Scrap steel at sea

How ship recycling can help decarbonise European steel production

NGO SHIPBREAKING PLATFORM

sandbag
smarter climate policy

UNIVERSITÀ DEGLI STUDI DELLA TUSCIA
DIPARTIMENTO DI ECONOMIA, INGEGNERIA, SOCIETÀ E IMPRESA

About the authors

NGO Shipbreaking Platform

The NGO Shipbreaking Platform is a coalition of environmental, human and labour rights organisations promoting safe and environmentally sound ship recycling globally. The Platform was first created in September 2005 after the few NGOs working on the issue noticed that a broader base of support and strong network of organisations from ship-owning and shipbreaking countries were needed to challenge the political clout of the shipping industry. The coalition quickly evolved from being a European Platform to a global one, including NGOs based in the major shipbreaking countries India, Bangladesh, Pakistan and Turkey, and now has 17 member organisations and ten partners in 12 countries. The Platform is recognised by United Nations agencies, the European Union and leading media outlets as the preeminent international civil society organisation advocating for sustainable ship recycling.

Committed to finding solutions based on the respect for human rights and the principles of environmental justice, producer responsibility, 'polluter pays' and clean production, our vision is that vessels are no longer dumped on the beaches of developing countries, but instead recycled in facilities that ensure clean, safe and just practices, offering decent jobs.

Sandbag - Smarter Climate Policy

Sandbag is a think tank conducting data-driven and evidence-based advocacy to improve EU climate policy. They combine expertise in decarbonisation with data analysis to propose policies that drive impactful, cost-effective emissions reductions in the EU and beyond. Through a holistic approach, they ensure that recommendations are not only well-informed and effective but also inclusive, considering economic and geostrategic realities.

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Prof. Enrico Maria Mosconi is Full Professor of Technology and Production Management at the University of Tuscia, and the Coordinator of the Civitavecchia University of Tuscia. He directs postgraduate Master's programmes in Complex Logistics and Competitive Finance and is active in commissions and centres focusing on innovation, sustainable resource use, and the circular economy. As Head of Circular Economy and Innovation for the Blue Economy and Mediterranean Sea Growth, he leads research on aligning industrial systems with environmental sustainability in marine and coastal contexts. Francesco Tola is Ph.D. graduate in Economics, Management and Quantitative Methods at the University of Tuscia. His research interests lie in statistical modelling, data analysis, and applications in maritime economics, ship recycling, and sustainability transitions. Expert in developing analysis and models with advance statistical tools. Mariarita Tarantino is a PhD Candidate in Management and Quantitative Methods at the University of Tuscia, curriculum in Circular Economy and Sustainability. Her doctoral research focuses on European strategies for packaging within the transition towards a circular economy, with particular emphasis on Extended Producer Responsibility (EPR) and harmonised labelling of packaging and waste receptacles. Her academic work includes publications on packaging sustainability, waste management, and circular supply chain models.

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Glossary

Basel Convention: A global treaty that regulates the transboundary movements of hazardous wastes and their disposal to protect human health and the environment.

Basel Ban Amendment: An amendment to the Basel Convention that prohibits the export of hazardous waste from OECD to non-OECD countries.

Beneficial Owner: The 'real' owner of a ship and the company that makes the commercial decision to sell a vessel for scrap. The Beneficial Owner is deemed to be the ultimate owning entity or representative thereof (either individual, company, group or organisation) and is the entity that benefits from the rent and/or the sale of the asset.

BF (Blast Furnace): A traditional steelmaking furnace that produces molten iron by chemically reducing iron ore with coke at high temperatures. This method relies heavily on coal and results in high CO_2 emissions, making it less environmentally friendly compared to electric arc furnaces (EAFs).

Cash Buyer: A company specialising in the trade of end-of-life vessels to beaching yards. Cash buyers pay ship owners upfront before the ships reach their final destinations and are dismantled. Cash buyers sell ships to shipbreakers that can offer the highest price and are notorious for hiding business dealings and dodging waste export laws by re-registering vessels under flags of convenience and anonymous post box companies.

CSs (Classification Societies): Independent organisations that establish and maintain technical standards for the construction and operation of ships and offshore structures. They verify compliance through inspections and certifications to ensure safety and seaworthiness.

DRI (Direct Reduced Iron): Iron produced from the direct reduction of iron ore using reducing gases or carbon, used as a raw material in steelmaking.

EAF (Electric Arc Furnace): A steelmaking furnace that melts scrap steel using electric arcs, allowing for energy-efficient and low-emission steel production.

ESPR (Ecodesign for Sustainable Products Regulation): A EU regulation to improve the sustainability of products through better design, aiming to reduce environmental impacts across their life cycle.

EU SRR (European Union Ship Recycling Regulation): Regulation aiming to ensure that EU-flagged ships are recycled in safe and environmentally sound conditions in the EU-approved ship recycling facilities.

EU WFD (European Union Waste Framework Directive): Directive setting the basic concepts and definitions related to waste management, including the waste hierarchy and recycling targets.

EU WSR (European Union Waste Shipment Regulation): Regulation governing the transboundary movement of waste to protect human health and the environment.

HKC (Hong Kong Convention): An international treaty developed by the IMO on ship recycling.

IACS (International Association of Classification Societies): A global organisation of classification societies.

IHM (Inventory of Hazardous Materials): A document listing all hazardous materials on board a ship, required under the HKC and EU SRR for safe recycling and maintenance.

ISRI (Institute of Scrap Recycling Industries): A U.S.-based trade association representing the scrap recycling industry, including metals, paper, plastics, and electronics.

Light Displacement Tonnage (LDT): The weight of the ship with all its permanent equipment, excluding the weight of cargo, fuel, water, ballast, stores, passengers, and crew, but usually including the weight of permanent ballast and water used to operate steam machinery. EoL ships are sold on the basis of USD per LDT as an indicator of the steel value.

LDT (Light Displacement Ton): A measure of a ship's weight without cargo, fuel, crew, or stores, commonly used in ship recycling to estimate the amount of recoverable steel.

NISST (National Institute of Secondary Steel Technology): The Indian institute dedicated to the research, development, and promotion of secondary steel production technologies.

NORM (Naturally Occurring Radioactive Material): Material found in the environment that contains radioactive elements such as uranium, thorium, or radon. These substances can become concentrated during industrial processes like mining, oil and gas production, or scrap metal recycling.

PCBs (Polychlorinated Biphenyls): Toxic synthetic organic chemicals used in electrical equipment and other applications; linked to serious environmental and health risks.

TMCP (Thermo-Mechanical Controlled Processing): A steel production process that combines controlled rolling and cooling to improve strength and toughness.

TMT Bars (Thermo-Mechanically Treated Bars): High-strength reinforcement bars, widely used in construction for their durability and resistance.

9R: A hierarchical framework in circular economy thinking that prioritises resource efficiency through nine strategies (Refuse, Rethink, Reduce, Reuse, Repair, Refurbish, Remanufacture, Repurpose, and Recycle) aimed at keeping materials in use for as long as possible while minimising waste.

7R: A simplified circular economy framework focusing on Reduce, Reuse, Recycle, Recover, Redesign, Remanufacture, and Refurbish to guide sustainable production and consumption practices by extending product lifecycles and minimising environmental impact.

Executive Summary

Steel plays a central role in the European Union's industrial strategy, and shifting to more sustainable production is essential to achieving the EU's climate neutrality goals. One of the most effective pathways to decarbonise steelmaking is by increasing the use of scrap steel as it can dramatically reduce CO_2 emissions, energy consumption, and water use. Among available technologies for steel production, Electric Arc Furnaces (EAF) stand out for their capacity to incorporate high proportions of recycled steel, achieving emission reductions of up to 80% compared to traditional Blast Furnace processes. However, this shift requires a steady, reliable supply of high-quality scrap.

The steel industry expects a rising demand for scrap in the coming years due to demands for lower carbon footprints and the implementation of new steelmaking technologies. Ship recycling presents a significant and largely untapped opportunity to meet this demand. Ship steel is recognised for its consistently high quality, certified through uniformed standards developed by global classification societies. As the EU/EFTA-owned fleet ages, the availability of end-of-life (EoL) assets is set to grow substantially. The forecasting analysis of the 11,902 EU/EFTA-owned vessels over 10 years old highlights the mid-2030s as the critical period for ship demolitions, with annual retirements exceeding 700 units. This level of recycling demand may translate to an estimated 10–15 million tons of scrap steel recoverable annually throughout the decade throughout the decade, which represents up to 20% of annual scrap steel consumption in the EU.

Beyond recycling, innovative companies are also exploring ways to extend ships' life cycles, trace materials and components from construction to EoL, and reuse steel plates directly in construction applications. Cross-industrial synergies are needed to unlock the full potential of ship recycling, as well as more research to achieve greater transparency in steel documentation, including contamination risks from coatings, and improved data on future supply of EoL vessels to allow clear forecasting for the demolition market.

To fully harness the potential of ship steel within a circular economy, policies should furthermore support the development of safe and environmentally sound ship recycling, and stimulate material recovery and reuse. Policies should clearly promote the development of best practice guidelines aligned with ship recycling regulations and consistent with the EU's circular economy principles, including the 9Rs hierarchy and the waste management pyramid. Ultimately, by recognising ship recycling as a valuable source of high-quality scrap steel, the EU can reduce dependence on imports, conserve valuable resources, and advance toward climate neutrality. This transition will foster innovation, strengthen industrial resilience, create green quality jobs, preserve and develop maritime skills, and position ship recycling as a key contributor to enhancing circularity in the maritime sector.

Methodology

This research was conducted through a collaborative effort between three organisations: NGO Shipbreaking Platform, Sandbag, and the University of Tuscia. Sandbag was involved in an in-depth review of literature, policy documents, and industrial data to assess the role of scrap steel as a strategic contributor to a circular and low-carbon steel economy. Then, data on global ship recycling practices, trends, challenges and the treatment of ship steel were collected by the NGO Shipbreaking Platform, leveraging the organisation's expertise and years of monitoring, investigations, and advocacy. To assess the quality, certification pathways, and reuse potential of ship steel, the study combined desktop research, such as reviewing literature and data from academia, steel producers and shipbuilding sources, with informal interviews and conversations involving stakeholders across the value chain, including manufacturers, recyclers, shipyards, and certification bodies. Finally, the University of Tuscia supported the quantitative analysis of the EU/EFTA-owned fleet. Using fleet data and predictive modelling techniques such as ARIMA and WEIBULL, the report estimates the volume and timeline of ships reaching EoL over the next decades. These forecasts provide critical context for understanding the future availability of ship scrap steel and the urgency to develop and scale compliant recycling capacity. A detailed explanation of the forecasting methodologies applied in this research is provided in Annex I.

One barrier encountered was the low response rates of stakeholders contacted to provide insights on ship steel quality and its potential for steelmaking, which may reflect the limited awareness in Europe of ship recycling as a source of high-quality scrap steel. Lack of awareness is likely due to the current relatively small scale of the EU ship recycling market, as well as the geographical disconnect between shipbuilding (concentrated in East Asia) and ship recycling (primarily occurring in South Asia). Future research should enhance a deeper engagement between maritime and steel industries.

Introduction

As more ships reach the end of their operational life, the high-quality scrap steel they contain presents a valuable opportunity for the EU steel industry to reduce its carbon emissions. With industry experts indicating that between 70% and 95% of an EoL ship's weight can be recovered as scrap[1], it is crucial to have more available data on ship scrap steel quality and availability. This report aims to foster industrial synergies and to analyse EU ship recycling policies from the perspective of material recovery and their contribution towards building a circular economy.

The report seeks to answer the following key questions:

1. What are the environmental benefits of using greater amounts of scrap steel in steel production?

2. What are the key enablers and barriers to integrating high-quality scrap steel into the steel decarbonisation strategy?

3. Are there specific qualitative characteristics that make ship steel an attractive raw material for steel makers?

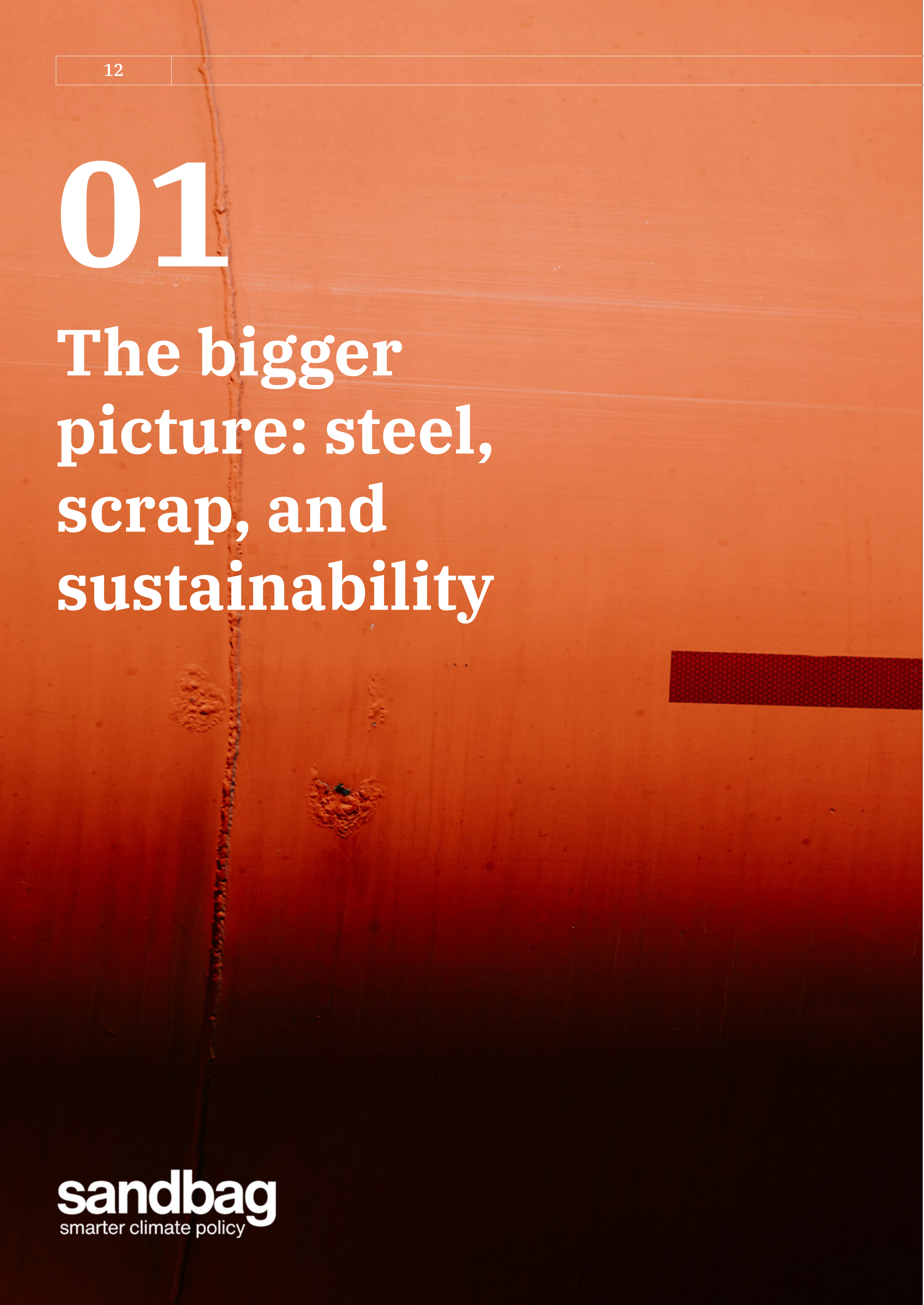
4. What is the estimated availability of scrap steel from vessels owned by EU/EFTA companies?

5. To what extent do current EU ship recycling policies support material circularity and resource efficiency, and are they aligned with the EU Waste Hierarchy and the key pillars of the EU Circular Economy Action Plan?

6. How can EU companies and policymakers enhance optimised material recovery from EoL ships?

By fostering dialogue between key stakeholders, this research aims to promote safe and sustainable dismantling practices while unlocking the strategic value of ship scrap steel in achieving Europe's industrial goals. Chapter 1 examines the broader role of scrap steel in the EU economy, reviewing its benefits and contribution to achieving decarbonisation goals, as well as barriers to its increased use. Chapter 2 focuses on current ship recycling practices and the technical characteristics of ship steel. It also provides an analysis of the volume of scrap steel available from EU/EFTA-owned vessels, including recycling forecasts over the next decade. Chapter 3 evaluates the extent to which current EU policies on ship recycling promote the recovery of high-quality scrap steel and are aligned with the guiding frameworks of the EU Circular Economy Action Plan and the Waste Hierarchy. Finally, the report offers recommendations to policymakers, as well as to the shipping and steel industries, on necessary steps to boost ship recycling in order to advance a climate-neutral economy.

01 Sandbag. (2022). European scrap steel floats away under carbon market incentives. Retrieved May 2, 2025, from https://sandbag.be/2022/09/22/european-scrap-steel-floats-away-under-carbon-market-incentives/



01
The bigger picture: steel, scrap, and sustainability

1.1 Overview

Scrap in steel production

Climate context

The European Union (EU) needs to decarbonise its economy to meet its 2030 and 2050 climate targets. An ambitious emissions target is a key driver of climate mitigation as it determines the ambition of the climate policies necessary to achieve corresponding emission reductions – driving mitigation efforts. The EU has the world's most ambitious climate policy in place, with a 55% reduction target by 2030 compared to 1990, and a net zero target of 2050. The European Green Deal set a 55% emissions reduction target for 2030 supported by the Fit-for-55 package. Industrial sectors, and notably steel, play a major role in this effort. The steel industry is one of the largest industrial sources of greenhouse gas emissions, accounting for approximately 8-10% of global emissions, which translates to about 2.6 billion tonnes[2]. This substantial contribution to global emissions highlights the need for decarbonisation of the sector.

In Europe, the steel industry's carbon footprint is significant, accounting for approximately 5% of emissions[3], amounting to approximately 190 million tonnes of CO_2. Reducing the sector's climate footprint is essential to achieving the EU's decarbonisation goals. One key lever to lower emissions from steelmaking is to increase the use of secondary steel produced with scrap. Recycling scrap requires significantly less energy than producing steel from primary raw materials and leads to far lower emissions, making it a strategic solution for the transition to climate neutrality.

An ambitious target for 2040 is essential to provide necessary incentives for secondary steelmaking and a pathway for the EU towards zero emissions by 2050. Following a recommendation of 90-95% emission reduction relative to 1990 from the European Scientific Advisory Board on Climate Change, the Commission proposed a 90% net emission reduction target for 2040 in early 2024[4]. However, over a year later, the proposal has not yet been adopted by policymakers, likely due to political opposition. Consequently, the EU missed the deadline to report the 2035 Nationally determined Contribution (NDC) to the U.N. in February 2025. In the communication of the Clean Industrial Deal on February 26th 2025, the Commission President Ursula Von Der Leyen announced that the Commission would stay the course with a 90% net emission reduction target compared to 1990[5], which will be enshrined into the EU Climate Law.

02 IEA. (2023). Emissions Measurement and Data Collection for a Net Zero Steel Industry.

03 European Commission. (2022). EU climate targets: how to decarbonise the steel industry.

04 European Commission. (2024). Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. Securing our future. Europe's 2040 climate target and path to climate neutrality by 2050 building a sustainable, just and prosperous society.

05 European Commission. (2025). Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. The Clean Industrial Deal: A joint roadmap for competitiveness and decarbonisation.

ENVIRONMENTAL BENEFITS OF SCRAP STEEL USE

Increasing the use of scrap steel in production brings substantial environmental benefits beyond reducing fossil carbon emissions.

UP TO 72% LESS ENERGY

Producing steel from recycled scrap requires up to 72% less energy compared to primary steel production from iron ore [6]

95% LESS EMISSIONS

Producing steel from recycled scrap can reduce direct CO_2 emissions (scope 1) by up to 95% - generating less air pollution. [7]

40% WATER USE REDUCTION

Scrap-based steelmaking uses approximately 40% less water leading to less water pollution.[8]

Iron and steel production technologies

Steel production technologies, historically dominated by the Blast Furnace - Basic Oxygen Furnace (BF-BOF) route, have evolved significantly with the rise of the more sustainable Electric Arc Furnace (EAF) method.

Blast Furnace - Basic Oxygen Furnace (BF-BOF: The BF-BOF route is the traditional primary steel production method, using iron ore and coal as primary raw materials. This process is highly carbon-intensive, emitting about 1.81 tonnes of CO_2 per tonne of crude steel in Europe[9] (scope 1 and 2). While it incorporates 10-20% scrap[10], the process's design limits further scrap use and 20–25% is currently the maximum input for BF-BOF[11]. The oxygen blow from the top of the BOF restricts this mixing, preventing a higher scrap rate and maintaining reliance on emission-intensive primary steel production by reducing iron ore with coal.

Electric Arc Furnace (EAF): The EAF process primarily uses steel scrap as its raw material. An EAF can incorporate up to 100% scrap, making it a key technology for increasing the circularity of steel production. In Europe, the EAF secondary route's emissions are 0.24 tonnes of CO_2 per tonne of crude steel (scope 1 and 2)[12]. Additionally, an EAF can use Direct Reduced Iron (DRI) as a feedstock. DRI is sponge iron produced through the reduction of iron ore using natural gas or hydrogen. Combining DRI with scrap in the EAF process allows for flexibility in feedstock use, and emissions can be significantly reduced depending on the share of scrap and DRI input. This process is notably more environmentally friendly than the traditional BF-BOF route, which is heavily reliant on coal and coke. The EAF method offers significant potential for decarbonisation, especially as more steel scrap is used for production.

Currently, around 40% of steel production in the EU uses EAFs, while the majority (60%) still relies on the traditional BF-BOF method, see Figure 1[13]. Meeting climate targets requires a significant shift toward EAF-based steel production with an increased use of scrap.

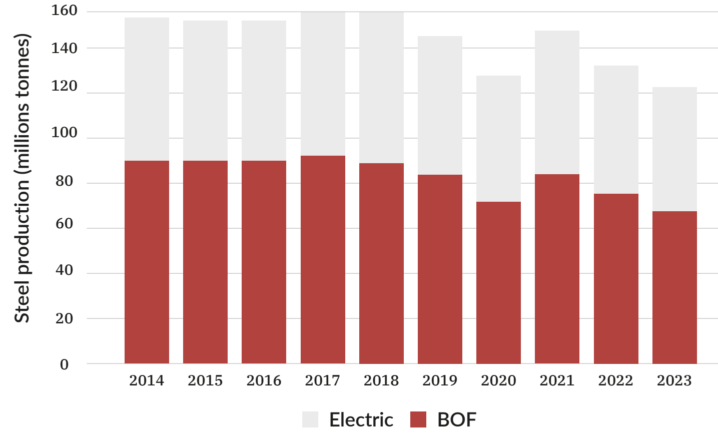


Figure 1: European steel production by route over the years (2014-2023)

Steel products and scrap utilisation

Steel products are broadly categorised into two main types: long steel products and flat steel products. The potential for incorporating scrap varies significantly between these categories due to differences in quality requirements and production constraints.

Long steel products

Long steel products, such as beams, rebars, and struc-

06 Europa EuRIC. (n.d.). Circular economy: Metal recycling factsheet.

07 NDC-Aspects, 2024 Policy Brief "The potential of scrap use for EU steel decarbonization

08 Söderholm, P., & Ejdemo, T. (2008). Steel scrap markets in Europe and the USA. https://www.diva-portal.org/smash/get/diva2:985707/FULLTEXT01.pdf

9 Joint Research Centre. (2022). Greenhouse gas intensities of the EU steel industry and its trading partners.

10 ArcelorMittal. (2022). Recycled scrap content declaration. https://www.arcelormittal-warszawa.com/wp-content/uploads/2022/10/LEED-ArcelorMittal-Europe-Long-Products-Recycled-Content-2021-2022-01-27.pdf

11 Kildahl, H. (2023). Cost-effective decarbonisation of blast furnace–basic oxygen furnace steel production through thermochemical sector coupling. [Master's thesis, Norwegian University of Science and Technology]. https://www.sciencedirect.com/science/article/pii/S095965262300121X

12 Joint Research Centre. (2022). Greenhouse gas intensities of the EU steel industry and its trading partners.

13 Eurofer. (2024). European steel in figures. European Steel Association. https://www.eurofer.eu/assets/publications/brochures-booklets-and-factsheets/european-steel-in-figures-2024/European-Steel-In-Figures-2024-v2.pdf

tural components, are primarily used in construction and infrastructure. These products have a higher tolerance for impurities compared to flat steel, allowing for a greater portion of scrap in their production.

Due to their mechanical properties and less stringent purity requirements, long steel products can incorporate higher percentages of scrap without compromising quality. In Europe, 98% of long steel products are produced using scrap via the EAF process. This includes products like Heavy Sections, Merchant Bars, Rebars, and Wire Rods, which can be produced with lower-quality scrap, see Figure 2.

Figure 2: Long products

Flat steel products

Flat steel products are used in industries requiring high-quality steel, such as automotive (car bodies, chassis), household appliances (washing machines, refrigerators), and specialised applications (pipelines, shipbuilding). These products must meet strict purity standards, limiting the amount of scrap, particularly due to copper contamination, which affects the steel's properties.

Hot rolled coil: Used in automotive components, this product requires high-purity scrap to avoid contaminants that could impair its mechanical properties. Copper contamination reduces the quality of the product, leading producers to limit post-consumer scrap use.

Quarto Plate: Mostly used in heavy construction and shipbuilding.

Flat steel in Europe is predominantly produced using the BF-BOF route. One notable exception in Europe is Arvedi, which produces flat steel using EAF technology at its Cremona production site in Italy.

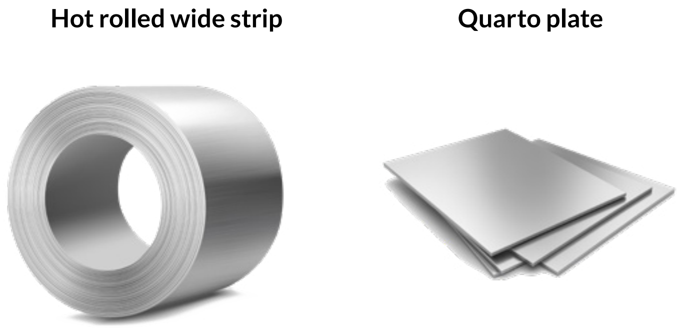


Figure 3: Flat products

Scrap content in long and flat product

Currently, the demand for flat products in the EU is higher than for long products, see Figure 4 -Top, posing a challenge for scrap utilisation. Most available scrap is of lower quality, making it more suitable for long products, while the flat steel sector continues to depend heavily on blast furnace production. Flat steel production requires high purity and therefore higher-quality scrap, blended with certain amounts of ore-based metallics (OBM) such as Pig Iron or DRI,

see Figure 4[14] - Bottom. Current flat steel production is significantly more emission-intensive due to its reliance on BF-BOF.

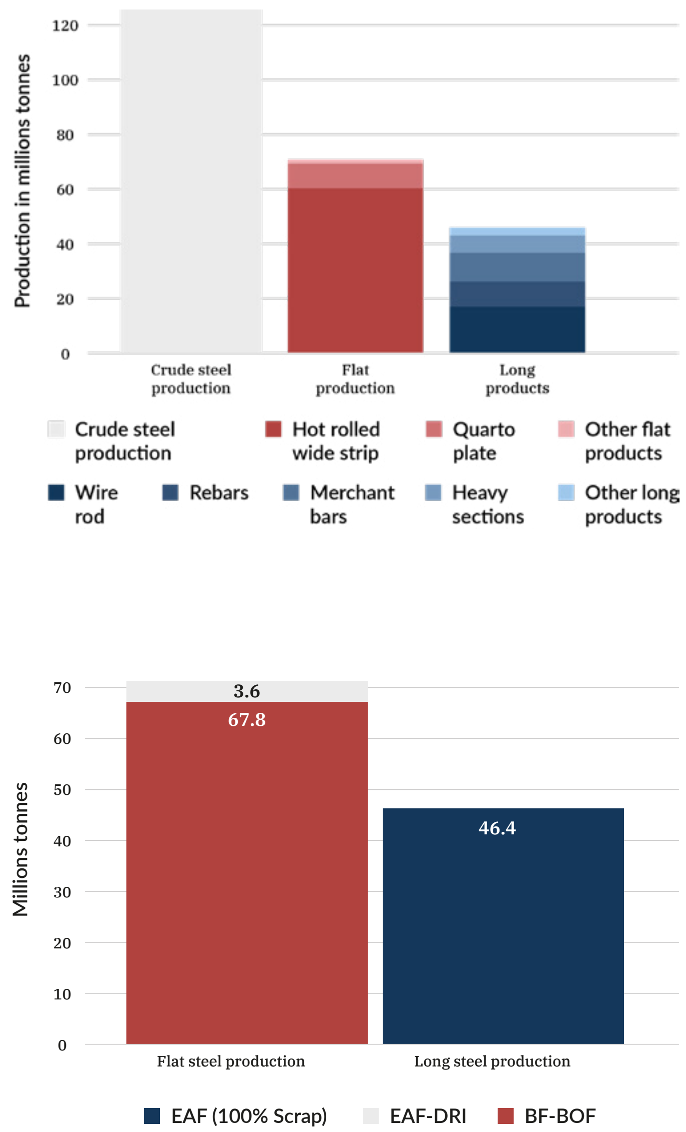


Figure 4 :
Top: Production of steel per type of product in 2023,
Bottom: Steel Production routes by product type
EU-27 in 2023

14 Data from Eurofer, NetZeros industry and Averdi

1.2

Barriers

The transition to a scrap-based EAF model faces two key challenges: Scrap availability and scrap quality. The presence of impurities such as copper or tin can alter the properties of the final product, particularly for automotive or packaging applications. To meet quality requirements, flat steel production through an EAF is often based on a mixture of high-quality scrap, Pig Iron, or DRI/HBI. A high share of scrap input requires high-quality scrap when flat steel is produced through an EAF.

Scrap availability

The availability of steel scrap depends on the volume of end-of-life products and the efficiency of collection systems. In Europe, nearly all long EAF steel is produced from scrap, and nearly all flat steel is produced through BF-BOF, as the current availability of DRI is marginal[15]. Figure 5 shows a Sankey diagram of material flows related to steel production, consumption, and recycling in the EU-27 for 2023. Key data—steel production (primary and secondary), apparent and real consumption, and trade—are sourced from Eurofer (2023). Primary production (70 Mt) corresponds to the BF–BOF route, while secondary production (56 Mt) comes from EAF processes. For BF–BOF, an average scrap input of 15% is assumed[16].

15 World Steel Association. (2023). World steel in figures 2023. https://worldsteel.org/data/world-steel-in-figures/world-steel-in-figures-2023/

16 ArcelorMittal. (2022). Recycled scrap content declaration. https://www.arcelormittal-warsza-

Yield losses are estimated at 10% of total collected scrap, though this varies by sector[17]. The collected end-of-life steel (91 Mt) is based on real consumption (138 Mt), reduced by the net addition to the stock (31 Mt), assuming an 85% collection rate[18]. The remaining 15% (17 Mt) reflects unrecovered steel. The gap between apparent and real consumption (126 Mt vs. 138 Mt) reflects steel embedded in finished goods (indirect trade).

Scrap quality

Steel recycling depends on different categories of scrap that vary based on their origin and quality. In Europe, the capacity to recycle and reuse scrap is a key lever to reduce emissions in the steel sector. However, secondary flat steel production is limited by strict scrap quality requirements, especially for automotive applications and high-strength steels. Typically, scrap can be differentiated into two categories:

Pre-consumer scrap: This is scrap generated directly within the steel mill, such as scrap, trimmings, or steel pieces produced during the manufacturing process. This type of scrap is typically of high quality because it hasn't been exposed to external contaminants. Further down the processing, industrial scrap is produced before the steel becomes a finished product, for example, trimmings and offcuts from steel processing industries. This scrap is also of high quality and can be recycled quickly.

Post-consumer scrap: This is steel that has reached the end of its life cycle, such as scrapped cars, end-of-life ships, demolished buildings, or household appliances. This type of scrap is often more contaminated (e.g., with copper, zinc, etc.), which makes it more difficult to recycle for high-quality applications.

Challenges of scrap collection and quality control

In Europe, the scrap collection process is highly fragmented, with numerous independent scrap collectors operating across different countries. This lack of centralisation and transparency creates inefficiencies in both the collection and management of scrap. Without uniform standards or centralised control, it is challenging for steelmakers to ensure a consistent supply of high-quality scrap. The scrap supplied to steelmakers in general is a mixed material based on optical checks without chemical measurements. The main measures are "trust", visual inspection, and occasional spot checks by hand-held XRFs[20].

In contrast, the steel industry in the United States (U.S.) benefits from a more integrated system, where mini-mills often own scrap collection facilities. This internal control creates better traceability and quality assurance, contributing to a more efficient recycling operation[21].

wa.com/wp-content/uploads/2022/10/LEED-ArcelorMittal-Europe-Long-Products-Recycled-Content-2021-2022-01-27.pdf

17 Organisation for Economic Co-operation and Development (OECD). (2024). Unlocking potential in the global scrap steel market. https://www.oecd.org/content/dam/oecd/en/publications/reports/2024/12/unlocking-potential-in-the-global-scrap-steel-market_b7014135/d7557242-en.pdf

18 World Steel Association. (2021). Life cycle inventory study. https://worldsteel.org/wp-content/uploads/2021-LCA-Study-Report.pdf

19 Values marked with an asterisk (*) indicate approximated data based on assumptions and secondary sources.

20 SUSTAIN. (n.d.). High-quality scrap. https://www.sustainsteel.ac.uk/core-research/high-quality-scrap

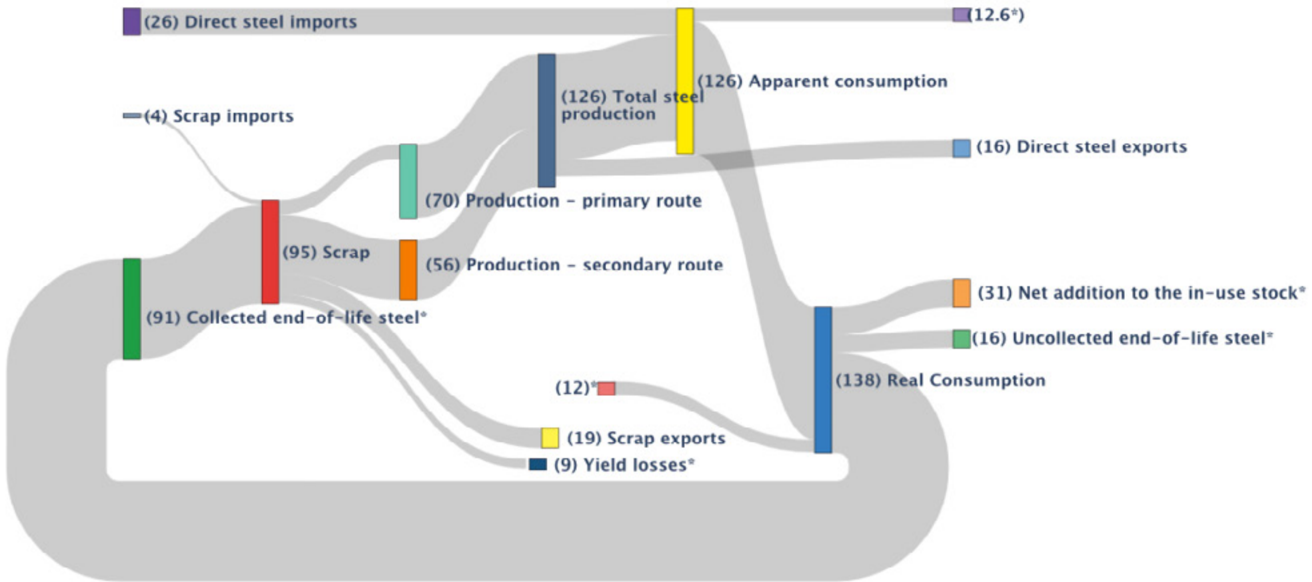


Figure 5: Flow of steel in the EU-27 in 2023[19]

Different countries have varying classification systems, leading to ineffective sourcing of available scrap with different qualities. While Europe has introduced standardised classifications, they remain less precise compared to the U.S., where scrap quality is more rigorously monitored and classified. This variability makes it difficult for steelmakers to source the specific materials required for high-quality steel production, causing inefficiencies in manufacturing.

Scrap quality and steel purity requirements

Scrap quality used in steelmaking poses a significant challenge to product quality. Steel products are typically classified into four categories (P1 to P4) based on their tolerance for impurities, so-called tramp elements. Categories P1 and P2 represent high-purity flat products, and P3 and P4 cover lower-specification flat and long products.

Steel scrap can be classified by quality based on its average content of five major tramp elements (Cu, Sn, Cr, Ni and Mo). In Dworak et al. (2022), scrap is categorised into four quality grades (Q1 to Q4) depending on these impurity levels. However, while the Q1–Q4 classification is useful from a material purity perspective, the European steel industry more commonly uses the EFR (European Ferrous Recovery) standard[22], which classifies scrap into specific grades (e.g., E2, E3, E5M, EHRB) based on composition, origin, and physical characteristics. These EFR grades serve as a practical basis for trade, processing, and recycling, and are widely used in commercial transactions as part of the well-established European recycling practice.

The relationship between the Q1–Q4 quality levels

21 Boston Consulting Group. (2024). Shortfalls in scrap will challenge the steel industry. https://www.bcg.com/publications/2024/shortfalls-in-scrap-will-challenge-steel-industry

22 EU-27 Steel Scrap Specification – EFR Standards. (2007). EU-27 steel scrap specification. https://studylib.net/doc/18366587/eu-27-steel-scrap-specification

Quality categories	Average content of impurities (Cu, Sn, Cr, Ni & Mo)	EFR categories	Typical steel intermediates	Share in total volume of scrap	Currently used for
Primary iron	<0.05				P1-2 products
Q1	0.13	E2 – E8 – E6	Most flat products (cold rolled coils) – deep drawing quality, interstitial-free steel	21%	P3-4 products
Q2	0.21	E3	Tubes, plates, hot rolled products in construction, wire rod (other than construction)	10%	P3-4 products
Q3	0.3	E3 - EHRB	Hot rolled bar, plates (construction), wire rod (construction)	35%	P3-4 products
Q4	0.40	E5M – EHRM - E46	Heavy section, light section, rail section, reinforcing bar, hot rolled bar (construction)	34%	P3-4 products or exported

Table 1: Steel qualities (tolerable content of tramp elements) considered[23]

and the EFR categories is summarised in Table 1. This mapping provides a practical bridge between metallurgical criteria and scrap used in production.[23]

Currently, most scrap used in Europe is directed toward the production of P3 and P4 steel products, which tolerate higher impurity levels. High-quality P1 and P2 flat steel products still depend heavily on primary iron sources due to their strict purity requirements. While the U.S. has a high share of EAFs, high-quality flat steel for automotive applications is mostly produced through BF-BOF. However, Q1 scrap (and its associated EFR grades such as E2, E6, and E8) could partially substitute for primary iron in these applications if sufficient volumes of well-sorted material are available.

Meanwhile, the European steel industry exports a significant share of lower-quality scrap (Q4)[24], while generally retaining higher-quality scrap domestically. Exports are thus dominated by lower-purity material, whereas imports tend to consist of higher-grade scrap[25]. However, detailed data on the specific types and quality of exported scrap remains limited. Rather than exporting this surplus low-purity scrap, it could be more effectively utilised by blending it with primary steel sources (i.e., Pig Iron or Direct Reduced Iron) for domestic secondary steel production.

Although high-purity scrap (Q1 and E2-E8-E6) could partially replace primary iron in high-quality flat steel production (P1-P2), these products still require input of Pig Iron or DRI/HBI. Nucor, for example, uses an average of 55-60% scrap in high-grade steel production (e.g., sheets and pipes). Similarly, Arvedi, which is the only European producer of flat steel via EAF, blends 2.4 Mt of scrap with 0.6-0.7 Mt of Pig Iron and 0.4-0.5 Mt of HBI annually[26]. In Canada, Algoma's sheet mills typically use an EAF

23 Dworak et al. (2021). Steel scrap generation in the EU-28 since 1946 – Sources and composition. https://www.sciencedirect.com/science/article/pii/S0921344921003013

24 European Steel Technology Platform (ESTEP). (n.d.). PURITY: Imprv. of scrap metal. https://www.estep.eu/assets/Publications/PURESCRAP-Flyer-Nr-1.pdf

25 Systemiq. (2023). Circular steel: A system perspective on recycled content targets. https://www.systemiq.earth/wp-content/uploads/2024/02/Circular_Steel_Recycled_Content_Targets_Systemiq_2023.pdf

26 Eurometal (2021). Italian steelmaker Arvedi working to use more scrap, less metallics. https://eurometal.net/italian-steelmaker-arvedi-working-to-use-more-scrap-less-metallics/

mix consisting of 60% Q1 scrap, 20% Pig Iron, and 20% post-consumer scrap[27]. Some companies are also investing in technologies to improve scrap quality by reducing contamination and better sorting material according to its composition. For example, Thermo Fisher has developed portable analysers that provide rapid and accurate identification of metal alloys, enabling more precise scrap sorting by quality[28]. Meanwhile, Purified Metal Company (PMC) proposed high-temperature decontamination processes to remove tramp elements[29].

For Europe to absorb currently exported low-purity scrap (Q4), it would first need to be redirected to existing EAF facilities producing long products (P4), displacing higher-purity scrap (Q1-Q2). This cleaner scrap would then become available for new EAFs dedicated to flat steel, albeit still requiring some input of Pig Iron or DRI/HBI.

Contamination

Copper contamination is a significant barrier in steel recycling as it degrades steel quality, especially for high-grade applications. Copper is pervasive in end-of-life scrap, originating mostly from copper wires, motors in automobiles, ship hull anti-fouling paints, appliances, and machinery that attach to steel during shredding. Copper is widely used in anti-fouling paints applied to ship hulls to prevent biofouling, contributing to scrap contamination from marine sources[30]. This contamination limits the applicability of recycled steel[31,32]:

- → Reinforcing bars have a nominal tolerance of 0.4 weight per cent copper.
- → Flat products requiring excellent formability have the strictest limits, typically below 0.06 weight per cent copper (e.g., drawing steels).
- → When copper content exceeds 0.1 weight per cent, metallurgical issues such as "hot shortness" and reduced ductility can occur, affecting the quality of steel products.

If not addressed, copper contamination could hinder increased circularity in the steel industry and restrict the technological options for steel decarbonisation.

Other contaminants such as lead and cadmium are also present in scrap, particularly from sources like lead-based paints, electronic components, and cer-

27 Recycling Today. (n.d.). A time of transition. https://www.recyclingtoday.com/article/a-time-of-transition-for-canada-steelmaking/

28 Thermo Fisher Scientific. (2025). Advancing Clean Steel Manufacturing with Modern Technologies. https://www.thermofisher.com/blog/metals/advancing-clean-steel-manufacturing-with-modern-technologies/

29 Recycling International. (2021). Killing contaminants in steel scrap. https://recyclinginternational.com/business/killing-contaminants-in-steel-scrap/45668/

30 European Commission. (2023). Ship hull anti-fouling: Are silicone-based coatings a viable, sustainable alternative to toxic, copper-based coatings in the Baltic Sea? https://environment.ec.europa.eu/news/ship-hull-anti-fouling-are-silicone-based-coatings-viable-sustainable-alternative-toxic-copper-based-2023-05-24_en

31 Material Economics. (2019). Industrial transformation 2050: Pathways to net-zero emissions from EU heavy industry.

32 Daehn, K. E., Cabrera Serrenho, A., & Allwood, J. M. (2017). How will copper contamination constrain future global steel recycling? Environmental Science & Technology, 51(11), 6599–6606. https://pubs.acs.org/doi/epdf/10.1021/acs.est.7b00997?ref=article_openPDF

tain coatings on end-of-life machinery and vehicles[33,34]. While asbestos-containing materials must be physically removed from scrap before melting due to severe health risks and regulatory requirements[35], lead and cadmium are typically not separated beforehand. Instead, these elements volatilise at high furnace temperatures and are captured by air pollution control systems such as baghouse filters or scrubbers during the steelmaking process[36 37].

1.3

Enablers

Technological enablers

In contrast to the current Blast Furnace (BF) production route, the technological route of Direct Reduction (DR) allows for the produced sponge iron to be input material to an Electric Arc Furnace (EAF) instead of a Blast Oxygen Furnace (BOF) for steel production. This is a key enabler to increase scrap utilisation as an EAF is technologically unrestrained in the amount of scrap that can be put into the mix, whereas the BOF is constrained to a maximum of 20-25%. Thus, the benefit of DR is twofold. First, it enables lower emissions by a low-emission reducing agent, and second, it enables increased circularity in the steel industry by allowing a higher scrap charge in primary steel production.

Additionally, the DRI-EAF route enables trade of HBI (Hot Briquetted Iron), which is a compacted form of DRI. The benefit of HBI-trade is that European primary steelmakers could potentially have quicker access to green iron, which could be input into EAFs, which subsequently allows for a quicker increase use of scrap compared to if European steelmakers had to install all DR capacity themselves.

Policy enablers

A key enabler for both decarbonisation and increased circular use of steel is an effective carbon price. Currently, the steel industry receives free allocation, which hinders a carbon cost on steel. High-quality scrap is an expensive and scarce resource, where an effective carbon price would drive improvements in the secondary scrap market. By increasing the demand for higher-quality scrap through an effective carbon price, the sector is incentivised to pay a premium for better-treated materials, which could unlock investment in advanced post-treatment facilities that would otherwise be unprofitable. For the option of HBI-trade, strategic coordination and bilateral agreements could facilitate trade partnerships that enhance the feasibility of this option.

A high effective carbon price through the EU Emissions Trading System (ETS) combined with improved procedural standards for recycling would be even more effective in driving circularity in the steel industry than a carbon price alone. High-quality scrap required for high-quality flat steel requires minimum contamination from other elements. For example, improved standards for the dismantling of cars and ships could minimise such contamination and increase the availability of high-quality scrap. This specific objective could be achieved by setting a minimum target for recycled steel content in cars in the End-of-Life Vehicle (ELV) Regulation, or by creating a specific scrap recycling corridor from identified sources.

Additionally, an EAF is considerably more electricity-intensive than a BOF, and therefore, its cost-competitiveness is more dependent on the electricity price. Hence, the cost-competitiveness of an increased use of scrap is also very dependent on the electricity price and would benefit from policies acting on the deployment of low-cost renewables and low-cost grid connections and reduced grid fees.

1.4

EU legislation

A wide range of complementary policies is required for decarbonisation and circularity through an increased use of scrap. First, broad policies acting on all related sectors, e.g. an EU climate target or circularity target, are necessary to set the policy direction towards a net-zero economy. Second, sector-specific policies and policies tailored to specific challenges should complement the overarching policy direction. These policies should act on specific parameters such as cost, practices, and information, through, for example, carbon prices, supply and demand practices, and standards. The EU is one of the world's frontrunners in this regard and is, through the Clean Industrial Deal, further expanding its portfolio of policies to achieve the emissions reduction targets set in the EU Climate Law.

CLEAN INDUSTRIAL DEAL

Steel and Metals Action Plan

Following the strategic dialogue held on the 4th of March, the communication of the Steel and Metals Action Plan (SMAP) was published on the 19th of March. The Plan aims to address the current European challenges of competitiveness and decarbonisation and lays out areas for additional policies to enable competitiveness and decarbonisation to go hand in hand. While the substantial parts of the Plan address the scale-up of affordable renewable electricity, the speed of enabling new grid connections, and trade defence measures, one chapter of the plan is entirely dedicated to circularity. The Plan recognises circularity as an important pathway for decarbonisation of the steel industry and lays out five key actions to enable this.

The five actions are: considering trade measures to ensure scrap availability by Q3 2025, presenting a feasibility study on the recycled steel and aluminium content obligations under the End-of-Life Vehicles Regulation by Q4 2026, enhancing the market for secondary raw materials and recycled content obligations in relevant construction products through the Circular Economy Act by Q4 2026, and introduce recyclability and/or recycled content requirements under the Ecodesign for Sustainable Products Regulation (ESPR).

33 United Nations Environment Programme (UNEP). (2023). Global Alliance to Eliminate Lead Paint: Frequently asked questions. https://www.unep.org/explore-topics/chemicals-waste/what-we-do/emerging-issues/global-alliance-eliminate-lead-paint/faq

34 Cadmium Association. (n.d.). Key applications of cadmium coatings. https://www.cadmium.org/applications/coatings/

35 U.S. Environmental Protection Agency (EPA). (2023). Asbestos-containing materials (ACM) and demolition. https://www.epa.gov/large-scale-residential-demolition/asbestos-containing-materials-acm-and-demolition

36 U.S. Environmental Protection Agency (EPA). (2001). Lead use in foundries [Referencing IFC EHS Guidelines for Foundries, 2007]. https://archive.epa.gov/epawaste/hazard/wastemin/web/pdf/lead-2.pdf

37 U.S. Environmental Protection Agency (EPA). (n.d.). Cadmium emissions and regulations. https://www3.epa.gov/ttn/chief/le/cadmium.pdf

Circular Economy Act

The Circular Economy Act (CEA) is, together with the other circularity policies (e.g. ELV and ESPR), designed to accelerate the ambition of the EU to become a world leader in circularity by 2030. To achieve the goal of 24% circularity by 2030 compared to 11.8% today, the CEA will make use of the EU single market to enable free movement of circular products and secondary raw materials by harmonising end-of-waste criteria to increase the amount of valuable secondary raw materials. By extending producer responsibility and digitalisation, the CEA incentivises the use of scrap through, for example, mandatory digitalisation of demolition permits and pre-demolition audits. Although the CEA will not be adopted until Q4 2026, the Commission will launch a Clean Industrial Dialogue on circularity to support the preparation of the CEA[38].

Industrial Decarbonisation Accelerator Act

The Industrial Decarbonisation Accelerator Act (IDAA), to be announced in Q4 2025, sets out to develop a voluntary product label on the carbon intensity, starting with steel[39]. The label, with criteria for circularity, will be based on the data and methodology of the EU's carbon pricing instruments, ETS and CBAM. With such a label, the IDAA aims to establish a lead market for low-carbon products. While at this stage undetermined, the IDAA could benefit from the use of scrap if the label, albeit voluntary, includes ambitious criteria for recycled content or reusability.

38 European Commission (2025). Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. The Clean Industrial Deal: A joint roadmap for competitiveness and decarbonisation.

39 European Commission (2025). Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. The Clean Industrial Deal: A joint roadmap for competitiveness and decarbonisation.

EU Emissions Trading System

The EU Emissions Trading System (ETS) is the world's most ambitious carbon pricing instrument and the EU's flagship climate policy. The ETS is a cap-and-trade system by which a certain amount (cap) of emission allowances is allocated and traded for a price per allowance. The cap decreases over time, which drives the price of the allowances and thus incentivises investments in decarbonisation, material efficiency, and circularity practices. However, due to the amount of allowances given for free (free allocation), the price effect of the ETS on the European steel industry has thus far been low. In fact, over the period 2010-2023, the European steel industry received more free allowances than it emitted greenhouse gases[40] – overcompensating for the emissions of the European steel industry. In addition to this over-allocation of free allowances, there has been a larger supply of allowances to all sectors covered, leading to an insufficient price signal for decarbonising heavy industry.

However, to promote emission reductions for the upcoming 55% EU emissions reduction target in 2030, significant changes to the ETS are on the horizon. First, the target reduction of the cap has been increased to 62% in 2030 relative to 2005 levels. To enable this ambition, the overall supply of allowances is reduced. In addition to a reduction of the cap in 2024 of 90 million allowances, the yearly rate by which the cap decreases will increase from 2.2% per year to 4.3% for 2024-2027, and to 4.4% for 2028-2030[41]. Second, the free allocation received by the European steel industry will be phased out over a period from 2026 to 2034[42], which will create an increasing price signal. Lastly, DRI has been included in the hot metal benchmark by which ironmaking receives free allocation through the ETS. As DRI enables EAF steelmaking, which can utilise high scrap charges, this inclusion incentivises the use of scrap over the traditional BF-BOF route. Overall, the future ETS will create a price signal which promotes circularity practices and incentivises steelmaking routes by which higher scrap mixes can be utilised.

40 Carbon Market Watch, World Wildlife Fund. (2025). A clean industrial revolution. How the EU carbon market can accelerate decarbonisation by making polluters pay.

Ecodesign for Sustainable Products Regulation

As part of the European Green Deal Circular Economy Action Plan (CEAP), the Ecodesign for Sustainable Products Regulation (ESPR) was launched in 2024 to set ecodesign requirements for products to be put on the market. Since the ESPR is supposed to replace the Ecodesign Directive, the ESPR has a transitional period to 2030 to mitigate a regulatory gap. Iron and steel are part of the prioritised group to be part of the first working plan to be adopted by 19 April 2025, which shall cover a period of at least three years. A series of delegated acts are to be adopted which will set the ecodesign requirements, which will include among others but not limited to, the extent of a product's: reusability, resource and energy use and efficiency, recycled content, recyclability, possibility of the recovery of materials, and environmental impacts including carbon and environmental footprint[43]. The ESPR will also establish a product passport to ensure that actors along the value chain can easily access and understand product information relevant to them, and may additionally adopt labels for specific products

The ESPR aims to increase circularity by setting principles for the environmental impact of a product's lifecycle, as well as improve the information on product's environmental sustainability for consumers and the value chain. This will drive a demand for low-carbon and circular products, which in turn promote circular business models and the increased use of scrap in the steel industry.

41 European Commission. (2024). Report from the Commission to the European Parliament and the Council on the functioning of the European carbon market in 2023

42 Directive (EU) 2023/959. Directive (EU) 2023/959 of the European Parliament and of the Council amending Directive 2003/87/EC establishing a system for greenhouse gas emission allowance trading within the Union and Decision (EU) 2015/1814 concerning the establishment and operation of a market stability reserve for the Union greenhouse gas emission trading system 2023.

43 Regulation (EU) 2024/1781. Regulation (EU) 2024/1781 of the European Parliament and of the Council establishing a framework for the setting of ecodesign requirements for sustainable products, amending Directive (EU) 2020/1828 and Regulation (EU) 2023/1542 and repealing Directive 2009/125/EC.

Construction Products Regulation

On the 7th of January 2025, a new Construction Products Regulation (CPR) entered into force, replacing the old rules from 2011. The CPR aims to establish harmonised rules of performance and sustainability of construction products and promote new construction techniques such as prefabricated and modular construction elements. A notable addition compared to the previous regulation is the harmonised technical specifications related to the life cycle assessment of a product (Annex II), for example, climate change effects related to fossil fuels and particulate matter. While some parts of the regulation entered into force with the publication of the regulation, other components will apply from January 2026 or January 2027 (Article 96). As such, three stages will enable the phase-in of different components of the mandatory declaration of a product's performance.

To complement the Waste Framework Directive, the CPR also lays down the technical specifications required for products that are not waste or have ceased to be waste ('used products') in accordance with that Directive, to be placed on the Union single market. These specifications and requirements are aimed at achieving the goals of the Circular Economy Action Plan by promoting the use of secondary materials through improving resource efficiency, preventing waste generation, prioritising repair, and increased reusability by improving the separation of products in processes such as demolition and deinstallation[44].

44 Regulation (EU) 2024/3110. Regulation (EU) 2024/3110 of the European Parliament and of the Council laying down harmonised rules for the marketing of construction products and repealing Regulation (EU) No 305/2011.

End-of-Life Vehicles

The current End-of-Life Vehicles (ELV) Directive lays down the legal framework for Member States to ensure necessary systems for collection, treatment, and reuse of ELVs to promote circularity in the automotive sector[45]. Connected to this Directive is a planned Regulation, which was initially proposed in 2023, but not adopted. Following rigorous impact assessments, the rapporteur for the Regulation drafted a report to support the Regulation in January 2025. However, as part of the SMAP, the Commission declared ambitions to present a feasibility study on the recycled steel content obligations under the ELV Regulation by Q4 2026[46], adding to the uncertainty of the legislative timeline.

A minimum recycled steel content obligation under the ELV Regulation would, if set at a proper level[47], make use of the valuable resources of an end-of-life car for the production of new cars – increasing circularity. The EU has around 286 million motor vehicles, out of which 6.5 million vehicles are scrapped every year. The recycling rate of steel from end-of-life vehicles (ELVs) is around 90%[48]. However, much of this recycled steel is downcycled into construction applications rather than being reused in new vehicle production. As a result, currently only 6% of recycled steel from ELVs finds its way back into car manufacturing[49]. As such, there is potential for significant improvements in dismantling and recycling practices, which could drive investments in scrap post-treatment facilities and enable both increased demand and supply of high-quality scrap for steel production beyond the automotive sector.

45 Directive 2000/53/EC. Directive 2000/53/EC of the European Parliament and of the Council/on end-of life vehicles.

46 European Commission. (2025). Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. A European Steel and Metals Action Plan.

47 Sandbag. (2025). Towards a minimum recycled steel content in passenger cars: setting an initial target.

48 European Commission. (2024). Eurostat. End-of-life vehicle statistics.

Waste Framework Directive and End-of-Waste Regulation

In order to strengthen circularity practices with high-quality secondary materials and reduce resource consumption, the Waste Framework Directive (WFD) establishes criteria and hierarchies of treatment. The WFD determines the hierarchical order as: waste prevention, preparation for reuse, recycling, and last disposal (Article 4). While the WFD provides the general legal framework for managing waste and applies to decommissioned ships when qualify as such[50], ships are regulated more specifically under the Ship Recycling Regulation. The End-of-Waste for Iron and Steel Scrap Regulation[51] determines criteria for iron and steel scrap, which incentivise circularity throughout the steel industry value chains.

49 European Federation for Transport and Environment. (2024). Cleaning up steel in cars: why and how?

50 Directive (EU) 2008/98/EC. (2023). Directive 2008/98/EC of the European Parliament and of the Council on waste and repealing certain Directives.

51 European Council. (2011). Council Regulation (EU) No 333/2011 establishing criteria determining when certain types of scrap metal cease to be waste under Directive 2008/98/EC of the European Parliament and of the Council.

Scrap export restrictions

Although the European scrap market is saturated overall, Eurofer has called for scrap export restrictions, arguing for security of supply[52]. The Commission acknowledges this in the SMAP and considers proposing trade measures if necessary "to ensure sufficient availability of scrap in the EU" by Q3 2025[53]. As there is a current oversupply of scrap overall, an export restriction would likely lead to a price decrease of scrap.

52 The European Steel Association. (2024). Open letter. Call for urgent action to save the European steel industry and the livelihood of our workers.

53 European Commission. (2025). Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. A European Steel and Metals Action Plan.

02

Breaking ships, building futures

2.1

The issue

Today, only a fraction of EoL ships are handled in a safe and clean manner as a almost 90% of the world tonnage is dismantled on beaches in India, Bangladesh, and Pakistan[54]. There, due to lack of protective measures and infrastructure, shipbreaking activities cause significant harm, including the release of hazardous materials to sensitive coastal ecosystems, fatal accidents and occupational diseases. The coastal pollution resulting from shipbreaking operations has led to a loss of biodiversity and livelihoods, affecting farming and fishing. Additionally, poor hazardous waste management has caused inland toxic spills, further impacting vulnerable local communities. While Turkey[55] is the other main destination for EoL vessels, facilities operating in the rest of the world, including the EU, account for only three per cent of the ships scrapped globally every year.

Globally, shipowners are attracted by South Asian yards due to the higher prices offered for end-of-life vessels. Typically, a shipowner selling an EoL vessel to a beaching yard in South Asia can expect to receive approximately $450 to $500 per Light Displacement Ton (hereinafter LDT), the unit of measure used in EoL negotiations to indicate the weight of the vessel's steel. In contrast, Turkish yards can offer approximately $250–$300 per LDT. Choosing a European yard yields even less, around €100–€150 per LDT. These gaps between demolition rates reflect not only the distinctive characteristics of domestic steel markets, but are also directly linked to labour costs, investment in infrastructure and safety, and hazardous waste management practices—as well as methods used for the recycling of scrap steel. Higher prices offered for EoL ships usually means lower dismantling and recycling standards.

Steel remains the most valuable material in obsolete maritime assets: while offering homogeneous and high-quality demolition scrap, its recycling is not without challenges. Contaminants such as lead, copper, mercury, and chromium-6 from paints, as well as mercury and naturally occurring radioactive materi-

Shipowners earn the most at South Asian beaching yards (~$450–$500/LDT), far less in Turkey (~$250–$300), and the least in Europe (~€100–€150), mainly because weaker standards and underinvestment in infrastructure, safety, and hazardous-waste management keep costs lower outside Europe.

54 According to the annual list of all ships dismantled globally collected and published in open access by the NGO Shipbreaking Platform. See https://shipbreakingplatform.org/annual-lists/

55 NGO Shipbreaking Platform (2023). Ship Recycling in Turkey. Challenges and Future direction. https://shipbreakingplatform.org/wp-content/uploads/2023/12/Turkey-Report-2023-NGOSBP.pdf

als (NORM) from oil and gas assets, need to be managed in an environmentally sound manner[56]. When torch-cutting a ship's structure, paints containing heavy metals release toxic vapours, the inhalation of which can cause chronic respiratory diseases, neurological damage, and other long-term health complications. Therefore, the use of adequate protective equipment becomes necessary. Studies on the ship reaking sites of Bangladesh[57] and Turkey[58] also identified plate-cutting as a primary source of ecosystem contamination. When steel is cut on the beach, metal fragments and rust, in addition to heavy metal-laden paint chips, accumulate on the shoreline, contaminating the surrounding soil, sediments and water can easily transfer up the food chain to fish and humans, threatening seafood safety and local environmental stability.

Ship scrap steel cold-rerolling

In South Asia, recovered steel from beaching yards is sent primarily to local steel re-rolling mills for further processing, where the scrap steel is heated at low temperatures and re-rolled into reinforcing rods used in the construction industry. In this case, the hazardous materials embedded in the steel are rarely removed before processing. This results in the release of toxic fumes during the re-rolling process and, in the absence of dust filters, in exposure of workers and nearby communities to serious health risks. Notably, lead vapours released during hot cutting and re-rolling can cause lead poisoning, while PCBs and foam insulation release additional toxins when exposed to high temperatures that can cause pollution of groundwater and agricultural land. A study assessing air quality near recycling steel plants in Chittagong, Bangladesh, found that mills processing ship steel emitted alarming levels of formaldehyde (HCHO), total volatile organic compounds (TVOCs), and particulate matter (PM2.5 and PM10), exceeding US EPA and WHO safety limits. Health risk assessments showed significant threats to both children and adults from chronic inhalation of these pollutants. The study recommends mandatory installation of advanced pollution control technologies to reduce harmful emissions and protect public health.[59]

Steel produced through cold re-rolling often retains impurities from the original material, resulting in lower quality and raising concerns about structural integrity and safety, particularly when used in construction.Concerns over the quality and standardisation of scrap steel re-rolling practices have brought renewed attention to the lack of transparency regarding the origins and composition of the re-rolled raw material. A decision by the Indian Steel Ministry rejected the use of shipbreaking steel plates for producing Thermo Mechanically Treated bars (hereafter TMT) over 6mm in diameter[60], a common practice in the

56 NGO Shipbreaking Platform. (2022). South Asia Quarterly Update #29. Page 13 Decommissioning of FSOS and FPSOS https://shipbreakingplatform.org/wp-content/uploads/2022/04/SAQU-29.pdf

57 Hasan, A. B. et al. (2024) Origin, spatial distribution, sediment contamination, ecological and health risk evaluation of trace metals in sediments of ship breaking area of Bangladesh. J. Hazard. Mater. 465, 133214.

58 Yılmaz, A. et al. (2016) Organic and heavy metal pollution in shipbreaking yards. Ocean Eng. 123, 452–457.

59 Hossain, M.S., Shiropa, S. & Siddique, M.A.M. (2025) Assessing air quality of the recycled steel industries and associated health risks in a mega port city of Southeast Asia. Air Qual Atmos Health. https://doi.org/10.1007/s11869-025-01760-1

60 TMT bars are widely used in reinforced concrete structures to provide support, resist tension forces, and ensure structural stability.

South Asian ship recycling area, due to significant inconsistencies in the material properties[61]. A steel Ministry committee conducted testing on samples collected from ship recycling yards in Alang. Stress tests on rebars rolled from ship plates revealed variations in diameter and mechanical properties, raising concerns about the structural integrity of the re-rolled product. Furthermore, the lack of a documented metallurgy history for these materials makes it difficult to ensure compliance with safety standards. Specifically, the absence of corrosion resistance studies and insufficient data prevent the direct grading of the rebars, making their safe re-rolling into structural products uncertain.

A report jointly published by Climate Zero and Climate Catalyst[62] focuses on ship scrap steel recycling practices in India, while also gathering insights into cold re-rolling practices in the shipbreaking hubs of Bangladesh and Pakistan. The report identifies how fewer restrictions on re-rolled steel in Bangladesh and Pakistan, reflecting a weaker regulatory environment, enable steelmakers in those countries to operate with greater profitability than their Indian counterparts. According to the report, Bangladesh hosts around 300 steel plants, of which approximately 150 are ~~re-rolling mills~~ and 30 are auto steel mills. An estimated 60–70%[63] of the steel used in Bangladesh's re-rolling sector comes from the shipbreaking industry. Facing competitive disadvantages due to stricter domestic quality controls on re-rolled steel, the Indian shipbreakers have argued for regulatory rollbacks within India and for unrestricted sale of steel plates to re-rolling mills as a way to bypass the higher melting costs.

61 Law, A. (2023). Set-back for industry. Steel Ministry panel rejects proposal for TMT bars made from ship-breaking plates. The Hindu Business Line. Retrieved March 18, 2025, from https://www.thehindubusinessline.com/economy/set-back-for-industry-steel-ministry-panel-rejects-proposal-to-use-ship-breaking-steel-plates-for-tmt-bars/article67673497.ece

62 Climate Catalyst, Climate Group (2024). Turning the tide: Ship recycling as a source of green steel in India.https://climatecatalyst.org/wp-content/uploads/2024/12/Turning-the-Tide-Ship-Recycling-as-a-Source-of-Green-Steel-in-India.pdf

2.2

Ocean yields: high-quality steel from EoL vessels

Steel properties, chemical composition and coatings

The physical and the mechanical characteristics of ship steel play a crucial role in determining how well a structure can perform its intended function, support loads, and withstand forces or environmental conditions. The following properties are essential for determining the suitability of steel for ship construction and are tested and evaluated accordingly:

63 Ibid.

- Yield strength, which is the material's ability to resist stress before it is permanently deformed and changes shape;

- Tensile strength, measured to understand the ultimate material's breaking point;

- Ductility, that is the ability of the material to deform itself, is tested to understand how 'soft' or malleable the material is;

- Brittleness can be described as the opposite of ductility; therefore, when a material cracks under stress without plastic deformation (for example, it shatters like glass). This can be due to high-yield strength steel, overloading, and sudden temperature changes.

- Toughness is the ability of a material to absorb energy before cracking.

A series of elements are added to the recipe of ship steel to enhance its properties: each steel grade requires a specific chemical composition. Some of these are:

- Chromium (Cr), which improves strength and corrosion resistance;

- Nickel (Ni), which improves ductility and enhances atmospheric corrosion resistance, and when in combination with other elements such as copper or phosphorus, it increases corrosion resistance against seawater;

- Molybdenum (Mo) works as a strengthener and, when the steel undergoes quenching, it increases hardenability and decreases its tendency to become brittle. Also, like chromium, it forms several types of solid compounds that are important for wear-resistant steel;

- Manganese (Mn) is the principal strengthening element in high-strength structural steels. Without this element, the sulphur would combine with iron and form a compound that would present more brittleness and lower ductility and toughness, which would lead to cracks during the hot rolling phase;

- Silicon (Si) removes oxygen from molten steel during the steel-refining process. Oxygen can have a negative impact on the steel ductility, toughness, and fatigue resistance;

- Vanadium (V) is important for hardenability and for making the metal's internal structure finer and more even (grain refinement). Vanadium compounds help make the material more wear-resistant[64];

- Boron (B) and Copper (Cu) are used in very small amounts for additional strengthening, especially in thick plates.

The type and quantity of alloying elements play a crucial role in determining its properties[65]. For example, Chromium and Copper work together to create a thin protective film on the steel surface, a barrier against the corrosive effects of seawater.

64 Aung, H. (2007). An analysis of the study of mechanical properties and microstructural relationship of HSLA steels used in ship hulls. World Maritime University. The Maritime Commons: Digital Repository of the World Maritime University. Dissertation.

65 Wang, D., Li, G., Yin, W., Yan, L., Wang, Z., Zhang, P., Hu, X., Li, B., & Zhang, W. (2023). Studying on Alloying Elements, Phases, Microstructure and Texture in FH36 Ship Plate Steel. Materials, 16(13), 4762. https://doi.org/10.3390/ma16134762

Ship steel manufacturing

The final stages of steel processing are particularly crucial for ship steel production: shipbuilding steel undergoes advanced refining to enhance mechanical properties such as toughness, ductility, and weldability[66]. One significant technological advancement that has contributed to the production of safer, high-performance materials for shipbuilding is the Thermo-Mechanical Control Process (hereinafter TMCP). TMCP is a microstructural control technique that integrates controlled rolling and controlled cooling to enhance key properties of steel plates, such as high strength, toughness, and weldability[67 68]. Depending on product requirements, some high-strength steel products can undergo heat treatments, which broadly consist of heating, soaking, and cooling the material to change the metallurgical structure into a stronger, more uniform one with fewer impurities. One of these treatments is called quenching, in which the material is heated and then quickly cooled using water, oil, forced air, or inert gases like nitrogen. This process produces a very hard structure with a higher tensile strength. Finally, based on the application and the desired product, steel proceeds to coating, such as galvanising (adding a layer of zinc to protect from corrosion).[69]

Ship steel is often treated with anti-corrosive coatings, forming a protective layer that chemically bonds with the steel surface, and creating a barrier that prevents oxygen and harmful chloride ions from reaching the metal. This helps extend the lifespan of the ship, keeping it safe and durable throughout its time at sea. The application of ship hull paints is also crucial to prevent marine growth, which could cause increased fuel consumption and reduced speed, as well as the introduction of invasive species into fragile ecosystems. Biofouling, however, accelerates material corrosion, shortening the lifespan of the metal and increasing maintenance[70]. Over the past decades, organotin coatings such as tributyltin-containing paints have been proven effective, but at a great cost to marine ecosystems. While the International Maritime Organisation (IMO) has banned the use of organotin compounds, ship paints containing heavy metals, such as lead, or PCBs are still found[71]. Recent research has led to the development and introduction of new technologies, including polyurethane, acrylic, zinc-aluminium, and nickel-based coatings.[72]

The fact that ship steel is coated and painted im-

66 Eyres, D. J., & Bruce, G. J. (2012). Ship construction. Butterworth-Heinemann. Chapter 5: Steels.

67 Igi, S., Miyake, M. (2021). Development of Thermo-Mechanical Control Process (TMCP) and High Performance Steels in JFE Steel. Originally published in JFE GIHO No. 46 (Aug. 2020), p. 1–7. https://www.jfe-steel.co.jp/en/research/report/026/pdf/026-18.pdf

68 Imai, S. (2008). Recent progress and future trends for shipbuilding steel. Welding International, 22(11), 755–761. https://doi.org/10.1080/09507110802550661

69 Ibid.

70 Liang, H., Shi, X., & Li, Y. (2024). Technologies in Marine Antifouling and Anti-Corrosion Coatings: A Comprehensive Review. Coatings, 14(12), 1487. https://doi.org/10.3390/coatings14121487

71 Du, Z., Zhang, S., Zhou, Q., Yuen, K., Wong, Y. (2018). Hazardous materials analysis and disposal procedures during ship recycling. Resources, Conservation and Recycling, 131(), 158–171. doi:10.1016/j.resconrec.2018.01.006. See also Sakin, E. (2023). Ship Recycling in Turkey. Challenges and Future Direction. NGO Shipbreaking Platform. https://shipbreaking-platform.org/wp-content/uploads/2023/12/Turkey-Report-2023-NGOSBP.pdf

72 Liang, H., Shi, X., & Li, Y. (2024). Technologies in Marine Antifouling and Anti-Corrosion Coatings: A Comprehensive Review. Coatings, 14(12), 1487. https://doi.org/10.3390/coatings14121487

pacts the EoL recycling process. For example, asbestos-containing paints must be safely removed before handling the steel plate. When steel scrap melts in furnaces, parts of the coating evaporate and must be captured through cleaning systems, while others oxidise into slag or dissolve into the steel. Some academic literature describes, for example, that Zinc from steel coatings typically evaporates under reducing conditions and can be recovered from collected dust.[73] While this example shows promising potential for recovering specific materials through targeted processes and effective pollution control, standardising coating removal practices across the global ship recycling sector is still a challenge. Whether this removal occurs at the ship recycling facility or later at steel recycling plants, hindering dispersion of paint chips and toxic emissions during the process is essential to protect both environmental and human health.

Steel grades, material certification and the role of classification societies

Ship steel is categorised by grades based on toughness and strength to meet the diverse structural requirements of different vessel types. Normal-strength steels, often referred to as mild steels, are typically used for welding small to medium-sized ships (< 90 mt in length). High-strength ship steels are used for large, ocean-going vessels that must withstand extreme stresses. Shipbuilding steel is classified by grades: grade A, B, D and E for normal-strength grades, grade AH32, DH32, EH32, AH36, DH36, EH36, and FH36 for high-strength steel, which are commonly employed in critical ship parts like deck plates, bulkheads, and for offshore structures. High-strength steels offer better strength and toughness, good ductility, fine-grained microstructure, and improved corrosion resistance due to micro-alloying. Ship hull structural materials can be divided in steel plates, used in hull components such as shell plating, deck plating and partitions, and section steels, also known as profiles, such as angle steel, T-beams, and channel steel, primarily used for framing. A search of ship steel manufacturers[74] reveals that each company typically offers a wide range of steel grades, all certified against the requirements of one or more classification societies (hereafter CSs). Manufacturers publish product portfolios listing detailed specifications, including grade classification, dimensional ranges, and heat treatment processes. The product certifications ensure that the steel conforms to international shipbuilding standards and meets the technical requirements for safe and reliable maritime construction.

CSs play a key role in the harmonisation of steel grades and composition used in shipbuilding. These independent organisations establish technical standards for the design, construction, maintenance, and repair of ships, and are internationally coordinated through the International Association of Classification Societies (IACS). IACS, a non-governmental organisation with consultative status at the IMO since 1969, ensures unified technical criteria across the sector[75]. IACS members include: American Bureau of Shipping (USA), Bureau Veritas (France), China Classification Society (China), Det Norske Veritas (Norway), Indian Register of Shipping (India), Korean Register (Republic of Korea), Lloyd's Register (UK), Nippon Kaiji Kyokai (Japan), Registro Italiano Navale (Italy). To produce steel suitable for shipbuilding, a manufacturing facility must first obtain approval from a CS, which depends on strict compliance with requirements concerning chemical composition, production techniques, and testing protocols. The testing process itself is rigorously controlled: the CS surveyor outlines the procedures, accredited laboratories carry out the tests, and the results are reviewed by qualified engineers before being officially stamped by the surveyor. Once approved, all steel products from that facility must continue to meet the CSs' rules regarding composition and manufacturing processes. Materials used in critical ship components, particularly the hull, as well as certain machinery and piping, must adhere to high-quality and safety standards, designed to ensure structural integrity, safety at sea, and environmental protection.

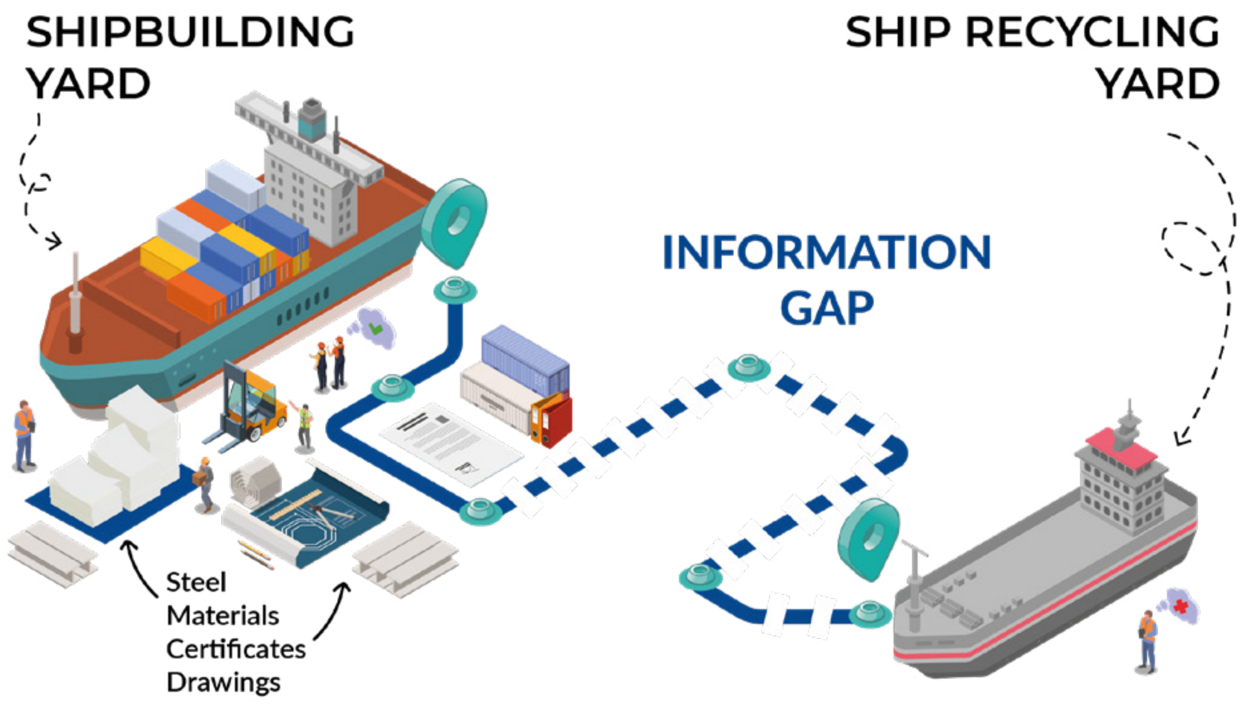
Although materials and production methods in steel shipbuilding are highly regulated, a critical question arises: ***Why do these steel material certificates fail to accompany the vessel to its EoL phase?*** According to some EU-based ship recyclers, there is generally no available information about the grade, type, or exact location of the steel used in ship structures. As a result, the identification and segregation of different steel types is left to the visual assessment and experience of scrap steel experts, whether they work within the facility or as external consultants. Furthermore, it is generally understood as common practice in the steel recycling sector that higher-quality steel scrap tends to be sold to local EU-based buyers, while lower-quality material is often exported through scrap brokers who place it on markets offering the highest return. Several stakeholders have highlighted that having steel material quality certificates available at the dismantling stage would significantly enhance the reuse potential and enable more effective separation of steel grades, strengthening the shipyard's capacity to manage steel scrap. The documentation gap[76] around steel certificates has been identified as a key barrier to enabling the upcycling of maritime steel also by Nordic Circles, a Norwegian start-up working to repurpose EoL ship steel plates for direct reuse in the construction sector. Improving traceability and access to original material documentation is critical for establishing a reliable, high-quality supply of reused steel.

73 Björkman, B. (2014). Handbook of Recycling. Recycling of Steel. Elsevier Inc. 65–83. doi:10.1016/B978-0-12-396459-5.00006-4

74 Companies' websites consulted for this section include: Dillinger (https://en.dillinger.de/products/applications/shipbuilding-jackup/), SSAB (https://www.ssab.com/en-us/brands-and-products/commercial-steel/structural-steel/astm-a131/grade-a-b-d-e), Bbn ship steel factory (https://www.shipbuilding-steel.com/News/what-are-grades-of-steel-used-in-ship-construction_2471.html) , UnionStahl (https://www.unionstahl.com/sortiment/schiffbaustahle/), SteelPro Group (https://steelprogroup.com/shipbuilding-steel/grades/), NLMK Europe (https://shop.eu.nlmk.com/Structural-steels/Shipbuilding-steels), ArcelorMittal Europe (https://europe.arcelormittal.com/marketsegmentseurope/shipbuilding/steel-for-shipbuilding), Voestalpine Group (https://www.voestalpine.com/welding/global-en/solutions/industry-solutions/mobility/shipbuilding/).

75 Ayob, F. (2013). Steel hull construction in relation to classification society and IACS shipbuilding standards. Department of Marine Engineering Technology, Malaysian Institute of Marine Engineering Technology, Universiti Kuala Lumpur. Marine frontier. Mimet technical bulletin volume 4 edition 2 2013.

76 Notably, one CS recommends an onboard documentation plan specifying the steel types and grades used in the hull. It also advises recording the mechanical and chemical properties, along with workmanship requirements, for any alternative steel grades applied. Bureau Veritas. NR467 Rules for the classification of steel ships. Part B - Hull and Stability. Edition Jul 2025. https://erules.veristar.com/dy/data/bv/pdf/467-NR_PartB_2025-07.pdf Page 118.



UPCYCLING OF STEEL

The case study by AF Decom and Nordic Circles

In 2024, under the framework of the Research Council of Norway's Green Platform program, a consortium of Norwegian companies launched an ambitious initiative - Oppsirk[77] - to explore how maritime metals from decommissioned ships and oil platforms can be upcycled into low-carbon building materials. Led by the EU-listed ship recycling facility AF Offshore Decom, the project aims to go beyond traditional recycling methods by embracing upcycling, which means preserving and enhancing the value of ship materials and components through cross-sector collaboration.

The consortium brings together a broad spectrum of partners, including academic institutions, research organisations, public authorities, and key players from the finance, shipping, energy, construction, property development, and recycling sectors. With its extensive experience in dismantling offshore installations and maritime assets, AF Offshore Decom has deep knowledge of the downstream journey of EoL steel, which is typically collected, sorted, and melted down to produce new steel products.

The project has several objectives, such as assessing the circularity of the entire value chain and exploring how to adapt disposal contracts to support upcycling. A central partner in this effort is the Norwegian company Nordic Circles, which is developing innovative solutions to unlock the potential of one of the most valuable materials found on ships: high-quality scrap steel.

Nordic Circles offers a model to transform maritime metal into a ready-to-use building material with a significantly reduced carbon footprint. The goal is to create a streamlined value chain where steel from the maritime sector can be repurposed to benefit industries such as construction and infrastructure. This approach challenges the conventional siloed mentality and promotes a "circular hub" mindset, encouraging transparency and cooperation between industries.

77 See https://www.oppsirk.no/about

A core focus of the initiative is to simplify the process of testing and validating second-hand steel, making it more accessible and cost-effective for businesses to integrate reused materials into their operations. This could help normalise the continuous reuse of steel and unlock new upcycling opportunities across sectors.

One of the most significant challenges is the documentation gap. While vessels begin their lifecycle with detailed certifications outlining the properties and grades of the steel used, these documents are often inaccessible when the ship reaches a recycling facility. In such cases, recyclers are forced to perform costly and time-consuming sampling and testing, which discourages reuse. To address this, AF Offshore Decom and Nordic Circles advocate for improved traceability through the retention and transfer of original material certificates, along with access to technical drawings that indicate where certified steel was used throughout the vessel.

In cases where documentation cannot be recovered, standardised testing procedures must be established to assess steel quality and ensure safe reuse. To that end, Nordic Circles and other project stakeholders are developing a set of industry guidelines for the reuse and upcycling of maritime metals. These will establish shared standards for quality, safety, and traceability and will align with the European technical specification CEN/TS 1090-201:2024 for reused steel components.

Finally, the project is driven by several converging priorities, including the urgent need to decarbonise the steel industry and the opportunity to revitalise underused ship recycling yards, many of which are facing declining activity. Nordic Circles has already demonstrated that up to 25% of steel from an EoL ship (and up to 30% in the case of car carriers) can be successfully upcycled, i.e. directly re-used, with the remainder recycled through traditional methods. This new business model is projected to be up to ten times more profitable than conventional steel recycling through melting.

"Our goal is to give maritime steel a new and dignified life on land. Our steel has 97% less carbon emissions than average steel emissions in the building industry. But upcycling is more than reduction; it's about building bridges between industries and creating an entirely new value chain for maritime steel. And maybe most important these days, it is about ensuring that the EU has access to steel as an invaluable strategic raw material. Throughout our research, we have proved that circular economy is not only possible but profitable – for both the environment and the economy."

John Jacobsen and Fredrik Barth
Founders of Nordic Circles

Ship scrap steel: need for categorisation?

According to a major steel producer, ships provide a significant source of high-quality, homogeneous raw material, called E3 scrap[78]. In the European Scrap

78 Stephane Tondo, Arcelor Mittal's presentation at the Ship Reycling Lab (2022), Rotterdam.

Steel Specification[79], this category of scrap consists of old steel generally thicker than 6mm and with stable, low-tramp elements (like Cu, Cr, Mn, and Ni)[80]. Ship scrap steel is a raw material highly valued for its consistency and purity[81]. As highlighted in Chapter 1, inconsistencies between European and international scrap classification systems may hinder global trade in recycled materials and the development of a common trading language. Well-defined categories are essential to maximise industrial synergies and the environmental benefits of recycling. In the case of ship scrap steel, the EU's 'E3' category, under which this material appears to fall, has no direct equivalent in the international classification system. This discrepancy raises key questions: Which category can best fit ship scrap steel? And how can these systems be better aligned? Addressing these gaps would improve price predictability, encourage investment in disassembly and sorting technologies, and help the recycling industry establish long-term partnerships for the effective recovery and reuse of this valuable resource.

Additionally, in current EU steel scrap recycling practices, quality segregation and testing are typically carried out based on customer requirements and rely primarily on visual inspections or, in some cases, X-ray and basic chemical analyses. However, the ongoing transition towards EAF technology introduces a shift in quality demands. Unlike BFs, where scrap steel is often used primarily as a cooling agent and therefore subject to minimal quality scrutiny, EAFs require a more precise and consistent feedstock, where accurate identification of scrap quality is crucial. This shift underscores the need for enhanced traceability, standardised testing protocols, and clearer documentation of scrap characteristics throughout the recycling value chain.

2.3 Mapping the EU/EFTA-owned ships: fleet analysis and demolition scenarios

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An analysis of ship steel properties is incomplete without addressing the broader context of vessel lifecycles, as the timing of ship retirement not only affects the volume of scrap steel entering the market but also shapes future supply trends.

Generally, the operational life of a ship oscillates between 25-30 years. Technological advancements, new environmental regulations, changes in trade geography and freight prices are all factors that influence future decisions by shipowners on when to recycle their vessels. Still, several studies agree that between 2025 and 2040 there will be an increase in the number of ships being sent for demolition.[82] [83] Industry experts project that by 2033 the number of ships reaching EoL will increase fivefold, significantly boosting the availability of scrap steel.[84] [85]

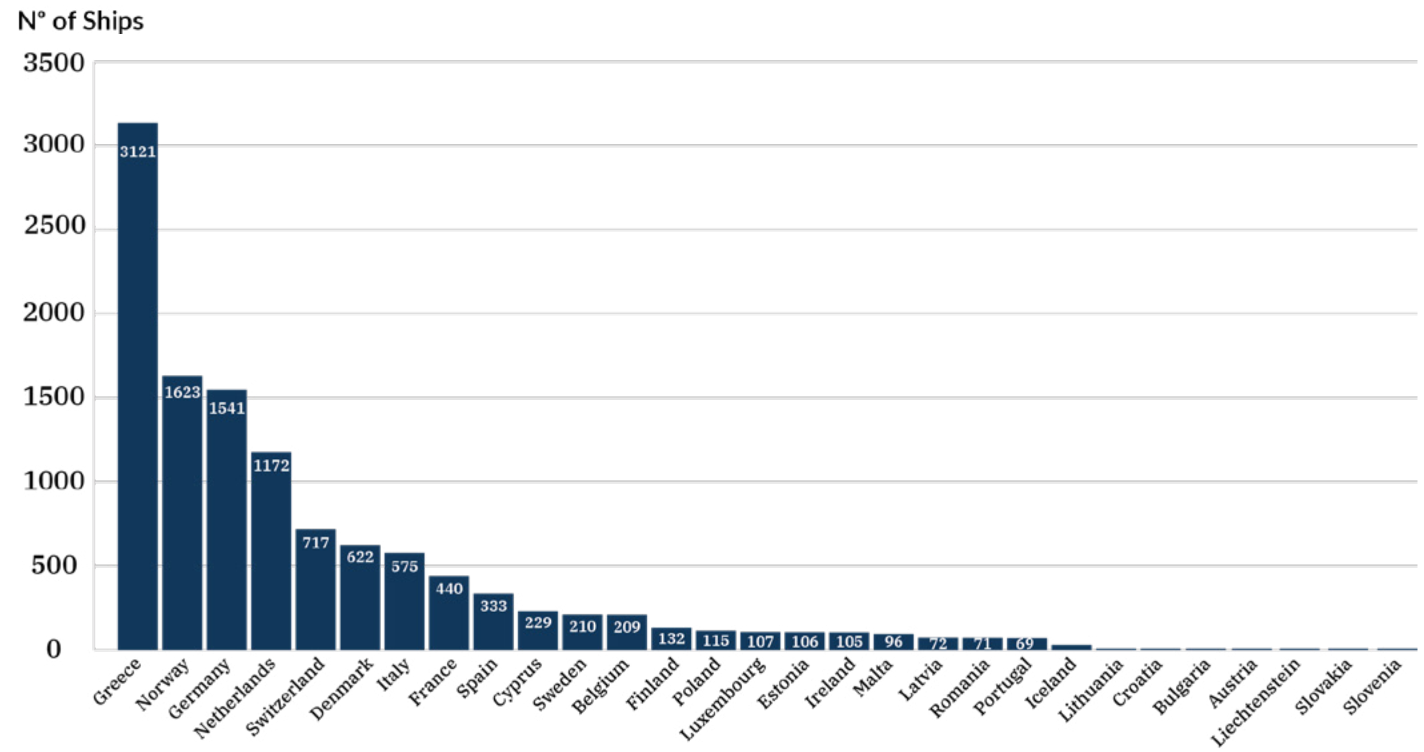


Figure 6: Number of ships owned, based on Beneficial Ownership

To examine how this trend may unfold in practice, we analysed the EU/EFTA-owned fleet older than 10 years bigger than 500GT, as these vessels are expected to become eligible for scrapping within the next decades. The dataset comprised 11,902 ships. The first analytical dimension examines the fleet's composition by vessel type, with ship categories consolidated into broader functional macro-groups. Tankers and bulk carriers make up the backbone of the EU/EFTA fleet: 2,228 tankers (18.7%) and 2,098 bulk carriers (17.6%). These are followed by container ships with 1,821 units (15.3%) and general cargo vessels with 1,755 units (14.7%). The "Other" category is also significant, comprising 2,037 specialised vessels (17.1%) that do not fit neatly into the main classifications. Passenger and cruise ships number 897 units (7.5%), offshore and drilling vessels 204 units (1.7%), dredgers and construction vessels 185 units (1.6%), fishing vessels 480 units (4.0%), Ro-Ro ships 186

79 Bundesverband Sekundärrohstoffe und Entsorgung (n.d.). European steel scrap specification. Retrieved Ferbuary 18, 2025, from https://www.bvse.de/images/pdf/schott-elektro-kfz/schrottsorten_en.pdf

80 The EU Scrap Steel Specification sets strict safety and cleanliness standards, excluding hazardous and non-ferrous materials, and allowing only minimal levels of elements like copper, tin, and lead to protect steel quality.

81 New Energy Coalition (2024). Unlocking Vessel Dismantling Opportunities: Towards steel Circularity. https://www.newenergies-coalition.com/static/8746b75abf953037955c955ae4fbd223/NewEnergiesCoalition-UnlockingVesselDismantlingOpportunities-October2024.pdf

82 Tola, F., Mosconi, E. M., & Gianvincenzi, M. (2024). Demolition of the European ships fleet: A scenario analysis. Marine Policy, 166, 106222. https://doi.org/10.1016/j.marpol.2024.106222

83 Rahman, S. M. M., Kim, J., & Laratte, B. (2021). Disruption in circularity? Impact analysis of COVID-19 on ship recycling using Weibull tonnage estimation and scenario analysis method. Resources, Conservation and Recycling, 164, 105139. https://doi.org/10.1016/j.resconrec.2020.105139

84 Sustainable Shipping Initiative. (2021). Exploring shipping's transition to a circular industry. https://www.sustainableshipping.org/resources/shippings-transition-to-a-circular-industry/

85 BIMCO. (2023, May 16). Shipping number of the week: Over 15,000 ships could be recycled by 2032, up more than 100% on the last 10 years. Retrieved March 18, 2025, from https://www.bimco.org/news-and-trends/market-reports/shipping-number-of-the-week/20230516-snow

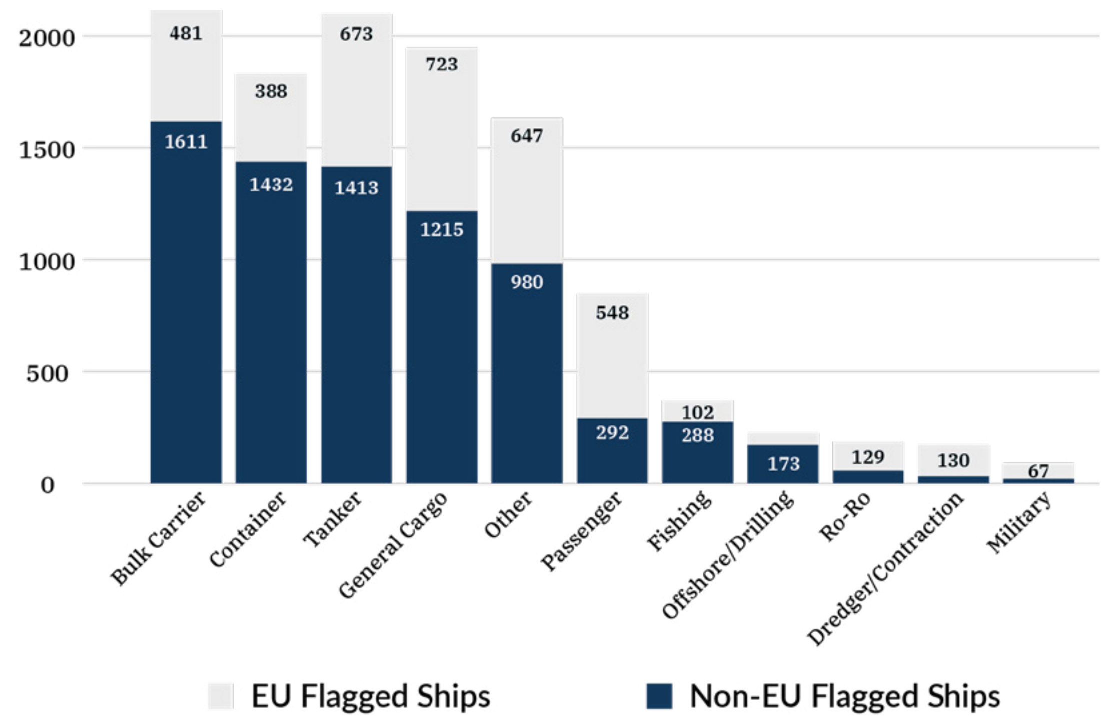


Figure 7: Distribution of EU-flagged and non-EU-flagged vessels by ship type

units (1.6%), and military vessels just 11 units.

A second dimension considers ownership patterns, focusing specifically on beneficial ownership. Greece holds a dominant position with 3,121 vessels, far surpassing other countries. Norway follows with 1,623 ships, Germany with 1,541, the Netherlands with 1,172, and Denmark with 622. Switzerland also maintains a notable fleet of 717 vessels, while Italy and France own 575 and 440, respectively. Other significant contributors include Spain (333 vessels), Cyprus (229), Sweden (210), Belgium (209), and Finland (132).

A third dimension considers flags. Of the total fleet, 4,244 ships (35.6%) sail under an EU member state's flag, while the majority, 7,658 ships (64.4%), are registered in non-EU countries. This highlights the major role played by open flag registries and the current discrepancy between ownership and flag states. Ship type is a key factor in this distinction: bulk carriers, tankers, and general cargo vessels are predominantly registered under non-EU flags, reflecting their reliance on non-EU registries, whereas passenger vessels and specialised categories such as fishing and offshore units exhibit a higher share of EU-flagged ships.

In examining future demolition scenarios for the ship sample of EU/EFTA-owned fleet older than 10 years, two forecasting methods have been assessed: ARIMA and Weibull. Taken together, the two approaches are complementary: ARIMA is particularly effective for analysing cyclical patterns and their intensity over time, while Weibull provides a probability-based framework for understanding the distribution of demolitions within the fleet. The comparative analysis of these models enables us to identify the time frame in which the highest concentration of demolitions for EU/EFTA-owned vessels older than 10 years is expected in the coming decade. Both methods converge in highlighting the period between 2030 and 2038 as the critical phase, marked by a peak in the number of EU/EFTA-owned ships entering the recycling system.

The Weibull methodology estimates the probability of demolition within the ship sample. It captures both lower and upper bounds of demolition events,

reflecting variability across ship classes and service lifetimes. According to this model, demolitions build up gradually, peaking in the mid-2030s, while offering a probabilistic perspective anchored in the statistical distribution of vessel lifespans. Specifically, it projects that annual demolitions for current EU/EFTA owned vessels will surpass 700 units between 2032 and 2036, with a maximum of 736 ships in 2033. At this peak, the scrapped tonnage yield approximately 12 million tons of scrap steel, remaining above 10 million tons per year between 2032 and 2037. The model thus clearly identifies the mid-2030s as the period of greatest demolition intensity.

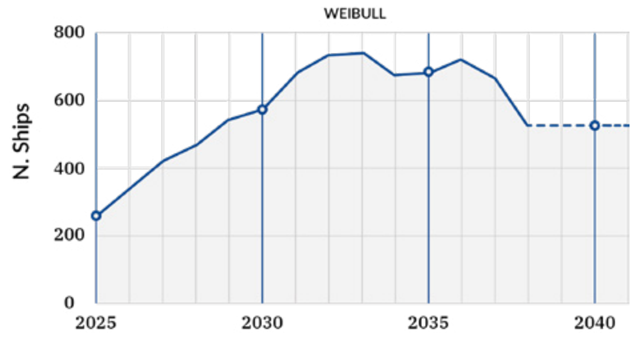


Figure 8: WEIBULL demolition forecast of EU/EFTA-owned ships (2025-2038)

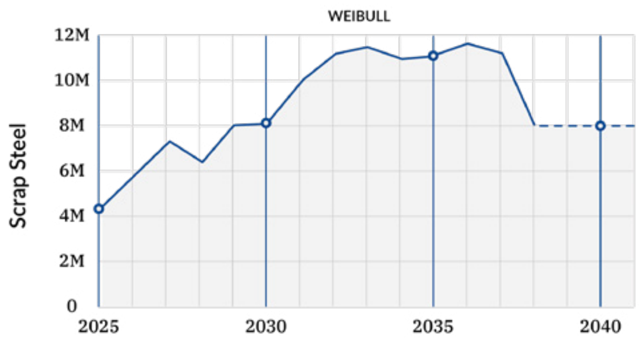


Figure 9: Projected trend scrap steel million tons Weibull Model (2025-2038)

The ARIMA model, by contrast, emphasises the cyclical dimension of ship demolitions, applying a moving average framework to capture temporal seasonality and fluctuations in vessel EoL dynamics. It reveals a broadly similar trend, but with important differences: the maximum number of demolitions occurs slightly later, with 813 units projected for 2037, when scrapped volume peaks at nearly 15 million tons of scrap steel. The period from 2033 to 2037 emerges as the core of the phenomenon, with more than 600 demolitions annually.

Both models are based exclusively on the current EU/EFTA-owned fleet older than 10 years and do not account for the younger segment and newbuilds that will progressively enter the cycle and eventually reach EoL. For this reason, forecasts remain robust only as the time horizon reflects the characteristics of the fleet sample, approximately until 2038.

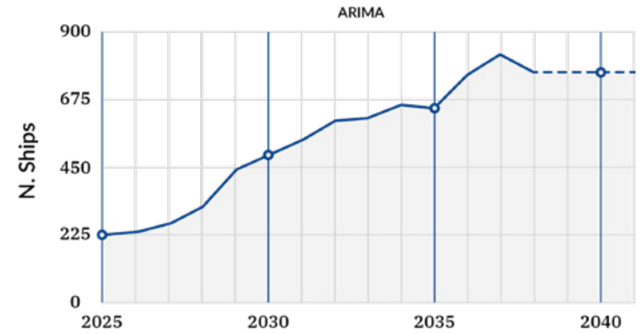


Figure 10: ARIMA demolition forecast of EU/EFTA-owned ships (2025-2038)

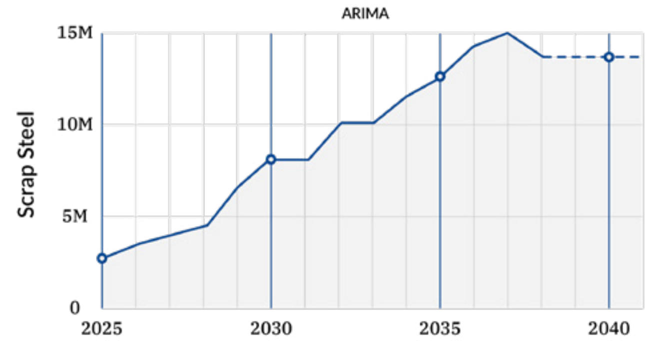
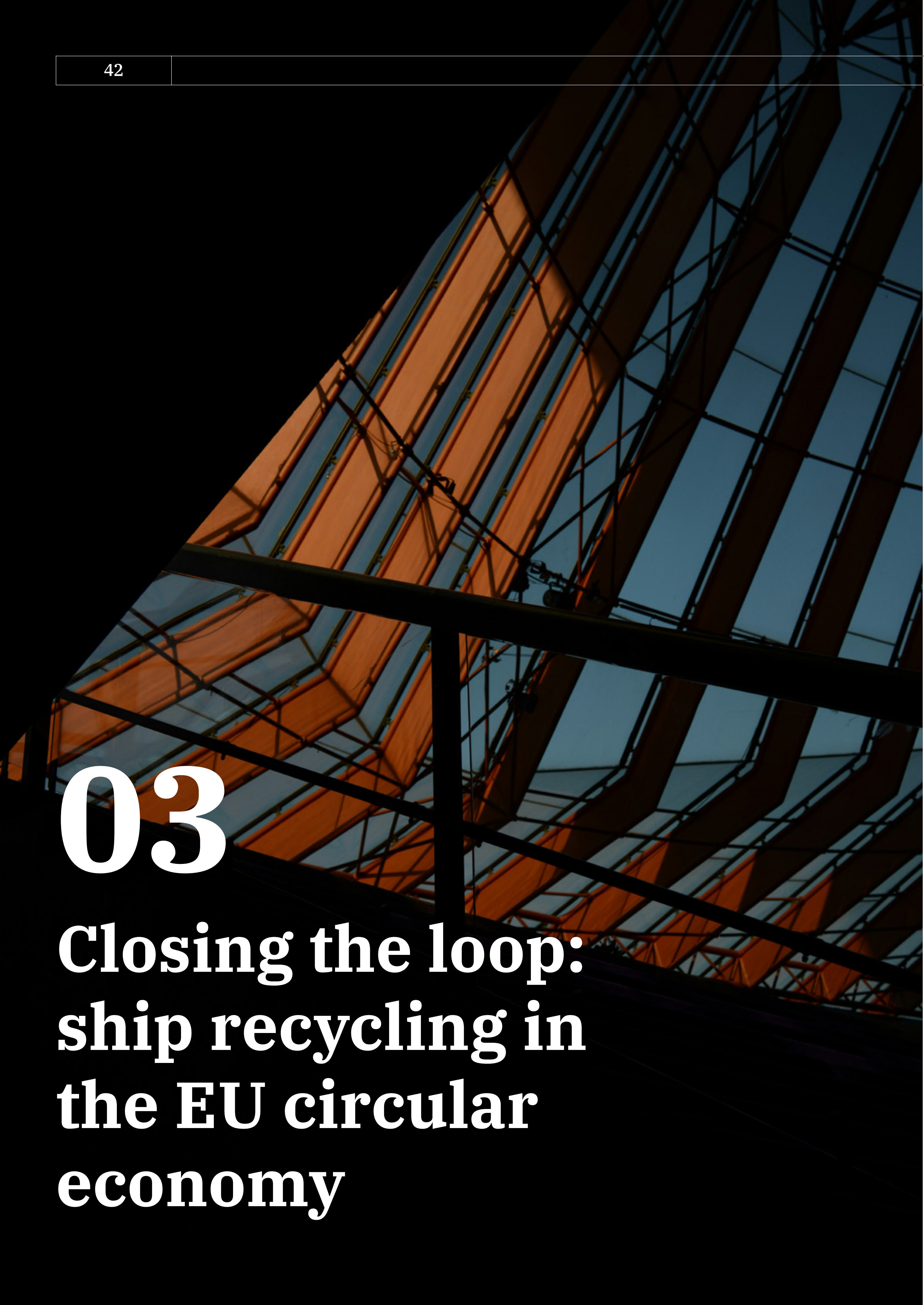


Figure 11: Projected trend scrap steel million tons ARIMA model (2025-2038)

Beyond this point, results become less representative, as they have not incorporated younger vessel generations. Reliability has been set at a 95% confidence level, meaning that forecasts within this horizon have strong statistical robustness. In the Weibull model, a ship is assigned to a specific demolition year only when its estimated probability of retirement exceeds 90%, ensuring that temporal allocations reflect a near-certain risk of dismantling.



03

Closing the loop: ship recycling in the EU circular economy

3.1
The need for alignment

The scale and location of EoL ship recycling will shape not only global steel flows but also the EU's ability to secure secondary raw materials. Against this backdrop, ship recycling emerges as a strategic opportunity for Europe's sustainability and industrial policies. Sustainably managing steel recovered from vessels would directly support the EU's goals on climate neutrality and material self-sufficiency. At the same time, optimising resource recovery can create jobs, strengthen regional recycling hubs, and advance the EU Green Deal[86] by reducing CO_2 emissions, lowering energy consumption, and decreasing reliance on virgin materials.

These benefits align closely with the priorities of the EU's Circular Economy Action Plan[87], which is structured around sustainable product design, circularity in high-impact value chains, waste prevention, and strengthening secondary raw material markets. It includes cross-cutting actions that integrate circular principles into broader economic and innovation policies. In particular, the pillar "Less Waste, More Value"[88] is directly relevant to maximising the recovery of resources from waste streams, including metals. Its overarching objectives are to:

- Enhance policy in support of waste prevention and circularity, and that will effectively promote a waste reduction target, recycled content target, and ensure high-quality materials separation for effective recycling.
- Enhance circularity in a toxic-free environment including solutions for high-quality sorting and the removal of hazardous contaminants from waste.
- Create a well-functioning EU market for secondary raw materials based on requirements for recycled content in products, developing EU-wide end-of-waste criteria, enhancing standardisation, enforcing restrictions on hazardous substances, and exploring the feasibility of a market observatory for key secondary materials.
- Address waste exports from the EU by promoting "recycled in the EU" as a benchmark for quality, enhancing recycling capacity, and reviewing EU waste shipment rules to restrict harmful waste exports and improve enforcement against illegal shipments.

The commitment to a new Circular Economy Act, as outlined in the 2024-2029 EU political guidelines of the Commission[89], presents an opportunity to ful-

86 European Commission (2020). Communication from the Commission to the European Parliament, the European Council, the Council, the European Economic and Social Committee and the Committee of the Regions. The European Green Deal. COM/2019/640 final. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52019DC0640

87 European Commission (2020). Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Commitee of the Regions. A new Circular Economy Action Plan For a cleaner and more competitive Europe. COM/2020/98 final. https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1583933814386&uri=COM:2020:98:FIN

88 Ibid. Page 12

89 Ursula von der Leyen. (2024). Europe's choice: Political guidelines for the next European Commission 2024–2029. Retrieved May 2, 2025, from https://

ly integrate the ship recycling sector into the EU's broader strategy for a competitive secondary raw materials market. The steel industry projects that Europe will become a net importer of scrap steel by 2050[90], and securing a resilient and sustainable supply chain by ensuring that ship recycling contributes meaningfully to the EU secondary raw materials market would reinforce the supply of high-quality recycled materials.

Currently, two regulations at EU level specifically address EoL ship management.

(1) Waste Shipment Regulation, (EU) 2024/1157

The EU Waste Shipment Regulation (hereinafter EU WSR)[91] incorporates the Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal (hereinafter Basel Convention) and the Basel Ban Amendment into EU law. The EU WSR prohibits all exports of hazardous waste to non-OECD countries and bans waste exports for disposal outside the EU and EFTA. As it regulates the trade of hazardous and non-hazardous wastes, it is relevant for ship dismantling, as a ship usually contains hazardous materials in its structure and is thus considered a hazardous waste at EoL. The instrument was revised as part of the roadmap proposed by the Commission under the New Circular Economy Action Plan. The new EU Waste Shipment Regulation (WSR), in effect since 20 May 2024, aims to prevent the export of waste challenges to third countries, promote environmentally sound waste management, strengthen enforcement against illegal shipments, and improve traceability to support recycling and reuse within the EU. The Regulation aims to ensure that waste management aligns with sustainable practices and reduces the risk of environmental harm caused by uncontrolled waste exports.

(2) Ship Recycling Regulation, (EU) No 1257/2013

The EU Ship Recycling Regulation (hereinafter EU SRR), which entered into force on 31 December 2018, incorporates into EU law the Hong Kong Convention on the Safe and Environmentally Sound Recycling of Ships (hereinafter HKC), adopted by the IMO in 2009. The Regulation applies to EU-flagged vessels over 500 GT and establishes requirements for ship recycling, importantly setting environmental protection and occupational health and safety standards that exceed the standards set by the HKC, including with regards to downstream waste management. The EU also maintains a global list of approved recycling facilities of which EU-flagged commercial vessels are required to be recycled.

commission.europa.eu/document/download/e6cd4328-673c-4e7a-8683-f63ffb2cf648_en

90 Yermolenko, H. (2023). EU could become scrap importer in less than 5 years – forecast. GMK Center. Retrieved May 2, 2025, from https://gmk.center/en/news/eu-could-become-scrap-importer-in-less-than-5-years-forecast/

91 European Union (2024). Regulation (EU) 2024/1157 of the European Parliament and of the Council of 11 April 2024 on shipments of waste, amending Regulations (EU) No 1257/2013 and (EU) 2020/1056 and repealing Regulation (EC) No 1013/2006. Official Journal of the European Union. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32024R1157

3.2

Harmonised reference to Waste Hierarchy and existing best practice needed to support material recovery

To understand how these EU ship recycling policies address scrap steel recovery and its role in enhancing the broader circular economy, it is essential to refer back to the EU Waste Framework Directive (hereinafter WFD),[92] which lays out core principles such as the Waste Hierarchy, the "polluter pays" principle, and "extended producer responsibility."

The Waste Hierarchy prioritises prevention, reuse, recycling, and recovery over disposal. Complementary to this are the 7R and 9R frameworks, which offer expanded circularity strategies, from refuse and rethink to remanufacture and repurpose, emphasising a more holistic approach to resource management.

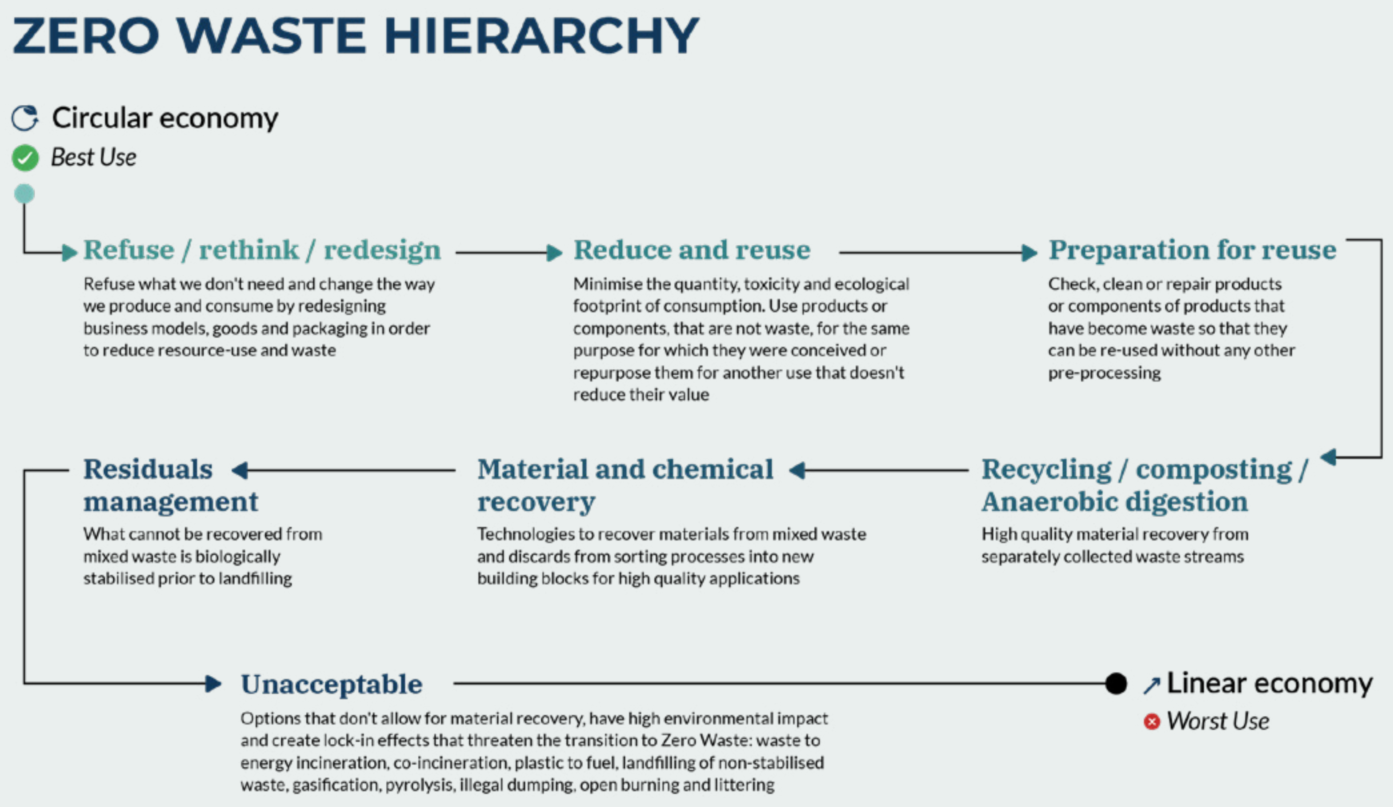
92 Directive 2008/98/EC of the European Parliament and of the Council of 19 November 2008 on waste and repealing certain Directives. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A02008L0098-20240218

Guiding principles for circular resource management: 7R and 9R

In addition to the waste hierarchy, the 7R and 9R frameworks emerged to address the full potential of the circular economy, to provide a structured approach for minimising resource use and waste across the entire product life cycle. They account for critical elements like product design, smarter material selection, or strategies to retain the highest possible value of materials throughout their lifecycle. The 7R model includes: Rethink, Refuse, Reduce, Reuse, Repair, Recycle, and Recover, guiding businesses to prioritise higher-value retention over disposal, while the 9R framework adds Repurpose and remanufacture, further looking at the product life cycle extension.[93]

The 7R and 9R models were developed to help organisations and policy makers move beyond linear models toward a regenerative economy. For businesses, adopting the 7R or 9R hierarchies enhances their competitiveness. They help to cut costs thanks to fewer material inputs, support innovation, and contribute to environmental and economic resilience.

93 CE Grow Circular (n.d.). 9R Framework. https://grow-circular.eu/knowledge-base/9r-framework/. And European Commission. (2020). Categorisation System for the Circular Economy. A sector-agnostic approach for activities contributing to the circular economy. Page 7. https://circulareconomy.europa.eu/platform/sites/default/files/categorisation_system_for_the_ce.pdf



Recital 13 of the EU SRR states: "*For the purposes of this Regulation, the term 'recycling' should not have the same meaning as defined in Directive 2008/98/EC. This Regulation should therefore introduce a specific definition for the term 'ship recycling'.*"[94] The EU SRR in fact provides the following definition of 'ship recycling': "*the activity of complete or partial dismantling of a ship at a ship recycling facility in order to recover components and materials for reprocessing, for preparation for re-use or for re-use, whilst ensuring the management of hazardous and other materials, and includes associated operations such as storage and treatment of components and materials on site, but not their further processing or disposal in separate facilities.*"[95] It furthermore states: "*For the purposes of Article 7(2) (d) and Articles 13,*[96] *15 and 16, (a) 'waste', 'hazardous waste', 'treatment' and 'waste management' have the same meaning as in Article 3 of Directive 2008/98/EC.*"

By deviating from the WFD's established definitions, it may seem that 'ship recycling' is isolated from the broader EU waste management and recycling framework, ultimately weakening the potential for coherence with EU-wide efforts on resource recovery and waste reduction.

However, it is key to note that the EU SRR recognises that there are waste management operations at 'ship recycling' facilities and that these facilities also generate wastes that need to be managed in an environmentally sound manner, including when they leave the 'ship recycling' facility. This makes it implicit that the WFD is key to understanding the requirements for the management of waste and hazardous materials at the facilities and with regard to their further processing downstream. Terms such as "treatment of components", "preparation for re-use", and "re-use" must therefore be understood within the existing EU guidance tools, standards on material recovery and reuse, and Best Available Techniques (BAT) documents.

Given the potential confusion created by introducing a definition of 'ship recycling' in the EU SRR that deviates from the WFD, it would be beneficial to provide explicit clarity that EU standards for waste management continue to apply. This should include outlining how such standards address the types of waste and hazardous materials typically found on ships and generated during dismantling. Without such operational guidance, the implementation of circularity strategies risks being limited, leaving innovation in material recovery dependent on voluntary initiatives by individual companies rather than supported and scaled through regulatory direction.

While the EU WSR explicitly anchors its provisions in the WFD, integrating principles such as the waste hierarchy and environmentally sound material management (Article 3), the EU SRR does not reference the higher tiers of the waste hierarchy, including prevention and re-use. Although the EU WSR reflects overarching goals such as climate neutrality and circularity (Recital 1), these principles would be more effectively translated into practice through measures that encourage upstream actions, such as promoting design for re-use and enabling advanced waste sorting operations. Linking more clearly to practical frameworks such as the 7R or 9R ladders would provide concrete strategies for avoiding waste generation, extending product lifespans, and maximising resource efficiency along the recycling chain.

Furthermore, Article 29 of the EU WSR sets out end-of-waste criteria in line with the WFD. Harmonising these criteria is expected to be a central agenda item in the forthcoming Circular Economy Act (2026). Streamlining practices across Member States will be essential: iron and steel products should be better separated, cleaned of contaminants where necessary, and sorted in a way that allows them to cease being classified as waste and instead be marketed directly as secondary raw materials, adding both economic and environmental value to ship recycling operations.

3.3

Preventing waste exports and strengthening EU domestic recycling capacity: effectiveness undermined by scope

94 Regulation (EU) No 1257/2013. Recital 13. Official Journal of the European Union. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A32013R1257

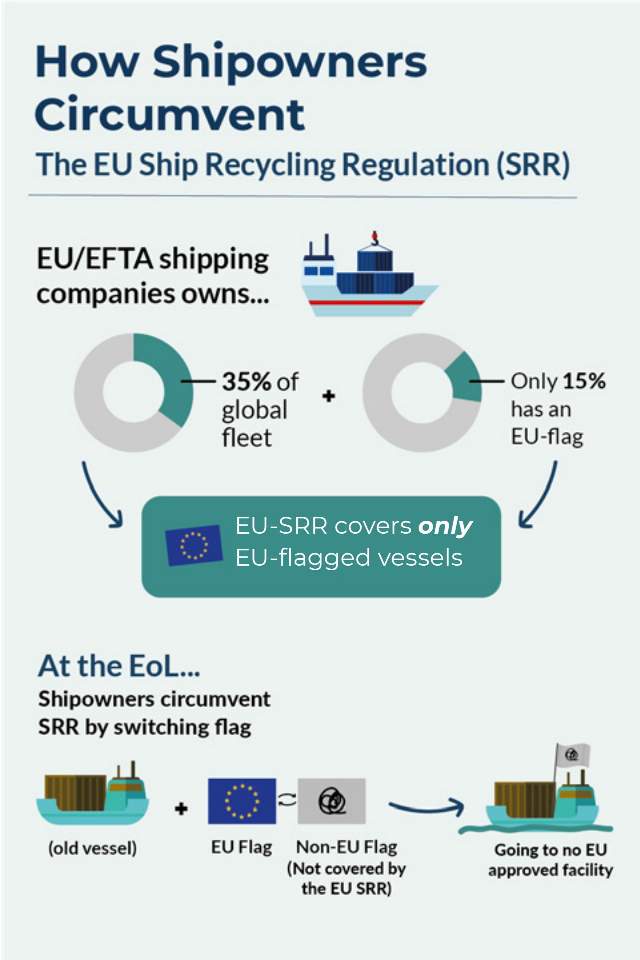
95 Ibid. Article 3.

96 Regulation (EU) No 1257/2013. Article 13(1). "(g) it ensures safe and environmentally sound management and storage of hazardous materials and waste, including: (i) the containment of all hazardous materials present onboard during the entire ship recycling process so as to prevent any release of those materials into the environment; and in addition, the handling of hazardous materials, and of waste generated during the ship recycling process, only on impermeable floors with effective drainage systems; (ii) that all waste generated from the ship recycling activity and their quantities are documented and are only transferred to waste management facilities, including waste recycling facilities, authorised to deal with their treatment without endangering human health and in an environmentally sound manner."

The EU WSR, through Article 39, establishes a clear prohibition on the export of hazardous and certain other wastes, including EoL vessels containing hazardous materials, to non-OECD countries. This restriction directly prevents transboundary movements to locations where the environmentally sound management of wastes cannot be guaranteed, while indirectly encouraging domestic recovery operations. It also helps retain valuable secondary raw materials within the EU market and prevents the externalisation of waste-related environmental and social impacts to vulnerable third countries.

However, despite successful prosecutions of attempted illegal exports of EoL vessels from EU waters, the current jurisdictional basis of the EU WSR limits the capacity of authorities to fully enforce its provisions on ships. Although vessels are considered waste under the Regulation once there is an intent to dispose of them, in practice shipowners can circumvent the legislation with relative ease. By failing to notify authorities of their disposal intentions, or by presenting false documentation claiming further operational use, repair, or refitting outside EU jurisdiction, shipowners are able to redirect vessels to substandard dismantling facilities. This practice not only undermines the Regulation's objectives but also perpetuates environmental degradation and social harm in third countries.

Shortcomings are evident also in the EU SRR, which has a very limited scope. The Regulation is in fact only applicable to vessels registered under an EU/EFTA flag. Although EU/EFTA shipping companies own over 35% of the global fleet[97], only 15% of these vessels sail under an EU flag[98], and as they approach EoL, the share carrying an EU/EFTA flag drops even further. Moreover, shipowners can re-flag their vessels to non-EU/EFTA registries just weeks before scrapping, thereby circumventing the requirements of the Regulation. The recent EU SRR evaluation report[99] identifies re-flagging as the main method shipowners use to circumvent the law in order to



97 ECSA (European Community Shipowners Association) (2025). European shipping key for Europe's security with 35% of global fleet, studies find. https://ecsa.eu/european-shipping-key-for-europes-security-with-35-of-global-fleet-studies-find/

98 EMSA (European Maritime Safety Angecy) (2025). The EU Maritime Profile – the maritime cluster in the EU. https://www.emsa.europa.eu/eumaritimeprofile/section-2-the-eu-maritime-cluster.html

99 REPORT FROM THE COMMISSION TO THE COUNCIL AND THE EUROPEAN PARLIAMENT on the application of Regulation (EU) No 1257/2013 of the European Parliament and of the Council of 20 November 2013 on ship recycling and amending Regulation (EC) No 1013/2006 and Directive 2009/16/

engage in dismantling practices that fall below EU standards. This regulatory gap not only undermines the goal of preventing waste export but also weakens the EU's internal ship recycling sector, as companies will have to work with a limited market share and compete with other recycling facilities that are not bound to operate under the same environmental and social protection rules.

By allowing regulatory gaps to persist in both regulations, the EU loses the ability to retain and manage the availability of valuable raw materials from ships, making it difficult to create a mutually beneficial commercial environment for the shipping and steel industries. This reduces the market confidence needed for recyclers, innovators, and start-ups to invest in new technologies and infrastructure. In the case of the EU WSR, Recital 3 of the Regulation underscores the importance of retaining more waste within the EU to reduce reliance on strategic raw materials.

Expanding the two regulations' scope by looking at beneficial ownership instead of flag or the exporting State jurisdiction would significantly strengthen their impact. This shift would bring a larger share of the global fleet under EU oversight at EoL, enabling more accurate forecasting of scrap steel availability and fostering long-term partnerships among shipowners, dismantling yards, and scrap recyclers within circular hubs.

EC. https://op.europa.eu/en/publication-detail/-/publication/cc026b18-eeb0-11ef-b5e9-01aa75ed71a1/language-en

3.4 Material traceability as a foundation for circularity

Material transparency is a critical enabler for circularity, safety, and economic efficiency in the ship recycling value chain. The EU SRR mandates detailed documentation for hazardous substances through the Inventory of Hazardous Materials (IHM), including type, quantity, location, and sampling certification, essential for the safety of workers during dismantling operations and for their safe storage and disposal. However, there is no similar requirement for non-hazardous materials, leading to a lack of data on ship high-quality components. The EU SRR evaluation report[100] underscores the need for stronger alignment between the ship recycling measures and the EU's broader material circularity objectives. According to the study: "While the definition of 'ship recycling' in the SRR mentions the recovery and reuse of materials, the Regulation does not include any concrete requirements for the amount or proportion of materials required to be reprocessed or reused versus disposed of." Besides metal scrap, many non-ferrous materials are disposed of instead of being recycled. The information gap on the ship's equipment maintenance history was identified as the main

100 European Commission, Directorate-General for Environment. (2025). EU Ship Recycling Regulation: Evaluation and list update. Retrieved February 25, 2025, from https://environment.ec.europa.eu/news/eu-ship-recycling-regulation-evaluation-and-list-update-2025-02-19_en

cause[101]. Without proper certification or material inventories, opportunities for reuse and recovery are often missed or poorly executed, ultimately hindering optimised recycling and reducing the circular potential and value of the ship. This information gap can lead to:

- Lower asset evaluation at EoL due to uncertainty in material quality;
- Delays in the dismantling and material separation process due to uncertainty in material type, quality and location on the vessel;
- Lost opportunities for cross-sectoral reuse of high-value materials and components

The EU WSR, for its part, provides a strong institutional framework for transparency on what is being shipped and how it will be treated. Article 5, along with Annex VII, detail requirements for pre-notification, material classification codes, recovery operations, and the final destination of waste. These mechanisms support regulatory oversight and tracking of waste movements across borders, and the verification that materials reach licensed facilities and are treated in an environmentally sound manner. Yet, while the WSR captures important administrative traceability, it would benefit from the integration of a more granular, product-based material identification approach.

Implementing a material inventory or digital product passport for ships, maintained up until EoL, would significantly enhance traceability of materials. As industry R&D is developing, such a passport would provide exporters, importers, recyclers, and remanufacturers with critical information to identify contaminants, assess steel grade and function, and accurately sort materials for reuse, recovery, or recycling in line with the Waste Hierarchy and 7R/9R frameworks. This would enable high-value reuse, improve emissions accounting, and support EU policies like the Ecodesign for Sustainable Products Regulation (ESPR)[102] by facilitating design for disassembly, supply chain transparency, and low-carbon procurement.

101 European Commission (2024). Support study for the Evaluation of Regulation (EU) No 1257/2013 on ship recycling. Final report. Page 13. Retrieved on May 2, 2025, from https://environment.ec.europa.eu/document/f717f65b-7293-43eb-9b52-2890277bc6d8_en

CirclesOfLife:

Driving circularity with the Ship Circular Materials Passport and Ship Lifecycle Passport

The Horizon Europe-funded CirclesOfLife (COL) project is charting a bold new course for the maritime industry, one defined by full material transparency, accountability, and circularity. COL brings together a diverse consortium of 15 maritime organisations from across Europe, uniting experts in sustainable shipbuilding, environmental technology, and maritime innovation.

One of the project's main objectives is the development of a blueprint for the Ship Lifecycle Passport (SLP) and the Ship Circular Materials Passport (SCMP). These passports will document every material and component used in shipbuilding, from origin to recycling, supporting data-driven decisions on maintenance, repair, reuse, and safe dismantling. They can be the solution for the maritime industry to resolve challenges such as extending material lifespans, reducing waste, and optimising the use of high-quality materials, particularly steel, in line with the EU waste legislation. Both tools are designed to bring clarity, traceability, and innovation to shipbuilding throughout the maritime supply chain.

102 European Commission. (n.d.). Ecodesign for Sustainable Products Regulation. Retrieved March 20, 2025, from https://commission.europa.eu/energy-climate-change-environment/standards-tools-and-labels/products-labelling-rules-and-requirements/ecodesign-sustainable-products-regulation_en

At the core of COL is a commitment to collaborative innovation, which is essential in a sector that is not well-known for its transparency. By developing practical, standardised solutions to manage and trace material flows throughout a ship's lifecycle, the project empowers industry actors to make better decisions, starting from design to dismantling.

"It is essential to involve the full maritime value chain in developing the solutions of COL to make sure that the solutions that are created support not only enhancing circularity and lowering product environmental footprint, but also create new business opportunities. We need to work collectively to make sustainable and circular practices the new industry standard." - Martin Verboom, Development Engineer Sustainability at Damen

Inspired by similar initiatives in other sectors, from batteries to construction materials, COL is working extensively to create the framework and blueprint for the Passports which will be aligned with the evolving EU regulatory landscape in terms of circularity, such as the framework of the Ecodesign for Sustainable Products Regulation (ESPR), Digital Product Passport (DPP) and ISO 59000.

The project is focusing on mapping the regulatory and policy framework to ensure its tools are robust, practical, and future-proof. In particular, EoL perspective emerges as a key priority to consider, intending to provide clear, actionable guidance on how the passports can be effectively applied during the final stage of a ship's life. To this end, the project is also looking at dismantling practices and circularity indicators to enable the reuse and upcycling of ship components. One promising avenue is the upcycling of maritime-grade steel developed by Nordic Circles, which sets a new benchmark for ship steel reuse in the construction sector. If disassembling is supported by traceability and certification mechanisms, these materials can be reintroduced into the European industrial ecosystem. This contributes not only to the objectives of the EU Critical Raw Materials Act but also aligns with the broader ambitions outlined in the recent European Steel and Metals Action Plan and the upcoming Circular Economy Act.

As COL enters the second half of the project, the focus shifts to piloting concepts with real-world stakeholders, advancing both a sustainable maritime sector and a stronger European secondary raw materials market.

04
The way forward

This report has highlighted the role of EoL ships as a potential source of high-quality scrap steel, and the opportunity this presents not only for decarbonising steelmaking but also for enhancing circularity practices in maritime and steel sector hubs. Ensuring that material value is not lost, but instead preserved and reintroduced in the economy as raw material, aligns with the overarching principles of circularity. To move from concept to competitive solutions, policies and business practices must be improved to support capacity development. Additionally, we identified below key areas for future research that can inform and strengthen these efforts, ensuring more effective and scalable implementation.

4.1 Full circle ahead: strategic recommendations for policy-makers

Align ship recycling with EU Waste standards. Clarify the relationship between the EU SRR and the WFD by explicitly affirming the applicability of EU waste management standards for ship recycling. Provide clear operational guidance on handling wastes and hazardous materials commonly found on ships to support the consistent implementation of circularity strategies and reduce reliance on voluntary industry initiatives.

Close legal loopholes on EoL ships' exports. Despite the application of the EU SRR and the EU WSR, many EU/EFTA-owned vessels continue to be scrapped in substandard yards due to widespread out-flagging practices and fraudulent claims of further operational use, enabling hazardous waste to be exported illegally. Only a small portion of steel from EU/EFTA-owned EoL ships is recovered and reintegrated into the EU's secondary raw materials market. Expanding regulatory scope to include beneficial ownership of vessels, and the criminalisation of flag-swapping intended to evade EU ship recycling rules, would ensure that EU/EFTA-based shipowners remain accountable for the EoL treatment of their assets in line with EU ship recycling and due diligence standards.

Support best practices and finance circular innovation. Identify and promote best practices in material traceability, environmentally friendly coatings, and scrap management through linked legislation across shipping and materials policies. Support pilot projects and R&D in areas such as material passports, upcycling and reusing technologies, and the transformation of shipyards into circular hubs, enabling the development and scaling of new and economically viable circular business models.

Introduce a ship recycling return scheme. Establish a financial incentive mechanism that collects contributions throughout the operational life of the vessel to support safe and environmentally sound ship recycling, helping to bridge the cost gap between substandard and compliant yards. This measure would encourage shipowners to plan responsibly for EoL management, while also disincentivising flag-swapping. It would contribute to internalising environmental costs across the ship's life cycle, and align with the polluter pays principle. Forfeited funds could be reinvested in R&D, infrastructure, and capacity building. By directing more vessels to compliant EU facilities, the scheme would strengthen the EU's ability to recover and recycle high-quality ship steel.

Introduce effective carbon pricing and material standards to boost scrap steel use. Implement an effective carbon price to stimulate improvements in the secondary steel market, accompanied by a phased-out approach to free allocations in the steel sector. Complement this with harmonised sorting and recycling standards to increase the availability of high-quality scrap, creating the conditions for investment in advanced scrap treatment across EU industries. Finally, sector-specific recycled content targets should be supported by harmonised end-of-waste criteria to enable the efficient flow of high-quality scrap.

Ensure the Circular Economy Act remains aligned with the Circular Economy Action Plan by tracking progress, promoting transparency, and advocating for strong, enforceable measures that reflect CEAP's long-term circularity vision. The Act should uphold the 9R framework as a guiding principle, which enables savings in waste disposal costs, improved process efficiency, reduced environmental and social impacts, provides opportunities for industrial synergies, and strengthens competitiveness. Within this framework, ship recycling should be explicitly recognised as a contributor to the circular economy and a valuable source of high-quality scrap steel.

Beyond recycling: reuse and life extension for sustainable ship design

It is increasingly evident that traditional circularity approaches, centred primarily on recycling, are not sufficient to reach climate goals. As the maritime industry intensifies efforts to meet the urgent demand for decarbonisation during the operational life of its assets, greater emphasis will be placed on aligning the non-operational phases of ships with principles of circularity and emission reduction.

At the forefront of this shift is the TNO Department of Naval and Offshore Structures in Delft, The Netherlands, which proposes a radical rethinking of the value of an end-of-life ship by assessing its functional value over the scrap value. This utilises the broad spectrum of the sustainability pyramid instead of only recycling by remelting (which should be the last resort). While traditional optimisation of ship hull structures has focused on performance, cost, and regulatory compliance, now circularity and GHG emission reductions must be added to the equation.

TNO identifies two pivotal transitions required for a sustainable future in ship design:

- Incorporating the strategic and environmental value of reclaimed steel: reuse of structural steel, properly assessed and certified, can significantly lower embodied emissions in new builds.
- Redefining end-of-life value: a vessel should no longer be seen as scrap at the end of its life. Instead, it should be viewed as a reservoir of high-value structural components with untapped potential.

While steel demand is growing and raw material resources are constrained, extending the functional life of ship structures and components becomes an ecological and economic imperative. TNO introduces a refined hierarchy of reuse, where lifetime extension is considered the first and most direct form of reuse. This involves keeping the ship in its original operational context but for a longer duration, typically through design improvements that mitigate fatigue and wear. Beyond this, four additional levels of reuse are identified:

- **Whole ship repurposing:** reassigning an entire vessel to a new operational role without structural modifications.
- **Modular repurposing:** salvaging and reusing intact sections or modules from decommissioned ships.
- **Panel repurposing:** reclaiming stiffened panels from end-of-life vessels for use in new builds.
- **Elemental repurposing:** reusing individual components, such as plates, profiles, or bars, cut from old structures.

Each of these reuse routes presents its own technical challenges, particularly in evaluating and certifying the condition of reclaimed materials. Key enablers include visual inspections, non-destructive testing, and the development of material passports to ensure traceability and accountability. This system could be increasingly automated in the future, with the ultimate vision of making reuse cost-effective and mainstream, without compromising on safety or quality.

"A shift towards "design with reuse" means that designers and structural engineers are facing a pre-determined feedstock of structural components today, whilst being able to facilitate further reuse in the future. We must consider the future reusability of components as part of the initial design process. This represents a profound transformation: today's design becomes tomorrow's material feedstock." says Marije Deul, scientist specialist and naval architect at TNO.

For a truly circular economy to thrive, the economic value of reclaimed materials must be recognised. TNO recommends that, as part of developing innovative business models, partial return fees or trade-in schemes should be examined, allowing ship owners to receive value for returning vessels with reusable components. These methods would incentivise the return of high-quality materials into the supply chain and ensure reuse is not only technically feasible but economically viable.

In conclusion, the TNO vision represents more than a technical roadmap, it's a cultural and philosophical shift. It calls for human creativity to be at the heart of the engineering practice. By designing with reuse in mind, today's naval architects can create vessels that are not only efficient and safe but also form part of a regenerative maritime ecosystem. Circularity is not a destination, but a design principle.

4.2

Industry-level recommendations

Invest in material traceability and circular value recognition. Collaborate with industry frontrunners developing material passport solutions to retain essential data and support research and innovation in traceability systems. Engage with pioneers advancing steel reuse processes that enhance environmental performance. Actively participate in initiatives to define robust standards for the collection, sorting, and classification of ship scrap steel to build trust in and drive uptake of secondary steel in European markets.

Champion circularity in shipping. Recognise and elevate the shipping sector as a strategic contributor to Europe's circular economy and the **EU/EFTA-owned fleet as a strategic reservoir** of high-quality secondary raw materials that can significantly support Europe's steel decarbonisation agenda. Embed circularity from the design phase by encouraging shipbuilders to prioritise durability, modularity, reparability, and disassembly to extend material lifespans and improve recyclability. Collaborate with shipyards, start-ups and academia to develop pilot projects to test life extension design, innovative ship paints, and new technologies to reduce the environmental and social impacts of the non-operational phase of ships.

Align with EU circularity regulations to future-proof steelmaking. Align corporate long-term strategies with upcoming EU circularity and climate regulations. Invest in and raise awareness about the importance of transparent upstream information on scrap steel, covering its origin, quality, sorting processes, and potential contaminants, to build trust and enable more efficient and high-value recycling. With the Clean Industrial Deal, ESPR, and forthcoming Circular Economy Act on the horizon, investment in circular infrastructure will ensure compliance with future recycled content requirements and unlock access to premium low-carbon markets. Accelerate and scale the transition to EAF and DRI production, and build strategic supply agreements with sectors such as shipping to source high-quality secondary steel, enabling greater scrap input, reduced emissions, and stronger positioning in a decarbonising market.

4.3

Future research

The following research areas have been identified as priorities for developing evidence-based policies that foster circularity, promote responsible ship recycling, and support the strategic integration of secondary steel into the EU market.

Regenerative design and material passport: Focus on developing a comprehensive traceability system for all ship materials, building on the IHM to include steel and other materials, with interoperable material passports across stakeholders. Research should also address the impact of coatings on the recyclability and quality of steel, exploring alternative, non-degrading options. Additionally, exploring methods for the life extension of high-quality materials, particularly steel, is essential, including maintenance practices and design choices. Finally, targeted research should aim to harmonise and categorise ship scrap steel, developing a consistent classification and end-of-waste criteria to enhance market confidence in secondary steel from ships.

Strategic capacity planning for EoL: EU shipping companies can improve fleet retirement planning by fostering stronger synergies with the ship recycling and steel sectors, especially as more actors move away from beaching practices to align with EU regulations. Research should assess current and future capacity gaps, identify infrastructure needs, and explore the potential for establishing robust, compliant ship recycling hubs within the EU.

Annex I

Methodology for elaborating EU/EFTA-owned fleet demolition scenarios.

The dataset of EU/EFTA-owned ships was provided by the NGO Shipbreaking Platform, who based the research on commercial maritime databases. All vessels in the dataset are bigger than 500 GT and older than 10 years old, placing them on track to become eligible for recycling in the near future.

ARIMA

The Autoregressive Integrated Moving Average (ARIMA) model is one of the most widely applied statistical approaches for time series forecasting. It is particularly effective when observations are sequentially time-ordered. In the context of ship recycling, ARIMA can be used to forecast both the number of vessels reaching the end of their service life and the corresponding gross tonnage (GT) available for demolition. The methodology begins with the analysis of historical demolition records, expressed in annual counts and GT, in order to identify the temporal structure of the data. The ARIMA model is composed of three main components:

- **Autoregression (AR):** captures the relationship between present and past values.
- **Integration (I):** involves differencing the series to achieve stationarity.
- **Moving Average (MA):** models the error term as a linear combination of past forecast errors.

The optimal ARIMA order is determined using information criteria such as the Akaike Information Criterion (AIC) or the Bayesian Information Criterion (BIC). Once estimated, the model generates point forecasts and confidence intervals, which support scenario-based planning. This approach is especially appropriate where ship demolition activity follows relatively stable, long-term fleet renewal cycles. However, ARIMA has limitations. It relies exclusively on historical statistical relationships and does not explicitly capture technological advances, market shocks, or regulatory changes. As a result, its performance may deteriorate when structural shifts occur in the data. For this reason, ARIMA outputs should be interpreted with caution and complemented with scenario analysis or alternative forecasting tools.

Within ship recycling studies, ARIMA forecasts provide a baseline expectation for the future supply of vessels to be dismantled, which in turn informs projections of scrap steel availability. The estimated average demolition ages are:

- 26 years for bulk carriers
- 24 years for container ships
- 36 years for dredger/construction vessels
- 38 years for fishing vessels
- 29 years for general cargo ships
- 35 years for military units
- 31 years for offshore/drilling vessels
- 34 years for vessels in the “Other” category
- 33 years for passenger vessels
- 31 years for Ro-Ro ships
- 25 years for tankers

These values provide reference points for forecasting vessel retirements across categories, reflecting the heterogeneous operational lifespans of the EU/EFTA-owned fleet.

WEIBULL

The Weibull distribution is particularly suited to modeling the probability of ship retirement as a function of age. The density distribution of ship end-of-life age follows a bell-shaped curve: starting with low values, increasing progressively to a peak at 25–30 years, and then gradually declining. This pattern reflects the typical life cycle of a vessel: very few demolitions occur in the early years, the central peak marks the age of highest probability of retirement, and at older ages only a residual share of ships remains in operation. The Weibull distribution effectively captures this process, as it accounts for fleet growth, maturity, and decline phases. It is mathematically described by a probability density function, where p(t) represents the probability of demolition at age t.

$$p(t) = \frac{a}{b}\left(\frac{t}{b}\right)^{a-1} \exp\left[-\left(\frac{t}{b}\right)^{a}\right]$$

Two parameters define the distribution:

- Shape (k): governs the slope of the curve,
- Scale (λ): indicates the typical lifespan.

For practical interpretation, these parameters can be re-expressed as:

- l: the maximum expected lifespan of a vessel,
- m: the most frequent demolition age (median of the distribution).

The corresponding equations are:

$$T < l = 1 - \exp\left[-\left(\frac{t}{b}\right)^{a}\right]$$

$$m = \frac{b \cdot (a-1)^{1/a}}{a}$$

The estimated parameters for the European fleet currently in service allow for a more precise assessment of demolition ages by ship type and provide a robust basis for forecasting future recycling flows. Values elaborated for each ship type derived from demolition records collected by the NGO Shipbreaking Platform, and reflect actual decommissioning patterns observed in practice. The estimation approach deliberately avoids clustering by subgroups in order to maximize sample size and heterogeneity, reduce the variance of estimates, and obtain stable parameters for each ship category. In this way, the Weibull distribution captures the phenomenon comprehensively. It is important to note that, while the parameters are estimated from global demolition records, the forecasted demolition counts are calculated only for the EU/EFTA fleet aged 10 years or older. In practice, the risk functions (Weibull for age and ARIMA for cyclical/temporal dynamics) are applied to the EU/EFTA fleet, yielding the expected number of demolitions specifically for the European segment.

Future estimates

LDT is the unit of measure used in EoL negotiations to determine the steel content of vessels, and it represents the key reference point for assessing scrap steel weight potential. However, LDT figures are often unavailable for vessels still in operation. To overcome this gap, a method was developed to estimate missing LDT values as accurately as possible. The relationship between GT and LDT is central to this process. The GT/LDT ratio serves as an indicator of structural efficiency:

- Lower ratios are typical of vessels such as bulk carriers and tankers, which are designed to maximize payload capacity relative to structural mass.
- Higher ratios are found in categories such as fishing vessels and offshore units, reflecting heavier reinforcements and specialized superstructures.

By analyzing data from both dismantled ships and the fleet currently in service, it is possible to refine the estimation of conversion coefficients. Historical records provide a solid reference baseline, while comparison with the existing fleet allows for adjustments that improve accuracy. These parameters are fundamental for ship recycling studies, as they form the basis for quantifying the future supply of recoverable steel from the EU/EFTA-owned fleet.

The methodology proceeds in two steps:

- Historical baseline (dismantled ships): Ratios derived from vessels already demolished establish reference coefficients for GT-to-LDT conversion, ensuring comparability across ship types. These values represent the average efficiency observed in past demolition cases. The overall average ratio from dismantled ships is 0.58.

- Adjustment with current fleet data: Ratios were recalculated using the dataset of EU/EFTA-owned vessels currently in service. This step captures design differences and structural features specific to the active fleet. The overall average ratio for the current fleet is 0.87.

Finally, a central value was computed for each ship type by combining the historical (demolished ships) and current (in-service fleet) coefficients. This approach ensures robust estimates that reflect both observed decommissioning practices and the characteristics of the operational fleet.

The next step is to calculate the future supply of recyclable steel scrap resulting from ship demolitions. The integration of the forecasting methods used to estimate demolition flows, combined with the analysis of material composition and the adoption of the central value of the GT into LDT conversion coefficient, makes it possible to develop an estimation of the amount of steel that will enter recycling circuits in the coming decades. In this context, steel is by far the most significant component, with recovery rates ranging between 60% and 80% of the estimation of the LDT, depending on the type of vessel. The formula adopted to estimate the potential of steel scrap is as follows:

Future steel scrap=
$(GT_{\text{ship type}} / \text{Central Value}_{\text{LDT}}) \times \%\ \text{Ferrous Scrap}_{\text{ship type}}$

Ship Type	Demolished ships	EU/EFTA-owned fleet	Central Value
Bulk Carrier	0.35	0.61	0.48
Container	0.55	0.79	0.67
Dredger/Construction	0.83	0.70	0.77
Fishing	1.45	0.79	1.12
General Cargo	0.68	1.05	0.87
Military	0.87	0.76	0.82
Offshore/Drilling	1.02	0.97	1.00
Other	0.90	1.56	1.23
Passenger	0.63	0.86	0.75
Ro-Ro	0.55	0.52	0.54
Tanker	0.46	0.95	0.71
Overall Average	**0.58**	**0.87**	**0.73**

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