HM Government

Unlocking Resource Efficiency

Phase 1 Vehicles Report

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Organisation	Type of Organisation
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British Tyre Manufacturers' Association	Trade Association
Composite Braiding	Manufacturer
Cornerstone Technologies	End-of-Life Vehicles
European Metal Recycling Ltd	End-of-Life Vehicles
Green Alliance	Research
Heriot Watt University – Centre for Sustainable Road Freight	Research
Oakdene Hollins	Research
Prodrive Composites	Manufacturer
The Society of Motor Manufacturers and Traders Limited	Trade Association
Toyota	Manufacturer
Vehicle Recycling Association	Trade Association

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Introduction

The Department for Energy Security and Net Zero commissioned a research project to explore the potential benefits from increasing resource efficiency in the UK. This research was carried out in collaboration with the Department for Environment, Food & Rural Affairs. This report outlines the findings for the vehicles sector.

For the purposes of this report, resource efficiency is defined as any action that achieves a lower level of resource use for a given level of final consumption. This can occur at any stage of the supply chain including production, consumption, and end-of-life. While material substitution may not always meet the definition of resource efficiency set out above, it is in scope of this research where it reduces whole life carbon.

This research was conducted in the first half of 2023, and reports were written in August 2023. As such, this report does not reflect sector developments beyond that point. The Department for Energy Security and Net Zero has consulted with technical experts as part of research activities for this report. The following report is our understanding of the available evidence and is accurate to the best of our knowledge; however, if any factual errors are encountered, please contact us at Resource_efficiency@energysecurity.gov.uk.

Methodology

This aim of this research was to achieve four key objectives:

- Identify a comprehensive list of resource efficiency measures for each sector;
- Identify current and anticipated drivers and barriers which are affecting improvements in the identified resource efficiency measures in each sector, and their relative importance;
- Build consensus estimates for the current "level of efficiency" and maximum "level of efficiency" in 2035, for each of the identified resource efficiency measures in each sector; and
- Identify the extent to which industry is currently improving resource efficiency and build consensus estimates for the likely "levels of efficiency" in 2035 given current private sector incentives and the existing policy mix (a "business-as-usual" scenario), for each of the identified resource efficiency measures in each sector.

To achieve these research objectives a mixed-methods methodology was developed. A literature review was conducted for each sector to synthesise evidence from the existing literature relevant to these objectives. The findings from this literature review were presented and tested in facilitated workshops with industry and academic experts. The aim of the workshops was to test the findings of the literature and fill any outstanding evidence gaps. This project did not aim to identify policy recommendations but rather understand the potential for resource efficiency in the UK.

This project has attempted to identify three levels of efficiency estimates for each resource efficiency measure:

- The **current level of efficiency,** which is the best estimate for the current level of efficiency of the measure, i.e. what is happening in the UK now (in 2023)
- The **maximum level of efficiency,** which is the maximum level of efficiency that is technically possible by 2035 in the UK, without factoring in barriers that could be overcome by 2035 i.e. what is the maximum level that could be achieved; and
- The **business-as-usual (BAU),** scenario which is the level of efficiency that would be expected in the UK by 2035 with the current policy mix and private sector incentives, i.e. what would happen if there were no substantial changes in the policy or private sector environment.

These levels of efficiencies have been identified to understand the potential for resource efficiency and do not represent government targets.

To estimate these levels of efficiency, an indicator has been developed for each of the identified measures. These indicators have been chosen based on how well they capture the impact of the relevant measure and how much data there is available on this basis (both in the literature review and from expert stakeholders).

Note, the purpose of the indicators in this research is to enable estimates on the current, maximum and BAU level of efficiency to be developed on a consistent basis. They are not intended be used as metrics to monitor the progress of these resource efficiency measures over time, or to be used as metrics for resource efficiency policies.

A high-level overview of the research stages is presented below. A more detailed version of this methodology is presented in the Technical Summary which accompanies this publication.

Literature Review

The literature sources were identified through an online search, and through known sources from Defra, the Department for Energy Security and Net Zero, the research team, and expert stakeholders.

Once literature sources had been identified, they were reviewed by the research team and given an Indicative Applicability Score (IAS) ranging from 1 to 5, which indicated the applicability of the sources to the research objectives of this study. This score was based on five key criteria: geography, date of publication, sector applicability, methodologies used and level of peer review.

After the five criteria of the IAS had been evaluated, the overall IAS score was calculated, ranging from 1 to 5, according to the number of criteria scoring ‘high’ and ‘low.’

Table 1: Methodology for the calculation of the IAS

Number of ‘low’ criteria	Number of ‘high’ criteria	IAS
3 or more	<= 2 t	1
2	<= 1	2
2	>= 2	3
1	<= 2	3

Number of ‘low’ criteria	Number of ‘high’ criteria	IAS
1	>= 3	4
None	<= 1	3
None	2	4
None	>= 3	5

A detailed overview of the parameters used to assess high / medium / low scores for each of the five criteria feeding into the IAS calculation can be found in Appendix A.

The research team drafted literature summaries for each sector which synthesised the best available evidence from the literature for each of the four research objectives. When drafting these summaries, literature sources with a higher IAS score were weighted more than those with lower IAS score.

Facilitated workshops

The findings from these literature summaries were then presented at two half-day facilitated workshops per sector. The workshops were attended by a range of sector experts from both academia and industry (covering different aspects of the value chain). The purpose of these workshops was to test the findings of the literature review against stakeholder expertise, and to fill any evidence gaps from the literature.

The stakeholders contributed through sticky notes in a shared virtual Mural board, by participating in the verbal discussions and by voting on pre-defined ranges on the levels of efficiency and the top drivers & barriers.

Finally, the findings of the literature review and the stakeholder engagement were combined to reach final conclusions against each research objective. For the estimates on the level of efficiency for each measure (Objectives 3 and 4), a five-tier evidence RAG rating was assigned to indicate the level of evidence supporting the proposed figures. Only where the datapoints were supported by literature sources with high IAS and a high degree of consensus amongst experts in the workshops, were the datapoints considered to have a “green” evidence RAG rating. The definitions are as follows:

- **Red:** Limited evidence available from literature review or stakeholders
- **Red-amber:** Some evidence available from literature review but it is not relevant/out of date, limited evidence from stakeholders, stakeholders are not experts on this measure
- **Amber:** High quality evidence from either literature or stakeholders
- **Amber-green:** High quality evidence from literature or stakeholders, evidence from stakeholders is supported by some information in the literature (or vice versa)
- **Green:** High quality evidence from literature supported by stakeholder expertise.

It should be noted that the business-as-usual (BAU) level of efficiency was only informed by the stakeholder engagement, so the maximum evidence RAG rating for the BAU is amber.

Sector Introduction

The UK vehicles sector is a key sector within the UK economy, with the automotive sector alone generating an estimated £67 billion in turnover in 2021.[1] According to ONS data, 11% by value of all UK manufactured goods were motor vehicles, trailers and semi-trailers in 2021.[2] Additionally, automotive and motor vehicles were the UK's most exported commodities by value at £32 billion in 2022.[3] Furthermore, the wider supply chain is a major employer and economic contributor to the UK economy:

Figure 1: Automotive supply chain in the UK, Society of Motor Manufacturers and Traders (2023)[4]

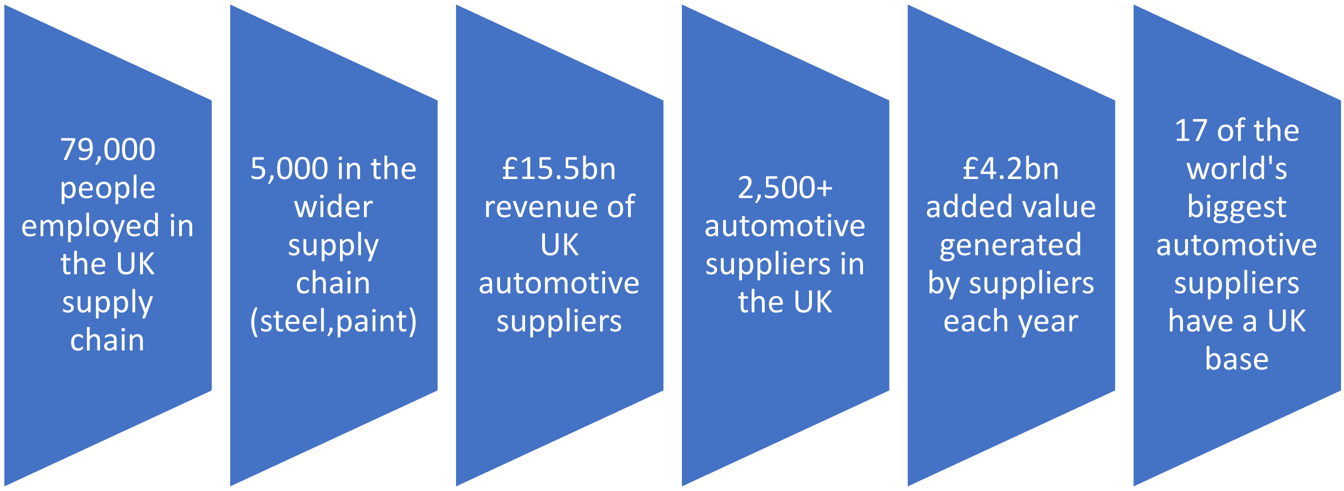
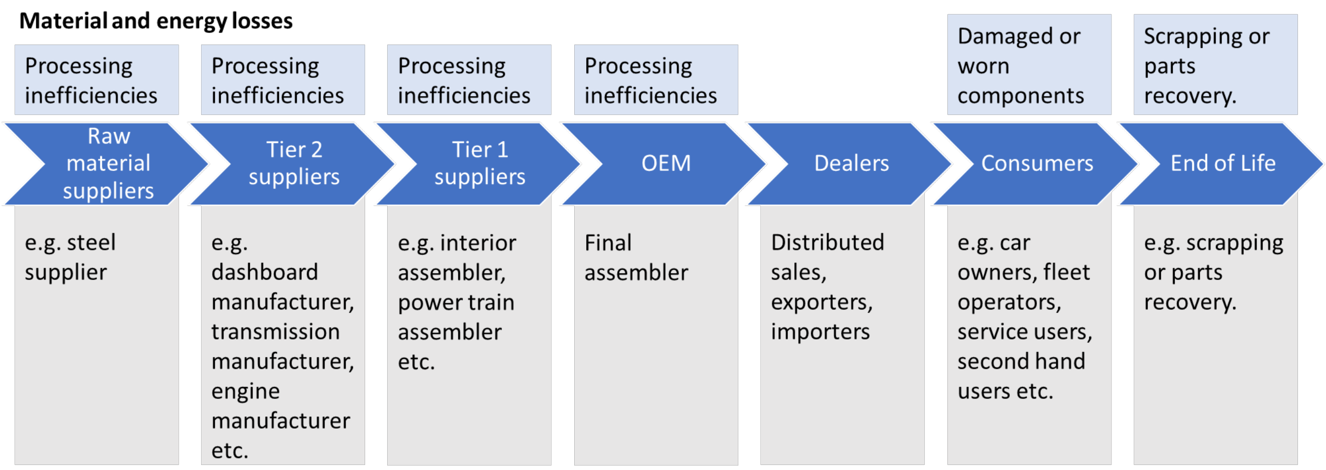


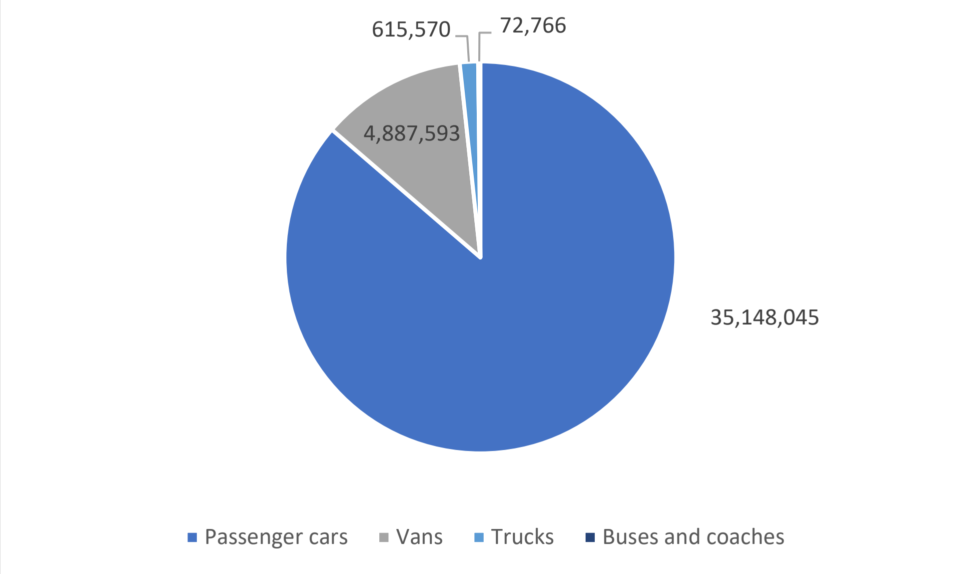
Figure 2: Material and energy losses in the supply chain



[1] The Society of Motor Manufacturers and Traders (2023) SMMT Motor Industry Facts 2023 link
[2] Office for National Statistics (2022) UK manufacturers' sales by product link
[3] The Society of Motor Manufacturers and Traders (2023) SMMT Motor Industry Facts 2023 link
[4] The Society of Motor Manufacturers and Traders (2023) SMMT Motor Industry Facts 2023 link

The automotive sector is dominated by passenger cars and light commercial vehicles such as vans. These two categories together made up 98% of all automotive vehicles on the road in the UK in 2022.

Figure 3: Vehicles on the road in 2022[5]



Within passenger cars, a clear trend is visible towards larger and heavier vehicles. According to Green NCAP, between 2012 and 2022 the average weight of automotive vehicles sold in Europe increased by 9% or around 100 kg.[6] This is reflected in UK sales figures too, in 2013 SUVs, or dual-purpose vehicles, made up 11% of new vehicle registrations, whereas in 2022 this figure stood at 27%.[7]

The UK vehicles sector also significantly contributes to the UK's resource consumption; in 2019 the automotive industry and the aerospace industry were the largest and second largest users of basic iron and steel, by value, in the UK.[8] Additionally, the automotive industry was the second largest user of rubber and plastic products as well as paints, varnishes and similar coatings, only behind the construction industry in both.[9]

Resource efficiency in the vehicles sector focuses on optimising the use of materials throughout the entire lifecycle of the vehicles from raw material extraction to end of life (EoL). Examples of key resource efficiency measures in the sector include:

- efficient use of materials in production through light-weighting and improved waste-management;
- using materials with a lower whole-life carbon;
- using vehicles more efficiently, for example through car-sharing, ride-hailing etc.
- extending vehicle lifetime through enhancing their durability and designing for repair at EoL.

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[5] The Society of Motor Manufacturers and Traders (2023) SMMT Motor Industry Facts 2023 link
[6] Green NCAP (2023) Green NCAP: the size of your car does matter link
[7] The Society of Motor Manufacturers and Traders (2023) SMMT Motor Industry Facts 2023 link
[8] Office for National Statistics (2023) UK input-output analytical tables, product by product. Table "Use BP PxI" link
[9] Office for National Statistics (2023) UK input-output analytical tables, product by product. Table "Use BP PxI" link

Vehicles production requires significant quantities of raw materials, particularly steel which are energy and carbon intensive to produce. Resource efficiency measures therefore help reduce the overall environmental impact of the sector by optimising material usage, reducing emissions, minimising waste generation and conserving energy.

Using resources more efficiently can also result in cost savings through a reduction in raw material use, and a switch to potentially cheaper alternative materials. The vehicles sector is resource-intensive, and any wastage or inefficiency in material usage can result in significant financial losses. By adopting resource-efficient practices, the sector can reduce costs and enhance its competitiveness.

Decarbonisation in the vehicles sector

Currently the vast majority of UK vehicles use petrol and diesel. However, as part of the drive to decarbonise the vehicles sector, in line with the UK commitment to reach Net Zero greenhouse gas emissions by 2050[10] the UK Government has committed to ensuring that 80% of new cars and 70% of new vans sold in Great Britain will be zero emission by 2030, increasing to 100% by 2035.[11]As a result, the industry is undergoing a substantial transition, with battery power vehicles making up a growing proportion of the market. According to vehicle licensing statistics from January to March 2023, battery EVs accounted for 17% of new car registrations in the UK, while plug-in hybrid EVs made up 12%, and this is expected to continue to grow at a rapid rate[12].

The trend towards electric vehicles is driving substantial changes in the vehicles sector which impact the potential and incentives for different resource efficiency measures. These are discussed in detail in this report.

Additionally, carsharing and ridesharing services have risen in prominence and now make up a significant part of the vehicles on the UK's roads, with the potential to increase car occupancy levels and in turn reducing overall miles travelled.

Sector scope

The scope of this report covers resource efficiency measures as they relate to road vehicles. While predominantly focussing on passenger vehicles it includes light goods vehicles, HGVs, buses and coaches. The focus of interest is on aspects of design and manufacturer, considering lightweighting and selection of materials as well as management of materials in production. Some aspects of life extension and re-purposing are also considered.

The following topics are out of scope:

- Vehicles: Non-road mobile machinery, agricultural vehicles, motorcycles/mopeds/scooters, maritime, air and rail transport vehicles;
- Modal shift: No consideration of modal shift is included in the current analysis. Passenger behaviours in terms of use of vehicles is assumed to be as current modal mix;
- Alternative fuels and energy efficiency: Current energy use and default fuel use in vehicles are not considered as resource efficiency measures here. Environmental

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[10] UK Government (2019) UK becomes first major economy to pass net zero emissions law link
[11] UK Government (2023) Government sets out path to zero emission vehicles by 2035. Available at link
[12] Department for Transport (2023) Vehicle licensing statistics: January to March 2023 link

initiatives involving alternative fuels or deep decarbonisation, such as Carbon Capture Utilisation and Storage (CCUS), are excluded.

Literature review approach

The literature review identified 93 sources that covered resource efficiency in the vehicles sector, of which 46 are used within this report. These were identified using a range of search strings relating to resource efficiency, the circular economy, and the vehicles sector. The search strings are listed in Appendix B. Further sources were identified from sector experts via the workshops and the pre-workshop survey. The full list of sources reviewed are listed in Appendix C.

The literature reviewed in this research comprises:

- 38 academic papers/reports/theses;
- 22 industry reports;
- 22 website articles;
- 6 policy documents; and
- 5 other reports/studies.

The sources were considered of generally high applicability and credibility when assessed against the data assessment framework, which recognises the relevance of the sources and the strength of their methodology. The sources had an average IAS of 3.8 (out of 5), with 63 sources exhibiting a score of 4 or above, meaning that the literature used was generally of good quality. Thirty-two sources were specific to the UK market and nineteen were specific to Europe. Stakeholder responses to the pre-workshop survey indicated that the initial literature review was reasonably comprehensive, although they also suggested some additional sources which were then incorporated.

More detail on the purpose and approach for these literature reviews can be found in the accompanying Technical Summary.

Workshop approach

There were 12 participants in attendance at the first workshop and 10 participants at the second workshop (with a total of 14 stakeholders across both workshops). The stakeholders broadly represented the full value chain of the vehicles sector: five vehicles manufacturers, two waste management organisations, three stakeholders from research backgrounds, and four trade association.

List of resource efficiency measures

The list of resource efficiency measures in the vehicles sector identified via the literature review and the facilitated workshops can be found in Table 2. These consist of:

- Four resource efficiency measures in the design phase
- Two resource efficiency measures in the manufacturing and assembly phase
- Two resource efficiency measures in the sale and use phases
- One resource efficiency measure in the end-of-life phase

A further 12 measures were identified and discarded. These are listed in Appendix D with reasons for their removal.

Whilst there are interdependencies with other sectors, such as steel and plastics, all measures are directly applicable to the vehicles sector. The relevant interdependencies are further explored in the discussion of each individual measure.

Table 2: List of resource efficiency measures for the vehicles sector

#	Lifecycle stage	Strategy	Measure name	Measure indicator
1	Design	Light-weighting	Light-weighting through material substitution	The % of reduction of average passenger vehicle weight relative to 2023 levels.
2	Design	Light-weighting	Light-weighting through reducing vehicle size	The % of reduction of average passenger vehicle weight relative to 2023 levels.
3	Design	Use of secondary raw materials	Use of recycled content in vehicle products	The % weight of recycled content in vehicle products that displace virgin material.
4	Design	Use of secondary raw materials	Use of biobased materials in vehicle products	The % vehicle weight that is biobased content and displaces virgin or recycled plastics.
5	Manufacture and Assembly	Production efficiencies	Recycling of wastes generated in production processes	The recycling rate of waste from production processes.
6	Sales and Use	Collaborative consumption	Car-sharing and increased vehicle occupancy	The % of vehicles within car clubs, car rental organisations, private car hires and car rideshares as a proportion of vehicles on the road.
7	Sales and Use	Life extension	Life extension	The % of vehicles whose lifetime is extended through electrification at end of life.

#	Lifecycle stage	Strategy	Measure name	Measure indicator
				The % of vehicles that are currently scrapped whose lifespan could be extended through repair.
8	End-of-life measures	Remanufacturing	Remanufacturing, reuse and reconditioning of parts	The % vehicle weight reused, remanufactured or reconditioned.
9	Manufacture and Assembly	Production efficiencies	Reducing waste in manufacturing	The production waste avoided as a % of vehicle weight.

Measures 1 and 2 both relate to lightweighting but have been considered separately. This is because the materials and associated drivers and barriers significantly differ between them. The net impact on the average weight of a vehicle will be a result of a combination of Measures 1 and 2, this interdependency is covered in more detail in the interdependencies section of this report.

Measures 3 and 4 both consider the use of secondary raw materials. However, these have been separated out because biobased products and recycled products are likely to be used instead of one another. As such, it is important to consider them separately, as there will likely be differing drivers and barriers associated with these measures.

Drivers and Barriers

Drivers and barriers were categorised using two separate systems:

1. The PESTLE framework which is focused on the types of changes: political, economic, social, technological, legal and environmental.

2. The COM-B framework which is focused on behaviour change:
   - **Capability**: can this behaviour be accomplished in practice?
     - Physical Capability – e.g., measure may not be compatible for certain processes
     - Psychological Capability – e.g., lack of knowledge
   - **Opportunity**: is there sufficient opportunity for the behaviour to occur?
     - Physical Opportunity: e.g., bad timing, lack of capital
     - Social Opportunity: e.g., not the norm amongst the competition
   - **Motivation**: is there sufficient motivation for the behaviour to occur?
     - Reflective motivation: e.g., inability to understand the costs and benefits,
     - Automatic motivation: e.g., lack of interest from customers, greater priorities

1.0 Measure 1 – Light-weighting through material substitution

1.1 Vehicles resource efficiency measure

1.1.1 Description

Vehicle production using fewer materials overall.

Measure 1 is the light-weighting of a vehicle or vehicle components so that the vehicle can be produced with fewer materials overall. This includes both replacing materials with a smaller quantity of a higher strength version of the same material (e.g., replacing steel with higher strength steel), or material substitution of heavier materials for lighter ones (e.g., replacing steel with aluminium).

In addition to a reduction in material use, light-weighting can bring further benefits including improved journey range and greater fuel economy improvements. It should be noted, however, that materials used for light-weighting usually require more energy to produce. For example, lightweight alternatives such as aluminium and magnesium are more energy intensive to produce than steel and can therefore lead to higher emissions during production.[13]

Stakeholders indicated that light-weighting of vehicles is already an established practice across manufacturers. However, it was highlighted throughout the workshops that the impacts on resource use of light-weighting, through material substitution, remain an area of uncertainty. It was noted by stakeholders that the transition to electric vehicles (EVs) is likely to result in increased overall vehicle weights due to the weight of battery material (which makes up one third to half the weight of an EV), compared to internal combustion engine (ICE) vehicles, which in turn will drive efforts to lightweight other vehicle components. The shift towards electrics vehicles should therefore be considered when discussing the potential of this measure and its associated drivers and barriers.

1.1.2 Measure indicator

The selected indicator was **'the % reduction of average vehicle weight relative to 2023 levels'.**

This indicator was chosen because of its ability to capture both of the main methods of material substitution, that is using less of a stronger material or replacing a heavier material with a lighter one. This indicator excludes the weight of batteries and engines. This is because EV batteries are heavier and therefore the transition to EV vehicles could result in a net neutral or net negative impact on total car weight, which could impact this indicator if it included these components. Other indicators that were identified but not selected included:

- Weight of input material saved
- Kg of non-steel material used to substitute steel.

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[13] Hertwich et al. (2022). Material efficiency strategies to reducing greenhouse gas emissions associated with buildings, vehicles, and electronics—a review. Available at: link

- % reduction in cast iron and/or steel used in vehicles
- % material of steel substituted by other materials
- Reduction in kg of steel used for vehicles

The reasons for dismissing these indicators are as follows:

- The first indicator was not chosen as it was deemed that an absolute value of weight saved did not allow for comparisons across vehicle types and sizes. Instead, the preferred indicator looks at the proportion of weight reduction.
- The remaining four indicators were not selected because they were deemed too narrow, as they excluded the potential to substitute non-steel materials.

1.1.3 Examples in practice

There are several examples of light-weighting, through material substitution, identified in the literature. These examples predominantly highlight opportunities to replace steel components with light-weight materials, such as high-strength steel, magnesium (Mg) alloys, aluminium (Al) alloys, carbon fibre, and polymer composites, which can directly reduce the weight of a vehicle's body and chassis.[14] Of these materials, the most suggested alternative to steel is aluminium.[15,16]

1.2 Available sources

1.2.1 Literature review

Light-weighting through material substitution is a measure which has been identified in six literature sources. These comprised of:

- two academic papers;[17,18]
- two industry reports;[19,20]
- one website article and,[21]
- one technical study.[22]

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[14] Wolfram et al. (2020). Material efficiency and climate change mitigation of passenger vehicles. Available at: link
[15] Hertwich et al. (2022). Material efficiency strategies to reducing greenhouse gas emissions associated with buildings, vehicles, and electronics—a review. Available at: link
[16] IEA. (2020). Iron and Steel Technology roadmap: Towards more sustainable steelmaking. Available at: link
[17] Wolfram et al. (2020). Material efficiency and climate change mitigation of passenger vehicles. Available at: link
[18] Hertwich et al. (2022). Material efficiency strategies to reducing greenhouse gas emissions associated with buildings, vehicles, and electronics—a review. Available at: link
[19] WSP & Parsons Brinckerhoff (2015). Industrial Decarbonisation and Energy Efficiency. Available at: link
[20] IEA (2020). Iron and Steel Technology roadmap: Towards more sustainable steelmaking. Available at: link
[21] Ford Motor Company (2021). Leading a sustainable revolution: Ford and HP collaborate to transform 3D waste into auto parts: an industry first. Available at: link
[22] World Steel Association (2017). Latest Mass Benchmarking Study Reveals Steel Lightweighting Opportunities. Available at: link

Notable examples are Wolfram et al.'s *Material efficiency and climate change mitigation of passenger vehicles*[23] and Hertwich et al.'s *Material efficiency strategies to reducing greenhouse gas emissions associated with buildings, vehicles, and electronics—a review*.[24]

While six sources is a relatively small number, four of these sources were judged to be of high quality when using the data assessment framework, scoring the maximum score of 5. The high quality of the identified sources partially counteracts the small number and gives confidence in the evidence found.

The literature highlighted the potential weight reductions and fuel economy improvements that can be achieved through material substitution. For example, Wolfram et al. found that up to 50 percent of a vehicle's body and chassis currently made from cast iron and steel components could be replaced with lightweight materials such as high strength steel, magnesium alloys and aluminium.[25] However, this is challenged by the World Steel Association[26] suggesting that the weight reduction in substituting steel for aluminium may be closer to a 19 percent reduction in specific components, when compared to efficient steel design of similar components.

Because of the conflicting data found in the literature around the level of efficiency, the workshop was used to gather consensus on both the suitability of the indicator and the estimates on the levels of efficiency.

1.2.2 Workshops

This measure received a good level of engagement in both workshops. The stakeholders had a good level of insight into the measure due to direct or indirect involvement and so were able to proactively contribute to the discussion. Discussion centred around the range of materials that can be substituted, which alternative materials have been tried and tested, and the potential impacts and challenges associated with this measure. Discussion also explored the appetite for this measure among both manufacturers, and consumers, with manufacturers commenting that the benefits must outweigh the economic costs of any change. It was also stated that legislative requirements to adopt non-steel alternatives are anticipated by the sector suggesting that a change to alternative materials is expected. Conflicting with this, however, was an inconclusive discussion regarding the existence of capable recycling facilities for alternative materials such as composites.

The level of engagement in both workshops was as follows:

- **Workshop 1** – Eight stakeholders across industry and academia were active on the mural board and four stakeholders actively contributed to verbal discussion.
- **Workshop 2** – Six stakeholders from industry were active on the mural board and five stakeholders actively contributed to verbal discussion.

[23] Wolfram et al. (2020). Material efficiency and climate change mitigation of passenger vehicles. Available at: link
[24] Hertwich et al. (2022). Material efficiency strategies to reducing greenhouse gas emissions associated with buildings, vehicles, and electronics—a review. Available at: link
[25] Wolfram et al. (2020). Material efficiency and climate change mitigation of passenger vehicles. Available at: link
[26] World Steel Association (2017). Latest Mass Benchmarking Study Reveals Steel Lightweighting Opportunities. Available at: link

1.3 Drivers & Barriers

A wide range of drivers and barriers influence the appetite, uptake and outcomes of this measure. Drivers and barriers were identified from both the literature and within the workshop discussions. The most notable drivers and barriers, including their PESTLE and COM-B categorisation, are described in the following sub-sections.

1.3.1 Drivers

The literature review identified that environmental considerations were the key drivers for this measure.[27] However, consultation with stakeholders identified numerous other drivers.

Below are all the drivers that have been identified for Measure 1, including their PESTLE and COM-B categorisation. Drivers in bold represent the most important drivers indicated by stakeholders during voting and in discussion.

Table 3: Drivers for vehicles Measure 1

Driver	PESTLE	COM-B
Improved journey range for EVs	**Technological**	**Opportunity – physical**
Consumer demand for "greener" vehicles	**Social**	**Opportunity - social**
Innovation in new materials (e.g., composites)	Technological	Capability – physical
Innovation in new production processes (e.g., additive manufacturing)	Technological	Capability – physical
Lightweighting also reduces tailpipe emissions and air pollution which has positive impacts on air quality (ICE vehicles)	Environmental	Motivation – reflective
Lightweighting to increase payload	Economic	Opportunity - physical
Tax incentives (e.g., to fall within target weight requirements)	Political	Motivation – reflective

Improved journey range for EVs

The most important driver, as indicated in discussion and through voting in workshops, is the shift to EVs, and the fact that lightweighting EVs can substantially increase their journey range, which is a key consideration for consumers.

Consumer demand for "greener" vehicles

Another key driver identified was the consumer demand for more sustainable and "greener" products. Lightweighting vehicles reduces material use and so reduces the environmental impact associated with raw material consumption and waste throughout the supply chain.

[27] Wolfram et al. (2020). Material efficiency and climate change mitigation of passenger vehicles. Available at: link

Lightweighting also improves fuel economy, reducing associated tailpipe emissions and air pollution.

It should be noted, however, that there are some negative impacts of some types/applications of lightweighting which may require greater energy/emissions in manufacturing and be difficult to reuse/recycle at end of life. This is discussed in the barriers section below.

Innovation in new materials

Stakeholders highlighted that innovation in new materials can reduce vehicle weight. For example, composite materials can improve the strength of materials per unit mass. Stakeholders indicated that composite materials may offer production and recycling efficiencies to original equipment manufacturers (OEMs), as they can be produced quickly and can (theoretically) be more recyclable (such as in thermoset plastic composites). However, this was queried by some stakeholders as discussed in the barriers section.

Innovation in production processes

Innovation in production processes can also reduce vehicle weight. For example, additive manufacturing techniques can produce stronger structures using less material. Stakeholders indicated that business opportunities are accelerating in this area.

Lightweighting to increase payload

Stakeholders suggested that vehicles (freight vehicles in particular) must trade off range against payload.[28] For example, where electric vehicles seek to compete with the range of internal combustion engine (ICE) vehicles, the electric vehicles require larger batteries and so require additional space/weight that would otherwise be taken up by cargo. Therefore, commercial vehicle manufacturers must explore lightweighting in other areas of the vehicle, from an economic perspective, to maximise range and payload.

Tax incentives

Stakeholders indicated that there is already a tax incentive to produce lighter vehicles such that they fall within certain tax bands for a given weight for commercial vehicles (including freight), and indirectly for passenger vehicles, as tax rates are based on CO_2 emissions with lighter vehicles more likely to produce less emissions than heavier vehicles.

1.3.2 Barriers

Below are the barriers that have been identified for Measure 1, including their PESTLE and COM-B categorisation. Barriers in bold represent the most important barriers indicated by stakeholders during voting and in discussion.

[28] A payload refers to the weight or capacity of passengers, cargo, or equipment that a vehicle can carry or transport.

Table 4: Barriers for vehicles Measure 1

Barrier	PESTLE	COM-B
Uncertainty on wider environmental impacts	**Technological**	**Motivation – reflective**
Increased complexity of EoL treatment for certain materials	**Technological**	**Motivation – reflective**
Increased costs to OEMs	**Economic**	**Opportunity – physical**
Costs of substitution, including production methods	Economic	Opportunity – physical
Regulations and policies restrict materials	Legal	Motivation – reflective
Capacity and practicality in recycling certain materials	Technological	Opportunity – physical
Presences of harmful chemicals may prevent recycling	Environmental	Motivation – reflective

Existing barriers

Uncertainty on wider environmental impacts

The literature review identified that environmental considerations were the key drivers for this measure. However, the environmental impact of light-weighting is complicated and still the subject of debate.

Although light-weighting can reduce in-use emissions, manufacturing emissions may be higher for some material substitutes than for the material they are replacing. There is therefore a lack of consensus in academia around whether lightweighting reduces the whole-life carbon emissions of a vehicles, although one source did find evidence that there is on average there is an emission reduction from lightweighting.[29]

Stakeholders in the workshops could not agree a consensus position on the environmental impact of light-weighting and stated it is highly dependent on material choice and production method.

Increased complexity of EoL treatment for certain materials; Capacity and practicality in recycling certain materials

Certain lightweight materials can increase complexity of waste management and decrease recycling opportunities as they may be technically harder to recycle using current technology and could lead to downcycling. For example, some materials such as carbon fibre are in the early stages of development for full closed-loop recycling. Currently, the most common methods of recycling result in chopped carbon fibres which prevents its use in many applications.

[29] Wolfram et al. (2020). Material efficiency and climate change mitigation of passenger vehicles. Available at: link

Another example is the recycling of materials such as thermoplastics. There was mixed opinion from stakeholders on the capacity for recycling of thermoplastics, with stakeholders disagreeing on the availability of proven recyclers in the UK. It was agreed, however, that, even if recycling of thermoplastics is technically feasible, it requires the development of a market for material which could take many years.

Increased costs to OEMs

In general light-weighting is more expensive than the status quo, either because the material cost savings are out-weighed by the design costs of lightweight structures, or because the substitute material is more expensive (which is generally the case for innovative materials).

Increased costs to OEMs of researching, sourcing, using lightweight materials and production methods was also considered important by stakeholders. Innovation in materials, production methods, procurements and scaling require significant investment by OEMs.

These costs may ultimately be borne by the consumer, with one stakeholder providing the example that lightweight trailers can cost up to four times as much as a conventional trailer.

Costs of substitution, including production methods

Substitution of materials is not necessarily always straightforward in terms of integrating within production. Where an alternative material requires different treatment (e.g. different annealing or treatment finishes, different shaping and forming etc.) then this will have implications regarding resources used in production. In some instances, this can increase the costs of production. There may also be associated indirect costs associated with regulatory compliance (environmental and health and safety) associated with the use of different materials or process modifications (e.g. storage requirements, ventilation or odour management requirements).

Regulations and policies restrict materials

Regulations and policies negatively impact light weighting measures by limiting materials allowed for certain components. For example, safety regulations dictate the materials permitted in vehicle bumpers, which prevents innovation in material substitution for this part of the vehicle. This barrier was highlighted by stakeholders as a concern during discussion. Stakeholders also noted that regulations impact what is possible in freight vehicles.

Capacity and practicality in recycling certain materials

Use of novel or composite materials may reduce the capacity to recycle in some instances. This can be due to local capacity to accept materials – where there simply aren't facilities to recycle given waste streams. This is particularly true with aspects of composites and carbon fibre materials, for example. There can also be issues with treatments applied to components, such as specific fire-retardant chemicals or other potentially hazardous materials present in trace amounts but sufficient to make recycling impractical.

Other barriers

Other barriers identified in the discussion included the durability and safety considerations of alternative materials, and concern over the technical limits on production. One stakeholder also identified, as a technical barrier, that the rate of production for carbon fibre components is 4-5 times slower than traditional components and that if power fails during certain (adhesive) stages then the material needs to be scrapped. However, other stakeholders argued that modern composite manufacturing technology have overcome these technical limitations.

1.4 Levels of efficiency

Note, the level of efficiency estimates for this measure refer to the % weight reduction as a result of the substitution of the steel in vehicles with lighter alternatives (e.g. substituting steel with high-strength steel, steel for aluminium). This is because limited quantitative data was found for other material substitutions. This is thought to be because these materials substitutions are not currently widely used in the UK vehicles industry, and/or because they rely on relatively new materials (e.g. composites).

The indicator for this measure excludes the weight of batteries and engines. EV batteries are heavier and therefore the transition to EV vehicles could result in a net neutral or net negative impact on total car weight. Consequently, a measure which included these components could mask the effect of light-weighting, so they have been excluded.

Stakeholder discussion at the workshops did cover alternative substitutions and suggested that additional savings could be achieved if these were included, though they did not feel comfortable quantifying these savings due to the greater uncertainties.

Table 5: Levels of efficiency for vehicles Measure 1

Indicator: % of reduction of average vehicle weight relative to 2023 levels			
Level of efficiency	Current	Maximum in 2050	Business-as-usual in 2035
Value	0%	20 – 35% (by 2050)	10 – 20%
Evidence RAG	N/A	Amber-Green	Red-Amber

1.4.1 Current level of efficiency

Given the indicator is a percentage reduction, the current level of efficiency is set at 0% to create a baseline with which to compare the maximum level of efficiency and the business-as-usual scenarios.

Feedback from the pre-workshop survey suggests that savings of between 10-15% have already been made on some vehicle models and another stakeholder suggested an efficiency level of around 5%. However, it is not certain what the baseline or evidence is for these figures.

1.4.2 Maximum level of efficiency in 2050

Within literature, it was identified that use of lightweight materials could reduce the GHGs emitted over a vehicle's lifecycle by up to 50%.[30] In an 'aluminium-extreme' modelling scenario identified by Hertwich et al. (2022), average vehicle mass could be reduced by 26%, resulting in a lifecycle emissions reduction of 8%. The same model also showed that, by 2050, a 'steel-intensive light-weighting' scenario can result in a 11% reduction of mass compared to the

[30] Paul Wolfram, Qingshi Tu, Niko Heeren, Stefan Pauliuk, Edgar G. Hertwich (2020) Material efficiency and climate change mitigation of passenger vehicles Available at: link

baseline (in 2014), resulting in a 5% reduction in fuel consumption and emissions in the use of the vehicle.[31]

Stakeholders generally agreed that significant levels of weight reduction could be achieved through material substitution; however, with varying levels of efficiency.

- One stakeholder believes that it is going to be hard to improve on current levels of efficiency.
- Another stakeholder has observed weight reductions of between 50% to 70% using advanced polymer composites in place of steel. This approach, however, has not been implemented at scale and it is uncertain whether this scale of saving refers to the entire vehicle or just steel components.
- Another stakeholder indicated that savings of up to 35% on overall vehicle weight is achievable through substituting steel with reinforced plastics. One stakeholder argued that achieving this level of plastic substitution will be difficult but generally agreed that the maximum level of efficiency (of non-battery components) could be 20% – 35% and that this could increase to 40% by 2040. Another agreed (based on professional judgement) that a level of around 25% would be achievable by 2050.

When voting on the maximum levels of efficiency based on measure, a majority of 6 stakeholders agreed that the maximum level of efficiency was ‘20%-40%’ with one vote each for ‘0%-20%’, ‘>40%’.Therefore, based on literature, the feedback in the workshops and on the voting, there is general agreement that maximum levels of efficiency could be between 20%-35% by 2050.

Note, the maximum level of efficiency for this measure is the level that could be achieved in 2050, not 2035 like the other measures. This is because the literature evidence provided quantitative values for 2050, and as a result the stakeholder discussion during the workshops also centred on 2050.

The evidence RAG rating for this level of efficiency rated amber-green, as there was some consensus among stakeholders and literature but not a high degree of alignment in the values.

1.4.3 Business-as-usual in 2035

One stakeholder estimated a business-as-usual level of efficiency in 2035 of 20% and another of 10% (constrained by BEVs being heavier). This was supported by the workshop vote.

When voting, six votes were collected across three options. Two-thirds of the stakeholders felt that in a BAU scenario in 2035 ‘10%-20%’ would be achieved, with the remaining two votes for ‘0%-10%’ and ‘20%-30%’. In the discussion, stakeholders generally agreed that gains would be made in levels of efficiency compared to current levels, as electrification will demand lower-weight vehicles (especially for commercial vehicles). One stakeholder suggested that reduced weight of fluid and materials associated with powertrains will be driven by the transition to zero-emission vehicles (ZEV). However, it was noted by stakeholders that the transition to electric vehicles (EVs) is likely to result in increased overall vehicle weights due to the weight of battery

[31] Hertwich et al. (2022). Material efficiency strategies to reducing greenhouse gas emissions associated with buildings, vehicles, and electronics—a review. Available at: link

material (which makes up one third to half the weight of an EV), compared to internal combustion engine (ICE) vehicles.

Based on feedback in the workshops and on the voting, there is general agreement that BAU levels of efficiency are likely to be between 10%-20%. The evidence RAG rating is red-amber, as there was limited consensus among stakeholders.

1.5 Other insights

No amendments were proposed to the measure or indicator. However, it was suggested that consideration should be given to material-specific indicators. Stakeholders expressed concern that the measure might be too simplistic and different measures for different material types should be considered. At the same time, stakeholders also warned against being too prescriptive in the materials presented as this could fail to consider innovation using novel materials.

2.0 Measure 2 – Light-weighting through reducing vehicle size

2.1 Vehicles resource efficiency measure

2.1.1 Description

Reduction of material use through a shift to smaller vehicle sizes.

This measure explores the resource efficiency opportunities that reduce material use when consumers switch from larger vehicles to smaller vehicles, also known as downsizing.

This measure is only applicable to passenger vehicles, as commercial and freight vehicles generally operate at capacity and aim to maximise payload, so are not subject to the same consumer preferences. Furthermore, downsizing of commercial/freight could lead to an increased number of vehicles to provide an equal capacity in passenger seats or storage space.

This measure comprises two key elements. The first entails transitioning from a larger car (e.g. a 4-seater) to a smaller one (e.g. a 2-seater). This is premised on the observation that a significant proportion of passenger journeys involve only one or two passengers, rendering a 2-seater vehicle more efficient and practical in such instances.[32] The second element involves downsizing from a larger car, such as a 4-seater, to a smaller one that has an equivalent capacity (e.g. an SUV to a hatch-back). This approach is designed to achieve the benefits of downsizing, such as reducing fuel consumption and carbon emissions, while maintaining the same level of passenger capacity.

Both elements significantly reduce resource consumption both in the manufacturing phase and in the use phase. The smaller size of the vehicle requires less input material, such as steel or alternatives, and reduces overall vehicle weight. Due to the lower weight of the vehicle, fuel consumption is also significantly reduced.[33]

While downsizing has a large potential in reducing resource use, recent consumer trends in passenger vehicles have been going the opposite way, with a trend towards larger vehicles. In 2018, SUVs accounted for 21.2% of new car purchases in the UK, compared to 13.5% in 2015.[34]

2.1.2 Measure indicator

The selected indicator is '**the % reduction of average passenger vehicle weight relative to 2023 levels**'. This indicator was selected as it broadly covers the resource efficiency benefits of vehicle downsizing and allows for a clear comparison of the impact of the measure, against

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[32] Paul Wolfram, Qingshi Tu, Niko Heeren, Stefan Pauliuk, Edgar G. Hertwich (2020) Material efficiency and climate change mitigation of passenger vehicles
[33] Paul Wolfram, Qingshi Tu, Niko Heeren, Stefan Pauliuk, Edgar G. Hertwich (2020) Material efficiency and climate change mitigation of passenger vehicles
[34] Anable, J., Brand, C. and Mullen, C. (2019) Transport: taming of the SUV?

a standard passenger vehicle. This indicator was agreed by the project team based on both the data available in the literature review as well as feedback from stakeholders in workshop 1.

However, stakeholders expressed concern over the scope of this indicator (i.e., whether it measures individual vehicles, OEM fleet or UK fleet). It was clarified that the indicator looks at the UK fleet.

One stakeholder also expressed concerns over the indicator being similar to the one for Measure 1, making it difficult to know if a reduction in weight is due to material substitution or reduction in size. However, given the indicators in this report are being used to estimate the potential from these measures, and not as metrics to monitor changes in these measures over time, this was not considered an issue in the context of this project.

Similar to Measure 1, this indicator excludes the weight of batteries and engines. EV batteries are heavier and therefore the transition to EV vehicles could result in a net neutral or net negative impact on total car weight. Consequently, a measure which included these components could mask the effect of downsizing, so they have been excluded.

The following indicators were identified and excluded:

- the number of 1-2 person vehicles entering the market
- average mass in running order (MIRO)[35]
- vehicle weight per seat
- composition of vehicle sales in terms of size

The reasons for dismissing these indicators are as follows:

- The first indicator above was deemed too narrow an indicator to capture the full effects of this measure, which includes downsizing within vehicle classes, rather than just the shift to 1-2 person vehicles.
- The second was discarded due to its similarity to the final and preferred indicator, while also encountering significant challenges in data collection.
- The third potential indicator – vehicle weight per seat – was discounted as this was not considered a robust measure, failing to appropriately capture the resource efficiency benefits of downsizing (i.e. reduced overall material consumption). Furthermore, this indicator could also misrepresent the measure wherein vehicles with less seats could appear less efficient (when they can be more efficient as many passenger journeys are made with empty car seats).
- The final indicator was also discounted as it was considered weak in trying to accurately reflect quantified material efficiencies, whilst the preferred indicator allowed for quantified material savings in comparison.

2.1.3 Examples in practice

Stakeholders representing manufacturers highlighted the range of smaller vehicles available across the market, including 1- or 2-seater vehicles. However, it was also noted that the

[35] Industry term to report the mass of the basic vehicle with standard equipment plus a legally fixed standard weight of 75 kg for the driver.

average passenger vehicle placed on the market is increasing in size, with one manufacturer already indicating they have stopped producing one of their smallest models due to it no longer being financially attractive for the manufacturer to produce.

2.2 Available sources

2.2.1 Literature review

The reduction of resource consumption, through the light-weighting vehicles by reducing vehicle size, is a measure which has previously been explored in the literature to a limited extent and only six sources were identified, these comprised of:

- three academic papers and, [36, 37, 38]
- three published reports. [39, 40, 41]

The data sources are, however, of high quality when assessed against the data assessment framework, partly due to the strength of the methodology within each.

Key literature includes Wolfram et al.[42] research into the effects of vehicle downsizing in terms of resource efficiency and carbon footprint in the US, which found that downsizing could reduce vehicle weight by 16–44%, and research by Palencia et al., which found that downsizing could reduce iron and steel consumption by 25%.[43]

Another key source was a report by Anable et al. which explored the market trends around SUV ownership in the UK, and the efforts in place to decarbonise these vehicles.[44] They found that demand for SUVs is continuing to increase; a trend that could counteract efforts to increase downsizing among consumers and result in a negative BAU level of efficiency.

The literature identified for this measure provided robust quantitative values for the level of efficiency that were used as a baseline for the discussion with stakeholders. However, most of the quantitative input came from reports from other countries which may have limited relevance to the UK market. Therefore, the workshop was used to gather consensus on the suitability of the indicator and to determine if the identified values were appropriate for the UK market.

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[36] Paul Wolfram, Qingshi Tu, Niko Heeren, Stefan Pauliuk, Edgar G. Hertwich (2020) Material efficiency and climate change mitigation of passenger vehicles Available at: link

[37] Palencia et al (2021) Energy, environmental and economic impact of mini-sized and zero-emission vehicle diffusion on a light-duty vehicle fleet. Available at: link

[38] Cheah, L.W. (2010) Cars on a Diet: The Material and Energy Impacts of Passenger Vehicle Weight Reduction in the U.S

[39] Anable, J., Brand, C. and Mullen, C. (2021) Transport: taming of the SUV? Available at link

[40] International Council on Clean Transportation (2019) European vehicle market statistics 2018/2019 Available at: link

[41] Low Carbon Vehicle Partnership (2019) Powered Light Vehicles: Opportunities for Low Carbon L-category Vehicles in the UK Available at: link

[42] Paul Wolfram, Qingshi Tu, Niko Heeren, Stefan Pauliuk, Edgar G. Hertwich (2020) Material efficiency and climate change mitigation of passenger vehicles Available at: link

[43] Palencia et al (2021) Energy, environmental and economic impact of mini-sized and zero-emission vehicle diffusion on a light-duty vehicle fleet. Available at: link

[44] Anable, J., Brand, C. and Mullen, C. (2021) Transport: taming of the SUV? Available at link

2.2.2 Workshop

This measure generated significant levels of discussion across the stakeholder engagement exercise, culminating in a high level of contributions from stakeholders in both the workshops and the pre-workshop survey from manufacturers, industry representatives and academics.

The stakeholders elaborated upon the challenges in encouraging consumers to move from larger SUVs into smaller vehicles. It was noted by stakeholders that where consumers have one vehicle in a family household, these are often larger vehicles – as SUVs often cater to the space requirements of the household, even though a smaller vehicle would meet the driver's needs for almost all their journeys. Discussion also noted that, where households have more than one car, the second car is often a smaller vehicle, used for most journeys and where the larger capacity of the SUV is not required. It was also noted that the move to SUVs is driven not only from consumers' demands for higher seating position and safety, but they are also being promoted by OEMs due to their higher profitability - with some OEMs discontinuing smaller models due to lack of profitability in those smaller models. Building upon this, stakeholders reinforced the point that any adaption to smaller vehicles would also have to offer a robust economic argument, with attendees highlighting business concerns regarding any introduction of new, smaller vehicles, onto the market whilst larger vehicles offer higher profit margins.

Additionally, stakeholders reported that this measure is not universally applicable. Stakeholders noted that the measure is not an option for the like of freight vehicles or public transport as larger vehicles in these sectors are generally more resource efficient, due to their ability to carry more cargo or people.

This measure received a good level of engagement in both workshops. The level of engagement in both workshops was as follows:

- **Workshop 1** – Ten stakeholders across industry and academia were active on the mural board and five stakeholders actively contributed to verbal discussion.
- **Workshop 2** – Six stakeholders from industry were active on the mural board and four stakeholders actively contributed to verbal discussion.

2.3 Drivers & Barriers

A wide range of drivers and barriers influence the appetite, uptake and outcomes of this measure. Drivers and barriers were identified from both the literature and the workshop discussions. The most notable drivers and barriers, including their PESTLE and COM-B categorisation, are described in the following sub-sections.

2.3.1 Drivers

Below are the drivers that have been identified for Measure 2, including their PESTLE and COM-B categorisation. Drivers in bold represent the most important drivers indicated by stakeholders during voting and in discussion.

Table 6: Drivers for vehicles Measure 2

Driver	PESTLE	COM-B
Improved fuel range and efficiency	**Technological**	**Capability – physical**
Lower operational costs for consumers	Economic	Motivation – reflective
Smaller vehicles can offer lower emissions	Environmental	Capability – physical

The literature review identified that environmental and economic considerations were the key drivers for this measure, as reducing vehicle size and weight can result in reduced fuel consumption and therefore lower emissions and cost to consumers. This is in line with stakeholder voting, where the most important drivers were improved fuel range and efficiency, and lower operational costs for consumers.

Improved fuel range and efficiency

Stakeholders noted that the greater fuel range and efficiency offered by smaller vehicles might encourage consumers to choose smaller vehicles, although stakeholders noted that this may not apply to EVs due to larger, longer-range batteries requiring larger vehicles to accommodate them. For freight, it was argued that at a system level, bigger vehicles are more efficient than smaller vehicles, as fewer vehicles are required to transport the same payload.

Lower operational costs for consumers

Cost is an important factor for consumers; one stakeholder suggested that the higher base cost of electric vehicles can incentivise consumers to select a smaller vehicle to offset this cost. The same stakeholder noted that this cost may rise as larger EVs become proportionally more expensive.

Other insights

Stakeholders also noted that the range of smaller vehicles available to the consumer is currently limited, but that smaller vehicle production could increase in time due to technological developments that improve the profitability of smaller cars to OEMs, as well as the appeal to consumers. Greater choice will likely increase the appeal of smaller vehicles to consumers.

2.3.2 Barriers

Below are the barriers that have been identified for Measure 2, including their PESTLE and COM-B categorisation. Barriers in bold represent the most important barriers indicated by stakeholders during voting and in discussion.

Table 7: Barriers for vehicles Measure 2

Barrier	PESTLE	COM-B
Lack of flexibility / usefulness of smaller vehicles	**Technological**	**Capability – physical**
Consumer preference trending towards larger vehicles[45]	**Social**	**Motivation – automatic**
Technical challenges on battery requirements	**Technological**	**Capability – physical**
Smaller vehicles could mean more vehicles on the roads	**Environmental**	**Capability – physical**
Smaller passenger vehicles can be less profitable for manufacturers	**Economic**	**Motivation – reflective**
Regulations and policies negatively impact light weighting measures – safety requirements, etc.	Political/Legal	Motivation – reflective
Increased cost of EVs to consumers	Economic	Opportunity – Social
Higher value/markup from larger vehicles (manufacturer push). OEMs could be Reluctant to change current business models/strategies.	Economic	Motivation – reflective
OEMs promoting larger vehicles through advertising campaigns	Social	Motivation – reflective
Lack of consumer awareness/education of environmental benefits for smaller vehicles.	Social	Capability – psychological

Lack of flexibility/usefulness of smaller vehicles

Stakeholders argued that the lack of flexibility/usefulness associated with the use of smaller vehicles (e.g. able to carry fewer passengers or have less space to transport things) is a main barrier to downsizing for many customers.

Consumer preference trending towards larger vehicles

As mentioned previously, and identified in literature, consumer preference is trending towards larger vehicles. Stakeholders laid out the following key reasons for the demand for larger vehicles:

- Customer desire for one vehicle that suits whole family needs (e.g., can accommodate entire family for a holiday trip) therefore a smaller vehicle provides less flexibility.
- Greater comfort and safety (i.e., higher seating position and better safety ratings).
- Aspirations of larger vehicles pushed through advertising and other social aspects.
- Consumers being unaware of the environmental impacts of larger vehicles.

[45] Paul Wolfram, Qingshi Tu, Niko Heeren, Stefan Pauliuk, Edgar G. Hertwich (2020) Material efficiency and climate change mitigation of passenger vehicles

Smaller passenger vehicles can be less profitable for manufacturers

Smaller passenger vehicles are generally less profitable for manufacturers, so there is no incentive for manufacturers to promote the sale of these vehicles/reduce the sale of larger vehicles. In fact, stakeholders said that manufacturers have contributed to the increased demand for larger vehicles through advertising campaigns.

In the workshop, one stakeholder supported this view saying that one OEM recently pulled a smaller model from their range of EVs due to a lack of demand and reduced profitability compared to larger models.

Given this, stakeholders note that any shift in vehicle size will need to be driven by a substantial shift in consumer preferences and/or market regulations.

Technical challenges on battery requirements

Stakeholders also recognised technical limitations to the design of smaller vehicles, given the ongoing transition to electric vehicles. Currently, large wheelbases are needed in EVs for the batteries required to meet the range demanded by consumers (though it was noted that this is likely to shift with improved battery technology).

However, another stakeholder challenged this saying that the production of a four-seater EV under 900kg is proven.

Other barriers

Stakeholders also cited a lack of regulatory drive as a barrier to producing smaller vehicles, citing the policy push towards heavier EVs as well as ever increasing safety demands as reasons for heavier and larger vehicles.

When voting, the most-voted barrier was ‘lack of flexibility/usefulness of smaller vehicles’, meaning that the measure may not appeal to those who need the larger seat numbers, and space, that come with bigger vehicles.

Mitigations for the barriers

The following potential mitigations were suggested by stakeholders. These are not currently in place but could help mitigate the impact of the barriers and influence uptake of this measure were they to be introduced:

- Further regulation on embodied carbon could be a strong incentive for manufacturers to reduce the quantities of material used in vehicles. This could promote the production of smaller vehicles.
- Financial incentives – stakeholders highlighted that setting up (or expanding upon existing) taxation models for different vehicle classes might encourage uptake of smaller vehicles (by consumers and manufacturers). Reduced insurance premiums for owners of smaller vehicles was a suggested potential financial incentive. Examples also include parking charges linked to vehicle weight.[46]
- Practical incentives such as access to parking in high-demand areas like city centres. One stakeholder highlighted an example of incentives in Japan whereby ownership of

[46] Thompson (2023) French first as city brings in parking charges linked to car’s weight. Available at: link.

smaller ‘Kei class’ vehicles (which is similar to the European L class) allows users access to certain car parks. Though the stakeholder noted that they were not aware of their effectiveness.

- From an education perspective, if consumers are aspiring to larger vehicles, stakeholders noted that there is a need to educate them of the benefits of smaller vehicles to society and the environment. Furthermore, responsible corporate advertising could promote the use of smaller vehicles.
- Alternative business models could help reduce vehicle size. For example, car sharing models enable users to utilise the most appropriately sized car for a given purpose. For example, a lone commuter might only require a one or two-seater vehicle.

2.4 Levels of efficiency

Table 8: Levels of efficiency for vehicles Measure 2

Indicator: % of reduction of average passenger vehicle weight relative to 2023 levels			
Level of efficiency	Current	Maximum in 2035	Business-as-usual in 2035
Value	0%	20 – 40%	-10-0%
Evidence RAG	N/A	Amber-Green	Red

Note the levels of efficiency here are the levels of efficiency from lightweighting via downsizing only. They do not capture any impact of light-weighting via material substitution (Measure 1).

2.4.1 Current level of efficiency

Similar to Measure 1, for the purpose of this study, and in order to form a baseline, a value of 0% was defined for the current level of efficiency.

Stakeholders also reported geographic disparities in uptake; smaller vehicles are likely to be more prevalent in cities whereas rural (and more affluent) areas may have a higher proportion of larger vehicles.

2.4.2 Maximum level of efficiency in 2035

The literature review identified a robust academic source which estimated the maximum level of efficiency from downsizing (switching to a smaller vehicle class) to be between 16-44% reduction in weight,[47] depending on vehicle class and powertrain. Another robust literature source estimated that if all vehicles were downsized by one vehicle size classification, the average vehicle weight would be reduced by 10%.[48] Therefore, the range of values identified in literature is between 10-40%. No value for switching from a 4-seater to a 2-seater was identified in the literature.

[47] Paul Wolfram, Qingshi Tu, Niko Heeren, Stefan Pauliuk, Edgar G. Hertwich (2020) Material efficiency and climate change mitigation of passenger vehicles
[48] González Palencia, J. C., Araki, M. and Shiga, S. (2016). Energy, environmental and economic impact of mini-sized and zero-emission vehicle diffusion on a light-duty vehicle fleet.

The workshops were used to gather more granular estimates on the maximum levels of efficiency. Stakeholders generally agreed (4 out of 9 votes) that a more likely value for the technical maximum is over 40%, with 2 votes for 20-40% and 3 for "don't know". As a compromise between the literature and the stakeholder voting, a value of 20-40% was agreed by the project team. However, this is dependent upon changes to consumer behaviours, and existing market trends, which currently show an increase in appetite for larger vehicles. Because this is a value that finds some support in both literature and from stakeholders but no full consensus, the evidence RAG rating is amber-green.

2.4.3 Business-as-usual in 2035

Literature and some stakeholder feedback suggests that there is a trend for increased vehicle size which stakeholders believe is likely to continue for several reasons, included due to advertising pushing consumer choice towards larger SUVs. If market trends continue, this could result in a zero, or negative business-as-usual level, of efficiency by 2035. Stakeholders largely agreed that improvement in this area is unlikely without policy intervention.

However, there were some stakeholders who disagreed, arguing that future lightweighting would be driven by the need for larger EV batteries, increased economic pressures on consumers, and modal shifts all contributing to an increase in a BAU scenario. This was supported by the voting on this measure where the most voted option was a 10-20% weight reduction.

Given the lack of consensus and despite potential drivers in both directions it was agreed that current trends in vehicle size are the best indicator for expected direction on this level and so a BAU range of -10-0% was agreed by the project team – indicating that it is expected that the BAU level for this measure is unlikely to improve in a BAU scenario. This has an evidence RAG rating of red to reflect the substantial uncertainty.

3.0 Measure 3 – Use of recycled content in vehicle products

3.1 Vehicles resource efficiency measure

3.1.1 Description

The use of recycled materials in vehicle production reducing demand for virgin materials.

Measure 3 involves the use of recycled content within vehicles including but not limited to the use of recycled steel, recycled plastics and recycled aluminium. This reduces the demand for the production and manufacturing of virgin materials, reducing the associated energy demand and carbon emissions, while generally also offering cost savings. The main materials used in vehicles are steel, plastic, aluminium, rubber and glass. It is estimated that steel makes up around 60% of an average car's weight with aluminium accounting for an estimated 10%.[49]

3.1.2 Measure indicator

The selected indicator for use of recycled content in vehicle products is the '**% weight of recycled content in vehicles that displace virgin material**'. The selected indicator was chosen for its ability to quantify and compare the resource efficiency benefits of reducing the consumption of virgin materials with recycled alternatives in vehicles of any size and of any composition. Additionally, by specifying that the recycled content must displace virgin material it is ensured that there are resource efficiency gains, as scenarios where recycled content gets added but without a reduction in virgin material, do not count towards the indicator.

However, there were concerns among stakeholders with regards to the suitability of the indicator for this measure. One stakeholder raised concerns in the preworkshop survey that a "bulk weight indicator is not appropriate as some materials will be a higher proportion of total weight than others. For example, rare earth elements and other critical metals are included in vehicles in very small amounts, but they are of very high value. More broadly, this could incentivise recycled content of major materials by weight, rather than by environmental impact of virgin extraction/carbon intensity/ease of recyclability. Material-specific indicators are needed, especially if they are to be used to set targets or monitor progress towards increased resource efficiency." Another stakeholder agreed that more material-specific indicators are required to successfully implement this measure, such as a need to split between cast and wrought aluminium.

The project team agreed that these are valid concerns. However, it also noted that the indicators in this project will not be used to monitor progress against this measure or to inform targets, but to inform research on the potential for this resource efficiency measure in aggregate. Given this, it was agreed that the suggested indicator would be retained for the purposes of this research.

[49] Norton, K & Desai, P. (2010) FACTBOX-Some facts about aluminium and steel in cars. Available at: URL

One stakeholder also noted that this indicator doesn't consider the potential for reuse of components. The reuse of vehicle components in considered later in this report under Measure 8.

The following other indicators were considered but excluded due to limitations in their ability to comparatively assess the use of recycled content between vehicles in a clear and robust way.

- % of recycled content in vehicle
- weight of recycled content in vehicle products
- % of plastic that is recycled

The reasons for dismissing these indicators are as follows:

- The first indicator above was discounted because an overall proportion of recycled content could see an increase in the indicator when there are no resource efficiency gains. For example, in the scenario in which additional recycled materials are used in the production of a vehicle, without the reduction of virgin materials.
- The second indicator was discounted because an absolute value of recycled content inherently favours heavier vehicles.
- The third indicator was discounted as it was deemed too narrow, since plastic is only one of the materials that can be made of recycled content.

3.1.3 Examples in practice

Recycled materials are already widely used in UK car production, as the following examples illustrate.

Plastics

The literature review has shown that recycled plastic of various varieties is increasingly used in the manufacture of cars across a range of brands. For example, Skoda uses recycled plastic from PET bottles in rugs, floors, in the luggage compartment and in seat covers, in total the Skoda Scala contains 14 kg of recycled plastic.[50] Ford also use recycled plastics for passenger seat cushions in a range of their models.[51] PET bottles are also used in Jaguar to make seats. Jaguar and Land Rover use a material derived from waste plastic transformed into pyrolysis oil to manufacture dashboards and exterior surfaces in their vehicles.[52] Volvo have replaced plastic components with parts containing recycled plastics in their SUV plugin hybrid XC60 T8. The interior of the SUV XC60 T8 is partly comprised of recycled fibres and plastics derived from ship ropes and fishing nets.[53]

[50] Mitalová, Z., Dupláková, D., Mital, D. (2022) Application of Recycled Plastics in Automotive Industry: a short review. Available at: link
[51] Mitalová, Z., Dupláková, D., Mital, D. (2022) Application of Recycled Plastics in Automotive Industry: a short review. Available at: link
[52] Mitalová, Z., Dupláková, D., Mital, D. (2022) Application of Recycled Plastics in Automotive Industry: a short review. Available at: link
[53] Mitalová, Z., Dupláková, D., Mital, D. (2022) Application of Recycled Plastics in Automotive Industry: a short review. Available at: link

Aluminium

Aluminium scrap can be used in place of virgin aluminium and processed into aluminium casting alloys. These castings can be used in engine blocks, cylinder heads and gearboxes. Some of the benefits of substituting virgin aluminium for recycled aluminium are that it uses 90% less energy than producing virgin aluminium and is between 20-30% cheaper.[67] There is also plentiful supply of scrap aluminium in the UK as there are approximately one million cars scrapped per year and a supply of approximately 300,000 tonnes of used aluminium from the UK construction industry.[54] Jaguar Land Rover are among the companies to make efforts to reduce the need for primary aluminium in the manufacture of their vehicles, by substituting with recycled aluminium. Primary aluminium now only accounts for 25% of the aluminium used in the production of their cars, a figure that previously stood at 40-50%. End-of-life scrap accounts for another 25% and post-industrial scrap for 50% of the required aluminium.[55]

Volvo have also set targets for the use of recycled content in the manufacture of their vehicles. By 2025 they aim to use 25% recycled or biobased plastics, 40% recycled aluminium and 25% recycled steel.

3.2 Available sources

3.2.1 Literature review

Only four sources were found around the use of recycled content in vehicle products. However, the identified literature is considered highly relevant. Of these:

- two academic papers;[56,57]
- one policy document and,[58]
- one website article.[59]

Three of the sources were found to have an IAS rating of 5, these being Zero Waste Scotland's *Vehicle Tyres: Policy Options for a Circular Economy,*[60] Wolfram et al.'s *Material efficiency and climate change mitigation of passenger vehicles*,[61] and Baldassarre et al.'s *Drivers and Barriers to the Circular Economy Transition: The Case of Recycled Plastics in the Automotive Sector in the European Union*.[62]

While a few high-quality sources were identified, comprehensive quantitative data relating to levels of recycled content in vehicles is minimal. Due to the limited evidence base that was

[54] UKRI (2021) Using more recycled aluminium in new cars. Available at: link
[55] UKRI (2021) Using more recycled aluminium in new cars. Available at: link
[56] Paul Wolfram, Qingshi Tu, Niko Heeren, Stefan Pauliuk, Edgar G. Hertwich (2020) Material efficiency and climate change mitigation of passenger vehicles. Available at: link
[57] Baldassarre, B., Maury, T., Mathieux, F., Garbarino, E., Antonopoulos, I., Sala, S. (2022) Drivers and Barriers to the Circular Economy Transition: the Case of Recycled Plastics in the Automotive Sector in the European Union. Available at: link
[58] Zero Waste Scotland (2020) Vehicle Tyres: Policy Options for a Circular Economy. Available at: link
[59] UKRI (2021) Using more recycled aluminium in new cars. Available at: link
[60] Zero Waste Scotland (2020) Vehicle Tyres: Policy Options for a Circular Economy. Available at: link
[61] Paul Wolfram, Qingshi Tu, Niko Heeren, Stefan Pauliuk, Edgar G. Hertwich (2020) Material efficiency and climate change mitigation of passenger vehicles. Available at: link
[62] Baldassarre, B., Maury, T., Mathieux, F., Garbarino, E., Antonopoulos, I., Sala, S. (2022) Drivers and Barriers to the Circular Economy Transition: the Case of Recycled Plastics in the Automotive Sector in the European Union. Available at: link

identified in the literature review, further information, both qualitatively and quantitatively, was needed from the stakeholders in the workshop. The workshop was also used to gather consensus on the suitability of the indicator.

3.2.2 Workshops

This measure received a good level of engagement in both workshops. Discussions in the workshop focused on the difficulties around sourcing high quality recycled material which meets all technical and legal requirements around performance and safety. Manufacturing stakeholders provided valuable insights into the technical specifications that each recycled material has to meet. Furthermore, stakeholders discussed the challenge in convincing the public that the recycled content will perform as expected. The level of engagement in both workshops was as follows:

- **Workshop 1** – Seven stakeholders across industry and academia were active on the mural board and four stakeholders actively contributed to verbal discussion.
- **Workshop 2** - Five stakeholders from industry were active on the mural board and four stakeholders actively contributed to verbal discussion.

3.3 Drivers & Barriers

A wide range of drivers and barriers influence the appetite, uptake and outcomes of this measure. The most notable drivers and barriers, including their PESTLE and COM-B categorisation, are described in the following sub-sections.

3.3.1 Drivers

Below are the drivers that have been identified for Measure 3, including their PESTLE and COM-B categorisation. Drivers in bold represent the most important drivers indicated by stakeholders during voting and in discussion.

Table 9: Drivers for Measure 3

Driver	PESTLE	COM-B
Reduce the reliance on virgin materials and associated supply chain pressures.	**Economic**	**Opportunity – social**
Sustainability commitments by OEMs.	Environmental	Motivation – reflective
Sustainability benefits continue to be recognised.	Technological	Capability – physical
Consumer awareness and positive public perception.	Social	Opportunity – social
Improvement in current/future technology that enable greater recycling	Technological	Capability - physical
Embodied carbon savings directly related to the material and energy savings.	Environmental	Opportunity – social

When voting on the key drivers, the most-voted option for drivers was ‘displacement of virgin materials’, wherein recycled content would reduce the demand for virgin material. This was followed by ‘improvements in current/future technology that enables greater recycling’ and improved ‘improvements in production processes to meet safety standards.’

Reduce the reliance on virgin materials and associated supply chain pressures

The reduced reliance on virgin materials - and associated supply chain pressures – was identified as a potential key driver. This was corroborated by stakeholders and was the most voted-for measure in workshops. This reflects both competitive pressure for resources and increased scrutiny on ethical aspects of supply chain (e.g. Modern Slavery Act compliance and wider ESG related concerns).

Sustainability commitments by OEMs

Furthermore, sustainability commitments by OEMs (e.g., commitments to net zero supply chains such as green steel, zero waste and recycling targets etc.) - which are often driven by consumer awareness and positive public perception of sustainable products - was considered a key driver, and stakeholders noted this is already having an impact on recycling rates.[63]

Sustainability benefits continue to be recognised

More widely, the overall reduction in use of virgin materials, and therefore global impacts associated with the extraction and use of such, continues to be a point of focus. This reflects, in part, recognition of competing end uses for critical primary materials as decarbonisation drives technological change across all sectors of the economy.

Embodied carbon savings directly related to the material and energy savings

Stakeholders highlighted that greater OEM focus on the lifecycle analysis of embodied carbon (in part driven by sustainability commitments) is promoting the use of recycled materials in certain components.

Improvement in current/future technology that enable greater recycling

Stakeholders noted that improving recycling technology is also driving the increased use of recycled content in vehicles and vehicle components. This is particularly relevant for newer materials such as composites. For example, long format carbon fibre[64] can now be recovered (rather than reconstituted chopped fibres); however, it should be noted that this technology is still in its infancy and not yet widespread. One stakeholder noted that the advanced composite industry has developed recycling technologies that could support the maximum levels of efficiency outlined later in this section, though they are not yet widely commercialised. Furthermore, stakeholders noted advancements in other related sectors; for example, high-quality steel for car bodies can now be produced from recycled material in an electric arc furnace (EAF), which is encouraging the use of recycled materials.

[63] Baldassarre, B., Maury, T., Mathieux, F., Garbarino, E., Antonopoulos, I., Sala, S. (2022) Drivers and Barriers to the Circular Economy Transition: the Case of Recycled Plastics in the Automotive Sector in the European Union. Available at: link

[64] Carbon fibres of continuous strands that enable greater functionality and more applications than chopped recycled fibres

3.3.2 Barriers

Below are the barriers that have been identified for Measure 3, including their PESTLE and COM-B categorisation. Barriers in bold represent the most important barriers indicated by stakeholders during voting and in discussion.

Table 10: Barriers for vehicles Measure 3

Barrier	PESTLE	COM-B
Supply chain issues result in inconsistent feedstock and competition.	**Technological**	**Capability – physical**
Downcycling of ELV materials limits closed-loop recycling.	**Social**	**Motivation – reflective**
Safety regulations and policies that limit use of recycled content in certain components.	Legal	Motivation – reflective
Regulatory limitations on treatment options for certain materials.	Legal	Motivation – reflective
Customer perception of recycled content being of inferior quality may deter sales.	Social	Opportunity – social
Limited collection services / recyclers available for certain composite materials.	Technological	Capability – physical
Insufficient information flow from higher tier manufacturers.	Technological	Motivation – reflective
Knock-on effects from introducing mandatory recycled content limits.	Political	Opportunity – physical
Immature market for secondary material.	Economic	Capability – physical
Regulation / standardisation for recycled material.	Technological	Opportunity – physical
Uncertainty around future of EAF may prevent steel recycling.	Economic	Opportunity – social
High price volatility for secondary material vs virgin materials.	Economic	Opportunity – social
Missing information on chemical additives prevent recycling.	Technological	Motivation – reflective

When voting on the key barriers, eight votes were collected across five barriers. The most-voted option for barriers were ‘supply chain issues for provision of recycled material’ followed by ‘downcycling of materials limits closed-loop recycling’. This demonstrates a need for greater security, and less volatility, in supplies of recycled materials. As manufacturers continue to increase the recycled content in components, pressure to secure materials may increase.

Existing barriers

Uncertainty of the quality of secondary materials.

The literature review highlighted a lack of information on materials throughout the supply chain, and insufficient information through the supply chain to protect competitive advantages as a barrier to recycling.[65] This creates uncertainty over the quality of secondary materials.

For example, recyclers are unable to process potentially valuable secondary material, due to missing information on chemical additives and potentially harmful content in waste streams such as persistent organic pollutants (POPs). This was echoed by one stakeholder who highlighted this as a risk to improving recycling rates.

Linked to this, stakeholders also noted that there are concerns over the quality and performance of recycled feedstocks over virgin feedstocks for certain applications. The vehicles industry is heavily regulated and safety-critical components (e.g., plastic bumpers) need to perform the same as virgin material.

Downcycling of ELV materials limits closed-loop recycling

Stakeholders emphasised the need to recycle materials in their original specifications to avoid downcycling, which reduces material availability and hinders closed-loop recycling. For certain materials, open-loop recycling is unavoidable using current technology. For example, one stakeholder noted that the potential for mechanical tyre-to-tyre recycling is limited, and incorporating powdered tyre rubber into new tyres affects performance. The same stakeholder noted that there is a need to destigmatise chemical recycling of hard-to recycle products like tyres where mechanical recycling can't deliver the requisite outcomes.

Supply chain issues result in inconsistent feedstock and competition

Secondary material feedstocks are typically inconsistent and the cost for recycled content fluctuates more than for virgin materials (particularly for plastics). There is therefore an incentive to use virgin feedstocks for certain applications.

Immature market for secondary material

The market for secondary material has not yet matured and there is lack of regulation/standardisation (e.g., for battery recycling) which prevents availability of consistent secondary material feedstock. There is also a time delay on the material available for recovery. For example, the composition of a vehicle design changes over time and the materials used today will be in use for a long lifecycle (estimated by one stakeholder as 15 years and 6 owners) and may migrate to other countries as vehicles age. This prevents a consistent source of closed-loop secondary material when it is most needed. This is particularly the case for batteries and the aluminium chassis beginning to be used by certain OEMs.

Limited collection services / recyclers available for certain composite materials

Stakeholders noted that a major barrier for recycled content in vehicles is the limited collection services / recyclers available for certain materials (particularly composites).

Uncertainty around future of EAF may prevent steel recycling

Stakeholders noted that for steel, if electronic arc furnacing (EAF) is not adopted then the use of secondary scrap steel in high-value applications such as vehicles in the UK will be hindered.

[65] Baldassarre, B., Maury, T., Mathieux, F., Garbarino, E., Antonopoulos, I., Sala, S. (2022) Drivers and Barriers to the Circular Economy Transition: the Case of Recycled Plastics in the Automotive Sector in the European Union. Available at: link

Stakeholders were generally supportive of a push for the use of EAF technology to use as much scrap as possible and enable scrap content to increase.

Other barriers

Stakeholders clearly stated a concern that the battery reconditioning and recycling industries are underdeveloped within the UK, with only ad hoc activities occurring with little regulation or co-ordination. The stakeholders noted that there is a significant opportunity for recycling spent batteries; however, this is dependent on how batteries are assembled or how easy it is to exchange cells etc, and at the present time, information on these aspects remains severely limited. Stakeholders noted that there is plenty of research into this area. However, there is currently limited recycling capacity for batteries in the UK and that most of the 'black mass' material extracted from end-of-life batteries is exported to the Netherlands and Belgium for extraction of valuable materials.

Potential barriers

Knock-on effects from introducing mandatory recycled content limits

One stakeholder raised concern over potential rapid deployment of policy levers that could have knock on effects on the wider economy. For example, were mandatory requirements for certain amounts of recycled content to be set, this could create huge demand for recycled content overnight leading to wider impacts on the secondary material market. This could affect other sectors that are reliant on this material. As a result, this may encourage scrapping of parts for secondary material and open-loop recycling which is less preferable than other recovery methods.

Other stakeholder agreed that it is important to avoid distortions whereby high-profile sectors absorb scrap at the expense of other sectors. For example, using recycled PET in fibres may displace material from PET bottle manufacturers. The vehicles sector should not impact demand in other sectors where value could be higher or where there are fewer alternatives. Manufacturers should therefore consider whether there are better materials to use instead.

Mitigations

The following actions were suggested by stakeholders as potential mitigations to these barriers. These are not currently in place but could influence uptake of this measure were they to be introduced:

- Improvements in current and future technology to enable greater recycling. Whilst recent improvements have been made, there remains opportunity to build on capability and capacity of recycling technologies for certain materials. For example, the UK does not produce virgin carbon fibre, but there is potential to foster a recycled carbon fibre industry using novel technology. Stakeholders also highlighted the opportunity for more thermoplastic recycling if waste streams developed as discussed in Measure 1.
- Safety regulations could be adapted to promote the use of recycled content in certain safety-critical components where they have historically been unable to due to technical limitations. Regulations could be updated to reflect the technology available today.
- As discussed further in Measure 9, stakeholders highlighted that design for disassembly will enable better material recovery by making components available for recycling (where they cannot be remanufactured, reused or reconditioned). This will enable a

higher quality of feedstock that can be more readily recycled and maximise closed loop recycling rates.

- Regulations which set mandatory requirements for recycled content in certain components (e.g., batteries and plastics) could be applied by setting recyclability requirements through eco-design standards. This would increase recycling rates and boost demand for secondary materials. However, one stakeholder warned that sudden enforcement could lead to wider impacts on the secondary material market.
- Stakeholders noted that Material Passports would help to enable the uptake of this measure in supporting the vehicle manufacturing industry to share information across the lifespan of the vehicle, and this information would better equip re-processors to recycle components back into use within, or out with, the vehicles sector.

3.4 Levels of efficiency

Table 11: Levels of efficiency for vehicles Measure 3

Indicator: % weight of recycled content in vehicle products that displace virgin material			
Level of efficiency	Current	Maximum in 2035	Business-as-usual in 2035
Value	10 – 16%	80 – 100%	30 – 40%
Evidence RAG	Red	Red	Red

3.4.1 Current level of efficiency

Form the literature review, one industry source with an IAS of 3 found that approximately 25% of the steel used in car bodies is currently recycled content and internal steel and iron parts are often manufactured with higher percentages of recycled steel.[66] The same source estimates that steel and iron make up 65% of a typical passenger car by weight, therefore a value of 16% (25% x 65%) can be derived for the overall vehicle.[67] Much of the steel scrap which is used in car manufacture is derived from the automobile industry; however, it is also sourced from steel cans, appliances and construction material.[68] Further whole-vehicle recycling rates could not be identified in literature; therefore, the workshops were used to verify or adjust the current levels of efficiency.

Stakeholders noted that the levels of efficiency vary considerably by material and production method. For example, one stakeholder reported that wrought aluminium is primarily sourced from virgin material, whereas cast aluminium is 100% recycled and therefore cannot increase any further. However, this measure is likely to continue to absorb waste steel for recycling. Stakeholders estimated that recycled content in composite materials is very low and recycled content in plastics is <25%. One stakeholder estimated a level of efficiency of around 10% on average for the entire vehicle.

When voting on the current level of efficiency, 12 votes were highly split. The vast majority of stakeholders (seven votes) voted for 'don't know', which highlights the level of uncertainty with

[66] World Steel Association (2022) Recycling Steel and Iron Used in Automobiles. Available at: link
[67] World Steel Association (2022) Recycling Steel and Iron Used in Automobiles. Available at: link
[68] World Steel Association (2022) Recycling Steel and Iron Used in Automobiles. Available at: link

this response. The next most-voted option (three votes) was ‘80%-100%’ though this is likely to be for select materials rather than for a whole vehicle. Two votes were received for ‘0%-20%’ and one ‘20%-40%’ as well. As a result, no consensus was reached on the current level of efficiency.

In the absence of better data, a range from 10-16% across all materials has been taken forward, as this has been considered a reasonable value based on the discussion with stakeholders and data within literature. However, due to the spread of votes, and very limited data in literature to support this, the evidence RAG rating for this figure is red.

3.4.2 Maximum level of efficiency in 2035

The literature review identified some targets for recycling rates set by OEMs as a basis for estimates. For example, Volvo have set targets for the use of 25% recycled or biobased plastics, 40% recycled aluminium and 25% recycled steel by 2025.[69] Whole-vehicle estimates for 2035 were not available in literature, therefore engagement with stakeholders was used to determine better estimates for a maximum possible level of efficiency.

As with current levels of efficiency, stakeholders noted that the levels vary considerably by material and production method, and that this depends highly on the development of key industries by 2035. For example:

- Industry estimates suggest that up to 50% of end-of-life tyres could ultimately be recycled into new tyres, principally through chemical recycling.
- Some organisations are looking at 100% aluminium for all auto volume with 100% recyclate.
- Steel may be 75% maximum but will require the industry to move away from blast furnace to EAF.

One stakeholder estimates that a 20% efficiency level is feasible if recycled material has a lower mechanical performance although another stakeholder estimates that this could reach 80% by 2050.

12 votes were collected for the maximum level of efficiency for Measure 3 of which three quarters voted for ‘80%-100%’. Of the remaining votes, 2 were for ‘don’t know’ while 1 was for ‘20%-40%’. Multiple stakeholders did emphasise that this differs significantly between materials.

There was consensus among stakeholders that the estimated maximum levels of efficiency were between ’80%-100%’. Therefore, this figure has been taken forward. However, due to the reasonably wide range and the lack of data in literature to support this, the evidence RAG rating is ‘red’.

It was clear from the discussion in the workshop that this max level of efficiency is dependent on the materials used in vehicles in 2035 being suited to high levels of recycling/recycled content, and sufficient technological development to support high recycling rates across all input materials.

[69] Volvo (2022) Sustainability. Available at: link

3.4.3 Business-as-usual in 2035

As with the efficiency levels, the business-as-usual scenario is likely to differ considerably by material and OEM production method. Stakeholders indicated that most material sectors are currently taking steps to improve recycling rates, for example:

- The tyre industry is pursuing internationally recognised product standards for tyre-derived recycled materials to facilitate growth in this sector. Tyre manufacturers are already incorporating recycled non-tyre material into new tyres, such as textile reinforcement made from recycled PET bottles and silica made from rice husk ash.
- The aluminium and steel industry are seeking to maximise resource efficiency, meaning the business-as-usual (assuming a move towards EAF) may achieve levels close to the maximum levels of efficiency (i.e., 100% aluminium and 100% steel)

One stakeholder estimated a level of efficiency of around 15% on average for the entire vehicles, while in the workshop itself one of the stakeholders indicated they expect the value to be heading to 40%, if not more, in a business-as-usual scenario.

When voting, five stakeholders voted across two options. Most respondents did not know what the business-as-usual level of efficiency could be and so either voted ‘don’t know’ or did not cast a vote. The remaining two stakeholders voted for a BAU level of 30%-40%.

As with the maximum level of efficiency, this will depend on the design of and material used in vehicles in 2035, and the development of UK recycling infrastructure.

In the absence of better data, a range between 30%-40% has been selected based on the input from stakeholders. However, given the mixed response of votes and lack of consensus there is a ‘red’ evidence RAG rating on this figure.

4.0 Measure 4 – Use of biobased plastics in vehicle products

4.1 Vehicles resource efficiency measure

4.1.1 Description

Use of biobased materials in vehicles or vehicle components.

Measure 4 is the use of biobased materials in vehicles or vehicle components. Biobased materials are fully or partially made from biological resources, rather than fossil raw materials. They are not necessarily biodegradable or compostable.

Biobased plastics, notably biobased polyamides, PTT, biobased polyolefins and PLA-blends are used in vehicle manufacture. Their use has a multitude of benefits. They can contribute to lower greenhouse gas emissions, reduce demand for fossil resources, provide a light-weight alternative to metals, and reduce the dependency on fossil fuels.[70] It is important to note that biobased materials can also have a negative environmental impact as land use, fresh water and fertilisers are required to grow the feedstock when using virgin materials.[71] The environmental impact of biobased materials should therefore be considered on a whole lifecycle perspective, and compared to the impact of the materials they are replacing.

Measures 3 and 4 both consider the use of secondary raw materials; however, these have been separated out because biobased products and recycled products are likely to be substitutes. As such, it is important to consider them separately; they will likely have differing drivers and barriers.

4.1.2 Measure indicator

The selected indicator for use of biobased materials in vehicle products (Measure 4) is the '**% vehicle weight that is biobased content and displaces virgin or recycled plastics'**. The selected indicator was chosen for its ability to assess the resource efficiency benefits of reducing the consumption of fossil resources. The project team agreed this, considering data from the literature review and feedback from stakeholders.

One stakeholder did express concerns over the indicator, including the displacement of recycled plastics, as biobased content might be worse in terms of GHG emissions than recycled plastics. This is discussed further in the barriers section below. The following other indicators were considered but excluded:

- % of biobased materials in vehicle products
- Weight of biobased materials in vehicle products

The reason for dismissing these indicators was:

[70] European Bioplastics (2020) Bio-based plastics in the automotive market – clear benefits and strong performance. Available at: link
[71] CE Delft (2017) Biobased Plastics in a Circular Economy. Available at: link

- An increase in biobased materials does not necessarily mean a decrease in the overall virgin plastic usage, therefore the first indicator does not comprehensively cover the measure.

4.1.3 Examples in practice

Toyota has been a market leader in the use of bioplastics within vehicles, using biobased polyesters, biobased PET and PLA-blends in production processes and headliners, sun visor and floor mats (SAI and Prius models). The Prius in particular features automotive interior parts made of the DuPont™ Sorona® EP polymer, which exhibits similar performance and moulding characteristics to petroleum-based PBT (polybutylene terephthalate). In addition, as much as 60% of the interior fabrics are manufactured from biobased polyesters, whose performance has been deemed comparable or superior to PBT.[72]

4.2 Available sources

4.2.1 Literature review

The use of biobased materials in vehicles is a relatively novel topic, which has seen a limited amount of research to date. In the literature review, four sources were identified which consisted of:

- one academic paper;[73]
- one policy document;[74]
- one industry report and, [75]
- one website article.[76]

The identified sources were of relatively high quality, with three of them having an IAS of 4 and one an IAS of 5, using the data assessment framework. The academic paper by Wurster and Ladu[77] was particularly relevant as it covered biobased products in the automotive industry, including drivers and barriers.

One source highlighted the possible emission savings, lightweighting and reduced resource consumption that can be achieved using biobased materials.[78] Another source argued that additional drivers are needed to accelerate the uptake of biobased materials, such as the

[72] European Bioplastics (2020) Bio-based plastics in the automotive market – clear benefits and strong performance. Available at: link
[73] Wurster, S. and Ladu, L. (2020). Bio-Based Products in the Automotive Industry: The Need for Ecolabels, Standards, and Regulations. Available at: link
[74] CE Delft (2017) Biobased Plastics in a Circular Economy. Available at: link
[75] European Bioplastics (2020) Bio-based plastics in the automotive market – clear benefits and strong performance. Available at: link
[76] Volvo (2022) Sustainability. Available at: link
[77] Wurster, S. and Ladu, L. (2020). Bio-Based Products in the Automotive Industry: The Need for Ecolabels, Standards, and Regulations. Available at: link
[78] European Bioplastics (2020) Bio-based plastics in the automotive market – clear benefits and strong performance. Available at: link

development of formal standards or labels for biobased materials, which can create awareness on the environmental benefits amongst consumers.[79]

Given the novelty of this measure, no comprehensive quantitative data relating to levels of efficiency were identified. Therefore, the workshops were used to inform quantitative level of efficiency estimates.

4.2.2 Workshops

This measure received a reasonable level of engagement in the first workshop and low engagement in the second workshop. The discussion in the workshops mainly revolved around the need for greater understanding around biobased plastics. There was uncertainty around the environmental benefits compared to 'traditional' materials when taking the whole lifecycle into account, partially because of the need for increased land use to produce biobased plastics. Additionally, there were concerns around the quality, reliability and consistency of the supply of biobased materials, and significant questions around the performance of biobased materials. The level of engagement in both workshops was as follows:

- **Workshop 1** – Six stakeholders across industry and academia were active on the mural board but only one stakeholder actively contributed to verbal discussion.
- **Workshop 2** – Three stakeholders from industry were active on the mural board and three stakeholders actively contributed to verbal discussion.

4.3 Drivers & Barriers

A wide range of drivers and barriers influence the appetite, uptake and outcomes of this measure. The most notable drivers and barriers, including their PESTLE and COM-B categorisation, are described in the following sub-sections.

4.3.1 Drivers

Below are the drivers that have been identified for Measure 4, including their PESTLE and COM-B categorisation. The voting did not identify a particular driver/s as most significant, so no drivers are in bold.

Table 12: Drivers for vehicles Measure 4

Driver	PESTLE	COM-B
Improved efficiencies from replacing heavier parts with biobased plastic alternatives.	Technological	Capability – Physical
Environmental benefits through reducing fossil resource consumption.	Environmental	Opportunity – Social
Greater OEM focus on lifecycle analysis of embodied carbon will promote the use of biobased materials.	Environmental	Motivation – Reflective

[79] Wurster, S. and Ladu, L. (2020). Bio-Based Products in the Automotive Industry: The Need for Ecolabels, Standards, and Regulations. Available at: link

Improved efficiencies from replacing heavier parts with biobased plastic alternatives

The literature review identified the potential to reduce fuel use and associated emissions through replacing heavier materials with lighter biobased ones. This was validated by stakeholders in the workshops with one stakeholder stating that substituting heavier materials for lighter weight biobased materials could improve efficiencies fairly dramatically.

Environmental benefits through reducing fossil resource consumption/ Greater OEM focus on lifecycle analysis of embodied carbon will promote the use of biobased materials

Stakeholders agreed that biobased plastics could contribute to lower greenhouse gas emissions compared to fossil fuel-based plastics and reduce the demand for fossil resources.[80] This could be a substantial driver as OEMs start to focus more on the lifecycle analysis of embodied carbon, due to efforts to decarbonise the industry and the wider economy.

It should be noted that there is some disagreement about the impact of biobased plastics on lifetime emissions. This is discussed further in the barriers section below.

Other drivers

One OEM stakeholder noted that certain plastics such as polypropylene are used heavily and that if there was a good biobased technical solution that meets safety regulations, then this alternative material could be rolled out quickly. The stakeholder noted that other specialised plastics are used in much lower proportions; therefore, whilst they might be harder to replace with biobased plastics, they have less of an impact.

4.3.2 Barriers

Below are the drivers that have been identified for Measure 4, including their PESTLE and COM-B categorisation. Barriers in bold represent the most important barriers indicated by stakeholders during voting and in discussion.

[80] CE Delft (2017) Biobased Plastics in a Circular Economy. Available at: link

Table 13: Barriers for vehicles Measure 4

Barrier	PESTLE	COM-B
Limited understanding of environmental benefits (or otherwise), including carbon impacts and recyclability can hinder or deter greater uptake	**Social**	**Capability – Psychological**
Customer perception of biobased plastic content regarding safety can deter sales	Social	Opportunity – Social
Potentially unethical supply chains can deter use of biobased plastics by OEMs and sales to consumers	Social	Opportunity – Social
The business case to OEMs in terms of the economic feasibility of biobased materials remains unclear	Economic	Opportunity – Physical
Negative impact on natural resources – biobased plastics require natural resources, such as fertile land, fresh water and phosphate fertilisers.	Economic	Opportunity – Physical
Inconsistent material performance in terms of safety and durability.	Technical	Capability - Physical

Barriers

Limited understanding of environmental benefits, including carbon impacts and recyclability can hinder or deter greater uptake; Negative impact on natural resources (biobased plastics)

The literature review highlighted a lack of understanding surrounding the environmental impact of biobased materials as the most prominent barrier to this measure. This was corroborated by the stakeholders who emphasised that the impacts of biobased materials are not universally positive, as is sometimes promoted. For example, virgin biobased materials require land, fresh water and fertiliser to grow, which may have wider environmental and social impacts[81] and they are not necessarily biodegradable or compostable. Furthermore, the literature review revealed a lack of reliable information on the environmental, social and economic sustainability of biobased vehicle components as a barrier to uptake of this measure.[82] Therefore it is important to examine the full lifecycle of biobased plastics, to ensure that they are beneficial to the environment beyond the reduction in use of fossil resources.

Potentially unethical supply chains can deter use of biobased plastics by OEMs and sales to consumers

Ethical supply chain concerns can deter use of biobased plastics by OEMs as well as sales to consumers due to wider social, economic and environmental impacts from growing biobased materials for use in biobased plastics, such as deforestation, impacts on indigenous people and food vs fuel debates. Furthermore, the use of some biobased materials such as leather upholstery raises concerns with consumers over animal welfare.

[81] CE Delft (2017) Biobased Plastics in a Circular Economy. Available at: link
[82] Wurster, S. and Ladu, L. (2020). Bio-Based Products in the Automotive Industry: The Need for Ecolabels, Standards, and Regulations. Available at: link

Inconsistent material performance in terms of safety and durability; Customer perception of biobased plastic content regarding safety can deter sales

One stakeholder pointed out that the perception of biobased materials, and the ability of biobased plastics to perform to a similar standard as conventional plastics, forms a barrier to the uptake of this measure. Customers who have a negative perception on the safety of biobased material may be less likely to buy vehicles containing them. This is exacerbated by a limited understanding of the environmental benefits (or otherwise).

The business case to OEMs in terms of the economic feasibility of biobased materials remains unclear

Another barrier identified by stakeholders was the unclear business case for biobased materials to OEMs. If biobased materials are financially unattractive, it is unlikely that OEMs will increase the uptake of this measure.

Other barriers

The findings from the literature review were corroborated by stakeholders who noted that the supply chains of biobased materials could form a barrier if the production competes with other industries. Stakeholders noted that it is important to consider competing uses of biomass in other industries and ensure use of bioplastics in vehicles are not incentivised to the point of competing for land use with other demands such as food production and nature. Even if bio-plastics were made only from waste (and if so, this should be specified), there are competing demands on available bio-waste supplies, and as we move to a more circular economy with decreasing waste volumes, this will lead to a reduction in available waste feedstocks.

Mitigations

The following actions were suggested by stakeholders. These are not currently in place but could help mitigate some barriers and influence uptake of this measure were they to be introduced:

- Regulatory intervention could promote the use of biobased materials. For example, one of the stakeholders suggested that a minimum required proportion of biobased materials could accelerate the uptake of biobased materials in vehicles.
- Customer perception of biobased materials. One of the stakeholders suggested that advertising a high proportion of biobased material could be attractive to sell if customers associate it with a positive environmental impact.

4.4 Levels of efficiency

Table 14: Levels of efficiency for vehicles Measure 4

Indicator: The % vehicle weight that is biobased content and displaces virgin or recycled plastics			
Level of efficiency	Current	Maximum in 2035	Business-as-usual in 2035
Value	5%	10 – 40%	N/A
Evidence RAG	Red-Amber	Red-Amber	Red

4.4.1 Current level of efficiency

The literature review[83] and stakeholder feedback suggest that the proportion of biobased content in vehicles is at a low level; however, no current level of efficiency has been identified in the literature. Therefore, the workshops were used to gather information on the current level of efficiency.

In the pre workshop survey, one stakeholder indicated that they estimate the current level of efficiency to be less than 5%. Another stakeholder indicated that for certain parts this can be as high as 28%, such as for tyres that consist partially of natural alternatives; however, they were unable to provide a value for the overall vehicle. Discussion around this measure in the workshop was limited due to the novelty of the measure; one manufacturer did provide an estimate of 5%, with another manufacturer suggesting less than 5%.

When voting on the current level of efficiency for Measure 4, 7 votes were collected across two options. A slim majority of votes were for 'don't know' followed by the range '0%-20%'. The majority of votes for 'don't know' may reflect that this measure is not one that the stakeholders have the right expertise to comment on.

Based on the provided estimates, the value of 5% was taken forward for the current level of efficiency. A red-amber evidence RAG rating has been selected due to the fact that there was some degree of agreement on the estimated level of efficiency and the estimate came from a stakeholder who had a good insight in the use of biobased materials.

4.4.2 Maximum level of efficiency in 2035

One source that was identified in the literature review found that the average automotive vehicle in the USA in 2021 weighed around 1945 kg and used around 186 kg of plastics, or just under 10% of the overall vehicle weight.[84] However, a study done in Sweden in 2019 which analysed 44 different models built between 2003 and 2018, found that the share of plastics in the vehicles ranged between 16-21%[85]. On the assumption that all plastics in vehicles could be replaced by biobased plastics with the same weight, at least 21% of the total weight could be biobased content in the more extreme scenarios. However, as one stakeholder indicated, plastics are not the only materials that could be (partially) replaced by biobased materials as tyres can be made using biobased alternatives too. This means that the maximum level of efficiency could be even higher than 21%.

Opinions were divided on the maximum level of efficiency in the workshop, with several stakeholders saying they believe the level to be higher than 10% with some stakeholders suggesting over 20% and as high as 40%. Others were less optimistic, with one stakeholder saying the real value is below 10% and another arguing that the percentage of biobased materials will naturally drop as vehicles become heavier due to the introduction of batteries.

In the voting, the majority voted for 'don't know', with 2 votes for '20%-40%' and 1 vote for '0%-20%'. Based on the literature review, discussion and the voting, there is a broad range in the potential efficiency level for this measure. Therefore, we have chosen to propose a range of 10-40%. A red-amber evidence RAG rating has been selected because literature sources were

[83] CE Delft (2017) Biobased Plastics in a Circular Economy. Available at: link
[84] American Chemistry Council (2023) Chemistry and Automobiles. Available at: link
[85] Erik Emilsson, Lisbeth Dahllöf, Maria Ljunggren Söderman (2019) Plastics in passenger cars. Available at: link

inconsistent and there was disagreement between stakeholders on what the maximum level of efficiency is.

4.4.3 Business-as-usual in 2035

Determining the business-as-usual value relied on stakeholder input; however, only three votes were collected in the workshop with all of them for ‘don’t know’. In the pre-workshop survey, a manufacturer representative provided an estimate of 30% for the business-as-usual scenario. However, no explanation or further discussion was held in the workshop around this value, and it does not align with the value that has been estimated for the maximum level of efficiency, which is based on more input. As a result, is has not been possible to estimate a BAU value for this measure because there is not enough evidence to support a 30% value.

5.0 Measure 5 – Recycling of wastes generated in production processes

5.1 Vehicles resource efficiency measure

5.1.1 Description

Capacity to recycle waste streams generated in vehicle production processes.

Measure 5 explores the opportunity to recycle the wastes generated in vehicle production processes. Waste that occurs during the production of vehicles consists predominantly of steel, aluminium, plastic and packaging. These tend to have high levels of recycling, however not all this waste is recycled.

Recycling production-related waste into new components reduces the need for virgin material and is generally higher quality than recycled materials from post-consumer waste, as it remains within the controlled environment of the manufacturing facility. Production waste typically comprises machining waste, such as off-cuts from stamping of metal sheeting, and other subtractive machining methods.

5.1.2 Measure indicator

The selected indicator for recycling of wastes generated in production processes (Measure 5) is '**Recycling rate of waste from production processes**'. The selected indicator was chosen for its ability to assess the resource efficiency benefits of improving recycling rates during the production process at a sector level. This was agreed upon by the project team, considering data from the literature review and feedback from stakeholders. It was reported by stakeholders that this granularity of data is already reported by OEMs.

The following indicators were considered but excluded:

- Number of schemes / agreements / pacts between manufacturers and EoL treatment companies
- % of production related wastes that are recycled

The reasons for dismissing these indicators are as follows:

- The first indicator was excluded due to its poor applicability to directly measuring resource efficiency.
- The second indicator was adapted into the selected indicator.

5.1.3 Examples in practice

Recycling of manufacturing wastes can keep valuable material in circulation, often helping to reduce supply and waste management costs for the manufacturer. In 2022, Volvo recycled 94% of their global production waste, which reduces demand for materials and manufacturing emissions. Such high recycling rates are common in vehicle production due to the (often) closed facilities where each component is made and/or assembled[86]. Volvo aim to achieve 100% recycling rates in their production processes[87].

5.2 Available sources

5.2.1 Literature review

Three sources discussed this measure:

- two website articles and,[88] [89]
- one policy document.[90]

Key sources informing this measure included the Policy document *Forging Ahead: A materials roadmap for the zero-carbon car* by the World Economic Forum.[91] This document emphasised the necessity of establishing standardised labelling and identification systems for materials across the supply chain. Such measures would support an increase in the recycling rate of waste generated during vehicle manufacturing. Additionally, the research team found valuable insights in a website article by Volvo, which highlighted the circular economy accomplishments and aspirations of the company in car production.[92] Stakeholders agreed that these achievements were attainable for most OEMs.

The World Economic Forum and Volvo sources were of rated as good quality. Although neither of them were specific to the UK, they were both considered as globally relevant documents that were reflective of trends that are experienced in the UK market.

Given the relative lack of literature found in this area, comprehensive quantitative data relating to levels of recycling rate of waste from production processes are minimal. Therefore, the workshop was used to gather consensus on both the suitability of the indicator and any quantitative level of efficiency estimates.

5.2.2 Workshops

There was less engagement with this measure in both workshops compared to other measures. No amendments were proposed to the measure, or indicator, based on feedback from stakeholders. Stakeholders agreed that current levels of recycling are already very high, and one stakeholder suggested that, as a result there are few benefits to monitoring this indicator. Others highlighted that whilst current levels of efficiency are high within OEMs, this does not necessarily extend throughout the entire supply chain.

The level of engagement in both workshops was as follows:

- **Workshop 1** – Six stakeholders across industry and academia were active on the mural board and four stakeholders actively contributed to verbal discussion.

[86] Volvo (2022) Sustainability link
[87] Stena Recycling (2023) News and Insights Re-made in Sweden link
[88] Volvo (2022) Sustainability link
[89] Stena Recycling (2023) News and Insights Re-made in Sweden link
[90] World Economic Forum (2020) Forging Ahead A materials roadmap for the zero-carbon car
[91] World Economic Forum (2020) Forging Ahead A materials roadmap for the zero-carbon car
[92] Volvo (2022) Sustainability link

- **Workshop 2** - Two stakeholders from industry were active on the mural board and only one stakeholder actively contributed to verbal discussion.

5.3 Drivers & Barriers

A wide range of drivers and barriers influence the appetite, uptake and outcomes of each measure. The most notable drivers and barriers, including their PESTLE and COM-B categorisation, are described in the following sub-sections.

5.3.1 Drivers

Below are the drivers that have been identified for Measure 5, including their PESTLE and COM-B categorisation. Drivers in bold represent the most important drivers indicated by stakeholders during voting and in discussion.

Table 15: Drivers for vehicles Measure 5

Driver	PESTLE	COM-B
OEM sustainability commitments.	**Environmental**	**Opportunity – Social**
Reduced reliance on virgin materials and associated supply chain pressures.	**Social**	**Opportunity – Social**
Political and consumer demand for zero waste products and organisations.	**Political / Social**	**Opportunity – Social**
Environmental benefits – embodied carbon savings directly related to the material and energy savings.	Environmental	Opportunity – Social
Increased material efficiency in production processes and less wastage and reduced production costs.	Economic	Opportunity – Social
Advancements in reusability of some novel materials (e.g., thermoplastic composites).	Economic	Opportunity – Social

Increased material efficiency in production processes and less wastage and reduced production costs

Stakeholders noted that OEMs naturally want to maximise the value of material they have purchased for production (a considerable production cost) through maximising process efficiencies and recovery of material. This is a key driver to recycle production waste.

OEM sustainability commitments / Political and consumer demand for zero waste products and organisations

Stakeholders highlighted that voluntary commitments by OEMs, such as “zero waste to landfill”, are considered to be key drivers of this measure that are ultimately led by consumer demand for sustainability.

Advancements in reusability of some novel materials

Another driver suggested by stakeholders was the possibility of increasing the recycling of certain materials that are not yet widely recycled, such as thermoplastic composite material, a lightweight material which can be used as an alternative to metals in some applications. Further developed recycling processes could lead to increased utilisation and availability of such secondary materials.

5.3.2 Barriers

Below are the barriers that have been identified for Measure 5, including their PESTLE and COM-B categorisation. Barriers in bold represent the most important barriers indicated by stakeholders during voting and in discussion.

Table 16: Barriers for vehicles Measure 5

Barrier	PESTLE	COM-B
Lack of clarity and robustness of waste data.	**Technological**	**Capability - Physical**
Poor collaboration between OEMs, suppliers and recyclers prevents closed-loop recovery.	**Social**	**Motivation - Automatic**
Missing information on chemical additives prevents recovery.	Technological	Motivation - Reflective
Difficulty in identifying suitable and cost-effective treatment routes.	Economic	Capability - Physical

Lack of clarity and robustness of waste data

A key barrier identified in this research is the lack of robust information on supply chain and waste data, which creates uncertainty around the components of recycling feedstocks. However, one stakeholder suggested that this is less relevant to production waste as companies tend to have good records about where the feedstock originated.

The findings from the workshop suggest an appetite to bridge an existing gap between manufacturers, suppliers and waste contractors, to ensure that the upstream value chain is designing and creating materials that can be captured, reused or recycled by the downstream value chain. Greater collaboration between all elements of the value chain would help improve the range of materials that can be recycled, whilst also opening dialogue to request the data that some stakeholders feel is lacking.

Poor collaboration between OEMs, suppliers and recyclers prevents closed-loop recovery

A concern highlighted by multiple stakeholders was the need to distinguish between closed-loop and open-loop recycling, particularly where energy from waste is considered to be recycling.[93] Stakeholders noted that while Scope 1[94] recycling rates are high, supply chain rates are often much lower. These rates are often not reported voluntarily by OEMs.

[93] Closed-loop recycling maintains material value by retaining it within the same product or production process whereas open-loop recycling converts material into a different product, often with reduced quality or functionality.
[94] Scope 1 recycling considers materials directly recycled by the OEM and excludes recycling rates throughout the supply chain.

Stakeholders also proposed a further barrier that poor collaboration between OEMs, suppliers and recyclers prevents closed-loop recovery.

Missing information on chemical additives prevents recovery

One barrier identified from the literature was that recyclers are unable to process potentially valuable secondary material, due to missing information on chemical additives and potentially hazardous content in waste streams.[95] This was corroborated by one stakeholder who agreed that this is a risk to improving recycling rates for certain materials such as engineering plastics that contain hard-to-recycle additives. However, another noted that OEMs should have good records about where the feedstock originated therefore this information can be easily transmitted to waste handlers.

Difficulty in identifying suitable and cost-effective treatment routes

One stakeholder noted that zero waste to landfill and incineration without energy recovery is possible for OEM's own factory but that suppliers (and some recycling processes and networks) may need support to reduce cost and improve possibilities / quality of recycled product. Linked to this one stakeholder noted that finding appropriate disposal routes is difficult and can be costly if it cannot be directly recycled within the organisation.

Another stakeholder noted that smaller SMEs in particular may find it difficult to improve recycling rates further without support. Stakeholders reported that there is often a lack of will to increase 'already high' recycling rates further by business leaders due to diminishing returns on investment.

Mitigations

The following actions were suggested by stakeholders. These are not currently in place but could help mitigate some barriers and influence uptake of this measure were they to be introduced. These are:

- Regulatory changes that promote recycled content may drive demand for secondary materials. One stakeholder noted that some legislation suggests a future possibility of mandatory recycled content.
- Regulatory changes on the definition of recycling and preferential handling of wastes according to the waste hierarchy may stimulate demand for secondary materials, thereby incentivising the shift of waste from recovery technologies (such as energy from waste) to recycling (and reuse) technologies.

[95] OECD, 2021 Labelling and Information Schemes for the Circular Economy link

5.4 Levels of efficiency

Table 17: Levels of efficiency for vehicles Measure 5

Indicator: Recycling rate of waste from production processes			
Level of efficiency	Current	Maximum in 2035	Business-as-usual in 2035
Value	94%[96]	100%[97]	98%
Evidence RAG	Green	Green	Amber

5.4.1 Current level of efficiency

The current level of efficiency, established in the literature was 94% recycling rate of waste from production processes with targets for 100% recycling rate.[98] In the workshop, stakeholders generally agreed that this is a correct estimate for large OEMs, however one stakeholder did mention in the pre-workshop survey that they considered this estimate to be too high.

When voting on the current level of efficiency for Measure 5, six votes were collected across options for whether the value identified in literature 'should be higher', was 'about right', 'should be lower' or if they 'don't know'. The most-voted option for current levels of efficiency was 'about right' (four votes) – implying that stakeholders generally agreed with the level of 94% recycling rate of waste from production processes identified in literature. Two stakeholders voted for 'don't know' and none disagreed with the proposed current level of efficiency.

Therefore, the value of 94% has been taken forward. A green evidence RAG rating has been selected, since there was consensus on the estimated levels of efficiency that supported data found in literature.

5.4.2 Maximum level of efficiency in 2035

From the literature review it was determined that the maximum level of efficiency that could be achieved in 2035 would be a 100% recycling rate of waste from production processes[99] which, according to stakeholders, has already been demonstrated by some larger OEMs. The stakeholders generally agreed that 100% was possible, however some of the stakeholders expressed concerns about the value. One stakeholder indicated that they weren't sure if 100% is possible due to inherent process losses at each stage and given material and financial constraints, while another pointed out that potential legislation which limits the presence of persistent organic pollutants (POPs) in plastics, could impact the recyclability of plastics.

The most-voted option from stakeholders in the workshop was that the estimated maximum level of efficiency was 'right' – implying that stakeholders generally agreed with the level identified in literature (100% recycling rate of waste from production processes), with only one vote thinking the maximum is lower. A green evidence RAG rating has been selected since

[96] Volvo, 2022 link
[97] Volvo, 2022 link
[98] Volvo, 2022 link
[99] Volvo, 2022 link

there was consensus on the estimated levels of efficiency and this supported data found in literature.

5.4.3 Business-as-usual in 2035

Business-as-usual data was collated from the workshops, as no quantifiable estimates of how this figure will develop into the future were found in the literature review. When voting, two votes were collected for 98%-100%. In discussion, stakeholders agreed that levels of efficiency approaching 100% could be achieved in a business-as-usual scenario as many OEMs have already made commitments to achieve this. Some larger OEMs have already demonstrated that 100% is possible.

However, stakeholders highlighted that smaller OEMs and small and medium enterprises (SMEs) are not likely to achieve this without support from supplier industry groups. Furthermore, without intervention, there may be a reluctance for OEMs to increase their already high recycling rates, due to disproportionate costs which are associated with increasing it further.

An amber evidence RAG rating has been selected since there was consensus on the estimated levels of efficiency.

6.0 Measure 6 – Car-sharing and increased vehicle occupancy

6.1 Vehicles resource efficiency measure

6.1.1 Description

Increased passenger vehicle occupancy reducing overall number of vehicles used to meet consumer demand.

Measure 6 explores the use of car sharing and leasing as a means of increasing vehicle occupancy and thus, reducing the number/size of vehicles needed to meet consumer demand by using the correctly sized vehicle for their journey (assuming the same level of travel/number of car journeys).

Car-pooling, car-sharing and lift sharing are three different approaches to reducing utilisation of private vehicles. Car-pooling is more established and is typically a not-for-profit way for multiple people to travel together in one vehicle to reduce overall costs. Lift sharing also aims to increase occupants; however, lift sharing is more often done commercially where drivers and passengers are matched together usually using an app. Car-sharing (e.g. car clubs) on the other hand does not necessarily increase the number of occupants of a vehicle for a particular journey, but it reduces the amount of time that a car is unused.

Privately owned personal vehicles typically spend 95% of their life inactive and these vehicles are on average used at only 1/3 of their capacity. These figures suggest that there is a significant volume of materials tied up in a largely stationary vehicle stock.[100] Estimating that one car club vehicle in the UK removes 20 private cars from the road, CoMoUK found that car-sharing represents an opportunity to reduce the amount of material inefficiently tied up within the vehicle stock.[101]

6.1.2 Measure indicator

The selected indicator for Car-sharing and increased vehicle occupancy (Measure 6) is '**the % of vehicles within car clubs, car rental organisations, private car hires and car rideshares as a proportion of vehicles on the road**'. The selected indicator was chosen for its ability to assess the resource efficiency benefits of improving vehicle utilisation and enable comparisons of the measure's impact. It was agreed upon by the project team, considering data from the literature review and feedback from stakeholders.

The following other indicators were considered but excluded due to limitations in data availability, and their comprehensive coverage of the measure.

- Total number of vehicles within car clubs, car rental organisations, private car hires and car rideshares.

[100] Edgar G Hertwich, Saleem Ali, Luca Ciacci, Tomer Fishman, Niko Heeren, Eric Masanet, Farnaz Nojavan Asghari, Elsa Olivetti, Stefan Pauliuk, Qingshi Tu, Paul Wolfram (2022) Material efficiency strategies to reducing greenhouse gas emissions associated with buildings, vehicles, and electronics—a review link
[101] Collaborative Mobility UK (2021). Car Club Annual Report - United Kingdom – 2021. Accessible here: link

- % of UK drivers currently members of a car sharing club
- No. of journeys made using shared mobility/car clubs
- % of total automotive kilometres done through car sharing
- Number of passengers in multi-passenger journeys
- Utilisation rate of car in %
- Number of shared mobility / car club vehicles in service
- Number of users signed up to car sharing schemes

The reasons for dismissing these indicators are as follows:

- The first and third indicators were discounted because an absolute increase in the number of vehicles dedicated to car-sharing could be achieved through more cars on the road overall, rather than an increased proportion of vehicles dedicated to car-sharing.
- The second indicator was discounted as drivers may be signed up to a car-sharing club but continue to run their own vehicle(s) therefore this indicator would not necessarily be reflective of resource consumption. Furthermore, car sharing clubs do not take into account other servitisation models.
- The fourth, fifth and sixth indicators were discounted because of the potential difficulty in obtaining data for these indicators.
- The seventh and eighth indicators were discounted because an absolute increase car-sharing services do not necessarily mean lower resource usage (similar to the second one).

6.1.3 Examples in practice

Most car-sharing business models are access-based services, where customers pay for temporary access to a product while the service provider retains ownership. These services are desirable for customers seeking convenience and monetary savings (dependant on use), by avoiding the hassle and expense of vehicle ownership. Hazée et al. (2017) report that access-based services involve high customer involvement, minimal supervision, and interpersonal anonymity. Car-sharing models vary in their implementation; Typical car-sharing models include Business to consumer (B2C), Business to business (B2B), Cooperative[102] and Peer-to-peer models.[103, 104]

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[102] A cooperative servitisation model involves multiple organisations collaborating to provide integrated product and service offerings.

[103] A peer-to-peer servitisation model facilitates direct exchange of services between individuals or businesses, bypassing intermediaries.

[104] Brenda Nansubuga, Christian Kowalkowski (2021) Carsharing: a systematic literature review and research agenda link

6.2 Available sources

6.2.1 Literature Review

This measure was recognised in a number of reports identified in the literature review.

Ten sources discussed this resource efficiency measure, these comprised:

- eight academic papers/reports and,[105] [106] [107] [108] [109] [110] [111] [112]
- one policy document.[113]

Most of these sources were of medium to high quality (IAS scores of 3-5). While not all were specific to the UK market, many were applicable to the UK manufacturing sector as they were based on similar markets (e.g., EU and US).

Some of the most notable sources were the Circular Economy framework for automobiles: Closing energy and material loops[114] and Material efficiency and climate change mitigation of passenger vehicles.[115] While the number of topic-relevant sources was limited and literature did not only cover the processes to deliver resource efficiency, they consistently highlighted that increased car sharing and vehicle occupancy has the potential to reduce resource consumption. The literature was primarily focused on the potential for resource efficiency (i.e., ex-ante assessment) based on theoretical limits, rather than evidence of resource efficiency (i.e., ex-post assessment). Resultingly, the literature was unable to provide empirical data on efficiency levels for this analysis.

Across the literature, there was relatively little applicable quantitative data relating to levels of efficiency according to the selected indicator. The only quantitative data found was from the CoMoUK's Car Club Annual Report 2021 (with an IAS of 4) which identified that there were an estimated 450,231 active car club members in the UK using 5,608 car club vehicles – almost double than the previous year.[116] This corresponds to 0.01% of licensed UK vehicles belonging to a car club.[117] The workshop was used to gather sources and estimates for resource efficiency data.

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105 CE Center Circular Economy (2019) Car-sharing in Flanders link
106 Laura C. Aguilar Esteva, Akshat Kasliwal, Michael S. Kinzler, Hyung Chul Kim, Gregory A. Keoleian (2020) Circular Economy framework for automobiles: Closing energy and material loops link
107 Paul Wolfram, Qingshi Tu, Niko Heeren, Stefan Pauliuk, Edgar G. Hertwich (2020) Material efficiency and climate change mitigation of passenger vehicles link
108 Ecologic Institute (2018) Car sharing in Germany: a case study on the circular economy link
109 Simone Cooper et al. (2016) A multi-method approach for analysing the potential employment impacts of material efficiency link
110 Ahuja, J., Dawson, L., Lee, R. (2020) A circular economy for electric vehicle batteries: driving the change link
111 Edgar G Hertwich, Saleem Ali, Luca Ciacci, Tomer Fishman, Niko Heeren, Eric Masanet, Farnaz Najvan Asghari, Elsa Olivetti, Stefan Pauliuk, Qingshi Tu, Paul Wolfram (2019) Material efficiency strategies to reducing greenhouse gas emissions associated with buildings, vehicles, and electronics—a review link
112 Pauliuk, S., Heeren, N., Berrill, P. et al. (2021) Global scenarios of resource and emission savings from material efficiency in residential buildings and cars link
113 Zero Waste Scotland (2020) Vehicle Tyres: Policy Options for a Circular Economy link
114 Laura C. Aguilar Esteva, Akshat Kasliwal, Michael S. Kinzler, Hyung Chul Kim, Gregory A. Keoleian (2020) Circular Economy framework for automobiles: Closing energy and material loops link
115 Paul Wolfram, Qingshi Tu, Niko Heeren, Stefan Pauliuk, Edgar G. Hertwich (2020) Material efficiency and climate change mitigation of passenger vehicles link
116 Collaborative Mobility UK (2021). Car Club Annual Report - United Kingdom – 2021. Accessible here: link
117 UK Government (2021) Vehicle licensing statistics: April to June 2021. link

6.2.2 Workshops

This measure received a good level of engagement in both workshops. However, none of the stakeholders were specifically involved in car-sharing businesses though demonstrated good understanding of them. The level of engagement in both workshops was as follows:

- **Workshop 1** – Ten stakeholders across, industry and academia were active on the mural board and three stakeholders actively contributed to verbal discussion.
- **Workshop 2** - Five stakeholders from industry were active on the mural board and three stakeholders actively contributed to verbal discussion.

6.3 Drivers & Barriers

A wide range of drivers and barriers influence the appetite, uptake and outcomes of each measure. Drivers and barriers were identified from both the literature and within the workshop discussions. The most notable drivers and barriers, including their PESTLE and COM-B categorisation, are described in the following sub-sections.

6.3.1 Drivers

Below are the drivers that have been identified for Measure 6, including their PESTLE and COM-B categorisation. Drivers in bold represent the most important drivers indicated by stakeholders during voting and in discussion.

Table 18: Drivers for vehicles Measure 6

Driver	PESTLE	COM-B
Incentivisation for the public to use car sharing clubs.	**Social**	**Motivation – Automatic**
Changing consumer attitudes towards non-ownership models.	**Social**	**Motivation – Automatic**
Environmental and health benefits of reduced air pollution.	**Environmental/ Social**	**Motivation – Reflective**
Non-owned vehicles could be cheaper and easier to use than an owned vehicle.	Economic	Motivation – Reflective
Increasing competitiveness of non-ownership models.	Economic	Opportunity – Social
Potential parking and entry charging benefits for shared vehicles.	Economic	Capability – Physical
Car-sharing reduces material tied up within the vehicle stock.	Economic	Opportunity – Physical
Fuel savings and emissions savings per passenger/mile through increased vehicle occupancy.	Environmental	Opportunity – Physical
Faster uptake of new vehicles with improved technology.	Technological	Opportunity – Physical

Driver	PESTLE	COM-B
Services offering driver (can give consumers more flexibility).	Social	Capability – Psychological
Improved digital platforms and user interface may increase uptake.	Technological/ Economic	Motivation – Automatic
Improved availability of vehicles to facilitate increased confidence, and use, of the service.	Economic/ Social	Motivation – Reflective

Incentivisation for the public to use car sharing clubs

Indirect incentivisation for use of car clubs comes from a number of sources. These include the cost of parking permits in residential areas, introduction or extension of low emission zones and associated costs of driving older, more polluting cars and the prohibitive outright cost of purchase of EVs for many consumers.

The introduction of more prominent charging infrastructure for EVs used by car clubs, and free parking for car club members, offers direct incentives for increased use.

Changing consumer attitudes towards non-ownership models

Stakeholder highlighted that consumers' changing attitudes towards non-ownership models was another key driver, particularly among younger consumers. The flexibility of car club models, essentially enabling multi-modal choices based on the nature and duration of travel requirements, while also affording access to EVs, is increasingly attractive to these consumers.

Car-sharing reduces material tied up within the vehicle stock

Car-sharing presents an opportunity to reduce the amount of material inefficiently tied up within the vehicle stock. Increased occupancy and better utilisation of vehicles can result in fuel savings, lower GHG emissions and better air quality per passenger/mile. Stakeholders noted that consumers are increasingly aware of these benefits.

Non-owned vehicles could be cheaper and easier to use than an owned vehicle

Car-pooling is cheaper than car ownership for most users and is a key driver for uptake of this measure, and increasing competitiveness of car sharing options (and therefore lower prices) could increase uptake further.

Faster uptake of new vehicles with improved technology

As vehicles are used more heavily, vehicle turnover is greater, therefore car sharing models allow for faster uptake of technologies such as zero emission vehicles. Furthermore, the higher cost of zero emissions vehicles can be spread across many users.[118]

Services offering a driver (can give consumers more flexibility; Improved digital platforms and user interface may increase uptake

[118] Tyrer, D., Orchard, K. (2021) Barriers and opportunities for shared battery electric vehicles - A report for Transport and Environment link

Other servitisation models such as those offering a driver (e.g., Uber) can give consumers more flexibility in certain scenarios (e.g., ability to consume alcohol). Stakeholders noted this could increase with the adoption of autonomous vehicles. Furthermore, stakeholders noted that business models with good digital platforms and user interfaces achieve greater uptake.

Other insights

It was noted by a stakeholder that car-sharing and other methods to increase vehicle occupancy generally replace a household's second or third vehicle, rather than their primary vehicle. This suggests that while there are drivers to their uptake, they are currently not strong enough to encourage people to move away from car ownership completely.

6.3.2 Barriers

Below are the barriers that have been identified for Measure 6, including their PESTLE and COM-B categorisation. Barriers in bold represent the most important barriers indicated by stakeholders during voting and in discussion.

Table 19: Barriers for vehicles Measure 6

Barrier	PESTLE	COM-B
Lack of convenience, flexibility and reliability compared to ownership models.	**Social**	**Motivation – Reflective**
Poor journey planning integration.	**Technological**	**Motivation – Reflective**
Lack of coherent national policy and messaging.	**Political**	**Motivation – Automatic**
Desire for ownership hinders growth in uptake.	Social	Motivation – Automatic
Consumer concerns regarding hygiene, etc.	Social	Motivation – Automatic
Coordination costs and concerns over damage liability.	Economic	Opportunity – Physical
Reluctance to share with unknown people	Social	Motivation – Psychological
Ambiguity as to whether shared mobility platforms have a positive impact on resource efficiency.	Technological	Capability – Psychological
Increased vehicle turnover results in greater resource consumption.	Environmental	Opportunity – Physical
Poorer service for rural users.	Social	Capability – Physical
For freight, mechanisms will need to be in place to ensure minimum service levels.	Social	Motivation – Reflective

When voting on the key barriers, the most-voted option for barriers was 'convenience of use and access continues to be an issue'. Throughout the discussion, stakeholders agreed that car sharing and rental schemes had to be within easy access to consumers whilst also offering the range of vehicle sizes, and facilities, that consumers may need e.g., larger storage spaces for families with pushchairs.

Lack of convenience, flexibility and reliability compared to ownership models

The literature review identified that a key barrier to the uptake of this measure is a lack of data and consensus on the resource efficiency benefits of car sharing and increased vehicle occupancy. This is because there is uncertainty on the impact that car sharing might have on the road, for example, whether car sharing may displace public transport/cycling rather than other vehicles and therefore contribute to an increase in vehicles on the road[119, 120].

Increased vehicle turnover results in greater resource consumption

Furthermore, there may be increased vehicle turnover as car sharing vehicles reach EoL at a quicker rate resulting in increased material consumption (though there are benefits to this as discussed above).[121]

Lack of coherent national policy and messaging

The literature review also highlighted a lack of coherent national policy and messaging around car clubs.[122] There is no specific and coherent guidance published nationally and disseminated to local authorities. Consequently, there is no consistency in understanding what potential benefits car clubs may offer in transport decarbonisation pathways within local authorities. With competing pressures on funding, this means regional variations in support or promotion of car clubs, and in some cases a focus on other transport modes (active travel corridors, bus services etc.) at the expense of car clubs.

Lack of convenience, flexibility and reliability compared to ownership models; Desire for ownership hinders growth in uptake (e.g. due to Poorer service for rural users; Poor journey planning integration; Consumer concerns regarding hygiene; For freight, mechanisms will need to be in place to ensure minimum service levels)

Stakeholders highlighted the consumer desire for ownership models which prevents uptake of this measure. The key reasons for this include:

- Convenience of use and access continues to be an issue particularly in more rural areas. There is a need to overcome the perceived flexibility and reliability offered by conventional ownership models. Existing car-sharing often does not give consumers the required flexibility (e.g., access to vehicles and the range/size of vehicles required, location of car sharing clubs, practicality of access, availability, range of fleet, size of fleet, baby seat access).
- Reluctance to share with unknown people and concerns regarding hygiene, etc. The COVID-19 pandemic may have exacerbated this issue.
- Lack of journey planning integration with other transport prevents uptake as there is limited confidence that the appropriate vehicle will be available when required. Timeliness is important for consumers and businesses, so consistency is required. For freight, mechanisms will need to be in place to ensure minimum service levels.

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[119] CE Center Circular Economy (2019) Car-sharing in Flanders link
[120] Gehrke, S.R., Felix, A., Reardon, T., G. (2019) Substitution of Ride-Hailing Services for More Sustainable Travel Options in the Greater Boston Region link
[121] Laura C. Aguilar Esteva, Akshat Kasliwal, Michael S. Kinzler, Hyung Chul Kim, Gregory A. Keoleian (2020) Circular Economy framework for automobiles: Closing energy and material loops link
[122] Tyrer, D., Orchard, K. (2021) Barriers and opportunities for shared battery electric vehicles - A report for Transport and Environment link

- Coordination costs and concerns over damage liability including insurance costs.

Ambiguity as to whether shared mobility platforms have a positive impact on resource efficiency

In the workshops, there was discussion over the resource efficiency benefits of car-sharing as to whether they would result in displacement from public transport or cycling, and so potential more vehicles on the road. Another key consideration is whether car-sharing and increased vehicle occupancy approaches makes car journeys more accessible to a greater pool or people, again increasing vehicles on the road rather than decreasing it.

Mitigations

The following actions were suggested by stakeholders. These are not currently in place at scale but could help mitigate some barriers and influence uptake of this measure were they to be introduced:

- Incentivisation for the public to use car sharing clubs through e.g., reduced costs, tax incentives, dedicated parking facilities, as well as parking and entry charging benefits for shared vehicles (e.g., multi-person occupancy lanes on motorways, such as those found in the US) may promote car-sharing and a more extensive range of vehicles. Car sharing is frequently encouraged by UK local authorities through guidance.[123]
- Increased use of autonomous vehicles may improve uptake as it provides a more flexible options without the overhead costs of driving.
- Improved digital platforms and user interface may increase uptake. Introduction of 'gamification' or rewards may incentivise consumers. Mobility as a Service (MaaS) combines different transport options into one convenient platform, providing users with easy access to various modes of transportation and streamlined payment methods through a single app.[124]
- Improved journey planning integration between services can increase the use of this measure, in particular the availability of the service close to public and/or active travel services, could improve access to car sharing opportunities. MaaS could streamline this service with the support of local authorities and transport providers.
- Improved availability of vehicles to facilitate increased confidence, and use, of the service. This is also an issue for freight vehicles where there is currently no established network for collaboration. Stakeholders noted a need to implement mechanisms to secure minimum service levels. A zero-emission vehicle mandate and CO_2 emissions regulation for new cars and vans in the UK could encourage sales of zero emission vehicles to car clubs.[125]

[123] UK Government (2022) Guidance: Car clubs: local authority toolkit. link
[124] MaaS Alliance (2022) Mobility as a Service? link
[125] UK Government (2023) zero emission vehicle (ZEV) mandate and CO_2 emissions regulation for new cars and vans in the UK. link

6.4 Levels of efficiency

Table 20: Levels of efficiency for vehicles Measure 6

Indicator: The % of vehicles within car clubs, car rental organisations, private car hires and car rideshares as a proportion of vehicles on the road			
Level of efficiency	Current	Maximum in 2035	Business-as-usual in 2035
Value	0.01%	30 – 40%	10 – 20%
Evidence RAG	Green	Red-Amber	Red-Amber

6.4.1 Current level of efficiency

According to one source, the number of car club members has almost doubled in the last year, and this is believed to have taken 116,000 cars off Britain's roads using 5,806 shared cars. [126] Another source found that currently an estimated 0.01% of UK vehicles belong to a car club.[127] [128] Limited data was identified for other forms of car sharing such as car rental and lift sharing in the literature review.

The stakeholders generally agreed that the proportion of shared vehicles currently on UK roads was likely to be very low. Stakeholders did mention that there are likely big discrepancies between urban and rural areas, as well as between older and younger generations, with urban areas and younger generations being more likely to make use of car- or ridesharing.

As the measure indicator was updated between the first and second workshop, two rounds of voting were collected. During the first round of voting, when voting on the current levels of efficiency, 17 votes were collected. Most stakeholders generally agreed with the level identified in literature (0.01%). During the second round of voting, the most voted for option was '0%-10% which aligns with the literature findings. A green evidence RAG rating has been selected since there was consensus on the estimated levels of efficiency and this supported data found in literature.

6.4.2 Maximum level of efficiency in 2035

No quantifiable estimates on the potential likely uptake of this measure using the chosen indicator were found in the literature. However, a modal shift to non-privatised vehicles could theoretically achieve 100% efficiency, which was agreed with by stakeholders in the workshop. On the other hand, while stakeholders stated they agreed with a theoretical limit of 100%, they said feasible limit is probably significantly lower due to the impracticality of car- or ridesharing for certain groups, such as rural communities or families.

The literature review did find some estimates on how vehicle occupancy could increase through this measure. For example, one study found that lift sharing could lead to a 25–75%

[126] Collaborative Mobility UK (2021). Car Club Annual Report - United Kingdom – 2021. Accessible here: link
[127] UK Government (2023) zero emission vehicle (ZEV) mandate and CO_2 emissions regulation for new cars and vans in the UK. link
[128] Collaborative Mobility UK (2021). Car Club Annual Report - United Kingdom – 2021. Accessible here: link

increase in vehicle occupancy were this to be applied to all vehicles.[129] Another found that more intensive use implies an increase in vehicle occupancy from 1.5 to 2.0 passengers, lowering vehicle- and energy-cycle emissions per passenger by 25%, regardless of energy mix, powertrain, or vehicle class.[130]

Voting for this measure was limited with only four votes collected, the most popular of which (with two votes) was ‘30-40%. A red-amber evidence RAG rating has been selected since there was limited degree of consensus on the estimated levels of efficiency.

6.4.3 Business-as-usual in 2035

Business-as-usual data was collated from workshops as no quantifiable estimates of how this figure will develop into the future were found in the literature review. When voting on the business-as-usual, four votes were collected across two options. The most-voted option was ‘10%-20%’ and one stakeholder voted for ‘20%-30%’.

Stakeholders generally agreed that gains could be made in levels of efficiency under the business-as-usual scenario, and that current levels are low. One stakeholder noted that car clubs have been around for a while and yet make up a tiny proportion of the market. However, CoMoUK reported a 24% increase in total car club members and a 96% increase in active members between November 2020 and October 2021[131]. It should be noted that this data would have been impacted by the COVID19 pandemic response. A red-amber evidence RAG rating has been selected since there was some degree of consensus on the estimated levels of efficiency.

6.5 Other insights

Stakeholders noted that the success of this measure is highly dependent on the information technology sector (i.e., user experience on mobile apps) and collaboration with the public transport sector to connect the use of different modes of transport.

[129] Paul Wolfram, Qingshi Tu, Niko Heeren, Stefan Pauliuk, Edgar G. Hertwich (2020) Material efficiency and climate change mitigation of passenger vehicles link
[130] Paul Wolfram, Qingshi Tu, Niko Heeren, Stefan Pauliuk, Edgar G. Hertwich (2020) Material efficiency and climate change mitigation of passenger vehicles link
[131] Collaborative Mobility UK (2021). Car Club Annual Report - United Kingdom – 2021. Accessible here: link

7.0 Measure 7 – Vehicle life extension

7.1 Vehicles resource efficiency measure

7.1.1 Description

Prolonging the useful life of a vehicle via electrification or extending the life of components.

Measure 7 is life extension of End of Life (EoL) vehicles, where EoL is defined as the point at which a motor vehicle has reached the end of its usable life and is no longer intended for road use or further use by the owner (i.e. the vehicle and their components is categorised as waste). EoL vehicles are typically aged, damaged, worn-out, or no longer economically viable or convenient to repair. Life extension can prolong the useful life of a vehicle.

This measure comprises two key elements. The first entails electrification of existing internal combustion engine (ICE) vehicles to extend the life of components. Conversion of vehicles to extend their life would make a significant contribution to the mitigation of GHG emissions from transport, both during use (up to three times more fuel efficient[132]) but also by preventing the production of an entirely new EV and the associated embodied carbon emissions.

The second entails repair of vehicles to extend their lifetime. Extending the life of a vehicle through repairs would reduce the quantity of material that is required by reducing the frequency with which an entirely new vehicle needs to be purchased and retaining the value of materials in their most valuable form as a product (i.e., a functioning vehicle). Vehicles typically reach their EoL due to failure of, or damage to, a critical component (e.g., engine) or because the cost of repairs is no longer economically viable. In either case, many of the other components are still functioning and therefore their value should be retained by keeping them within a functioning product through repairs to the failed component. Whilst vehicle repair is widespread in the UK, this measure investigates whether more can be done to further extend the lifetime of vehicles.

7.1.2 Measure indicator

There are two selected indicators for Life extension (Measure 7), reflecting the two aspects of the measure. The first is the '**% of vehicles whose lifetime is extended through electrification at end of life**'. The second is '**% of vehicles that are currently scrapped whose lifespan could be extended through repair**'. The selected indicators were chosen for their ability to comprehensively assess the resource efficiency benefits of extending vehicle lifetime compared to current scrappage rates. It was agreed upon by the project team, considering data from the literature review and feedback from stakeholders. The following other indicators were considered but excluded due to limitations in data availability, and their comprehensive coverage of the measure.

- Reduction in materials used in vehicles and/or reduction in waste
- Year on year increase in the number of components that are designed to be modular

[132] Watts, Ghosh and Hinshelwood, University of Exeter (2021) Exploring the Potential for Electric Retrofit Regulations and an Accreditation Scheme for the UK link

- Number of vehicle components that are standardised
- % use of repairable or modular components in vehicles
- % increase in vehicle service life
- Average lifetime of vehicle
- Annual increase of battery capacity or lifespan as %
- Number of staff or members of the public completing eco-driving / sustainability training to maximise lifespan of vehicles or reduce wastes

The reasons for discounting these indicators are as follows:

- The first, fifth and sixth indicators were discounted because they were considered too broad to reflect this measure (and difficult to benchmark in respect of variation in vehicle service life or average lifetime).
- The second and third indicators were discounted because they did not comprehensively cover this measure, as modular design is only one aspect of life extension.
- The fourth indicator was discounted due to expected difficulties in data collection.
- The seventh indicator was discounted because it was deemed too narrow as this measure includes vehicles other than BEVs.
- The final indicator was discounted because it only focuses on a small part of the measure and thus does not reflect the measure fully.

7.1.3 Examples in practice

Electrification

Electrification of ICE vehicles through retrofitting of EV batteries is in its infancy and currently under investigation. CICERO (Classic Car Electrification) is an ongoing study between Aspire Engineering, PatrimonyEV, Loughborough University, and HSSMI – with funding from Innovate UK – that is exploring the opportunities of EoL EV batteries being deployed into niche applications such as classic/heritage cars. In this context, the EV batteries will require limited dismantling to then be restructured to suit the host vehicles.[133] Retrofitting cars in this way can give used cars a second chance at life, lower CO_2 emissions, extends the comfort and functional life of a vehicle after it has served its initial purpose and save consumers the costs in replacing vehicles. Retrofitting an EV battery into an ICE vehicle can be up to two-thirds less than the cost of a new EV vehicle.[134]

Diesel buses can also be converted (or repowered) to become zero emission buses by replacing the existing diesel bus engines with a new zero emission drivetrain. In the UK there are several companies who offer this service, including Kleanbus and Saietta, at a cost of £200K per vehicle compared to £400K for a new EV double decker bus. Repowering buses in this way contributes to an immediate reduction in operating costs, extends the life and value of the existing fleet and addresses the problem of old diesel buses.[135] In Ankara, Turkey, the

[133] HSSMI (2021) Retrofitting Classic Cars with Second-Life EV Batteries link
[134] REMATEC (2022) Retrofitting Cars; A new Sustainable Way to Enter the Electric Vehicle Market link
[135] Parkin, L. (2022) Retrofitting buses is a fast route to greener public transport link

electrification of diesel buses has shown that electrification can extend the lifetime of buses by up to 15 years, while energy usage can be reduced in the use phase by 25%.[136] The benefits are not limited to the use phase. UK estimates suggest that repowering diesel buses can prevent the considerable environmental impact in the manufacture of new electric buses, which can be as much as 40-80% of their total lifecycle carbon footprint.[137] However, this figure is unavailable for cars.

Repair

Repair refers to those measures undertaken in order to extend the useful life of the vehicle beyond current scrappage rates. This therefore incorporates reconditioning of parts, where currently the vehicle owner has decided it is uneconomic to do so. It also includes replacement of worn/damaged components and engine reconditioning, where feasible to undertake.

7.2 Available sources

7.2.1 Literature Review

Eleven sources discussed this resource efficiency measure, these comprised:

- Seven academic papers/reports;[138, 139, 140, 141, 142, 143, 144]
- two policy documents;[145, 146]
- one industry report[147] and,
- one website article[148]

Most of these sources were of medium to high quality (IAS scores of 3-5); however, a couple of references scored 2 on the IAS rating, although both references discussed specific measures, such as improving energy management in EVs to prolong life in the US and trends in modularity. Five of the sources covered global measures; while not all were specific to the UK

[136] Circle Economy & Deloitte (2023) The Circularity Gap Report 2023 link
[137] Parkin, L. (2022) Retrofitting buses is a fast route to greener public transport link
[138] Fabian Rücker, Ilka Bremer, Sebastian Linden, Julia Badeda, Dirk Uwe Sauer (2016) Development and Evaluation of a Battery Lifetime Extending Charging Algorithm for an Electric Vehicle Fleet link
[139] Edgar G Hertwich, Saleem Ali, Luca Ciacci, Tomer Fishman, Niko Heeren, Eric Masanet, Farnaz Najvan Asghari, Elsa Olivetti, Stefan Pauliuk, Qingshi Tu, Paul Wolfram (2019) Material efficiency strategies to reducing greenhouse gas emissions associated with buildings, vehicles, and electronics—a review link
[140] Simon Schmidt, Jan Clausen, Robin van der Auwera, Oliver Klapp, Rico Schmerler, David Löffler, Maximilian Jakob Werner and Lukas Block (2022) Novel Battery Module design for increased resource efficiency link
[141] Picatoste, A., Justel, D., Mendoza, J.M.F. (2022) Exploring the applicability of circular design criteria for electric vehicle batteries link
[142] Schuhmann, D., Merkel, M., Reusch, S., Harrison, D. (2021) Development of a hybrid electric powertrain for non-road mobile machinery by means of application-adapted driving profiles link
[143] Richter, T., Slezak, L., Johnson, C., Young, H., Funcannon, D. (2008) Advanced Hybrid Propulsion and Energy Management System for High Efficiency, Off Highway, 240 Ton Class, Diesel Electric Haul Trucks link
[144] Jeevanandam.s, Mohan Rao. S.L (2015) Modularity Techniques in Commercial Vehicles link
[145] Zero Waste Scotland (2020) Vehicle Tyres: Policy Options for a Circular Economy link
[146] World Economic Forum (2020) Forging Ahead A materials roadmap for the zero-carbon car link
[147] Accenture and World Economic Forum (2020) Raising Ambitions: A new roadmap for the automotive circular economy link
[148] FEV (2021) Top Trends in Modular Electric Vehicle Design link

market, many were applicable to the UK manufacturing sector because they were based on similar markets (e.g., EU and US).

Some of the most notable sources were the *Material efficiency strategies to reducing greenhouse gas emissions associated with buildings, vehicles, and electronics—a review*[149] and *Forging Ahead: A materials roadmap for the zero-carbon car*.[150] Much of the literature focussed on enablers of this measure (e.g., 'design for modularity' and 'increasing battery capacity lifetime') rather than high level indicators encompassing various aspects of life extension.

Across the literature, there was little applicable quantitative data relating to levels of efficiency for the selected indicator. The only data identified was from Hertwich et al (2022) (with an IAS of 5) which identified that the effect of lifetime extension (whilst ambiguous) may in fact increase total GHG emissions by 1.8–3% per year. This is because the reduced material and energy requirements gained from extending the life of vehicles as opposed to producing new vehicles, can be offset by performance differentials between new and used vehicles if fuel efficiency increases.[151] As such, the workshop was used to verify this information and to identify estimates for the level of efficiency.

7.2.2 Workshops

It was agreed during the workshop that EoL would be defined as the point at which the vehicle has reached the end of its usable life and is no longer intended for road use or further use by the owner.

This measure received a different response from stakeholders between electrification and repair.

For electrification, stakeholders universally agreed that the technical and safety complexities of large-scale retrospective electrification for passenger vehicles is impractical/infeasible.

For repair, some stakeholders noted that in most cases, vehicle lifetime is maximised through the already good levels of repair and that using this as a measure might not achieve significantly greater levels of resource efficiency. Stakeholders also highlighted the importance of distinguishing between repairs vs upgrades and module replacements.

Nevertheless, this measure received a good level of engagement in both workshops. Most of the stakeholders had good knowledge of life-extension measures at a technical level and at an operational level through engagement with the insurance industry. The level of engagement in both workshops was as follows:

- **Workshop 1** – Nine stakeholders across industry and academia were active on the mural board and five stakeholders actively contributed to verbal discussion.

[149] Edgar G Hertwich, Saleem Ali, Luca Ciacci, Tomer Fishman, Niko Heeren, Eric Masanet, Farnaz Nojavan Asghari, Elsa Olivetti, Stefan Pauliuk, Qingshi Tu, Paul Wolfram (2022) Material efficiency strategies to reducing greenhouse gas emissions associated with buildings, vehicles, and electronics—a review link
[150] Paul Wolfram, Qingshi Tu, Niko Heeren, Stefan Pauliuk, Edgar G. Hertwich (2020) Material efficiency and climate change mitigation of passenger vehicles link
[151] Edgar G Hertwich, Saleem Ali, Luca Ciacci, Tomer Fishman, Niko Heeren, Eric Masanet, Farnaz Nojavan Asghari, Elsa Olivetti, Stefan Pauliuk, Qingshi Tu, Paul Wolfram (2022) Material efficiency strategies to reducing greenhouse gas emissions associated with buildings, vehicles, and electronics—a review link

- **Workshop 2** - Seven stakeholders from industry were active on the mural board and four stakeholders actively contributed to verbal discussion.

7.3 Drivers & Barriers

A wide range of drivers and barriers influence the appetite, uptake and outcomes of each measure. The most notable drivers and barriers, including their PESTLE and COM-B categorisation, are described in the following sub-sections. Due to the differences between electrification and repair, the drivers and barriers were separated between the two for this measure.

7.3.1 Drivers

Below are the drivers that have been identified for Measure 7, including their PESTLE and COM-B categorisation. Drivers in bold represent the most important drivers indicated by stakeholders during voting and in discussion.

Table 21: Drivers for vehicles Measure 7

Driver	PESTLE	COM-B
Electrification		
Lifecycle carbon savings from reduced energy in production and few in-use emissions.	**Environmental**	**Capability – Physical**
The simplicity in design and manufacture of EVs can facilitate repair.	Technological	Capability - Physical
Modular design / manufacturing can facilitate EoL electrification.	Technological	Capability - Physical
Electrification can reduce vehicle / fleet turnover	Economic	Opportunity – Physical
Electrification may be suitable for commercial vehicles	Economic	Opportunity – Physical
Retrofitted electrification can be cheaper than producing a new vehicle	Economic	Opportunity – Social
Retrofitting cars to electric powertrains can extend vehicle life	Economic / Environmental	Motivation - Reflective
Repair		
Incentives through ownership models	**Economic**	**Opportunity – Physical**
Existing public acceptance for repair processes.	**Social / Economic**	**Capability – Physical**
Repairs will reduce vehicle fleet turnover.	Economic / Environmental	Opportunity – Physical
Increasing use of reused parts.	Economic	Opportunity – Social

Driver	PESTLE	COM-B
Good network for EoL repair facilities.	Technological	Opportunity – Physical
Premature scrapping of damaged vehicles presents opportunity for life extension.	Economic	Opportunity – Physical
EVs have fewer working parts so may last longer.	Technological	Capability - Physical

Electrification

The literature revealed that the key drivers for electrification include lifecycle carbon savings directly related to material savings, transition from fossil fuels, and reduced energy use during production.[152] For larger commercial vehicles such as buses, converting vehicles in this way is estimated to be cheaper than purchase of new EVs.[153]

Lifecycle carbon savings from reduced energy in production and few in-use emissions

Extending the life of vehicles via electrification offers potential lifecycle benefits in comparison with both the energy used in production (leaner process for retrofit works) and a reduction in subsequent in-use tailpipe emissions. This is true for larger commercial vehicles such as buses, as well as for cars.

Repair

The literature review revealed limited information on the repair of vehicles as a method of life extension. However, stakeholders reported the following drivers for repair.

- Repairs will reduce vehicle fleet turnover due to extended lifespan which results in reduced resource consumption in production as discussed in Measure 6.
- Extending vehicle lifetime through repair is already a widespread (and well regulated) practice. Therefore, existing support and acceptance for repair processes will continue to drive up use of repair opportunities. There is currently a good network for EoL repair facilities, and this will continue to exist, or grow, to allow ready access to consumers.
- Ownership models often incentivise repair due to the cost of purchasing new vehicles. However, there comes a point where this is no longer economically viable.
- There is increasing recognition from manufacturers, consumers and the insurance industry that reused parts are an economically viable (lower cost) method of life extension and that there is work underway to further develop standards to maximise their use in repaired vehicles as further discussed in Measure 8.
- There are opportunities for ELV life extension as these vehicles tend to be prematurely scrapped due to accident damage or costly repair. There is therefore significant opportunity to extend the life of many components as further discussed in Measure 8.

[152] Watts, Ghosh and Hinshelwood, University of Exeter (2021) Exploring the Potential for Electric Retrofit Regulations and an Accreditation Scheme for the UK link
[153] Circle Economy & Deloitte (2023) The Circularity Gap Report 2023 link

- The simplicity in design and manufacture of EVs will continue to facilitate repair of these vehicles as they have fewer working parts and so may last longer, though a secondary market is in its infancy.

The most-voted drivers were ‘existing support / acceptance for repair processes will continue to drive up use of repair opportunities’ and ‘Incentives through ownership models’ - whereby vehicle owners are incentivised to extend lives (e.g., through tax incentives). Stakeholder support for these measures suggest that the measure is already a developed practice among consumers, however further incentives – such as tax incentives for continuing to repair or electrify vehicles – could increase uptake. Discussion did, however, question whether the environmental impact of older vehicles, with poorer safety features, would be an acceptable measure for consumers.

7.3.2 Barriers

Below are the barriers that have been identified for Measure 7, including their PESTLE and COM-B categorisation. Barriers in bold represent the most important barriers indicated by stakeholders during voting and in discussion.

Table 22: Barriers for vehicles Measure 7

Barrier	PESTLE	COM-B
Electrification		
Underdeveloped legislative / safety requirements around electrification deters uptake by consumers and manufacturers.	**Legal**	**Opportunity - Social**
Technical requirements hinder uptake of electrification	**Technological**	**Capability – Physical**
Limited proof of performance.	Technological	Capability – Physical
Large variety of makes, models, and operational requirements can complicate retrofitting.	Technological	Opportunity - Physical
OEMs continue to have a preference to sell new products over repaired/upgraded goods.	Economic	Motivation – Reflective
Significant safety concerns around unregulated electrification of vehicles.	Legal	Opportunity - Social
Repair		
Repairs will reduce vehicle / fleet turnover which could result in loss of innovation offered by new products, including safety and comfort features	Technological	Motivation - Reflective
Supply chain issues limit opportunities to secure supplies of repaired components in a timely manner.	Technological / Political	Capability - Physical
High cost of repair and running costs towards EoL could outweigh cost of new vehicle.	Economic	Opportunity - Physical
Consumer preference for repaired parts remains low, due to perceived safety concerns.	Social	Motivation - Automatic

Barrier	PESTLE	COM-B
Lack of widespread standards for reused/repaired parts.	Technological / Legal	Capability - Physical
Access to parts - and their removal from vehicle - can be complex using current practices. Parts should be accessible and repairable.	Technological	Capability - Physical

Electrification

The most voted for drivers were ‘Underdeveloped legislative / safety requirements around electrification deters uptake by consumers and manufacturers’ and ‘Technical requirements hinder uptake of electrification’. Other barriers also received numerous votes suggesting that there are numerous significant barriers to this measure.

Large variety of makes, models, and operational requirements can complicate retrofitting

The literature review identified that retroactive electrification of ICE vehicles is relatively niche and there is currently limited proof of performance at scale which prevents widespread uptake of this measure.[154] Furthermore the large variety of makes and models, and operational requirements can complicate retrofitting.[155]

Significant safety concerns around unregulated electrification of vehicles

During consultation, stakeholders were highly critical of life extension through electrification particularly with regards to the safety concerns in an unregulated market. Stakeholders also expressed concern over a loss of innovation as a result of reduced fleet turnover and questioned whether there would be consumer demand for a retrofitted vehicle with outdated features.

Technical requirements hinder uptake of electrification

Retrofitting EoL vehicles may not be practical as there may be other components (beyond the drivetrain) that may limit the vehicle lifetime. Therefore, there is a risk that an electrification upgrade to a near EoL vehicle, will see it fail the following year (due to other components), resulting in no net benefit. Furthermore, stakeholders noted that new electric vehicles are engineered from the ground up to achieve the required efficiencies. Retrofitting ICE vehicles would result in significant inefficiencies from parasitic weight etc. which would prevent them from operating properly. Stakeholders also expressed concerns over potential supply issues for batteries due to competition with OEMs for new EVs.

Underdeveloped legislative / safety requirements around electrification deters uptake by consumers and manufacturers

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[154] Watts, Ghosh and Hinshelwood, University of Exeter (2021) Exploring the Potential for Electric Retrofit Regulations and an Accreditation Scheme for the UK link
[155] Watts, Ghosh and Hinshelwood, University of Exeter (2021) Exploring the Potential for Electric Retrofit Regulations and an Accreditation Scheme for the UK link

Stakeholders agreed that large-scale electrification of ICE passenger vehicles was infeasible and undesirable due to safety, technical barriers, and regulatory issues. Safety legislation can also prohibit retrofitting and is often country-specific which prevents widescale adoption.

Electrification of freight vehicles was considered to be a “non-starter”. Retrofit of batteries is difficult to achieve without reducing overall available payload and some modifications to the powertrain. This is unattractive to hauliers that need to remain cost-competitive.

Repair

Stakeholders were more receptive to life extension through repair. They noted that in most cases, vehicle lifetime is currently maximised as far as practicable through the already good levels of repair, therefore significantly greater levels of resource efficiency may not be achievable. However, stakeholders noted that, beyond a certain point, the cost of repair and running costs could outweigh cost of new vehicle. Leasing models (including car hire), such as those seen in the aviation industry, can encourage owners to maximise the vehicle lifetime. As with electrification, stakeholders raised concerns that reduced vehicle fleet turnover which could result in loss of innovation. Discussion also did question whether the environmental impact of older vehicles, with poorer safety features, would be acceptable for consumers.

Lack of widespread standards for reused/repaired parts

Quality assurance of repaired parts is an issue for consumers. There is currently a lack of widespread standards for reused/repaired parts although these are under development.

Consumer preference for repaired parts remains low, due to perceived safety concerns

Consumer preference for repaired parts remains low, due to perceived safety concerns. Linked to this, one stakeholder noted that in many cases, damage to vehicles is not reported to insurance and therefore is not recorded when a vehicle is sold.

Access to parts - and their removal from vehicle - can be complex using current practices. Parts should be accessible and repairable

Stakeholders noted that access to parts - and their removal from vehicles - can be complex using current practices and vehicle design (as discussed further in Measure 8) and supply chain issues can limit opportunities to secure supplies of secondary components (particularly batteries) in a timely manner.

For some replacement components such as tyres, many retailers prefer to sell a new replacement tyre, motivated by the higher sales value, even though some tyre damage and punctures can be safely repaired. Furthermore, low-cost tyres offer greater profits for retailers; they are not suitable for re-grooving (which can extend the tyre life by up to 25%) resulting in greater sales due to more frequent replacement.

7.4 Levels of efficiency

Table 23: Levels of efficiency for vehicles Measure 7

Indicator: **The % of vehicles whose lifetime is extended through electrification at end of life** **The % vehicles that are currently scrapped whose lifetime could be extended through repair**			
Level of efficiency	Current	Maximum in 2035	Business-as-usual in 2035
Value (electrification)	0 – 5%	0 – 20%	0 – 10%
Value (repair)	0 – 20%	20 – 40%	N/A
Evidence RAG for each option	Red-Amber	Red-Amber	Red

7.4.1 Current level of efficiency

No quantifiable current levels of efficiency using the proposed indicators were identified in the literature review, therefore, the workshops were used to determine estimates.

One stakeholder indicated that the level of repair and electrification is likely to be less than 1%, due to the business models of OEMs not currently supporting this type of activity. A different stakeholder on the other hand argued that the system currently in the UK, where second-hand dealers make choices about extending the life of a vehicle is already pretty good, suggesting that the scope for improving this could be limited.

When voting on the current levels of efficiency, the voting was split into two indicators, one for electrification and one for repair at end-of-life. 14 votes were collected across both indicators. 13 out of the 14 votes for current levels of efficiency were for ‘0%-20%’ for both levels of electrification and levels of repair, with only one vote for ‘don’t know’. Stakeholders were unable to provide greater granularity as to the level of efficiency, between 0%-20% and this range has been taken as the current level of efficiency value for repair.

With regards to the current level of efficiency for electrification, it is reasonable to conclude that this measure is only currently applicable to extremely niche areas of the UK vehicles sector – being buses and very few passenger vehicles; as such, the overall current level for the vehicle sector as a whole is taken to be between 0% and 5%.

A red-amber evidence RAG rating has been selected because although the stakeholders agreed on ‘0%-20%’ as a range, no data in the literature was identified to support this value, and we were unable to narrow this range for repair.

7.4.2 Maximum level of efficiency in 2035

No quantifiable maximum levels of efficiency using the proposed indicators were identified in the literature review; however, it was reported that electrification of cars or buses could replace new vehicles on a 1-for-1 basis by bringing low emission vehicles onto the roads at a fraction of the cost of producing new EV vehicles.

Several stakeholders expressed uncertainty over the maximum level of efficiency for this measure in terms of electrification, with one stakeholder mentioning that the technical limit depends on the reasons for vehicles that are currently scrapped, which there is limited insight on currently. Furthermore, one stakeholder mentioned that competition for batteries with new EV vehicles may constrain the growth of this measure. One stakeholder indicated that the maximum efficiency would be 5% for this measure.

When voting on the maximum levels of efficiency, votes for electrification and repair were collected separately. For electrification the most voted for option was '0%-20%' with a significant majority, with only one vote for 40%-60%. For repair, a majority of five stakeholders voted for '20%-40%', with a significant number of votes for higher values (1 vote for 40%-60% and 3 votes for 60%-80%).

The differences between the maximum levels of efficiencies for electrification and repair suggests that repair is a more promising method of lifetime extension than electrification. This in part reflected a view that certification and warranty of electrification was potentially more challenging than a similar position with repair. That, in turn, reflects a more mature understanding of repair processes for specific components, as understood within current sector and insurance services, rather than fledgling retrofit works in terms of electrification.

Considering the combined discussion and voting, a range for the maximum level of efficiency of 0%-20% for electrification and 20%-40% for repair was taken forward. Stakeholders were unable to provide greater granularity as to the potential maximum level of efficiency, for either electrification or repair. A red-amber evidence RAG rating has been selected since there was low consensus on the estimated levels of efficiency and there was no data identified in the literature to support this.

7.4.3 Business-as-usual in 2035

No quantifiable levels of efficiency using the proposed indicators were identified in the literature review for passenger vehicles under a business-as-usual scenario.

Stakeholders highlighted that there has been an improved network for EoL repair over last 20 years and there has been recent penetration of market by reused parts which suggests a BAU increase on current levels.

For electrification, one stakeholder mentioned they only expect it to be a niche application. Furthermore, one stakeholder indicated they think the BAU efficiency for electrification could be 5%; however, no information on the BAU efficiency for repairs could be provided by stakeholders.

When voting, four votes were collected across one option. The only option voted for BAU was '0%-10%' for electrification and there were no votes on BAU for repair. On the basis of the discussion, it was assumed that the BAU level of efficiency is between 0%-10% for electrification with no further accuracy available. No data could be obtained for the BAU level of repairs therefore, in the absence of better data, the current levels of efficiency of N/A have been used in place. A red evidence RAG rating has been selected since there was limited input and no consensus on the estimated levels of efficiency and no data identified in the literature to support this.

Overall, there was very limited evidence from either the literature review or the stakeholders to provide reliable figures for the efficiency levels for Measure 7, therefore the final figures should be treated with caution.

8.0 Measure 8 – Remanufacturing, reuse and reconditioning of vehicle parts

8.1 Vehicles resource efficiency measure

8.1.1 Description

Options for remanufacturing, reuse and reconditioning of vehicle parts.

Measure 8 explores the option for remanufacturing, reuse and reconditioning of vehicle parts. When a vehicle reaches EoL, traditionally a large share of the vehicle are recycled, shredded, sorted, incinerated, or landfilled. Most vehicles, however, contain many components that could be dismantled, potentially refurbished or remanufactured, and then reused in other vehicles.[156] The process of refurbishing, remanufacturing or reconditioning of vehicle components takes up a fraction of the resources compared to using new components while delivering similar performance. Dismantling and reusing ELV components can increase the ELV remanufacturing, reuse and reconditioning rates, though components cannot be indefinitely reused and will eventually end up in the recycling stream.[157]

Novel production processes such as additive manufacturing - which uses computer-aided design (CAD) and 3D-printers to create a variety of objects - offer the ability to produce specialist or discontinued parts allowing for improved refurbishment and remanufacturing of components that would otherwise be uneconomical to implement.

8.1.2 Measure indicator

The selected indicator for Remanufacturing, reuse and reconditioning of parts (Measure 8) is the '**% vehicle weight reused, remanufactured or reconditioned**'. The selected indicator was chosen for its ability to assess the resource efficiency benefits of remanufacturing, reuse and reconditioning of parts due to the availability of data regarding the weight of components, and the ability to then quantify this as a percentage of the vehicle weight. It was agreed upon by the project team, given feedback from stakeholders. Stakeholders suggested that the indicator could be amended to separate the efficiency level of "reuse" from "reconditioned/ remanufactured". However, it was agreed by the project team that these should be combined as a single indicator due to the complexity in gathering data for these sub-indicators.

The following other indicators were considered but excluded due to limitations in data availability, and their comprehensive coverage of the measure.

- Number of vehicles that include remanufactured parts
- % of materials or components re-used or recycled
- Weight of parts remanufactured and/or reconditioned

[156] Mélanie Despeissea, Yusuke Kishitab, Masaru Nakanoc, Michael Barwood (2015) Towards a circular economy for end-of-life vehicles: A comparative study UK – Japan link
[157] Mélanie Despeissea, Yusuke Kishitab, Masaru Nakanoc, Michael Barwood (2015) Towards a circular economy for end-of-life vehicles: A comparative study UK – Japan link

- Number of warranties issued for reused parts
- % of spare parts that are remanufactured
- Number of reused parts in vehicles that are now under warranties
- Number of tyres reused/repaired
- Number of tyres designed for repair/reuse
- % of ELV recovered for closed loop and/or open loop recycling
- % reduction in alloying elements needed in furnaces to recycle alloys and metals
- % of vehicles using a remanufactured diesel engine

The reasons for dismissing these indicators are as follows:

- The first indicator was discounted because it was deemed to not accurately measure resource efficiency, as it does not consider reused or reconditioned parts; the second indicator was discounted as it did not consider reconditioned parts, and the ninth indicator was discounted because it was deemed too narrow, as it did not include re-use.
- The third indicator was discounted as an absolute value is biased towards heavier vehicles and would thus not accurately reflect resource efficiency between lighter and heavier vehicles.
- The fourth, fifth and sixth indicators were discounted as being potential enablers for this measure rather than indicators of resource efficiency.
- The seventh and eighth indicators were discounted as only focused on one part of vehicles rather than the whole vehicle.
- The tenth and eleventh indicators were discounted because they only reflect a niche within this measure rather than being an appropriate indicator for the whole measure.

8.1.3 Examples in practice

The main parts that can be remanufactured include, gearboxes, engines, turbos and injectors. Remanufacturing ELV components can be cost-efficient, despite the labour-intensive processes that require skills and costly equipment. However, remanufactured components require rigorous testing to ensure that performance and reliability is equivalent to factory products which could be considered a deterrent for actors in the automotive industry.[158]

Re-use of components can, for example, include simple recovery of headlight units, seats and upholstery, mirrors and windscreen wipers. Reconditioning meanwhile can involve components associated with the drivetrain and exhaust systems.

[158] Mélanie Despeissea, Yusuke Kishitab, Masaru Nakanoc, Michael Barwood (2015) Towards a circular economy for end-of-life vehicles: A comparative study UK – Japan link

8.2 Available sources

8.2.1 Literature review

This measure was recognised in a variety of reports identified in the literature review. Some of the most notable sources were the 'Circular Economy framework for automobiles: Closing energy and material loops',[159] 'Europe's first circular economy factory for vehicles: Renault' [160] and 'A systematic review on drivers, barriers, and practices towards circular economy: a supply chain perspective'.[161] The literature was primarily focused on the potential for future resource efficiency rather than providing evidence of existing resource efficiency practices.

Thirteen sources discussed this resource efficiency measure, these comprised:

- Eight academic papers/reports;[162, 163, 164, 165, 166, 167, 168, 169]
- one website article[170], and
- one policy document[171]

Most of these sources were of high quality (IAS scores of 4-5). Four of the sources covered global measures; while not all were specific to the UK market, many were applicable to the UK manufacturing sector as they were based on similar markets (e.g., EU and US).

Much of the literature focused on the resource efficiency benefits during the manufacturing stage. For example one paper pointed out that the process of refurbishing, remanufacturing or reconditioning of vehicle components takes up a fraction of the resources compared to new components while delivering similar performance.[172] However, the same source acknowledges that these processes tend to be labour-intensive and require rigorous testing to ensure their performance and reliability, potentially reducing their attractiveness. Another source found that

159 Laura C. Aguilar Esteva, Akshat Kasliwal, Michael S. Kinzler, Hyung Chul Kim, Gregory A. Keoleian (2020) Circular Economy framework for automobiles: Closing energy and material loops link
160 Ellen Macarthur Foundation (n.d.) Europe's first circular economy factory for vehicles: Renault link
161 Govindan, K., Hasanagic, M. (2018) A systematic review on drivers, barriers, and practices towards circular economy: a supply chain perspective link
162 Laura C. Aguilar Esteva, Akshat Kasliwal, Michael S. Kinzler, Hyung Chul Kim, Gregory A. Keoleian (2020) Circular Economy framework for automobiles: Closing energy and material loops link
163 Paul Wolfram, Qingshi Tu, Niko Heeren, Stefan Pauliuk, Edgar G. Hertwich (2020) Material efficiency and climate change mitigation of passenger vehicles link
164 Mélanie Despeissea, Yusuke Kishitab, Masaru Nakanoc, Michael Barwood (2015) Towards a circular economy for end-of-life vehicles: A comparative study UK – Japan link
165 Gigli, S., Landi, D. & Germani, M. (2019) Cost-benefit analysis of a circular economy project: a study on a recycling system for end-of-life tyres link
166 Jansson, K. (2016) Circular Economy in Shipbuilding and Marine Networks – A Focus on Remanufacturing in Ship Repair link
167 Circle Economy & Deloitte (2023) The Circularity Gap Report 2023 link
168 Govindan, K., Hasanagic, M. (2018) A systematic review on drivers, barriers, and practices towards circular economy: a supply chain perspective link
169 Edgar G Hertwich, Saleem Ali, Luca Ciacci, Tomer Fishman, Niko Heeren, Eric Masanet, Farnaz Najvan Asghari, Elsa Olivetti, Stefan Pauliuk, Qingshi Tu, Paul Wolfram (2019) Material efficiency strategies to reducing greenhouse gas emissions associated with buildings, vehicles, and electronics—a review link
170 Ellen Macarthur Foundation (n.d.) Europe's first circular economy factory for vehicles: Renault link
171 Zero Waste Scotland (2020) Vehicle Tyres: Policy Options for a Circular Economy link
172 Mélanie Despeissea, Yusuke Kishitab, Masaru Nakanoc, Michael Barwood (2015) Towards a circular economy for end-of-life vehicles: A comparative study UK – Japan link

a remanufactured diesel engine can save 69% of embodied GHG emissions and result in a 90% energy use reduction compared to a new one.[173]

Across the literature, some quantitative data relating to levels of efficiency and methods to improve resource efficiency were identified. Esteva et al (2020) (with an IAS of 4) reported that almost 80% of vehicle components can be remanufactured.[174] However, most data sources provided qualitative information on measures and potential indicators. As such, the workshop was used to gather consensus on levels of efficiency estimates.

8.2.2 Workshops

In the workshops much of the discussion around this measure was centred around its feasibility. Specifically, it was mentioned how insurance companies influence which parts can or cannot be used for repairs of a vehicle. This is particularly true where components could be seen to influence safety or performance (e.g. re-use of passenger air bags, reconditioned brake shoes etc.). Similarly, the stakeholders mentioned there could be concerns from insurance companies as well as consumers about the quality and safety of remanufactured, reused or reconditioned parts, when compared to new parts.

Stakeholders also emphasised that this measure is more applicable to certain vehicle components than others, for example bodywork is more likely to be reused than a suspension is.

This measure received a high level of engagement in both workshops. The level of engagement in both workshops was as follows:

- **Workshop 1** – Nine stakeholders across industry and academia were active on the mural board and four stakeholders actively contributed to verbal discussion.
- **Workshop 2** - Five stakeholders from industry were active on the mural board and three stakeholders actively contributed to verbal discussion.

8.3 Drivers & Barriers

A wide range of drivers and barriers influence the appetite, uptake and outcomes of each measure. The most notable drivers and barriers, including their PESTLE and COM-B categorisation, are described in the following sub-sections.

8.3.1 Drivers

Below are the drivers that have been identified for Measure 8, including their PESTLE and COM-B categorisation. Drivers in bold represent the most important drivers indicated by stakeholders during voting and in discussion.

[173] Hertwich et al. (2019) Material efficiency strategies to reducing greenhouse gas emissions associated with buildings, vehicles, and electronics—a review link
[174] Laura C. Aguilar Esteva, Akshat Kasliwal, Michael S. Kinzler, Hyung Chul Kim, Gregory A. Keoleian (2020) Circular Economy framework for automobiles: Closing energy and material loops link

Table 24: Drivers for vehicles Measure 8

Driver	PESTLE	COM-B
Supply chain benefits.	**Economic**	**Opportunity – Physical**
Interest from insurers to use remanufactured, refurbished and reused parts.	**Economic**	**Opportunity – Social**
OEM (or government enhanced) reuse / recycled content targets.	Political	Opportunity – Social
Standards for the use of remanufactured, reused or reconditioned parts.	Technological	Capability – Physical
Environmental benefits from reduced extraction and processing.	Environmental	Opportunity – Social
Cost benefits of remanufactured, reused and reconditioned parts.	Economic	Opportunity – Social
E-commerce could drive uptake of this measure by improving parts distribution.	Technological	Capability – Physical

The literature review found that there are environmental benefits for this measure in the form of reduced extraction of virgin material and landfill diversion, energy and water use, which lead to overall carbon savings,[175] and economic benefits due to the potentially lower cost of remanufactured, reused and reconditioned parts[176]. However, these were not considered to be key drivers by stakeholders. In fact, one stakeholder queried the lower cost of secondary parts given the difficulty in extracting them from vehicles and ensuring supply.

Supply chain benefits; Interest from insurers to use remanufactured, refurbished and reused parts.

Instead, they suggested that the use of reused parts is highly influenced by the insurance industry. Therefore, encouragement and interest from insurers to use remanufactured, refurbished and reused parts acts as a driver for the uptake of this measure. Standards for the use of remanufactured, reused or reconditioned parts are being developed with the insurance industry.

Stakeholders noted that there are supply chain benefits in reducing existing competition (to an extent) for virgin materials by using reused parts. Workshop stakeholders discussed the uncertainty in ensuring the quality of such products – and supplies of materials – which could limit consumer appetite for this option. Reuse targets were also considered to be a key driver towards the uptake of this measure.

When voting on the key drivers, the most-voted option for drivers was 'Supply chain benefits in reducing competition for virgin materials'. Uptake of this measure could be further enhanced if

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[175] Edgar G Hertwich, Saleem Ali, Luca Ciacci, Tomer Fishman, Niko Heeren, Eric Masanet, Farnaz Nojavan Asghari, Elsa Olivetti, Stefan Pauliuk, Qingshi Tu, Paul Wolfram (2022) Material efficiency strategies to reducing greenhouse gas emissions associated with buildings, vehicles, and electronics—a review link
[176] Watts, Ghosh and Hinshelwood, University of Exeter (2021) Exploring the Potential for Electric Retrofit Regulations and an Accreditation Scheme for the UK link

manufacturers were incentivised to repair and sell refurbished parts before new parts, without this invalidating consumer warranties, or if consumers themselves could be incentivised to procure refurbished parts over new parts.

8.3.2 Barriers

Below are the barriers that have been identified for Measure 8, including their PESTLE and COM-B categorisation. Barriers in bold represent the most important barriers indicated by stakeholders during voting and in discussion.

Table 25: Barriers for vehicles Measure 8

Barrier	PESTLE	COM-B
Lack of economic incentives discourages disassembling and recovering parts.	Economic	Motivation – Reflective
Insurance requirements prevent reuse of parts.	Legal	Capability - Physical
Lack of clear guidance and standards to ensure safety.	Legal	Capability – Physical
Technical limitations in disassembly for reuse.	Technological	Capability – Physical
Compatibility with insurance / warranty.	Legal	Opportunity - Physical
Consumer and manufacturer perceived quality / reliability of reused, refurbished goods.	Social	Motivation – Reflective
Perceived and actual availability of correctly specified components.	Technological	Capability – Physical
Perceived and actual costs.	Social	Capability – Psychological
Different quality/performance requirements for vehicle components.	Technological	Capability – Physical
Improved training and data management.	Technological	Capability – Psychological
Complex distribution of parts reduces availability.	Technological	Capability – Physical

Numerous barriers were identified for this measure. The literature review identified the following three key barriers:

- Perceived and actual availability of correctly specified components to be reused (issues associated with quality assurance and risk etc.)[177],
- The consumer and manufacturer perceived quality of reused, refurbished goods[178]

[177] Edgar G Hertwich, Saleem Ali, Luca Ciacci, Tomer Fishman, Niko Heeren, Eric Masanet, Farnaz Nojavan Asghari, Elsa Olivetti, Stefan Pauliuk, Qingshi Tu, Paul Wolfram (2022) Material efficiency strategies to reducing greenhouse gas emissions associated with buildings, vehicles, and electronics—a review link
[178] OECD, 2021 Labelling and Information Schemes for the Circular Economy link

- The perceived and actual costs, because of technology obsolescence, lack of reverse supply chain infrastructure and data quality, privacy and security[179].

Workshop stakeholders supported these findings by highlighting that the challenges facing component reuse and recycling are numerous (as indicated in Measure 3). The key barriers of concern that were discussed in the workshops included: The perceived safety of remanufactured vehicles, unscrupulous repairers posing a risk to the system, limited access to specific materials and components, complexities arising from time-consuming component removal and the presence of multiple materials within a single component. They also highlighted challenges related to component provenance that arise when vehicles change hands (e.g., mileage associated with component, source of component via insurance claim market or elsewhere).

When voting on the key barriers, six votes were evenly distributed across six options (one vote each) so no "most significant" barriers were identified. The barriers highlighted by stakeholders included:

- Emphasis that insurance companies influence the options for reuse and recycling by dictating permissible components for damaged vehicles. Compatibility with insurance / warranty if incorrectly specified components are used for repairs.
- Lack of clear guidance and standards to ensure safety. There is currently inconsistency in the quality of supply of reconditioned parts. According to one stakeholder, standards have been developed recently (August 2020) for the insurance industry and these have to be better understood and promoted by consumers and repairers. Stakeholders highlighted that a lack of such guidance could allow for abuse by unscrupulous repairers.
- Current economic incentives favour shredding and export as waste. This is a major barrier for businesses, who do not see the value in disassembly and recovery of parts for sale.
- Technical limitations continue to reduce the uptake of reused, reconditioned or remanufactured parts because it can be time consuming, complex and sometimes infeasible to remove components and to remanufacture or reuse such components given the wear and tear of multi-material products.
- Limited technical capabilities of additive manufacturing which may continue to be unsuitable for mass production. Furthermore, additive manufacturing turnaround times could continue to be uncompetitive and unsuitable for OEMs.
- Limited understanding of environmental benefits (or otherwise) of additive manufacturing, including material demand, carbon impacts and recyclability of additive manufacturing products.
- Different quality/performance requirements for vehicle components (and level of quality assurance) can complicate component availability.

The range of components in a vehicle are broadly similar across manufacturers, however the design and material selection can vary; this leads to some uncertainty regarding the

[179] Edgar G Hertwich, Saleem Ali, Luca Ciacci, Tomer Fishman, Niko Heeren, Eric Masanet, Farnaz Nojavan Asghari, Elsa Olivetti, Stefan Pauliuk, Qingshi Tu, Paul Wolfram (2022) Material efficiency strategies to reducing greenhouse gas emissions associated with buildings, vehicles, and electronics—a review link

environmental impacts of material substitution unless considered against a like-for-like component within the same manufacturer.

Mitigations

The following potential actions were suggested by stakeholders. These are not currently in place but could help mitigate some barriers and influence uptake of this measure were they to be introduced:

- Stakeholders suggested that OEM (or government enhanced) reused (and recycled) content targets may create clear market demand for the recovered parts. Implementing Material Passports would also support the sharing of information in the vehicle manufacturing industry, aiding reprocessors in recovering, repairing, or recycling components.
- Adopting more modular design and design for disassembly could enhance material efficiency and consumer access to a wider range of repair components by allowing part of the vehicle to be replaced or upgraded. This would allow the vehicle to be updated with new technology without the need to replace the entire vehicle.
- Trading standards enforcing design and quality standards for repaired components would instil consumer confidence. Remanufactured parts are attractive due to their lower cost, making them appealing to consumers and businesses.
- Stakeholders highlighted that promoting the use of remanufactured and reusable components through public awareness campaigns could facilitate this measure.
- E-commerce could play a significant role in the distribution of remanufactured, reused or reconditioned parts as this means that secondary components can be directly delivered to where it is needed. IT systems to identify stocks of secondary components are likely to be necessary for implementation of this measure.
- Cost reductions for consumer and insurers. Incentives for consumers (e.g., lower insurance premiums for second hand parts etc.) could increase uptake of the measure.

8.4 Levels of efficiency

Table 26: Levels of efficiency for vehicles Measure 8

Indicator: % vehicle weight reused, remanufactured or reconditioned			
Level of efficiency	Current	Maximum in 2035	Business-as-usual in 2035
Value	0 – 10%	40%	8 – 10%
Evidence RAG	Red	Amber-Green	Red

8.4.1 Current level of efficiency

Literature on the current level of efficiency was limited. One source provided a value of 20%-30% of weight of each scrapped vehicle being reused in the Japanese market,[180] however this was deemed unlikely to be a representative figure for the UK market. Therefore, the workshops were used to gather evidence on current levels of efficiency.

A range of values were provided by stakeholders in the discussion; one stakeholder indicated (anecdotally) that is could be as high as 25%, while another estimated <5%. One stakeholder estimated around 3-10% market penetration for remanufacturing lines can be typical in the aftermarket. Others indicated it would likely be less than 5%. Multiple stakeholders mentioned that insurance companies play an important role in the development of this measure as they offer reused, remanufactured, or reconditioned parts as a way of lowering repair costs. Additionally, stakeholders mentioned that supply chain constraints because of the Covid-19 pandemic have boosted remanufacturing.

When voting on the current level of efficiency, 9 votes were collected across four options. The most-voted option for current level of efficiency was 'don't know' with the rest of the votes split across a wide range of options between 0% and >40% – there was no consensus on the current levels of efficiency which was also reflected during the discussion. It is important to note that the stakeholders who voted >40% included 'recycling', which has since been removed from this measure. Therefore, the real value is likely to be lower.

While several stakeholders mentioned that they believe the current level of efficiency to be low, there was a lack of consensus on an exact value. Therefore, a current level of efficiency range of between 0-10% is taken forward based on the most-likely estimates provided by stakeholders at the workshops. A red evidence RAG rating has been selected because there was no consensus on the estimated levels of efficiency and no data was found in the literature to support this.

8.4.2 Maximum level of efficiency in 2035

According to one source identified in the literature review, up to 40% of the ELV weight (80% of vehicle components) can be recovered through dismantling and can be reused as spare parts (or, alternatively, recycled).[181] When compared with manufacture of new parts, remanufacturing can yield savings of 80-90% less energy and 69% fewer embodied emissions.[182]

In the pre-workshop survey, one stakeholder broadly agreed with the value of 40% while another indicated they believe it to be closer to 20%. During the discussion in the workshop, several stakeholders argued the maximum value could be higher than 40%, depending on business models and design philosophies changing to ones that support repair, remanufacturing and reuse. Achieving maximum efficiency levels relied on further acceptance within the insurance sector regarding re-use/reconditioning of parts, and continued consumer pressure regarding the overall environmental impact of vehicles.

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[180] Fernando Enzo Kenta Sato, Takaaki Furubayashi, Toshihiko Nakata (2019) Application of energy and CO_2 reduction assessments for end-of-life vehicles recycling in Japan link

[181] Laura C. Aguilar Esteva, Akshat Kasliwal, Michael S. Kinzler, Hyung Chul Kim, Gregory A. Keoleian (2020) Circular Economy framework for automobiles: Closing energy and material loops link

[182] Edgar G Hertwich, Saleem Ali, Luca Ciacci, Tomer Fishman, Niko Heeren, Eric Masanet, Farnaz Nojavan Asghari, Elsa Olivetti, Stefan Pauliuk, Qingshi Tu, Paul Wolfram (2022) Material efficiency strategies to reducing greenhouse gas emissions associated with buildings, vehicles, and electronics—a review link

When voting on the maximum levels of efficiency, 9 votes were collected across two options. The majority of the votes for maximum levels of efficiency were for '>40%'; however, 'don't know' received a significant share of the results as well. While there were no votes for values lower than 40%, two of the stakeholders who voted '>40%' explicitly included recycling, which is not included in the final indicator. Taking this into account as well as the significant number of 'don't know' votes, a value of 40% by weight was taken forward as the maximum level of efficiency likely to be achievable. An amber-green evidence RAG rating has been selected since there was consensus on the estimated levels of efficiency which supported those found in literature.

8.4.3 Business-as-usual in 2035

One stakeholder provided a value of 8-10% for this measure in a business-as-usual scenario in the pre-workshop survey, however no further justification was given for this value. During the workshop, no further comments or estimates were provided by stakeholders, reflecting the uncertainty around this measure. However, one stakeholder suggested that there was growing interest from insurance companies which could drive a higher BAU efficiency level.

When voting, five votes were collected for 'don't know', therefore none of the stakeholders were able to provide an estimate for the business-as-usual levels of efficiency. However, stakeholders did indicate that there is likely to be an increase in reused, remanufactured or reconditioned parts on the market as there has been increased interest within the insurance industry in recent years which may see more widespread uptake.

Given the absence of alternative values, the value of 8-10% provided by one stakeholder was taken forward. However, a red evidence RAG rating has been selected because there was no consensus on the estimated level of efficiency and no data in literature to support this.

9.0 Measure 9 – Reducing waste in manufacturing processes

9.1 Vehicles resource efficiency measure

9.1.1 Description

Reduction in waste generation within manufacturing processes.

Measure 9 explores opportunities to reduce waste in the manufacturing processes of vehicles. Waste in manufacturing currently refers to material that is not recycled (both open-loop and closed loop). However, this is discussed further throughout this section. The two main categories of waste generated through the manufacture of vehicles are general waste, such as packaging and office waste, and production waste (primarily metals from stamping and machining processes).[183]

Commitments and actions to reduce manufacturing waste are an established practice with many car manufacturers already proactively seeking to reduce the quantity of waste generated in the manufacturing process. As a result, there has been an industry wide reduction in the total amount of waste generated during car production in the past few decades.[184]

Producing components to 'near net-shape'[185] can significantly reduce the waste generated during manufacturing therefore this measure also includes the use of additive manufacturing. Additive manufacturing is a process that uses computer-aided design (CAD) and 3D-printers to create a variety of objects. This approach can be used to develop a wide range of vehicle components and due to its layer-by-layer approach, results in significantly less material wasted compared to subtractive machining used in more traditional manufacturing processes, which is a process in which a material is cut down to a desired final shape and size.[186]

9.1.2 Measure indicator

The selected indicator for Reducing waste in manufacturing (Measure 9) is the '**production waste avoided as a % of vehicle weight**'. The selected indicator was chosen for its ability to assess the resource efficiency benefits of improvements in the manufacturing process against the weight of the finished product. It was agreed upon by the project team, considering the available production waste data from the literature review and feedback from stakeholders. It was noted by one stakeholder that OEM performance of this indicator is collected for the EU27 by the European Automobile Manufacturers Association (ACEA). The following other indicators were considered but excluded due to limitations in data availability, and their comprehensive coverage of the measure.

- Reduction in materials used in vehicles and/or reduction in waste

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[183] Automotive Manufacturing Solutions (AMS). (2008). Wasting away link
[184] European Automobile Manufacturer's Association (ACEA). (2022). Waste from car production in the EU link
[185] Near net shape manufacturing aims to produce finished or near-finished products with minimal material waste and post-processing, utilising techniques like casting, forging, and additive manufacturing.
[186] Schuhmann, Dirk; Pinto, Grithen; Merkel, Markus; Harrison, David K. (2022). A Study on Additive Manufacturing of Metal Components for Mobility in the Area of After-Sales with Spare and Performance Parts link

- Year on year increase in the number of components that are designed to be modular
- Number of vehicle components that are standardised
- Quantity of components produced using 3D printing (tonnage may be unsuitable due to lighter materials however could be used on a year-on-year basis)
- % of cars containing components using 3D printing
- % of polymeric parts in cars that are 3D printed

The reasons for dismissing these indicators are as follows:

- The first indicator was discounted because an absolute value is biased towards heavier vehicles and thus does not accurately reflect resource efficiency comparisons between lighter and heavier vehicles.
- The second, third, fourth, fifth and final indicator were discounted because they were deemed to be a potential enabler for reducing waste, rather than an indicator for measuring resource efficiency.

9.1.3 Examples in practice

A common approach by carmakers to reduce packaging waste is to opt for the use of reusable containers for component supply. Volkswagen - in addition to routinely recovering, reusing or recycling packaging - classifies and sorts plastic packaging and protective peels for later resale to internal and external suppliers. The Volkswagen plant in Braunschweig does not use disposable packaging, instead it uses standardised pallets and containers that can be returned to suppliers. The reuse of pallets is also practised in the Subaru factory in the US.[187]

Volkswagen also minimises metal waste through an optimisation programme which establishes the minimum required surface area before stamping panels, thus reducing wastage. Optimised tooling has been introduced at the commercial vehicles plant, based in Hannover, resulting in the saving of 840 tonnes of steel per annum.[188] BMW uses a similar system – minimising total waste arising and then ensuring that all waste material from the stamping shop is collected and returned to the steel or aluminium supplier's production cycle.[189]

9.2 Available sources

9.2.1 Literature review

The literature that discussed this measure was limited, comprising:

- Three academic papers[190, 191, 192]

[187] Automotive Manufacturing Solutions (AMS). (2008). Wasting away link
[188] Automotive Manufacturing Solutions (AMS). (2008). Wasting away link
[189] Automotive Manufacturing Solutions (AMS). (2008). Wasting away link
[190] Omar Jumaah. (2018). A Study on 3D Printing and its Effects on the Future of Transportation link
[191] Schuhmann, Dirk; Pinto, Grithen; Merkel, Markus; Harrison, David K. (2022). A Study on Additive Manufacturing of Metal Components for Mobility in the Area of After-Sales with Spare and Performance Parts link
[192] Paul Wolfram, Qingshi Tu, Niko Heeren, Stefan Pauliuk, Edgar G. Hertwich (2020) Material efficiency and climate change mitigation of passenger vehicles. Available at: link

Two of the sources were of high quality (IAS of 4 and 5), while one source was considered lower quality (IAS of 2). None of the identified sources were specific to the UK market, though they were based on similar markets to the UK (e.g., Germany and US).

Most of the literature focused on enablers of reducing process waste through technological developments, particularly around additive manufacturing. The most notable sources were *A Study on Additive Manufacturing of Metal Components for Mobility in the Area of After-Sales with Spare and Performance Parts*[193] and *A Study on 3D Printing and its Effects on the Future of Transportation*.[194]

Across the literature, none of the sources provided quantitative data relating to levels of efficiency. As such, the workshop was used to gather estimates for levels of efficiency estimates.

9.2.2 Workshops

This measure received a reasonable level of engagement in the first workshop and a low level of engagement in the second workshop. Input on this measure came mainly from manufacturers who noted that the measure is in line with other business objectives such as cost reduction, and as a result, OEM factories are already reducing wastes to a high standard. However, stakeholders acknowledged that there is still room for improvement, particularly in the supply chain where there is less insight and scrutiny on the amount of manufacturing waste generated. The level of engagement in both workshops was as follows:

- **Workshop 1** – Seven stakeholders across industry and academia were active on the mural board and three stakeholders actively contributed to verbal discussion.
- **Workshop 2** - Two stakeholders from industry were active on the mural board and only one stakeholder actively contributed to verbal discussion.

9.3 Drivers & Barriers

A wide range of drivers and barriers influence the appetite, uptake and outcomes of each measure. The most notable drivers and barriers, including their PESTLE and COM-B categorisation, are described in the following sub-sections.

9.3.1 Drivers

Below are the drivers that have been identified for Measure 9, including their PESTLE and COM-B categorisation. Drivers in bold represent the most important drivers indicated by stakeholders during voting and in discussion.

[193] Schuhmann, Dirk; Pinto, Grithen; Merkel, Markus; Harrison, David K. (2022). A Study on Additive Manufacturing of Metal Components for Mobility in the Area of After-Sales with Spare and Performance Parts link
[194] Omar Jumaah. (2018). A Study on 3D Printing and its Effects on the Future of Transportation link

Table 27: Drivers for vehicles Measure 9

Driver	PESTLE	COM-B
Reduced supply costs and reduced waste management costs.	**Economic**	**Opportunity – Social**
OEM sustainability commitments facilitate waste reductions.	**Environmental**	**Motivation - Reflective**
Innovative production processes facilitate waste reductions.	Technological	Capability - Physical
Reduced material wastage associated with traditional manufacturing processes.	Economic / Environmental	Opportunity - Psychological
Increased material efficiency in production processes and less wastage.	Economic	Opportunity – Social
Embodied carbon savings directly related to the material and energy savings.	Environmental	Opportunity – Social
Reduced reliance on virgin materials and associated supply chain pressures.	Social	Opportunity – Social

The literature review revealed that key drivers for this measure were maximising the value of materials and reducing supply chain pressures through improving resource efficiency. [195, 196, 197]

When voting on the key drivers in the workshops, five votes were collected across three options. The most-voted options for drivers were 'OEMs continue to recognise the economic benefits regarding supplies and waste management costs' and 'sustainability commitments in OEMs continue to facilitate waste reductions' suggesting that cost incentives and consumer demand are key drivers.

Reduced supply costs and reduced waste management costs

This was supported by stakeholders who noted that OEMs are keen to maximise material efficiency to avoid wastage of materials that have already been paid for. OEMs recognise the economic benefits regarding reduced supply costs and reduced waste management costs and therefore this measure is widely implemented.

OEM sustainability commitments facilitate waste reductions

Stakeholders reported that OEMs are investigating material wastage and many have set recycling commitments, such as "Zero waste to landfill", "Zero waste to incineration without energy recovery", and "100% closed-loop recycling" by 2050. This is ultimately influenced by consumer demand for sustainability and is considered a key driver by stakeholders. Whilst OEM scope 1 material wastage may be low, stakeholders reported that performance may be

[195] Omar Jumaah. (2018). A Study on 3D Printing and its Effects on the Future of Transportation link
[196] Volvo (2022) Sustainability. Available at: link
[197] Paul Wolfram, Qingshi Tu, Niko Heeren, Stefan Pauliuk, Edgar G. Hertwich (2020) Material efficiency and climate change mitigation of passenger vehicles. Available at: link

poorer across the supply chain. However, stakeholders noted that OEMs have influence in improving supplier recovery rates.

Innovative production processes facilitate waste reductions; Reduced material wastage associated with traditional manufacturing processes; Increased material efficiency in production processes and less wastage

According to one stakeholder, to optimise the recovery of steel from the stamping process, it is often most efficient to return it to the supplier. Whilst there are some process losses (particularly steel from press offcuts), some of the value of this material can be recovered through recycling. 'Internal' scrap is of greater value to recyclers, as it is cleaner, and the provenance is known. One stakeholder noted that whilst recycling rates are high (see Measure 5), there are cumulative losses (in material and energy) during each recycle loop (even when closed loop recycling takes place) and so this initial wastage should be reduced in the first place. A stakeholder suggested that the industry is transitioning to 'near net-shape' components and on process recycling to reduce this waste.

Stakeholders noted that evolving production processes continue to facilitate waste reductions. For example, near net-shape components, additive manufacturing and smart stamping processes reduce the material required in the first place and avoid wasted material from traditional subtractive machining processes. Stakeholders reported that single-use packaging waste for is no longer widely used by industry except for some prototype components.

9.3.2 Barriers

Below are the barriers that have been identified for Measure 9, including their PESTLE and COM-B categorisation. Barriers in bold represent the most important barriers indicated by stakeholders during voting and in discussion.

Table 28: Barriers for vehicles Measure 9

Barrier	PESTLE	COM-B
Limitations in consumer and purchaser appetite for open loop recycling	**Social**	**Motivation – Reflective**
Lack of knowledge and human resources in the supply chain around closed loop recycling.	**Social**	**Capability –Psychological**
Limited capacity to treat materials at third party sites.	Technological	Capability – Physical
Waste performance is published voluntarily.	Social	Motivation – Reflective
Currently limited technical capabilities of additive manufacturing for mass production.	Technological	Capability – Physical
Limited understanding of environmental benefits of additive manufacturing.	Environmental/ Social	Capability – Psychological

Barriers

Stakeholders discussed similar barriers to those identified for Measure 5. They stated that OEM factories are implementing actions that seek to reduce manufacturing wastes; however, they also noted that supply chains are not performing to the same level. It should be noted however, that no elaboration was provided on whether this also applied to manufacturers of particular components or materials. OEMs have a strong oversight of the efforts in place to reduce manufacturing wastes in their organisations but have a limited visibility on the actions – and results of actions – implemented by suppliers. The insight from stakeholders does, however, suggest that the supply chain may be importing more wastes than necessary into the OEM plants through, for example, surplus levels of packaging wastes which could be avoided. This presents an opportunity for OEMs in the industry to support suppliers, to encourage takeback of surplus materials or wastes that originate across the supply chain. For example, packaging and steel (from stamping processes) could be recovered most efficiently by returning this to supplier of sheet aluminium.

Limitations in consumer and purchaser appetite for open loop recycling

Consumers are familiar with open loop recycling routes via local municipal authority recycling schemes. However, in the context of vehicles there is a familiarity with use of components and parts (often assumed) sourced from virgin materials and therefore a caution around open loop recycling from a perceived safety risk. From a purchaser perspective, there is a focus on confidence in component performance. This means retaining existing supply chains where working relationship is well characterised, rather than readily switching to suppliers offering wider uptake of open loop sourced components/parts.

Lack of knowledge and human resources in the supply chain around closed loop recycling

Stakeholders highlighted a lack of knowledge and human resources in the supply chain with regards to improving closed loop recycling which prevents the most appropriate treatment of material. Furthermore, limited capacity to treat materials at third party sites hinders opportunities for further uptake of the measure.

Waste performance is published voluntarily

Stakeholders noted that whilst indicators for this measure are recorded, waste performance is published voluntarily by OEMs, therefore there is lack of uniformity in reporting (and transparency) across the sector. Furthermore, this data often does not include supply chain performance.

Potential barriers

As discussed previously, 'internal' scrap is of greater value to recyclers. Removal of this material stream may threaten further uptake of other measures by reducing opportunities to secure consistent supplies of recycled material at known quality, volume and cost.

9.4 Levels of efficiency

Table 29: Levels of efficiency for vehicles Measure 9

Indicator: Production waste avoided as a % of vehicle weight			
Level of efficiency	Current	Maximum in 2035	Business-as-usual in 2035
Value	60-80%	80-100%	80%
Evidence RAG	Red	Red-Amber	Red

9.4.1 Current level of efficiency

Limited information on the current level of efficiency was found in literature though it is generally agreed that there has been an industry wide reduction in the total amount of waste generated during car production in the past few decades.

In the EU, waste has reduced by 31.3% since 2006 with the waste generated per unit produced by the manufacturing of passenger cars dropping by 5.3% over 15 years.[198] These figures demonstrate an overall sector shift in reducing the volume of waste being landfilled (via a combination of measures including open loop recycling and energy recovery from waste). The lower percentage figure for waste generated per unit reflects continued improvements in process efficiency, noting that fluctuations in the overall trend in the reporting period are linked to changing volumes of overall vehicle manufacture. This was supported by one stakeholder who provided data (from the Society of Motor Manufacturers and Traders) suggesting a 96.2% reduction in waste to landfill per vehicle produced since 1999. However, these are not appropriate data sources as they include open loop recycling and energy recovery from waste rather than process efficiency.

The workshops were used to identify estimates, although feedback varied considerably. One stakeholder estimated that the current level of efficiency is already quite high (between 70-80%) whereas others estimated this to be lower with one suggesting 50% and another as low as 5% (excluding scrap steel from press offcuts).

When voting on the current level of efficiency, 8 votes were collected across five different ranges. The most-voted option was ‘don’t know’ followed by ‘60-80%’, with the rest of the votes split across a wide range of values from ‘20-40%’ to ‘80-100%’ – showing that stakeholders were not able to agree on the current level of efficiency.

Although consensus could not be agreed at the workshops, a figure of 60-80% was taken forward as this range received the most votes, albeit by a very slim margin. The evidence RAG rating is red because there was no clear consensus in the workshop and no data in the literature was found to back up this value.

9.4.2 Maximum level of efficiency in 2035

A maximum level of efficiency was not identified in literature; therefore, the workshops were used to identify estimates. One stakeholder estimated that the maximum level of efficiency could be as high as 95% while another estimated this closer to 10%, however this latter value is excluding scrap steel from press offcuts.

When voting on the maximum level of efficiency, 9 votes were collected across three ranges. The most-voted option for maximum levels of efficiency was ‘80%-100%’ with a majority of the votes, however, ‘don’t know’ also received a significant share of the results. Given the provided estimates and the voting results, a range of 80%-100% was selected with a red-amber evidence RAG rating. The evidence level was selected because whilst there was general agreement in feedback from stakeholders, this was not supported in the literature and there was no clear consensus in workshop voting.

[198] European Automobile Manufacturer’s Association (ACEA). (2022). Waste from car production in the EU link

9.4.3 Business-as-usual in 2035

One stakeholder provided a value of 80%; however, no further justification was provided for this value and no additional comments or estimates were provided during the workshop. General discussions centred around continued end of life requirements placed on vehicle production in terms of levels of recycling and therefore associated focus from manufacturers in selection of materials and associated process efficiency in production. Cost of production remains an important metric for producers, particularly in switching to electric vehicles, so seeking further process efficiency by minimising waste production will remain a focus.

When voting on the BAU, two votes were collected for ‘don’t know’ with none of the stakeholders being able to provide an estimate for the BAU levels of efficiency. Therefore, the provided value of 80% is taken forward. The evidence RAG rating for this is red because there was little feedback from stakeholders in the workshops.

10.0 Interdependencies

This report has discussed each of the measures identified for the vehicles sector and presented estimates for the maximum and BAU level of efficiency they could achieve independently, that is, not considering any interdependencies or interactions between measures.

However, in practice these measures are likely to occur in tandem, and the levels of efficiency that are reached in each will depend on progress against other measures. The precise nature of these interdependencies should be considered when using any of the level of efficiency estimates from this report in further research or modelling exercises that attempt to produce an estimate of the cumulative impact of these measures over time.

A summary of the key interactions/interdependencies between the measures in this report with other measures in the sector, and with measures in other sectors is presented below. Note, as Phase 2 of this research project is still in the fieldwork stage, the dependencies with other sectors reflect dependencies with other Phase 1 sectors only. The Phase 2 reports will seek to capture any further interdependencies with Phase 2 sectors.

Note, the estimates for the current level of efficiency will by their nature reflect the interactions and interdependencies between measures as they currently occur.

10.1 Interdependencies within the sector

Measure 1 & 2

- Measure 1 – Light-weighting through material substitution
- Measure 2 – Light-weighting through reducing vehicle size

Both measures related to light-weighting and the indicators are very similar. Thus, any resource efficiency gain in either Measure 1 or 2 would affect the outcomes of the other measure. The ongoing shift to electric vehicle design requires consideration of a number of balancing factors in terms of size of battery, associated net weight of vehicles and consumer demands associated with charging frequency and range. Some OEMs have already considered removing smaller vehicles from production given challenging economics to accommodate a larger enough battery. If consumer preference for larger vehicles is sustained, then the focus of light-weighting efforts will be on material substitution; if there is equal or greater focus on smaller vehicles then this measure will become of greater significance.

Measure 1 & 3 & 5

- Measure 1 – Light-weighting through material substitution
- Measure 3 – Use of recycled content in vehicle products
- Measure 5 – Recycling of wastes generated in production processes

The selection of materials used in substitution impacts the capacity and capability of recycling at EoL. For example, carbon fibre materials are difficult to recycle due to the need to either heat or chemically treat the resin in order to release the fibres for re-use. Thermoplastics are also challenging given the difficulty in suitable heating regimes that can offer a high enough recovery rate to be cost-effective. This affects the materials available for closed-loop recycling therefore should be considered alongside each other.

Measure 1 & 4

- Measure 1 – Light-weighting through material substitution
- Measure 4 – Use of biobased materials in vehicle products

Biobased materials can be used as a lighter alternative to conventional materials such as metals and fossil-based plastics. This means that they can be used to achieve Measure 1.

Measure 1 & 9

- Measure 1 – Light-weighting through material substitution
- Measure 9 – Reducing waste in manufacturing processes

Selection of substituted materials should consider the production process. Use of technologies such as additive manufacturing can not only result in increased material efficiencies but can also reduce the material wasted during production.

Measure 2 & 6

- Measure 2 – Light-weighting through reducing vehicle size
- Measure 6 – Car-sharing and increased vehicle occupancy

Measure 6 includes provisions for car rental, which can contribute to the use of smaller vehicles over larger vehicles where suitable to the customer. By renting a vehicle, individuals have the flexibility to choose a vehicle that is appropriate for their specific travel needs, such as opting for a one-person vehicle if traveling alone. No literature, or contribution from any stakeholders, discussed this interdependency or proposed any quantifiable impacts, drivers or barriers for consideration. If, for example, car rental pricing included consideration of the number of occupants of a vehicle, or defaulted to smaller vehicles for single occupant hire, then this would support delivery of Measure 2.

Measure 3 & 4

- Measure 3 – Use of recycled content in vehicle products
- Measure 4 – Use of biobased materials in vehicle products

The use of biobased plastics could displace recycled material in vehicles, as it can be perceived as an alternative. There is an inherent link between the two, given the need to consider the capacity to recycle or re-use materials. The primary focus of biobased materials in terms of substitution will be the existing plastics components of vehicles. If there is a perceived benefit of biobased material substitution (from a whole life sustainability perspective) but a lack of capacity and/or difficulty in recycling, then the overall extent of recycled material used in vehicles could fall. Alternatively, if biobased materials are selected for use over harder to recycle materials such as carbon fibre composites or thermoplastics due, in part, to an enhanced capacity to recycle then this will benefit Measure 3. Material performance, and adherence to relevant standards (such as bumper characteristics for example), may limit the extent to which Measure 4 can be delivered, if there aren't feasible biobased alternatives.

Measure 3 & 5

- Measure 3 – Use of recycled content in vehicle products
- Measure 5 – Recycling of wastes generated in production processes

Both measures are related to recycling in vehicle manufacture, just at different stages of the manufacturing process. Given that the materials involved in these recycling processes are likely to be similar, it may be that recycled waste from production processes can be used, in place of virgin material, in production of other vehicles. Driving enhanced process efficiency through minimisation of landfilled waste streams will support higher efficiency in Measure 3.

Measure 3 & 9

- Measure 3 – Use of recycled content in vehicle products
- Measure 9 – Reducing waste in manufacturing processes

Measure 9 is also linked to Measure 3 as both measures are related to maximising material recovery, though this includes maximising material from other sectors' open loop. Given that the materials involved in these recycling processes are likely to be similar, it may be that recycled waste from production processes can be used in the place of virgin material, in production of other vehicles. This therefore enhances efficiency in Measure 3.

Measure 4 & 5

- Measure 4 – Use of biobased materials in vehicle products
- Measure 5 – Recycling of wastes generated in production processes

Revised processes involving use of alternative materials will alter what and how much of given materials arise in production waste (e.g., retained process versus 3D printing). Any selection of biobased materials will be based, in part, on the capacity to increase overall recycling (in contrast to harder to treat materials such as composites or thermoplastics). This would also be a benefit in enhancing the capacity to recycle wastes generated in production processes.

Measure 5 & 9

- Measure 5 – Recycling of wastes generated in production processes
- Measure 9 – Reducing waste in manufacturing processes.

Both measures focus on the manufacturing process and a reduction of either recycled waste or all waste (whether recycled or unrecycled). Reducing waste (Measure 9) would reduce the amount of waste available to recycle and thus reduce potential impact of Measure 5.

Measure 6 & 7

- Measure 6 – Car-sharing and increased vehicle occupancy
- Measure 7 – Life extension

Non-ownership models place the burden on businesses to take charge of the vehicle which may incentivise them to prolong their life and use more robust materials and use of repaired parts, etc. Fleet ownership and management encourages prolonged vehicle life, in contrast to individual ownership models that typically incentivise vehicle upgrade on the cycle of contract payment terms.

Measure 7 & 8

- Measure 7 – Life extension
- Measure 8 – Remanufacturing, reuse and reconditioning of vehicle parts

The lifetime of vehicles and their components are inherently increased through reuse, remanufacture or reconditioning.

Measure 7 & 9

- Measure 7 – Life extension
- Measure 9 – Reducing waste in manufacturing processes

The lifetime of vehicles and their components are inherently increased through reuse, remanufacture or reconditioning. Modular design further enables both measures by providing greater uniformity in the components used across the models developed by a manufacturer, or the components produced by the industry as a whole.

10.2 Interdependencies with other sectors

Measure 1

- Measure 1 – Light-weighting through material substitution

The measure has limited interdependencies with other sectors. However, increased use of light-weighting, through material substitution, could reduce demand from certain materials such as steel. Stakeholders noted that the UK vehicles sector is currently dependent on British steel, particularly where OEMs have made commitments to using recycled material. This reflects both supply chain consolidation encouraging local production, but the need for suitable collection and recycling facilities to enable effective light weighting. In the case where steel would be replaced by plastics, this would lead to increased demand in the plastics sector.

Measure 2

- Measure 2 – Light-weighting through reducing vehicle size

Due to the large amount of steel involved in the production of vehicles (currently around 50% of typical vehicle weight),[199] light-weighting through reducing vehicle size will have a significant impact on the outputs of the steel industry. Increased use of light-weighting, through reducing vehicle size, could reduce demand of certain materials such as steel. Stakeholders noted that

[199] Paul Wolfram, Qingshi Tu, Niko Heeren, Stefan Pauliuk, Edgar G. Hertwich (2020) Material efficiency and climate change mitigation of passenger vehicles

the UK vehicle manufacturing is dependent on steel, particularly where OEMs have made commitments to using recycled material.

Measure 3

- Measure 3 – Use of recycled content in vehicle products

This measure is interdependent on the steel sector. If electric arc furnaces (EAF) are not adopted by the steel sector, then the use of secondary scrap steel in high-value applications such as vehicles in the UK will be hindered. Conversely, if the steel industry switches to EAF then more scrap will be available to create quality of steel and increase recycling rates. There is an inherent dependency on waste management hierarchies across all sectors, in supporting sufficient capacity for the collection and management of different waste streams. Selection of materials (e.g. grades of steel, biobased plastics and composite plastics) is informed, in part, by the capacity to reliably capture and re-use/recycle predominantly within the UK market. Use of non-UK recycling infrastructure would need sufficient provenance and supply chain guarantees to maintain confidence in net environmental benefits and associated ESG targets among OEMs.

Measure 4

- Measure 4 – Use of biobased materials in vehicle products

This measure is interdependent with the plastics sector as biobased materials are most likely to replace plastic materials.

Measure 5

- Measure 5 – Recycling of wastes generated in production processes

The reduction of waste from recycling is likely to have an impact on the steel, aluminium and plastic sectors, as it is these materials which will likely be recycled. This would potentially lead to an increase in closed loop recycling and/or in sector open loop, potentially reducing the overall material being supplied into the recycling streams for these sectors.

There is a strong interdependency with the steel sector for Measure 3, as the vehicles sector depends on a large enough supply of recycled steel to increase its recycled content. Similarly, there is an interdependency with the plastics sector for a sufficient supply of recycled plastic material.

Measure 9

- Measure 9 – Reducing waste in manufacturing processes

The reduction of waste from recycling is likely to have an impact on the steel, aluminium and plastic recycling sectors, as these are the key materials that are likely to be recycled. A continued fall in the overall waste streams from the vehicle sector would mean a fall in the total volume available in these recycling sectors. This would imply either a reduction in the overall availability of recycled materials (for specific waste streams) and/or encouragement for higher level of closed loop recycling.

Glossary and abbreviations

B2B	business to business
B2C	business to consumer
BEV	battery electric vehicle
EAF	electric arc furnace
ELV	end-of-life vehicle
EoL	end-of-life
EV	electric vehicle
ICE	internal combustion engine
MaaS	mobility as a service
OEM	original equipment manufacturer
SME	small and medium enterprise
SUV	sport utility vehicles
ZEV	zero-emission vehicles

Appendix A: IAS Scoring Parameters

Table 30: IAS Scoring Parameters

Criteria	High	Medium	Low
Geography	Specific to UK	Non-UK but applicable to the UK	Non-UK and not applicable to the UK
Date of publication	< 10 years	10 to 20 years	> 20 years
Sector applicability	Sector and measure-specific, discusses RE and circularity	Sector and measure-specific, focus on decarbonisation	Cross-sector
Methodology	Research methodology well defined and deemed appropriate	Research methodology well defined but not deemed appropriate / Minor description of research methodology	No research methodology
Peer Review	Explicitly mentioned peer review	Not explicitly mentioned, but assumed to have been peer reviewed	Unknown

Appendix B: Search strings

- 3d printing AND circular* AND (vehicle* OR automotiv* OR car*)
- barrier AND circular economy AND vehicle
- (car shar* OR car-shar*) AND circular economy
- driver AND vehicle AND circularity
- electric vehicle* AND circular*
- EV battery AND resource efficiency
- EV battery AND material substitution
- EV battery AND recycl*
- non-road mobile machinery AND resource efficiency OR circular economy
- resource efficiency AND (‘non-road machinery’ OR ‘non-road mobile machinery’ OR ‘off-road machinery’ OR ‘off-road mobile machinery’ OR ‘off-highway’ OR ‘off-highway machinery’)
- (ride shar* OR ride-shar*) AND circular economy
- tyre AND reycl*
- (vehicle*OR automot*) AND 3D printing
- (vehicle*OR automot*) AND 3D printing AND efficiencies AND paper
- (vehicle*OR automot*) AND aluminium
- (vehicle*OR automot*) AND (automat* OR self-driv* OR autonom*)
- (vehicl* OR automot*) AND battery AND recycl*
- (vehicle*OR automot*) AND biobased
- (vehicle*OR automot*) AND car club
- (vehicle*OR automot*) AND (car sharing OR car-shar*)
- (vehicle*OR automot*) AND circular*
- (vehicle*OR automot*) AND circular economy
- (vehicle*OR automot*) AND "design for circularity"
- (vehicle*OR automot*) AND (light* OR lightweight*)
- (vehicle*OR automot*) AND longevity
- (vehicle*OR automot*) AND material efficiency OR resource efficiency

- (vehicle*OR automot*) AND "material passport"
- (vehicle*OR automot*) AND material substitution
- (vehicle*OR automot*) AND (modul* OR modul* design*)
- (vehicle*OR automot*) AND production AND substitution
- (vehicle*OR automot*) AND recycl*
- (vehicle*OR automot*) AND "recycled content"
- (vehicle*OR automot*) AND reduced material
- (vehicle*OR automot*) AND remanufact*
- (vehicle*OR automot*) AND (rent* OR leas*)
- (vehicle*OR automot*) AND repair
- (vehicle*OR automot*) AND reuse
- (vehicle*OR automot*) AND (ride sharing OR ride-shar*)
- (vehicle*OR automot*) AND servitisation
- (vehicle*OR automot*) AND shared mobility
- (vehicle*OR automot*) AND sustainability
- (vehicle*OR automot*) AND waste reduction
- (vehicle*OR automot*) AND waste recycl*
- (vehicle*OR automot*) AND waste minimisation
- (vehicle*OR automot*) AND waste reduction

Search strings were devised with the names of UK manufacturers:

- BMW AND resource efficiency
- Honda AND resource efficiency
- (Jaguar OR Land Rover) AND resource efficiency
- Nissan AND resource efficiency
- Toyota AND resource efficiency
- Vauxhall AND resource efficiency
- Rolls Royce AND vehicl* AND resource efficiency
- McLaren AND resource efficiency

Appendix C: Literature sources

Table 31: List of literature sources for the Vehicles sector

Title	URL	Author	Year	IAS
Cost-benefit analysis of a circular economy project: a study on a recycling system for end-of-life tyres	link	Gigli, S., Landi, D. & Germani, M.	2019	5
Circular Economy in Shipbuilding and Marine Networks – A Focus on Remanufacturing in Ship Repair	link	Jansson, K.	2016	4
Modularity Techniques in Commercial Vehicles	link	Jeevanandam.s, Mohan Rao. S. L	2015	3
Energy, environmental and economic impact of mini-sized and zero-emission vehicle diffusion on a light-duty vehicle fleet	link	González Palencia, J. C., Araki, M. and Shiga, S	2016	3
Development and Evaluation of a Battery Lifetime Extending Charging Algorithm for an Electric Vehicle Fleet	link	Fabian Rücker, Ilka Bremer, Sebastian Linden, Julia Badeda, Dirk Uwe Sauer,	2016	5
Car sharing in Germany: a case study on the circular economy	link	Ecologic Institute	2018	4
A systematic review on drivers, barriers, and practices towards circular economy: a supply chain perspective	link	Govindan, K., Hasanagic, M.	2018	5
Transport: taming of the SUV?	link	Anable, J., Brand, C. and Mullen, C.	2019	5
Powered Light Vehicles: Opportunities for Low Carbon 'L-category Vehicles in the UK	link	Low Carbon Vehicle Partnership	2019	3
European vehicle market statistics 2018/2019	link	International Council on Clean Transportation	2019	3
Car-sharing in Flanders	link	CE Center Circular Economy	2019	5
Circular Economy framework for automobiles: Closing energy and material loops	link	Laura C. Aguilar Esteva, Akshat Kasliwal, Michael S. Kinzler, Hyung Chul Kim, Gregory A. Keoleian	2020	3
Raising Ambitions: A new roadmap for the automotive circular economy	link	Accenture and World Economic Forum	2020	4
Top Trends in Modular Electric Vehicle Design	link	FEV	2021	2

Title	URL	Author	Year	IAS
Novel Battery Module design for increased resource efficiency	link	Simon Schmidt, Jan Clausen, Robin van der Auwera, Oliver Klapp, Rico Schmerler, David Löffler, Maximilian Jakob Werner and Lukas Block	2022	5
A Study on Additive Manufacturing of Metal Components for Mobility in the Area of After-Sales with Spare and Performance Parts	link	Schuhmann, Dirk; Pinto, Grithen; Merkel, Markus; Harrison, David K.	2022	5
Drivers and Barriers to the Circular Economy Transition: the Case of Recycled Plastics in the Automotive Sector in the European Union	link	Baldassarre, B., Maury, T., Mathieux, F., Garbarino, E., Antonopoulos, I., Sala, S.	2022	5
The Circularity Gap Report 2023	link	Circle Economy & Deloitte	2023	3
Cars on a Diet: The Material and Energy Impacts of Passenger Vehicle Weight Reduction in the U.S	link	Cheah, L. W	2010	3
Towards a circular economy for end-of-life vehicles: A comparative study UK – Japan	link	Mélanie Despeissea, Yusuke Kishitab, Masaru Nakanoc, Michael Barwood	2015	5
Latest Mass Benchmarking Study Reveals Steel Lightweighting Opportunities	link	World Steel Association	2017	4
Applying the Theory of Inventive Problem Solving (TRIZ) to identify design opportunities for improved passenger car eco-effectiveness	link	Carvalho, I., Simoes, R. and Silva, A.	2018	4
A Study on 3D Printing and its Effects on the Future of Transportation	link	Omar Jumaah	2018	3
Vehicle Tyres: Policy Options for a Circular Economy	link	Zero Waste Scotland	2020	5
Material efficiency and climate change mitigation of passenger vehicles	link	Paul Wolfram, Qingshi Tu, Niko Heeren, Stefan Pauliuk, Edgar G. Hertwich	2020	5
Lightweight Materials for Cars and Trucks	link	Office of Energy Efficiency and Renewable Energy	2020	5
Forging Ahead A materials roadmap for the zero-carbon car	link	World Economic Forum	2020	4
Material efficiency strategies to reducing greenhouse gas emissions associated with buildings, vehicles, and electronics—a review	link	Edgar G Hertwich, Saleem Ali, Luca Ciacci, Tomer Fishman, Niko Heeren, Eric Masanet, Farnaz Najvan Asghari, Elsa Olivetti, Stefan Pauliuk, Qingshi Tu, Paul Wolfram	2022	5

Title	URL	Author	Year	IAS
Sustainability	link	Volvo	2022	4
What is the contribution of different business processes to material circularity at company-level? A case study for electric vehicle batteries	link	Schulz-Mönninghoff, Magnus; Neidhardt, Michael;Niero, Monia	2023	5
Europe's first circular economy factory for vehicles: Renault	link	Ellen Macarthur Foundation	n.d.	5
Exploring the applicability of circular design criteria for electric vehicle batteries	link	Picatoste, A., Justel, D., Mendoza, J.M.F.	2022	4
A circular economy for electric vehicle batteries: driving the change	link	Ahuja, J., Dawson, L., Lee, R.	2020	5
Development of a hybrid electric powertrain for non-road mobile machinery by means of application-adapted driving profiles	link	Schuhmann, D., Merkel, M., Reusch, S., Harrison, D.	2021	5
Advanced Hybrid Propulsion and Energy Management System for High Efficiency, Off Highway, 240 Ton Class, Diesel Electric Haul Trucks	link	Richter, T., Slezak, L., Johnson, C., Young, H., Funcannon, D.	2008	3
3D Printing as a Disruptive Technology for the Circular Economy of Plastic Components of End-of-Life Vehicles: A Systematic Review	link	Ruiz, L., Pinho, A., Resende, D.	2022	5
Leading a sustainable revolution: Ford and HP collaborate to transform 3D waste into auto parts, an industry first	link	Ford Motor Company	2021	4
Global scenarios of resource and emission savings from material efficiency in residential buildings and cars	link	Pauliuk, S., Heeren, N., Berrill, P. et al.	2021	4
Bio-Based Products in the Automotive Industry: The Need for Ecolabels, Standards, and Regulations	link	Wurster, S. and Ladu, L.	2020	5
Retrofitting buses is a fast route to greener public transport	link	Lucy Parkin	2022	3
Barriers and opportunities for shared battery electric vehicles - A report for Transport and Environment	link	Tyrer, D., Orchard, K.	2021	4
Labelling and Information Schemes for the Circular Economy	link	OECD	2021	4
Motor Vehicle Manufacturing in the UK - Market Size 2010–2028	link	Ibis World	2022	3

Title	URL	Author	Year	IAS
Yearly number of passenger cars produced in the United Kingdom (UK) between 2003 and 2021	link	Statista	2022	3
SMMT Motor Industry Facts 2023	link	The Society of Motor Manufacturers and Traders	2023	3
Comparison of leading car companies' market share in the United Kingdom in 2021	link	Statista	2022	3
What Raw Materials do Auto Manufacturers Use?	link	J.B. Maverick	2022	2
What Are Cars Made Of? 10 Of The Top Materials Used In Auto Manufacturing	link	Mayco International	2019	2
Public buses in the UK - statistics & facts	link	Statista	2022	3
Industry revenue of “manufacture of railway locomotives, rolling stock“ in the United Kingdom from 2012 to 2025	link	Statista	2021	3
The Rail Industry	link	UK Manufacturing Review	2019	3
Aluminium use in the production of trains steams ahead	link	Aluminium Insider	2017	3
Annual turnover of the United Kingdom's (UK) aerospace sector from 2010 to 2020	link	Statista	2021	3
What Materials Are Aircraft Made Of (& Why) – Plane Design Priorities	link	Aerocorner	0	1
Aerospace Materials	link	Thyssenkrupp	0	1
Guidance - Regulations: end-of-life vehicles (ELVs) - Guidance for manufacturers and importers.	link	Office for Product Safety and Standards and Department for Environment, Food & Rural Affairs	2021	4
2021 UK AUTOMOTIVE SUSTAINABILITY REPORT 22ND EDITION - 2020 DATA	link	The Society of Motor Manufacturers and Traders	2022	3
Rail Environment Policy Statement On Track for a Cleaner, Greener Railway	link	Department for Transport	2021	4
United Kingdom - Country Commercial Guide	link	International Trade Administration	2022	2
COMPOSITE MATERIAL APPLICATIONS IN AEROSPACE	link	Aerospace Technology Institute	2018	3
End-of-Life in the railway sector: Analysis of recyclability and recoverability for different vehicle case studies	link	Massimo Delogu, Francesco Del Pero, Lorenzo Berzi, Marco Pierini	2016	5

Title	URL	Author	Year	IAS
Plastics makers plot the future of the car	link	Alexander H. Tullo	2017	2
Car Club Annual Report - United Kingdom - 2021	link	Collaborative Mobility UK	2021	4
Biobased Plastics in a Circular Economy	link	CE Delft	2017	4
Substitution of Ride-Hailing Services for More Sustainable Travel Options in the Greater Boston Region	link	Gehrke, S.R., Felix, A., Reardon, T., G.,	2019	5
Impact of Car-Sharing and Ridesourcing on Public Transport Use: Attitudes, Preferences, and Future Intentions Regarding Sustainable Urban Mobility in the Post-Soviet City	link	Tarnovetckaia, R., and Mostofi, H	2022	5
Exploring the Potential for Electric Retrofit Regulations and an Accreditation Scheme for the UK	link	Watts, R., Ghosh, A., Hinshelwood, J.,	2021	5
News and Insights: Re-made in Sweden	link	Stena Recycling	2023	3
Material efficiency strategies to reducing greenhouse gas emissions associated with buildings, vehicles, and electronics—a review	link	Hertwich, E.,G., Ali, S., Ciacci, L., Fishman, T., Heeren, N., Masanet, E., Asghari, F., N., Oilvetti, E., Pauliuk, S., Tu, Q.,	2019	5
Application of Recycled Plastics in Automotive Industry: a short review	link	Mitaľová, Z., Dupláková, D., Mitaľ, D.,	2022	3
Using more recycled aluminium in new cars	link	UKRI	2021	3
Bio-based plastics in the automotive market – clear benefits and strong performance	link	European Bioplastics	2020	4
Recycling Steel and Iron Used in Automobiles	link	World Steel Association	2022	3
Driving Global Britain; UK Automotive Trade Report 2021	link	The Society of Motor Manufacturers and Traders	2021	5
Retrofitting Classic Cars With Second-Life EV Batteries	link	HSSMI	2021	5
Exploring the Potential for Electric Retrofit Regulations and an Accreditation Scheme for the UK	link	Watts, Ghosh and Hinshelwood, University of Exeter	2021	5
Retrofitting Cars; A new Sustainable Way to Enter the Electric Vehicle Market	link	REMATEC	2022	3
Waste from car production in the EU	link	European Automobile Manufacturer's Association (ACEA)	2022	4

Title	URL	Author	Year	IAS
Average statistics of new passenger cars by member state	link	European Environment Agency	2015	5
Wasting away	link	Automotive Manufacturing Solutions (AMS)	2008	1
UK active car club membership doubles in 12 months	link	Martin Guttridge-Hewitt	2022	3
Number of car repairs in the United Kingdom (UK) from 2013 to 2021	link	Placek M	2022	4
Application of energy and CO_2 reduction assessments for end-of-life vehicles recycling in Japan	link	Fernando Enzo Kenta Sato, Takaaki Furubayashi, Toshihiko Nakata	2019	3
Chemistry and Automobiles	link	American Chemistry Council	2023	5
Plastics in passenger cars	link	Erik Emilsson, Lisbeth Dahllöf, Maria Ljunggren Söderman	2019	5
Carsharing: a systematic literature review and research agenda	link	Brenda Nansubuga, Christian Kowalkowski	2021	5
Vehicle licensing statistics: April to June 2021	link	UK Government	2021	5
Guidance: Car clubs: local authority toolkit	link	UK Government	2022	5
Mobility as a Service?	link	MaaS Alliance	2022	4
zero emission vehicle (ZEV) mandate and CO_2 emissions regulation for new cars and vans in the UK	link	UK Government	2023	5
End of Life Vehicles	link	CIWM	n.d.	5
Average vehicle could incorporate 350 kg of plastics by 2020	link	Plastics Today	2016	3
SMMT Motor Industry Facts 2023	link	The Society of Motor Manufacturers and Traders	2023	5
UK manufacturers' sales by product	link	Office for National Statistics	2022	5
UK input-output analytical tables, product by product. Table "Use BP Pxl"	link	Office for National Statistics	2023	5
Industrial Decarbonisation and Energy Efficiency	link	WSP & Parsons Brinckerhoff	2015	5
Electric vehicles and infrastructure	link	House of Commons Library	2023	5
Iron and Steel Technology roadmap: Towards more sustainable steelmaking	link	IEA	2020	5

Title	URL	Author	Year	IAS
The Persistent Organic Pollutants Regulations 2007	link	UK Government	2007	4
Amendments to the persistent organic pollutants (POPs) regulation	link	UK Government	2023	5

Appendix D: List of discarded measures

During the literature review, several measures were de-prioritised due to several reasons, such as overlaps in the definition, or outside of the agreed scope (e.g., relating to energy efficiency such as kiln fuel substitution as well as carbon capture, usage and storage). These discarded measures are listed below alongside the reason for exclusion.

Table 32: List of discarded resource efficiency measures for the vehicles sector

Theme	Sub-theme	Measure name	Measure indicator	Reason for De-prioritisation
Manufacture	Waste reduction upon assembly	Use of additive manufacturing / 3D printing	Quantity of components produced using 3D printing % of cars containing components using 3D printing % of polymeric parts in cars that are 3D printed	Primary function considered to be 'reduced production waste' therefore incorporated within Measure 9. However, it was also noted that this could also result in lighter-weight structures
Further assembly	Use of pre-fabricated modules	Design for modularity	Reduction in materials used in vehicles and/or reduction in waste Year on year increase in the number of components that are designed to be modular % use of repairable or modular components in vehicles No. of vehicle components that are standardised	Primary function considered to be 'life extension' therefore incorporated within Measure 7. However, it was also noted that this could also result in improved remanufacturing, reuse, recycling and reconditioning.
Design	Material passports	Common standards in labelling to allow for clearer identification of material throughout value chain	No. of manufacturers that use and adhere to standards for identifying and labelling materials in products Introduction and use of centralised database for materials (e.g., SCIP) Annual increase of materials within the database Annual increase in quantity of materials recycled, recovered - or	Considered to be an enabler of other measures (facilitating repair, recovery, recycling etc)

Theme	Sub-theme	Measure name	Measure indicator	Reason for De-prioritisation
			tracked - using the database	
Design	Value chain optimisation	Capability-building with education and certification	No of companies with certification of circular economy education programmes No of companies with training programmes for designers and engineers to reduce waste / adopt circularity Increase in vehicle servicing bookings Reduced tyre changes due to increased care / responsible driving.	Considered to be an enabler for various measures therefore excluded
Supply Chain	Data and traceability	Data sharing across supply chain and consumers	Introduction and use of centralised database for materials (e.g., SCIP) Annual increase of materials within the database Annual increase in quantity of materials developed - or tracked - using the database	Considered to be an enabler for various measures therefore excluded
Use	Performance monitoring	Standard test for tyres and other wearing components	Implementation of standards on tyres and other wearing vehicle components Annual increase in tyres within scope of the tests	Deemed to be too niche by considering only one vehicle component
Supply Chain	Material substitution	Low carbon energy use in production/design processes	% use of low-carbon steel in supply chain % reduction in GHG emissions due to low carbon energy	Carbon reduction considered out of scope
Use	Value chain optimisation	Reduction in vehicle sales which drive changes in transport use/activity	Average number of miles driven per year by car owners	Modal shift considered out of scope

Theme	Sub-theme	Measure name	Measure indicator	Reason for De-prioritisation
Use	Value chain optimisation	Low carbon energy use in production/design processes	Kilometres travelled for commuting Use of virtual digital workspaces	Carbon reduction considered out of scope
Use	Function and Operation	Improved driving practices	No of staff or members of the public completing eco-driving / sustainability training to maximise lifespan of vehicles or reduce wastes	Primary function considered to be 'reuse' therefore incorporated within Measure 8.
EoL	Reuse	Issuing warranties for reused parts	No. of warranties issued for reused parts	Considered to be enabler for reuse/repair therefore incorporated within Measure 8.
EoL	Waste reduction upon disassembly	Dismantling and sorting of parts at end-of-life	No of reused parts in vehicles that are now under warranties % of ELV recovered for closed loop and/or open loop recycling	Considered to be enabler for reuse/repair therefore incorporated within Measure 8.

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