicle is in the wire harness and in the engine, e.g. in the ventilation and heating systems (Argonne 2021). If about 50% of the main wire harness can be removed prior to shredding, this, combined with the dismantling of electric motors and generators in BEVs, could reduce the copper content in steel scrap from about 0.4% to about 0.2%. As the wires run through the entire vehicle, it is not economically feasible to dismantle the entire wire harness.

However, a reduction of the copper content to below 0.2% is not sufficient to achieve the high purity of steel scrap required for flat steel products, therefore, further technical measures have to be taken in downstream processing to remove the copper.

3.3 Residual copper removal from steel scrap

This chapter provides more information about dismantling and other possible technological options to remove the copper.

Should recycled content targets necessitate the use of high shares of recycled content also in components produced of high-quality steel, it is probable that the treatment of ELVs would need to include more removal of steel components of higher quality for the sake of separate recycling. In particular Quality class Q1 components could be expected to be targeted by dismantlers for removal, as they would probably retrieve higher revenues for such parts in comparison with when they are shredded. This relates to components constructed of flat steel and long products.

Steel components of higher quality can be dismantled by the ATF prior to shredding, allowing for their separate recycling and thus creating a stream of higher quality steel scrap. In some cases, such components will be removed with the aim of their reuse. Whereas some of the removed components will be sold for reuse, others will be retained for a while in the ATF's storage and sent to separate recycling if not sold over a certain period (this can differ between components and models and brands). In cases where the component is damaged during the removal process it will also be sent to separate recycling.

To allow integrating the economic impacts of the measures addressed in chapter 6 into the model, data is being collected for the above-mentioned steel components as to their weights and the related dismantling time or cost. The compilation of results obtained so far has been included in Annex V and could be used at a later stage to quantify, to the degree possible, costs of dismantling in the related measures under review. The costs collected there refer to removal for the sake of reuse, i.e.

non-destructive removal. Such removal is often performed manually, and the cost is related to the tools needed for the task (investments) and the working time needed for removal (labour).

Furthermore, where reuse is not of relevance (or where the ATF has enough components for reuse in stock), the components can be removed in a destructive manner, which translates to lower costs for removal. In some facilities this is done with machines such as the "VRS Powerhand":

> *"The order of the dismantling process varies from vehicle to vehicle and the preference of the operator. However, the key extra profit materials that can easily be extracted are; the high value copper wiring loom, heavy steel components from axle and suspension assemblies, electric motors and, the engine and transmission assembly. The engine and transmission assembly can then be split down into its component materials, such as the alloy gearbox and engine head […] Depending on vehicle type and the amount of added value materials being extracted, operators of the VRS advise that they can process in excess of five cars per hour and generate between £ 40 and £ 60[19] in extra added profit per vehicle, making VRS an attractive investment for recycling companies.".*[20]

Based on input from an ATF facility who has 4 powerhand devices at their disposal, the time needed to process a vehicle is between 10-15 minutes. In contrast, the manual removal of a headlight for example takes about 1-10 minutes in their facility depending on the number of screws that need to be loosened and on whether the bumper needs to be removed in the process. This clarifies the economic efficiency of devices like the VRS Powerhand.

A further exchange with a facility using a device like the power hand provides insights as to possible investments. The device costs relate to the body of an excavator and the customised installation that has been developed for it for dismantling of the vehicle to allow pulling out the motor (so as to remove the catalytic inverter) and to allow pulling out of the main wire harness. Investment in an excavator requires between 90 and 150 thousand Euro, depending on whether it is a conventional or an electric vehicle, respectively. The additional installation was developed together with a company who builds excavators and required an investment of ca. 350 thousand Euro. This makes for a total investment of around 450,000 Euro. It was further explained that even if the device were only used to extract the copper wire harness, the return on investment could be expected after a year. This is the case for a facility which treats over 10,000 ELVs per annum. Operation costs include the cost of the operator (labour) along with fuel and maintenance costs. Even if a non-customised device (e.g., the power hand) would cost less, it is still expected to be in the same order of magnitude. Though it has not been discussed with stakeholders, we assume that without a requirement to dismantle the main wire harness, that only facilities with a similar (or higher) annual capacity for treating vehicles would invest in such devices, especially those that are generally more engaged in removal of parts for reuse.

The table below summarises advantages and disadvantages of ELV treatment technologies that play a role in the quality of steel scrap especially in its Cu-contamination.

---

[19] The data is from 16.7.2018. At the time this meant 45-68 EUR. The British Pound to EURO exchange rate on Monday 16th July 2018 is given as: 1 GBP = 1.1304 EUR in https://www.exchangerates.org.uk/historical/find-exchange-rate-history-for-16_07_2018

[20] See: https://atfpro.co.uk/2018/07/16/maximising-profits-from-elvs-with-the-powerhand-vrs-the-days-of-hand-stripping-an-elv-are-dwindling/ for further details.

Table 3-1 Quality of steel scrap: advantages and disadvantages of ELV treatment technologies

Technology	Advantages	Disadvantages
Dismantling prior to shredding	For parts that are made of high-quality steel: opportunity to send to separate steel recycling which allows retaining a higher quality of the recyclate. Currently practiced by dismantlers at times where the steel market fluctuations increase the costs of primary steel, meaning that ATFs can obtain higher revenues when selling separately dismantled steel scrap. For parts that contain components with Cu: chance to remove Cu-intensive component and send it to Cu-recycling directly. Revenues generated from the sale of spare parts and the sale of components for recycling, e.g. copper from wire harnesses.	Higher labour costs for removal of parts for reuse (usually manual and must be non-destructive so more time consuming). Higher investment costs for mechanical removal (powerhand). Higher demand on storage for dismantled parts waiting for transport to recyclers.
Shredding	Separation of ELVs into various fractions incl. steel fraction. With advanced technologies, it is possible to separate copper more effectively, thus obtaining steel scrap of higher quality. Revenues generated from the sale of separated fractions.	Steel lost in the process, i.e. in the SLF, especially when not treated in PST. In case of lack of advanced separation technologies, steel scrap fraction with high Cu-contamination. Investment costs for advanced technologies or/and manual sorting. No revenues from the sale of dismantled spare parts.
Post-shredding	With advanced technologies, may reduce the need for dismantling. Revenues generated from the sale of separated fractions.	Investment costs. Without further sorting, lower quality of separated fractions in the shredder, e.g. steel scrap with higher Cu-contamination..

Source: compilation, Oeko-Institut

Under some of the measures under consideration in this study (see section 6.2) it can also be expected that ATFs would increase the dismantling of copper components. Though copper has a significantly higher market value then steel, at present, only some ATFs take time to dismantle copper relevant components like the main wire harness. However, under some of the proposed measures, an increase in dismantling of copper components may be aimed at by ATFs as they will likely be able to obtain a higher price for vehicle carcasses where certain copper components have been removed. For this purpose, the following components are of relevance for removing relevant amounts of copper from shredder scrap (these parts are also listed in the EU proposal in annex VII part C for mandatory removal prior to shredding):

- The main wire harnesses, internal and external charging cables if present[21];
- E-drive motors, including their casing, generators or alternators and cooling fan motors if present, control units, wiring and other parts, components and materials directly fastened or attached to E-drive motors[22] (also relevant for removal of CRMs);
- Combustion engine blocks with generators, starter alternators, radiator/cooling fan motors and associated devices[23] (also relevant for removal of aluminium);
- Rims[24] (also relevant for removal of aluminium);
- Gearboxes with control units if present (not relevant for ICEs)[25];
- Electrical and electronic components, including inverters and DC-DC converters above 24V of the electric vehicles and control modules and valve boxes for the automatic transmission;[26]
- Small motors

These components have also been taken into consideration in the compilation of data included in annex V.

Annex VI furthermore specifies the revenues that can be retrieved for the sale of scrap by ATFs and by sales of secondary materials by recyclers, which shall also be used for calculating economic impacts. For example, based on OKRAM data[27] for copper, an ATF selling e.g., copper dismantled with the wire harness, could receive 4,200 EURO per tonne of copper scrap. This value has also been used to calculate revenues for shredders and PST operators selling copper scrap to recyclers after implementing advanced shredding and treatment techniques during or after the shredder to remove more copper from steel scrap. After the scrap is melted it can be sold by the recycler, returning a revenue of 6,286 €[28].

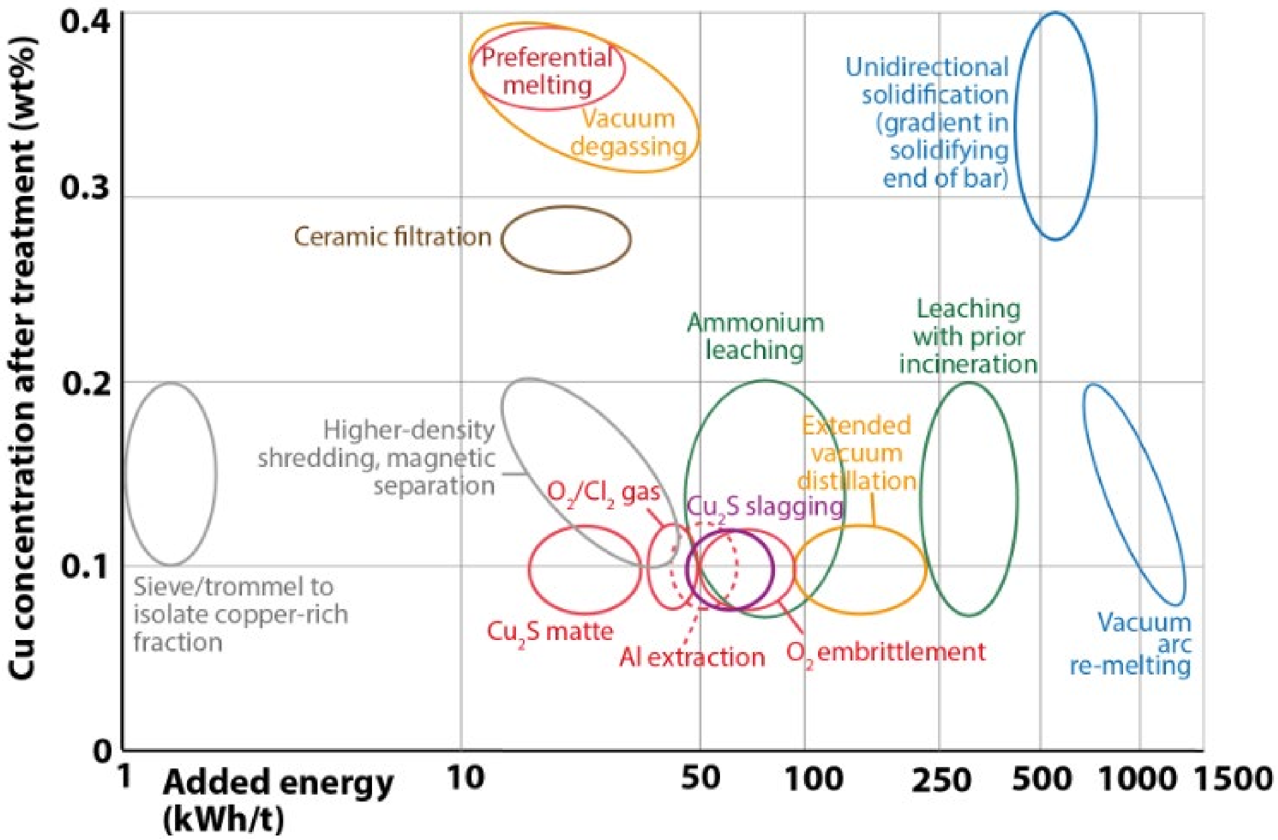
As the quality of steel scrap depends on the level of copper impurities, various methods are discussed to remove copper from steel scrap. Daehn et al. (2017) explain that the commonly practiced hammer shredding pounds copper particles from wiring onto steel, making it more difficult to separate the copper, so that subsequent magnetic separation is only 80% effective. However, further disassembly could remove copper-containing parts prior to shredding. To this end, in this section, we also look at the components of the vehicle that contain large amounts of copper (see above). Furthermore, Daehn et al. (2017) and Daehn (2019) detail various alternatives to dismantling:

[21] EC Proposal Annex VII Part C: ‘Wire harnesses‘
[22] EC Proposal Annex VII Part C: ‘E-drive motors, including their casings and any associated control units, wiring, and other parts, components and materials’
[23] EC Proposal Annex VII Part C: ‘Engines‘
[24] EC Proposal Annex VII Part C: ‘Wheels‘
[25] EC Proposal Annex VII Part C: ‘Gearboxes‘
[26] EC Proposal Annex VII Part C: ‘Electrical and electronic components, including inverters of the electric vehicles and control modules and valve boxes for the automatic transmission’
[27] Groke, M.; Kaerger, W.; Sander, K.; Bergamos, M. (2017): Optimierung der Separation von Bauteilen und Materialien aus Altfahrzeugen zur Rückgewinnung kritischer Metalle (ORKAM). In: Umweltbundesamt, UBA Texte (02/2017).
[28] See footnote 4

- Alternative shredding processes for improved sorting and for determining copper content prior to melting to allow strategic upgrading include:
  - laser-induced breakdown spectroscopy,
  - X-ray fluorescence,
  - neutron activation analysis,
  - image processing of a conveyor belt of scrap.
- In current EAF steelmaking and refining, copper remains in the melt, but removable mechanisms can be applied, including:
  - oxidation (such as vaporization).
  - forming a copper sulfide or chloride.
- Furthermore, the copper tolerance of products can be increased by manipulating processing (i.e., shorter oxidation times and surface quenching) and composition (adding nickel or silicon and avoiding tin) to overcome hot shortness. This has been the approach of Nucor, the largest steel recycling company in the United States, who have been able to penetrate the automotive steel market with EAF steel.
- Finally, vehicle design changes may also reduce the need for such interventions. Designs exist for weight-saving aluminium wire harnesses, and for the wiring wrapping around the vehicle to be detachable with one mechanical motion, making dismantling obsolete or at least easier.

As shown in Figure 3-3 with increasing copper concentration in the scrap, the energy required for processing would also increase.

Figure 3-3: The copper concentration reduction from 0.4wt% and estimated specific energy consumption for the various processes analysed in Daehn (2019)



Source: Daehn (2019)

The Company Tomra offers sensor-based technologies to separate non-ferrous metals, copper cables, copper, brass, aluminium, stainless steel from the post-shredder output material. For instance, X-Ray Transmission (XRT) is a sensor-based technology which aims to sort out material based on the atomic density irrespective of surface properties and thickness.[29] The X-Tract Separator uses dual energy X-ray Transmission imaging, which provides a wide range of material classification possibilities, such as material's average atomic density, shape, and internal structure, without sensitivity to surface contamination.[30] With x-ray power supply of up to 1000W, X-TRACT™ provides high-speed processing across multiple applications and grain sizes, including aluminium fines and copper wires.[31]

A variety of techniques are available to remove copper contaminations and to reduce the copper content to make it usable for the production of new passenger cars. But currently for most of the ATFs it is not economical, since there is no demand / no (economic / policy incentive)

[29] https://www.tomra.com/-/media/project/tomra/tomra/investor-relations/quarterly-results-files/2021/1q/210423-investor-presentation.pdf

[30] https://www.environmental-expert.com/products/titech-x-tract-model-xrf-metal-density-sorting-systems-140619

[31] https://www.tomra.com/en/waste-metal-recycling/products/machines/new-x-tract

The quality of steel depends on the proportion of tramp elements, especially copper. The lower the proportion of these tramp elements, the higher the quality of the steel applications could be.

Today, recycled steel via the electric arc furnace (EAF) route usually contains a significantly higher proportion of copper (typically 0.3-0.4% Cu) than primary steel via the blast furnace - basic oxygen furnace (BF-BOF) route (< 0.02% Cu).

While higher Cu values could be tolerated for production of long steel and cast iron, a high purity (< 0.1% Cu) is required for production of flat steel.

This requires an additional treatment step. In principle, there are two options that are being discussed: Dismantling of copper-containing components before shredding and additional sorting of the steel scrap after shredding.

4 Overview on scrap usage in the automotive industry in EU & Germany

The primary steel production route using blast oxygen furnaces can be used for producing both long and flat steel products. The share of scrap used in this case is usually supplied at plant level, mainly based on the pre-consumer scrap (high-quality scrap).

The secondary steel production using an electric arc furnace (EAF) is mostly used for long products, for which no high-quality scrap is required, so that post-consumer scrap (low-quality scrap) can be used. Wittig (2021) modelled the origin of steel scrap for the steel market in the EU. For 2018, it indicated that around 6 % of steel scrap originated from ELVs. (i.e., post-consumer low quality scrap)

While up to 100 % scrap can be used in electric arc furnaces[32], the possible proportion of total steel scrap in blast furnaces is significantly lower.

ArcelorMittal Europe, for example, uses two main routes for the production of long products:

- the BF-BOF route, which uses the iron ore and coal for steel production; the scrap usage rate varies between 10 to 20%
- the EAF route, in which the steel scrap is melted using electric energy where the scrap usage rate can be up to 100%. In the ArcelorMittal Europe plants the recycled content varies between 40 to 95% also in their DRI-EAF plants.

No post-consumer scrap is currently used in blast furnaces in the EU for the production of flat products.

Table 4-1 shows the share of scrap usage in steel and iron products used in the production of passenger cars in the EU, which is considered in this study.

[32] See for example the declaration on recycled content by the Swedish steel producer Ovako: https://www.ovako.com/49f36c/globalassets/downloads/sustainability/statement-recycled-content-ovako-20210621.pdf

Table 4-1 Share of scrap usage in production of flat and long steel and cast iron

Vehicle	Flat steel	Long steel	Cast iron
In-house scrap[33] (from steel plants)	2%	8.7%	11%
Pre-consumer scrap (post-industrial)	19%	13.6%	
Post-consumer scrap	0%	32.6%	43%

Source: Own table based on ArcelorMittal Europe Long Products (2022) for long steel and Daehn 2019 for flat steel and cast iron

From these shares of scrap usage we calculated total scrap usage for the different types of passenger cars, see Table 4-2. Published figures on the current recycled content of steel in new vehicles often refer to pure post-consumer scrap. In the further calculations in this study, the RC targets are also only assessed with post-consumer scrap.

Table 4-2 Share of steel scrap usage in production of passenger cars by engine type

Vehicle	In-house scrap	Pre-consumer scrap	Post-consumer scrap
ICEV	4.4%	15.5%	11.3%
HEV	4.3%	15.6%	11.3%
PHEV	4.4%	15.5%	11.4%
EV	3.1%	17.8%	5.2%

Source: Own calculation, based on model

There are several research projects in Germany aimed at increasing the use of recycled post-consumer steel in vehicles:

In light of the decarbonisation of steel production, Thyssenkrupp declares the involvement of TSR[40] in conventional production routes (blast furnace) alongside the use of ore[34]. The cooperation in the research project **REDER** between ThyssenKrupp and TSR started in 2021. The aim of this project was developing an advanced shredder technology that produces a steel fraction ready to be used in the flat steel production[35]. In the meantime, the new TSR shredder plant in Duisburg is operative. The plant is expected to process up to 450 000 tonnes of different input materials annually – such as end-of-life vehicles, mixed scrap, or large household appliances[36]. The output of TSR40 is

33 Metal that has been shaved, cropped, or slit off in various stages of casting and rolling of ingots into sheets.

34 https://www.euwid-recycling.de/news/wirtschaft/schrottrecycler-tsr-nimmt-in-duisburg-neue-aufbereitungsanlage-in-betrieb-280423/

35 https://www.thyssenkrupp-steel.com/de/newsroom/pressemitteilungen/steel-und-tsr-testen-innovatives-verfahren-zum-einsatz-von-hochwertigem-schrott-im-hochofen.html

36 https://www.euwid-recycling.de/news/wirtschaft/schrottrecycler-tsr-nimmt-in-duisburg-neue-aufbereitungsanlage-in-betrieb-280423/

300 000 tonnes. It was funded by the state of North Rhine-Westphalia with a total of 6.4 million Euro. In 2023, for example, the new TSR recycling plant in Duisburg announced that, thanks to newly developed measuring, detection and separation techniques, it is possible to reliably identify and remove interfering elements in the raw material during production and to precisely determine accompanying elements such as copper, nickel and chromium. According to TSR, the TSR40 product from the new steel scrap preparation process achieves a high purity (Cu < 0.08 %, Cr < 0.25 %, Mn < 0.4 %, Mo < 0.02 %, Ni < 0.07 %), which is also suitable for primary steel production in the blast furnace and converter and can therefore also be used for the production of high-quality flat steel.[37] In mid-2024, Remondis opened a second TSR40 plant in Amsterdam. It is currently building two more TSR40 facilities in Hamburg and Magdeburg, which are expected to start activity in 2025 and 2026, respectively.[38]

In April 2023, BMW reported about the research project **Car2Car**. The project will focus on several materials, including aluminium, steel, glass, copper, and plastic. According to BMW, “innovative dismantling and automated sorting methods should allow for far larger quantities of the resources to be recovered from ELVs to be made suitable for use in the production of new cars than has been the case to date.” In addition to several universities and trade groups, the Car2Car consortium partners include BMW, Scholz Recycling GmbH, Steinert UniSort GmbH, Thyssenkrupp Steel Europe AG, Salzgitter Mannesmann Forschung GmbH, Aurubis AG, Novelis Deutschland GmbH, Oetinger Aluminium GmbH, and Pilkington Automotive Deutschland GmbH.

There is already a small proportion of secondary steel from post-consumer scrap in new vehicles today (11.3% in ICEs, 5.3 % in EVs). Due to the shift towards electromobility the average share will decrease in the future, as the proportion of long steel and cast iron in electric vehicles is significantly lower and, on the other hand, flat steel is currently not produced from secondary material from post-consumer scrap.

5 Green steel

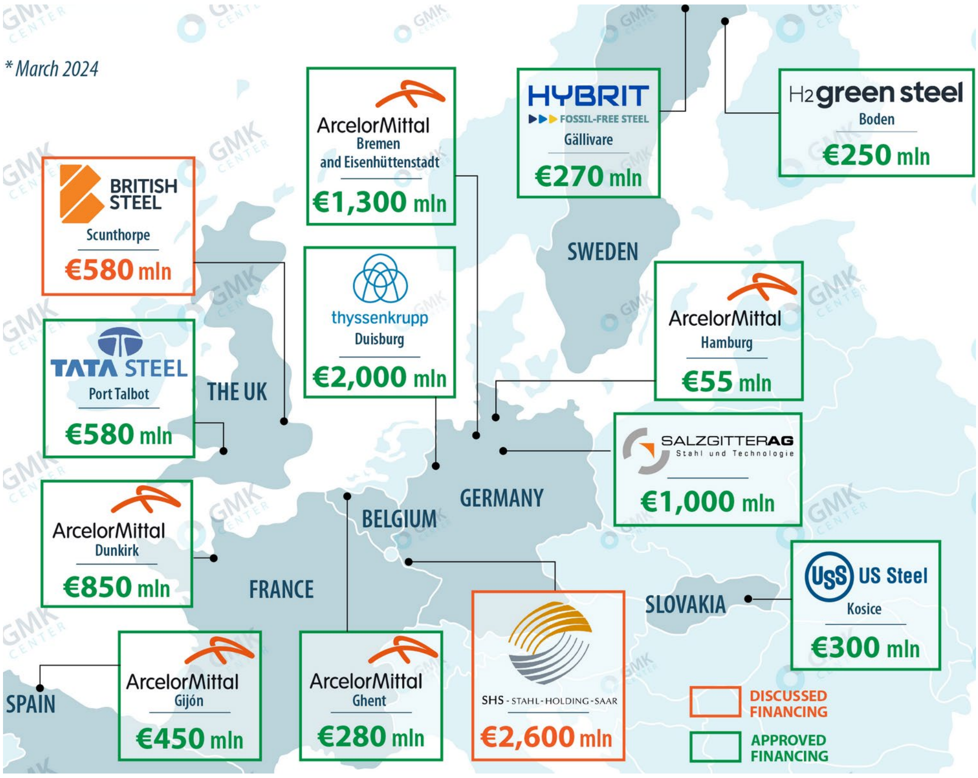
The European and German steel industry today relies to 100% on the blast furnace and oxygen blowing process for primary steel production. The electric arc furnace (EAF) process is used in Europe for secondary steel production. The European transition strategy for decarbonisation of the steel sector aims to replace the existing BO-BOF route by direct reduced iron (DRI) installations and subsequent EAF. This transition is supported by governmental aid as displayed in Figure 5-1. As an example, Thyssenkrupp Steel has commissioned the engineering, delivery and construction of a hydrogen-powered direct reduction plant with a capacity of 2.5 million tonnes per annum and two connected innovative melters and associated ancillary units at the Duisburg site with a contract

37 https://arn.nl/wp-content/uploads/pdf_presentation-hks-arn-relatiedag-2-oktober-2024.pdf

38 https://www.euwid-recycling.com/news/business/metals-recycler-tsr-and-papenburg-considering-offer-to-acquire-steelmaker-salzgitter-ag/

volume of 1.8 billion EURO[39]. A subsidy for the construction of 550 million EURO is granted by governmental aid and subsequent aid of up to 1.45 billion EURO is granted for the purchase of H_2.[40]

Figure 5-1: Governmental aid for green steel transition for steelmakers in Europe as published in the period January 2023 to March 2024



Source: GMK centre, https://gmk.center/en/infographic/european-countries-granted-e10-5-bln-for-decarbonization-of-the-steel-sector-in-2023-2024/ 02 Dec 02

Compared to the investment and the cost for the operation of a DRI-H_2 plant, the investment cost for advanced shredder technology, targeting the separation of post-consumer flat steel, are - as published by Remondis - about 35 million EURO only for a plant with a capacity of around 300 000 t/a output of high quality steel scrap for the flat steel production with a copper content of less than 0.08%[41]. For more details of this TSR shredder see chapter 4.

Building the new DRI-based assets will require significant capital expenditures (CAPEX) and operational expenditures (OPEX), estimated at ~190 €/t crude steel in total: ~40 €/t crude steel per annum. specific CAPEX to build an average DRI plant, and ~150 €/t crude steel per annum of additional OPEX compared to BF-BOF production.[42]

[39] https://www.thyssenkrupp.com/de/newsroom/pressemeldungen/pressedetailseite/thyssenkrupp-steel-vergibt-milliardenauftrag-fur-direktreduktionsanlage-an-sms-group--start-eines-der-weltweit-grossten-industriellen-dekarbonisierungsprojekte-163183 (accessed 02 Dec 2024)

[40] https://www.tagesschau.de/wirtschaft/unternehmen/gruener-stahl-thyssenkrupp-100.html

[41] https://www.reviews-magazin.de/fileadmin/user_upload/reviews_magazin/epaper-01_2022/index.html#22 Page 23, accessed 2 Dec 2024

[42] https://www.deloitte.com/de/de/issues/sustainability-climate/green-steel-transformation.html

As an example, Thyssenkrupp Steel has commissioned the engineering, delivery and construction of a hydrogen-powered direct reduction plant with a capacity of 2.5 million tonnes per year and two connected innovative melters and associated ancillary units at the Duisburg site with a contract volume of 1.8 Billion €[43]. A subsidy for the construction of 550 million is granted by governmental aid and subsequent aid of up to 1.45 billion EURO is granted for the purchase of H_2.[44]

Green H_2 is expected to make up 40-50% of the total OPEX of green steel production for an average EU-based DRI-plant in 2030.[45] This is due to a substantial expected H_2 supply gap in the EU, despite EU efforts to build a hydrogen backbone.

On the other hand, the EU steel industry has produced ~228 Mt CO_2eq in 2021. For ~44 Mt CO_2eq (~24% of ~185 Mt CO_2eq direct emissions), the EU steel industry had to buy allowances of the EU-ETS (Emissions Trading Scheme) for ~60 €/t CO_2eq, yielding a total CO_2eq cost of ~2.6 billion EURO in 2021, i.e., ~2% of the EU steel industry revenue of ~125 billion EURO (the remaining ~76% of direct CO_2eq were free allowances).[46]

By 2035, the business-as-usual situation would be expected to become much worse for conventional primary steel production: assuming no CO_2eq decrease in the production process, direct CO_2eq would grow in line with the primary steel market to ~200 Mt CO_2eq. Moreover, free allowances are expected to decline by at least ~2.2% per annum and to end at the latest by around 2035, after phase 4 of the EU-ETS. Likewise, CO_2eq prices are expected to rise to ~100-150 €/t CO_2-eq by about 2035. This would yield total CO_2-eq costs to be at least ~26 billion €.[47] The rising CO_2-eq costs will gradually make conventional primary steel production unprofitable. In addition to the ETS system, the EU's CBAM mechanism (Carbon Border Adjustment Mechanism), which will impose similar CO_2-eq costs on importers of conventional primary steel from 2026, will also have an impact here in future. The free CO_2-eq certificates of the EU ETS are to be replaced by the border mechanism. In addition, it is foreseeable that the IPCEI (Important Project of Common European Interest) process will identify projects with special financing needs and examine their compatibility with competition regulation and state aid, with a strong focus on hydrogen projects.

In other words, the general strive of the steel sector towards decarbonisation could also motivate some plants to invest in technologies such as TSR40 so as to save costs related to excess CO_2 emissions. This would have the aim of reducing the dependencies on primary steel as a means of accelerating decarbonisation.

6 In-depth techno-economic impact study

This chapter covers an in-depth techno-economic impact study of the potential for the new ELV regulation to accelerate cost effective uptake of recycled steel in new vehicles in the EU. The

[43] https://www.thyssenkrupp.com/de/newsroom/pressemeldungen/pressedetailseite/thyssenkrupp-steel-vergibt-milliardenauftrag-fur-direktreduktionsanlage-an-sms-group--start-eines-der-weltweit-grossten-industriellen-dekarbonisierungsprojekte-163183 (accessed 02 Dec 2024)

[44] https://www.tagesschau.de/wirtschaft/unternehmen/gruener-stahl-thyssenkrupp-100.html

[45] https://www.deloitte.com/de/de/issues/sustainability-climate/green-steel-transformation.html

[46] https://www.eurofer.eu/assets/Uploads/EUROFER-Low-Carbon-Roadmap-Pathways-to-a-CO2-neutral-European-Steel-Industry.pdf

[47] https://www.eurofer.eu/assets/publications/position-papers/joint-statement-by-energy-intensive-sectors-on-cbam/202111_CBAM_ETS-impact_EU-steel-industry.pdf

technical feasibility of additional policies was being investigated and environmental and economic impacts were assessed in a quantitative analysis.

6.1 Model description

This subchapter describes key aspects of the model developed by Oeko-Institut as part of the impact assessment study for the European Commission. This model was also used to assess some of the impacts of relevance in this study. Since the model contains various confidential data from databases and information from companies, it is not possible to publish the model.

The main task of the model is to determine the impacts of the policy options examined in this study. Environmental and economic impacts are being assessed in a quantitative analysis. The model cannot be used to determine whether measures are technically feasible; this has to be investigated separately.

The mass flows from sales until the end-of-life stages of the vehicle's life cycle play a key role in the model. Impacts are directly linked and proportional to the mass flows. This applies especially to environmental impacts. The main environmental impact category that is given as a default by the model is the global warming potential (GWP in t CO_2-eq). Some economic data is directly linked to mass flows, too.

The geopolitical scope of the model covers the EU-27, but results can also be calculated for individual member states, e.g. Germany. The model covers the period up to the year 2040. Results are available for the years 2025 to 2040 in 5 year increments. As a starting point for comparison – mainly for developing, checking and adapting modelled vehicle mass flows – we use time series that go back to the year 2009 for all applications except for ICEVs which have been modelled back to 1990. The most recent data from ACEA are available for the reference year 2020. The future perspective is based on data from the Euro 7 impact assessment[48].

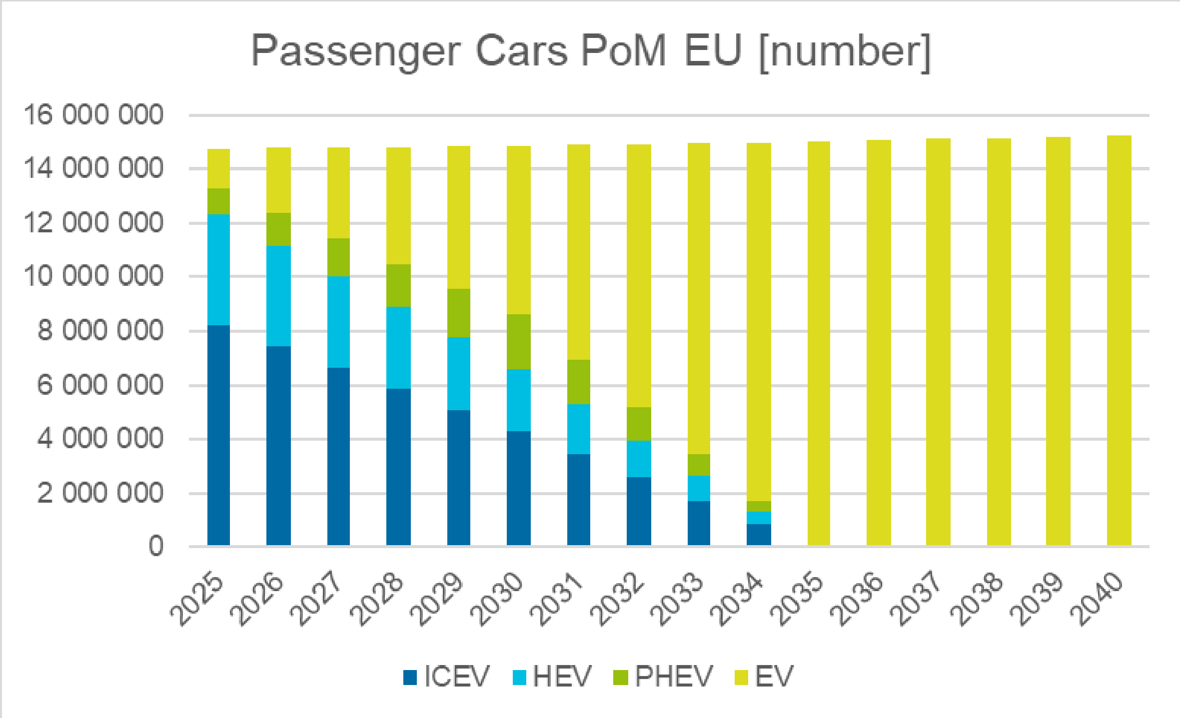
For each individual life cycle stage, the mass flows are differentiated into the relevant engine types of ELVs. The following engine types are addressed in the model:

- Internal combustion engines (ICEs),
- Battery electric vehicles (BEVs),
- Hybrid electric vehicles (HEVs), and
- Plug-in-Hybrid electric vehicles (PHEVs).

Figure 6-1 shows the development of the passenger cars placed on the market (PoM) in the EU from 2025 to 2040. As a de facto ban on internal combustion engines will come into force for new registrations in the EU from 2035, the modelling of drive types based on the data from the Euro 7 Impact Assessment shows a massive shift towards electric drives.

[48] Aeris Europe: Euro 7 Impact Assessment: The outlook for air quality compliance in the EU and the role of the road transport sector. 2021. Available online under https://aeriseurope.com/papers-and-articles/euro-7-impact-assessment-the-outlook-for-air-quality-compliance-in-the-eu-and-the-role-of-the-road-transport-sector/

Figure 6-1: Number of passenger cars PoM in the EU by engine type



Source: own illustration, based on data from Euro 7 IA

To model the material composition of passenger cars, data from JRC-RMIS[49] on the composition of passenger cars was used, supplemented by data from the Greet model. The percentage composition was calculated down to the average weight of the vehicles.

The average weight of passenger cars PoM in the EU was modelled according to iCCT data. In the last 20 years, the average weight of passenger cars PoM has risen by around 1% per annum due to the increase in SUVs. The model still assumes an increase in vehicle weight for the next 15 years, but only an average increase of 0.5 % per annum.

Similarly, the weight of an average end-of-life vehicle in the EU was also modelled. This was based on data from Eurostat and an increase in the average weight of end-of-life vehicles of 1 % per annum up to 2040 was assumed.

Table 6-1 shows the average weights for passenger cars and ELVs, which are used in the model.

To describe the probability of a vehicle reaching its end-of-life, a Weibull distribution has been used. Since no long-term data on the lifetimes of EVs are currently available, estimates based on literature, interviews with the automotive industry and own expert judgement have been used to determine reasonable assumptions for the lifetime of EVs.

[49] https://rmis.jrc.ec.europa.eu/apps/veh/#/p/viewer

Table 6-1 Average weights of passenger cars PoM and ELVs in the EU for the years 2025, 2030 and 2035

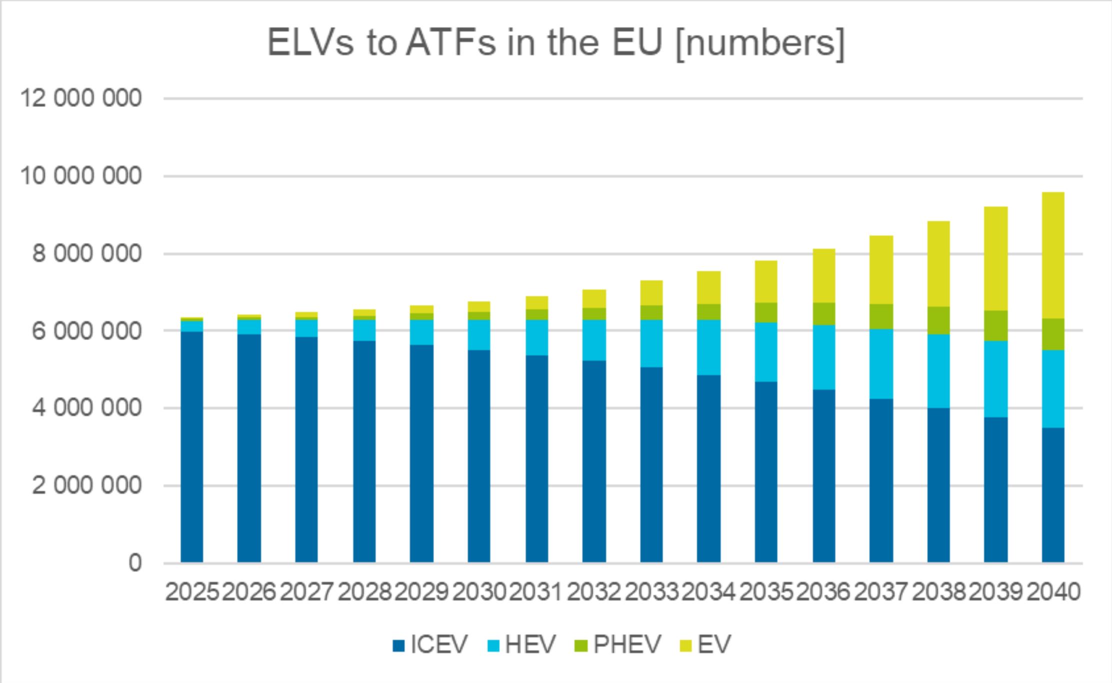
Vehicle	In-house scrap	Pre-consumer scrap	Post-consumer scrap
Vehicle	Average weight in 2025 [kg]	Average weight in 2030 [kg]	Average weight in 2035 [kg]
Passenger car PoM	1549	1588	1628
End-of-life vehicle	1197	1258	1322

Source: Own table, based on desktop research

If the numbers of end-of-life vehicles that are regularly disposed of in the EU are compared with the numbers that should reach the EoL according to the model, it is noticeable that these figures are around 50% lower than the number of modeled EoL vehicles. This is due to vehicles that are exported from the EU to non-EU countries during their lifetime, and due to vehicles, that are either (illegally) exported as ELVs or dismantled illegally. For the modelling, it is assumed that 50% of the vehicles that are placed on the market in the European Union are also disposed of in the EU in accordance with regulations. This is the typical ratio between new registrations and ELVs treated in the last 10 years according to Eurostat data. The remaining 50% is made up of changes in stock, exported used cars and missing vehicles. Currently, no official data is published by Eurostat with a calculated collection rate. The recycling of the end-of-life vehicles is modelled in different steps: depollution, dismantling, shredding, post-shredder technologies (PST) and material specific recycling processes. For HEVs, PEVs and EVs it is assumed that 90% of the vehicles are processed in recycling plants in the EU. This assumption was made following interviews with OEMs and recycling companies as part of the ELV Impact Assessment supporting study on their expectations regarding the return rate. Due to the valuable materials in electric cars, there is a much greater interest of OEMs in establishing closed-loop recycling within the EU.

Figure 6-2 shows the development of decommissioned ELVs in the EU, which are processed in ATFs from 2025 to 2040. The shift towards electric cars due to the ban on internal combustion engines from 2035 is evident here with a significant time delay.

Figure 6-2: Number of decommissioned ELVs to be processed in ATFs in the EU



Source: own illustration, based on model

In modelling, a distinction is made between flat and long steel as well as cast iron. Flat steel is mainly used for the body-in-white (body, doors, boot/bonnet, bumpers etc.) and for non-exposed components, chassis & others (fuel tank, exhaust system, radiator, wheels etc.). The main applications for long products are engine, transmission, powertrain, steering and suspension. According to ArcelorMittal "165 kg of long products can be found in a passenger car."[50] In a previous publication in 2018[51], ArcelorMittal mentions a share of 44% of flat products and 12% of long products and 44% other materials. As a second source, a survey by Steelonthenet[52] revealed an average total weight of 1440 kg per passenger car. Of this, 1085 kg (75 %) is metal (including iron, steel, aluminium, magnesium, copper, and zinc). The steel content was 830 kg (58%). In this assessment, flat steel products amount to 667 kg (46%) and long products to 163 kg (11%). The above data applies to ICE vehicles. Battery electric vehicles neither have a crank shaft nor a piston. Therefore, the assumption is that fewer long products are needed for BEV. According to personal communication from ArcelorMittal[53], the share of long steel in BEV is estimated at about 100 kg/BEV, compared to 165 kg/ICE-vehicle. For this study, we assume that the share of long steel for BEV will be 40% less compared to ICE vehicles. The lower proportion of long steel and

[50] https://germany.arcelormittal.com/Innovation/Loesungen-aus-Stahl/Autos/Langstahlprodukte-in-ihrem-Fahzeug: "These are forged, machined, cold-formed, heat-treated, rolled as well as drawn parts. Main applications […]: Engine, transmission, powertrain, steering and suspension. Examples: Crankshafts, connecting rods, fuel injectors, engine mounting bolts, transmission shafts, pinions, wheel hubs, ring gears, steering, axle and clutch springs, ball studs, wheel caps, wheel nuts, flange shafts, ball bearings, cable pulls, drive shafts, windshield wiper arms, tire cords, and more".

[51] Jan Bollen, ArcelorMittal (2018): New steels driving the circular economy, innovative solutions for future mobility, presentation at the International Automotive Recycling Conference, Vienna, 2018-03-14

[52] https://www.steelonthenet.com/files/automotive.html

[53] E-Mail of Jan Bollen (ArcelorMittal), 2023-04-27

the higher proportion of flat steel in BEVs compared to ICEs means that with the shift to electric drives, the use of recycled steel in new cars is even more difficult to implement.

Table 6-2 shows the shares of steel and iron product in passenger cars PoM in the EU, which are used in the model. These shares are also used for the calculation of the ELVs.

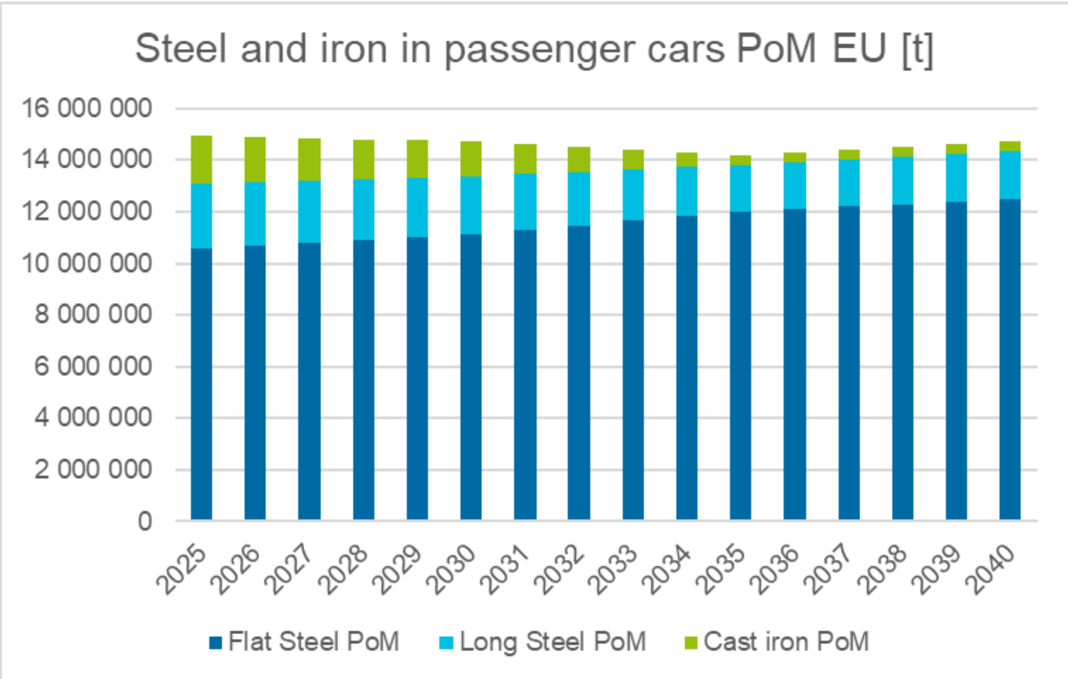
Table 6-2 Share of steel and iron products in passenger cars PoM in the EU [% of total weight]

Material	ICEV	HEV	PHEV	BEV
Steel	57.4%	58.0%	54.6%	56.5%
Flat steel	46.0%	46.5%	43.8%	49.1%
Long products	11.4%	11.5%	10.8%	7.4%
Cast Iron	8.9%	8.8%	8.5%	1.4%

Source: Support Study Oeko (2022), expressed in %; additional assumptions for flat steel and long products

Figure 6-3 shows the amounts of flat steel, long steel and cast iron used in passenger cars PoM in the EU from 2025 to 2040.

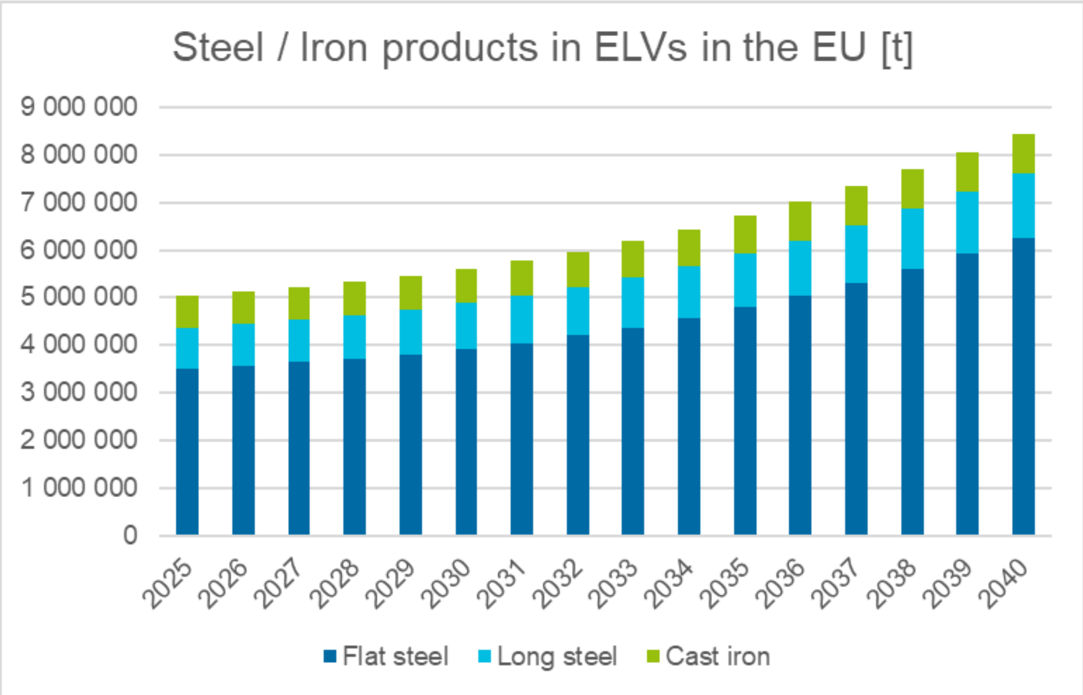
Figure 6-3: Total amounts of flat steel, long steel and cast iron used in passenger cars PoM in the EU



Source: own illustration, based on model

Figure 6-4 shows the amounts of flat steel, long steel and cast iron contained in ELVs processed in recycling plants in the EU from 2025 to 2040. Due to the larger number of vehicles treated in ATFs and the shift towards electric cars, the quantity of flat steel from the ELVs will increase by around 80% between 2040 and 2025, the quantity of long steel by around 50% and the quantity of cast iron by around 25%. As the proportion of flat steel compared to long steel and cast iron will be higher in the future, it will be more difficult to achieve ambitious recycled contend targets in the future.

Figure 6-4: Total amounts of flat steel, long steel and cast iron contained in ELVs treated in the EU



Source: own illustration, based on model

Similar to the ELV impact assessment supporting study, we calculated different end-of-life scenarios for the treatment of ELVs. The two scenarios (seeTable 6-3) differ in the proportion of material (here steel and iron) that goes into reuse or remanufacturing of components, as well as the proportion of materials that is manually dismantled prior to shredding and can thus be recycled at a higher quality. In the case of steel in particular, this means that no further copper contamination is added to the dismantled steel parts through shredding.

Table 6-3 End-of-life scenarios for ELVs treated in the EU

	EoL scenario 1	EoL scenario 2
Steel from ELVs, contained in reused and remanufactured components	10%	15%
Steel from ELVs, which is dismantled prior to shredding	2%	5%
Steel from ELVs, which is shredded	88%	80%

Source: own assumptions

For the shredding process, an efficiency of 99% is assumed for the separation of steel and iron. For the subsequent steel recycling in the electric arc furnace, a recycling efficiency of 88% is assumed. For the years 2025, 2030 and 2035, Table 6-4 shows the quantities of steel/iron from ELVs in the EU that is contained in reused/remanufactured components or is being recycled based on the described assumptions in the two EoL scenarios. The amounts of steel dismantled prior to shredding and then recycled could be used for applications, which need higher steel quality. In contrast, the steel scrap from the shredding process can only be used for applications where lower steel qualities are tolerated, e.g. in construction. If these quantities of steel scrap are to be used for the automotive sector, further processing is required in which the copper content is significantly reduced.

Table 6-4 Amounts of steel reused/remanufactured and recycled steel from ELVs treated in the EU [in t]

		2025	2030	2035
EoL 1	**Reused/ Remanufactured**	504 803	560 695	671 969
	Dismantled prior to shredding	88 845	98 682	118 267
	Shredded	3 870 104	4 298 602	5 151 692
EoL 2	**Reused/ Remanufactured**	757 205	841 043	1 007 954
	Dismantled prior to shredding	222 113	246 706	295 666
	Shredded	3 518 276	3 907 820	4 683 357

Source: Own calculation, based on model

6.2 Analysis of additional policies

The following additional measures were analysed and evaluated as part of this study:

- mandatory recycled content targets for steel for new passenger cars in the EU based on a fleet level,
- mandatory targets for copper removal from steel scrap from ELVs,
- mandatory targets for green steel,
- mandatory obligation to recycle ELVs and white goods separately.

6.2.1 Mandatory recycled content targets for steel

In order to assess the impact of mandatory targets, four scenarios were examined. Firstly, targets were set that were of varying levels of ambition (level 1: 25% in 2030 and 30% in 2035, level 2: 30% in 2030 and 50% in 2035). Secondly, the scenarios differentiated whether the recycled content targets should apply to the entire proportion of steel and iron in cars or whether the targets should apply equally to flat steel, long steel and cast iron. Table 6-5 shows the four recycled content (RC) scenarios that were formed from the combination of ambition level and calculation method and evaluated in the study.

Table 6-5 Combination of calculation method and level of ambition for RC targets to different RC scenarios

	RC targets apply equally to flat steel, long steel and cast iron	RC targets apply to the total amount of steel and iron
RC target 25% in 2030 and 30% in 2035	RC 1	RC 3
RC target 30% in 2030 and 50% in 2035	RC 2	RC 4

Source: Own table

Since the long steel and cast iron production already contain shares of recycled content from post-consumer scrap, the calculations for these materials start with the RC shares currently available, while the modelling for flat steel is based on a current 0% share of recycled content.

Table 6-6 shows the shares of steel and iron product in passenger cars placed on the market in the EU, which are used in the model. Since the shares of recycled content steel in long steel and cast iron can already be very high from a technical point of view, the increase in the targets for flat steel can be lower than if the targets for flat steel, long steel and cast iron apply equally (RC 1 and RC 2 scenarios). However, since the share of long steel and especially cast iron in new cars will be lower in the future due to the shift towards electric cars, a target of 43% in 2035 must also be set for flat steel in the ambitious scenario 4 in order to achieve a total share of 50% RC.

Table 6-6 RC targets for steel and iron products in passenger cars PoM in the EU

	Material	2025	2030	2035
RC 1	**Flat steel**	0%	25%	30%
	Long steel	33%	33%	33%
	Cast Iron	42%	42%	42%
RC 2	**Flat steel**	0%	30%	50%
	Long steel	33%	33%	50%
	Cast Iron	42%	42%	50%
RC 3	**Flat steel**	0%	7%	19%
	Long steel	33%	80%	90%

	Cast Iron	42%	80%	90%
RC 4	**Flat steel**	0%	14%	43%
	Long steel	33%	80%	90%
	Cast Iron	42%	80%	90%

Source: Own assumptions

Table 6-7 shows the demand for recycled flat steel, long steel and cast iron in the production of new passenger cars in the EU in order to meet the RC targets examined in the scenarios.

Table 6-7 Demand for recycled flat steel, long steel and cast iron in passenger cars PoM in order to meet the RC targets examined

	Material	2025	2030	2035
RC 1	**Flat steel [t]**	0	2 775 705	3 602 945
	Long steel [t]	817 890	741 422	586 989
	Cast Iron [t]	776 118	564 503	148 582
RC 2	**Flat steel [t]**	0	3 330 846	6 004 908
	Long steel [t]	817 890	741 422	900 290
	Cast Iron [t]	776 118	564 503	176 883
RC 3	**Flat steel [t]**	0	777 197	2 281 865
	Long steel [t]	817 890	1 819 440	1 620 523
	Cast Iron [t]	776 118	1 075 244	318 390
RC 4	**Flat steel [t]**	0	1 554 395	5 164 221
	Long steel [t]	817 890	1 819 440	1 620 523
	Cast Iron [t]	776 118	1 075 244	318 390

Source: Own calculation, based on model

A comparison of the quantities of recycled steel and iron required to comply with the RC targets (see Table 6-8) and the quantities of recycled steel available from ELV recycling (seeTable 6-4) shows that even if the quantities that are reused/remanufactured are included in the RC quota, the total quantities of steel from closed loop recycling in 2035 will not be sufficient to comply with the corresponding RC quota in the ambitious RC scenarios RC 2 and RC 4 (seeTable 6-8). For this reason, the achievement of RC targets in the ambitious scenarios is only possible by including recycled steel from other applications (open-loop recycling). However, for the year 2030, the quantities from the end-of-life of ELVs in the EU would be sufficient to achieve the targets in a closed-loop recycling, but due to the lower quality of the steel scrap, further processing is urgently required, in particular the significant reduction of the copper content.

Table 6-8 Comparison of total demand for recycled steel/iron in cars PoM in the case of RC targets and total amounts of steel reused/remanufactured and recycled steel from ELVs in the EU

	Scenario	2025	2030	2035
total demand of recycled steel/iron for cars PoM [t]	**RC 1**	1 594 008	4 081 630	4 338 516
	RC 2	1 594 008	4 636 771	7 082 081
	RC 3	1 594 008	3 671 882	4 220 778
	RC 4	1 594 008	4 449 079	7 103 133
total amounts of recycled steel/iron from ELVs [t]	**EoL 1**	4 463 752	4 957 980	5 941 928
	EoL 2	4 497 594	4 995 569	5 986 977

Source: Own calculations, based on model

The quantities that can be obtained from reuse / remanufacturing or from high-quality recycling of steel without shredding are not sufficient to cover any recycled content targets for steel. As significantly higher qualities are required for flat steel than is possible with the shredding process commonly used today, additional further processing of the steel scrap is necessary if recycled content targets are to be set. This further processing of the steel scrap is investigated in the next sub-chapter.

The quantities of recycled steel that can be recovered from ELVs in the EU in the future would, in principle, be sufficient to achieve a recycled content target in the automotive sector of 30% from post-consumer scrap by 2035 in a closed loop.

However, this requires an efficient reduction of the copper content in steel scrap to well below 0.1%, and even below 0.06% for some applications.

If higher recycled content targets are to be set (e.g. 50% by 2035), the quantities of recycled steel from ELVs would not be sufficient in the long term to achieve a closed loop.

In this case, further measures would have to be taken, in particular to increase the collection rate and significantly reduce the number of ELVs that are disposed of illegally.

6.2.2 Mandatory targets for copper removal from steel scrap

In order to comply with the quality specifications for the production of flat steel, the copper content in the steel scrap must be reduced to < 0.1%. This requires additional energy input for processing. Daehn 2019 investigated various processes to reduce the copper content, some start with the processing of the steel scrap after the shredder. Other processes try to reduce the copper content in the steel melt. However, these processes for separating the copper from the steel melt are all still at a laboratory scale in terms of their technology readiness level (TRL) and are not yet available on an industrial scale.

What is already available on a smaller industrial scale are plants in which manual or automated dismantling of copper-containing components takes place before the shredder. Dismantling the main wire harness in particular promises significant improvements in the copper content of the steel scrap at a manageable additional cost. Dismantling of e-drive motors also has a potential to contribute, seeing as it will probably be required to support the recycling of permanent magnets and due to the large volume of copper included in EV motors (close to 29 kg in an average EV motor[54]). Though such dismantling could be developed into automated processes in the future, manual dismantling is mainly limited at present due to its financial implications.

The second process, which is already available at a significantly higher TLR level, is the mechanical processing of steel scrap after shredding, in which free copper is removed. Some plants are already in operation here, with others currently being under construction.

There is no published data from industrial-scale plants on the amount of additional energy required for the copper removal processing step. For this study, data on energy consumption was used, which Daehn 2019 compiled from publications on corresponding research work.

The copper content of 0.4 % in the steel scrap after shredding is firstly due to copper that was already intrinsically present in the steel alloy during car production. Secondly, the shredding process introduces free copper from copper-containing components into the steel fraction. While the intrinsic copper cannot be removed by processes that are economically feasible under today's conditions, a reduction of the free copper to almost 0% is possible in principle through treatment processes as part of or after the shredding process.

According to Daehn 2019, the intrinsic copper content for primary steel from the BOF is around 0.02% (from copper impurities in the iron ore and the used pre-consumer scrap) and for secondary steel from the EAF it is around 0.15% (from copper impurities in the post-consumer scrap). The intrinsic copper content of steel and cast iron (flat steel: 0.02%, long steel: 0.06%, cast iron: 0.08%) and thus also the intrinsic total copper content in steel scrap from EAFs (0.04%) can therefore be

[54] Tazi et al. (2023): Initial analysis of selected measures to improve the circularity of critical raw materials and other materials in Passenger cars. Unter Mitarbeit von Tazi, N., Orefice, M., Marmy, C., Baron, Y., Ljunggren, M., Wäger, P. and Mathieux, F. Hg. v. Publications Office of the European Union. Joint Research Centre (JRC). Luxembourg. Online verfügbar unter https://publications.jrc.ec.europa.eu/repository/handle/JRC132821, zuletzt geprüft am 06.12.2024

estimated using the proportions of primary and secondary metal. Therefore, a target of 0.06% copper content in steel scrap would in principle be possible through careful processing of the steel scrap.

However, there is also information from the recycling industry that contradicts this and assumes an intrinsic copper content of >0.1% in the steel fraction.

Three measures were modelled and analysed:

- As a first measure, if 50 % of the main wire harness is dismantled before the shredder, the copper content in the steel scrap after the shredder is only around 0.2% according to various studies.
-
- As a second measure, mechanical processing of the steel scrap after the shredder was investigated, in which the copper content is reduced from 0.4 % to 0.1 %.
- As a third measure, mechanical processing of the steel scrap after the shredder was investigated, in which the copper content is reduced from 0.4 % to 0.06 %.

The quantities of recovered copper are calculated for all three measures.

Table 6-9 shows the amounts of copper contained in the dismantled main wire harness for the years 2025, 2030 and 2035.

Table 6-9 Copper recovered from dismantling of main wire harness

	2025	2030	2035
Copper in dismantled main wire harness [t]	28 678	30 438	35 177

Source: Own calculation, based on model

Table 6-10 shows the amounts of copper contained in the steel scrap from ELVs after shredding without further treatment for the years 2025, 2030 and 2035 in EoL scenario 1 and EoL scenario 2. As in EoL scenario 2 lower quantities of steel are shredded (seeTable 6-3) because of dismantling before the shredder, also lower quantities of copper will be removed from steel scrap after shredding.

Table 6-10 Copper content in steel scrap from ELVs after shredding without further treatments

	2025	2030	2035
Copper in steel scrap in EoL Scenario 1 [t]	15 480	17 194	20 607
Copper in steel scrap in EoL Scenario 2 [t]	14 073	15 631	18 733

Source: Own calculation, based on model

Table 6-11 shows quantities for the removed copper under the different copper removal measures for the years 2025, 2030 and 2035 in EoL scenario 1 and EoL scenario 2.

Table 6-11 Quantities for copper removed from steel scrap from ELVs in different copper removal measures

		2025	2030	2035
Reduction of Cu content in steel scrap from 0,4% to 0.1%	removed Cu in EoL 1 [t]	11 610	12 896	15 455
	removed Cu in EoL 2 [t]	10 555	11 723	14 050
Reduction of Cu content in steel scrap from 0,4% to 0.06%	removed Cu in EoL 1 [t]	13 158	14 615	17 516
	removed Cu in EoL 2 [t]	11 962	13 287	15 923

Source: Own calculation, based on model

To estimate the costs of the different measures, their consumption of energy or of labor was taken into consideration.

For the additional energy required for mechanical processing of the steel scrap in or after the shredder, Daehn 2019 specifies that 20 to 40 kWh of electricity are required per tonne of steel scrap. In this study, 20 kWh of electricity per tonne of scrap is assumed for the additional electricity requirement of reducing the copper content from 0.4% to 0.1%, and 40 kWh of electricity per tonne of scrap for reducing the copper content from 0.4% to 0.06%.

In this study a manual dismantling is considered to remove the copper wire harness prior to shredding and no additional energy consumption is calculated for this measure. Based on data provided by EGARA in an exchange, the removal of the main wire harness from an ELV requires between 5 and 20 minutes or 12 minutes on average. Restrepo et al. (2018)[55] specifies a much shorter dismantling time at 1.7 minutes and respective costs of 2.84 CHF, however this may represent use of tools such as the Powerhand VRS that would support a much shorter dismantling time. The dismantling time can be applied to calculate the costs of manual removal. As a conservative assumption, costs for the removal of the copper wire harness have been calculated based on a dismantling time of 12 minutes per vehicle.

Table 6-12 shows the calculated costs for the three measures in which the copper is reduced by a dismantling step by the ATF or by a mechanical treatment step after the shredder. An average electricity price of 65 EURO per MWh is considered for the EU up to 2035.[56] For the investment costs the published information on the new sorting plant of TSR (see section 0) are used (35 Million EURO investment, output 300 000 tonnes of steel scrap). For the dismantling of the main

[55] Restrepo et al. (2018): Projekt "EVA": Elektronik – Verwertung - Altautos. "Zusammenfassung der Aktivitäten und Resultate". Zusammenfassung EVA und Schlussbericht zum Arbeitspaket C5. Unter Mitarbeit von Restrepo E., Løvik, A., Haarman A. & Widmer, R. Hg. v. Working-group EVA and Bundesamt für Umwelt (BAFU). EMPA.

[56] EU Energy Outlook 2060, Summary available on https://montel.energy/blog/europes-energy-markets-2060-scenarios-trends-and-insights

wire harness prior to shredding no additional electricity demand was considered. To calculate the dismantling costs, hourly wages of 50 €/hour were considered based on the time needed for dismantling. According to recyclers the dismantling with a powerhand needs 10 to 12 minutes per ELV (i.e., dismantling also other components aside from the copper main wire harness). The investment costs were calculated according to the information in chapter 3 (450 000 EURO investment, 10,000 ELVs per year), though this can be considered to be an overestimation as some ATFs would rely on manual removal with available tools rather than investing in a powerhand or similar equipment.

Table 6-12 Additional costs for copper removal (dismantling or PST) in the various scenarios

		2025	2030	2035
Dismantling of main wire harness	Additional costs [€]	78 067 955	82 858 520	95 760 799
Removal of copper to 0.1%	Additional costs EoL 1 [€]	27 606 741	30 663 362	36 748 739
	Additional costs EoL 2 [€]	25 097 037	27 875 784	33 407 944
Removal of copper to 0.06%	Additional costs EoL 1 [€]	31 258 783	34 719 759	41 610 158
	Additional costs EoL 2 [€]	28 417 076	31 563 417	37 827 416

Source: Own calculation, based on model

Table 6-13 shows the calculated additional revenues from sales of the recovered copper by recyclers (secondary material) or ATFs in the three copper removal measures. A market price of 6 286 EURO per t secondary copper is considered to calculate recycler revenues, when recycling takes place after the PST.[57] For copper from dismantling of the main wire harness a market price of 4 200 EURO per t secondary copper is considered for calculating ATF revenues.[58]´

Table 6-13 Additional revenues for copper removal (dismantling or PST) in the various scenarios

		2025	2030	2035
Dismantling of main wire harness	Additional ATF revenues [€]	120 447 702	127 838 859	147 745 233
Removal of copper to 0.1%	Additional recycler revenues EoL 1 [€]	72 983 890	81 064 674	97 152 572

[57] based on ELV IA, Oeko
[58] based on Groke et al. 2017

	Additional recycler revenues EoL 2 [€]	66 348 991	73 695 158	88 320 520
Removal of copper to 0.06%	Additional recycler revenues EoL 1 [€]	82 715 075	91 873 297	110 106 248
	Additional recycler revenues EoL 2 [€]	75 195 523	83 521 179	100 096 589

Source: Own calculation, based on model

With the better sorting of the steel scrap, it can be assumed that this is mainly done mechanically and hardly any additional jobs are created in the EU. But the additional work time required for dismantling of the main wire harness can be used to calculate the number of additional jobs that could potentially be created in the EU for this purpose. The calculation is based on the assumption of 8 hours per day and 220 days per year. As a result, the potential additional jobs for 2025 are 724, 769 in 2030 and 888 in 2035.

Though the costs and benefits derived above provide a partial picture, the comparison of the additional costs with the possible additional revenues shows that a separation of the copper could already be economically feasible today. The fact that this does not happen is due to the fact that such further processing would require additional investment for the shredder companies, which is not economical given the current sales opportunities for processed steel scrap[59]. As for dismantling, some ATFs already dismantle the copper wire harness, but this depends on the facility and its capabilities: manual dismantling will probably be more common in countries with lower costs of labor and only some facilities have tools like the Powerhand VRM that could make the dismantling more cost effective. This could change if the ELVR requires the dismantling of the wire harness as is currently proposed.

Mandatory dismantling of copper-containing components (e.g. main wire harness, electric motor) can help to reduce the copper content in the steel scrap, but further processing of the steel scrap after the shredder is still necessary in order to achieve the high quality requirements for the production of flat steel.

If there is a market for high-quality steel, e.g. via mandatory recycled content targets, then additional sorting effort would already be economically feasible.

[59] Current economic feasibility of sales of higher quality steel from the shredder or post treatment operator to the recycler is not stable. This is due to the fluctuations in the price of primary steel. Recyclers willingness to purchase higher quality steel at a higher price from ATFs, shredders or PST operators, depends on the market price for primary steel. Though their willingness increases in periods with high costs for primary steel, the opposite is also true. ATFs can react to such fluctuations to some degree through increasing manual dismantling of high-quality steel parts (or scrapping of high-quality steel parts set aside for reuse in previous periods). However, for shredders and recyclers this lack of stability in transactions means a high uncertainty for returns on investments in relevant sorting and treatment techniques. For data on fluctuations in primary steel prices over the years 2019-2024 see: https://www.gordian.com/resources/steel-price-updates/

6.2.3 Mandatory obligation to recycle ELVs and white goods separately

As not only ELVs are treated in the shredders, but also mixed scraps (for example from white goods), the question arises whether a mandatory separate treatment of the different input streams would bring advantages with regard to the quality of the recycled steel.

The total input of the 45 body shell shredders in Germany was around 3.1 million tonnes in 2021. The share of body shells (car bodies) from the total input increased from 9.6% in 2020 to 10.9% in 2021. The most important other input materials of the body shell shredders in 2021 comes from other scrap streams: iron and steel (51%), ferrous metals (22%), non-ferrous metals and mixed metals (8%) and waste electrical and electronic equipment (7%).[60][61] There is no information available how much steel scrap comes from white goods. Neither was published information available on how the quality of steel scrap would change if ELVs and white goods were treated separately as a mandatory requirement and not together in the shredder as is common practice today. However, discussions with experts from the recycling industry suggest that the joint shredding of white goods would not have a negative impact on the quality of the scrap in the steel fraction, as the copper content of white goods tends to be lower than that of ELVs in white goods, and high-quality flat steel is also often used in the production of the white goods.

6.2.4 Tax deductions or CO_2-related incentives for the usage of recycled copper and high-quality scrap

Tax incentives and disincentives comprise a way of supporting or discouraging various economic activities. In the context of the current study, increasing the capacities of waste management practices that could support the production of secondary steel of a higher quality (or less GHG intensive) could be considered as an indirect way of influencing how the market develops. A screening of existing mechanisms was conducted, and its results are presented in Annex VII.

Some legislation already exists at European level that supports facilities that are less CO_2 (or GHG) intensive, and these could have a positive impact on the market for secondary steel in the future, though not directly addressed at steel or copper recycling let alone waste management of ELVs.

Most existing initiatives that address recycling activities were identified outside the EU (in particular in the USA). These include tax incentives of different kinds that are relevant to waste management operators such as tax deductions on investments in equipment. Most of these are also general in nature and address recycling activities and not specifically steel and/or copper recycling. Though a few incentives of this kind in the EU were mentioned in an OECD study, it seems that they are less common in the EU.

It is not clear if the ELVR can require the introduction of tax incentives and other fiscal instruments, however perhaps this direction could be mentioned in the legislation as a recommendation, aimed at promoting investments in the sector that could improve the qualities of steel recycling.

---

[60] Jahresbericht über die Altfahrzeug-Verwertungsquoten in Deutschland im Jahr 2022, KOM Tabelle 1. Online available at: https://www.bmuv.de/fileadmin/Daten_BMU/Download_PDF/Verkehr/jahresbericht_altfahrzeug_verwertungsquoten_2022_bf.pdf; last accessed 27-11-2024

[61] https://www.umweltbundesamt.de/bild/input-in-schredderanlagen-in-deutschland-2021

6.2.5 Assess the uncertainties identified by the EU COM which led to not propose steel recycled content targets

The Proposal for a Regulation refers to the possibility of a recycled content target for steel in Article 6 as follows:

> *"3. The Commission is empowered to adopt delegated acts, in accordance with Article 50, to supplement this Regulation by establishing a minimum share of steel recycled from post-consumer steel waste to be present and incorporated into vehicle types to be type-approved in accordance with this Regulation and Regulation (EU) 2018/858.*
>
> *The minimum share of recycled steel referred to in the first subparagraph shall be based on a feasibility study, carried out by the Commission. The study shall be finalised by [OP: Please insert the date = the last day of the month following 23 months after the date of entry into force of this Regulation], […]*
>
> *The Commission may adopt an implementing act establishing the methodology for the calculation and verification of the share of steel recycled from post-consumer steel waste present in and incorporated into vehicle types".*

This empowers the Commission to set a target for recycled steel content in newly approved vehicles, based on a feasibility study. The feasibility study is to be prepared within 23 months of the entry into force of the Regulation however it is not specified by when the EC bring forward a proposal for such a target. This approach suggests that the knowledge base at the time the proposal was formulated did not allow a clear conclusion as to the need to set a target. The Proposal furthermore specifies what aspects the study should look into, which also suggests what aspects were associated with uncertainty at the time of writing of the proposal:

> *"(a)the current and forecasted availability of steel recycled from post-consumer sources of steel waste;*
>
> *(b)the current share of post-consumer waste in various steel semi-products and intermediates used in vehicles;*
>
> *(c)the potential uptake of post-consumer recycled steel by manufacturers in vehicles to be type-approved in the future;*
>
> *(d)the relative demand of the automotive sector in comparison to the demand for post-consumer steel waste of other sectors;*
>
> *(e)economic viability, technical and scientific progress, including changes in the availability of recycling technologies concerning steel recycling rates;*
>
> *(f)the contribution of a minimum share of recycled content of steel in vehicles to the Union's open strategic autonomy, climate and environmental objectives;*
>
> *(g)the need to prevent disproportionate negative impacts on the affordability of vehicles; and*
>
> *(h)the influence on the overall costs and competitiveness of the automotive sector.*

The following table notes the above points and to how they have been dealt with in this study.

Tabelle 6-1: Aspects referred to in the ELVR proposal under Article 6(3) and how they have been dealt with in this study

Aspect mentioned in Article 6(3)	Manner addressed in current study
(a) the current and forecasted availability of steel recycled from post-consumer sources of steel waste;	The study tries to assess the current and forecasted availability of steel recycled from various sources and its potential use in the manufacture of vehicle components.
(b) the current share of post-consumer waste in various steel semi-products and intermediates used in vehicles;	The study provides some statements on the current share of post-consumer waste in various steel intermediates used in vehicles. Basically, such scrap can mainly be used in the manufacture of long steel components.
(c) the potential uptake of post-consumer recycled steel by manufacturers in vehicles to be type-approved in the future;	This is addressed at a general level (referring to possibility to take up scrap in the manufacture of long steel automotive components, however pledges of manufacturers to base demand on fossil free or reduced emissions intensity steel are also mentioned which can be indirectly related.
(d) the relative demand of the automotive sector in comparison to the demand for post-consumer steel waste of other sectors;	Demand of other sectors is not investigated but rather only the automotive demand in comparison with the total steel production (BOF and EAF).
(e) economic viability, technical and scientific progress, including changes in the availability of recycling technologies concerning steel recycling rates;	Technologies understood to be technologically viable (or at developing stages in terms of TRL but showing potential) are considered in the various scenarios or mentioned as possibly relevant for the future. An initial check of economic feasibility is performed through the different measures looked, however only addressing partial costs and thus indicative.
(f) the contribution of a minimum share of recycled content of steel in vehicles to the Union's open strategic autonomy, climate and environmental objectives;	not addressed
(g) the need to prevent disproportionate negative impacts on the affordability of vehicles	not addressed
(h) the influence on the overall costs and competitiveness of the automotive sector	Not addressed

Quelle: Own compilation

Recital 20 of the proposal also addresses the need for a recycled content target for steel and specifies that "the establishment of a future target should be preceded by a dedicated study by the Commission covering all **relevant technical, environmental and economic factors** linked to the feasibility of such target. In order to ensure uniform conditions for the implementation this obligation, implementing powers should be conferred on the Commission to establish methodology for the calculation and verification of the share of steel recovered from post-consumer steel waste present in and incorporated into the vehicle type". In so far it can be assumed that at the time of writing that data was still lacking on the technical, environmental and economic aspects and that a methodology for the calculation and verification of the closed loop share of the target still required development.

In the impact assessment performed by the EC and presented at the beginning of the ELVR proposal document it is also stated that "the steel industry did not support a target on recycled content for steel in new vehicles". However, seeing as the proposal empowers the EC to investigate this aspect further, it is assumed that the data supporting the steel industries argumentation was not comprehensive.

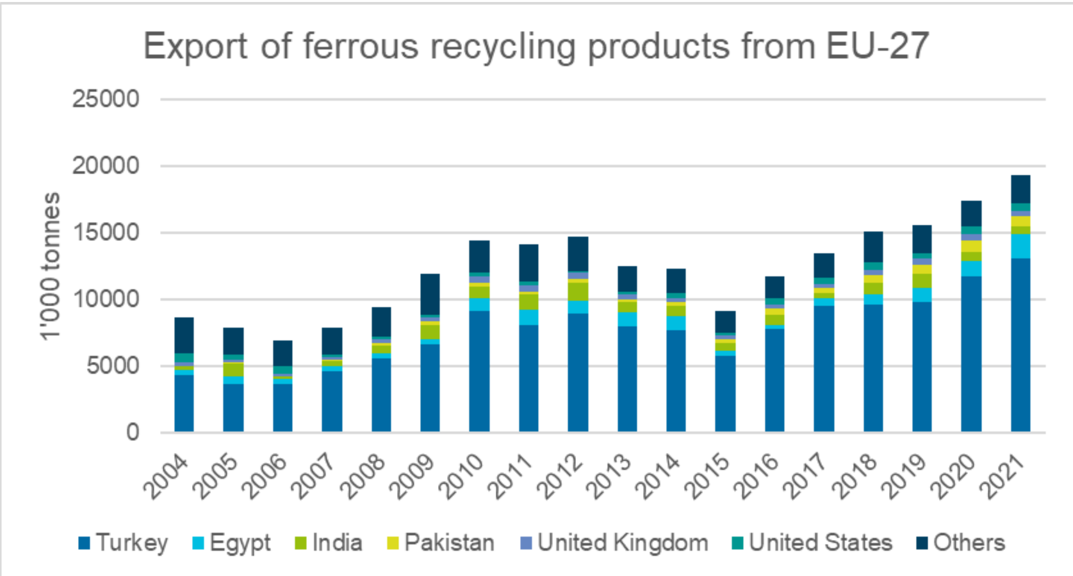
More details could not be found in the public realm as to possible uncertainties.

6.2.6 Implications for the scrap trade with Turkey, UK, US & India in 2030 / 2035

There are various possibilities as to where the additional quantities of high-quality recycled steel required to meet possible future recycled content rates could come from. On the one hand, recycled steel could be used that has so far gone into other applications, e.g. the construction sector, and on the other hand, recycled steel that has previously been exported to non-EU countries could be used. A third option would be imported recycled steel. In all cases, the recycled steel is currently not processed to the quality required for use as flat steel in the automotive sector, so that further processing is necessary regardless of the source, in particular the separation of copper.

Figure 6-5 shows the development of exports of recycled ferrous products from the EU-27 to non-EU countries in the period between 2005 to 2021 and the shares of the most important destination countries. Turkey was the most important destination country throughout the entire period; in recent years, around 2/3 of exports of recycled ferrous products from the EU-27 went to Turkey.

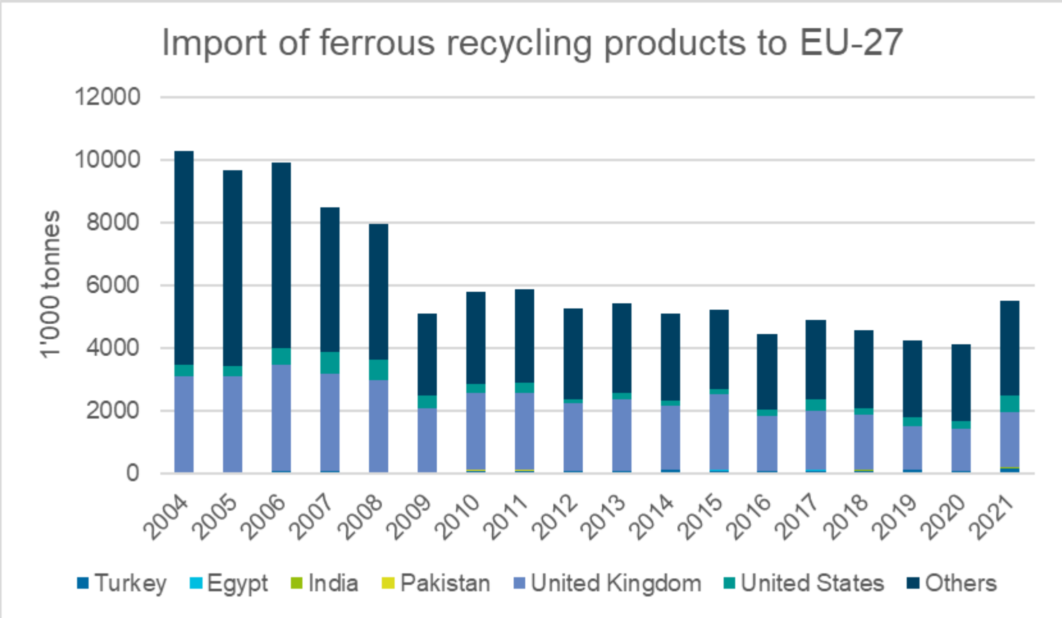
Figure 6-5: Export of ferrous recycling products from EU-27



Source: own illustration, based on Eurostat

Figure 6-6 shows the development of imports of recycled ferrous products to EU-27 countries over the same period.

Figure 6-6: Import of ferrous recycling products to EU-27



Source: own illustration, based on Eurostat

A comparison of the quantities of high-quality recycled steel required in the future and the quantity of recycled steel exported in 2021 shows that the RC steel required in 2025 corresponds to around 8% of recycled steel exported in 2021 and increases by 2035 from 22% to 37% of the quantity exported in 2021, depending on the RC scenario. In comparison, the quantities of recycled steel imported into the EU in 2021 account for around 29% of the quantities of RC steel required in 2025; by 2035, this ratio increases to between 77% and 130%, depending on the RC scenario. If RC targets are introduced for steel in the automotive sector, it is therefore to be expected that exports of recycled steel from the EU to non-EU countries will fall significantly, especially for the recycled steel trade with Turkey because this is the biggest market for European recycled steel.

6.2.7 Implications for scrap prices in the EU

Scrap prices have experienced significant volatility over the past decade, influenced by various factors such as global market supply and demand, changes in trade policies, and economic and political events. For instance, in 2016, prices dropped to a low of approximately €178.7/t due to oversupply and weak demand. In contrast, between 2021 and 2022, prices surged to around €383-404/t, driven by a raw material shortage and high steel demand following the pandemic. In 2023, the average scrap price in the EU was €346.7/t.[62]

[62] Prices given for Scrap E3 covering Germany and Italy. These are the biggest steel producer in Europe thus the scrap prices can be seen as representative for EU (https://gmk.center/en/infographic/eu-scrap-market-balance/ online available on 5 December 2024)

There are many implications on steel scrap prices in Europe, both individually and as a collective. Based on various sources/studies, it is possible to list, as of a given date, the elements that appear to be the most relevant. These are:

- Transformation to green steel,
- Prices for CO_2 emissions allowances (more in chapter 6.2.4),
- National/EU-wide incentives/subsidies,
- Market demand, i.e., decrease in demand for steel scrap, including import export balance,
- Availability of scrap input with the needed quality (please refer to chapter 3.2),
- Collection of scrap,
- Transition of the steel production to other global regions and the import of consumer products (like vehicles) from these regions are not covered by the European Carbon Border Adjustment Mechanism (CBAM).

Steel is produced throughout the EU, mainly through BF-BOF 'primary' steelmaking process, as well as the 'secondary' EAF method.

In Europe, the EAF process is primarily used for secondary steel production. The European decarbonization strategy for the steel sector aims to replace the existing BF-BOF route with direct reduced iron (DRI) installations followed by EAF. This transformation holds significant untapped potential to boost scrap usage as part of steelmakers' decarbonization strategies. While the decarbonization of the EU steel industry is often linked to the shift toward electric arc furnace steel production using green hydrogen-based DRI, the actual reduction in carbon emissions will likely be driven by an increase in the share of EAF production, and consequently, a rise in scrap consumption, thus increasing its demand and in result also prices.

Increased use of steel scrap in steel production also influences the demand for steel scrap of higher quality. A further factor driving the demand for high-quality scrap is the push of some car manufacturers to reduce the carbon footprint of the materials they use. For example, Mercedes-Benz has signed a memorandum of understanding with TSR to support this effort. Mercedes aims to increase the share of secondary raw materials in its car fleet to an average of 40% by 2030.

Scrap collection in the EU continues to be a crucial component of green steel production. From 2013 to 2021, scrap collection gradually increased, driven by advancements in collection and processing technologies. However, scrap consumption remained stable, with only a slight rise in demand in Central and Eastern Europe.

The economic downturn in the EU, triggered by the COVID-19 pandemic and the Russian invasion of Ukraine in 2022, resulted in a temporary decline in steel production and, as a result, a drop in scrap consumption and its prices.

Over the past decade, the volumes of scrap exports and imports in the European Union have varied considerably. Its export from the EU is influenced by demand from major consumers like Turkey and China. The demand for steel scrap outside the EU has a significant impact on scrap prices. There has been a downward trend in the Chinese steel industry over the past two years. Experts predict that steel scrap prices are likely to remain volatile in the short term[63].

[63] https://gmk.center/en/news/scrap-consumption-in-china-to-fall-by-3-y-y-in-2024-analysts/ (online available on 5 December 2024)

Nowadays, scrap has become a strategic raw material for the steel industry's decarbonization efforts[64].

Nowadays, scrap has become a strategic raw material for the steel industry's decarbonization efforts. The green transition underway in the EU is setting the stage for restrictions on exports of this critical raw material. The EU is already actively addressing this issue, driven by the growing demand within the bloc and the need to protect its own steel industry. On one hand, local market prices will be constrained by trade restrictions, while on the other, global competition for high-quality scrap will intensify. With reference to the last one, the current investments in the collection, sorting, and processing of scrap in the EU market will have significant impact.

7 Case Study on scrap usage in the US automotive industry

Steel and ferrous components make up about 50-66% of the weight of an average vehicle. According to a major European vehicle manufacturer, 80% of steel procured for vehicle production is flat steel (sheet metal) which for safety reasons is usually made with scrap metal within a range of 10-25%. 20% of steel for vehicular production is so-called long steel used in the production of screws, bolts and the like, with scrap metal being utilized to a very high degree (90% scrap metal in an Electric Arc Furnace (EAF) for this purpose is not uncommon according to the manufacturer).

However, the dynamics are different in the United States. Firms using the EAF route of steel making are increasingly looking to produce flat steel by using prime scrap[65] mixed with pure iron resulting in products with lower impurities (Tolomeo et. al 2019). The work of these firms has put EAF produced steel at a 70% share[66] of all steel produced in the USA. According to analysts such as the S&P Global, the United States is leading globally in the shift towards EAF production of flat steel.

This case study seeks to investigate through desktop research and limited stakeholder interviews, the use of scrap metal in the automotive sector in the United States of America. Concretely the study seeks to assess;

1. To what extent is the US auto industry using secondary EAF steel (scrap-based steel) and for which vehicle parts?
2. Is the share of recycled steel / EAF steel being used in the US car industry higher compared to Germany/Europe?
3. If yes, what are the key factors / policy conditions which are responsible for this?
4. Can the front-runners (steel and auto industry) be identified?

[64] https://gmk.center/en/infographic/eu-scrap-market-balance/ (online available on 5 December 2024)

[65] Prime scrap refers to pre-consumer scrap or leftovers from a manufacturing process. In this way, the chemical composition is known leading to a better determination of additives and processes needed to arrive at a higher quality product at a profitable cost.

[66] See Steel Manufacturer´s Association: https://steelnet.org/

7.1 Use of scrap-based steel components in the American Automotive Industry

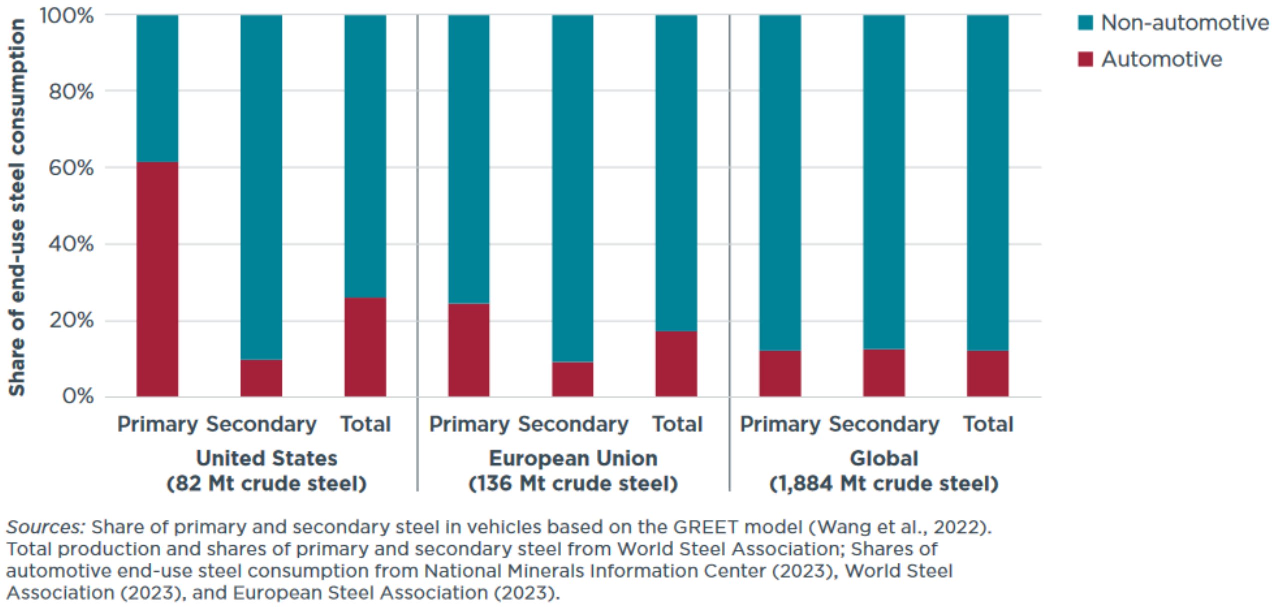
In the USA, a total 82 Mt of steel (primary and secondary) was produced in 2022 with 26% being consumed by the automotive industry. According to a report by the iCCT, 56Mt (68%) of steel produced in the USA comes from secondary steel produced from recycled scrap. Given that recycled scrap is used most extensively in the EAF[67] process, and the prevalence of EAF mills (small furnaces with electric arc capability popularized by innovation from firms such as NUCOR), it can be safely assumed that these amounts can be classified as secondary EAF steel (Bui et. al 2024).

Within the automotive sector, there is wide consensus that 75% of steel used in vehicular production is primary steel. The iCCT estimates based on this data that the US automotive sector required about 16 Mt of primary steel representing around 60% of primary steel production. It further indicates that the sector utilized 5 Mt of secondary EAF steel representing 9% of secondary steel production in the country as of 2022 (Bui et. al 2024).

By contrast, in the European Union steel production stood at 136 Mt in 2022 with primary steel accounting for 52% of production. According to the industry association Eurofer, the automotive sector in the EU consumes about 17% of total steel produced (about 23 Mt). Assuming the same baselines and vehicle production processes in the USA and the EU, it can be determined that the sector used 13% (17 Mt) of total EU primary steel. The report also notes that the use of EAF secondary steel was roughly 6 Mt, equivalent to about 9% of the regional bloc´s secondary steel production (Bui et. al 2024). By purely percentage shares, the USA and the EU appear to consume equivalent amounts of secondary EAF steel in the automotive sector. Figure 7-1 below elaborates this in graphical terms.

[67] A major vehicles manufacturer states that 15% of scrap metal is used in flat steel production in the EU but by contrast EAF can use between 80-100% scrap depending on availability. Furthermore, the figures from the manufacturer cannot be independently verified.

Figure 7-1: Share of the automotive sector in primary, secondary, and total steel consumption, excluding imports, 2022



Source: Bui et. al (2024)

The United States automotive sector utilized 5 Mt of secondary EAF steel representing 9% of secondary steel production in the country as of 2022. The use of EAF secondary steel in the EU was roughly 6 Mt, equivalent to about 9% of the regional bloc´s secondary steel production in the same timeframe. By purely percentage shares, the USA and the EU appear to consume equivalent amounts of secondary EAF steel in the automotive sector.

Which vehicular parts are made using secondary EAF steel?

According to a report on material composition trends in vehicles from the Joint Research Centre of the EU and based on North American light vehicles, the use of standard steel and high strength steel (HSS) are decreasing and being replaced with advanced high strength steel (AHSS) and ultra-high strength steel (UHSS) that have the same material characteristics with a lower mass. The use of steel is also decreasing due to the increasing use of aluminium alloys. The report indicates that these trends are expected to continue (Lovik et al 2021). While it is difficult to state categorically which specific parts of vehicles are made with secondary EAF steel, it can be safely assumed that since flat steel is mainly steel from the BF-BOF route and used for components necessary for safety and structural integrity, these would be based on primary steel (stamped components for roofs, hoods, and doors for example). Other components which are not part of the external vehicular body or required to provide structural integrity are mainly high in secondary EAF steel[68]. Table 7-1 below presents an overview.

[68] The iCCT puts EAF percentages at between 15-20% through the BF-BOF route. See Lovik et. al (2021).

Table 7-1 Components of a typical vehicle based on flat and long steel utilization

Category	Sub-component	Components
Flat steel	Body-in-white	Body, doors, boot / bonnet, bumpers, etc.
	Non-exposed, chassis, etc.	Fuel tank, exhaust system, radiator, wheels, other non-exposed chassis, etc.
Long steel	Engineering steel	Drive, suspension, engine, transmission, steering.
	Steel cord and wires	Seating wires, tyre cord, etc

Source: Own table based on desktop research[69]

7.2 Who are the leading firms in secondary EAF production and use in the automotive sector?

According to the industry association UK Steel[70], firms such as Nucor, Steel Dynamic Incorporated, and Big River Steel are the leading innovators in the USA in the use of EAF to produce all product ranges of steel. However, it must be noted that this is done using 30% of pig-iron (ore-based primary steel) to control impurity levels. Impurities are further mitigated by using high-quality steel scrap[71]. In automotive terms, NUCOR is reportedly developing the capability to produce ultra-high strength materials used extensively by electric vehicle producers. The company utilizes a vertical integration strategy by producing its own low-copper shred[72] as feedstock for its Direct Reduced Iron production and on to its electric arc furnaces for further processing.

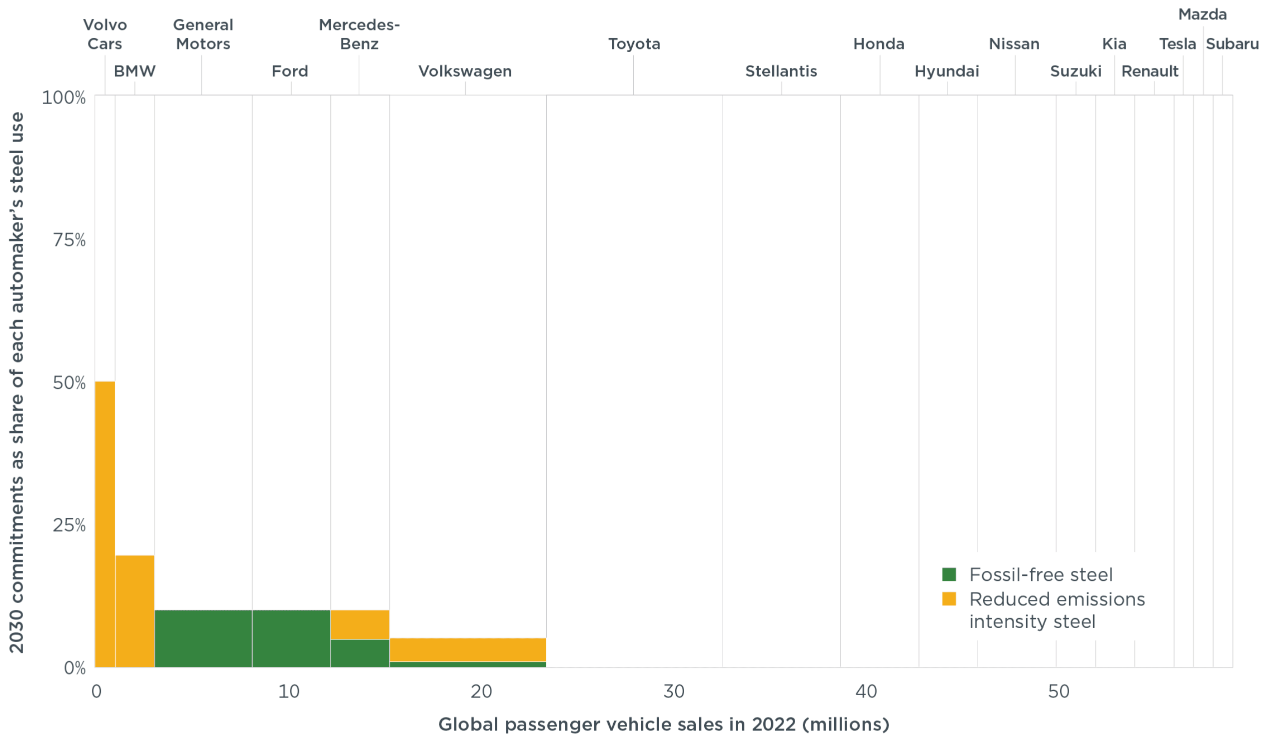
Firms such as Nucor, Steel Dynamic Incorporated, and Big River Steel are the leading innovators in the USA in the use of EAF to produce all product ranges of steel. Nucor for example uses a vertical integration strategy by producing its own low-copper shred as feedstock for its Direct Reduced Iron production and on to its electric arc furnaces for further processing.

There is insufficient data on which vehicle producers utilize the most secondary EAF steel, however a major vehicle manufacturer states that its policy is to enable competition between steel-making

69 Main source of information was gathered on Steel on the net. A web portal providing industry information on steel. See here: https://www.steelonthenet.com/files/automotive.html
70 See the association´s paper on EAF steel here: https://www.uksteel.org/electric-arc-furnaces-1
71 This is mainly sourced from scrap generated directly from the steel making process and or highly sorted steel scrap.
72 Low-copper shred is an upgraded shredded scrap grade capable of replacing prime scrap in melt mixes with a maximum copper content usually not greater than 0.17-0.20%, compared to traditional shredded scrap which typically ranges from 0.30-0.50% according to an industry expert.

technologies thereby implying that the sector procures materials based on material characteristics and regulatory requirements. The ICCT reports that among vehicle producers selling products in Europe and North America, four have pledged to procure any fossil-free steel by 2030 including steel produced via the EAF route (Negri et. al 2024). Two of these are the American automakers General Motors and Ford. In their 2023 sustainability reports[73], both automakers inform on their strategic purchase agreements with Nucor, US Steel and ArcelorMittal for lower emission steel. They commit that at least 10% of steel[74] used in manufacturing of sheet metal will be near-zero by 2030 through their membership of the First Movers Coalition[75].

Figure 7-2: Share of the automakers' global steel demand for passenger vehicle production to be fossil-free or reduced GHG emissions intensity in 2030, based on automakers' public commitments.



Source: Negri et. al (2024)

---

[73] Specific purchase volumes were not observed neither in publications nor in the sustainability reports. However crude steel would in this case be produced via DRI-EAF route hence the possibility of a 90% scrap metal content.

[74] Press releases indicate that the supplied steel will have a recycled content of about 90%. See: https://www.steeltimesint.com/news/general-motors-to-receive-recycled-steel-supply. See their sustainability reports here: General Motors: https://www.gm.com/commitments/sustainability. Ford https://corporate.ford.com/social-impact/sustainability.html

[75] The First Movers Coalition (a World Economic Forum Initiative) is a global initiative to use the purchasing power and supply chains to create early markets for innovative clean energy technologies. More than 50 companies with a collective market value of about $8.5 trillion across five continents are part of the coalition to drive demand for zero-carbon technologies. See https://initiatives.weforum.org/first-movers-coalition/home

7.3 Are there any lessons learned from the US vehicle dismantling & recycling industry for the EU ELV revision process?

The USA does not have a centralized Extended Producer Responsibility (EPR) framework at the national level but instead various facets, ranging from collection to fully fledged EPR systems make-up a patchwork of legislations across states[76]. Within these different waste frameworks, scrap collection is via separation bins organized by municipalities or by individuals and corporations making use of scrap yards to dispose of their `waste` in return for cash. Leading firms in the secondary EAF steel sector such as Nucor have subsidiaries operating in scrap brokerage creating linkages with scrap yards and municipalities as well as dismantling services to industries seeming to adopt a strategy of vertical integration. Nucor uses post-production processes such as shorter oxidation times and surface treatments such as quenching to increase the copper tolerance of products. Chemical composition is also manipulated by the addition of nickel or silicon and the avoidance of tin as an alloying element (Daehn et. al, 2017). Innovations such as these have led to the situation where EAF steel production accounts for 70% of steel production in the USA[77]. Despite a high EAF percentage share in steel production, there is no evidence that EAF secondary steel use in vehicles is higher than in the EU. Various actors of the steel production sector in the US were approached for the purpose of confirming this observation and to assess what barriers prevent the use of increased amounts of EAF steel in the vehicle production process, however a response was not received in the course of this study.

In terms of recycled steel content in vehicles, the United States does not yet have policies or legislation mandating this, however the Environmental Protection Agency encourages the public procurement agencies to make use of `rebuilt` or `remanufactured` parts[78]. It appears that the success of the EAF-route for steel production in commercial scale is a clear driver in increasing secondary EAF steel availability. It must be noted that the European industry plans to begin a shift to EAF technology from 2025[79]. While the United States does not have specific legislation for recycled steel content in vehicles, the World Economic Forum[80] offers the following recommendations in the promotion of secondary EAF steel;

- **Ensuring sufficient supply of high-quality scraps in advance of mandatory recycled content targets**: ensuring that mandatory recycled content targets are announced well in advance to allow supply chains to develop to support the achievement of the target.
- **Improving transparency around steel scrap quantity, quality, and prices**: Developing harmonized definitions for the steel scrap industry to facilitate trade in the industry and allow for the traceability of scrap.

---

[76] See reporting by Deutsche Recycling here: https://deutsche-recycling.com/blog/epr-in-the-usa-a-major-challenge/

[77] See report from Steel Manufacturers Association here: https://steelnet.org/independent-study-validates-that-steelmaking-by-electric-arc-furnace-manufacturers-in-u-s-produces-75-lower-carbon-emissions/

[78] See recommendation from USEPA here: https://www.epa.gov/smm/comprehensive-procurement-guidelines-vehicular-products#02

[79] See the briefing from S&P global here: https://www.spglobal.com/commodityinsights/en/market-insights/latest-news/coal/052121-shift-from-bf-to-eaf-steelmaking-to-start-in-earnest-2025-eurometal-webinar

[80] See WEF publication on Closing the Loop on Automotive Steel here: https://www3.weforum.org/docs/WEF_Closing_Loop_Automotive_Steel_2023.pdf

- **Investing in the development of sorting and separation technologies**: Development of high-quality steel through EAF will depend on the availability of highly sorted scrap. Hence research and development into scrap sorting and separation technologies will support treatment of steel scrap to produce materials low in impurities such as copper. For example, it is observed in the definition of the European steel scrap grade list[81] that scrap is to be free of `visible` metallic copper with the exception of insignificant quantities. However, according to the industry this definition still leaves copper in the metal charging mix that cannot be separated during processing. While residual copper in steel possesses metallurgical problems and affects steel quality, it also leads to economic losses given the comparatively higher cost[82] of copper compared to steel.

8 Recommendations

As envisaged in the EU ELV proposal, also in this study the focus is on post-consumer scrap, as pre-consumer scrap is already produced in high purity and can therefore generally already flow back into the primary production of steel in closed loop approaches.

There is already a small proportion of secondary steel from post-consumer scrap in new vehicles today (~6 Mt or 9% EAF secondary steel used in automotive sector in 2022), but this secondary share is projected to decrease in the future. This is due to the shift towards electromobility, as the proportion of long steel and cast iron in electric vehicles is significantly lower and, on the other hand, flat steel is currently not produced from secondary material from post-consumer scrap. In order to increase the proportion of secondary steel from ELVs (from post-consumer scrap) in new vehicles in the future, additional processing of the steel scrap is necessary to reduce the proportion of tramp elements in the steel scrap, especially copper.

However, investments in better sorting technologies will probably only be made if a higher demand for high-quality secondary steel is also generated. Therefore, from a regulatory perspective, the following points should be addressed:

- A requirement to reduce the copper content in the steel scrap down to < 0.1 % Cu. There are various ways in which this target can be achieved, e.g. mandatory dismantling of copper-containing components before shredding, e.g. the main wire harness and the electric motor in electric vehicles, or a mandatory requirement that free copper must be removed from the steel scrap after shredding through better sorting.
- Secondly, an average recycled content target for all steel products in new vehicles from post-consumer scrap should be set to increase demand. A target of 25% to 30% seems technically feasible in the foreseeable future.

When considering a timeframe for individual measures aimed at improving the quality of steel scrap, the timeline by when a surplus of steel scrap is to develop should be taken into account. The earlier the time frame can be communicated, the longer the time available for industry to make the transition, making the burden of compliance more manageable.

[81] See the European Steel grade list here: https://www.bvse.de/images/pdf/schott-elektro-kfz/schrottsorten.pdf

[82] Currently 1 tonne of copper goes for 7,000 EUR compared to about 320 EUR for a tonne of steel.

In order to have enough recycled steel available for ambitious recycled content targets, it is necessary to bring more vehicles to the legal EoL routes.

End-of-life vehicles with unknown whereabouts can occur for a number of reasons, including undeclared export or undeclared treatment. The Oeko-Institut's support study for the impact assessment on the revision of the ELV Directive[83], specifies a list of measures with the aim to increase the number of end-of-life vehicles legally treated in the EU and to improve the tracking of exports of used vehicles in order to obtain more ELVs for the treatment and materials (including steel scrap) for recycling. These include, for example:

- Interoperability between national registration authorities, including the obligation for Member States to provide reasons for de-registration.
- Action at international level to promote the introduction of criteria for the export of used vehicles such as roadworthiness and taking into account age and emission rules of vehicles allowed to be imported in certain countries.
- Obligations for dismantlers/recyclers to inspect and report on ELVs/CoDs

It is further recommended to improve the transparency around steel scrap quantity, quality, and prices through the development of harmonized definitions for the steel scrap industry to facilitate its trade and allow for the traceability of scrap.

[83] https://op.europa.eu/en/publication-detail/-/publication/ef0b9a03-728e-11ec-9136-01aa75ed71a1/language-en

List of References

Allwood, J. M. (2016). A bright future for uk steel: A strategy for innovation and leadership through up-cycling and integration.

Amund N. Løvik, Charles Marmy, Maria Ljunggren, Duncan Kushnir, Jaco Huisman, Silvia Bobba, Thibaut Maury,Theodor Ciuta, Elisa Garbossa, Fabrice Mathieux, Patrick Wäger, Material composition trends in vehicles: critical raw materials and other relevant metals. Preparing a dataset on secondary raw materials for the Raw Materials Information System, EUR 30916 EN, Publications Office of the European Union, Luxembourg, 2021, ISBN 978-92-76-45213-3, doi:10.2760/351825, JRC126564.

Argonne (2021): Argonne National Laboratory. GREET Model: The Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation Model. 2021. GREET2: vehicle manufacturing cycle model of vehicle technologies. Available online: https://greet.es.anl.gov

Baroyan, A.; Kravchenko, O.; Prates, C.; Vercammen, S.; Zeumer, B. (18 Apr 2023): The resilience of steel: Navigating the crossroads. In: *McKinsey & Company*, 18 Apr 2023. Online available at https://www.mckinsey.com/industries/metals-and-mining/our-insights/the-resilience-of-steel-navigating-the-crossroads, last accessed on 18 Nov 2024.

Björkman, B.; Samuelsson, C. (ed.) (2013): Recycling of Steel. In Handbook of Recycling. In collaboration with Worrell, E., Reuter, M. Oxford, UK: Elsevier.

Bui, A. N.; Isenstadt, A.; Zhou, Y.; Bieker, G.; Negri, M. (2024): Technologies to reduce greenhouse gas emissions from automotive steel in the United States and the European Union. The International Council on Clean Transportation, 2024. Online available at https://theicct.org/wp-content/uploads/2024/07/ID-158-%E2%80%93-Green-steel_final.pdf, last accessed on 18 Nov 2024.

Brahmst, E. (2006): Copper in End-of-Life Vehicle Recycling. Manufacturing, Engineering & Technology Group Center for Automotive Research. Copper Development Association (ed.). Online available at https://www.cargroup.org/wp-content/uploads/2017/02/Copper-in-End_of_Life-Vehicle-Recycling.pdf.

Daehn, K. E. (2019): Copper contamination in end-of-life steel recycling, developing a new strategy from million-tonnes to milligrams. University of Cambridge (ed.).

Daehn, K. E. Cabrere Serenho, A.; Allwood, J. M. (2017a): How Will Copper Contamination Constrain Future Global Steel Recycling? Environmental Science & Technology: 51, Pages 6599-6606.

Daehn, K.E. Cabrere Serenho, A.; Allwood, J. M. (2017b): How will copper contamination constrain future steel recycling? - Supplementary Information.

Directive 2000/53/EC (2000): European Commission. Directive 2000/53/EC of the European Parliament and of the Council of 18 September 2000 on end-of life vehicles, Directive 2000/53/EC. In: Official Journal of the European Commission (L 135).

EC (2024): Carbon Border Adjustment Mechanism. Hg. v. EC. Online available at https://taxation-customs.ec.europa.eu/carbon-border-adjustment-mechanism_en, last accessed on 6. December 2024.

EC, D. CLIMA (2023): What is the EU ETS? Hg. v. EC DG CLIMA. Online available at https://climate.ec.europa.eu/eu-action/eu-emissions-trading-system-eu-ets/what-eu-ets_en, last accessed on 6. December 2024.

EC: REA, Vu, H., Iacob, N., Cecchin, F. and Stroia, C (2022)., Climate-neutral steelmaking in Europe – Decarbonisation pathways, investment needs, policy conditions, recommendations, Iacob, N.(editor) and Stroia, C.(editor), Publications Office of the European Union, https://data.europa.eu/doi/10.2848/96439; accessed on 16 January 2025

Eurostat (2024), End-of-life vehicles by waste management operations - detailed data (env_waselv), End-of-life vehicles - reuse, recycling and recovery, totals (env_waselvt). Online available at https://ec.europa.eu/eurostat/databrowser/explore/all/envir?lang=en&subtheme=env.env_was.env_wasst&display=list&sort=category&extractionId=env_waselv

Foroohar, R. (23 Sep 2024): There are no easy answers for US Steel. In: Financial Times, 23 Sep 2024. Online available at https://www.ft.com/content/3ef2db10-290d-4b41-b99b-014cadac5a93, last accessed on 18 Nov 2024.

Groke, M.; Kaerger, W.; Sander, K.; Bergamos, M. (2017): Optimierung der Separation von Bauteilen und Materialien aus Altfahrzeugen zur Rückgewinnung kritischer Metalle (ORKAM). In: Umweltbundesamt, UBA Texte (02/2017).

GTS (2022): Environment with Tax Breaks for Companies. Hg. v. Global Trash Solutions. Online verfügbar unter https://globaltrashsolutions.com/blog/recycling-helps-environment-offers-companies-tax-breaks/, zuletzt aktualisiert am 04.12.2024.

Hatayama, H., Daigo, I., & Tahara, K. (2014). Tracking effective measures for closed-loop recycling of automobile steel in china. Resources, Conservation and Recycling, 87, 65–71. https://doi.org/10.1016/j.resconrec.2014.03.006

Ito, A.; Langefeld, B.; Götz, N. (2020): The future of steelmaking – How the European steel industry can achieve carbon neutrality. Roland Berger, 2020. Online available at https://www.rolandberger.com/en/Insights/Publications/Europe's-steel-industry-at-a-crossroads.html, last accessed on 18 Nov 2024.

Kim, J., Sovacool, B. K., Bazilian, M., Griffiths, S., Lee, J., Yang, M., & Lee, J. (2022). Decarbonizing the iron and steel industry: A systematic review of sociotechnical systems, technological innovations, and policy options. Energy Research & Social Science, 89, 102565. Online available at https://doi.org/10.1016/j.erss.2022.102565

Li, J.; Tong, C.; Zhang, R.; Shi, Z.; Lin, J. (2024): A data-informed review of scientific and technological developments and future trends in hot stamping. In: International Journal of Lightweight Materials and Manufacture 7 (2), pp. 327–343. DOI: 10.1016/j.ijlmm.2023.11.003.

McKenna (2014): European Auto Shredder List and Map, An interactive map of auto shredding plants in the 28 member states of the European Union plus Norway.

Mehlhart, G.; Möck, A.; Goldmann, D. (2018): Effects on ELV waste management as a consequence of the decisions from the Stockholm Convention on decaBDE. Oeko-Institut e. V. Online available at https://www.oeko.de/fileadmin/oekodoc/ACEA-DecaBDE-final-report.pdf, last accessed on 14 Jun 2022.

Mengden, Alex (2024): Carbon Taxes in Europe, 2024. Unter Mitarbeit von Alex Mengden. Hg. v. Europe Tax foundation. Online available at https://taxfoundation.org/data/all/eu/carbon-taxes-europe-2024/, last accessed on 4. December 2024.

Moors, C.; Coyne, J. (4 Mar 2024): US steel industry sees boost from CHIPS Act, infrastructure bills. In: S&P Global Commodity Insights, 4 Mar 2024:+00:00. Online available at https://www.spglobal.com/commodityinsights/en/market-insights/latest-news/metals/030424-us-steel-industry-sees-boost-from-chips-act-infrastructure-bills, last accessed on 18 Nov 2024.

Muslemani, H., Ascui, F., Xi, L., Kaesehage, K., & Wilson, J. (2022). Steeling the race: "Green steel" as the new clean material in the automotive sector. The Oxford Institute for Energy Studies. Retrieved 10 11, 2023: Online available at https://www.econstor.eu/bitstream/10419/253283/1/1795852747.pdf

Nakamura, S., Kondo, Y., Matsubae, K., Nakajima, K., Tasaki, T., & Nagasaka, T. (2012). Quality- and dilution losses in the recycling of ferrous materials from end-of-life passenger cars: Input-output analysis under explicit consideration of scrap quality. Environmental Science & Technology, 46(17), 9266–9273. https://doi.org/10.1021/es3013529

Nassaralla, C. L. (2001, January 1). Iron Production (K. H. J. Buschow, R. W. Cahn, M. C. Flemings, B. Ilschner, E. J. Kramer, S. Mahajan, & P. Veyssière, Eds.). ScienceDirect; Elsevier. https://www.sciencedirect.com/science/article/pii/B0080431526007543

Negri, M.; Bui, A. N.; Ordonez, Y.; Bieker, G.; Isenstadt, A. (2024): Which automakers are shifting to green steel?, An analysis of steel supply chains and future commitments to fossil-free steel. The International Council on Clean Transportation, 2024. Online available at https://theicct.org/wp-content/uploads/2024/09/ICCT-Green-Steel-Supply.pdf, last accessed on 18 Nov 2024.

OECD (2018): McCarthy, A. and P. Börkey. Mapping support for primary and secondary metal production. OECD Environment Working Papers, No. 135. Hg. v. OECD Publishing. Paris. Online verfügbar unter https://www.oecd-ilibrary.org/docserver/4eaa61d4-en.pdf?expires=1733356848&id=id&accname=ocid56027324&checksum=9B81B8E5F7F9F95A92D9A34D1BC71622, last accessed on 5. December 2024.

Oeko-Institut e. V. (2022): ELV Model. developed in the course of the ELV Impact Assessment Study.

Pao Ter Teo; Siti Koriah Zakaria; Siti Zuliana Salleh; Mustaffa Ali Azhar Taib; Nurulakmal Mohd Sharif; Anasyida Abu Seman; Julie Juliewatty Mohamed; Mahani Yusoff; Abdul Hafidz Yusoff; Mardawani Mohamad; Mohamad Najmi Masri and Sarizam Mamat: Assessment of Electric Arc Furnace (EAF) Steel Slag Waste's Recycling Options into Value Added Green Products: A Review. Online available at http://myscholar.umk.edu.my/bitstream/123456789/584/1/Assessment-of-electric-arc-furnace-EAF-steel-slag-wastes-recycling-options-into-value-added-green-products-A-reviewReview2020MetalsOpen-Access.pdf, last accessed on 18 Nov 2024.

Restrepo E., Løvik, A., Haarman A. & Widmer, R. (2018): Projekt "EVA": Elektronik – Verwertung - Altautos. "Zusammenfassung der Aktivitäten und Resultate". Zusammenfassung EVA und Schlussbericht zum Arbeitspaket C5. Hg. v. Working-group EVA and Bundesamt für Umwelt (BAFU). EMPA.

Russo, P.; Husson-Tissier, B.; van de Winkel, F.; Schunicht, J. (2011): X-traction of copper from shredder scrap by means of TITECH XRF-sensor based sorting technology. ArcelorMittal. Budapest, 24 Mar 2011.

Sander, K.; Rödig, L.; Wagner, L.; Jepsen, D.; Holzhauer, R.; Baberg, L.; Spiecker, T.; Zwisele, B.; Winterstein, M. (2020): Evaluierung und Fortschreibung der Methodik zur Ermittlung der Altfahrzeugverwertungsquoten durch Schredderversuche unter der EG-Altfahrzeugrichtlinie 2000/53/EG. Umweltbundesamt (ed.).

Somers J. (2022); Technologies to decarbonise the EU steel industry; EUR 30982 EN, Publications Office of the European Union, Luxembourg, 2021, ISBN 978-92-76-47147-9 (online), doi:10.2760/069150 (online), JRC127468

Tazi, N., Orefice, M., Marmy, C., Baron, Y., Ljunggren, M., Wäger, P., Mathieux, F. (2023): Initial analysis of selected measures to improve the circularity of critical raw materials and other materials in Passenger cars. Hg. v. Publications Office of the European Union. Joint Research Centre (JRC). Luxembourg. Online available at https://publications.jrc.ec.europa.eu/repository/handle/JRC132821, last accessed on 6. Dec 2024

Tolomeo, T.; Fitzgerald, ;.; Eckelman, J. (2019): US steel sector thrives as mills move up quality ladder, 9 May 2019. Online available at https://www.spglobal.com/commodityinsights/en/market-insights/blogs/metals/050919-us-steel-sector-thrives-as-mills-move-up-quality-ladder, last accessed on 18 Nov 2024.

UBA/BMUV (2024), Jahresbericht über die Altfahrzeug-Verwertungsquoten in Deutschland im Jahr 2022, Online available at https://www.bmuv.de/fileadmin/Daten_BMU/Download_PDF/Verkehr/jahresbericht_altfahrzeug_verwertungsquoten_2022_bf.pdf

USEPA (2016): State Recycling Tax Incentives. Hg. v. USEPA. Online verfügbar unter https://archive.epa.gov/wastes/conserve/tools/rmd/web/html/rec-tax.html, last accessed on 5. Dec 2024.

Wittig, S. (2021): Quantifizierung und Modellierung des Stahlrecyclings in Europa. Master thesis, University of Applied Sciences Mannheim (Ed.), Mannheim

Annex

Annex I. Steel making

Steel is typically produced by one of two routes: Either via the blast furnace – basic oxygen furnace (BF-BOF) route, or via the electric arc furnace (EAF) route.

Blast furnaces produce iron from ore, which is then turned into steel in a basic oxygen converter by adding scrap. The process relies on reduction, where carbon from coal combines with oxygen to form CO_2. Coal provides both the carbon and the heat needed to smelt iron, which reaches 1,500°C. Since iron is brittle, it is transformed into steel in the converter by blowing oxygen to burn impurities. The liquid steel is cast into slabs or ingots and further processed into long products like bars or wire or flat steel strip in several rolling operations. About 60% of EU steel is made using the BF-BOF[84] method, which, currently, typically contains 15%-25% scrap.[85] At present, a maximum of 20% scrap is typical in the EU.

Electric Arc Furnaces produce steel mainly from recycled scrap, though they can also use solidified or sponge iron. EAFs typically have a capacity of 1.5 million tonnes per year. The furnace uses graphite electrodes, and heat is generated by an electric arc, reaching temperatures up to 3,500°C, while the molten metal is around 1,800°C. EAFs are versatile, producing everything from basic products like rebar to stainless and high-alloy steels. Over 40% of EU steel is produced via the EAF route[16], which can be charged with 100% steel scrap.[17] None of the EAF steps can eliminate copper, and no industrial-scale technology currently exists for its removal (Daehn, 2019). Two strategies are used to address this issue: the first is to accept copper impurities in applications where it is tolerated, such as reinforcing bars, while the second is to reduce the copper content by diluting it with high-quality steel (Daehn, 2019).

Another commercially deployed method of primary steel production involves directly reducing iron ore to produce direct reduced iron (DRI or sponge iron) without using a blast furnace or coke oven. The reduction gases, hydrogen and carbon monoxide syngas, are generated from natural gas or coal. The sponge iron is then melted and refined into steel, often with added scrap, in an electric arc furnace. This method represents about 5% of global steel production but is growing rapidly, with DRI production increasing by 46% between 2015 and 2019. In the EU, ArcelorMittal's Hamburg plant produced 47 kt of DRI in 2019 (Somers J., 2022).

Annex II. Transformation to Green steel

The EU has established ambitious decarbonisation goals, aiming to cut GHG emissions by at least 55% by 2030 and to become the world's first climate-neutral continent by 2050. Achieving these targets will require significant transformation in the EU's industries, including the iron and steel sector, which currently relies on highly CO_2-intensive processes.

Various technologies and production pathways can reduce GHG emissions in steelmaking. Kim et al. (2022) classified 86 options by technology readiness, from commercially available but underutilized to experimental technologies expected post-2025. He and Wang (2017) identified 158

[84] https://www.eurofer.eu/about-steel/learn-about-steel/what-is-steel-and-how-is-steel-made
[85] https://worldsteel.org/wp-content/uploads/Fact-sheet-on-scrap_2021.pdf

technologies, with some overlap, and provided data on fuel use, energy savings, capital costs, and payback periods.

High-potential decarbonization technologies that could replace BF-BOF or other approaches that could support the decarbonization process, according to iCCT (Bui et.al, 2024) are:

- Hydrogen-based direct reduction process,
- Molten oxide electrolysis (MOE) and electrowinning,
- Carbon capture and utilization (CCU) or storage (CCS) - technology options that can be used to treat the carbon emissions produced from conventional steel making,
- Mass balancing – involves allocating the effect of emission reduction measures to single products, for instance, the companies reduce CO_2 emissions from existing plants by energy efficiency improvements, utilizing CCS or CCU, or making changes to BF feedstocks,
- Reducing primary steel demand by, for instance, increasing recycled steel share

Examples of activities that support decarbonisation in the steel sector include:

- Thyssenkrupp is working towards decarbonization of steel production by building new, hydrogen-powered direct reduction plants. However, the first of these plants will only be operative towards the end of 2026[86]. One of Thyssenkrupp's key customers is the automotive industry, which also wants to decarbonize the manufacturing process and market its products as green. Mercedes, for example, has set itself the goal of increasing the proportion of secondary raw materials for its car fleet to an average of 40 percent by 2030.
- Many automakers have revealed the percentage of secondary steel used in their vehicles. BMW reported an average of 25% secondary steel content, with plans to increase this to 50% by 2030. Renault Group estimated that the secondary steel content in its vehicles ranged from 17% for flat steel to over 90% for steel bars and cast iron in 2022. Stellantis mentioned using up to 30% recycled steel, including both pre- and post-consumer scrap. Volvo used 15% recycled steel in its vehicles in 2022, aiming to increase this to 25% by 2025 (iNegra et.al, 2024).

To this day, clean technologies with the potential to reduce emissions in steel recycling have been hindered by high costs. These technologies lead to higher production expenses, which in turn increase the overall cost of vehicles. As a result, this impacts competitiveness, as consumers may be unwilling or unable to pay the higher prices. There are two main reasons for this: the additional costs may be prohibitive for many medium-income customers, and consumers tend to prioritize fuel economy over the production methods of the vehicle (Muslemani et al., 2022).

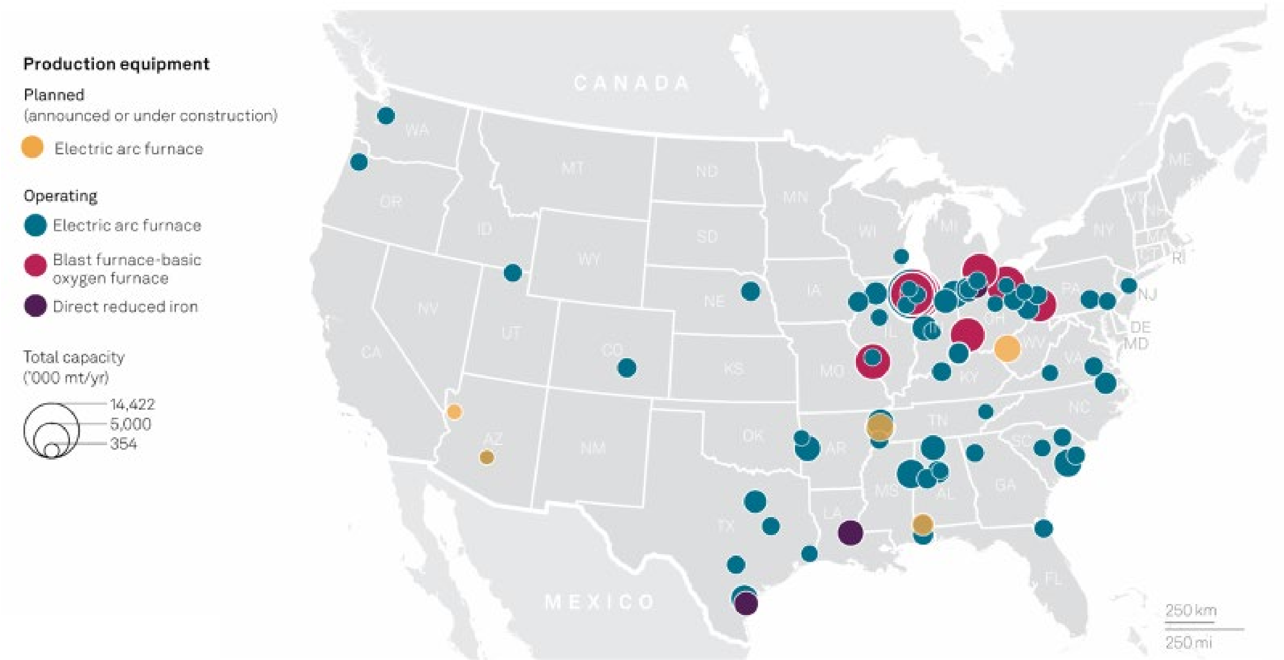
Annex III. An overview of EAF steel production in the USA

In 2024 the American steel industry appears to have received a boost from the combination of three pieces of legislation: the US CHIPS and Science Act which includes more than $50 billion in direct incentives for semiconductor manufacturing and 25% investment tax credit for capital expenses (Moors, 2024). While the impacts of this legislation are expected to be fleeting, further legislation such as the Bipartisan Infrastructure Law and the Inflation Reduction Act are expected to sustain the

[86] https://www.euwid-recycling.de/news/wirtschaft/schrottrecycler-tsr-nimmt-in-duisburg-neue-aufbereitungsanlage-in-betrieb-280423/

positive outlook for the industry by driving industrial construction, increasing the domestic production of electric vehicles and other specialized items.

US operating and planned steel plants



Source: Moors (2024)

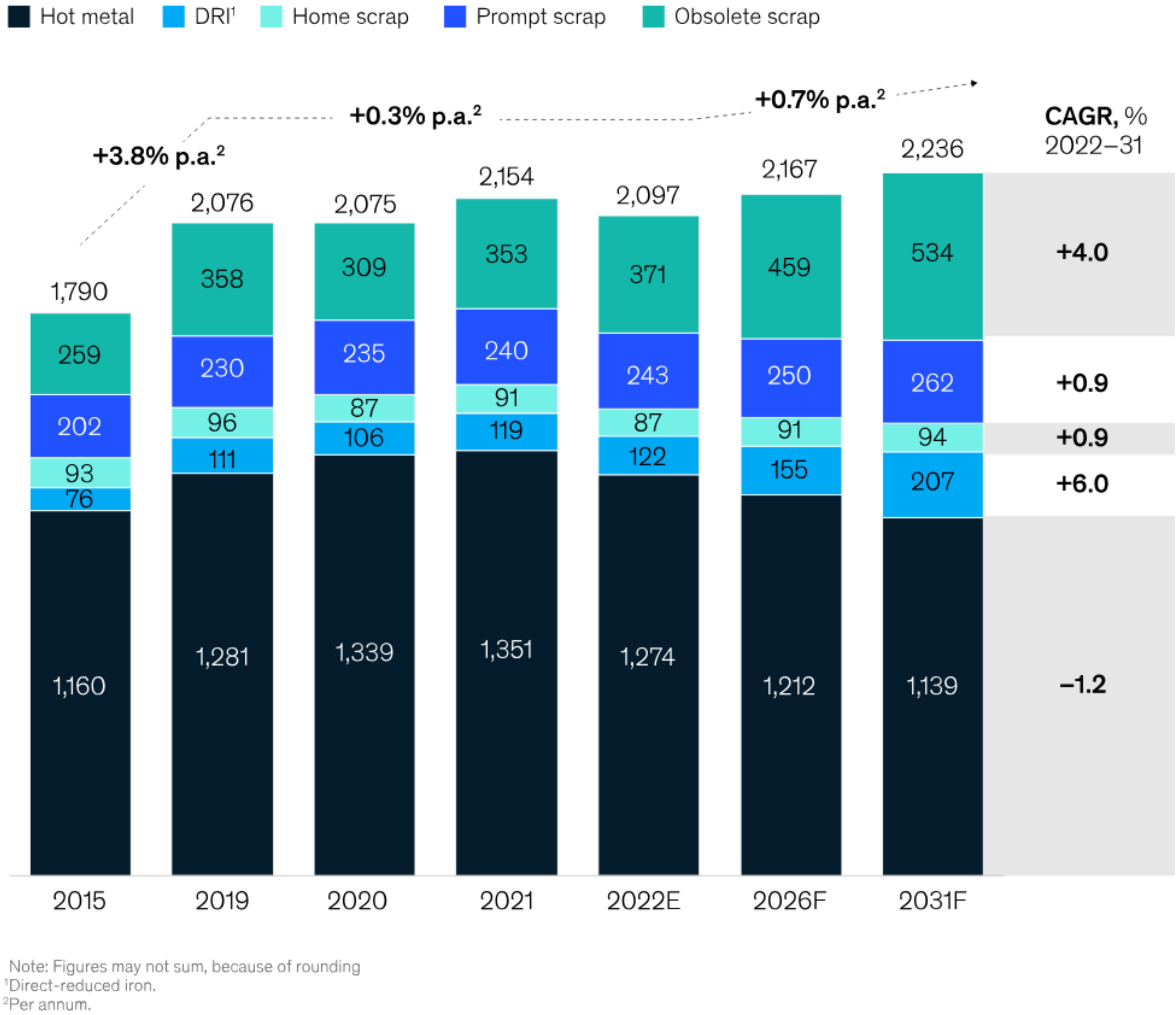
On the basis of current rebound effects due to stimulus initiatives and the reopening of economies, analysts such as the consulting firm McKinsey expect the global steel market to shift evermore towards decarbonization as countries seek to fulfil emissions pledges (Baroyan et. al, 2023). In practice, they expect that Direct-Reduced Iron[87] (DRI) and scrap metal[88] will increasingly replace carbon-intensive hot metal or pig iron[89] from blast furnaces.

[87] Direct-Reduced Iron is iron-ore that has oxygen molecules removed by using hydrogen and carbon monoxide. It is typically produced using natural gas or coal as a carbon monoxide source. The use of natural gas reduces the production of emissions such as sulfur oxide and carbon dioxide. DRI is usually part of an integrated steel mill located next to an electric arc furnace for the next stage in processing. See (Nassaralla, 2001)

[88] Scrap metal can be differentiated according to its source. Home scrap: left over pieces and trimmings from production processes; Prompt, or industrial scrap: generated in downstream manufacturing processes, Obsolete/Post-consumer scrap: collected at the end-of-life of a product containing metal. See: https://transitionasia.org/scrap-steel-explainer/

[89] This refers to `basic` steel produced iron-ore using blast furnaces. This process entails the use of reducing agents such as coal, oil, gas or coke and results in a product high in impurities such as sulfur and carbon leading to a brittle product with high compressive strength. See: https://vdeh.de/en/technology/stahlrouten/steelmaking/

Global metals mix forecast in metric tonnes



Source: Baroyan et. al (2023)

Annex IV. Electric Arc Furnaces and the use of scrap in steel production

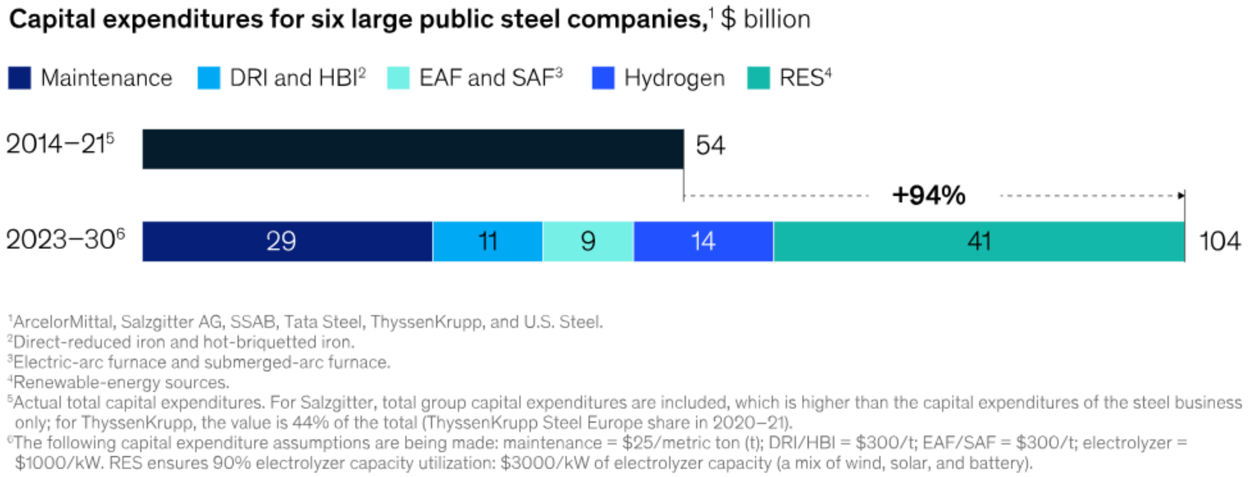
Due to the comparatively low capital and operational costs, Electric Arc Furnaces (EAFs) are increasingly popular in developed economies to produce steel. Traditional methods such as the Bessemer method-based Blast Furnace-Basic Oxygen Furnace (BF-BOF) route rely on iron ore, coke, and limestone as raw materials[90] as the basis for steel production (Pao Ter Teo et. al 2024). While this route held sway in the early 20th Century, technological advancements such as EAFs and Submerged Arc Furnaces (SAFs[91]) have shifted production dynamics. EAFs utilize electric arcs

[90] According to the World Steel Organization, steel scrap can also be used in the BF-BOF route of steel production. However, it requires the use of 125Kg of steel scrap mixed with 1,370Kg of iron ore. See https://worldsteel.org/about-steel/facts/steelfacts/what-is-steel/what-are-the-input-materials-to-make-steel-in-a-blast-furnace/

[91] Submerged-Arc Furnace is a progressive variant of an EAF. It offers lower noise levels and has the advantage of continuous production capabilities.

generated between electrodes (usually graphite) to melt (scrap and pig iron[92]) metal leading to higher energy efficiency. While this method was initially limited to non-valuable steel, this changed when firms such as the Nucor developed methods to produce valuable sheet metal using EAFs. This effectively tilted the market in favour of the new technology and led to a downward trend in the use of BF-BOF routes of steel production. The figure below shows the announced capital expenditures of six large public steel companies until 2030 showing a shift propelled by decarbonization suited to iron-making routes making use of scrap metal.

Capital expenditures for six large public steel companies



Source: Baroyan et. al (2023)

Annex V. Steel and copper components with potential for dismantling

To allow consideration of parts that may be dismantled to improve the quality of recyclates, two types of components were looked into:

- Steel components made of flat steel that could be dismantled prior to shredding so as to establish a fraction of high quality steel scrap;
- Copper components that could be dismantled prior to shredding so as to reduce the amount of free copper in steel scrap and thus the quality of melts produced using such scrap.

Various sources were consulted, including past studies in which Oeko-Institut was involved to collect such data.

“On average, 165 kg of long products can be found in a passenger car […] These are forged, machined, cold-formed, heat-treated, rolled as well as drawn parts. Main applications […]: Engine, transmission, powertrain, steering and suspension. Examples: Crankshafts, connecting rods, fuel injectors, engine mounting bolts, transmission shafts, pinions, wheel hubs, ring gears, steering, axle and clutch springs, ball studs, wheel caps, wheel nuts, flange shafts, ball bearings, cable pulls, drive shafts, windshield wiper arms, tire cords, and more”.

[92] According to the World Steel Organization, iron ore can also be added to the charge in EAF-routes. 710 Kg of steel scrap mixed with 586 Kg iron ore to produce 1000 Kg of crude steel. See https://worldsteel.org/about-steel/facts/steelfacts/what-is-steel/what-are-the-input-materials-to-make-steel-in-an-eaf/

A survey prepared by Steelonthenet estimated the total average weight of flat steel products in a vehicle at 667 kg (or 46% of total weight) and that of long products at 163 kg (or 11%). The survey refers to the following examples of such steel products:

- Flat steel: body, doors, boot/bonnet, bumpers, fuel tank, exhaust system, radiator, other non-exposed chassis components and other.
- Rolled steel: drive, suspension, engine, transmission, steering, seating wire, tyre cord, other.

The above data applies to ICE vehicles, whereas electric drivetrains can be expected to use less steel. In a contact from 2023, Acelormittal estimated that BEV vehicles contain only around 100 kg of steel per vehicle.

The following table details data collected on various steel and copper components that could be considered for dismantling to support the reduction of high-quality steel recycling. Aside from the specification of component types, the table also specifies data on the time and costs necessary for dismantling where such data could be found.

The following sources have been consulted in the preparation of the table below: The UBA ORKAM study[93] , The EVA I EMPA study[94], the supporting study to the ELV Directive Impact assessment (OEKO)[95], a JRC analysis focusing on measures to improve the circularity of vehicles[96], data provided by EGARA from an investigation of dismantling costs across the EU.

Material	Component	Weight, kg	Dismantling time, minutes	Dismantling cost	Comments
		Axle and clutch springs		9 (with engine & starter motor, UBA)	
Steel, rolled	Engine	PM HEV: (of 21.3) PM PHEV: (of 34.50) PM BEV: (of 44.87) IC BEV: (of 48.80) (JRC CRM) EV motor: 37.39 (of 103.59) IC motor: 50.15 (of 115.06) (Oeko)	43 average (5-180 range, with gear box, EGARA), 9 (with axle & starter motor, UBA) 10/20 for recycling/reuse (JRC)		EV motor: 37.39 Al, 28.79 Cu IC motor: 49.96 Al, 2.83 Cu (JRC)
	Muffler	14.28 (Osko)			
Steel, rolled	Transmission	29.01 (of 96.7) + 29.01 iron (Oeko) Transmission system/Gearbox: 19-15 depending on vehicle			+ 29.01 Al (Oeko) Transmission system/Gearbox: 6-16 CU, 6-23 Al

93 See footnote 27
94 See footnote 55
95 See footnote 4
96 See footnote 54

		type, 34 on average (Oeko)			depending on vehicle type (no ICEs), 12 Cu and 14 Al on average (Oeko)
	Transmission shafts	See transmission system			
	Power train	Powertrain system: 17-220 depending on vehicle type, 112 on average (Oeko)			Powertrain system: 2-23 CU, 6-24 Al depending on vehicle type (no ICEs), 10 Cu and 12 Al on average (Oeko)
Steel, rolled	Drive		25 (Electric drive motor, EVA II)		
Steel, rolled	Steering and suspension	Steering rack and pinion: 24.72 (Oeko)			43.67 Al (Oeko)
	Pinions	See streeing			
	Right/Left front drive shift	7.6 (Oeko)			
	Right/Left front drive strut	7.4 (Oeko)			
	Ball studs				
	Ball bearings				
Flat steel	Body	Body: 51-393, depending on vehicle type, 207 (Oeko)			Body: 9-21 CU, 15-53 Al depending on vehicle type (no ICEs), 14 Cu and 30 Al on average (Oeko)
Flat steel	Boot/bonnet	Bonnet: 15.2 Trunk door (boot):9.95 (Oeko)			
Flat steel	Bumpers	16.5 (steel) 8 (plastic steel, total 13.89) Fender: 4.03 (Oeko)	52 (front and back + wheel house liners, UBA)	57 € (UBA)	Some bumpers are from Al, some a mix of steel and plastic

	Cable pulls				
	Crankshafts				
	Connecting rods				
	Drive shafts				
Flat steel	Doors	Front door: 18.02 (of 28.18) Rear door: 14.74 (of 23.73) (Oeko)			Some doors from Aluminium (Oeko)
	Engine mounting bolts				
Flat steel	Exhaust system				
	Flange shafts				
	Fuel injectors		0.74 (Fuel pump actuator, EVA II)	1.34 CHF (fuel pump, EVA II)	Sometimes from aluminium (Oeko)
Flat steel	Fuel tank				Sometimes from plastic
Flat steel	Radiator	0.22 (of 0.26, Oeko)	8.32 (actuator, EVA II)	9.47 CHF (radiator fan motor, EVA II)	
	Ring gears				
Flat steel	other non-exposed chassis components				
Steel, rolled	Seating wire	Front: 15.99 Rear: 7.94			
Steel, rolled	Tire cords				
Flat steel	Wheels (hubs, caps, nuts)	22.07 (of 46.96, Oeko)	14 (4 wheels + spare, UBA)		Partially from Al: 24.88 (Oeko)
Flat steel	Windshield wiper arms				

Copper	Wire harness	9 (of 10, Oeko - Ademe 2017)	12 average (5-20 range, EGARA), 1.70 (EVA II)	2.84 CHF (EVA II)	

Source: Own table

Annex VI. Data for calculation of revenues

The following data was used in past Oeko Institut studies related to the review of the ELV Directive for the estimation of revenues related to material sales of the waste sector. To allow comparability with past results, the same data was consulted where relevant in the modelling done in this study.

Revenues from sales of ATFs (scrap), based on OKRAM[97]:

ATF Revenues for components/materials	€/kg	€/tonne
e-motor	0.37 €	370 €
iron/steel	0.13 €	130 €
aluminium	0.85 €	850 €
copper	4.20 €	4,200 €

Revenues from sales of recyclers (secondary material), based on supporting study to the ELV review, Oeko[98]:

Recycler revenues for materials (market value of scrap)	€/tonne
iron/steel	187 €
aluminium cast	967 €
aluminium wrought	1,161 €
copper	6,286 €
Neodymium	69,360 €

[97] See footnote 27.
[98] See footnote 4.

Source: Own calculation

Annex VII. Results of screening on tax deductions and CO_2 related incentives for the usage of recycled copper and high-quality scrap

The purpose of this sub-section is to provide information about tax deductions and CO_2 related incentives that promote the use of recycled copper and/or high-quality scrap. Very few initiatives were found that are applicable directly to copper or steel scrap. Thus, taking into consideration that there may not be direct incentives for their usage, a search was conducted on incentives and disincentives related to the promotion of recycling activities.

Furthermore, incentives and disincentives related to CO_2 emissions of industry were also looked at. The idea behind this being that incentives to reduce CO_2 emissions would also be relevant for the production of secondary steel and copper, which are less CO_2 emissions intensive then their primary counterparts. This is also the case for disincentives for CO_2 intensive production, which is aimed at creating a fairer playing field for industry with reduced CO_2 emissions.

- According to Mengden (2024)[99] "in recent years, several countries have taken measures to reduce carbon emissions, including instituting environmental regulations, emissions trading systems (ETSs), and carbon taxes. In 1990, Finland was the world's first country to introduce a carbon tax. Since then, 23 European countries have implemented carbon taxes […] Switzerland and Liechtenstein currently levy the highest carbon tax rate at €120.16 ($130.81) per tonne of carbon emissions, followed by Sweden (€115.34, $125.56) and Norway (€83.47, $90.86). The lowest carbon tax rates can be found in Poland (€0.09, $0.10) and Ukraine (€0.72, $0.77). The average carbon tax rate among the 23 European countries was €49.23 as of April 1, 2024". Such taxes can have a positive influence on the competitiveness of recycled copper and scrap steel, in particular at times where the prices for primary materials is low due to market fluctuations. Such taxes apply to different greenhouse gasses like carbon dioxide, methane, nitrous oxide, and fluorinated gases, meaning that not all will cover all forms of emissions.
- In the US, there are a number of tax incentives that apply to the recycling and management of waste and thus that can be assumed to apply also to recycled copper and to the processing of steel scrap. (GTS 2022)[100]
- At the country level, the IRS provides recycling related tax credits for which equipment and machinery used in the processing, collection, or distribution of recycling materials may be eligible.
- At the Federal level, some states provide credits on business income tax to corporations that buy equipment used for recycling. In Virginia for example, credits can account for up to 40% of the tax liability of a company for the year in question and unused amounts can be applied to later tax years. Similar income tax credits for recycling equipment purchases are applicable in New Mexico, Idaho, and Arizona.

[99] Mengden, Alex (2024): Carbon Taxes in Europe, 2024. Unter Mitarbeit von Alex Mengden. Hg. v. Europe Tax foundation. Online verfügbar unter https://taxfoundation.org/data/all/eu/carbon-taxes-europe-2024/, zuletzt aktualisiert am 04.12.2024.

[100] GTS (2022): Environment with Tax Breaks for Companies. Hg. v. Global Trash Solutions. Available online under https://globaltrashsolutions.com/blog/recycling-helps-environment-offers-companies-tax-breaks/, last viewed 04.12.2024.

- Some states offer property tax exemptions for recycling equipment and machinery, which can provide a cost savings for companies that recycle, though it is not clear if this applies also to copper and steel recyclers. Such programs exist in Nevada, Iowa, North Carolina, and Louisiana.
- In other States, sales tax exemptions on equipment purchases can be relevant for recyclers. For example, in North Carolina, eligible companies must manufacture recycled products or operate major recycling facilities and must create a minimum of 250 full-time jobs. Additional Sates with similar incentives for businesses focused on recycling are Iowa and New Jersey.

The following table provides a listing of further tax incentives that are available for recycling activities in the USA.

US tax incentives related to recycling activities (USEPA 2016)[101]

State	Description	Eligible applicants
AZ	Recycling equipment income tax credit for individuals and corporations equaling 10 percent of the installed cost of the equipment. Equipment must process postconsumer recyclables or produce finished products composed of at least 25 percent postconsumer recycled materials.	Individuals and corporations.
AR	Recycling equipment income tax credit equaling 30 percent of the equipment costs. Equipment must handle at least 10 percent postconsumer solid waste.	Recycling businesses.
DE	Recycling investment tax credit totaling $ 500 for each $ 100,000 invested. Recycling employment income tax credit of $ 500 for each new employee added as a result of incorporating recycled products into the process.	Recycling businesses that use at least 25 percent (by weight) recycled materials or materials removed from the state's solid waste stream.
FL	Recycling investment tax credit totaling $ 500 for each $ 100,000 invested. Recycling employment income tax credit of $ 500 for each new employee added as a result of incorporating recycled products into the process.	
GA	Personal income tax credit for investment in recycling facilities, machinery, or equipment. Amount of credit is equal to 3, 5, or 8 percent (based on tiers) of the qualified investment.	Manufacturing industries
HI	Recycling equipment sales tax reduction of between 0.5 and 4 percent.	Solid waste processing facilities.
IA	Personal and real property tax exemptions for machinery and equipment used for recycling or reprocessing of paper, cardboard, or plastic products. 100 percent sales tax exemption for purchases of industrial machinery, equipment, computers, and replacement parts used in the recycling or reprocessing of waste products.	Recycling businesses as specified in description.
KY	Recycling equipment personal income tax credit of up to 50 percent of the equipment costs. Recycling equipment sales and use tax exemption. Includes equipment used to collect, separate, compress, bale, shred, or handle waste materials for recycling.	Recycling businesses.
LA	Recycling equipment income tax credit for 20 percent of recycling equipment costs, less any other credits that are claimed. Equipment must process 100 percent postconsumer or recovered materials or make a product that contains 50 percent postconsumer or recovered materials. State, parish, and local property tax exemptions for recycling machinery and equipment	Recycling businesses as specified in description

[101] USEPA (2016): State Recycling Tax Incentives. Hg. v. USEPA. Available online under https://archive.epa.gov/wastes/conserve/tools/rmd/web/html/rec-tax.html, last viewed 05.12.2024

	for up to 10 years. Applies only to recycling manufacturing companies.	
MD	Personal property tax exemption on tools, implements, machinery, and manufacturing apparatus or engines. The exemption does not apply in certain counties.	Recycling businesses
MN	Sales tax exemption for construction costs for resource recovery facilities. Recycling processing equipment tax exemption for recycling processors only. Rebate of 6.5 or 7 percent of the equipment costs depending on whether the business is located in Minnesota.	Recycling businesses as specified in description.
MT	Recycling equipment income tax credit of 25 percent for the first $ 250,000 invested, 15 percent for the next $ 250,000, and 5 percent on the next $ 500,000. Reclaimable material income tax credit for taxpayers who purchase a product made from reclaimed materials. Tax credit is equal to 5 percent of the cost of the product.	
NC	Real and personal property tax, corporate state income tax, and franchise tax deductions for recycling plants, facilities, and/or equipment.	Businesses that purchase or construct facilities or equipment for recycling or resource recovery in North Carolina.
ND	Recycling equipment sales and use tax exemption for recycling machinery and equipment in new or expanding recycling facilities.	Recycling businesses
NJ	Sales tax exemption for the purchase of recycling equipment.	Recycling businesses
NM	Recycling equipment income tax credit equal to 5 percent of equipment costs. Tax credit is limited to recycling equipment that creates jobs, rather than reducing the workforce.	
NV	Personal property tax exemption of 75 percent for 10 years. Real property tax exemption of 25 percent for 20 years.	Manufacturing and recycling companies that meet the state's job creation and development goals and use raw or solid waste material from within Nevada.
OK	Recycling facility income tax credit of up to 15 percent for machinery and equipment, construction and renovation, and expansion financing.	Recycling businesses only, large manufacturers
OR	Three separate recycling tax credit programs with the credit taken against Oregon income tax. Credit can be taken from only one program. • Reclaimed plastic tax credit of 50 percent of the plastic recycling capital investment taken at a rate of 10 percent per year for 5 years. • Pollution control facility tax credit of 50 percent of the recycling equipment and facility capital cost taken at a rate of 5 percent per year for 10 years. • Business energy tax credit of 35 percent of the recycling equipment capital investment taken over 5 years.	
SC	Recycling equipment sales and use tax exemption for machines used in the collection, separation, processing, or reuse of materials that would otherwise become solid waste.	Recycling and manufacturing businesses
TX	Any equipment used for pollution control can receive a use determination from TCEQ that can be turned in to the appraisal district to get a property tax exemption. However, equipment used partially for pollution control and partly for production is eligible only for a partial use determination (i.e., you can only get the pollution control portion of the value). Since recycling is	

	generally for pollution control and production, the equipment may not be eligible for a 100% use determination.	
UT	Recycling income tax credits of 5 percent on equipment and machinery costs and 20 percent on operating costs (maximum $ 2,000). Only available for recycling collectors, processors, and manufacturers located in state Recycling Market Development Zones. Sales tax exemption for manufacturers purchasing and leasing machinery and equipment. Sales tax exemptions range from 30 to 100 percent depending on what year the machinery is purchased. Available for all manufacturers, including recyclers.	
VA	Recycling equipment income tax credit equal to 10 percent of the equipment purchase price. Machinery and equipment must be used to manufacture, process, compound, or produce items from recyclable materials. Retail sales and use tax exemption for machinery, equipment, and power used by industrial recyclers.	Recycling businesses
WI	Recycling property tax exemption for machinery and equipment, including parts, used exclusively and directly in waste reduction or recycling.	Recycling businesses

An OECD study investigated financial tools related to primary and secondary material production. Though most of the report refers to various tools in general, a few examples of existing incentives are specified: (OECD 2018)[102]

- “The OECD database of environmental taxation measures indicates that targeted accelerated depreciation provisions for recycling facilities are available, or potentially available, in France, Ireland, Japan, Netherlands, and the US. For example, the RISE program in the US entitles domestic recycling firms to write-off 50% of an assets value for tax purposes in the first year of operation. It was enacted in 2008 and was extended under the PATH act of 2015. Accelerated depreciation provisions improve project profitability by reducing the assessable tax base early in a project’s life”.
- “A number of countries provide support for firms in the secondary metal sector through value added taxes (VAT). The most common provision relates to the input tax portion of VAT; recycling firms which acquire metal scrap from VAT exempt or non-registered entities are entitled to claim a deemed input VAT credit. This credit can then be used to reduce the output tax portion of the VAT the firm is required to pay on behalf of its clients. Deemed input VAT tax credits are particularly important for scrap dealers situated at the top of the secondary metal supply chain. These firms often acquire scrap from VAT non-registered entities such as individuals or publicly owned and operated municipal waste collection organisations. Countries where deemed input VAT tax credits are available include South Korea, South Africa, and the United States”.
- “VAT-related tax relief is also available for recycling firms in China through targeted partial VAT rebates. Rebate rates vary between 30% and 100% depending on the commodity but are set at 30% for ferrous scrap”.

Very few measures were found at the EU level, though the information from the OECD study suggests that there may be some additional tax related initiative at Member State level. At the EU

[102] OECD (2018): McCarthy, A. and P. Börkey. Mapping support for primary and secondary metal production. OECD Environment Working Papers, No. 135. Hg. v. OECD Publishing. Paris. Available online under https://www.oecd-ilibrary.org/docserver/4eaa61d4-en.pdf?expires=1733356848&id=id&accname=ocid56027324&checksum=9B81B8E5F7F9F95A92D9A34D1BC71622, last viewed 05.12.2024.

level, though tax initiatives were not identified, a few frameworks have been developed to generally promote industry to decrease greenhouse gas (GHG) emissions and also to ensure that such measure do not lead to a shift of carbon intensive industries from the EU to other countries.

The Emissions Trading System (ETS - Directive 2003/87/EC) is based on a “cap” and “trade principal. It puts a general cap on the amount of GHG emissions that can be produced in the EU. The cap is reduced annually with the aim of reducing EU emissions over time. The EU ETS has helped reduce total emissions of power and industry plants by ca. 47% in the period between 2005 and 2023. The cap is translated into emission allowances, where one allowance allows the emission of one tonne of CO_2e (i.e., carbon dioxide equivalent). (EC 2023)[103]

The ETS requires polluters to pay for their greenhouse gas (GHG) emissions. The allowances are generally sold in auctions; however, companies receive some allowances for free and can trade with other companies in cases where their production is more efficient or where they require more allowances to cover their emissions. It is the world’s first carbon market and among the largest ones globally. (EC 2023)[104]

The ETS covers emissions from the electricity and heat generation, industrial manufacturing, and aviation sectors. This means that it also applies to smelters and recyclers of copper and steel and possibly also to other waste management activities. The carbon price provides an incentive for companies to reduce emissions cost-effectively. In this sense, the ETS indirectly supports recyclers to decrease the GHG emissions associated with the processing of copper and steel. (EC 2023)[105]

A further European system established only recently is the Carbon Border Adjustment Mechanism. The mechanism is to apply from 2026 with the aim of preventing carbon leakage: Carbon leakage occurs when companies based in the EU move carbon-intensive production abroad to countries where less stringent climate policies are in place than in the EU, or when EU products get replaced by more carbon-intensive imports. The mechanism puts “a fair price on the carbon emitted during the production of carbon intensive goods that are entering the EU, and to encourage cleaner industrial production in non-EU countries […] By confirming that a price has been paid for the embedded carbon emissions generated in the production of certain goods imported into the EU, the CBAM will ensure the carbon price of imports is equivalent to the carbon price of domestic production, and that the EU's climate objectives are not undermined”. (EC 2024)[106]

To ensure the above objective, the CBAM will initially apply to imports of selected goods and precursors with a carbon intensive production and thus at the highest risk of carbon leakage. This includes, iron, steel, and aluminium, electricity, and hydrogen. (EC 2024)[107]

[103] EC, D. CLIMAG (2023): What is the EU ETS? Hg. v. EC DG CLIMA. Online verfügbar unter https://climate.ec.europa.eu/eu-action/eu-emissions-trading-system-eu-ets/what-eu-ets_en, zuletzt aktualisiert am 06.12.2024.

[104] See Footnote 103

[105] See Footnote 103

[106] EC (2024): Carbon Border Adjustment Mechanism. Hg. v. EC. Online verfügbar unter https://taxation-customs.ec.europa.eu/carbon-border-adjustment-mechanism_en, zuletzt aktualisiert am 06.12.2024.

[107] See footnote 106

The CBAM is currently running at pilot scale and will only be completely implemented in 2026. During this period, importers of goods in the scope of the new rules will only have to report greenhouse gas emissions (GHG) embedded in their imports (direct and indirect emissions), without the need to buy and surrender certificates. Reporting is due on a quarterly basis. (EC 2024)[108]

For example, importers of iron or steel goods must submit quarterly reports on the quantities of iron and steel goods imported into the EU, the greenhouse gas emissions released as these products were produced (embedded in those goods), as well as information on effective carbon prices already due or paid on the goods during their production. Starting 2026, monetary payments will be due from the customs representative of the importing company that will be expected to buy and surrender CBAM certificates corresponding to the quantity (in proportion to the phasing out of free allocation under the EU ETS) of embedded emissions in the goods. (EC 2024). [109]

[108] See footnote 106
[109] See footnote 106