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## Towards a circular economy for end-of-life vehicles: A comparative study UK – Japan

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### Abstract

As the European Directive on end-of-life vehicle (ELV) treatment has heavily influenced policies in many countries, car manufacturers need to reconsider the early phases of the product design to enable better ELV treatment. This paper proposes policy, technical and business recommendations to improve the reuse, recycling and recovery (RRR) rate of ELVs. A comparative analysis between the United Kingdom and Japan is undertaken, in which the two countries' contextual background is described along with their RRR performance from a lifecycle perspective. Barriers and countermeasures to improve the RRR rates are discussed based upon mutual learning between the two countries.

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**Keywords:** End-of-life vehicle; Circular Economy; Reuse; Remanufacturing; Recycling; Material recovery; Energy recovery

### 1. Introduction

It is estimated that 7 million end-of-life vehicles (ELVs) are generated each year in Europe [1] and over 3 million in Japan [2]. The top 5 countries in Europe contribute to 70% of total ELVs in the EU27 (France, the United Kingdom, Italy, Spain and Germany). The recycling of ELVs is regulated in many countries with similar measures, heavily influenced by the 2000 EU Directive [3]. However the efficiency of their implementation varies greatly. This is the case in Europe where the ELV Directive, which set reuse, recycling and recovery (RRR) targets by 2015, is being implemented with different national regulations in each Member States. To avoid confusion with the Japanese 3R approach (*Reduce-Reuse-Recycle*), we use 'RRR' for *Reuse-Recycle-Recover*.

Some countries have already developed efficient recycling and recovery systems, such as Japan [4] where the ELV management is highly centralised, regulated and controlled by a government organisation (Japan Automobile Recycling Promotion Center; JARC) and supported by many companies and corporate associations (Japan Auto Recycling Partnership; JARP, Japan Automobile Manufacturers Association; JAMA,

and Japan Automobile Recycling System; JARS). However, even with these systems in place, the data collected is still insufficient to fully understand the fate of the components and materials from ELVs aside from fluorocarbons, airbags and automotive shredder residues (ASR) which are already heavily regulated [5]. In addition, such information and financial systems may not be replicable in Europe due to many factors. Reasons for this irreproducibility include the infrastructure and administrative systems already in place and the ensuing cost to adapt them, consumer acceptance of a recycling fee, and the lack of financial and information system to support a centralised management of ELVs.

In this paper, the authors are investigating the opportunities to move towards a Circular Economy state in the automotive industry whereby the value embedded in ELVs' components and materials is recaptured through reuse, recycling and recovery; the best waste treatment route being selected so to maximise the preservation of material quality [6]. We propose policy, technical and business recommendations to improve the RRR rate of ELVs based on mutual learning between the United Kingdom (UK) and Japan. We selected those two countries as case studies: Japan as a case of best practice for ELV recovery

with <1% landfill, and UK as a European case for ELV parts reuse and material recycling (this work is based on a study funded by the UK Technology Strategy Board). We first describe the regulatory and contextual background before reviewing the current recovery rates achieved in the UK and Japan since 2006. Then we compare the countries' respective performance to identify specific barriers and drivers in those two regions. Finally, we make recommendations which can be generalised for the automotive industry as a whole.

## 2. ELV Treatment Options and Definitions

ELV recovery is defined as the final productive use of the parts and materials embedded in ELVs. Cars reaching their end-of-life can be valuable resources as spare parts or raw materials. In order to extract these valuable parts and materials from ELVs, different techniques exist today. The preferred treatment route depends on the infrastructure in place and the potential profitability:

- Parts may be dismantled, refurbished or remanufactured and then reused in in-life vehicles and potentially in new vehicles;
- Materials may be either dismantled before being sent to recycling, shredded, sorted and incinerated with or without energy recovery, and finally landfilled if the material cannot take any of the recovery routes.

The ELV process flow is further detailed in Section 3.

In this paper, we define "recovery" as any kind of treatment diverting materials from landfill. Therefore, "recovery" includes:

1. reuse and remanufacture of parts,
2. recycling of materials for reuse in the same application ("closed-loop recycling" in EU or "horizontal recycling" in Japan) or for other products ("open-loop recycling" in EU or "vertical recycling" in Japan),
3. recovery of energy through chemical or thermo-chemical conversion and through thermal energy recovery.

It is important to note that this distinction is not made in many company reports and some of the regulatory texts analysed for this study. "Recycling" is often used as synonym to our use of the word "recovery", thus incineration of waste with energy recovery is sometimes considered as "recycling". To avoid confusion in this paper, we will use the following term: "reuse" for the first type of treatment listed above; "recycling" for the second type of treatment listed; and "recovery" for all types of treatment listed above.

## 3. Regulatory Background

Due to past ELV-related environmental issues, authorities have regulated the disposal and management of ELV since 2000 in Europe and 2002 in Japan. In what follows, the regulatory background of ELV management in UK and Japan is briefly described.

### 3.1. United Kingdom (European Union)

In the EU, there are many directives in place which affect the treatment of ELVs. The earliest directives regarding waste concerned landfill in 1999 and incineration in 2000. These

were shortly followed by the ELV Directive itself which aims to reduce waste from ELVs and prevent environmental pollution. Since it came into force in 2000, the ELV Directive was amended multiple times due to difficulties in its implementation [3]. Other related legal requirements include Waste Electrical & Electronic Equipment (WEEE) Directive (2002/96/EC), Restriction of Hazard Substances (RoHS) Directive (2002/95/EC), the RRR-type approval Directive (2005/64/EC), issue of Certification of Destruction (CoD) for ELV handling (2002/151/EC), components and material coding standard for vehicles (2003/138/EC) and the detailed rules for monitoring compliance with the ELV Directive targets (2005/293/EC). The ensuing improvements in the identification of parts and materials, reduction in toxic substance use and design for disassembly in new cars have largely contributed to the increase in the levels of ELV recycling and recovery [7].

In Europe, the total amount of material being recovered through the non-recycling route is also regulated (i.e. the material which is *recovered* but not *recycled*): a minimum of 85% of the ELV mass must be recycled and a maximum of 5% can be landfilled (95% recovery target). In the UK, the recovery rate is only gradually increasing and is unlikely to meet the 95% target by 2015 as illustrated in Figure 1.

### 3.2. Japan

In Japan, the Basic Environment Act was enacted in 1993 to define the fundamental principles and set the first policies on environmental protection, followed by the Basic Act on Establishing a Sound Material-Cycle Society in 2000 [8]. The Waste Management and Public Cleansing Act was later implemented to address the issues of illegal dumping, inappropriate storage and treatment of waste. The ELV Recycling Act, which was enacted in 2002 and enforced from January 2005, was a turning point for the Japanese ELV recovery system. While the ELV Recycling Act has been guiding practices towards today's high level of recovery, the primary motivation for improving ELV recovery was the illegal disposal of whole ELVs (particularly on small islands), the illegal dumping of ASR and the lack of landfill space [8].

The Japanese recovery target for ASR is 70% by 2015. But this target has been exceeded since 2008 and the target of 95% recovery as set in the European ELV Directive has been generally adopted. It must be noted that "recycling" in Japan corresponds to "recovery", i.e. includes "thermal recycling" (or energy recovery) in addition to actual material recycling as defined in this paper. As the distinction between recovery and recycling is not made, it is difficult to monitor the rates separately as it is done in Europe. The recovery performance in Japan is measured based on the amount of material finally reaching landfill (e.g. 1% landfill = 99% recovery) as opposed to measuring the actual amount of material being reused, recycled and recovered. The quality of the data for the regulated parts, i.e. fluorocarbons, airbags and ASR) is much higher and is centrally monitored and reported by JARC. Figure 2 shows the current levels of "Airbag recycling" and "ASR recycling".

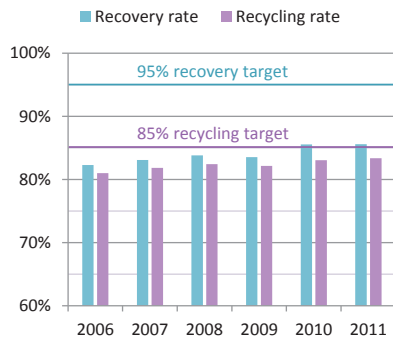


Fig. 1. Progress towards compliance with legal targets in the UK.  
Source: Eurostat, 2013 [1]

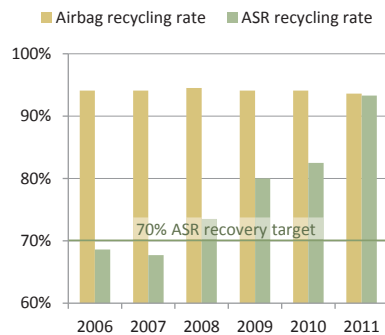


Fig. 2. Progress towards compliance with legal targets in Japan.  
Source: JARC, 2013 [2]

#### 4. ELV Management Systems in UK and Japan

This section describes the ELV management systems in UK and Japan, which have been implemented along with the regulations in Section 3.

##### 4.1. Typical process flow of ELV treatment

In this section, we describe the typical process flow for treating ELVs, which is very similar in the UK and Japan.

In both countries, the parts to be dismantled for reuse or recycling are not regulated and are mainly driven by market mechanisms. Dismantling enables the recovery of up to 40% of the total ELV weight for reuse as spare parts and for recycling of large metal and plastics components. Some of the liquids and parts from the depollution stage can also be reused, e.g., fuel. Other parts, such as engines, batteries and electronic components, are potentially reusable depending on their age and state of repair. Electric and electronic components which are not reusable are still dismantled due to their toxic content (regulated by the WEEE Directive). In some cases, materials of high value such as copper wires and platinum from catalytic converters are also collected prior to shredding.

After valuable components have been removed, the rest of the ELV is shredded. With up to 90% of the ELV weight being shredded, post-shredder sorting is a crucial process to recycle and recover materials. After the shredding process, dense media is separated from the light ASR, or shredder light

fraction (SLF), using an air classifier. Magnetic separation is then used to remove the ferrous fraction; non-ferrous materials such as aluminium and copper are collected at a later stage using eddy current separation. In some rare cases (mostly in Japan), there is further manual sorting of the heavy ASR fraction to maximise material recycling [9].

The remaining light and heavy ASR fractions then go to energy recovery and landfill [10]. While energy recovery is systematically performed in Japan, ASR is often directly landfilled in Europe because ASR recycling is not generally profitable. The EU ELV Directive targets less than 5% of the ELV weight ending up in landfill by 2015 but this can only be achieved with energy recovery.

##### 4.2. Characteristics of the UK's system

In Europe, ELVs must be collected at Authorised Treatment Facilities (ATFs) where a CoD is issued. In the UK, the ATF must issue the last owner with a CoD which demonstrates that the vehicle was collected at an ATF and enables deregistration of the vehicle from the Driver and Vehicle Licensing Agency (DVLA) database as shown in Figure 3. This system has been enforced EU-wide since 2002 to ensure a better monitoring of ELV. When a vehicle is collected at an ATF, a CoD must be issued to the customer and the vehicle must be deregistered. Then the ELV must be depolluted before any other treatment can be done. In Europe, the collection of components containing toxic substance and all fluids, called depollution, is regulated. Other parts are not regulated, and therefore, are treated based on economic rationality.

However there are still cases of ELV disposal which do not comply with the EU Directive, i.e. ELV are collected in non-registered facilities and no CoD is issued thus resulting in a gap in ELV data. In addition, it is estimated that as much as 30% of ELVs generated in the UK are being illegally exported as *used vehicles* to Eastern Europe and African countries. Such illegal exports represent a number of problems such as extended use of unsafe and/or polluting vehicles, environmental impact caused by dumped vehicles in countries with no or low regulatory requirements, and loss of valuable materials which would otherwise be recovered if taken through the appropriate waste treatment route. This adds to the difficulty of evaluating the actual number of ELVs and the real potential for RRR.

##### 4.3. Characteristics of Japan's system

In Japan, the system includes a recycling fee collected by JARC in order to support the financing of fluorocarbons, airbags and ASR recovery treatment. A simplified version of the system is represented in the second part of Figure 3; a complete version is available on the website of the Japanese Ministry of Economic, Trade and Industry [4].

As with the system in UK, depollution is also conducted, but the dismantling and handling of airbags, fluorocarbons and ASR are additionally regulated and controlled. As they are not economically attractive to treat, they have been allocated to the manufacturers' responsibility. The treatment of these parts is financially supported by the recycling fee collected from consumers as shown in Figure 3.

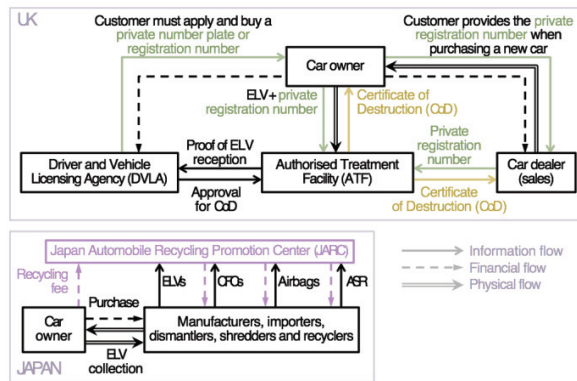


Fig. 3. Information, financial and physical flows for ELV management.

## 5. Challenges and Opportunities in Optimising ELV Treatment

Although the treatment of ELVs is now well-regulated, there still are a number of challenges to improve the RRR rates. In this paper, we focus on: (1) economic challenges, (2) information and legal challenges, (3) technical challenges, (4) social and behavioural challenges and (5) missed business opportunities.

### 5.1. Comparative analysis between the UK and Japan

The motivation to improve RRR rates in Japan differs from the European approach: while Japan has had serious issues of land scarcity (and thus limited landfill capacity) for decades, this is not the case in most European countries. The primary motivation for diverting ELVs from landfill is mainly environmental as ELVs contain potentially toxic substances which may leak and harm the environment and living conditions for local communities around landfill sites.

Therefore Japan has led the state-of-the-art in ELV management and currently achieves more than 99% diversion from landfill. In most of the UK, the recycling and recovery rate is still lower than 90%. This is in part explained by a more closely controlled ELV system, centralised information and financial systems as well as well-developed energy recovery technology in Japan. On the other hand, the UK benefits from a better potential for reuse, remanufacturing and recycling as there is a stronger market for spare parts in Europe. In addition, the EU Directive makes the distinction between reuse/recycling and recovery, thus leaving space for improvement with the recovery of high-value parts and materials. In Japan, the RRR performance is measured only with the percentage of ELV weight diverted from landfill which is already above 99%, thus leaving little space for measurable improvement.

### 5.2. General recommendations

This section discusses improvement opportunities to increase RRR rates globally (also summarised in Table 1). The next section focuses on recommendations specific to UK and Japan.

### High-value recovery through reuse and remanufacturing

While components cannot be indefinitely reused and eventually end up in the recycling stream, dismantling and reusing certain ELV components can increase the ELV RRR rates in a profitable manner. It is recognised that there is much more profit to be made from spare parts than from recycling metal scrap; ELV dismantling vs shredding case by Coates and Rahimifard [11]. Although the refurbishment and remanufacturing processes are labour intensive and require skills and costly equipment, recent research has shown that some of the ELV components can be remanufactured in a cost-efficient manner [12,13].

### Reduced unitary cost through higher yield rates and increased processing efficiency

New technology development together with the rising cost and scarcity of certain materials, such as lithium and platinum in new vehicles, encourages the recycling of these materials. Importantly, collaborative networks and regional/national effort are needed to create profitable volume [14].

Government support for research is needed in developing technology and practices for both pre- and post-shredder treatment. Although dismantling is labour-intensive, pre-shredder treatment should be prioritised where economically appropriate as it provides greater opportunities for high-value material recovery. The use of technology and skilled labour will play an important role in improving dismantling efficiency and making pre-shredder treatment more economical.

Current progress in post-shredder sorting is very encouraging and has shown good potential for high-level recycling with certain materials being recovered at quality levels close to their theoretical best [15]. But aside from a few exceptions, the sorted materials after shredding are often of insufficient quality to enable closed-loop recycling (i.e. there is a loss in material quality). Therefore the recycled material can only be reused in lower value applications (typically in the construction industry) and eventually ends up in landfill. We cannot emphasise enough the importance of increasing dismantling rates and its economic feasibility in order to increase the reuse and recycling of ELVs.

### Vehicle design improvements

Today's ELV management is mainly focused on recycling the metal fraction of ELVs as the technology exists and is well-established. However, the evolution of material technology and the diversity of materials used in newer vehicles also makes the recycling and recovery processes more challenging [16]. With current trends in material substitution for fuel efficiency and safety, the percentage of electronics, plastics, composites and other non-metallic parts is increasing. Thus improvements in metal sorting and recycling alone will be insufficient to achieve (and exceed) the target of 85% recycling. Technology capability to sort non-metallic materials is therefore critical.

Moreover, as the complexity and embedded value of vehicle is increasing, the incentive to maximise the RRR will become even greater for critical components and materials. Information about the materials in vehicles is also becoming more available, particularly since coding standards for components and materials are in place, and facilitate material identification and

recycling. In addition, vehicles are increasingly designed for disassembly, remanufacture and recycling, making reuse and recycling technically easier [17]. But even with a good design and the use of recyclable materials, the actual RRR performance still depends on the dismantlers and shredders; highlighting again the role and necessity of collaborative networks. Therefore, as pointed out by Sakai et al. [18], technologies and practices for the reuse and recycling of ELVs need to be developed in conjunction with the evolution of new vehicle designs.

#### *Policy and Incentives*

In order to increase RRR rates, additional incentives can be created through landfill tax and prevention of illegal exports. In Japan where the landfill tax is already high, the prevention of illegal exports is particularly important. A better ELV tracing system can help address the issue of illegal export as well as improve the data collection process. Two other drivers which can be enforced through regulations and policies are consumers' payment of a recycling fee and competition between car manufacturers to improve recycling rates.

#### *Consumer Behaviour*

Incineration and landfill have a poor reputation and thus public awareness and opinion can be significant drivers that influence future regulations, create a demand for remanufactured products and recycled materials, and help direct waste towards the best recovery routes. The participation of customers in the ELV system should be primarily behavioural (e.g. dispose of the vehicle at ATFs, accept and recognise the quality of recycled materials) but should also financial (e.g. shared contribution amongst stakeholders through recycling fees).

In addition, a change in ownership structure, such as renting, leasing or car sharing, need to be accepted by consumers in order to successfully implement new business models for higher RRR performance. Such business models offer the advantage of increased capacity for monitoring resource use, controlling parts and materials for the vehicles on the road, and organizing end-of-life treatment and resource reclamation. This is further encouraging design for disassembly and recycling as an important distinction is drawn between the life of the various parts and materials making a vehicle (particularly those considered as high value), and the life of the vehicle itself [19].

#### *5.3. Recommendations specific to UK and Japan*

In the UK (and more broadly in the European Union), a financial support system for the recycling and recovery of ELV components and materials should be in place. Shared responsibility should be allocated to all stakeholders involved that have a degree of control on the fate of the ELV rather than allocate all the responsibility to the car manufacturer who does not have full control of the material flows. The customers also need to be more involved: by raising public awareness and sharing costs and responsibility amongst all stakeholders, better RRR of ELVs can be achieved. Finally, material traceability would help identify materials which can be easily sorted post-shredder and thus can be most cost-efficiently

recycled; on-going research on this front [15]. For all other components and materials, as more value can be extracted from spare parts than recycled material, we should prioritise and encourage dismantling over shredding whenever possible.

In Japan, recycling and recovery must be distinguished and should be calculated separately as it is currently done in Europe. Additionally, reuse and remanufacturing should be promoted by developing new business models such as leasing and car sharing.

For both countries, there should be a better control of illegal exports of ELVs. The material composition of new vehicles should determine the development of technologies and practices for ELV treatment. More support to develop pre-shredder technology and practices is needed to achieve the 85% recycling target set by the EU Directive.

#### *5.4. Other opportunities to be further explored*

- Technology, products, parts and materials evolution
- Material (in)compatibility
- Parts (in)compatibility
- Cannot reuse of parts from older vehicles in new ones
- Design for upgradability and modular part design
- Reuse in different applications / industry

## **6. Conclusion**

The evolution of regulatory and economic conditions in the past 15 years has led to the development of networks to reuse, refurbish, remanufacture, recycle and recover parts and materials embedded in ELVs. The car industry has greatly progressed in reducing the amount of ELV waste going to landfill and significantly increased the level of recycling and recovery. In this paper, we reviewed the current situation in Japan and in the UK, and highlighted some of the major differences and similarities in their respective ELV systems. The key factors for successfully diverting ELVs parts and materials from landfill have been identified and discussed. Finally recommendations for further improving reuse, recycling and recovery rates were made based on mutual learning from the best practices in the UK and Japan. The main barriers to RRR performance improvement are economic and technical. The main recommendations are to develop a shared vision and increase collaboration between stakeholders.

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Table 1. List of challenges and recommendations.

| Challenges                                                                                                                                                                                                                                                                                                                                                                       | Recommendations                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Economic</b>                                                                                                                                                                                                                                                                                                                                                                  |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |
| <ul style="list-style-type: none"> <li>Materials that can be sold at lower prices will not be recycled or recovered</li> <li>Lack of demand for specific recycled materials due to the lower price of virgin materials</li> <li>Low processing volume makes unitary price of recycled materials higher than virgin materials</li> </ul>                                          | <ul style="list-style-type: none"> <li>Introduce new technologies to increase capacity and processing efficiency, e.g., non-destructive dismantling or mechanical sorting</li> <li>Design for disassembly</li> <li>Enforcement of critical materials recycling (e.g., indium and lithium)</li> <li>Launch lease business to ease spare parts reuse and remanufacturing</li> </ul>                                                                                                                             |
| <b>Information and legal</b>                                                                                                                                                                                                                                                                                                                                                     |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |
| <i>Illegal export and traceability</i>                                                                                                                                                                                                                                                                                                                                           |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |
| <ul style="list-style-type: none"> <li>Illegal export to avoid or reduce ELV treatment costs</li> <li>Sub-optimal ELV treatment in countries with low or no legal requirements</li> <li>Poor ELV treatment results in environmental degradation</li> </ul>                                                                                                                       | <ul style="list-style-type: none"> <li>Control ELV treatment practices at a global level, to enable (lower cost) international recycling</li> <li>Develop ASR recycling businesses close to where the demand is for those materials</li> <li>Build and implement an international traceability system</li> </ul>                                                                                                                                                                                              |
| <b>Technical</b>                                                                                                                                                                                                                                                                                                                                                                 |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |
| <i>Disassembly</i>                                                                                                                                                                                                                                                                                                                                                               |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |
| <ul style="list-style-type: none"> <li>Older ELVs not designed for disassembly, destructive disassembly</li> <li>Post-shredder treatment is currently prioritised over disassembly to reduce cost but results in lower recycling rates and lower material quality</li> </ul>                                                                                                     | <ul style="list-style-type: none"> <li>Specialised technology for disassembly</li> <li>Centralised, large-scale treatment centres to deliver higher yield rates</li> </ul>                                                                                                                                                                                                                                                                                                                                    |
| <i>Material issues</i>                                                                                                                                                                                                                                                                                                                                                           |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |
| <ul style="list-style-type: none"> <li>Issues with toxic, non-renewable, scarce, expensive, critical, strategic materials</li> <li>Some materials cannot be easily identified and therefore cannot be properly recycled</li> <li>Outputs of low-value recycling cannot be reused for the same application, thus virgin materials are still required</li> </ul>                   | <ul style="list-style-type: none"> <li>Adopt material substitution and dematerialisation strategies</li> <li>Identify materials using standard labelling systems</li> <li>Dismantling or post-shredder sorting technology</li> <li>Material compatibility between different models, possibility to upgrade recycled materials to match new requirements</li> </ul>                                                                                                                                            |
| <b>Stakeholders responsibility, social and behavioural</b>                                                                                                                                                                                                                                                                                                                       |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |
| <ul style="list-style-type: none"> <li>Diverging interests</li> <li>Producer has the full responsibility for ELV treatment although it does not have full control of the material flow (in the UK)</li> <li>Customer unwillingness to pay for recycling (in the UK)</li> <li>Traffic, congestion, pollution, growing car fleet vs. limited space in urban areas, etc.</li> </ul> | <ul style="list-style-type: none"> <li>Develop a common vision for RRR</li> <li>Knowledge transfer policies to encourage collaboration between stakeholders</li> <li>Raise awareness of the impact of ELVs if not treated properly to encourage customers to bring ELVs to the correct network for optimum treatment</li> <li>Establish supporting financial system based on recycling fee, shared cost amongst stakeholders</li> <li>Encourage the adoption of shared ownership and servitization</li> </ul> |
| <b>Business opportunity</b>                                                                                                                                                                                                                                                                                                                                                      |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |
| <ul style="list-style-type: none"> <li>Hybrid and electric vehicles have higher embedded value (materials and components)</li> <li>Precious and rare materials are becoming scarcer and thus more expensive</li> </ul>                                                                                                                                                           | <ul style="list-style-type: none"> <li>Encourage new business models for hybrid and electric vehicles to better recapture embedded value, e.g. remanufacturing, leasing and renting</li> </ul>                                                                                                                                                                                                                                                                                                                |

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