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CAR TO CAR STEEL

Potential of End-of-Life Vehicle deep-dismantling and deep-sorting to produce copper-depolluted steel scrap and decarbonize automotive flat steel production

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INSTITUT MOBILITÉS EN TRANSITION

REPORT

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NOTE

This study builds on the findings of a previous study *Car to car Steel* published in March 2025 and compares them against new trial results. It was conducted with full economic independence as funding was provided solely by two philanthropic organizations, and all sampling and analysis costs were borne independently, without any financial contribution from industry.

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CAR-TO-CAR STEEL

POTENTIAL OF END-OF-LIFE VEHICLE DEEP-DISMANTLING AND DEEP-SORTING TO PRODUCE COPPER-DEPOLLUTED STEEL SCRAP AND DECARBONIZE AUTOMOTIVE FLAT STEEL PRODUCTION

Hannah Gross, Jean-Philippe Hermine, Bertille Rault

EXECUTIVE SUMMARY

Project overview

Scope and purpose: improving and securing the circularity and decarbonisation of automotive steel, while creating additional value through upgraded shredded steel fraction and copper recovery from end-of-life vehicles (ELV).

Decarbonising mobility requires action on several fronts at the same time, notably improving vehicle efficiency, encouraging modal shift, accelerating electrification and reducing the manufacturing footprint of vehicles. Lowering embedded emissions in materials and supply chains is especially important for electric vehicles, whose remaining environmental impact is increasingly concentrated in the production phase.

Steel is a strategic priority in this context. It remains the most widely used material in passenger cars and trucks and is the second-largest contributor to greenhouse gas emissions in electric vehicle manufacturing after the battery.

Beyond reducing emissions from primary steelmaking through the deployment of Electric Arc Furnaces (EAFs) fed with Direct Reduced Iron (DRI), provided it is produced with green hydrogen and low-carbon electricity, the sector can also significantly reduce both emissions and material footprint by improving the use of secondary raw materials.

A major opportunity lies in better closing the loop for post-consumer and ELV steel scrap through the removal of excessive residual copper content. Copper is the primary pollutant in ELV steel scrap and its presence has increased steadily over the last two decades notably due to the growing presence of electronics, wiring, comfort systems and powered features in recent vehicles. Its concentration is expected to continue rising if current treatment practices do not evolve.

Reducing residual copper content in ELV scrap would avoid downcycling this high quality steel into lower-grade steel applications (e.g. for use in construction bars as long steel) and would strongly complement the transition from coal-based blast furnace/basic oxygen furnace (BF-BOF) production routes toward DRI-EAF routes. Indeed, EAFs can incorporate much higher shares of steel scrap than BF-BOF routes, including for demanding applications such as high-quality flat steel used in particular in automotive body stamping. In this context, the automotive sector is widely recognised as a major lead market for decarbonised steel and as one of the first sectors capable of absorbing the additional costs and investments associated with more sustainable production routes.

Reliable access to large volumes of high-quality scrap with low copper content would increase operational flexibility for EAF-based producers and provide greater confidence when deciding to replace coal-based BF-BOF capacity. It would also reduce dependence on fossil-gas-based DRI, a transitional feedstock used when hydrogen-based DRI is not yet available or competitive, whose economics remain highly sensitive to methane price volatility, as illustrated during the 2022 energy crisis and subsequent geopolitical tensions.

At the European level, circular economy is a central pillar of the Commission's Clean Industrial Deal presented in February 2025, aimed at strengthening industrial resilience, autonomy and competitiveness. This ambition is also reflected in the Regulation on circularity requirements for vehicles and the management of end-of-life vehicles (ELV Regulation), which replaces the existing 30-year-old ELV Directive, and the to-be-proposed Circular Economy Act (Q3 2026).

The new ELV Regulation, voted by the EU Parliament on the 18th June 2026, includes in particular the opportunity for the EU Commission to adopt delegated acts to set targets for the inclusion of a future mandatory minimum recycled steel content in new vehicles, that will be more precisely defined following an impact assessment by the Joint Research Center of the European Commission. It also includes a provision on copper concentration limits for shredded ELV steel scrap.

The decarbonisation incentives for carmakers are further reinforced by the revision of the CO_2 standards regulation for vehicles proposed by the Commission in December 2025, which includes offset mechanisms linked to green steel incorporation. This creates a direct economic interest for carmakers in securing access to certified low-carbon steel, further strengthening the business case for the entire upgraded scrap value chain.

This report assesses the feasibility and relevance of these ambitions, as well as their implications in terms of resource efficiency, competitiveness, value distribution, resilience of the European industry and its decarbonisation.

Approach: full-scale trials across the entire value chain

To provide an independent and neutral evidence base, the Institut Mobilités en Transition (IMT) proposed a large-scale study involving actors from the entire ELV value chain, namely recyclers (dismantlers (Authorized Treatment Facilities - ATFs) and shredders), steelmakers and automotive manufacturers.

Several representative batches of vehicles (around 220-300 vehicles per trial), reflecting the current ELV fleet in France and Europe in terms of age, type and category, were processed under different dismantling and post-shredding sorting protocols.

All trial protocols involved treatment standards above current average practices, but with varying allocations of effort between **dismantlers** (fluid removal, reusable parts extraction, removal of copper containing parts) and **shredders** (shredding and operator-based manual post-shredding sorting of copper containing parts - to be confronted to other alternatives e.g. automated extraction).

For each trial and processing stage, the study precisely documented quantities and value of recovered materials, quantities of copper extracted, treatment costs, and economic balance for each actor.

The upgraded steel scrap produced during the trials (E40 shredded steel scrap, directly used for steelmaking) was then melted under real industrial conditions to test its suitability for producing high-grade flat steel for automotive applications - which is today still supplied in Europe mainly through the BF-BOF routes.

While the concept itself is not new, the strength of the project lies in bringing together the entire value chain, including carmakers, both to define requirements (quality standards, higher recycled steel incorporation targets) and to analyse the results collectively.

Table ES-1. Presentation of the trials

	Batch content	ATF	Shredder	Measurements
Trial 1	100% ELV	INDRA Re-source ***Deep dismantling:*** *increased, targeted in-depth wire recovery*	Derichebourg *Site 1* *2 post-sorting operators*	Recovered Cu weighted E40 sample recovered according to thorough protocol • 1 large-scale analysis (ArcelorMittal) • 2 laboratory analysis (ArcelorMittal R&D, IRT M2P)
Trial 2	100% ELV	INDRA Re-source ***Medium dismantling:*** *half of the wire content extracted, assumed to be self-financing (INDRA Re-source medium dismantling)*	Derichebourg *Site 1* *4 post-sorting operators*	Recovered Cu weighted E40 sample recovered according to thorough protocol • 1 large-scale analysis (AM) • 1 laboratory analysis (ArcelorMittal R&D)
Trial 3	100% ELV	INDRA Deconstruction Auto Villeton ***Low dismantling:*** *average level of copper wire removal in France.*	Derichebourg *Site 2* *4 post-sorting operators*	Recovered Cu weighted E40 sample recovered according to thorough protocol • 1 large-scale analysis (AM) • 1 laboratory analysis (ArcelorMittal R&D)
Preliminary Trial	Average ferrous feedstock	*None*	Derichebourg *Site 1* *2, 3 then 4 post-sorting operators for 10 days each*	Recovered Cu weighted

The involvement of an independent institute like the IMT with no commercial interest, nor political mandate, was essential to objectively document whether future quality targets are technically achievable, where regulatory incentives are necessary to trigger change and how value can be created and shared across the chain, so that better scrap quality can support both circularity and decarbonisation objectives.

This evidence is particularly valuable for public decision-makers and for the Joint Research Centre of the European Commission, which require robust data to evaluate the optimal pathways for achieving Europe's circular economy ambitions and complement the regulatory framework.

Beyond informing these public stakeholders, the economic data produced by the study were specifically designed to support structured dialogue between economic actors themselves (dismantlers, shredders, steelmakers and automotive manufacturers) on the basis of objective and third-party-documented figures. The aim is to identify an optimal distribution of the additional value generated by circular economy practices, so that this distribution itself acts as a lever for improving ELV treatment standards across Europe.

Key Findings

Key Finding #1
Recovering more copper from end-of-life vehicles creates more value than cost

Extracting copper in the form of wiring harnesses at the dismantler level, or post-shredding copper containing parts at the shredder level requires additional efforts, and generates costs that are systematically offset by the resale value of the recovered copper components within current copper market price ranges. The business case documented in France becomes even stronger in regions with lower labor costs, such as parts of Central and Southern Europe.

This constitutes a very encouraging result for the feasibility of the future regulatory framework. It also enabled the project team to design full-scale optimisation scenarios combining deeper dismantling and reinforced post-shredding sorting, all of which showing positive economic outcomes on the copper recovery perimeter.

However, current contractual arrangements across the value chain do not always provide sufficient incentives for optimal copper removal, on the contrary: today, depolluted vehicle hulks are purchased by shredders on a weight basis only, with no quality indexation linked to dismantling quality. As a result, each copper-containing component extracted by a dismantler must individually justify a net resale value higher than the weight-equivalent value of the hulk it represents. This condition is not always met for smaller or less accessible items. The same applies at the shredder stage: shredded steel scrap (E40) is purchased by steelmakers according to iron ore and steel market prices in Europe or export markets, with no premium awarded for improved quality due to reduced residual copper content. This pricing structure means that neither dismantlers nor shredders are commercially rewarded for producing higher-quality, lower-copper output.

Future regulatory copper concentration thresholds in the ELV Regulation (starting at 0.25% for the main steel fraction of shredded ELVs, and reduced to 0.15% after 5 years) will play a major role in changing incentives.

In addition, market mechanisms could go further and faster. A stable residual copper level below 0.15%, guaranteed on every E40 batch and therefore more demanding than the first average threshold set by the regulation, would be particularly valuable for steelmakers. At this quality standard, post-consumer scrap could be massively incorporated alongside DRI to produce high-grade automotive flat steel.

This higher-quality steel scrap, referred to in the report as **E40+**, could justify a premium over conventional E40 prices. That premium could then cascade upstream: shredders would have stronger incentives to reward better-prepared hulks, and dismantlers would be rewarded for extracting copper containing parts more effectively.

One of the project's core objectives, supported by industrial melting trials at one of ArcelorMittal's plant with the contribution of their R&D department, was precisely to identify which combinations of dismantling depth and shredder sorting deliver these upgraded quality levels.

Key Finding #2
The future 0.25% regulatory threshold for residual copper in ELV steel scrap (main fraction) was achieved in all tested protocols, and the 0.15% level was reached without sophisticated technology.

The full-scale trials combined different levels of dismantling effort (low, medium and deep extraction of copper wires at ATF stage) with different levels of post-shredder sorting intensity (notably through the variation of number of sorting operators on the post-shredding sorting conveyor belt).
Details on the trials are presented in **Table ES-1** and the analysis results are shown in **Figure ES-1**. The results show that :

1. Deep-dismantling strongly facilitates very low copper levels

Residual copper levels close to 0.11% were achieved when copper containing parts were extensively removed before shredding. This allowed to generate a premium-grade E40+ product likely to be valued by steelmakers seeking decontaminated scrap.

2. Limited dismantling at ATF stage still allows compliance with the proposed targets of the upcoming regulation but requires stronger post-shredding action

Where dismantlers recover little copper (as is currently the case for the majority of dismantlers in France, where on average only 13%[1] of the copper wires contained in ELV are recovered, a level broadly representative of practices across Europe), the 0.25% threshold can still be achieved, and possibly 0.15% as well, but only if shredders reinforce sorting through additional operators or automated systems.

3. Medium dismantling combined with reinforced post-shredder sorting also performs well

Systematic removal of accessible wiring bundles, main connectors and of some small electric motors included in parts removed for resale, followed by robust post-shredding sorting (manual or possibly automated), also delivered copper levels below 0.15% in the trial conditions.

1 ADEME (2024), Données Automobiles 2022, https://librairie.ademe.fr/

In short, the 0.25% regulatory target appears broadly achievable, while 0.15% is also realistic through several practical combinations of improved treatment methods.

Key Finding #3
Value sharing for E40+ scrap is possible without disrupting the existing industry structure. Premium levels needed to support best practices along the value chain can be roughly estimated.

The study indicates that a fair distribution of the additional value created by upgraded low-copper E40+ scrap can be achieved through reasonable premiums between actors, without requiring vertical integration or a redesign of the current value chain.
The report provides an economic analysis including, at each stage of the value chain :

- additional treatment costs;
- value generated through copper recovery;
- value lost through reduced copper weight in the vehicle hulk after upstream extraction;
- higher downstream value of upgraded scrap;

Based on this analysis, the report estimates the order of magnitude of the premiums that would need to be considered between dismantlers and shredders for well-prepared low-copper hulks, and between shredders and steelmakers for E40+ scrap. Indeed, Key finding #1 shows that the revenue from copper sales compensates for the additional costs incurred by the ATF for deep-dismantling. However, this net cost balance is not an incentive per se to implement best practices. The study investigates the possibility of a price premium for deep-dismantled ELV hulks, referred to as "hulk+" in the study. This would provide an economic incentive for ATFs and reward the value created throughout the rest of the value chain. Figure ES-2 illustrates the minimum premium for E40, as a function of copper and hulk market prices, for the French case (labor cost being a key parameter).
The analysis was conducted for France as a base case and is designed to be adaptable to other Member States, with sensitivity analysis covering variations in labor costs (particularly relevant for Central and Southern Europe, where the business case for additional copper recovery is even stronger) and commodity price

ranges for both copper and steel scrap. According to these calculations, with a copper wire price of 2500€/t and a 15% increase in hulk price (+15€/t), there should be an 10% increase in E40+ price (around +30€/t). All prices and calculations are based on market conditions at the time of the report and should be interpreted in the context of large-scale market deployment rather than small or punctual volumes, which may not reflect the same economic dynamics.

These estimated values provide a practical basis for dialogue between market participants.
The overarching conclusion is that all actors can economically incentivise one another to improve practices, provided that upgraded quality is recognised and rewarded in commercial transactions.

FIGURE ES-1. Measurements of the residual copper in E40 for the ELV Trials

Average of the 3 samples measurements for each of the 3 ELV Trials

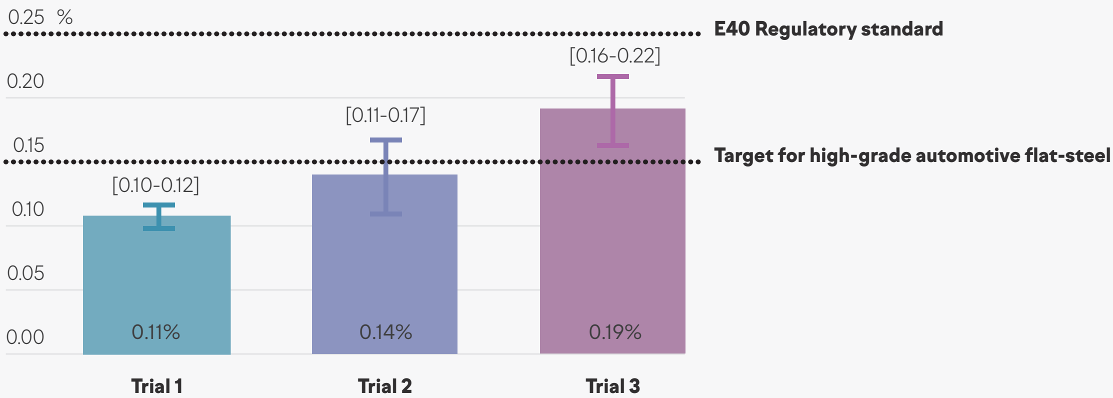
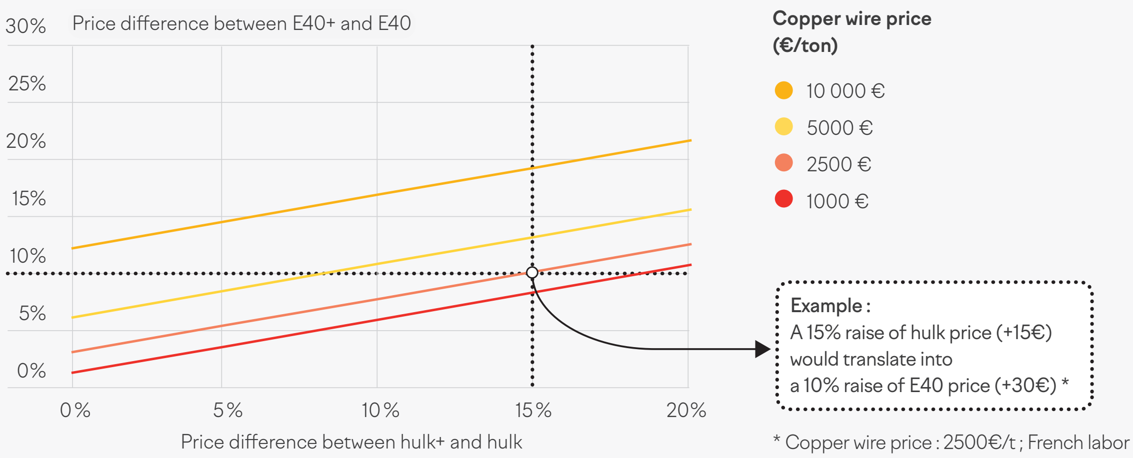


FIGURE ES-2. Estimation of the price premium for E40+ required to offset the shredder's losses

Based on the premium paid to the dismantler for Hulk+ and the price of copper wires.
Labor cost considered : French. Hulk base price : 100€/t, E40 base price : 300€/t.



CONTEXT & CHALLENGES

Decarbonizing the automotive industry requires decarbonizing steel production. Improved end-of-life vehicle recycling will contribute to that objective.

Emissions from the transport sector account for 23% of global energy-related CO_2 emissions (tailpipe emissions), and 70% of direct transport emissions are due to road vehicles.[2] In the current context of climate change, decarbonizing the mobility and transport sector is crucial. As part of the EU's climate commitments, the transport sector is required to achieve a 90% reduction in GHG emissions by 2050 compared to 1990 levels.[3]

2 IPCC Working Group III (2022), Climate Change 2022 Mitigation of Climate Change (Sixth Assessment Report), doi: 10.1017/9781009157926.012

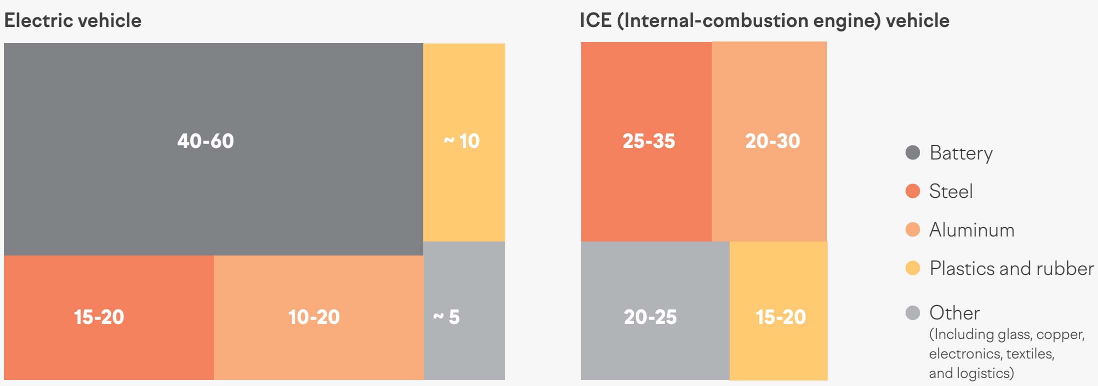
3 European Commission (2020), Sustainable and Smart Mobility Strategy, COM/2020/789 final — CELEX:52020DC0789

Alongside modal shift, electrification of transport (in particular of passenger cars, light commercial vehicles and trucks) is required to tackle road transport vehicle emissions.

However, for decarbonization to be effective, reducing tailpipe emissions through electrification must go hand in hand with a reduction of embedded emissions due to vehicle production. Steel represents 25 to 35 % of embedded upstream emissions for an ICE vehicle, and 15 to 20 % for a BEV (**Figure 1**).

FIGURE 1. Typical upstream battery-electric-vehicle emissions (%)

Typical embedded emissions of an electric vehicle vs a combustion vehicle: steel is the second largest source of embedded emissions after the battery



Including all upstream emissions from raw material extraction to the OEM, including logistics.

Source: McKinsey & Company, 2023 (The race to decarbonize electric-vehicle batteries)
https://www.mckinsey.com/industries/automotive-and-assembly/our-insights/the-race-to-decarbonize-electric-vehicle-batteries

The automotive sector represented about 19% of steel consumption in the European Union in 2025 (~26Mt).[4] In the EU, a typical passenger car currently uses an average of 800-900 kg of steel, making up approximately 50-66% of the vehicle mass, depending on its age, model, segment and powertrain type.[5] About 58% of the steel is used in the body[6] and 80% of the steel in the body consists of flat steel[7] and thus requires a very low copper contamination rate to meet the required high quality steel specifications set by the car makers. This flat steel produced in the EU is mainly produced through the BF-BOF route[8] and the steel scrap incorporation rate is inherently technically limited to a maximum of 15-20% (pre- and post-consumer scrap).[9] The post-consumer scrap use in the BF-BOF route is very low and represents only a few percent at maximum today, notably also due to the high copper concentration levels.

The EU aims to decarbonize its steel production, using regulatory incentives, obligations and protections, such as EU ETS and CBAM, while the recently announced Industrial Accelerator Act (IAA) aims at accelerating the "industrial investment and decarbonisation in strategic sectors" such as the steel industry.[10] In parallel, the ELV Regulation may introduce mandatory recycled content targets for steel in new vehicles as well as mandatory quality requirements for steel scrap from ELVs, amending the ELV Directive that had been regulating the ELV management for almost 30 years.[11]

It is acknowledged by all industrial stakeholders that the decarbonization of the steel industry will require progressive decommissioning of the BF-BOF route and the development of decarbonized DRI furnaces combined with EAFs. The switch to EAF will also allow a larger incorporation of scrap quantities, provided that the quality of this scrap can drastically be improved. The use of steel scrap in EAFs using green H_2-DRI could contribute to the reduction of GHG emissions in steel production and limit the need for primary raw material's extraction. More importantly in the decision process to decommission BF-BOF and move to EAF for high performance flat steel production, from a resource diversity supply standpoint, including some geostrategic autonomy issues, the access to high quality steel scrap plays a key role. Indeed it provides agility and flexibility in feedstock in the context of energy crisis and huge price volatility (especially if CH_4-DRI supply is temporarily considered until H_2-DRI is largely available and affordable). From an agility, competitiveness, supply and security perspective, the development of a much larger circular steel usage (closed loop recycling and supply) is essential to secure the EU clean industry ambition plan and investment decisions (BF-BOF decommissioning and replacement).

As the automotive sector is a key consumer of the steel industry and has particularly stringent requirements, successfully demonstrating the possibility of an increased recycled steel usage in this industry would encourage other sectors to follow suit.

In light of this and considering that the automotive industry will be a lead market for the development of near-zero steel production, we decided to study the challenges surrounding circularity in the automotive scope. Therefore, we set the focus on the required conditions for implementing increased ELV recycling. This study is dedicated to the challenge of managing decarbonized steel production with a focus on the car's life cycle to assess the contribution of end-of-life recycling to this ambition.

4 Eurofer (2025), Economic and steel market outlook 2025-2026 Q4 report, https://www.eurofer.eu/assets/publications/economic-market-outlook/economic-and-steel-market-outlook-2025-2026-fourth-quarter/EUROFER-Economic-and-Steel-Market-Outlook-Q4-2025.pdf

5 ICCT (2024), Technologies to reduce greenhouse gas emissions from automotive steel in the United States and the European Union, https://theicct.org/wp-content/uploads/2024/07/ID-158-%E2%80%93-Green-steel_final.pdf

6 Argonne National Laboratory, Center for Transportation (2022), Greenhouse gases, Regulated Emissions, and Energy use in Technologies Model (2022 Excel), https://doi.org/10.11578/GREET-Excel-2022/ dc.20220908.1

7 Metals Consulting International (2024), Automotive steel weight analysis, https://www.steelonthenet.com/files/automotive.html

8 Xerfi (2022), La filière sidérurgique en France, https://www.xerfi.com/presentationetude/le-marche-de-la-siderurgie_MET12; ADEME, Deloitte, (2023) Etude du potentiel d'amélioration du recyclage des métaux en France, https://www.actu-environnement.com/media/pdf/news-43668-potentiel-amelioration-recyclage-metaux.pdf

9 Currently, scrap demand is adequately met by the availability of home and pre-consumer scrap. However, this situation is likely to evolve in the coming years due to the growing demand for steel scrap (in EAF) and finite volume of pre-consumer and home scrap available, EUROFER (2019), Low Carbon Roadmap, Pathways to a CO_2-neutral European Steel Industry, https://www.eurofer.eu/assets/Uploads/EUROFER-Low-Carbon-Roadmap-Pathways-to-a-CO_2-neutral-European-Steel-Industry.pdf

10 European Commission (2026), Industrial Accelerator Act: strengthening Europe's clean industrial base, https://ec.europa.eu/newsroom/growth/items/928572/en

11 When reference is made to the ELV Directive, this refers to the Directive 2000/53/EC of the European Parliament and of the Council of 18 September 2000 on end-of life vehicles; when reference is made to the ELV Regulation, this refers to the Regulation on circularity requirements for vehicle design and on management of end-of-life vehicles, adopted by the Parliament in plenary the 18th June 2026, https://www.europarl.europa.eu/doceo/document/TA-10-2026-0227_EN.html.

Current and future steel production route

Steel is mainly produced from mined iron ore, reduced at high temperatures for the production of various steel categories.

Worldwide, approximately 1.9 billion tonnes of steel are produced yearly,[12] making the sector responsible for around 11% of global CO_2 emissions and over 8% of global GHG emissions.[13] In Europe, the steel industry accounts for 5% of the EU's total GHG emissions and over a quarter of its industrial emissions, a disproportionately high share driven by the continued dominance of the blast furnace - basic oxygen furnace (BF-BOF) route, which still represents over 50% of EU steel production and remains essential for producing the high-quality flat steel grades demanded by the automotive sector.[14]

The traditional steelmaking process, also called primary steelmaking, reduces the iron ore at high temperatures through the addition of coal and oxygen in a blast-furnace (BF). The produced iron then enters a basic oxygen furnace (BOF), to which up to 15-20% of steel scrap (mainly pre-consumer scrap, and a few variable percentages of post-consumer scrap) can be added for the production of crude steel. This crude steel is then processed in so-called secondary metallurgy to reach the required compositional characteristics.

The primary route of steel production is very GHG intensive, in particular due to the use of coal in the BF. The secondary route produces steel from steel scrap in Electric Arc Furnaces (EAF). To date in Europe, this route is mainly used for the production of long steel.

A new technological route has appeared in recent years intended to reduce GHG emissions through the use of hydrogen as a reduction agent of iron ore in the solid state. This Direct Reduced Iron (DRI) technology is already used regionally with the injection of natural gas but has been implemented only on a limited scale with hydrogen (HYBRIT (SSAB, LKAB & Vattenfall), Sweden)[15].

This new H_2-DRI route reduces iron ore with hydrogen in a direct reduction plant. The produced DRI can then be melted to steel in an EAF.

Not only is the production of steel through the H_2-DRI-EAF route less GHG emitting thanks to the use of decarbonized electricity[16] (for H_2 electrolysis, energy supply of the DRI, EAF plants etc.), but the use of EAF allows the introduction of higher amounts of steel scrap. In comparison to the BF-BOF route, which can only accept up to 20% of steel scrap, an EAF can today theoretically accept up to 100% steel scrap (up to 60% for high grade steel production)[17].

Indeed, steel is technically highly recyclable provided it is not polluted and depending on the quality and composition of the steel scrap, the type of alloys and the type of steel produced. The recycling of steel scrap for steel production could help decrease the carbon footprint of a steel product and limit the need to extract primary raw materials.[18]

In the current context of non-secured availability of green H_2, the sourcing of depolluted steel scrap to enter EAFs, including for the production of high-quality flat steel, provides increased flexibility to steelmakers, both short and long-term. This is a securing element for the strategic roadmap of the steel industry, which requires important and substantial investment decisions in low-carbon production infrastructures, in particular in H_2-DRI facilities. However, various postponements of planned investments across the EU are slowing down this transition. As a result, reliance on scrap in the short to medium term might be necessary to compensate for the delayed deployment of European H_2-DRI.

12 World Steel Association (2024), World Steel in Figures, https://worldsteel.org/data/world-steel-in-figures-2024/

13 Global Efficiency Intelligence (2022), Steel Climate Impact An International Benchmarking of Energy and CO_2 Intensities, https://www.globalefficiencyintel.com/steel-climate-impact-international-benchmarking-energy-co2-intensities

14 Sandbag (2024), A closer look at 2023 emissions: steelmaking caused a quarter of industry pollution, https://sandbag.be/wp-content/uploads/Sanbag_Brief_October24_A-closer-look-at-2023-emissions-1.pdf; Beyond Fossil Fuels (2025), The State of the European Steel Transition, https://beyondfossilfuels.org/wp-content/uploads/2025/03/The-State-of-European-Steel-Transition_Report.pdf

15 HYBRIT (2024), Six years of research paves the way for fossil-free iron and steel production on an industrial scale, https://www.ssab.com/en/news/2024/08/hybrit-six-years-of-research-paves-the-way-for-fossilfree-iron-and-steel-production-on-an-industrial

16 ICCT (2024), Technologies to reduce greenhouse gas emissions from automotive steel in the United States and the European Union, https://theicct.org/wp-content/uploads/2024/07/ID-158-%E2%80%93-Green-steel_final.pdf

17 Nucor (2023), 2022 Recycled content averages for Nucor steel mill products, https://nucoryamato.com/StaticData/RecycledContent.pdf; ICCT (2024), Which automakers are shifting to green steel? An analysis of steel supply chains and future commitments to fossil-free steel, https://theicct.org/wp-content/uploads/2024/09/ICCT-Green-Steel-Supply.pdf

18 ICCT (2024), Technologies to reduce greenhouse gas emissions from automotive steel in the United States and the European Union, https://theicct.org/wp-content/uploads/2024/07/ID-158-%E2%80%93-Green-steel_final.pdf

A dynamic regulatory framework related to end-of-life vehicles

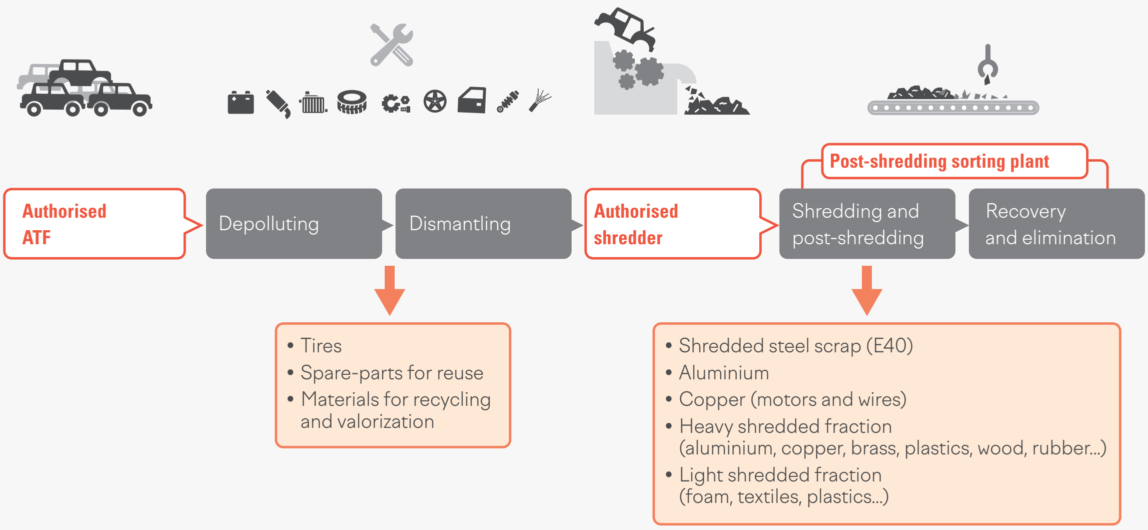
In order to understand the economic and commercial challenges related to ELV deep-dismantling or strengthened post-shredding sorting, it is important to examine the organization of the ELV value chain, including its traditional division of labor and value distribution.

The business of scrap metal from ELVs is organized around the collection, separation, depolluting, treatment and transformation of scrap metal by a range of specialized players, with very diverse activities (**Figure 2**).

Under the current European ELV Directive (in force since 18 September 2000), an end-of-life vehicle must first pass through a specific collection point, namely an Authorized Treatment Facility (ATF). This Directive contains some mandatory extraction stages and mandatory reuse or recovery targets of 95% (spare-parts and material, of which at least 85% of material recycling). However, it does not specify how this target is to be achieved and does not set any specific targets regarding the quality of the produced recycled material. Moreover, the dismantler's profession developed around the recovery of spare-parts, leaving low attention to the recovery of materials. This led to a rather counterproductive material recovery model, in which the price of the hulk sold to the shredder barely reflects the quality or quantity of materials remaining after depolluting and spare parts removal. Only the progressive increase of material value led to increased material separated recovery over the past decade. However, it remains a relatively recent phenomenon, and its viability is too sensitive to market price volatility to constitute a sustainable practice. The shredder then reduces the hulks and, depending on the process, sorts the scrap through manual and/or automated mechanism, to eventually sell the produced E40 to steelmakers (more details provided in *Improving scrap quality through deep-dismantling and post-shredding deep-sorting: advantages and disadvantages*).

The new ELV Regulation aims at filling this gap by introducing mandatory quality targets for the recovery of certain materials, as well as boosting the demand for these recycled materials through the introduction of mandatory recycled content targets, particularly for steel.

FIGURE 2. Explanatory schematic of the ELV value chain



Source: IMT, ADEME.

Current and future European regulatory framework on ELVs

The ELV Directive, implemented in 2000, marked the EU's initial effort to establish a unified framework ensuring environmentally responsible treatment of ELVs. The Directive sets clear targets for ELVs and their components regarding reuse, recycling and recovery obligations. It aims to prevent and limit waste from ELVs and improve the environmental performance of all economic operators involved in the life-cycle of vehicles. It has often but not significantly been amended in the last decades. Its review launched in 2021 resulted in a proposal for a new Regulation in 2023, merging it with the type-approval of vehicles for reusability, recyclability, and recoverability (3R type-approval Directive) to cover the entire lifecycle of a vehicle, from its design and market entry to its final treatment at the end-of-life stage.

Increasingly, European regulation tends to foster recycling and circularity in the automotive industry. While the current ELV Directive already imposes general average recycling rates (minimum 85% recycling and reuse ratio applying to the total mass of a vehicle), the upcoming ELV Regulation will assess the introduction of mandatory recycling targets of various metals to foster material recycling, in particular through the obligation to increase the quantity of recycled steel in new vehicles (Article 6).

Indeed, while the current Directive contains an obligation at Annex I to remove metal components containing copper at the dismantling stage if they are not segregated in the shredding process, it does not define specific targets regarding the quantities of copper to be removed. The upcoming regulation is intended to rectify this gap.

The latest version of the ELV Regulation was adopted by the European Parliament on the 18^{th} June 2026 and by the Council on the 29^{th} June 2026. It introduces two key provisions on steel recycling.

First, it introduces prescriptive treatment requirements for ELVs through Annex VII Part G, which sets quality standards governing dismantling, mixed shredding, and landfilling of shredder residues, notably including a copper contamination limit in the main steel fraction set at 0.25%, tightening to 0.15% after 60 months.

Second, it requires a feasibility study on steel recycled content in new vehicles (Article 6(7)) which should be conducted by the Joint Research Center (JRC) of the European Commission within 12 months. A delegated act shall then be adopted within 24 months to set recycled steel content targets and a calculation methodology. The JRC launched a stakeholder consultation survey during the first quarter of 2026 and will proceed to various technical workshops over the course of the year to ensure that any future targets are technically feasible, economically viable, and aligned with the realities of the automotive value chain.

It is worth noting that the ELV Regulation does not include any specific provisions regarding the calculation or verification methods for the quality requirements applicable to output fractions. No indication is given as to how compliance should be controlled or demonstrated regarding the residual copper in the main steel fraction. In our interpretation, two enforcement pathways could therefore be considered: unannounced spot checks verifying that, at any given moment, the main steel fraction (E40) meets the threshold values regardless of the share of ELVs processed - a relatively demanding approach for shredders and the control body - or alternatively, an average compliance demonstration over a defined reference period (e.g. 3 months to 1 year), combining precise input/output reporting with an annual performance test of the shredder carried out on a dedicated ELV batch, with a methodology that could be developed by or commissioned to the JRC.

In that sense, regulatory compliance alone is insufficient to ensure a steady, low copper content in E40 scrap and does not guarantee a consistency on day-to-day operations, as a voluntary commercial standard could provide. This is why our trial protocols investigated the technical and economic conditions required to achieve a stable level of decontamination that would offer steelmakers the reliability they need.

This study is part of a broader, highly dynamic, and emerging European regulatory framework concerning the steel and automotive sectors. Whilst the review of the ELV Directive, which dates back almost 30 years, began in July 2023, recent months have not only seen concrete progress on updating the Directive, but have also been accompanied by growing attention to steel decarbonization within both the policy debate and the European regulatory agenda.

Thus, without going into detail in this report, it is important to highlight that steel decarbonization has become a key priority in current EU policies. It is for example a central component of the Industrial Accelerator Act, but it has also been introduced into the

Commission's Automotive package proposal, where from 2035, up to 7% of tailpipe emissions reduction target would be able to "be compensated through the use of low-carbon steel Made in the Union".[19]
More specifically, with regard to recycling and circularity, greening steel production will remain high on the agenda of the upcoming legislative developments and negotiations, in particular as part of the future Circular Economy Act.

Contribution of the Car-to-Car study to the debate surrounding the regulatory framework
Through the full scale trials conducted in 2024/25 and 2025/26, we wished to contribute to the reflection and dialogue between stakeholders and policymakers by developing an initial contribution to the decarbonization of steel through enhanced circularity in the automotive steel production. The study introduces technical and economic data to the debate regarding the potential of using recycled ELV steel to reduce new vehicle's embodied carbon footprint.

This report aims at determining how and at what extra cost if any, an improved steel scrap quality can allow and foster an ambitious mandatory recycled steel content in new vehicles, as it will be evaluated in the future Impact Assessment of the JRC commissioned in the frame of the ELV Regulation.

19 European Commission (2026), Commission takes action for clean and competitive automotive sector, https://ec.europa.eu/newsroom/growth/items/928572/en.

Copper contamination of steel scrap

Increasing the share of recycled steel in new vehicle production (including potentially from ELVs) as may be required under the new ELV Regulation hinges on improving scrap quality. To that end, the Regulation also sets maximum copper contamination thresholds for the main steel fraction, namely 0.25% upon entry into force, tightening to 0.15% after 60 months.
Currently, E40 scrap from ELVs is mainly downcycled and for a significant part (around 20%) exported outside the EU for use in construction bars (long steel), as its quality does not meet the required standards for an extensive usage for the production of high-quality automotive flat steel.[20] Indeed, high levels of contaminants, particularly copper, prevent this steel scrap from meeting the necessary mechanical and technical properties required by the automotive industry to be used as feedstock for the production of high-quality flat steel. Copper cannot be removed in steelmaking, unlike other elements (like Al, Zn, Si, S, P and non-metallics), and it can cause casting, deteriorated surface quality, coating, and welding problems as well as become a potential unwanted hardening element (for soft drawing grades).
Historically, steelmakers have dealt with this problem through a dilution strategy: rather than completely removing impurities, notably copper, they would mix contaminated scrap with cleaner material (notably primary raw material) and pre-consumer scrap, effectively reducing the concentration of pollutants to acceptable levels.[21] This method has been sufficient for maintaining scrap quality - until now.
Recent years have witnessed a significant increase in copper content within ELVs, primarily driven by the increasing electronification of vehicles and the associated exponential growth of copper wires. This trend shows no sign of slowing down and the situation is set to deteriorate further for two compounding reasons. First, the copper content in vehicles has tripled over the last

20 According to recent analysis by the JRC, higher export volumes of European scrap can be attributed to weak domestic demand, export restrictions of steel scrap or bans implemented in other regions, which shifted the global demand towards increased scrap sourcing from the EU (Joint Research Center (2025), Analysis of the EU Steel supply chain - Characterisation & use of EU steel scrap in relation to global trade dimensions, https://publications.jrc.ec.europa.eu/repository/handle/JRC143881).

21 Daehn et al. (2017), Environmental Science & Technology, How Will Copper Contamination Constrain Future Global Steel Recycling?, https://www.researchgate.net/publication/316502506_How_Will_Copper_Contamination_Constrain_Future_Global_Steel_Recycling

20 years and will continue to grow with electrification: while an ICE vehicle contains approximately 20 kg of copper, a BEV requires around 80 kg,[22] meaning that vehicles produced today and in the years to come will contain far more copper than current ELVs, which are on average 20 years old and already causing significant problems (cf. *Current and future copper contamination*). Second, steel currently in circulation already contains a share of recycled steel and thus diluted copper, a contamination that is likely to worsen incrementally over time, gradually eroding the dilution potential of scrap.[23] Without improved end-of-life management processes, future steel production faces the risk of reaching residual copper contents close to 0.8% in E40 scrap. If left unaddressed, copper concentrations could surpass manageable levels to a point where even highly tolerant steel grades such as construction steel may become unattainable due to excessive copper content, presenting a growing concern not only for EU scrap quality but also for exported scrap outside the EU.

22 International Copper Association (2017), The Electric Vehicle Market and Copper Demand, https://internationalcopper.org/wp-content/uploads/2017/06/2017.06-E-Mobility-Factsheet-1.pdf

23 Dworak, Rechberger, Fellner (2022), How will tramp elements affect future steel recycling in Europe? – A dynamic material flow model for steel in the EU-28 for the period 1910 to 2050, Resources, Conservation and Recycling, https://doi.org/10.1016/j.resconrec.2021.106072

During the project, we first explored the potential of manual dismantling of copper wires at the ATF stage, because copper wires represent a major contamination factor of E40. This was the subject of our first report *Car to car Steel* published in March 2025. As a second move, we added the exploration of the potential of manual post-shredding deep-sorting, to remove small rotors and motors in addition to residual copper wires.

Understanding copper distribution in vehicles: wiring harnesses and electric motors

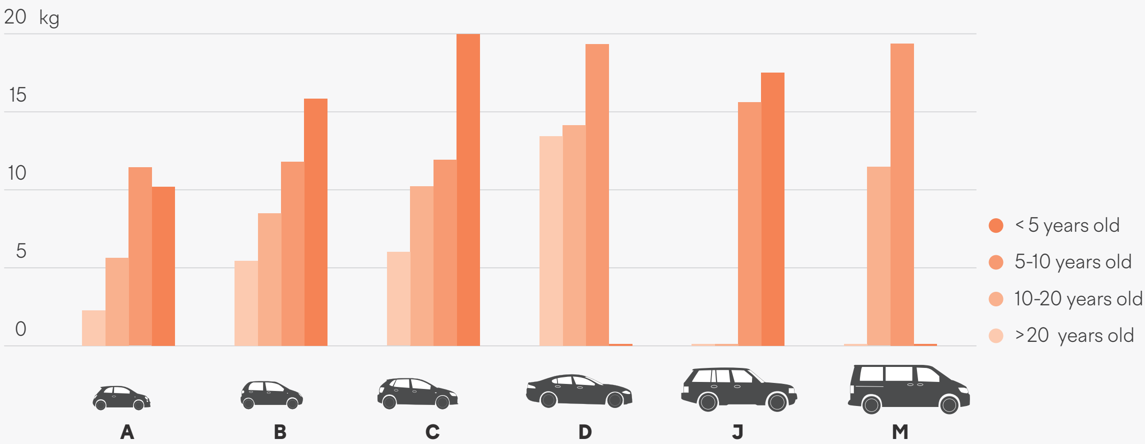
Copper in vehicles is present as copper wires and small motors and rotors. Indeed, copper is an excellent conductor, enabling the transfer of energy and information to different parts of the vehicle.

Copper wires

The volume of copper wires present in vehicles was estimated, depending on their age and segment. The results are shown in **Figure 3**.

Different sizes of harnesses are available for different applications, as well as high-voltage and low-voltage harnesses, classified in various systems (AWG, mm²...). Larger cable bundles are easier to remove compared to their thinner counterparts. The thinner

FIGURE 3. Evolution of the copper wires content in vehicles in kg per categorie



The data from the sample that has been analysed during this trial is representative of the current French and European ELV market.

Car categories help position each model in the automotive market. In Europe, categories are defined alphabetically:
A: Small city cars (e.g., Renault Twingo), B: Versatile city cars (e.g., Peugeot 208), C: Compact sedans (e.g., Renault Mégane),
D: Family sedans (e.g., Peugeot 408), E: Large executive sedans, F: Luxury limousines, J: SUV and pick-ups (e.g., Volkswagen Tiguan)
M: Multi-purpose-vehicle (e.g., Renault Scénic).

bundles, typically measuring 0.35 to 0.5 millimeters, are more concealed and present greater challenges during extraction at the dismantling stage. The predominant bundles are the larger ones, primarily composed of main harnesses with their primary and secondary branches. When successfully removing these larger harness sections, approximately 75% of the total cable network can be removed.

The main aim of an efficient cable attachment technique is to ensure a secure fastening that effectively prevents unwanted movement and minimizes potential noise generation. Among the various cable attachment methods currently available, staple-based fasteners have emerged as the most preferred approach. These attachments are engineered with a strong emphasis on durability and structural integrity, which consequently makes them difficult to remove. Indeed, in the current design process, the priority is currently placed on creating a robust mounting solution rather than facilitating easy disassembly.

Other attachment methods already exist such as adhesive plates, used for the construction of certain licence-free vehicles, which have a shorter lifetime than classic passenger cars (around 10 years vs. 20 years[24]).

Attaching the wires differently would require some R&D, but one could already think about attaching cables with hook-and-loop fasteners (Velcro® type) or other new methods, easily removable while remaining efficient and not leading to anticipated obsolescence. It must also be noted that some small copper wires can already be replaced with aluminum wires and do not pollute the steel scrap. Nevertheless, due to its properties, aluminum will not replace all copper wires.

Small motors

Modern vehicles incorporate an increasing number of small electric motors used across a wide range of functions, including comfort, safety, and auxiliary systems. These can include motors for windows, seats and mirrors, as well as pumps (fuel, cooling…), fans and Heating Ventilation and Air Conditioning (HVAC) systems, and various sensors such as those used in All Brakes System (ABS) or electric power steering. This trend is driven by the progressive electrification of vehicle functions, replacing mechanical components with electrically powered devices. As a result, a single vehicle can contain several dozen to even a few hundred electric motors, depending on its level of equipment. In electric vehicles, this phenomenon is further amplified by the addition of traction motors alongside an even greater number of auxiliary systems.[25]

24 ADEME (2023) Véhicules : données 2021 - Rapport annuel, https://librairie.ademe.fr/.

25 Texas Instruments (2020), How many electric motors are in your car, https://www.ti.com/lit/ta/sszt241/sszt241.pdf?ts=1775223263379

Increased copper removal from ELVs not only improves steel scrap quality, it also improves copper recycling rates, as an increasingly present metal in our vehicles. Copper is an essential material for the energy transition and as demand is growing, it is therefore crucial to recover and treat it properly.

Improving copper recycling is even more important today since the concentration of copper mines around the world decreases[26] and that the availability of currently planned and financed mining projects may not meet anticipated copper demand over the decade 2020-2030. In that context of an imbalance between supply and demand, price pressures and shortages can be expected.[27]

Moreover, the declining ore grade of copper mines might increase the mining environmental footprint and operating costs. As a matter of example, the average extraction concentration of copper ores could decrease by 1.5% to 3.7% every year over the upcoming decades, despite improved extraction and refining processes.[28]

26 Vidal (2018), Ressources minérales, progrès technologique et croissance, https://doi.org/10.4000/temporalites.5677

27 WWF, IMT, EY (2023), Métaux critiques: l'impasse des SUV Quel scénario pour réussir la transition de nos mobilités ?, https://www.wwf.fr/sites/default/files/doc-2023-11/WWF_Rapport%20Me%CC%81taux%20Critiques_0911_HD.pdf

28 Northey, Mohr, Mudd,Weng, Giurco (2014), Modelling future copper ore grade decline based on a detailed assessment of copper resources and mining, https://doi.org/10.1016/j.resconrec.2013.10.005; WWF, IMT, EY (2023), Métaux critiques: l'impasse des SUV Quel scénario pour réussir la transition de nos mobilités ?, https://www.wwf.fr/sites/default/files/doc-2023-11/WWF_Rapport%20Me%CC%81taux%20Critiques_0911_HD.pdf

Improving scrap quality through deep-dismantling and post-shredding deep-sorting: advantages and disadvantages

Scrap quality can be improved at two stages, either at the ATF through in-depth manual extraction of key polluting parts (deep-dismantling), or at the shredding plant through advanced post-shredding treatment and sorting (deep-sorting). Both techniques are considered to be complementary, since both have their strengths and weaknesses. However, for the matter of differentiated and precise analysis, it is necessary to test and document separately both technical approaches to identify their respective impacts, benefits and limits.

Management of ELVs (France case)

France has approximately 1,700 ATFs distributed across the country, with significant disparities in size and operational practices. ELVs undergo several extraction stages at these facilities to remove components and materials for reuse and recycling. The remaining vehicle hulk and residual materials are then sent to shredders. By comparison, only around 50 shredders operate across France, with considerable differences in processing capacities and in the post-shredding treatment used methods.

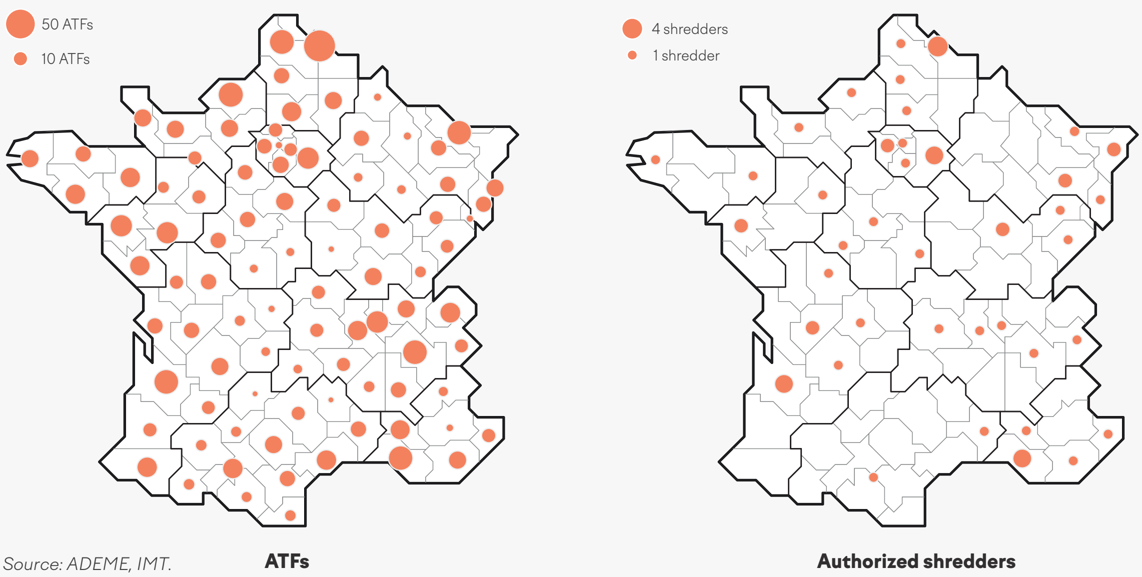
Ecosystem of ATFs

The ecosystem of dismantlers in France (and in Europe) is highly disparate and often simply organised, since it was historically built around small scrap yards focused on the removal of steel scrap or spare parts. Thus, the extraction capacities and business models of this ecosystem are very diverse. More recent and more industrialized dismantlers such as Re-source by INDRA have better extraction capacities than average French dismantlers.[29] Depending on their commercial strategy, dismantlers can choose to focus primarily on selling spare parts for the reuse market or generate additional revenue by recovering and sorting specific materials, which are then valorized separately from the hulk.

Despite the large variety of practices, the current ELV Directive does set out certain obligations for ELV management. When a vehicle arrives at an ATF, it must be depolluted according to the procedure laid down in

29 ADEME (2024), Données Automobiles 2022, https://librairie.ademe.fr/

FIGURE 4. Number of ATFs and authorized shredders per department



Source: ADEME, IMT.

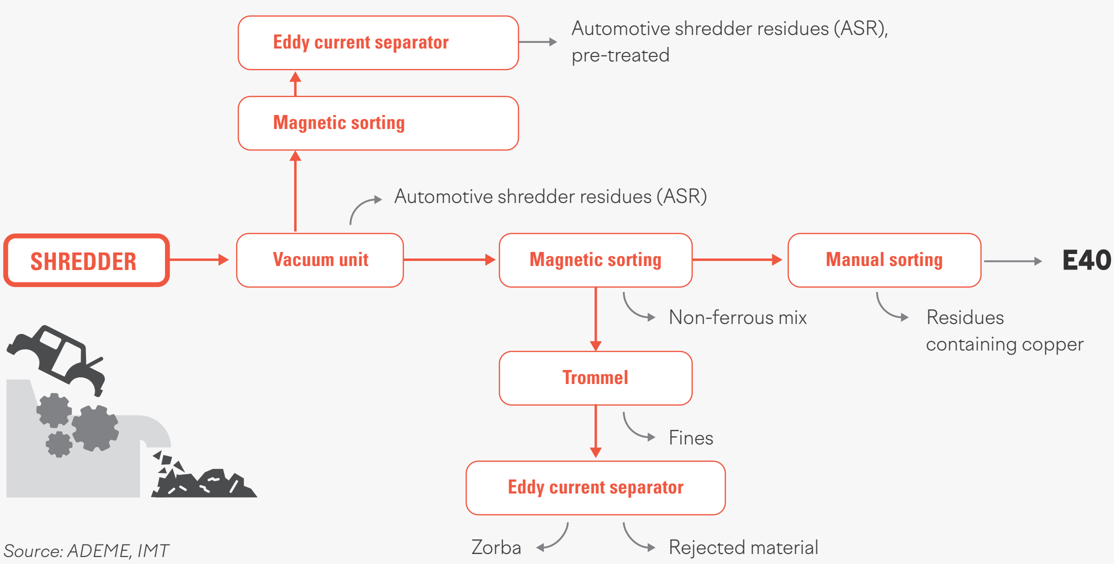
the Directive, which requires the removal of certain fluids (oils, coolant, brake fluid, air conditioning fluid) and parts (such as tires, batteries, catalytic converters, polluting materials containing lead, mercury, or certain chemicals). Dismantlers must also remove some materials to achieve the vehicle recycling and valorization targets contained in the Directive, as mentioned above (Cf. p.14 *A dynamic regulatory framework related to end-of-life vehicles*). Depending on the existence of suitable recovery channels and an attractive market value, other parts and materials can be removed too. In terms of re-use, for example, certain parts such as internal combustion engines can represent a large part of the business model of certain dismantlers, while in terms of materials, the recycling of aluminium, polypropylene and copper has also partly been developed. However, most dismantlers still leave several parts and materials in the hulk, driven by economic considerations. Indeed, leaving some materials in the vehicle can be more profitable than their removal, especially if the value of the extracted material is lower than their sale price as a hulk (which is a price per kilo). Additionally, lack of manpower or space may discourage dismantlers from proceeding to deeper material extraction operations.
As a result, the quantities of non-ferrous materials remaining in the hulk are significant and will only be partially extracted at the shredding stage following magnetic sorting and manual or automated sorting. Combined with the ever-increasing levels of pollutants content such as copper in vehicles E40, steel scrap quality is declining if no action are taken to sort copper wires and devices. The average residual wire rate in hulks sent to shredders in France today is of 87%[30].

The ecosystem of shredders

In contrast, the ecosystem of shredders in France is far more concentrated and industrialized, reflecting the capital-intensive nature of shredding operations. France relies on a limited number of large-scale facilities, operated by established industrial players, with significant variations in design, processing capacities and technological sophistication, leading to variable impurity removal capacities. The concentration of shredder infrastructure, combined with high investment requirements, also influences the geographical organization of flows, as ELVs and hulks are often transported over longer distances to reach these facilities.
Despite a variety of processes, most shredders function according to a common operational principle, which is illustrated in the following model (**Figure 5**). The shredder receives scrap metal from various sources (notably from ATFs, with which the shredders build partnerships). The shredder then reduces the size of the ferrous feedstock (composed of ELVs, household appliances, construction waste etc.) and extracts

30 ADEME (2024), Données Automobiles 2022, https://librairie.ademe.fr/

FIGURE 5. Typical shredding and post-shredding process and material flows



Source: ADEME, IMT

certain materials and pollutants (metallic, ferrous and non-ferrous fractions, non-recyclable fractions (steriles), etc.) using magnets, eddy currents, vacuum units, trommel and manual or automated sorting techniques. While some shredders are equipped with advanced post-shredding technologies enabling finer material separation and higher recovery rates, others operate with more basic configurations, resulting in heterogeneous performance levels across the sector. The extracted non-ferrous materials are then sold to specific valorization routes or disposed of, while the steel scrap is sold to steelmakers as E40 scrap for re-use in steel production. Depending on the scrap quality, the produced steel and the type of furnace (BF, EAF,...) the E40 used quantity will vary. The performance of the shredders is monitored during annual audits, including shredding trials with closely monitored and documented material flow reporting.

Advantages and disadvantages of these two methods

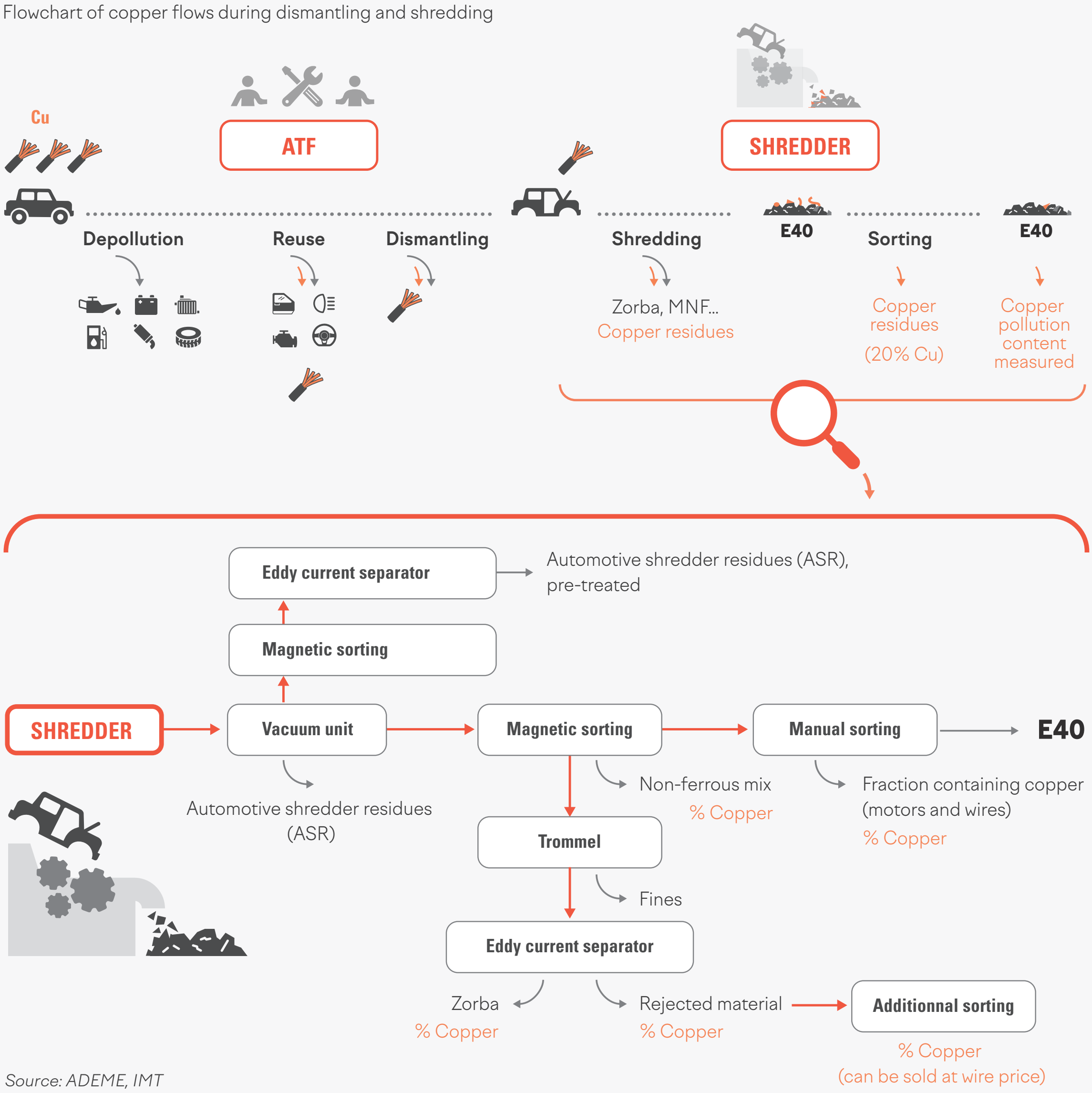
Deep-dismantling at ATFs presents the advantage of requiring low additional investment and can be implemented quickly and simply in already existing facilities. The materials and parts to extract can be precisely targeted and allow high agility thanks to the presence of human operators. Additionally, the large distribution of ATFs allows low logistic costs and emissions due to transport, since ATFs are usually ELVs' first owners.
However, deep-dismantling at ATFs can be very variable from one site to another due to the wide diversity of current practices, which leads notably to unsteadiness of quality control. Furthermore, the current business model of ATFs encourages the selling of non-valuable material in the vehicle hulk, since today the hulk value is estimated by weight and not by quality.
In contrast, post-shredding treatment allows working in batches, which facilitates quality control and stability, a crucial criteria for steelmakers. Due to its mode of operation, a shredder with increased and steady post-shredding sorting capacities can guarantee a certain steel scrap quality and thus facilitate the definition of specific steel scrap quality standards. Post-shredding treatment can either be automated, with the use of sensors and automated sorting techniques, or manual, with additional sorting operators on the conveyor belt identifying pollutants and removing them manually.
Automated solutions benefit from significant and recent technological advancements that enable increasingly efficient and precise sorting, ensuring consistent and reliable material quality. These technologies are likely to continue improving in the coming years. However, they can come with higher costs, they can halt production in case of technical issues and require qualified labor for operation and maintenance. Moreover, automated post-shredding technologies involve significant capital expenditure and long-term investment, which can slow their deployment and limit their geographical spread. As a result, concentrating advanced sorting capabilities in a limited number of sites can lead to increased waste centralization, generating additional logistical flows, transport costs, and associated emissions. For instance, France relies on around 50 shredders with varying performance levels.
Manual sorting following hulk shredding and magnetic separation, by contrast, offers greater agility, flexibility, and rapid implementation. They require little to no capital expenditure, are easily adaptable, and do not involve high repair costs or the need for highly specialized labor. These methods can better accommodate geographical and economic constraints while still delivering effective sorting quality. However, they may require adjustments to working conditions of sorting operators to protect their health from repetitive tasks in a difficult work environment, while maintaining their efficiency and consequently the steadiness of the sorting.
A combined approach of these techniques, namely deep-dismantling (at ATF) and deep-sorting (post-shredding) appears particularly relevant. Rather than opposing the methods, their complementarity makes it possible to significantly improve the overall quality of scrap and contribute to a more efficient and higher-quality recycling process. This granular approach and technological neutrality is particularly important given that the end-of-life value chain is very diverse and varies significantly across EU Member States, with a wide diversity of actors and practices ranging from artisanal to semi-industrial and fully industrial processes as well as a diverse economic framework.

Copper flows throughout the ELV management process

At the **ATF stage**, copper can be recovered from ELVs through two main routes: **reuse**, where components are removed for resale, and **dismantling** for recycling, where wiring can be extracted prior to shredding.
The **remaining copper**, still embedded in the vehicle carcass, **enters the shredder with the input stream** and is subsequently distributed among different output fractions depending on the type and performance of the post-shredding sorting processes.
During the **shredding and post-shredding process**, copper-containing materials are fragmented and distributed across several output fractions, depending on their form and the efficiency of sorting processes. An important portion remains in the ferrous fraction, typically trapped in composite components or attached to steel, contributing to steel scrap contamination.
Another share is recovered in the non-ferrous fraction through eddy current separation. Smaller or fragmented copper elements, such as fine wires, can end up in the light fraction or in fines and residues, leading to material losses if not further processed. Advanced post-shredding technologies can partially recover copper from these streams, improving overall recovery rates.
The exact composition of these flows is usually confidential and involves business interests for the shredders.
Figure 6 presents a schematic overview of the copper flows throughout the dismantling and shredding process.

FIGURE 6. Copper flows throughout the ELV management process

Flowchart of copper flows during dismantling and shredding



Source: ADEME, IMT

Current commercial steel scrap standards

Various commercial standards regulate the scrap metal business and can differ from one region to another. One of the most widely recognized being the European Steel Scrap Specification[31], which categorizes scrap metal into various types, notably the pre- (E8) and the post-consumer (E40) scrap.[32] These standards provide a description of the required specifications, taking into account safety aspects, tolerance to residual elements and cleanliness of the scrap. This report addresses the potential of circular car material. Hence, it will focus mostly on steel scrap from body stamping (including in E8 category) and from end-of-life vehicle recycling (shredder scrap entering in E40 category). Other steel/cast scraps are generated from car production,[33] but their nature and oil content prevent them from being reused for the production of high quality flat steel.

Currently, ELV hulks are shredded and marketed as E40 scrap. The E40 standard stipulates a maximum of 0.4% steriles (non-recyclable material) and 0.25% residual copper content. However, actual copper content in E40 scrap often exceeds these limits, averaging closer to 0.4%, and is expected to increase further if no action is taken (cf. p.16 *Copper contamination of steel scrap*).

Focus on current commercial standards in Europe related to automotive product and production: E8 and E40

E8

An important scrap standard used in automotive steel scrap production is E8 (generated as non-used parts of the steel foil following stamping operations). This scrap is clean of pollutants, as it is “pre-consumer” or “internal”, i.e. a by-product of steel production or car manufacturing. E8 scrap is already efficiently recycled and reused in the steel production.

E40

E40 is a shredded steel scrap standard of post-consumer material. It should theoretically be free of metallic copper and other steriles.

When discussing the growing use of scrap in steel production and the need for enhanced recycling, a special focus is set on post-consumer steel, since pre-consumer steel is already efficiently recycled. Currently, E40 scrap from ELVs is mainly downcycled and partly exported outside the EU for use in construction bars for example.

31 European Steel Scrap Specification is a standard developed by the European Ferrous Recovery & Recycling Federation (EFR) and the European Confederation of Iron and Steel Industries (EUROFER)

32 It should be noted that other scrap categories exist (e.g. E1, E3, EHRB, EHRM…) which are not related to the vehicle life cycle (except for some parts which can come from the mechanical engineering of certain parts). These categories will be mentioned in the report but not discussed further as they are not related to vehicle flat steel closed loop recycling, which is the focus and purpose of this study.

33 Notably from the mechanical engineering of engine parts.

APPROACH & METHODOLOGY

Project description & purpose

Scope of the study

This study is primarily intended to contribute to the debate surrounding the improvement of the quality of automotive steel scrap for the introduction of a recycled content target in automotive manufacturing. It aims to provide data and recommendations to institutional decision makers as well as to the various industrial stakeholders, in the context of the European Commission's proposal for an ELV Regulation and the Feasibility Study conducted by the Joint Research Center (European Commission) on recycled content targets for steel (and aluminium) in new vehicles (Article 6).

The idea developed in our study Car-to-car Steel is not new, but the context has evolved. The ELV Regulation now includes the opportunity for the European Commission to set mandatory recycled content targets for various materials including steel, whose ambition needs to be objectivized and challenged regarding its technical and economic aspects.

The car fleet data provided in this report are representative of the French market (see Annex *Representativeness of the ELV samples*) but are also considered to be sufficiently representative of western Europe situation to draw conclusions and recommendations that remain valid at EU level.

Indeed, the French ELV treatment sector stands out from other European countries by its scale, processing around 1.3 million ELVs per year through 1736 authorized ATFs and 60 shredders, which represents 26% of ELVs officially managed in the EU. This substantial volume makes France an ideal focus for in-depth research and development in ELV management practices.[34] Our focus will be set on the official and authorized ELV processing route, though we are aware that a significant number of ELVs are treated outside regulatory compliance.

34 Eurostat (2024), End-of-life vehicles by waste management operations, https://doi.org/10.2908/ENV_WASELV

The financial data provided in the report (Sections *Economic Results* and *Value sharing incentive mechanisms*) are also French market based. This conversely can hardly be considered as representative of the entire EU situation. Some of the findings related to the economy of the end-of-life business require to be confronted to each Member State specific market. For example, in the sensitivity analysis, when labour costs are adjusted according to other national standards, it is assumed that all other factors remain constant. In reality, however, these factors may vary by country, including commodity prices, resale prices of used parts and the age and category of end-of-life vehicles and their associated wiring harness content.

Focus on manual dismantling and manual post-shredding sorting

Automated sorting technologies are becoming increasingly efficient and popular among recyclers. However, for the purposes of this study, we chose to focus solely on manual sorting. This relatively simple approach, based on basic manual technology and processes, presents two advantages: (1) it can be implemented at any existing shredding site, and (2) it allows for technical leeway, ensuring a high degree of flexibility and adaptability, as well as a level of precision and transparency regarding cost and benefit documentation throughout the trials we conducted. The resulting economic data, on which a sensitivity analysis can easily be conducted, can serve as a reference point for recyclers: enabling them to compare their own performance against automated solutions in terms of costs, return on investment, material quality, and business case relevancy.

The first trial involved taking the dismantling of ELVs one step further than usual, in order to recover more copper wires (steel scrap contaminants) and determine whether the quality of the recovered scrap can be improved by dismantling alone and if it can result in an interesting business case. The shredding and post-shredding process was representative of the French average (no deep-sorting) to determine the impact of deep-dismantling.

The more recent trials focused on reinforcing manual advanced post-shredding sorting to recover more copper containing parts from the conveyor belt, notably copper wires but also small motors containing copper. Post-shredding sorting plays a key role in recovering rotors and stators that are difficult to access during the dismantling stage. As these components are typically made of combined steel and copper, they retain magnetic properties and are therefore predominantly captured within the ferrous fraction, which requires manual or automated recognition and sorting to avoid contaminating the steel scrap.

The trials

The scope of the project and the various trials and associated partners are presented in **Table 1**.

As part of the study, in 2024 (**Trial 1**) we focused on the ATF to improve the quality of the steel scrap and:

- identified the various stages of conventional dismantling and industrial dismantling at Re-source (INDRA) and added targeted in-depth dismantling steps (deep-dismantling) at Re-source to recover more copper wires.[35]
- shredded the deeply dismantled hulks as a batch in a shredder representative of the French average, without any advanced post-shredding sorting, to recover the improved steel scrap.

We then:

- analyzed the additional time spent by operators on each ELV for our project
- identified the quantity and quality of the additional material recovered by INDRA that is not sent to the shredder (copper, glass…)
- identified the positive and negative value of this additional material recovered
- calculated the discrepancy of time spent/cost/material gain
- analyzed the quality of the recovered improved scrap in an independent laboratory, at ArcelorMittal's R&D laboratory and on a large scale at a steel mill to produce flat steel coils.

35 Another trial was conducted in parallel to our project at INDRA Re-source in 2024 and involved removing the glass of the ELVs. This had no significant impact on the results of our trial, apart from a lower global hulk weight, that was taken into account for the analysis.

Table 1. Presentation of the trials

	Batch content	ATF	Shredder	Measurements
Trial 1	100% ELV	INDRA Re-source ***Deep dismantling:*** *increased, targeted in-depth wire recovery*	Derichebourg *Site 1* *2 post-sorting operators*	Recovered Cu weighted E40 sample recovered according to thorough protocol • 1 large-scale analysis (ArcelorMittal) • 2 laboratory analysis (ArcelorMittal R&D, IRT M2P)
Trial 2	100% ELV	INDRA Re-source ***Medium dismantling:*** *half of the wire content extracted, assumed to be self-financing (INDRA Re-source medium dismantling)*	Derichebourg *Site 1* *4 post-sorting operators*	Recovered Cu weighted E40 sample recovered according to thorough protocol • 1 large-scale analysis (AM) • 1 laboratory analysis (ArcelorMittal R&D)
Trial 3	100% ELV	INDRA Deconstruction Auto Villeton ***Low dismantling:*** *average level of copper wire removal in France.*	Derichebourg *Site 2* *4 post-sorting operators*	Recovered Cu weighted E40 sample recovered according to thorough protocol • 1 large-scale analysis (AM) • 1 laboratory analysis (ArcelorMittal R&D)
Preliminary Trial	Average ferrous feedstock	*None*	Derichebourg *Site 1* *2, 3 then 4 post-sorting operators for 10 days each*	Recovered Cu weighted

As part of the second study in 2025, we focused on improving post-shredding sorting as well as on a combination of dismantling and deep-sorting to recover more copper residues. We:

- identified the potential of improved post-shredding sorting on the conveyor belt through the variation of the amount of sorting operators recovering copper containing parts (please find a note hereunder on automated sorting).[36] As a **Preliminary Trial,** before testing an ELV batch, we changed the number of sorting operators on the conveyor belt of the shredding line over 10 days each on average ferrous feedstock[37], to provide a sensitivity analysis of the impact of additional sorting operators on the recovery of copper containing parts. We tested the economic relevance of these variations, in particular to determine if the cost of additional operators was offset by the additional recovered copper.
- After confirming that the more operators sort the ferrous material manual, the more copper value is recovered, we figured out that this recovery seemed to compensate for the additional labor costs (**Preliminary Trial**).
- As a consequence, for the following trials during which we shredded ELV batches (representative of the French market), we increased the amount of sorting operators to 4 operators on the conveyor belt to proceed to post-shredding deep-sorting.[38] We varied the level of dismantling: one batch was "medium-dismantled" before shredding (**Trial 2**), while the other one was "low-dismantled" before shredding and deep-sorting (**Trial 3**).
- We then analyzed the quality of the recovered improved steel scrap in ArcelorMittal's R&D laboratory and on a large scale at a steel mill to produce flat steel coils. We compared the different quality results, depending on the treatment applied to the sample.
- We identified the quantity and quality of the additional copper containing parts recovered by the shredder through deep-sorting.
- We calculated the discrepancy of time spent/cost/material gain for both the ATF and the shredder depending on the wire dismantling level.

On-site Implementation of the Trials

Within the framework of this full-scale project, IMT collaborated with a wide range of stakeholders across the ELV value chain, notably including a major steel producer. The processes implemented closely reflect standard industrial operations at the participating sites, ensuring representativeness of real-world conditions. Only a limited number of additional targeted operations, specifically aimed at enhancing material recovery, were introduced for the purposes of the trial, in order to maintain results that are directly comparable with current practices. To meet these requirements, extensive exchanges were conducted with all the partners involved.

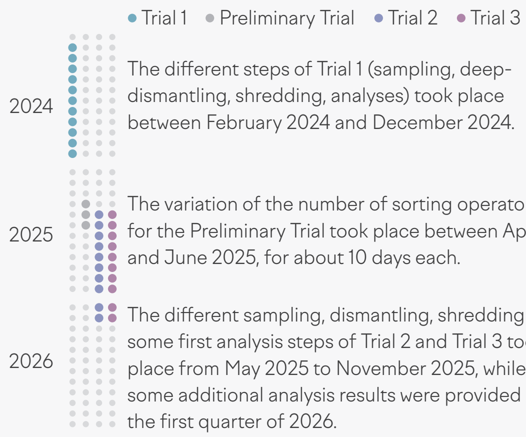
Project Timeline

The project took place over two years and included 4 different field trials (see **Figure 7**).

A first report focusing on deep-dismantling (Trial 1) was published in 2025. This second report focuses on deep-sorting and the collaboration between ATFs and shredders aims at supplementing the first results and recommendations.

FIGURE 7. Project Timeline

The project took place over two years.



The different steps of Trial 1 (sampling, deep-dismantling, shredding, analyses) took place between February 2024 and December 2024.

The variation of the number of sorting operators for the Preliminary Trial took place between April and June 2025, for about 10 days each.

The different sampling, dismantling, shredding and some first analysis steps of Trial 2 and Trial 3 took place from May 2025 to November 2025, while some additional analysis results were provided in the first quarter of 2026.

36 Automated sorting technologies are becoming increasingly efficient and popular among recyclers, however, for the course of our study, we have decided to focus solely on manual sorting. This ensures a high degree of flexibility, adaptability, as well as precision which allows transparency regarding costs and benefits. This transparency gives recyclers the possibility to compare and rank themselves regarding material quality and business case.

37 ELVs represent on average 1/3 of European shredders' ferrous feedstock. This proportion can vary depending on the business case of the shredder, various economic conditions, geographic and temporal variations etc.

38 For comparability purposes, the number of sorting operators has been normalised across both sites. For more details, please refer to the section "Partners involved in the Project".

Partners involved in the projects

Sampling representative ELV batches and dismantling steps: INDRA Automobile recycling (Re-source and Deconstruction Auto Villeton)

INDRA Automobile recycling provided two representative ELV batches from its dismantling site Re-source (Romorantin, France) for Trials 1 and 2, and one representative ELV batch from the ATF Deconstruction Auto Villeton (which is part of INDRA's ATF network) for Trial 3.

INDRA was chosen within a wide variety of dismantlers for its advanced expertise in end-of-life vehicle management as well as for its advanced dismantling process at Re-source.

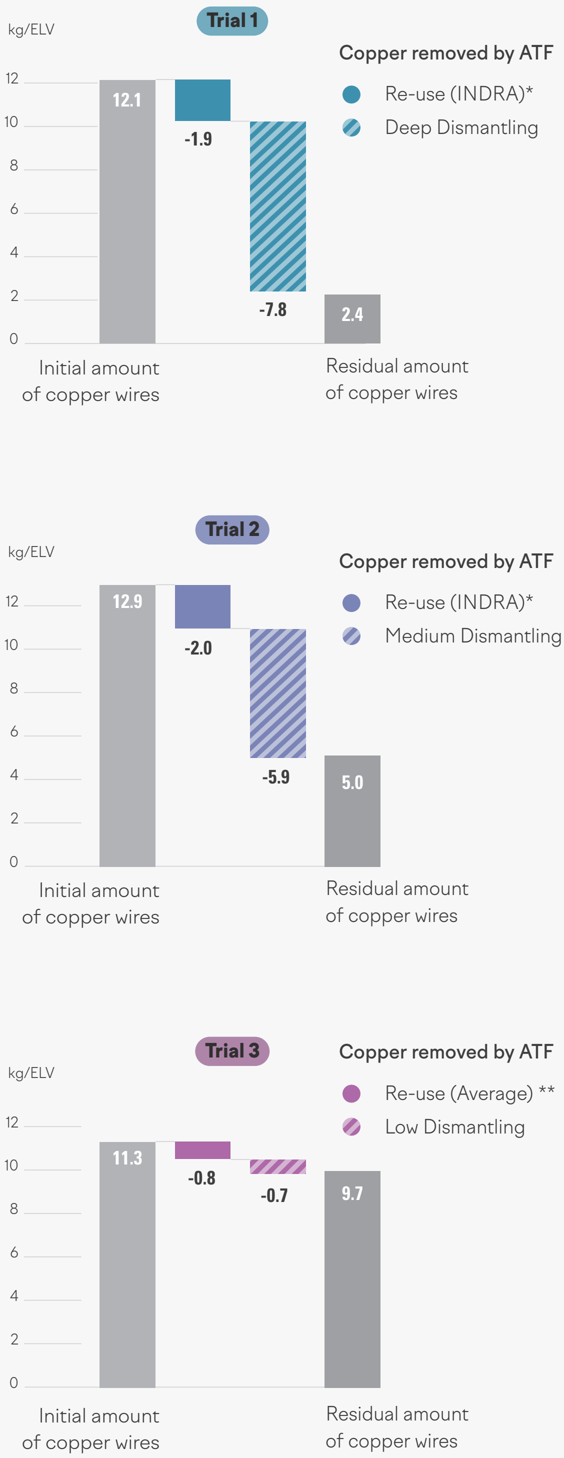
INDRA is also managing the largest dismantler network in France (about 300 independent facilities to fulfill OEM's regulatory obligations according to the current ELV directive) to which it provides ELV volumes (national contracts near insurance companies and OEM retail network) as well as engineering services and second-hand spare parts market place.

INDRA also provided some engineering support for the definition of the samples and the protocols. Following the completion of the trials, they also provided figures and data to proceed to a comprehensive technical and economic analysis.

INDRA's dismantling site Re-source in Romorantin is representative of the most modern dismantling sites, implementing best available techniques for an efficient dismantling in line with the ELV Directive. It represents a realistic and viable dismantling facility. It also presents the advantage of being managed very precisely and in a well-documented manner to fulfill the needs of INDRA's engineering division located on the same site (traceability, time counting, weight measurement and all relevant data for our study are parameters that have been monitored carefully for years on this site). Therefore, it represents an ideal experimental site for the deep-dismantling and medium dismantling trials.

The process has been improved for the deep-dismantling trial (Trial 1) with additional dismantling steps on elements that have so far gone unaddressed, despite already working beyond current industry standards. Indeed, Re-source is one of the players which has gone deep in extracting the copper wires for economic reasons. For the matter of Trial 1 however, we wished to go further and extract the harder to access wires and determine if there is a positive business case. Thus, INDRA Re-source added some specific steps to its medium dismantling line (**Figure 8**) to remove additional parts and materials to reduce the presence of copper in the hulk, the idea being to determine the limits of economic profitability of additional copper recovery. During this first trial, we also studied in detail the dismantling

FIGURE 8. Comparing the removal of copper wires by the ATF for an average trial ELV



** For Trial 1 and Trial 2, spare parts for re-use were removed according to INDRA Re-Source protocol.*
*** For Trial 3, extremely accessible wires were extracted (equivalent to average dismantling in France)*

INDRA, IMT.

steps, associated costs, and additional recovered materials (beyond steel scrap), by cross-referencing trial data with INDRA's internal datasets.

For Trial 2, the dismantling process at Re-source was representative of their usual practices ("Medium dismantling"), meaning that they manually recovered about half of the copper wires of an ELV. This medium classic process at this ATF is supposed to be self-financing.

Deconstruction Auto Villeton is representative of an average French ATF, and provided us with a batch of ELVs for Trial 3 ("Low dismantling"). This family business treats around 4500 ELVs per year and provides mandatory depolluting and recovery steps. They also recover spare parts for the reuse market and sell them onsite and online, but rarely recover copper wires as a material for recycling. Hence, for the purpose of the trial, only limited amounts of extremely accessible copper wires were extracted, without any deliberate dismantling effort, in order for the batch to be representative of low dismantling practices.

During Trials 2 and 3, we ensured consistent management of ELVs at the ATF stage and recorded all the steps performed on the vehicles.

The average weight of copper wires originally present per ELV in each Trial was calculated from Re-source internal data (details presented in the Annex *Calculation of the rate of copper wires in the ELVs* — p.42). **Figure 8** shows the average removal of copper wires during the Trials.

Shredding and post-shredding sorting: DERICHEBOURG ENVIRONNEMENT

Derichebourg Group is listed on the Paris stock market but controlled and managed by the DERICHEBOURG family. The group was founded in 1956, operating in 13 countries, mainly in Europe. In 2024, the Group produced above 5 million tons of recycled metals (steel, copper, aluminium, brass, stainless steel, zinc, etc.), backed by a dense territorial network of 280 collection and recycling facilities.

Derichebourg Environnement has historical expertise in the collection, recycling and recovery of materials and waste, in particular in the recycling and sorting of ferrous and non-ferrous materials, including notably the shredding of ELVs.

Derichebourg's recycling plant in a first site (Site 1) was chosen for Trials 1 and 2 and for the Preliminary Trial because it is representative of an average French recycling plant, that is to say a shredder without particularly advanced sorting technologies but with the possibility to vary the amount of operators removing copper at the end of the shredding process and work in batches.

Concretely, sorting operators work at the end of the shredding line, on conveyor belts on which the material flows after undergoing upstream shredding and separation processes. The operators are responsible for visually identifying and manually removing copper containing parts (wires, motors etc) as well as steriles and oversized metal pieces, typically large steel bars that do not meet E40 specifications. These materials are manually extracted and sorted into dedicated containers.

For Trial 1, the shredder was operated under standard conditions, with two operators working at the conveyor belt, in line with usual practices.

During the Preliminary Trial, on average ferrous feedstock, we varied the number of sorting operators over three different periods of about 10 days each (2, 3 and then 4 operators). To assess the impact of additional operators on copper recovery, the corresponding containers were weighed daily.

For Trial 2, the setup was modified by adding two additional operators to the sorting line (resulting in 4 sorting operators), in order to assess the impact of increased manual sorting capacity on material recovery.

Trial 3 was performed on Derichebourg's recycling plant on a second site (Site 2). It represents one of their most recent shredders in France, with an important flow rate and two conveyor belts at which 4 sorting operators per belt can sort the ferrous material. For comparability purposes, the number of sorting operators has been normalised across Site 1 and Site 2: although in practice Site 2 operated with 8 operators and Site 1 with 4 operators, the shredder at Site 2 has double the processing capacity of Site 1. Hence, on a per-throughput basis, Site 2 can be considered as operating with 4 sorters, making the two sites directly comparable. For ease of reading, both sites will hereafter be referred to as operating with 4 sorting operators.

Although the shredder of Site 2 has a modern post-shredding system for non-ferrous materials, it relies on sorting operators for the recovery of pollutants of the ferrous part, which was necessary for the purpose of the trial.

Both sites are capable of working in batches and to adapt their shredding processes to the trials as well as to provide a clean shredder, required for accurate analysis.[39] Data from the shredding stage, including recovered material volumes, were systematically compared with standard operating data to ensure consistency with usual practices.

39 It is important to bear in mind that shredders require specific calibration and are typically configured to process a balanced mix of input materials, including only a limited share of ELVs. They are therefore not optimized for ELV-only batches, which require higher shredding intensity and may lead to operational issues such as blockages, as observed during the trial. As a result, performance could likely be improved under optimized conditions. This study does not advocate for systematic ELV batch processing; batches were used to ensure representativeness and better understand ELV composition, while in practice operators should retain flexibility in defining their feedstock mix.

From scrap to steel: ARCELORMITTAL

ArcelorMittal is one of the world's leading integrated steel and mining companies with a presence in 60 countries and primary steelmaking operations in 15 countries. It is the largest steel producer in Europe, among the largest in the Americas, and has a growing presence in Asia through its joint venture AM/NS India. ArcelorMittal sells its products to a diverse range of customers including the automotive, engineering, construction and machinery industries.

Like other EU steel producers, ArcelorMittal has developed a decarbonization strategy that includes an increased use of steel scrap as well as the development of the DRI-EAF production route.

We chose to cooperate with ArcelorMittal to carry out R&D-sized and large-scale trials because of their importance in Europe regarding the production of steel for the automotive industry and their expertise in the use of steel scrap. Their ability to reproduce the conditions of an EAF in the BF-BOF route for the production of high-quality steel with increased levels of scrap and their various analysis capabilities at different scales were valuable for our trial. Steel scrap samples from Trial 1, 2 and 3 were used in two heats each time for the production of high-quality steel coils, and the chemical quality of the produced steel was analysed. In parallel, each scrap sample was analyzed thoroughly before and after melting at ArcelorMittal's R&D laboratory.

Other parties involved in the Project

To ensure that the entire value chain was integrated into the project, it was essential to engage OEMs from the outset. BMW and Renault, as two main European automobile manufacturers, engaged in discussion with IMT during the first year of the project on a regular basis to share data and feedback. These discussions were decisive to understand the challenges and strategy the manufacturers follow regarding the incorporation of recycled content in their vehicles, but also at the development (design and engineering) stage of the vehicles as it is important to capture a circular vision of the industry.

Over the course of the project, IMT exchanged with additional experts and parties of the automotive industry, the recycling industry and the steel industry, but also with European and international CSOs as well as national and European institutions.

TRIAL ANALYSIS & RESULTS OF THE STUDY

Key Finding #1 - Economic results

Recovering more copper from end-of-life vehicles creates more value than cost

Our results show that the best E40 quality results are achieved through a combination of deep-dismantling and classic manual post-shredding sorting. However, the economic stakes also need to be evaluated in order to provide a comprehensive analysis. The economic implications of each configuration, accounting for material recovery and labour costs at both the dismantler and shredder stages are analysed in this section.

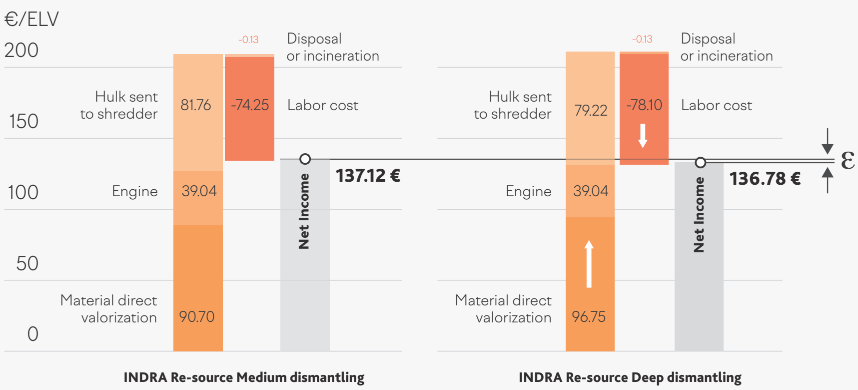
Economic assessment at the ATF stage

Deep-dismantling is close to economically neutral for the ATF and can become profitable under certain conditions.

In the French context, the additional deep-dismantling operations are almost economically neutral for a copper wire price of 2500€/t. We studied different contexts in the sensitivity analysis (see Section '*Sensitivity Analysis*').

Indeed, considering the trial conditions, the labor time spent for the matter of the deep-dismantling process is not significant in terms of costs in comparison to the baseline process of Re-source which is already profitable. Thus, the recovery of the 7.16 kg copper wires per ELV compensates the additional labor cost in terms of value. The deep-dismantling operation is self-financing in this trial, including considering the loss of hulk weight sent to the shredder and therefore not valorized (See **Figure 9**).

FIGURE 9. Comparing material sales and labour costs of a profitable medium dismantling process with those of a deep-dismantling process at INDRA Re-source for Trial 1



Source: INDRA, IMT.

During this trial, the total difference of the net income[40] is only 0.34€/ELV for a total net income of 137.12€ in a Medium baseline Re-source process (**Table 2**). This result is based on prices at the date of the trial (March 2024 - **Table 3**). Nevertheless, although the price difference between Medium and Deep dismantling remains limited, it may still not be sufficient to provide ATFs with a sufficient incentive to undertake the additional steps required for deep-dismantling. This reflects a structural limitation identified throughout this analysis: depolluted vehicle hulks are currently purchased by shredders on a weight basis only, with no quality indexation/recognition linked to dismantling depth.

40 "Net income" refers to the sale of spare parts and recycled materials according to ADEME and Re-source's average distribution compared to the dismantling time at Re-source. It excludes all site-specific costs that cannot be generalized, such as additional costs associated with packaging, on-site transport, storage or the additional administrative work involved in creating new material flows.

Economic assessment at the shredder stage.

Manual post-shredding sorting remains profitable for the shredder, although some configurations are more advantageous than others.

The sorting operators added to improve post-shredding sorting are self-financing in all three trials - which corresponds to various levels of copper extraction ambitions at the dismantling stage. Indeed, the labor costs related to manual post- shredding sorting are systematically compensated by sales of recovered copper in the trial conditions (See **Figure 10**).

Moreover, the two additional sorting operators present in Trials 2 and 3 are more beneficial compared to Trial 1, for which deep-dismantling at ATF reduced the residual copper value to be removed on the conveyor belt (see **Table 4**).

Table 2. Difference of the net income, medium vs deep-dismantling process at Re-source

	Sale of material	Work time	Work time	Labor cost	Net income
Re-source Medium dismantling	211.37€	2.25	2h15	74.25€	137.12€
Re-source Deep dismantling	214.88€	2.37	2h22	78.10€	136.78€

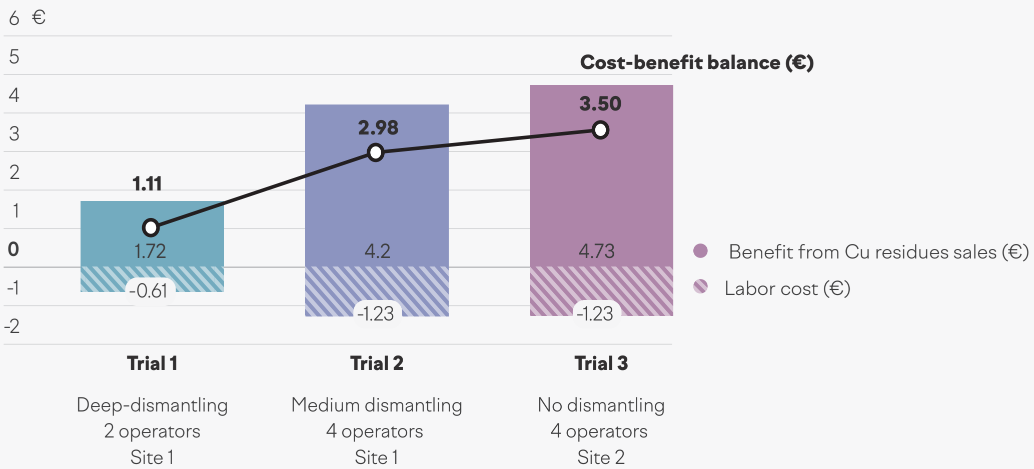
Table 3. March 2024 prices

ELV average weight (kg)	1175
Cost of work (€/h) *	33
Hulk (€/t)	100 €
Copper wires (€/t)	2500 €

Table 4. Costs and benefits from post-shredding sorting. Prices used : Copper residues = 1500€/t ; Labor cost = 24.5€/h.

	Labor cost (€/t hulk treated)	Benefit from Copper residues sales (€/t hulk treated)	Cost-benefit balance (€/t hulk treated)	Cost-benefit balance for 1 sorting operator (€/operator/t hulk treated)
Trial 1	-0.61	1.72	1.11	0.55
Trial 2	-1.23	4.20	2.98	0.74
Trial 3	-1.23	4.73	3.50	0.88

FIGURE 10. Recovered copper by sorting on conveyor belt : Costs & sales benefits for the shredder. Prices used : Copper residues = 1500€/t



* According to INSEE (the National Institute of Statistics and Economic Studies of France), the gross annual wage of a low-skilled worker is 30300 €, working on average 1611h annually. The average share of social contributions and other charges for the employer is 43.7%. The total hourly cost for the employer (including charges) is thus 18.8€×1.437≈27.06€/h. *We chose to take a broader, also more conservative, estimate of 33€/h.*

Sensitivity analysis

Impact of market fluctuation of hulk and copper prices on profitability of Deep dismantling

A sensitivity study confirmed that the market fluctuation of the hulk and copper prices have a limited to no impact on the profitability gap between Medium and Deep dismantling for the ATF (**Figure 11**). The difference between the economic balance of Medium dismantling and Deep dismantling at Re-source remains minimal regarding the price variations (on average, the difference is 1.90€ over the 2013-2024 period). Thus, it does not affect the potential of an interesting business case for improved copper dismantling.

Impact of Labor costs on profitability/relevance of Deep dismantling

A sensitivity estimate examined the impact of labor costs on the profitability of ATFs when performing deep-dismantling versus medium dismantling (which was evaluated in the previous Section). We compared labor costs in France with those in other European countries : Bulgaria, Romania, Portugal, Luxembourg, Denmark.

We estimate that deep-dismantling could be more profitable than medium dismantling for ATFs in countries with low labor costs (for instance, in Central and Southern Europe) (see **Figure 12**).

FIGURE 11. Sensitivity analysis of ATF net income

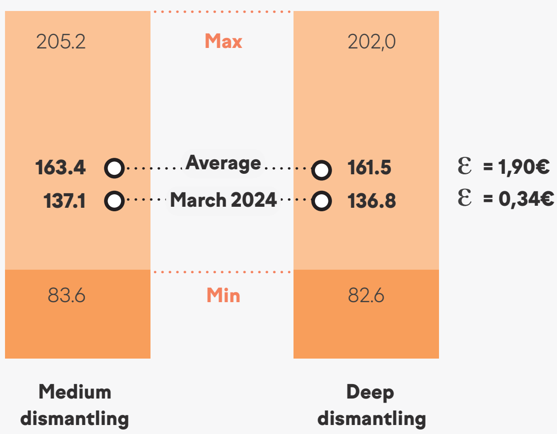
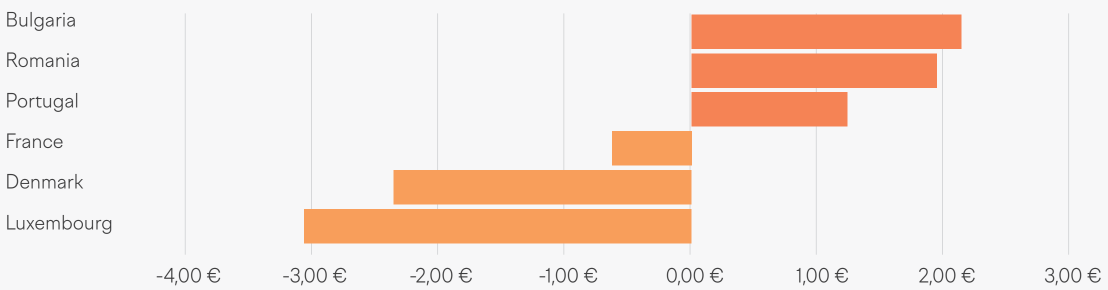


FIGURE 12. Difference in cost-benefit balance between deep and medium dismantling, depending on the country

Copper price considered : 5000€/t



Disclaimer : We are considering this variation on the assumption that all other factors remain constant. In reality, however, these factors may vary by country, including commodity prices, resale prices of used parts and the age and category of end-of-life vehicles and their associated wiring harness content.

Key Finding #2 - Quality results

The future 0.25% regulatory threshold for residual copper in ELV steel scrap (main fraction) was achieved in all tested protocols, and the 0.15% threshold was reached without sophisticated technology.

The analysis of the three steel scrap samples collected across the different trials indicates that both pathways, deep-dismantling (i) and advanced post-shredding (deep-sorting) (ii), as well as their succinct combination (iii), allow for a significant reduction in the residual copper content of E40.

Figure 13 presents the residual copper concentration measured in the E40 fraction for each ELV trial, expressed as a weight percentage. Each bar represents the average value across both measurements (1 large-scale analysis and 1 laboratory analysis), with the 95% confidence interval indicated by the error bar. The sampling protocol used for each measurement is described in Annex '*Steel scrap sampling at the shredder*' p.42.

The main results are the following :

- Trial 1 samples yield the lowest residual copper concentration (0.11%), followed by Trial 2 samples (0.14%) and Trial 3 samples (0.19%).
- All three trials remain significantly below the 0.25% threshold which corresponds to the first regulatory copper content threshold of the new ELV Regulation entering in force first. This value also corresponds to the current E40 theoretical standard (currently barely controlled and respected).
- Trial 1 and Trial 2 samples even fall below 0.15% residual copper concentration on average - the steel mill inlet requirement for high end automotive flat steel production[41] as well as the second regulatory threshold of max. 0.15% copper residues (starting 5 years after entry into force of the ELV Regulation) seems achievable with no substantial changes in the practices, though certain adaptations might need to be undertaken (training, additional human resources…).
- Manual Post-shredding sorting alone (4 operators in the trial conditions), however, does not always seem sufficient to reach this quality target on average, if no attempt to recover copper at the dismantling stage is part of the protocol at ATF (see Trial 3).

41 These numbers might vary depending on the steel grade, however it provides a representative estimate of the conditions required for the highest grades of automotive flat steel production.

FIGURE 13. Measurements of the residual copper in E40 for the ELV Trials

Average of the 3 samples measurements for each of the 3 ELV Trials

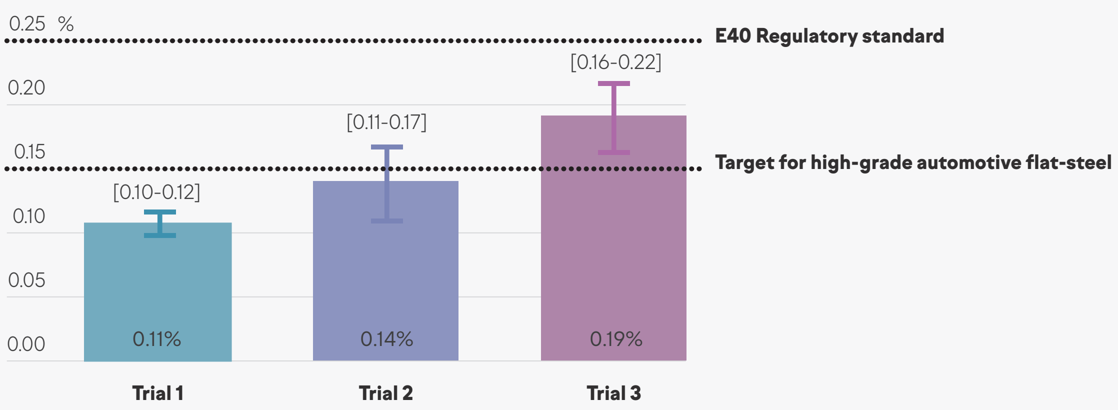
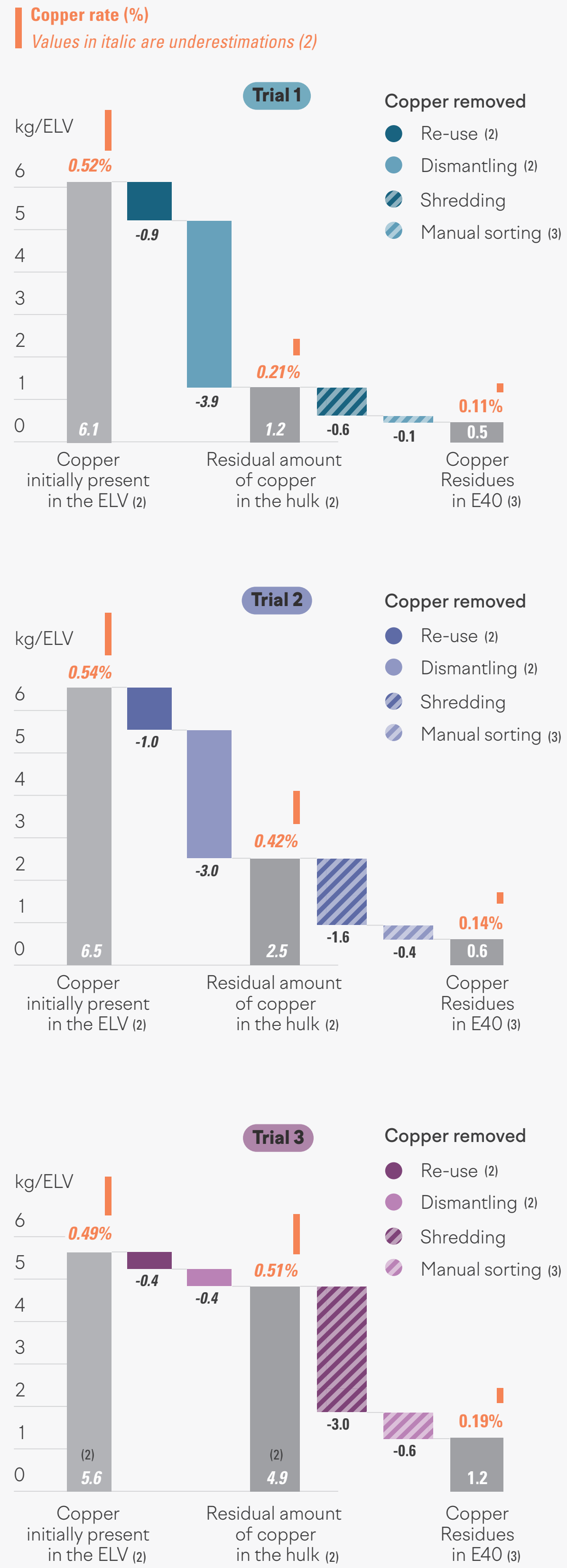


FIGURE 14. Representation of the copper flows modelled (ELV and Hulk stages) and measured (E40 stage) (1)

Calculation of the rate of copper wires in the ELVs



Notes
(1) The rates account for the weight estimation of net copper (not copper wires). We assumed that copper wires are composed of 50% net copper and 50% plastics. We assumed that cuprous residues removed by manual sorting are composed of 21% net copper.
(2) The copper quantities indicated in italics are an underestimation. The estimation of net copper contained in an ELV only includes copper wires. The presence of copper containing parts (e.g. small motors) in ELVs other than copper wires have not been estimated. However, these can be found in the E40 after shredding alongside copper wires without being able to tell them apart.
(3) These values were measured.

- Only Trial 1, including deep-dismantling at ATF, achieves less than 0.15% residual copper content with the stability needed for automotive-quality steel production (an imperative request for E40+ standard). This level of quality is also achievable with lower copper extraction at ATF if combined with automatized advanced post shredding technologies[42]. However, we could not evaluate the cost and economics of this technological approach and assess its relevancy compared to the protocols implemented in Trial 1 and 2.

The influence of the variability of the initial copper content present in the 3 ELV batches was assessed by analyzing the comparability of the batches (see Annex *"Representativeness of the ELV samples"*), and retracing the copper flows during both dismantling and post-shredding stages to show that it does not affect our conclusions on the efficiency of the studied processes.

The three ELV batches show comparable initial copper wire contents, as shown in **Figure 14**. The differences observed at the Hulk stage, particularly the higher copper wire quantity in Trial 3, are attributable to the level of dismantling rather than initial batch composition. Consequently, the copper concentrations measured at the E40 stage reflect the actual performance of the dismantling and post-shredding sorting processes. The decrease in E40 copper contamination from Trial 1 to Trial 3 can therefore be interpreted as an effect of the process, independently of the initial copper content of the vehicles. More details can be found in Annex *"Calculation of the rate of copper wires in the ELVs"*.

42 As a matter of example, TSR announced that their recycling plant in Duisburg (Germany) can produce a steel scrap produced with 100% post-consumer scrap called "TSR40" which achieves a high purity of tramp elements, in particular less than < 0.08 % residual Cu content (HKS Scrap Metals BV (2024), https://arn.nl/wp-content/uploads/pdf_presentation-hks-arn-relatiedag-2-oktober-2024.pdf)

Key Finding #3 - Value sharing and incentive mechanisms

Value sharing for E40+ scrap is possible without disrupting the existing industry structure. Premium levels needed to support best practices along the value chain can be roughly estimated.

This analysis intends to offer an in-depth insight into the economic implications of improving the quality of steel scrap, particularly in terms of value generated and how it may be distributed among the various stakeholders along the ELV value chain. It aims to stimulate discussions about investment choices, initiate contractual negotiations between stakeholders, and help define sourcing or vertical integration strategies within the sector. From an economic standpoint, the report suggests a way to better understand how value is generated and redistributed among actors of the ELV value chain, thereby contributing to a more transparent and informed dialogue across the industry.
In this section, we estimate the potential variations of the costs and material gains depending on the copper price, various EU labor costs and a variation of the hulk price depending on its dismantling level. Taking the above-mentioned value distribution issues into consideration, we provide an estimate of the potential price premium for higher-quality steel scrap (E40+). All prices and calculations are based on market conditions at the time of the report and should be interpreted in the context of a large-scale market deployment rather than small or punctual volumes, which may not reflect the same economic dynamics.

E40 quality improvement: value creation and trade-offs across the value chain

As demonstrated by the analysis of copper residues in the E40 steel type conducted across all three trials (see Section *Quality Results*), only the deep-dismantling path consistently delivers a residual copper content that is both sufficiently low and stable (below 0.15%) to enable the production of automotive-grade steel. This quality threshold is precisely what defines the E40+ standard introduced in this report (see Section *A new commercial quality standard: E40+*): E40+ designates a higher-grade shredded steel scrap that could justify a price premium over conventional E40, cascading upstream through the value chain as stronger incentives for both shredders and dismantlers.
A stable residual copper level below 0.15% would be particularly valuable to steelmakers. With such quality, post-consumer scrap could be massively incorporated in combination with DRI for the production of high-grade automotive flat steel.[43] While these figures may vary depending on the steel grade, they provide a representative estimate of the quality conditions required for automotive flat steel production.
However, it is noteworthy that deep-dismantling also results in lower residual copper in the hulk sent to the shredder. As observed in our trials, this may translate into reduced revenues for the shredder (see **Figure 10**). This creates an economic imbalance in the ELV end-of-life value chain under deep-dismantling conditions, even though the process generates value downstream through the production of low-copper scrap suitable for decarbonised steel manufacturing.

A new commercial quality standard: E40+

To address this imbalance, we examined how profitability and balance within the value chain could be restored, taking into account the downstream value created by high-quality E40+ scrap. The study indicates that a fair distribution of this additional value can be achieved through reasonable premiums between actors, without requiring vertical integration or a redesign of the current value chain.
We therefore propose to introduce commercial standards for high- quality hulk (hulk+) and high-quality E40 (E40+). The mechanism is explained in **Figure 15** below.
Based on an economic analysis conducted at each stage of the value chain covering additional treatment

43 Material Economics (2020), Preserving value in EU industrial materials – A value perspective on the use of steel, plastics, and aluminium, https://materialeconomics.com/node/15

costs, value generated through copper recovery, value lost through reduced copper weight in the hulk after upstream extraction, and the higher downstream value of upgraded scrap, the report estimates the minimum premiums that would need to be established:

- **Between dismantlers and shredders** for well-prepared, low-copper hulks (Hulk+), incentivising ATFs to perform deep-dismantling rather than medium dismantling by rewarding them with a higher hulk price. Even though Key finding #1 shows that the revenue from copper sales can (under certain conditions) compensate for the additional costs incurred by the ATF for deep-dismantling, it might be interesting to introduce a price premium for hulk+ in value order

FIGURE 15. Representation of the changes in economic flows in the ATF-shredder value chain in the case of deep dismantling, compared to medium dismantling

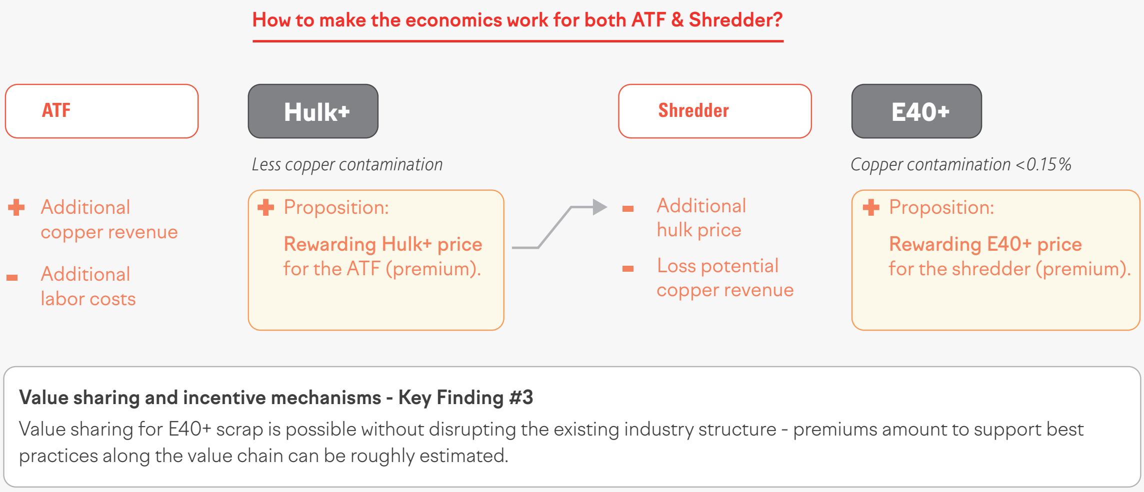
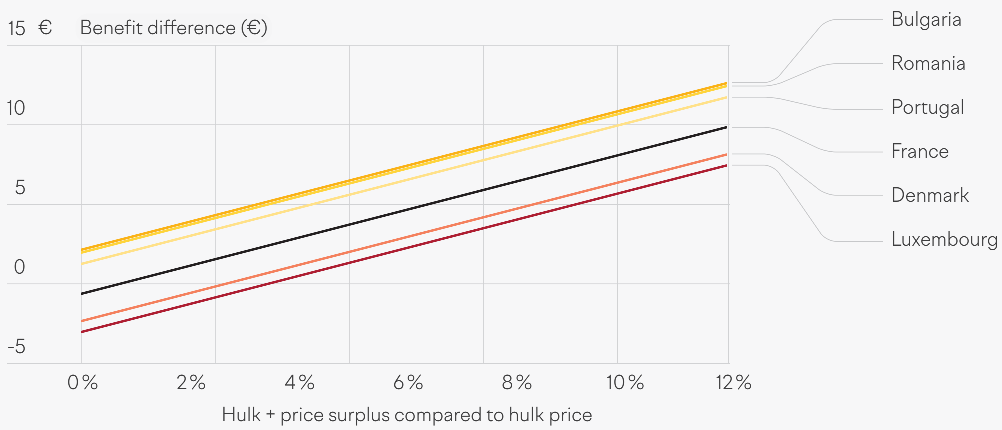


FIGURE 16. Cost benefit difference (= materials sale revenue - labour and disposal costs) per ELV between deep and medium dismantling, considering hulk price surplus

Assessment of potential hulk+ price



to provide a real incentive for ATFs, and reward the value created throughout the rest of the value chain - Section Assessment of potential hulk+ price

- **Between shredders and steelmakers for E40+ scrap,** compensating shredders for the loss of revenue resulting from hulks containing less copper - Section *Assessment of potential E40+ price* below.

Assessment of potential hulk+ price

To assess the potential suitable price for hulk+, we calculated the profitability of the ATF depending on the price premium received (difference between hulk+ price and regular hulk price), and on the cost of labor (see **Figure 16**). We find that a reasonable price premium for hulk+ (around 3 to 5%), could allow deep-dismantling to be profitable compared to medium dismantling, even for ATFs in countries with high labor costs, such as Denmark.

This price premium could be set higher than 5%, in order to introduce a real incentive for ATFs to produce batches of low copper content hulks.

Assessment of potential E40+ price

To assess the corresponding potential price suitable for E40+, we calculated the potential loss of revenue caused by treating high quality hulk with less recoverable copper for the shredder. We considered the loss in copper for the shredder to be equivalent to the additional quantity of copper wires removed during deep-dismantling, compared to medium dismantling[44]. In Trial 1, this quantity was 1.62 kg on average (cf. **Figure 8**).

We then calculated the E40+ price premium necessary to cover for the shredder's loss of revenue, depending on the price of copper, and the hulk+ price surplus paid to the ATF.

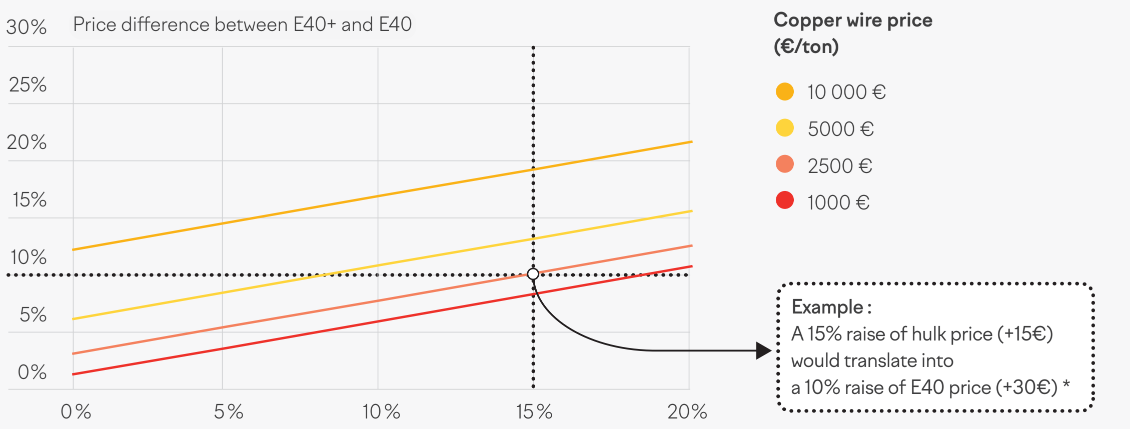
The results are shown in **Figure 17**.

According to these calculations, with a copper wire price of 2500€/t, and a 15% increase of hulk price (+15€/t), there should be an 10% raise of E40+ price (around +30€/t).

44 Labor costs are not taken into account, as we are only considering lost revenue. In a hypothetical medium dismantling configuration, we consider that the shredder can take steps to recover the additional copper present in the hulk, including that found in other flows such as NFM and Zorba.

FIGURE 17. Estimation of the price premium for E40+ required to offset the shredder's losses

Based on the premium paid to the dismantler for Hulk+ and the price of copper wires.
Labor cost considered : French. Hulk base price : 100€/t, E40 base price : 300€/t.



* Copper wire price : 2500€/t ; French labor

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ANNEXES

Details on the dismantling process

Re-source (INDRA)

A medium Re-source dismantling (as described in **Figure 18**) process lasts for 2h15 on average. After having recovered the fluids and other mandatory parts such as the rears and catalytic converter, the operators systematically remove the powertrain, plastics (polypropylene of the front shock absorbers…), as well as some of the wiring harnesses. About 15 min of labor are dedicated to the removal of copper wires (mainly located in the engine, the engine bay and the dashboard). Certain body parts such as the front doors can be removed and be sold as a spare part.[45] Removal is carried out manually, with adapted tools supporting the operators, notably in certain force-intensive gestures or to access certain hardly accessible areas.

Usually Re-source extracts in average 45% of the total wires found in an ELV. Additionally, at Re-source, about 15% of the wires are removed from the hulk through the sale of second-hand spare parts (e.g wires remaining in a door…). Once exiting a regular Re-source process, a car hulk thus contains about 39% of the total wires found in an ELV (**Figure 18**). In Trial 2, this process was applied and hulks contained in average 5.0 kg of wires, out of 12.9 kg initially present.

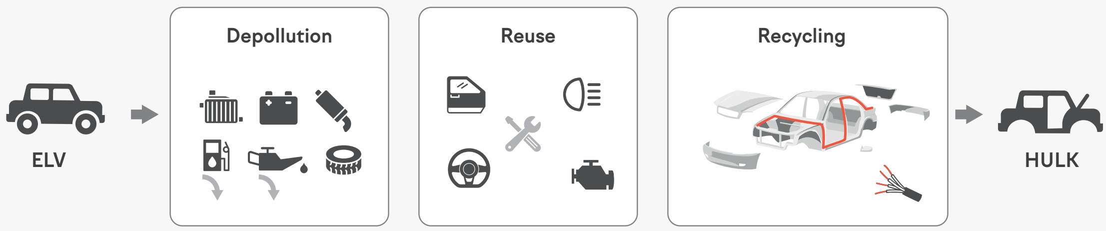
During the deep-dismantling process used in Trial 1, around 19% more wires were removed compared to the medium dismantling process, leaving around 2.4 kg of copper wires in the hulk out of the 12.1 kg initially present.

Deconstruction Auto Villeton

At Deconstruction Auto Villeton, after the removal of fluids and other mandatory spare parts, the ATF also removes the front shock absorbers to recover the polypropylene as well as selected components intended for reuse, including the engine block on certain vehicles. The recovery of additional copper wires depends on the volume of vehicles to be processed and is limited in case of high throughput. For the matter of the trial, we asked the ATF not to deliberately recover any additional copper wire.

45 These parts can also be sold as materials in a separate stream, which is not sold with the hulk to the shredder for process and logistical reasons. This specific flow, referred here as "shredder feed scrap", consists mainly of ferrous materials and has a similar composition than the hulk. It is a site-specificity of Re-source, for process and logistical reasons.

FIGURE 18. Regular compliant and profitable dismantling process at INDRA Re-source



On Re-source's dismantling line, once the ELV has been analyzed to determine the parts and materials to be removed depending on their condition and the market's demand, the vehicle is depolluted, and operators extract the spare parts and other components containing valuable materials for sale. The different material flows as well as the vehicle hulk are then sold to other actors of the ELV value chain.

Source: INDRA, IMT.

Effect of adding additional sorting operators on copper recovery at shredding stage (Preliminary Trial analysis)

We conducted several rounds of shredding on average ferrous feedstock, varying the number of sorting operators (cf. Section *The trials in short*). As we can see in **Figure 19** : each additional operator leads to an increased recovery of copper containing parts.

In terms of economic profitability, labor costs are compensated by the recovery of copper residues (cf. **Table 5**). During our tests, the average benefit generated by each operator is around 1€ per ton of hulk treated.

FIGURE 19. Proportion of recovered copper residues in average ferrous feedstock as a function of the number of sorting operators (%)

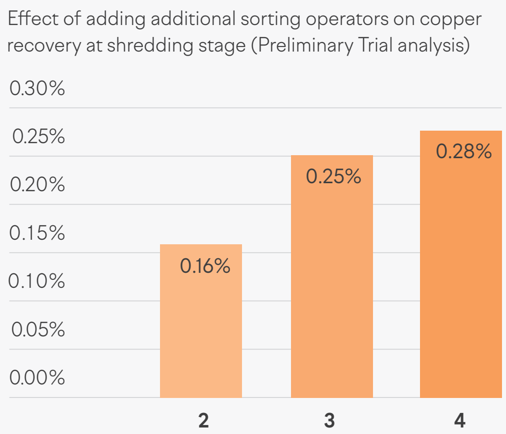


Table 5. Results from the shredding Trials on average ferrous feedstock.
Prices used : Copper residues = 1500€/t ; Labor cost = 24.5€/h.

Number of sorting operators	Proportion of recovered copper residues (%)	Cost-benefit balance from recovered copper (€/t hulk treated)	Cost-benefit balance from recovered copper per operator (€/t hulk treated /operator)
2	0.16%	1.76 €	0.88 €
3	0.25%	2.83 €	0.94 €
4	0.28%	2.97 €	0.74 €

Representativeness of the ELV samples

The three ELV batches (from Trials 1, 2 and 3) used in this study were characterized in terms of vehicle age and segment distribution. This analysis aimed to estimate copper wire content, assess the representativeness of the samples relative to the French ELV fleet, and enable comparisons across batches.

Age distribution

The age distributions of the three batches are presented in **Figure 20**. The average age of the batches of Trials 1, 2 and 3 is respectively 17, 16, and 19 years.

The Trial 3 batch displays a distribution closely aligned with the national ELV fleet (SDES), with a similar spread and an average close to the national average age of ELVs in France (19 years). Trial 2 batch has a slightly lower mean age, which is consistent with the way Re-source's sources its ELVs.

Segment and brand distribution

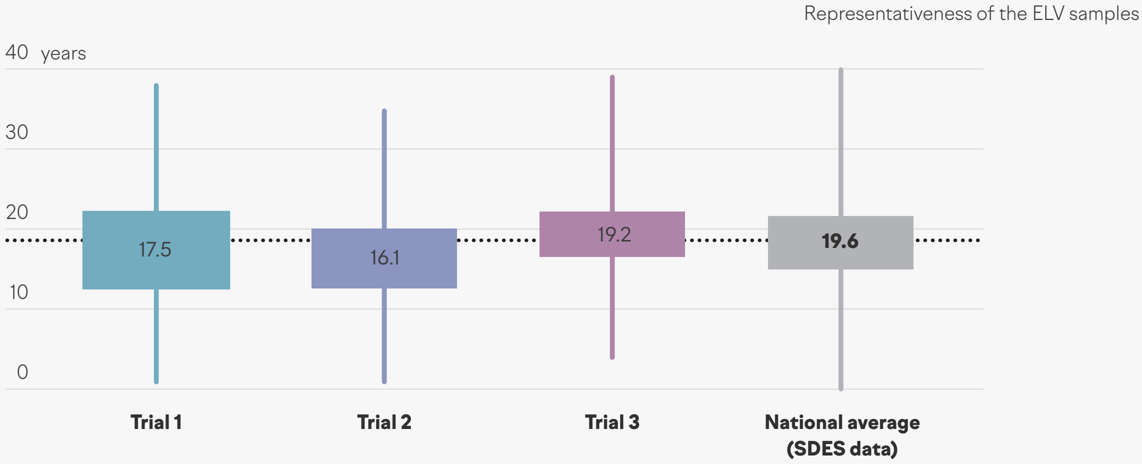
Figure 21 shows the segment and age composition of each batch. The segment distribution is globally similar across those batches.

All three batches include more than 20 different brands and approximately 100 different models, reflecting a broad diversity of the vehicles represented. **Figure 22** compares the brand distribution to the French average, showing that the brands accurately represent the French context.

Conclusion

The three trial batches are considered to be globally representative of the French average. Although a formal statistical equivalence test is beyond the scope of this analysis, the age and segment distributions presented above can be used to interpret cross-batch comparisons. Differences in batch composition, particularly the lower average age of the Trial 2 batch, are addressed by using the estimated copper wire content as a normalising variable. This allows copper recovery rates to be compared consistently across batches.

FIGURE 20. Age distribution across the 3 batches and in France



Sources : SDES (2024), 39,3 millions de voitures en circulation en France au 1er janvier 2024, https://www.statistiques.developpement-durable.gouv.fr/393-millions-de-voitures-en-circulation-en-france-au-1er-janvier-2024

FIGURE 21. Breakdown of the ELV batches by vehicle segment and age across the 3 Trials

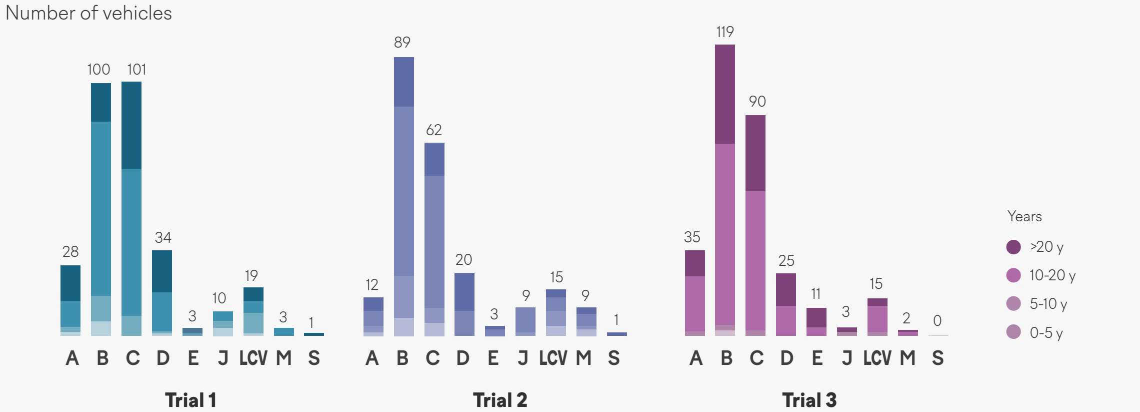
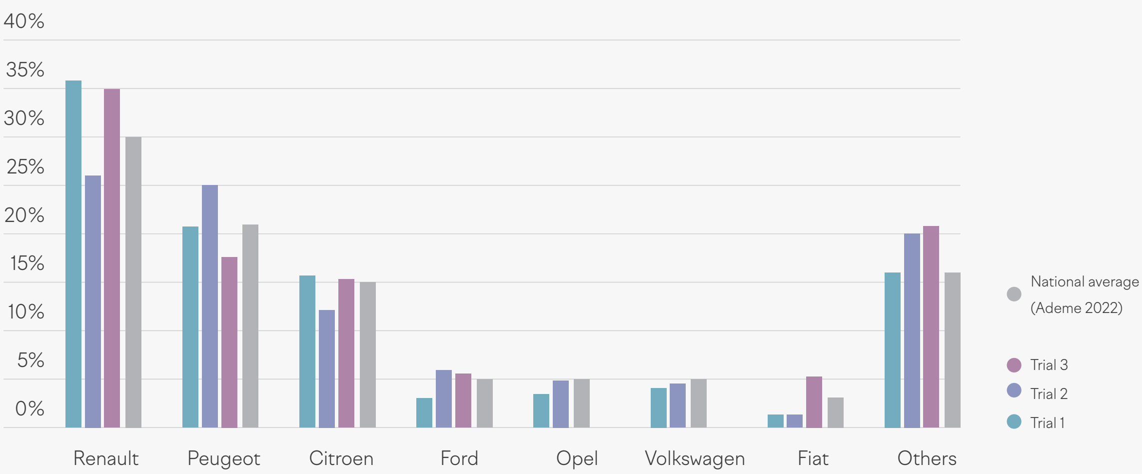


FIGURE 22. Brand repartition within the 3 batches



Calculation of the rate of copper wires in the ELVs

The theoretical wire content of the ELV used during the trials was based on internal data of Re-source, as they used to fully dismantle certain Renault vehicles of various ages and segments to determine their exact content of copper wire. Since vehicles of a certain segment and age usually contain the same options and equipment, these "reference vehicles" are considered, as a first hypothesis, as being representative to their equivalent of another brand regarding their wire content. To determine the theoretical average copper content of the trial ELVs, we hence classified the vehicles of our trials by segment and age and deduced the quantity of wires contained based on our "reference vehicles".

The theoretical copper wire content was estimated for each vehicle across the three batches using Re-source's reference database, by matching each vehicle to its corresponding segment and age category. The resulting estimated average copper wire content per vehicle showed an average of 12.1 kg per vehicle for Batch 1 (2024), 12.9kg for Batch 2 and 11.3 kg for Batch 3. The distribution is shown in **Figure 23**.

These differences can be explained by the average age of the samples, as more recent vehicles tend to contain higher amounts of copper wiring.

Reconstitution of the copper flows through the end-of-life value chain during the Trials

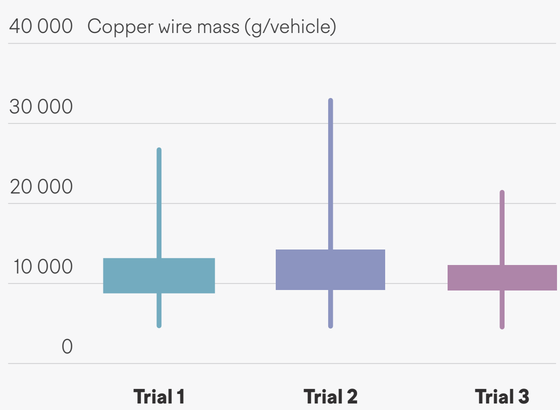
To assess the influence of copper content variability at each stage of the 3 ELV Trials processes, we analysed copper flows during the dismantling and post-shredding stages.

As detailed in Section *"Copper contamination of the steel scrap"*, in ELVs, copper is mainly present as wiring, but also as small motors, etc. The quantity of copper wires present in the ELVs prior dismantling was quantified using INDRA's internal database (see above), as well as the quantities removed by the ATF for reuse or recycling. However, we were unable to quantify the amount of other copper containing parts besides copper wires.

After shredding, the different forms of copper (wires and non-wires) are mixed. The data collected after each trial (quantity of copper containing parts collected by manual sorters and quantity of residual copper in E40, cf. **Table 1**) reflects both wiring and other copper containing components. Consequently, only a partial reconstruction of copper flows is possible, based on available data for wiring, while other copper containing parts such as small motors or connectors are not specifically quantified in this model (**Figure 23**).

Despite this limitation, the similar initial copper wire contents across the three batches confirm that batch variability does not affect the comparability of the trials. The differences observed at downstream stages can therefore be attributed to process conditions rather than to variations in the initial copper composition of the vehicles (see Section *Quality results*).

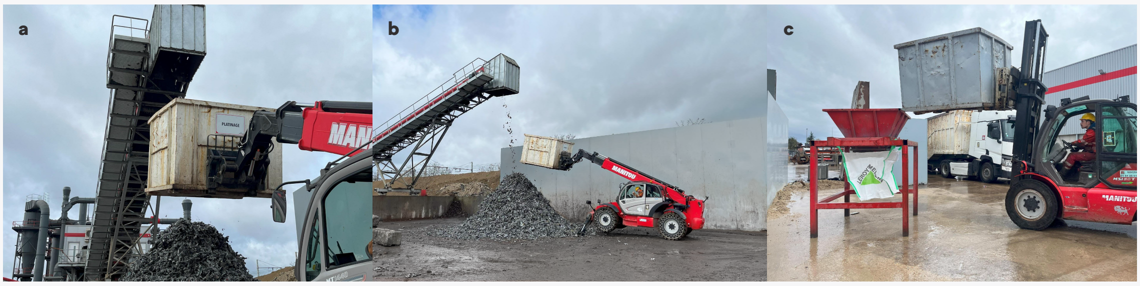
FIGURE 23. Copper wire content repartition across the 3 batches



Steel scrap sampling at the shredder

The sampling protocol of the three ELV batches was defined according to waste sampling standards, to collect a minimum of 600-700 kg (representative of the steel content of a shredded ELV). Sampling was carried out in three stages over the duration of the shredding process, and three samples of around 200-300 kg were recovered. The collection took place alternately under the scrap flow, at a rate defined on the basis of the theoretical scrap flow rate (calculated from the shredding speed of ELVs). The cadence was adapted over the course of the sampling campaign to ensure the most homogeneous sampling possible, since the shredder does not always operate at a constant rate due to technical contingencies (**Figure 24**).

FIGURE 24. Sampling
a. under the conveyor, **b.** under E40 scrap flow and **c.** sample being loaded into a big bag



Comparison of the Trials on ELV Batches

The three trials were conducted on batches of similar order of magnitude, ranging from 220 to 300 ELVs (**Table 6**).

The average weight sent to the shredder per vehicle varies significantly across batches, from 583 kg per vehicle in Trial 1 to 952 kg per vehicle in Trial 3 (**Table 7**).

Table 6. General data on the Trial ELV batches

	Trial 1	Trial 2	Trial 3
Number of ELVs	299	220	300
Theoretical average weight of copper wires (g)	12129	12947	11279
ELV average weight (kg)	1175	1192	1146

Table 7. Raw data on the shredding of the Trial ELV batches

	Trial 1	Trial 2	Trial 3
Total ELV batch			
Total input weight (t)	174.44	132.06	285.56
E40 (t)	126.06	95.38	193.42
Copper residues (t)*	0.20	0.37	0.90
Per vehicle			
Number of vehicles	299	220	300
Theoretical average weight per vehicle (kg)	1175	1192	1146
Average weight of hulk sent to shredder per vehicle (kg)	583	600	952
E40 recovered per vehicle (kg)	422	434	645
Copper residues recovered per vehicle (kg)*	0.7	1.7	3.0

* The copper residues recovered by manual sorters contain 20-22% copper.

This difference reflects both :

- the dismantling configuration : dismantling in Trials 1 and 2 removes a substantial mass of components prior to shredding, compared to the very light dismantling applied for Batch 3[46]
- the composition of the ELV Batches.

The E40 fraction recovered per vehicle ranges from 422 kg (Trial 1) to 645 kg (Trial 3), consistent with the differences in input mass per vehicle.

The mass of copper residues recovered by manual sorters increases substantially across trials, from 0.7 kg/vehicle in Trial 1 to 3.0 kg/vehicle in Trial 3, reflecting the combined effect of dismantling level, shredder performance, and number of sorting operators. These figures are expressed per vehicle to allow cross-batch comparison.

46 In the Deep dismantling and Medium dismantling configurations, some of the removed spare parts are sent to the shredder in pre-sorted batches, each with a specific market value. During the trials, however, we only sent the "main" hulks to the shredder, thus not taking into account these additional flows. The difference in weight can be explained by the systematic removal of engines and the separation of predominantly metallic components (which are divided into two categories : one consisting of copper-containing metals and mixed polymer materials and the other consisting of ferrous metals containing no copper).

The Institute for Mobility in Transition (IMT) is a spinoff of IDDRI (Institute for sustainable development and international relations) initiated in 2021. The organisation is a French independent think tank dedicated to the transition of the transport sector in France and Europe.
The aim is to objectify the environmental, social, industrial, and political issues at stake to facilitate the operational implementation of this transition. IMT produces analyses and recommendations to help French and European public decision-makers understand the issues, and to facilitate dialogue between stakeholders. The work is based on (1) multi-stakeholder consultation, within a platform that brings together players from diverse backgrounds to exchange ideas in a framework protected by the Chatham House Rule, (2) on a modeling tool comprising various databases, and (3) collaborations with European & international organisations on specific topics. The scope of scrutinised subjects includes amongst others: the decarbonisation of road transport, access to clean transportation, critical raw material supply and recycling, etc.