Zero Emission electric Vehicles enabled by haRmonised circularity

Deliverable 6.9

Relevant market & policy developments: observatory publications (preliminary version)

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ZEvRA project abstract

ZEvRA's main objective is to improve the circularity of light-duty EVs throughout their entire value chain, from materials supply and manufacturing to end-of-life (EoL) processes, which aligns with the European Union's goal of achieving zero CO2e emissions by 2035, particularly in the EV value chain. To do so, ZEvRA will develop a Design for Circularity (DfC) methodology and a holistic circularity assessment aimed at improving the production of electric vehicles (EVs) based on the 9Rs. This methodology will be validated by developing zero emission solutions for the most important automotive materials, covering > 84% material mix: steel, three versions of aluminium (wrought, casting, and foam), thermoplastics composites (long and continuous fibre-reinforced), unfiled/short fibre plastics, glass, tyres and Rare Earth Elements (REE). These solutions will be supported by a set of digital tools to support the manufacturing of the use cases, the assessment of circularity, traceability, and the virtual integration of components into a full replicable vehicle.

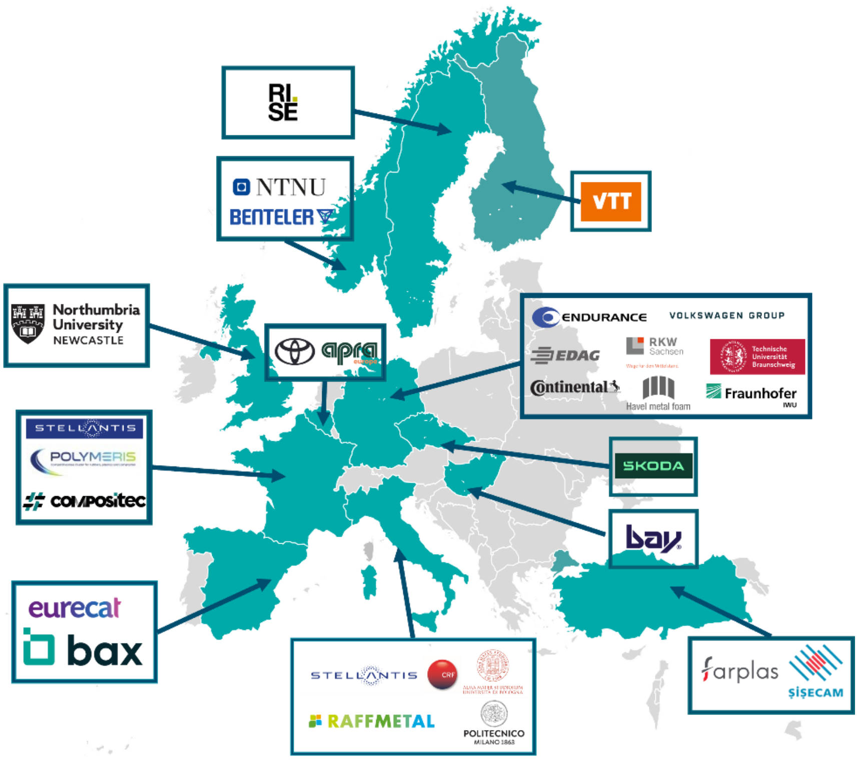

Figure 1: *ZEvRA Consortium*

To maximise the outreach of our methodology and zero emission solutions, ZEvRA will develop a dedicated training & upskilling programme for the automotive workforce and academia, together with activities aimed at increasing awareness & acceptability of the proposed zero emission solutions. Lastly, circular business models targeting EoL and logistics aimed at improving the economic feasibility of circularity in EVs are advanced. ZEvRA's innovations aim to improve zero emission approaches in the life cycle and value chain of at least 59% of European EVs by 2035 through the 5 OEMs and Tier 1's that are part of the consortium (Figure 1), which includes industry and academia covering the entire automotive value chain.

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Abbrevations and Acronyms

Table 1: *Abbreviations and Acronyms*

Abbr.	Full name
ABS	Acrylonitrile butadiene styrene
ACEA	The European Automobile Manufacturers Association
ASR	Automotive shredder residue
ATF	Authorized treatment facility
BEV	Battery electric vehicle
CE	Circular economy
DPP	Digital Product Passport
ELV	End-of-life vehicle
EoL	End of life
EoW	End of waste
EPR	Extended producer responsibility
EU	European Union
EV	Electric vehicle
FRP	Fibre-reinforced plastic
GMT	Glass mat thermoplastics
HDPE	High-density polyethylene
HVAC	Heating, ventilation, and air conditioning
ICE	Internal combustion engine
JRC	Joint Research Centre
LFT	Long-fiber thermoplastics
MFA	Material flow analysis
MSDS	Material safety data sheet
OECD	The Organisation for Economic Co-operation and Development
OEM	Original equipment manufacturer
PA	Polyamide
PC	Polycarbonate
PCR	Post-consumer recycled
PE	Polyethylene
PET	Polyethylene Terephthalate
PIR	Post-industrial recycled
PMMA	Poly(methyl methacrylate)
PO	Polyolefin
POP	Persistent organic pollutant
PP	Polypropylene
POM	Polyoxymethylene
PS	Polystyrene
PST	Post-shredder treatment
PUR	Polyurethane
PVC	Polyvinyl chloride
REACH	Registration, Evaluation, Authorisation and Restriction of Chemicals
SLF	Shredder light fraction
SVHC	Substances of very high concern
TDS	Technical datasheet
TPC	Thermoplastic composites
TRL	Technology readiness levels
WEEE	Waste electrical and electronic equipment
WFD	Waste framework directive

Executive summary

This preliminary report (Deliverable 6.9) presents a comprehensive overview of the policy and market landscape for plastics and composites in end-of-life vehicles (ELVs) within the European Union, with a focus on circularity and the utilization of recycled materials into automotive manufacturing. The main objective is to map the regulatory framework that influences the recycling and reuse of automotive plastics and composites, and to assess the current recycling capacity in Europe.

The EU's regulatory framework is evolving, and the proposed revision of the ELV Directive introduces ambitious recycled content targets for plastics, circularity strategies as well as a circularity vehicle passport. These measures are expected to drive innovation and subsequent investment in recycling technologies, however, their success hinges on the harmonized implementation across Member states.

The EU has achieved a mature, high-performing system for metals and major components, but significant blind spots remain for polymers and composites. Most automotive plastics are not separately dismantled, and end up in the automotive shredder residue (ASR), which is predominantly incinerated or sometimes landfilled, rather than being recycled back into new materials. Market and logistical challenges persist, including the low economic value of scrap plastics, lack of advanced sorting infrastructure, and fragmented logistics. Regulatory fragmentation, especially inconsistent end-of-waste criteria, further complicates the cross-border trade and market development for high-quality recyclates. Recent market disruptions, such as declining prices of virgin plastics, and increased imports of low-cost secondary materials, have led to closures of recycling facilities in Europe, further reducing domestic recycling capacity and increasing waste exports.

1 Introduction

This preliminary report D6.9 provides an overview of the policy and market landscape for plastics and composites in end-of-life vehicles (ELVs). It aims to map the regulatory framework influencing the recycling and reuse of automotive plastics, assess the current recycling capacity in Europe, and analyze the extent to which secondary plastics are utilized in vehicle manufacturing. The results of the logistics study of ELV plastics and composites from Task 6.2.2 are utilized. The objective is to identify drivers and barriers for business and innovation.

Within the ZEvRA project, plastics and composites are central to two automotive use cases: exterior structural parts (Objective 2.3, KER5) and interior trim components (Objective 2.4, KER6). For exterior parts, the focus is on thermoplastic composites (TPC) such as organo sheets, glass mat thermoplastics (GMT), and long-fiber thermoplastics (LFT), all developed to utilize 100 % recycled feedstock from post-consumer recycled (PCR) polypropylene (PP) or polyethylene terepthalate (PET) and post-industrial recycled (PIR) glass fiber scraps. For interior components, mineral-filled and short-fiber reinforced plastics are targeted, aiming for 70 % PCR content in TP formulations based on PP, acrylonitrile butadiene styrene (ABS) and polyamide (PA) upgraded through mechanical recycling and compounding with performance fillers and additives to meet automotive requirements.

Recycled plastics are already used in the automotive sector, primarily in non-structural components. However, technologies for recycling more complex materials, such as composites, plastics containing hazardous substances, and fiber-reinforced parts, remain at low technology readiness levels (TRL). While promising solutions are under development, their widespread adoption requires stronger legislative support, improved market conditions for secondary materials, and enhanced infrastructure for collection, sorting, and processing. Transparency and chemical safety of ELV plastics are also critical to enabling circularity.

The first part of this report (Chapter 2) reviews the most relevant EU legislation affecting plastics recycling from ELVs and the uptake of recycled plastics in new vehicle components. Special attention is given to regulatory drivers, barriers, and emerging requirements such as recycled content targets. The second part (Chapter 3) addresses end-of-life aspects for ELV plastics and composites. It describes the current state of ELV management in Europe, focusing on challenges related to plastics and composites from a logistics perspective. Existing recycling pathways and capabilities are summarized, followed by a discussion on the use of recycled plastics in vehicle components, their availability and the associated challenges.

The final version of this deliverable (D6.10, due in Month 36) will build on this preliminary analysis by presenting tailored circular economy solutions, incorporating results from stakeholder questionnaires, and considering the impact of certification and standardization in collaboration with Task 6.3.2 (Standardisation & certification recommendations).

Methodology and data sources

The analysis is based on a review of relevant EU policy documents related to ELVs and waste management, and mapping of recent literature and industry reports, focusing on developments in ELV plastics recovery, treatment technologies, and regulatory frameworks. The aim of the analysis is to identify key challenges, opportunities, and gaps in the context of ELV plastics management and utilization of recycled materials in the automotive sector in the EU.

In addition, a questionnaire was created in Google Forms to gather information on secondary material flows and to survey the potential needs of manufacturers as part of Task 6.2.2. RKW and POL created and distributed a survey on sources of polymer materials (primarily thermoplastics, but the survey does not exclude sources of thermosets, composites or rubber) and available glass, as well as gauging the needs of manufacturers. The survey focuses primarily on German and French manufacturers.

The survey was communicated during ELCA General Assembly and the workshop, both organized on the K Fair, in collaboration with S6.3.3 (Internationalisation and liaison to other related initiatives). Since this event, the survey has been communicated to Polymeris members on different media like LinkedIn and MyPolymeris platform, the Polymeris platform dedicated to innovation and accessible to our members.

2 Legislative overview

This section provides an overview of the key legislative and regulatory frameworks shaping the management of end-of-life vehicles (ELVs), and the recycling of their materials within the European Union, with a focus on plastics and composites. It covers the ELV Directive and the proposal for a new ELV Regulation, which sets targets for reuse, recycling, and recovery, and establishes extended producer responsibility for vehicle manufacturers. The Waste Framework Directive (WFD) is also discussed, outlining the waste hierarchy and defining essential concepts such as end-of-waste (EoW) criteria, which determine when recycled materials can re-enter the market as secondary raw materials. The section further examines the Waste Shipment Regulation, which governs the transboundary movement of waste, and the EU's chemical legislation, particularly REACH, which regulates the use of chemicals in recycled materials, once they re-enter the market as products or secondary raw materials. These frameworks provide the policy foundation for assessing and advancing circular solutions for ELV plastics and composites, ensuring environmental protection, market harmonization, and the development of high-quality recyclates for the automotive sector.

2.1 End-of-life vehicles Directive and the proposal for a new ELV Regulation

Directive 2000/53/EC on end-of-life vehicles (ELV) establishes measures to prevent and reduce waste from vehicles and their components, and to improve the environmental performance of all actors involved in the life cycle of vehicles [1]. In 2023, the European Commission launched a proposal for a new ELV Regulation, aimed at improving circularity during vehicle design and production, introducing mandatory targets for recycled content, and to reduce the exports of non-roadworthy vehicles [2]. In this proposal, the recycled content of plastics in vehicles would follow a phased target: at least 15 % after 6 years, increasing to 20 % after 8 years and reaching 25 % after 10 years, from the entry into force of the new Regulation. The ELV Directive sets clear targets for reuse, recycling and recovery of materials and components, with the overall goal of minimising the environmental impact of ELV generation and management [3].

The Directive prohibits the use of certain hazardous substances, including lead, mercury, cadmium and hexavalent chromium, in the manufacture of new vehicles, except under specific exemptions listed in Annex II. It also introduces extended producer responsibility (EPR) requiring producers to take financial responsibility for the collection, treatment and recovery of ELV, free of charge for the last owner. Article 4 further encourages vehicles design that facilitates dismantling and reuse and promotes the integration of recycled materials in vehicle manufacturing.

In the context of the ZEvRA project, the ELV Directive provides the core policy framework guiding the assessment of recycling processes for ELV plastics and composites. In addition, the proposed

ELV Regulation, introduces new and more ambitious circularity requirements that are particularly relevant for ZEvRA's focus on plastic and composite recycling in end-of-life vehicles.

2.2 Waste Framework Directive

The Waste Framework Directive (WFD) defines the basic principles and definitions for waste management, such as definitions of waste, recycling, recovery, end-of-waste criteria (EoW), and clarifying the distinction between waste and by-products. It also distinguishes between hazardous and non-hazardous waste [4]. The WFD further defines the waste hierarchy, establishing the priority order for management and disposal of waste (Figure 2-1). The key message of these principles is that waste should be treated in a sustainable matter, without causing harm to the environment or human health, waste shipments should be avoided if possible and waste should preferably be treated within the country or region where it is generated.

Figure 2-1: *Waste hierarchy concept setting priorities for the management and disposal of waste*

In the context of the ZEvRA project, the WFD provides the overarching policy framework for assessing the recycling and recovery of ELV materials. It defines the regulatory environment in which circular solutions must operate and sets the foundation for developing harmonized EoW criteria relevant to plastics and composites.

2.3 End-of-waste criteria

The End-of-waste (EoW) criteria specifies when certain waste ceases to be waste, and obtains a status of a product (or a secondary raw material). According to Article 6(1)-(2) of the WFD, certain specified waste shall cease to be waste when it has undergone a recovery or recycling operation and complies with specific criteria, in particular:

- the substance or object is commonly used for specific purposes;
- there is an existing market or demand for the substance or object;

- the use is lawful (substance or object fulfils the technical requirements for the specific purposes and meets the existing legislation and standards applicable to products);
- the use will not lead to overall adverse environmental or human health impacts.

The European Commission monitors national implementation of EoW-criteria and assesses the need to develop union-wide criteria. Implementing Act 2019/1004/EC establishes detailed criteria for applying conditions for EoW-criteria consistently [5]. Where no criteria have not been set at Union level, Member States may develop national criteria or assess case-by-case to take appropriate measures to verify whether a material has ceased to be waste. These detailed criteria shall consider any potential environmental and human health impacts of the substance or object and shall satisfy the requirements laid down in the WFD Article 6(2) and considering limit values for pollutants and any possible adverse environmental and human health impacts.

In the context of the ZEvRA project, the EoW framework is particularly relevant for defining when recycled plastics and composites from ELVs can re-enter the market as secondary raw materials. Moreover, EoW criteria are often set case-by-case or at national level, due to lack of harmonized EU-wide criteria. Clear and harmonized criteria are essential to facilitate trade of high-quality recyclates and support circular value chains in the European automotive sector.

2.4 Waste shipment legislation

The Waste Shipment Regulation (2024/1157) establishes the procedures for the shipment of waste, depending on the type of waste, the route of the shipment, and the intended treatment operation [6]. Replacing Regulation 1013/2006, it applies to waste shipments imported into and exported from the EU, between Member States, and transits through the EU. This regulation implements the commitments under the Basel Convention and the OECD Decision on waste movements into EU law.

The updated Regulation sets out stricter rules to ensure that waste is treated in an environmentally sound manner and that the EU does not export its waste to third countries. There is a general ban on waste exports for disposal as well as a ban on hazardous waste exports for recovery to non-OECD countries. The export of “green-listed” waste, i.e. non-hazardous waste, will be generally prohibited to non-OECD countries, unless certain conditions apply.

In the context of the ZEvRA project, the WSR is particularly relevant as it sets the conditions under which the ELV waste streams circulate within the EU.

2.5 Chemical legislation

The EU’s chemical legislation is principally governed by the Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH, Regulation No 1907/2006), establishing a comprehensive framework to manage chemical risks [7]. REACH aims to improve the protection of human health and environment from chemical risks, while supporting the competitiveness of the EU chemical industry. The regulation applies to the production, import and use of substances within the EU, whether on their own, in mixtures or incorporated into articles. For the recycling sector, REACH becomes applicable once waste ceases to be classified as waste and re-enters the market as a product or secondary raw material. At this point, recycled products are subject to the same compliance as virgin materials.

Complementing REACH, the Classification, Labelling and Packaging (CLP) Regulation (EC No 1272/2008) ensures that substances and mixtures are appropriately classified, labelled and packed [8]. Another important instrument is the Persistent Organic Pollution (POPs) Regulation (Regulation No 2019/1021), which establishes restrictions to substances and waste management for products containing POPs, such as certain brominated flame retardants (BFRs) [9].

In the context of the ZEvRA project, chemical legislation direct implications for the recycling of ELV plastics and composites. For instance, legacy additives in older vehicles may prevent recycled plastics from being put on the market, hindering the closed loop potential.

2.6 Regulatory drivers and barriers

This section discusses the main regulatory drivers and barriers influencing the circularity of ELVs. It also considers the impact of these on business and innovation within the sector.

2.6.1 Regulatory drivers

The European policy framework provides a strong legislative foundation that supports the transition towards circularity in the automotive sector, and recycling of ELVs, plastics and composites. Central to this is the ELV Directive (2000/53/EC), which sets clear targets: 85 % reuse and recycling, and 95 % on reuse and recovery of the average vehicle weight of ELVs per vehicle and year. However, the old Directive does not set specific targets for plastics, which has led to a lack of recycling data for ELV plastics.

The 2023 proposal to revise the ELV Directive introduces more ambitious and systemic provisions. It places a strong focus on design for circularity, underlining the role of vehicle design in enabling easier dismantling, separation of materials and reuse. Furthermore, Article 13 introduces the circularity vehicle passport, a digital tool intended to enable access to detailed information on safe removal and replacement of vehicle parts and components. The proposal is also complemented by strengthened labelling requirements (Annex VI), that aims to ensure standardised identification of key materials in vehicles. Integrating these considerations into the early stages of design and production supports the shift towards circularity, while functioning as catalysts for innovation in material formulation, product design and disassembly technologies. This in turn stimulates investment in advanced materials and recycling technologies.

The mandatory targets send a strong signal for the expansion of recycling capacity and create stronger market incentives for the use of secondary materials. Such targets may incentivise collaboration between recyclers, suppliers and OEMs, further fostering innovation in recycling technologies. In parallel, strengthened extended producer responsibility (EPR) requirements further create economic incentives for manufacturers to ensure that materials are efficiently collected and recycled, promoting closed-loops for plastics and composites.

The Waste Framework Directive (2008/98/EC) complements these measures by defining the waste hierarchy as a guiding principle for waste management. Such guiding principles reinforces efforts to extract most possible value from vehicle components, including plastics and composites.

Chemical legislation also plays a critical role in harmonising circularity with safety objectives. REACH ensures that recycled plastics meet standards for protection of human and environmental health. Thus, REACH incentivizes innovation in safer and more recyclable material formulations.

Other policy measures contribute to increased supply of recyclable waste streams. The ELV Directive's ban on the export of non-roadworthy vehicles could increase the availability of domestic feedstock for recycling, improving supply chain efficiency for secondary plastics.

Recent policy initiatives further amplify these drives. The Sustainable products regulation and the upcoming digital product passport (DPP) will enhance traceability and information flow along the product life cycle, enabling recyclers to identify material composition and origin more effectively. Moreover, the upcoming Circular Economy Act aims to establish a single market for secondary raw materials, enhancing the availability of high-quality recycled materials and stimulating demand for those materials [10].

Funding and coordination initiatives such as Horizon Europe further accelerate progress in this area e.g. in developing advanced recycling technologies, piloting new business models, and fostering partnerships between industry, academia, and public authorities.

2.6.2 Regulatory barriers

Despite a supporting EU policy framework promoting circularity, several regulatory challenges can be identified to hinder the transition towards increased usage and recovery of plastics and composites from ELVs.

One barrier consists of the differences in the implementation of EoW criteria between Member States, leading to uncertainty for recyclers, as in some countries waste ceases to be classified as waste under clear criteria, while in other countries case-by-case decisions prevail. This fragmentation complicates the cross-border trade in secondary raw materials, possibly limiting market development for high-quality recyclates.

Chemical legislation compliance represents another regulatory challenge. Recycled materials may contain substances that are restricted under REACH. Demonstrating this conformity requires testing, documentation, and material traceability, resulting in additional costs. The lack of harmonized databases and data-sharing mechanisms further limits transparency.

Logistical and administrative challenges arise from the Waste Shipment Regulation, which introduces stricter controls on exports. While justified, these rules may add procedural complexity, particularly for recyclers operating in multiple Member States or sourcing waste from cross-border streams.

Another key aspect is the potential loss of global competitiveness of the EU automotive industry if comparable requirements are not adopted internationally. If the use of recycled plastics does not become a norm globally, European manufacturers might face higher production costs and compliance burden compared to non-EU manufacturers. [11]

Another challenge includes the mismatch between regulatory evolution and the vehicle development cycles. Regulations governing material composition and recyclate quality tend to develop faster than the average 7-year design and production cycle of vehicles. This introduces uncertainty for manufacturers, that have to design components that stay compliant and recyclable over a longer period. The development and qualification of components with new plastic components typically require several years, possibly delaying implementation of recycled-content targets. [11]

Market distortions and certification challenges are also highlighted. Non-certified recyclates from third countries entering the EU-market may potentially undermine fair competition. Verifying and tracing recycled content in imported vehicles and components stay difficult, given the complex supply chains. [11]

Cross-sectoral market effects may be introduced as regulations increase demand for recycled plastics in automotive manufacturing. A large-scale uptake could create competition in sourcing and material bottlenecks across sectors like packaging, WEEE, and construction. If the supply of high-quality recyclates stay limited, industries might experience cost pressures, or shortages. Such imbalances could distort recycling markets [11]. Currently, limited availability of high-quality recycled plastics suitable for automotive applications, such as recycled polypropylene (rPP), polyethylene (rPE), and polyamide (rPA), has been identified as one of the primary challenges to meet the requirement of the ELV proposal. Supply remains limited because most plastics from end-of-life vehicles are downcycled into lower-value uses or incinerated, as collection and sorting systems are not yet standardized (more detailed description of the ELV plastics management in Chapter 3.3) [12].

The previous Deliverable in the ZEvRA project, D5.1., identified regulatory and market barriers in the context of improving awareness and acceptability of CE practices and identifying barriers to implementation. Some identified barriers could be translated further into the context of this deliverable, confirming the existence of overarching barriers. These include the lack of competitive prices of secondary raw, the absence of high-quality secondary raw materials and well-functioning markets for those, and weak innovation activity, limiting the businesses capability to transition to a circular economy.

3 ELV plastics and composites: recycling, utilization, and industry development

This chapter examines the current state of EoL management for plastics and composites in Europe. Plastics and composites represent a growing share of vehicle materials, offering lightweighting benefits but posing significant challenges at EoL. Unlike metals, which have well-established recycling loops, automotive plastics are often complex, multi-material, and contaminated with coatings or additives, making their recovery and reuse more difficult.

The chapter begins with an overview of ELV amounts, use of plastics and composites in the automotive sector, and how plastics are treated within existing ELV management systems, highlighting regulatory requirements and practical constraints. Current recycling pathways are briefly described, along with the available processing capacity in the EU. Finally, the chapter explores the use of secondary raw materials in automotive plastics, assessing availability, quality, and market uptake, and identifying key barriers.

This chapter outlines the current situation and challenges in end-of-life management of automotive plastics and composites, providing context for identifying areas where market development and policy measures could improve circularity.

3.1 Background on the ELV landscape

According to Eurostat data from 2024, approximately 4.7 million end-of-life passenger cars and light goods vehicles were processed in the EU-27 in 2022, resulting in about 5.5 million tonnes of material [13]. On average, 89.1 % of this material (by weight) was reused or recycled, surpassing the Directive's target of 85 %. The combined reuse and recovery rate reached 94.4 %, nearly achieving the 95 % objective set by Directive 2000/53/EC.

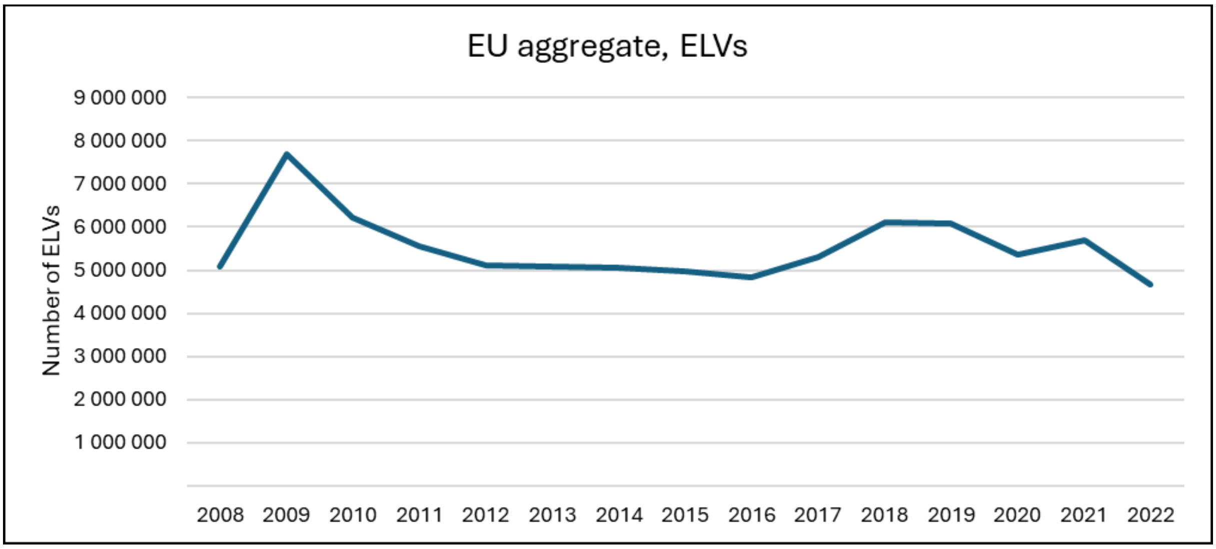

Figure 3-1: *EU-27 End-of-Life Vehicle (ELV) Trends (2008–2022).*

The absolute number of passenger cars and light goods vehicles treated as ELVs across the EU-27 from 2008 to 2022 is presented in Figure 3-1. The data reflect significant variations among Member States, driven by differences in fleet size, scrappage schemes, and reporting practices. Peaks (e.g. in 2009) correspond to scrappage incentives during the financial crisis, while recent years show stabilization. This provides context for the EU's consistently high reuse, recycling, and recovery rates in line with Directive targets.

At the national level, performance varies: some countries even exceed 95 % reuse/recovery, while a few fall below targets due to infrastructure gaps or reporting issues. From a logistics viewpoint, this continental scale translates into:

- Widespread dismantling infrastructure: a network of thousands of authorised treatment facilities (ATFs) handle vehicle depollution and parts removal in every Member State.
- Regional shredding capacity: several hundred shredders operate at regional levels, processing depolluted vehicle hulks to recover metals.
- Cross-border material flows: substantial transboundary shipments occur for secondary materials and residue (especially automotive shredder residue, ASR), reflecting specialization (e.g. some countries export ASR for treatment where capacity exists elsewhere).

However, the aggregate statistics lack material-specific resolution. Plastics and FRPs are effectively hidden within residual categories (like ASR), obscuring how these materials move through the ELV logistics chain. For a more comprehensive understanding of these macro-level trends, several contextual factors should be considered:

- Automotive fleet context: The scale of ELV arisings needs to be viewed in relation to the overall vehicle fleet and new vehicle registrations. Changes in Europe's car stock and sales influence ELV volumes [14]. For example, surges in new car sales or shifts to EVs eventually translate into corresponding patterns in scrappage. Broader automotive trends (vehicle longevity, consumer behavior, electrification) thus feed into the long-term ELV statistics.
- Policy framework: Europe's regulatory environment underpins the high performance on paper. Directive 2000/53/EC (ELV Directive), and its enforcement evaluated by the European Commission (2019), set ambitious reuse/recycling (≥85 %) and reuse/recovery (≥95 %) targets which Member States have largely adopted. National implementation of these rules drives investments in ELV processing infrastructure. However, the policy framework to date has primarily incentivized metal recovery; it provides less direct impetus for plastics or FRPs recycling, which is reflected in the current gap.
- Data and reporting challenges: There are known uncertainties in ELV data. For instance, a fraction of de-registered vehicles have unknown whereabouts [15], as they may be illegally dismantled, exported, or otherwise unaccounted, which can skew official figures. Anomalies in reported rates also occur; in certain years/countries the calculated reuse/recovery rate even exceeds 100 % (e.g. due to processing of stockpiled vehicles from previous years, as noted

in Eurostat's data footnotes). These issues suggest caution when interpreting the statistics and indicate the need for improved tracking of ELV flows, especially for non-metallic fractions.

- International benchmarking: Comparing the EU's ELV management to other regions highlights strengths and remaining gaps. Studies of ELV recycling systems in, for example, Japan and the US/Australia show that the EU is a front-runner in overall recovery performance thanks to its directive-driven system [16], [17]. However, these comparisons also emphasize that plastics recovery is a universal weak point, even advanced systems struggle to economically reclaim automotive plastics and composites. Learning from global best practices (such as specialized plastic part recycling programs in certain countries) could inform European improvements.

Together, these factors paint a nuanced picture of the ELV landscape: the EU has achieved a mature, high-performing system for metals and major components, but significant blind spots remain for polymers and composites. The following sections delve into those blind spots by examining the role of plastics and FRPs in vehicles and mapping their journey (or loss) through the end-of-life process.

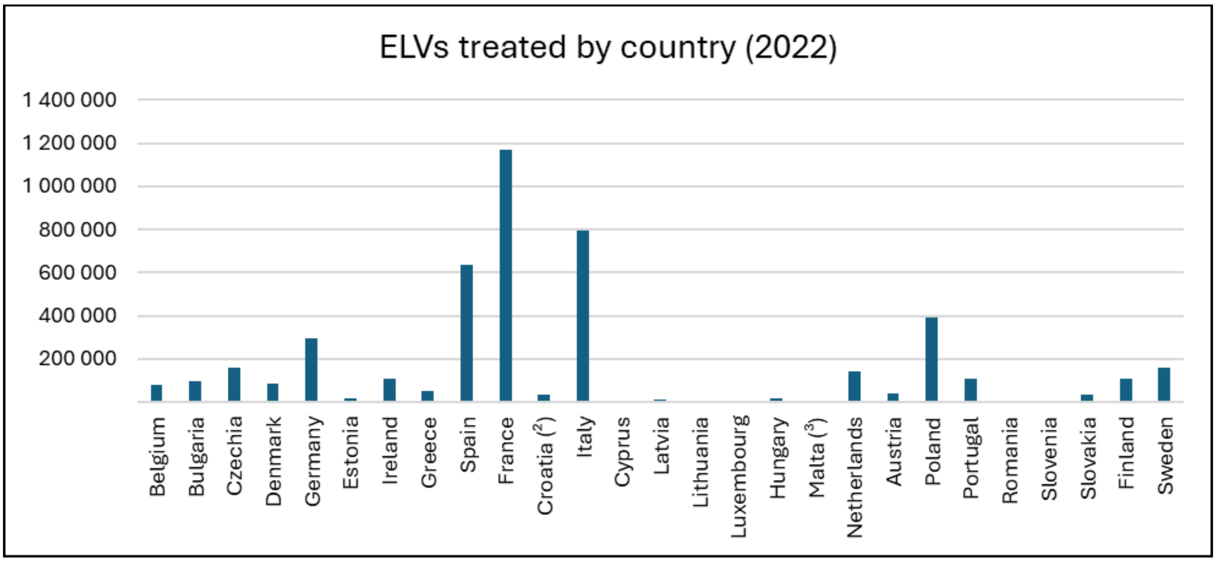

Figure 3-2: *End-of-life vehicles treated by country in 2022 (EU-27).*[1]

[1] The number of vehicles treated varies significantly across Member States, reflecting differences in fleet size, reporting practices, and treatment capacity. Larger countries (e.g. Spain, France, Italy) dominate the total volume, while smaller Member States show proportionally lower but still relevant flows.

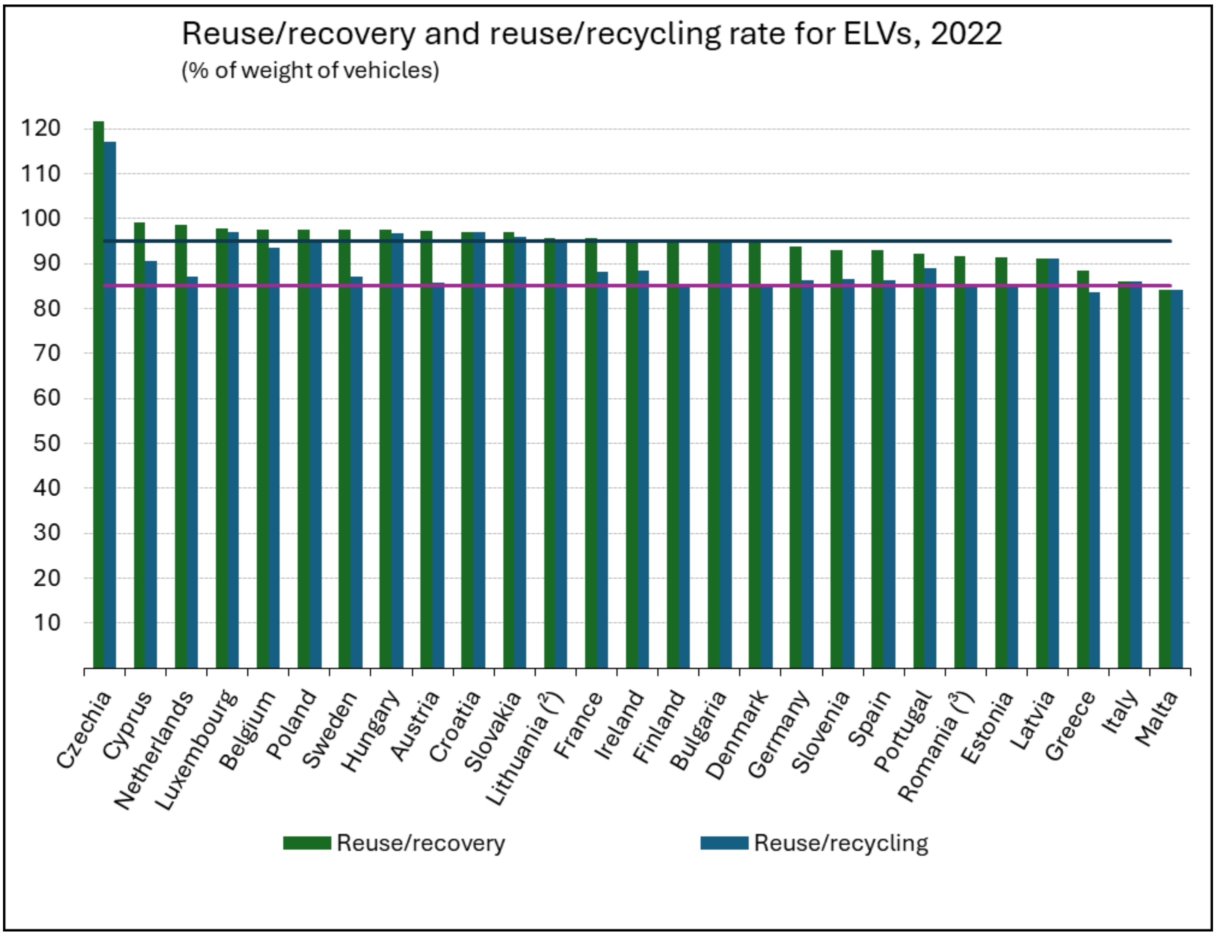

Figure 3-3: *EU-27 average reuse/recycling and reuse/recovery rates in 2022 compared with Directive thresholds.*[2]

3.2 Plastics and FRPs in the automotive sector

With a total demand for virgin plastic in Europe (EU27+3) at the level of 53.3 Mt in 2022, the automotive sector was responsible for approximately 9 % of that demand, 4.7 Mt [18]. Plastics typically constitute about 15–20 % of a vehicle's weight (roughly 250–300 kg per car), and this share is rising as manufacturers replace metal parts with lighter polymer components [19]. FRPs currently make up a much smaller fraction by weight (only a few percent in conventional cars), but their strategic importance is growing. FRPs, such as glass-fibre or carbon-fibre composites, are increasingly used in new vehicle designs for components like battery casings, body panels, and structural reinforcements, especially in EVs. However, due to their composite nature (fibres embedded in resin, often thermoset), FRPs are difficult to recycle using conventional mechanical processes. In practice, nearly all FRP material at EoL currently ends up in residual waste streams unless specialized technologies are applied.

[2] The EU-27 achieves an average reuse/recycling rate of 89.1 % and a reuse/recovery rate of 94.4 %. These values exceed the Directive 2000/53/EC target for reuse/recycling (≥85 %) and nearly meet the reuse/recovery target (≥95 %).

Table 2: *Compilation of plastic in vehicles, their main applications, and relative share in current and future ELV fleet [11].*

Main polymer type included in vehicles	Applications	Share of plastic type in ELVs currently reaching EoL	Share of plastic type in future ICE ELVs	Share of plastic type in future BEV ELV
Total plastic share in overall vehicle		12 %	16 %	13 %
Polypropylene (PP)	Front/rear bumpers, interior panels, dashboard, cable insulation	37 %	37 %	40 %
Polyurethane (PUR)	Flexible foam seating, foam insulation panels, elastomeric wheels and tires, automotive suspension bushings, cushions, electrical potting compounds, hard plastic parts	15 %	15 %	10 %
Polyamide (PA)	Gears, bushes, cams, bearings, weatherproof coatings, carpet fibers	12 %	12 %	8 %
Polyethylene (PE)	Car bodies (glass reinforced), fuel tank (HDPE), electrical insulation	8 %	8 %	15 %
Acrylonitrile Butadiene Styrene (ABS)	Body parts, dashboards, wheel covers	7 %	7 %	5 %
Polyethylene Terephthalate (PET)	Wiper arm and gear housings, headlamp retainer, engine cover, connector housings.	5 %	8 %	10 %
Others (e.g. PVC, PS, POM, PC, PMMA, etc.)	Instruments panels, electrical cables, pipes, doors, equipment housings, buttons, fittings, interior and exterior trims, fuel systems, small gears, bumpers, headlamp lenses, windows, displays, screens, door handles, carburetor components	16 %	13 %	12 %

The variety of plastics used in the automotive sector is wide, as is shown in Table 2, listing the main polymer types that are found in passenger cars [11]. The varying properties of these plastic materials are reflected in large variety of end applications they are found in. Furthermore, different conditions of use within the car, such as resistance to heat, moisture, chemicals, voltage, UV radiation, etc, pose requirements for the selection of the suitable plastics type [20]. The evolving vehicle fleet also affects the usage of plastics in the automotive sector, as shown in the variation of plastics shares between internal combustion engine (ICE) and battery electric vehicle (BEV), as well as in the difference between ELVs currently reaching end-of-life and future ELVs. The most common polymers found in the current ELVs include polypropylene and polyurethane. In addition to differences in other properties, the recyclability of different plastics are different from each other, with some polymers, such as PET and PE, being more recyclable, whereas others such as thermoset polyacrylate, are difficult to recycle [11].

The logistics handling of plastics and FRPs at end-of-life is challenging, defined by several key characteristics:

- Bulkiness of parts: Large plastic components, e.g. bumpers, dashboards, interior trim, are physically cumbersome. Their size and low density make storage and transport inefficient, consuming significant space for relatively little weight.
- Material diversity: Vehicles contain a wide variety of polymers (PP, PE, PVC, ABS, polyurethanes, etc.), often with fillers or bonded with other materials (metal inserts, foam, fibre reinforcement). This heterogeneity complicates identification, sorting, and separation during dismantling and recycling, as different plastics cannot be easily mixed for recycling processes.
- Low economic value: Compared to metals or certain engine parts, scrap plastics have a relatively low market value per tonne. The cost of manually removing and segregating plastic parts can exceed the revenue from selling them as recyclate. Consequently, dismantlers focus on components with clear reuse or resale value (e.g. intact bumpers, headlights) and leave lower-value plastics in the vehicle hulk.
- Special handling requirements: Some FRP components (especially those used in critical areas like battery housings or crash structures) require careful handling due to safety or regulatory considerations (for example, avoiding sparks or damage that could release fibres or cause fires). These specialized procedures slow down processing and may necessitate dedicated pathways or equipment for FRPs at end-of-life, which many facilities do not yet have.

These factors explain why the vast majority of plastics and FRPs from ELVs are not reclaimed individually but instead flow into the mixed shredder output. In current practice, most plastic and composite content is channelled into automotive shredder residue (ASR) after the shredding stage, and from there is predominantly sent to incineration with energy recovery (or sometimes landfill), rather than being recycled back into new materials.

Recent literature underscores how the role of plastics and FRPs in the automotive sector is rapidly evolving. Advances in polymer science are expanding the use of novel plastics and composites: for example, new lightweight blends and FRPs are being used for both structural and non-structural parts to improve vehicle efficiency [21]. At the same time, there is movement toward circular use of plastics. A study documents pilot projects for closed-loop polypropylene recycling in the automotive sector, in which plastics from ELVs are reclaimed and reprocessed into new car parts, an approach that meets sustainability goals but introduces new logistical and quality-control challenges [22]. Automotive manufacturers and the plastics industry are also responding through eco-design initiatives and material innovations [23], such as designing parts for easier recyclability, using more uniform plastic types, or incorporating recycled content in new vehicles. Together, these developments highlight the growing strategic importance of plastics and FRPs: not only are they a larger portion of modern vehicles, but they are also central to the industry's pursuit of circular economy solutions.

3.3 General overview on ELV management and logistics flows of plastics and FRPs

Figure 3-4 presents an overview on the plastics in the automotive sector and the corresponding stakeholders in different stages of the value chain.

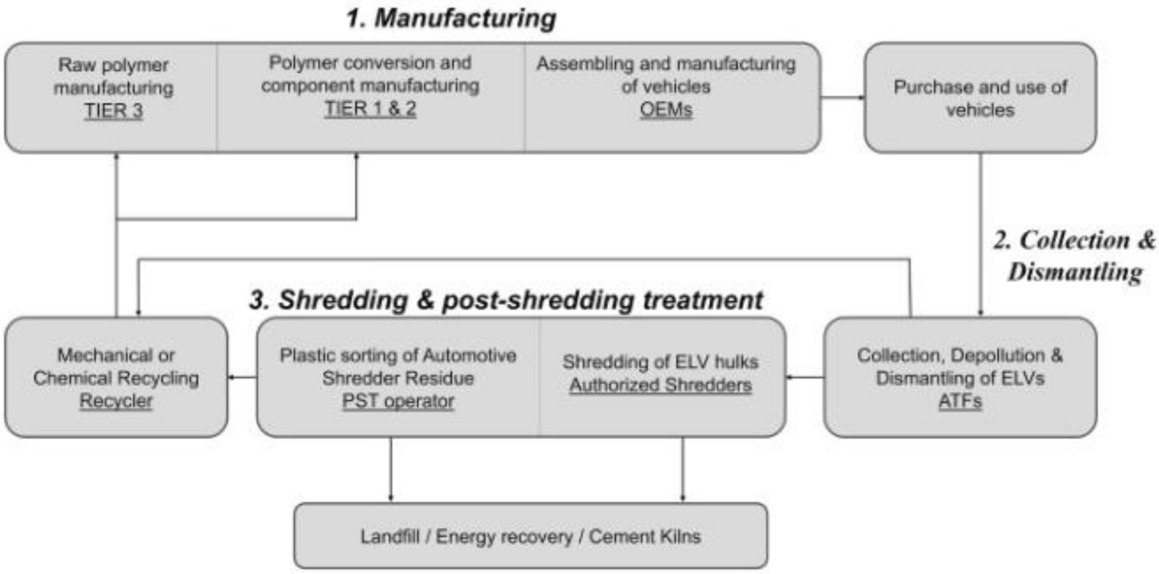

Figure 3-4: *Overview of the plastics value chain in the automotive sector in the EU [24].*

The end-of-life logistics chain for plastics and FRPs begins when ELVs arrive at authorized treatment facilities (ATFs). At the ATF dismantling stage, technicians first remove hazardous and high-value items (fluids, batteries, catalytic converters, tires, etc.). Plastics and FRPs, however, are only selectively extracted at this point. For instance, large exterior plastic parts like bumpers might be removed if they are in good condition for resale or if there is a specific recycling program, and components such as headlights may be taken out for reuse or material recovery of certain plastics. Although ELV Directive recommends separate removal of components such as bumpers, dashboards, and fluid containers, it is not a common practise [20]. The majority of polymer-based parts remain in the vehicle hulk and are not systematically separated during dismantling, due to the economic and practical constraints discussed in Section 3. In some EU countries, such as in the Netherlands, the removal of plastics parts for reuse is more common, driven by site specific economic incentives [25].

Next, the leftover hulks, still containing most of the plastics and FRPs, are transported to shredding facilities. There, each vehicle is fragmented by powerful shredders that primarily focus on metals. Ferrous metals (steel, iron) are separated by magnets, and non-ferrous metals (aluminium, copper, etc.) are sorted out by eddy current separators and other techniques. During this process, plastics and FRPs are not recovered as distinct streams; instead, they become part of the leftover mix known as automotive shredder residue (ASR). ASR typically makes up about 20–30 % of the vehicle's original weight after shredding (this fraction contains plastics, FRPs, foam, textiles, rubber, glass, dirt, and other non-metal materials).

After shredding, the metals extracted (about 70–75 % of the vehicle) go into well-established recycling channels (steel mills, smelters, etc.). In contrast, the ASR has a far more fragmented fate. Different regions and companies handle ASR differently: often it is sent to incineration with energy recovery (to reduce volume and recover some energy), and in some cases it is landfilled (especially where incineration capacity is lacking or landfill costs are low). A portion of ASR may also be exported to countries or facilities that claim to have specialized treatment technologies (sometimes for further material recovery or energy recovery). In all of these paths, plastics and FRPs constitute a large part of the ASR and thus largely end up being burned or disposed of rather than recycled.

Further downstream, any recovery of plastics from ASR is minimal. Key barriers include the high cost of transporting and processing a low-density material mix and technical difficulties in separating usable plastic from a dirty, heterogeneous residue. FRPs in ASR introduce additional complications: for example, fire safety regulations can restrict handling and storage of ASR (with flammable plastic and fibre content), and the inert fibre content of FRPs does not yield energy or material value easily. As a result, incineration remains the predominant EoL outcome for automotive plastics and FRPs. Only a very limited fraction of these materials is recycled or repurposed in current practice, typically when specific pilot programs or niche applications are in place. Technologies for post shredding treatment and recycling is discussed more in detail in the infobox below.

In rare cases, a portion of plastics (and potentially some FRPs) is diverted from the conventional disposal routes through innovative recovery efforts. These exceptional pathways include things like advanced chemical recycling (breaking plastics down into monomers or fuels), upcycling certain plastics into higher-value products (for example, shredder plastic being used to manufacture construction materials), or manufacturer-driven take-back schemes that collect specific plastic parts for recycling. FRPs are even less commonly recovered, but research projects have explored reusing ground fiberglass from FRPs in cement or recycling carbon fibers for new composites. While such initiatives are not yet widespread, they demonstrate the potential for more sustainable solutions beyond incineration or landfill, and highlight opportunities for future improvement in ELV material management.

Infobox - Post-shredder treatment and recycling of plastic fractions from ELVs
Various post-shredding treatments can be applied to ASR. Although these technologies are commercially available, their adoption in ELV waste management practices remains limited [25]. The selection and combination of technologies for treating plastic-containing fractions, and the resulting output, depend on the specific facility. Shredding, or size reduction, is the initial step for processing the leftover vehicle hulk. This process decreases particle size and liberates different materials, enabling subsequent separation. Typically, various types of crushers and shredders are used. Size control then separates the particle mix into more distinct size classes. Physical separation and enrichment techniques are then applied, relying on properties such as density, magnetism, and electrical conductivity to isolate desired fractions for further treatment. During these processes, plastics often end up in ASR, particularly in the shredder light fraction (SLF). However, because particles can be either mono-material or multi-material, the physical properties of multi-material particles are a combination of their constituents, making perfect separation challenging. Further separation and washing of polymers are crucial steps in plastic recycling. Removing dust, dirt, and incompatible plastic types is essential, as contaminants can deteriorate the mechanical properties of recycled plastics and limit their applications. Common methods for polymer separation include sensor-based recognition, which enables fast sorting of polymer types and identification of bromine-containing plastics. Shredded plastic particles are conveyed under automated sensor systems, which recognize target particles and activate separation mechanisms. Techniques used for sensor-based sorting include, for example, near-infrared (NIR) spectroscopy. After separation, plastics may undergo regranulation or pelletisation, during which the material is homogenized and processed into new products, accompanied by technical (TDS) and material safety datasheets (MSDS) [26], [27]. However, plastic separation can be difficult, especially when polymers are mixed with additives and impurities. This challenge has led to the development of various recycling concepts [26], [28], [29], [30], [31]. The plastics separated from ELVs are typically in the form of flakes, which can be used directly by recyclers. Through compacting, these flakes can be transformed into pellets suitable for manufacturing new plastic products. Mechanical recycling is currently the most common and convenient option for many polymers, particularly when the material is relatively clean, uncontaminated, and from a known origin. For plastic waste streams that cannot be feasibly treated via mechanical recycling, such as those containing hazardous components like halogens or carbon fibres, chemical recycling offers an alternative to incineration or landfilling, extracting further value from polymers [31], [32]. For example, carbon fibres from fibre-reinforced plastics (FRP) can be recovered during pyrolysis, which provides the high-temperature, low-oxygen conditions necessary to decompose the plastic matrix while preserving the carbon fibres for reuse [33].

Logistics bottlenecks

Despite some localized innovations, recovering plastics and FRPs from ELVs is hampered by several pervasive logistics bottlenecks. Unlike metals, which occur in bulk and have well-established markets, plastics and composites are dispersed in many parts and collected in relatively small quantities per vehicle, making it difficult to achieve the economies of scale that justify dedicated recovery efforts. This fragmentation means higher per-item logistics and handling costs, which in turn discourage investment in plastic-specific collection systems. Moreover, the low market value of most recycled plastics (relative to virgin plastic or to recycled metals) means there is little financial incentive under current conditions to sort and process them after shredding, as the default is to send the mixed residue to the cheapest disposal or energy recovery option.

Another significant barrier is the lack of comprehensive data tracking for plastic and FRP flows throughout the ELV process. While metals are weighed and recorded meticulously (due to their value and the Directive targets), plastics exiting the system (mostly via ASR) are not individually measured or reported. This creates a blind spot: stakeholders have an incomplete picture of how much and what types of plastic could be feasibly recovered. Without clear data, it is challenging to optimize logistics, justify new recycling infrastructure, or set policy targets for plastics and FRPs.

At the facility level, operational constraints also play a role. Dismantling and shredding facilities are typically not equipped with advanced sorting technologies for plastics. By the time plastics and FRPs have been mixed into ASR, they are much harder to recover. Even when some recovery is technically possible (e.g. extracting large plastic pieces from shredder output), the lack of integrated systems and specialized machinery at most ELV facilities means those plastics still end up in the residual waste pile.

While a few regions have experimented with targeted take-back or closed-loop logistics models for certain plastics (for example, collecting bumpers or dashboards separately and sending them to recyclers), these remain isolated pilot initiatives rather than sector-wide practices. The absence of consistent, widespread logistics solutions tailored to ELV plastics and FRPs keeps recovery rates low for these materials and undercuts the potential environmental benefits of a more circular approach. Overcoming these challenges will require a combination of technological upgrades (e.g. better sorting equipment, chemical recycling options) and systemic changes (e.g. improved data reporting, economic incentives, and updated regulations) to build more efficient and transparent logistics pathways for plastics and FRPs.

While metals from ELVs are recycled in well-monitored loops, the flows of plastics and FRPs remain opaque and fragmented [15], [34]. Post-dismantling, polymers and composites overwhelmingly end up in ASR. The majority is subsequently incinerated or landfilled, owing to limited sorting options and scant economic drivers to do otherwise.

Facility-level limitations are a core bottleneck:, most dismantlers and shredders lack the advanced separation technology needed to pull plastics or FRPs out of the stream. Consequently, a high proportion of these materials is effectively "lost" into mixed waste. [34]

Comparative studies indicate that some countries have piloted specialized collection systems which achieve higher plastic recovery from ELVs, but these successes are not yet broadly replicated [16], [17]. Best practices (such as dedicated plastic depollution lines or integrating plastic recovery into national ELV plans) have been identified but not standardized across the industry.

Policy plays an influential role in shaping logistics outcomes. While current regulations enforce overall recovery targets, they do not specifically ensure the recovery of plastics [15]. This regulatory gap means that even high-performing ELV systems can neglect plastics and FRPs without formal consequence. The lack of mandated tracking or recycling targets for these materials perpetuates under-documentation and undervaluation in the logistics chain.

On a positive note, innovative models are emerging. Reports describe early successes in closed-loop logistics for certain plastics (e.g. collecting polypropylene bumpers and remanufacturing them into new car parts). These systems involve dedicated sorting, cleaning, and reverse logistics for specific materials and illustrate a potential blueprint for broader implementation. Widespread adoption, however, will require demonstrating economic viability and possibly regulatory support. [22], [23]

Additionally, experts suggest that applying modern logistics optimization tools and digital tracking (for instance, tagging plastic components or using AI sorting) could significantly improve material routing and transparency. Such approaches could help identify where in the chain plastics and FRPs are being lost and how to intercept them more efficiently. [35]

In summary, the current ELV logistics for plastics and FRPs is suboptimal: materials slip through due to economics, technology gaps, and policy oversights. Tackling these issues will require coordinated efforts across the value chain, from redesigning vehicles for end-of-life recovery to upgrading facility processes and updating regulatory frameworks, which will be further explored as part of the ZEvRA project's ongoing work.

Table 3: *Expanded stepwise overview from collection to final fate and (logistics) bottlenecks*

Process Step	Materials Involved	Main Operations	Output Streams	Typical Fate	Bottlenecks / Barriers	Best Practice Examples
Collection	End-of-life vehicles (ELVs)	Vehicles gathered from last owners, collection points, or take-back schemes	ELVs delivered to treatment facilities	Vehicles staged for dismantling	Inconsistent coverage; illegal dumping; participation varies	Mandatory take-back programs; incentives for return
Dismantling	Plastics, FRPs, reusable parts	Manual removal of components; separation of reusable parts	Parts for reuse, plastics/FRPs for recycling, vehicle hulk	Some high-value plastics/FRPs recovered; most remain in vehicle hulk	Labor-intensive; incomplete removal; limited incentives	Specialized take-back systems in some regions
Shredding	Vehicle hulks (mixed metals, plastics, FRPs)	High-throughput mechanical shredding	Ferrous & non-ferrous metals, Automotive Shredder Residue (ASR)	Metals to recycling; plastics/FRPs mostly in ASR	Low separation of plastics/FRPs; cross-contamination	Advanced shredding with pre-sorting (rare)
Sorting & Initial Distribution	Metals, ASR (plastics, FRPs, rubber, glass etc.)	Magnetic & eddy current separation for metals, basic ASR sorting	Scrap metal, bulk ASR	Metals efficiently recycled; ASR poorly sorted	Lack of advanced plastics/FRPs sorters; fragmented logistics	Pilot ASR sorting plants; targeted trials
Downstream Treatment	ASR (plastics, FRPs, fines)	Incineration, landfill, occasional material recovery	Energy recovery, landfill mass, minor recycled streams	Incineration/landfill dominate; minor recycling	High transport costs, regulatory barriers, limited markets	Closed-loop PP collection (in pilot regions)
Exceptional Recovery (rare)	Specific plastics (e.g., PP), select FRPs	Targeted collection & dedicated logistics; material-specific processing	Clean recycled plastics/FRPs	Recycled into new components	Low scale; not widely adopted; cost/benefit issues	Closed-loop logistics, OEM partnerships

3.4 Available recycling capacity for ELV-plastics and ELV-composites in Europe

As described in previous sections, only a minor share of plastics in the end-of-life vehicles are recycled today. It is estimated that on EU level 19 % of the plastic fractions recovered after shredding of ELVs are currently sent to recycling [36]. Although the share of recycling in the management of post-consumer plastic waste from ELVs has increased in recent years (2018-2022), energy recovery and landfilling are still the major destinations in the EU. The energy recover rate is estimated to be 43.7 % in the EU (2022) and landfilling 37.5 %. During 2018-2022, the share of ELV plastics directed to recycling has risen by 50 % [18]. There is, however, significant differences between EU countries (EU27+3) in the waste management practices for ELV plastics. In some of the countries the share of ELV plastics directed to recycling is reported above 30 % (e.g. in France, Norway, Sweden, Slovenia, Estonia, Belgium), whereas in many other countries, the share of recycling is significantly below 10 % or close to zero (see Figure 3-5) [18]. These differences highlight varying waste management practices for ELVs across EU, availability of recycling facilities capable of treating mixed plastic waste such as ASR and policy and economic incentives in place.

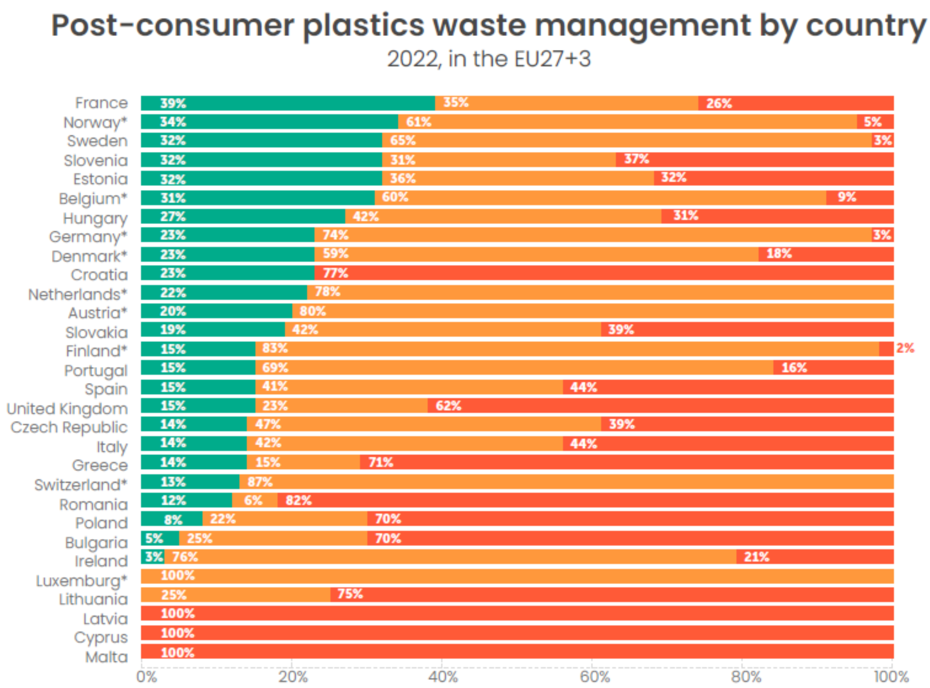

Figure 3-5: *Management of post consumer plastic waste from the automotive sector, where green represents recycling, orange energy recovery, and red landfilling. Reproduced from [18] with permission.*

Each year, end-of-life vehicles (ELVs) in Europe contain approximately 1.5 Mt plastics. 1 Mt of this plastics waste from ELVs is collected and processed at authorized treatment facilities (ATFs) which take care of the first steps of ELV dismantling and material recovery [20]. Europe has large network of ATFs, close to 14 000 facilities, operating under extended producer responsibility

(EPR) schemes and regulatory requirements to ensure proper ELV management. However, not all ELVs reach these authorized channels. Small share, 8 %, are legally exported outside EU, equalling 4 million vehicles and 0.5 Mt of plastics. In addition, significant fraction of ELVs also end up in unknown or informal pathways and decreasing the amount of materials available to recycling facilities and to produce secondary materials.

Steps in ELV management are described in previous Chapter 3.2. In short, the recycling of plastics and composites in the ELVs includes several stages: depollution and dismantling, shredding and, in some cases and parts of Europe, (advanced) post-shredder technologies (PSTs) [20]. Apart from the manual dismantling of some components, such as batteries and bumpers, large share of the plastics are not separately dismantled but ends up in the automotive shredder residue (ASR), a heterogeneous mixture that can include plastics, foam, rubber, unrecovered metals, glass, and more [11]. Once the plastic fraction have ended up in the ASR after shredding, various PSTs can be applied in theory, including several types of separation techniques to obtain separate fractions, as well as cleaning processes to improve the quality of the residue for further treatment [20]. Since only minor share of the plastics are either separately dismantled or recovered from the ASR, it is estimated that only a total amount of 350 000 tonnes of plastic waste from ELVs sent for recycling. From this amount, approximately 150 000 tonnes of recyclates are produced yearly for reprocessing into finished products [20].

Figure 3-6 presents average material flow of plastics in vehicles and the recovery and production of recyclates, based on an EU average (car level data).

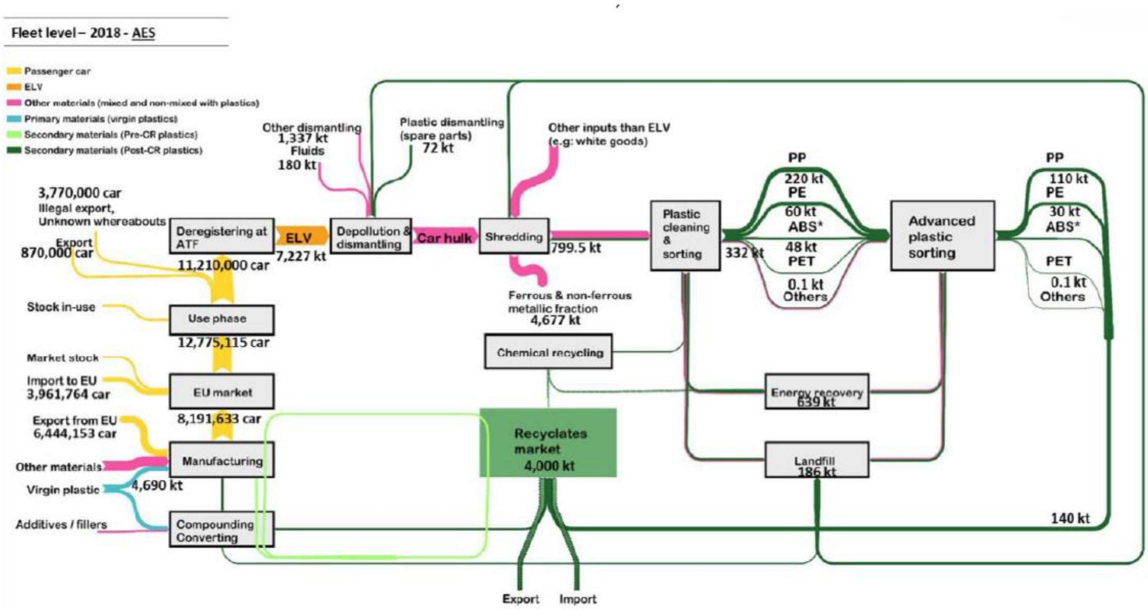

Figure 3-6: *Sankey diagram of plastic flows during the vehicle lifetime and production of recyclates at car level (in kg based on Average estimates (AES)). [11]*

It should be noted that the composition of the ASR highly depends on the content of the shredder input stream and on the technologies used in the shredding and sub-sequent processes [20]. In addition, typically other product types are often processed together with ELV (such as WEEE, white goods), and a shredder input consisting of ELVs only can be considered as an exception. A study estimates that the shredder input related to ELVs usually represents 25-33 % of the total input [11].

The challenges specific to recycling of ELV plastics need for complex sorting steps (e.g., due to association with other materials) and unsuitability for mechanical recycling due to presence of additives (e.g, brominated flame retardants) and contaminants (e.g., volatile organic compounds) [25], [37]. Incidental contamination, including impurities from improper material separation and cross-contamination during waste collection, also negatively affects the quality of recyclates. Additionally, plastics recovered from ELVs may be limited by the presence of odors, which should be removed before further use [30].

The total installed capacity plastics recycling in Europe amounted to 13.5 million tonnes in 2024 Major part of this capacity is dedicated to recycling of PO films, PET, PP, and HDPE for examples from packaging [38]. One study estimates that less than 10 % of recycling facilities across the EU are capable of sorting and recycling plastic fractions coming from end-of-life vehicles [36]. Plastics Recycling Europe report that 6 % of total recycling capacity (0.8 Mt) is dedicated to ELV, WEEE and other mixed streams, of which one third is dedicated to plastics from ELVs. Major part of this capacity is in the United Kingdom, France and Germany, and the Netherlands [39].

There are only a few examples of industrial scale recycling of ELV plastics in operations in Europe, where end-of-life plastics are recovered for use as secondary raw materials. Some examples of actors recycling plastics from ELVs within Europe include Galloo Plastics, MBA Polymers and Sicon GmBH. Galloo Plastics specializes in post-consumer plastic recycling and plastic waste management, recycling ELV plastics to new polypropylene grades specifically for the automotive industry. MBA Polymers recycles automotive plastic waste into materials for new vehicles. Sicon GmbH operates primarily as a technology provider, offering integrated systems for shredder residue treatment and post-shredder separation. [40], [41], [42], [43]

3.5 Utilization of secondary plastics and composites in vehicles in Europe

Recycled plastics are used in various components in vehicles. A study identifies following key applications for the different types of recycled polymers in automotive parts and components:

- recycled PP (polypropylene) is used for example in wheel arch, underbody panels, bumpers, luggage compartment ventilation. In ZEvRA, rPP is used in composites for non-structural parts, and tested for interior parts
- recycled PET (polyethylene terephthalate) is used for example in wheel arch, underbody panels, insulation layers in dashboards, air deflectors, seat fabrics. In ZEvRA, rPET is used in composites for structural parts

- recycled PA (polyamide, i.e. nylon) is used for example in wheel arch, underbody panels, carpets, engine covers, engine intake air pipes
- recycled ABS + PC (acrylonitrile butadiene styrene + polycarbonate) is used for example in brackets. In ZEvRA, recycled-content ABS is tested for interior parts
- recycled PU (polyurethane) is used for example in rear shelfs and acoustic insulation. [11].

According to a report, in Ford Focus more than 300 parts are made of recycled materials, which equals to 20 000 tons of textiles and plastics shifted away from landfills each year. Ford uses recycled plastics to make underbody shields, battery trays, replacement bumpers, sound proofing, insulation, carpets, heating, ventilation, and air conditioning (HVAC) housing, wheel arch liners, parcel shelves, and roof linings. [44]

The production of plastics of recycled origin has increased in recent years. In the automotive sector, the use of recycled plastics is still at lower level compared to some other sectors such as agriculture, farming and gardening, building and construction, and packaging. The share of recycled content in plastics used in the automotive sector is estimated to be 9 % of the total use (thus 0.4 tonnes of the total 4.5 tonnes) [18]. The recycled content originates from post-consumer sources, of which major share (4.4 % of the total use), is produced by mechanical recycling, and a minor share (0.2 % of the total) is produced by chemical recycling. The rest of the recycled content (4.4 % of the total use) originates from pre-consumer sources, i.e. waste arising from plastics manufacturing processes. There is, however, a large variance in the use of recycled plastics between different car manufacturers and models. A study estimates that currently only an average of about 3 % of the plastic in new vehicles is made of recycled plastic, but in some models even 20 % can be from recycled origins [11]. In the same study, the share of pre-consumer waste in the recycled plastics for automotive use was estimated significantly higher. Roughly 80 % of the recycled content was estimated to originate from pre-consumer waste from different industrial processes. The remaining 20 %, corresponding to only 109 kt yearly, originates from post-consumer sources, both from the ELVs, but also from post-consumer sources from other sectors, e.g. packaging. [45], [46].

Main difference for the pre-consumer and post-consumer plastic recyclates used in the automotive sector is the composition and recyclability of the source materials. As the composition of the pre-consumer waste stream is better known and contains less contaminants, the stream is significantly easier to process and further uptake the recyclates in new products. In contrast, the post-consumer waste streams are typically of unknown composition, and potentially contaminated or containing restricted substances, thus making those waste streams more challenging to recycle. The pre-consumer material is also associated with less degradation compared to the post-consumer waste stream which may have significantly degraded during the lifespan, resulting in lower quality. The availability of pre-consumer waste streams is more limited and should be minimized with higher production efficiency. For the post-consumer waste streams, which are currently less recycled, there is more room to improve. The price of the pre-consumer and post-consumer recyclates depends highly on composition and market demand, however, due to the higher purity, the pre-consumer recyclates is generally more expensive. Finally, the pre-consumer waste stream may be better suitable for interiors and components with higher aesthetic and safety requirements, compared to the recyclates from post-consumer waste streams, which may have more limited end uses [45], [46].

Utilization of recycled plastics is already somewhat common for many vehicle manufacturers, and the recycled materials may originate both from closed loop, i.e. recycled materials from the automotive industry, or from the open loop, i.e recycled materials from other sectors. Examples of the open loop sources include for example PET from packaging waste (e.g. plastic bottles) and PA from carpet recycling which is used especially in cars interiors textile [46]. Recycled plastic bottles are reported to be used by OEMs in production of car components such as seats by Polestar, Subaru, Mercedes-Benz, Nissan, Hyundai, Ford. In Ford Focus each vehicle's seat fabric contains 22 recycled plastic water bottles. In addition to seats bottles can be used to produce other car components, e.g., General Motors uses plastic caps and bottles to make air deflectors and radiator shrouds and Nissan uses plastic fibres from bottles to manufacture dashboard sound insulation layers [44].. Closed loop examples include for example use of PP recycled from bumpers, battery casing and dashboard panels [46]. Examples of OEMs sourcing recycled plastics from end-of-life vehicles are reported by Frost and Sullivan, e.g., Ford and Honda reuse bumpers, and from other streams such as polyurethane foam, which Chrysler employs in seat manufacturing [44].

The use of recycled plastics in the automotive sector is still behind other sectors, e.g. packaging, and is considered potentially more challenging for various reasons, including the potential difference in mechanical or aesthetics properties and substances composition between virgin and recycled materials [11]. The limited availability and security of supply of the required quality of recyclate in a constant composition is one of the key challenges for increasing the recycled content [47]. Lower and inconsistent quality remains a major barrier, as recyclate producers compete with virgin plastic suppliers and must guarantee performance and reliability. Furthermore, there are strict requirements for the presence of substances of concern in recycled materials, which causes challenges for the recycling due to the limitations in currently available waste treatment methods to deal with these substances [26], [47]. The list of substance classified as SVHC or POP is constantly expanding, and the use of e.g. fiber-reinforced plastics (FRPs) is also growing due to their durability and strength-weight ratio, which makes the closed loop recycling of ELV plastics rather complex [24].

3.6 Status and outlook

3.6.1 Key gaps in ELV plastics recycling

Despite the broad network of authorized treatment facilities and established metal recycling infrastructure in Europe, gaps remain in the management and recycling of plastics and composites from ELVs.

In the typical ELV management, the majority of plastics and FRPs are not separately dismantled but end up in automotive shredder residue (ASR), which is predominantly incinerated or landfilled. Currently there is limited recycling capacity for complex and mixed plastics waste streams such as from ELVs. Less than 10 % of plastics recycling facilities in the EU are equipped to handle ELV plastics, with most capacity concentrated in a few countries. Many regions lack specialized recyclers or dedicated logistics for ELV plastics and advanced sorting and recovery technologies are not widely implemented. As a result, only a minor share of ELV plastics is currently recycled in the EU. There are also significant differences between Member States in recycling rates and availability of specialized recycling facilities.

Finally, it should be noted that the barriers to plastics circularity are not only technical (e.g., mixed materials or hazardous additives) but also systemic, arising from product design, market structures, and policy frameworks [48]. There are also significant economic and regulatory barriers such as low market value of recycled plastics, high operational costs in the recycling, and regulatory fragmentation (e.g., inconsistent end-of-waste criteria) further hinder investment in new infrastructure and business models. Thus, in addition to addressing the observed gaps in the ELV value chain and missing infrastructure, also ecodesign, regulatory alignment, and market incentives should be considered.

Furthermore, there is lack of data and traceability. The flows of plastics and FRPs through the ELV value chain are poorly tracked, making it difficult to optimize logistics.

3.6.2 Current trend in plastics recycling

Recent trends in the European plastics recycling sector have further highlighted several challenges. European plastic circularity policies led to subsidizing recycling, binding recycling targets for plastic packaging, and minimum recycled content in products. For a while, European recycling increased and exported volumes diminished, however, in 2023 exports started growing again and recycling volumes diminishing. This is attributed to export markets being more competitive than domestic recycling.

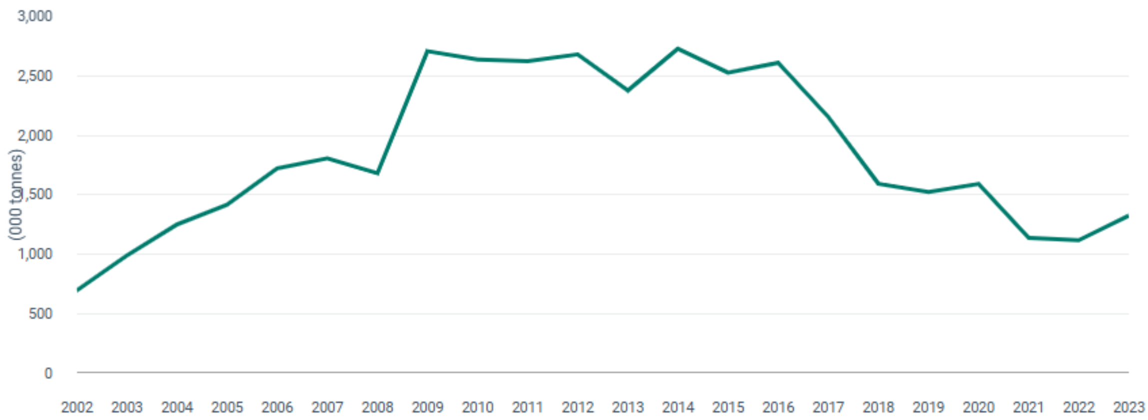

Figure 3-7: *plastic exports from the EU in 2002–2023 (HS 3915) [49].*

As of 2023, virgin plastic prices have significantly declined, due to an influx of low-cost imported virgin material from China, the Middle East, and the US due to major investments in the production of virgin plastics in these areas. Europe is also experiencing an increase in imported low-cost secondary plastic raw materials, some of which are labelled “recycled” without proper verification. Domestic recyclers struggle to compete with both cheap virgin and imported recycled materials, made under looser standards with lower labour and energy costs. Recycling is energy-intensive, in Europe, electricity’s share of operating costs can be higher than 50 % [49].

Public subsidies temporarily enabled recyclers to break even, however, did not lead to long-term self-sufficiency in recycling. The past years have delivered news about closures and shelved investments. The decrease in production and recycling capacity is negatively affecting the recycling sector, while also increasing waste exports subsequently. By the end of 2025, the territory is expected to have lost recycling facilities, amounting to almost one million tonnes of recycling capacity since 2023 [50]. While most of the recycling capacity in Europe has focused on packaging waste, these market disruptions and capacity losses also affect sectors like automotive, where recycling rates are lower, infrastructure is less developed, and the complexity of ELV plastics makes them less likely to be recovered.

4 Final remarks

4.1 Summary

This report provides an overview of the policy and market landscape for plastics and composites in ELVs in the European Union, with an emphasis on circularity and the use of recycled materials in automotive manufacturing. It aims to map the regulatory framework affecting the recycling and reuse of automotive plastics and composites, and to assess Europe's current recycling capacity.

The EU's regulatory framework is evolving, with the proposed revision of the ELV Directive introducing ambitious recycled content targets, circularity strategies and a circularity vehicle passport. These measures are expected to stimulate innovation and investment in recycling technologies, although their effectiveness depends on harmonized implementation across member states.

Key market and logistical challenges include the low economic value of scrap plastics, lack of advanced sorting infrastructure, and fragmented logistics. Regulatory inconsistencies, such as regarding EoW criteria, hinder cross-border trade and the development of high-quality recyclates. Recent market disruptions, such as declining prices of virgin plastics, and increased imports of low-cost secondary materials, have led to closures of recycling facilities in Europe, further reducing domestic recycling capacity and increasing waste exports.

4.2 Outlook

The final version of this deliverable (D6.10, due in Month 36) will build on the preliminary analysis presented here. Based on the preliminary analysis, there is significant variation across EU Member States in recycling rates of ELV plastics, current practices and the availability of facilities capable of sorting and recovering plastics from automotive shredder residue (ASR). The next deliverable will present tailored circular economy (CE) solutions for increasing material circularity for plastics and composites, focusing on 2-3 selected Member States, in collaboration with Task 6.2.1. By incorporating insights from stakeholder questionnaires (Task 6.2.2), the next phase will also deepen the understanding of manufacturers' needs and expectations for increasing the use of secondary plastics.

Finally, ZEvRA deliverable D1.3 has emphasized the importance of standardization in design and material classification to enable reuse and recycling—particularly for plastics and composites—as a key Design for Circularity (DfC) action. The final deliverable will also consider the role of certification and standardization, in close collaboration with Task 6.3.2.

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