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Is European end-of-life vehicle legislation living up to expectations? Assessing the impact of the ELV Directive on 'green' innovation and vehicle recovery

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Abstract

The end-of-life vehicle (ELV) Directive in Europe aims to generate environmental gains through increased levels of vehicle recovery and a reduction in the use of hazardous substances. This paper presents an evaluation framework based on five anticipated changes that could result from the ELV Directive. These changes relate to three areas: (a) vehicle design, (b) level of ELV recovery, and (c) information provision. We evaluate the extent to which expected outcomes have materialized since the establishment of the ELV Directive. Current information provides an emerging picture of the impact of ELV legislation. We show that legislative factors and market forces have led to innovation in recycling, increased hazardous substance removal and improved information dissemination. Such actions may be sufficient to reach ELV Directive targets and could have spill-over benefits to other industries. Carmakers are also taking steps to design for recycling and for disassembly. However, movement toward design for re-use and remanufacturing seems limited. Increasing the level of re-use and remanufacturing will be a key part of moving toward sustainable vehicle production.

Keywords: Innovation; Automotive; Extended Producer Responsibility; Recycling; Re-use

1. Introduction

Since its introduction four years ago, the global automotive industry and durable goods manufacturers in general have been carefully monitoring the effects of the European Union's end-of-life vehicle (ELV) Directive. The legislation aims to increase recovery of ELVs in order to reduce waste and improve environmental performance.

This analysis presents a framework for assessing the level of environmental performance generated by ELV regulations. It evaluates progress on five expected outcomes of European ELV legislation. While much of the literature has focused on the effects of the ELV Directive on recycling, the Directive aims to generate environmental gains through recovery in general. Thus, each recovery option (e.g. recycling, re-use, energy recovery) should be viewed as a means of moving toward environmentally sustainable production, rather than as an end in itself. Accordingly, this paper hopes to broaden the discussion of ELV legislation away from a narrow focus on recycling to one that incorporates green innovation and other vehicle recovery alternatives.

The ELV Directive may have heralded the start of a new era of waste management legislation for durable goods worldwide. The EU has already reinforced its intentions through the introduction of further regulations. Enacted in 2003, the Waste Electrical and Electronic Equipment Directive [1] was modelled on the ELV Directive. Japan, Taiwan and South Korea have instituted similar Extended Producer Responsibility (EPR) legislation over the past three years. EPR legislation is also becoming increasingly prevalent in North America.

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EPR bills have been introduced in nearly half of the 50 state legislatures in the United States [2]. Thus insights gained from evaluating the early impact of ELV may provide an indication of the future efficacy of EPR regulations worldwide. Additionally, such regulations may have ramifications for vehicle design and production globally as carmakers and regulators learn from the European experience.

2. EU take-back legislation and ELV targets

The ELV Directive [3] came into force on the 18th of September 2000. It aims to prevent waste from end-of-life vehicles and to protect the environment through promoting the collection, re-use and recycling of their components.

The Directive states that vehicle manufacturers and material and equipment manufacturers must meet the following objectives:

1. endeavour to reduce the use of hazardous substances when designing vehicles;
2. design and produce vehicles which facilitate the dismantling, re-use, recovery and recycling of end-of-life vehicles;
3. increase the use of recycled materials in vehicle manufacture;
4. ensure that components of vehicles placed on the market after 1 July 2003 do not contain mercury, hexavalent chromium, cadmium or lead (with a few exceptions as listed in Annex II of the Directive).

Currently 75–80% of each end-of-life vehicle is recycled or re-used, the vast majority of which is ferrous metal, as shown in Fig. 1 [4]. The Directive requires an increase in the rate of re-use and recovery (which includes energy recovery), as outlined in Fig. 2. Less stringent objectives may be set for vehicles produced before 1980. Professional importers of foreign vehicles are also required to comply with the above. To ensure that the 2015 recovery target is met, the Commission of European Communities has recently proposed that future vehicle approval be contingent on the vehicle's ability to be 95% reusable or recoverable. Such approval procedures will apply to vehicles put on the market 3 years after the new Directive enters into force (i.e. not before 2007) [5]. Salient dates for European ELV legislation are represented in Fig. 3.

To aid recycling efforts, vehicle and component manufacturers are required to use material coding standards, which allow identification of the various materials during dismantling. Additionally, vehicle manufacturers and importers must provide prospective purchasers of vehicles with information on the recovery and recycling of vehicle components, the treatment of end-of-life vehicles and progress with regard to re-use, recycling and recovery.

2.1. What should we expect will happen?

If legislation has been effective we should see progress toward the objectives outlined above. Under this scenario one could reasonably expect the legislation to have resulted in the following changes (“expectations”):

Design changes:

1. Changes in the material composition of new cars
   i. Increased use of recyclable and environmentally beneficial materials
   ii. Increased use of recycled material (“recyclate”)
   iii. Removal of ‘banned’ substances
2. Increased ‘design for disassembly, re-use and remanufacture’

Changes in the extent of ELV recovery:

3. Increased levels of re-use and remanufacture
4. Increased levels of recycling of ELV materials

Improved information provision:

5. Provision of the following information:
   a. Part coding standards
   b. Disassembly processes, disposal and recovery of vehicle parts
   c. ELV environmental performance, targeted at vehicle users/purchasers

For each expectation we provide (i) an analysis of the evidence needed to test outcomes, and (ii) an evaluation of the extent to which observed data provide empirical support for that expectation. In Section 3 we examine if the available data are

Material	% by Weight
Ferrous Metal	68.3%
Plastics	9.1%
Light Non-Ferrous Metal	6.3%
Tyres	3.5%
Glass	2.9%
Fluids	2.1%
Rubber	1.6%
Heavy Non-Ferrous Metal	1.5%
Other	1.5%
Battery	1.1%
Process Polymers	1.1%
Electrical/Electronics	0.7%
Carpet	0.4%

Fig. 1. Breakdown of a passenger vehicle. Figure shows the breakdown of an average car. Close to 100% of the steel within a vehicle is recycled. Due to their economic value, nearly 100% of car batteries are also already collected and recycled [62]. Additionally, the vast majority of tyres are recovered. The EU is on track to meet the objective to abolish the land filling of old tyres by 2006 [63]. Shredding facilities process crushed ELVs and other scrap metal-rich feedstock, such as white-goods. Seventy percent of shredder output is ‘shredded steel’, 25% is ‘shredder fluff’ and the remaining 5% is referred to as ‘heavy media’. Shredder fluff is made up of foam and a range of lightweight non-metallic materials, such as plastic and composite products that are difficult to recycle. This fluff is typically disposed off to landfill, although efforts are underway to develop methods of identification, separation, washing and recycling. The ‘heavy media’ are a mixture of non-ferrous materials and dense non-metallic material including rubber and concrete. This heavy fraction is sent for further processing at heavy media plants where copper, aluminium, magnesium, glass and some plastics are removed. Source: [35].

	Current	2006	2015
Re-use and recovery	75-80%*	85%	95%
Re-use and recycling		80%	85%
Implied allowable energy recovery		5%	10%

* [4]

Fig. 2. Recovery requirements for vehicles produced after 1980 by weight. The ELV Directive requires a 5–10% increase in recovery from current levels by 2006, and a 15–20% increase by 2015. Such improvements need to come from the 20–25% of the vehicle that is not currently recycled. This non-recycled component consists mainly of polymers, rubber, glass and electronic parts (most metals, including batteries, are already recycled). To reach the 2015 targets roughly half of these materials will need to be recoverable or vehicle material composition will need to shift toward materials that are already recyclable. As plastic comprises the largest proportion of the non-recycled component it is the logical focus of much of the current R&D directed toward recycling. * Ref. [4]. Note: energy recovery involves using the waste material to generate energy. This often involves utilising the heat generated from combustion of waste.

sufficient to establish whether change has occurred. In Section 4 we assess the extent to which the five expected outcomes have materialized in the aftermath of the ELV Directive. Conclusions are provided in Section 5.

3. What is the evidence?

So, what would constitute compelling evidence that the expectations above are being met? In general, transposition of the ELV Directive into member state legislation has occurred too recently to enable statistically rigorous quantitative analysis.[1] This partially explains the absence of such analysis to date, notwithstanding the abundance of existing commentary. Yet, an aggregation of publicly available information can provide an emerging picture of future outcomes. Such evidence is most compelling when either a large number of smaller European car manufacturers or a number of larger parent company manufacturers are moving in the same direction. Here 'parent company' refers to a company that owns and operates a number of smaller subsidiary car brands. For instance, Volkswagen is the parent company of the following brands that it manufactures: Volkswagen, Audi, Bentley, Bugatti, Lamborghini, SEAT and Skoda [7].

Our analysis uses data on European carmakers including company reports and websites, assessments made by governments and industry groups, and public media sources.[2] The parent company and brand reports reviewed in this analysis account for over 80% of the 2003 new passenger vehicle registrations shown in Fig. 4. Many car companies, including Toyota, Volkswagen, DaimlerChrysler, Ford, General Motors and the Fiat Group now publish detailed environmental reports. A growing number of carmakers also have dedicated environment/sustainability websites. Each of the 'expectations' above has been evaluated based on the evidence found in these sources and other publicly available reports (as listed in the references). In some cases, industry wide trends facilitate the assessment of environmental performance. In others, the available data are insufficient to clearly determine whether a given expectation will be met in the future.

The attribution of legislation as a driver of observed change also requires that such changes be distinguishable from trends that may occur regardless of regulatory impacts. Numerous factors can influence a company's decision to act. These include cost savings, brand image, regulatory constraints, consumer preferences and competitive pressures. Even without appropriate legislation, the 'invisible hand of the market' may move the automotive industry toward more (or less) sustainable practices. A decrease in the level of waste, energy use and water use can yield economic benefits in addition to being environmentally desirable. Decreasing resource requirements per unit output can mean lower costs of production and higher profits. Determining the level of influence of such factors vis-à-vis regulation is often difficult. While the conclusions of this study provide early evidence of the effectiveness of ELV legislation, the long-term implications of the ELV Directive are only beginning to unfold. A fuller understanding of the impact of ELV legislation will develop over the next decade.

4. Assessing expected outcomes

The automotive industry has had advanced notice that ELV legislation was on the agenda since at least 1989 [8]. Industry was also heavily involved in the legislative process that culminated in the ELV Directive. Improvements in ELV recovery have been influenced by national policies since 1990s. ELV regulations and/or voluntary agreements existed in 10 European countries prior to 2000 (Austria, Belgium, France, Germany, Italy, the Netherlands, Portugal, Spain, Sweden and the UK). Of these, Austria, France, Italy and the Netherlands had introduced national policies and agreements prior to the debate over the EU ELV Directive proposal, which was put forward in 1997. The other six countries established voluntary agreements and legislation between 1997 and 1999, in parallel with the debate over the ELV Directive. As a result, a number of technological and organisational innovations occurred in the 1990s. These included the creation of ELV treatment infrastructures and efforts to design for dismantling and recycling

[1] A large number of Member States have now enacted laws relating to the EU ELV Directive, though many did so after April 2002, the date specified for compliance in the ELV Directive itself [6] ACEA, *ELV Country Report Charts*. ACEA; 2004.

[2] Extensive searches were conducted on information databases including: Science Citation Index, LexisNexis, ABI/Inform and Business Source Premier.

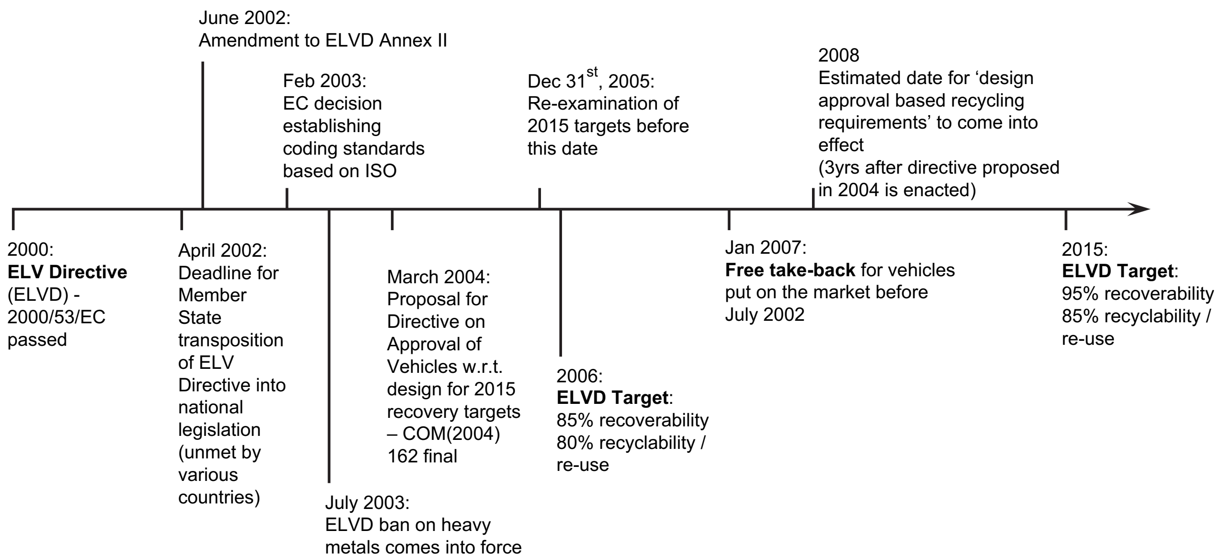

Fig. 3. ELV legislation timeline.

[8]. Current advances should be seen in the light of such innovations, which might have been stimulated by pending ELV legislation for over a decade.

Increases in the amount of industry wide Research and Development (R&D) into design for end-of-life would provide strong evidence that ELV legislation is having an effect. R&D into environmental protection can makeup a significant portion of a manufacturer's total R&D budget. For example, Renault states that around 40% of R&D programs are devoted to environmental protection [9]. In fact, recent information reveals that European automakers and suppliers are investing up to half of their R&D budgets on reducing carbon dioxide emissions [10]. Yet, there is little evidence that R&D expenditure on environmental management (including waste treatment, ELV recovery and emissions technologies) is increasing. Similarly, publicly available data did not show strong trends toward increased levels of environmental investment. For instance, Volkswagen *operating costs* for environmental protection increased by 30% between 1999 and 2003 (from Euro 150 million to 195 million). Of this 37% was spent on waste management. However, Volkswagen's *investment* in environmental protection has remained relatively steady over the past 4 years, ranging from Euro 24m to Euro 33m [11]. The environmental protection investments of Mercedes Car Group (part of DaimlerChrysler) jumped significantly from 2002 to 2003. Yet the level of its investments in 2001 and 2002 was smaller than those from 1998 to 2000 [12]. Industry and country-wide figures are also flat. R&D investment in the UK automotive industry has remained steady over the past 3 years at around £1 billion [13]. This represents approximately 2.3% of the total automotive manufacturing turnover, which held relatively constant between 1999 and 2002 at £42–44 billion [13]. Similarly, R&D by European automotive suppliers has remained steady at around 3.5% of revenue [14].

There is a lack of data on ELV specific R&D expenditure. Furthermore, due to the strong drive toward emissions reduction, fuel efficiency and energy consumption there are few clear signs that automotive manufacturers are making ELV recovery an R&D priority.[3] While access to detailed R&D investment data on ELV recovery would have been useful, there are other indicators (discussed in expectations 1–5 below) that provide insight into the impact of ELV legislation on 'green' innovation and vehicle recovery.

4.1. Expectation 1: changes in the material composition of new cars

Legislative, economic, technological and societal factors have all contributed to some distinctive material trends over the past few decades. The materials such as plastics and aluminium are increasingly being utilized due to their lightweight (resulting in less energy and fewer emissions to power a given vehicle) and desirable mechanical properties. Plastics are becoming central to vehicle production. The use of plastics has increased by 50% over the past 20 years [15]. European cars contained an average of 133 kg of plastics parts in 2003 [16]. Polymers are now used in over 1000 parts including bumpers, seats, dashboards, interior trim, fuel systems and upholstery. Plastic has prevailed despite its material predecessors being either easier to recycle (e.g. metals) or produced from renewable sources (e.g. wood).

Aluminium use in cars is also expected to increase dramatically over the coming decade [17]. ELV legislation may provide further incentives for this, as aluminium is easily and cost effectively recyclable to near 100% quality. As a result, ELV regulations may slow the use of composite materials, which could be replaced by metals such as aluminium [16].

[3] For example, the majority of Renault's efforts are targeted at emissions reduction, fuel efficiency and energy consumption. Similarly, the Fiat Group's 2003 Environmental Report states five research priorities targeted at environmental stewardship (p. 19). These deal with fuel efficiency, emissions, safety and traffic flow improvement. Efforts to increase the level of end-of-life vehicle recovery are not listed as a priority.

Parent Manufacturer	Share of New Registrations, 2003 (%)	Brands included
Volkswagen	18.2%	Audi, SEAT, Skoda, Volkswagen, others
PSA	14.8%	Citroen, Peugeot
Japanese Manufacturers	12.7%	Honda, Mazda, Mitsubishi, Nissan, Suzuki, Toyota, others
Ford	11.0%	Ford, Jaguar, Landrover, Volvo, others
Renault	10.6%	Dacia, Renault
GM	9.8%	OPEL, SAAB, others
FIAT	7.4%	Alfa Romeo, Fiat, Iveco, Lancia, others
Daimler Chrysler	6.5%	Chrysler, JEEP, Mercedes, Smart, other
BMW	4.4%	BMW, Mini, others
Korean Manufacturers	3.3%	Daewoo, Hyundai, Kia, others
MG Rover	1.0%	Rover
Other	0.3%	

Fig. 4. New passenger car registrations in Western Europe, 2003. Source: [64].

Consequently, it is predicted that the average European car will contain 240 kg of aluminium by 2010; a 120% increase from 2003 [16]. In addition to decreasing the amount of automotive waste going to landfill, recycling aluminium saves up to 95% of the energy needed to produce primary metal. Recycling 1 kg of aluminium can also save about 8 kg of bauxite and 4 kg of chemical products [18]. All of this adds up to sufficient economic savings to make the use of aluminium attractive.

Vehicle design remains driven by cost and functional properties. This is not surprising given that many experts believe that the environmental awareness of consumers is in decline [19]. As a result consumer demand is not a primary driver of environmental change in the automotive industry [19]. Still, some progress in design for end-of-life is being made, driven in part by regulatory pressures. Three ways in which change in a vehicle's material composition can manifest itself are discussed below.

4.1.1. Increased use of recyclable and environmentally beneficial materials

Increased emphasis on recyclability is leading to a rationalisation of plastic use. Fiat Group's 2003 Environmental Report states that the group's design efforts aim to maximise component recyclability, with hard-to-handle polymers being 'scaled back' in favour of other more easily recyclable plastics [20]. Similarly, Peugeot–Citroën state that efforts are made to (a) reduce the variety of materials to facilitate resource recovery after shredding, (b) use single family plastics per major function to enable entire sub-assemblies to be recycled without disassembly and (c) to reduce the variety of plastics in order to ensure optimal and profitable recovery processes [21]. GM and OPEL also aim to minimise the number of different plastics and to use non-blended compounds where possible [22,23]. Such efforts will impact a substantial number of car parts. For instance, Chrysler believes that by 2007, the company will modify up to 1000 parts per vehicle to ensure compliance with the ELV Directive [24]. A recent report by the SMMT includes numerous additional examples of environmentally friendly design and process improvements [25]. Notwithstanding the above, it is difficult to gauge the true extent of eco-design efforts and of the impact of such efforts (on a vehicle's material composition for example). It is similarly difficult to ascertain whether ELV legislation or cost improvements are driving these changes.

The impetus to minimise ELV waste may also fall counter to a company's desire to reduce the weight of a vehicle. As a rule of thumb a 10% weight reduction can lead to a 3–7% improvement in fuel efficiency and a subsequent reduction in air pollution [26]. A movement toward using recycled components could result in the need for heavier parts if recycled materials have inferior mechanical properties. A recent study by the APME found that such behaviour is counterproductive [27]. Using more recyclable materials that have poor mechanical properties would have the same effect. This has led some commentators to argue that ELV legislation could result in a movement away from plastics (which are light but often hard to recycle) toward metals such as aluminium (which is light and easily recycled) [19].

The drive toward recycling can also be at odds with other design trends. For instance the use of electronics in vehicles is increasing. Such parts typically contain metal–plastic composites and flame-retardant chemicals. This makes them difficult to separate and recover at the end of a vehicle's life. Similarly, products that use recycled content may also compromise recyclability. Composite products that comprise plastics reinforced with inorganic fibres such as fibreglass are increasingly being used due to their superior mechanical properties and lightweight. As a result, composite use is expected to rise by roughly 5% each year until 2008 [16]. However, the fibres themselves and the fillers used in the manufacturing process currently prohibit such materials from being economically recycled [28]. This has driven Ford to work on creating nanocomposite materials that are more recyclable, lighter and have better mechanical properties than regular composites [28].

Materials made of natural fibres have recently been making their way into car production. Carmakers have been testing hemp, flax, purified cellulose and native prairie grasses for automotive uses [29]. While the volumes are still relatively small, such fibres represent valuable alternatives to synthetic fibres. They are renewable, display excellent mechanical properties, are light in weight and can be combined with other materials to form natural fibre-reinforced composites. For these reasons, the Mercedes E-Class has more than 50 components produced in whole or in part from renewable materials [28]. Renault's Scenic II also contains 12 kg of renewable materials [9]. More than 140 auto parts at DaimlerChrysler contain natural fibres [30]. However, concerns have been raised that the ELV Directive may impede the use of raw materials, as recycling natural fibre-reinforced composites through means other than combustion is not currently commercially viable. As a result some experts are concerned that designers may switch to less favourable materials in order to meet mandatory recycling quotas [31].

It is also unclear whether ELV legislation will have a beneficial effect on the use of other new materials like bio-plastics. Such plastics are made from plant matter such as sugarcane, corn or soy and can be given biodegradable properties that allow them to be broken down by micro-organisms. They may also have environmental benefits such as reduced carbon emissions [32]. For instance, Ford is developing canola and soy based foams as an alternative to polyurethane foams which are widely used in car seats and cushions [29]. However, bio-plastics are not highly recyclable to date and as a result are not desirable from an ELV Directive standpoint [28].

Evidence that environmental concerns are being incorporated into the design process, as a first step toward the use of "green" materials is also instructive. The Society for Motor Manufacturers and Traders (SMMT) in the UK notes that 'Design for recycling' principles are gradually being adopted and implemented in the product design process [13]. Carmakers are increasingly using life cycle tools as part of the design process. For instance, all the materials in the Fiat Idea, a new compact car, were selected using Life Cycle Assessment (LCA) [20]. BMW is developing a life cycle simulation tool for the long-term design and maintenance of an environmentally safe recycling system [33]. Volvo has started to conduct life cycle analyses for all newly released models. These data are presented on Volvo's website for easy comparison between models [34]. In some cases specific tools have been devised to improve part recyclability. Renault's 'Index of Recyclability by Function (IRF)' was used on the Megane II functions and will be used to set common progress targets for suppliers. Nissan and Renault have also jointly devised the OPERA application (Overseas Project for Economical Recycling Analysis). OPERA is being used to simulate costs and recycling rates in the ELV recycling process [9]. GM's European operations have also adopted 'Design for Recycling' [23].

Overall, we conclude that ELV legislation has contributed to greater consideration of recyclability in the design process. This is already leading to a rationalisation of plastic use. Recylability and mechanical design considerations might also hasten the trend toward greater use of aluminium. However, the extent of movement toward recyclable materials is difficult to gauge. ELV regulation may also negatively impact the use of novel "green materials" like bio-plastics and natural fibres.

4.1.2. Increased use of recycled materials ("Recyclate")

A lack of industry and company-level data on recyclate use requires reliance on the aggregation of statements of intent and car-specific information. Evidence suggests that recyclate is increasingly being used in car parts [15,28]. For instance, Peugeot–Citroën state 'using recycled materials' as a criteria by which polymers are chosen in current designs [21]. BMW has also stated that it plans to gradually increase the share of recyclates in plastic components for future models [33].

Most ELV metals are relatively easily recycled (as discussed further below). However, the use of non-metallic recycled material remains low. Roughly 9% of the weight of a passenger car is plastic [35] and a common car weighs about 1100 kg [15]. Thus, even 30 kg of recycled material would equate to less than a third of the total plastics in a car. Most automobiles contain less than this amount. For example, Renault's Scenic II (an industry leader in terms of recyclability according to their 2003 annual report) contains 16 kg of recycled plastics out of a total of 150 kg (i.e. just over 10%) of plastic used in the car [9]. The Ford Focus also incorporates 39 recycled plastic parts, accounting for 21 kg of the car's weight [36]. Notably, Volvo has been providing externally verified Environmental Product Declarations (EPDs) for a number of their vehicles since 1998. Based on these EPDs, Volvo's 2004 vehicles contain between 7 kg of recycled non-metallic materials (the S80 model) and 23 kg (the S40 model) [34]. The BMW 3 Series contains 14% recycled plastics by weight [33].

Recyclate tends to be used in parts that do not require high structural/mechanical performance and in parts that are not generally visible to the occupant. For instance, the fuel tank and inner wheel housings contain the largest amount of recycled material in a Volvo [34]. The Volvo Car Corporation estimates that only 30 kg of recycled non-metallic materials could be used in a new car, subject to prevailing quality standards and the availability of materials [37]. Thus a figure of 100% non-metallic recycled materials as shown on Volvo's EPDs would signify 30 kg of recycled material being used. Similarly, OPEL's 2002 Sustainability Report outlines their goal to increase the share of recycled materials to 20% of the total plastic mass in the vehicle [22]. While it is possible to obtain high quality recyclate, it is rare to find automotive parts made from 100% recycled plastic. It is much more common to use a blend containing 25–50% recycled content [15]. This suggests that automotive plastics are being 'downcycled' rather than 'recycled'.

Recyclate is increasingly being used in car production. In the absence of ELV legislation the incentive to use such material would be significantly reduced. However, there is still a considerable way to go. A number of technological and economic barriers must be overcome before carmakers can replace existing plastics with their recycled counterparts.

4.1.3. Removal of 'banned' substances

The ELV Directive requires that components of vehicles placed on the market after 1 July 2003 do not contain mercury, hexavalent chromium, cadmium or lead. On the 27th of June 2002 the Directive was amended to modify the exceptions in Annex II, yet the target of heavy metal removal remains the same [38]. Evidence indicates that automotive manufacturers and their suppliers are complying with the ELV Directive's requirement [20,21,33,39]. Such changes are not restricted to

European cars. A recent report has found that the EU ELV Directive is, to some extent, driving activities in the US automotive market. In particular, the ELV Directive's aim to remove toxic and hazardous substances has resulted in international efforts to eliminate their use in vehicle manufacturing [28].

4.2. Expectation 2: increased ''Design for Disassembly, Re-use and Remanufacture''

The ELV Directive states that manufacturers must design and produce vehicles which facilitate the dismantling, re-use and recovery (including recycling) of end-of-life vehicles [3]. To this end there are indications that automotive manufacturers are investing resources to improve vehicle disassembly. However, there is little compelling proof that carmakers are designing vehicles to facilitate re-use and remanufacture. Several reasons for this are explored below.

To accurately understand the benefits of re-use and barriers to it in the automotive industry it is useful to place re-use in context with other forms of ELV recovery. Many authors have attested that there is strong evidence that the 3R framework (Reduce, Re-use, Recycle) is robust and generalisable [40]. Implicit within it is the notion that less material and energy use are usually better for the environment. Generally speaking, the higher up the process in the hierarchy the more environmentally friendly it is [41]. Hence re-use is theoretically preferable to recycling (see Fig. 5). Additionally, studies have shown that traditional recycling saves 10 times more energy than performing energy recovery [42].

While the 3Rs provide a useful starting point, a more granular breakdown of 're-use' would include upgrading, reprocessing, remanufacture, refurbishment, reconditioning, revalorisation and repair [43]. However, in order to strike a balance between simplicity and comprehensiveness this paper will consider remanufacture in detail. The aim of remanufacturing is to reprocess used products in such a manner that the quality of the products is as good or better than new in terms of appearance, reliability and performance [43]. Remanufacturing can often save more than half the energy and 80% of the material that would otherwise have been used to make a new product from scratch [44]. A recent study found that remanufactured engines could be produced with 68–83% less energy and 26–90% less raw materials than the manufacture of a new engine [45]. Fig. 5 incorporates remanufacturing and energy recovery into the 3R concept.

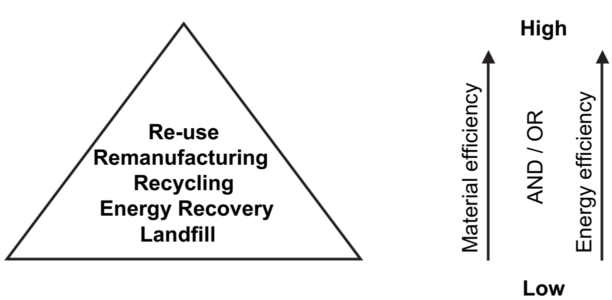

Fig. 5. Theoretical recovery hierarchy.

Vehicle manufacturers realise that there is a lot to be learnt from disassembling vehicles and analysing wear on old vehicle parts. Both Ford and BMW have established recycling and dismantling centres in Europe to integrate learning from end-of-life vehicles into design methods. BMW already has over 100 official dismantling facilities in Germany alone [46]. The information is used to benchmark and improve vehicle recovery (recycling in particular) [2,33]. DaimlerChrysler are also gaining disassembly and recycling knowledge from dismantling vehicles at Canada's Automotive R&D Center in Windsor [30].

Available information suggests that manufacturers are trying to improve design for disassembly.[4] For example, PSA Peugeot–Citroën claim to have embraced the principles of design for disassembly and re-use, with at least 95% of the average mass of new Peugeot and Citroën vehicles being reusable and recoverable. Renault also states that 95% of the Scenic II is recoverable [9]. Additionally, they profess to be contributing to a 'dual system' that incorporates part recovery for the used part trade in addition to material recovery for recycling. Similarly, OPEL engineers are encouraged to design for disassembly by avoiding the use of bonding agents and welded joints where possible and by using easily detachable clips or screws [22].

There is little evidence that car companies are investing in 'design for remanufacture'. Moreover, we have not come across any evidence that car parts are being designed to be remanufactured and then 're-used' in the production of future new vehicles. Such 'closed-loop' remanufacturing typically requires a significant change in design, operations and possibly industry structure. For instance, parts with inbuilt electronic components and design optimisation using finite element analysis have resulted in components becoming less economically feasible to remanufacture [43]. However, remanufacturing can be economically viable and is occurring in other industries. New electronic equipment such as photocopiers already contain a significant proportion of remanufactured parts; enabling the manufacturer to cut costs and increase the environmental performance of their products [47]. Remanufactured parts are also used in safety-critical applications such as aeroplane engines [43].

There may be a lack of remanufacturing because carmakers may not be the main beneficiaries of remanufacturing revenue. Until carmakers commit to remanufacturing their parts, increased profits will accrue to independent remanufacturers. Such a commitment could take the form of direct involvement in the manufacturing process or through close relationships between Original Equipment Manufacturers (OEMs) and remanufacturers.

At least three additional barriers exist to remanufacturing in a closed loop context. Firstly, the average age of ELVs in Europe is estimated to be approximately 10–12 years (with

[4] Improving the ease of disassembly is only one part of designing for re-use and remanufacture. The ability to re-use and remanufacture parts can be facilitated by designing them for greater durability. By doing so, a larger proportion of parts will be candidates for re-use when a vehicle reaches the end of its life.

significant variability among countries) [8]. Yet car designs change regularly; driven by consumer preferences and technological innovation. The combination of a long useful life and rapid technological change can inhibit closed loop remanufacturing, as by the time remanufactured parts are available many of the parts will be outdated. Yet this barrier alone need not prevent remanufacturing. Product leasing (which decreases the time before parts can be returned to the manufacturer) has been utilised effectively in conjunction with closed loop remanufacturing in the photocopier industry. Additionally, vehicle parts that are not forecast to change significantly may be better candidates for closed loop remanufacturing. Second, remanufactured parts are often perceived as being of poor quality and/or being 'old technology'. In high technology industries such as the automotive industry companies appear very cautious about doing anything that may affect their brand image of being an innovative company. It would be useful to understand the extent to which these perceptions continue to reflect customer sentiment.

Finally, design for closed loop remanufacturing must occur in parallel with a change in operations and logistics to be effective. Supply chains and inventory management processes must be altered to integrate remanufactured parts with new parts. 'Reverse supply chains' must be established to enable automotive manufacturers to collect used vehicles and then supply remanufactured parts back to the manufacturer. The remanufacturing process itself may require the acquisition of specific (and proprietary) knowledge and skills needed for disassembly and recovery, in addition to investment in customised equipment.

4.3. Expectation 3: increased levels of remanufacture and re-use

Re-use and remanufacture remain a small part of automobile recovery, partly due to the high cost of labour. But the industry is growing [48,49]. If ELV regulation has significantly affected re-use and remanufacture we would expect to see a jump in the volume of parts being used for this purpose. Observable changes in the eagerness of carmakers to participate in the after-use market would also suggest that the ELV Directive has had a direct effect in this area. However, such behaviour may be explained by economic motives as well, as discussed below.

Remanufactured parts typically end up in repair and aftermarket industries rather than going into new car production. In the UK, 69% by weight of total disposed vehicles is recycled/recovered, 11% is parts that were able to be re-used and the remaining 20% goes to landfill [25]. There may also be an opportunity to increase automotive remanufacturing in Europe. A comparison with US data suggests that the UK remanufacturing industry may generate revenues of several billion pounds [43]. However, market penetration for remanufactured products is higher in the United States than in Europe. Americans buy approximately 60 million remanufactured automotive products annually, while Europeans buy only 15 million. Yet, the total stock of vehicles is roughly comparable [48]. This highlights the potential for increased use of remanufactured components in Europe.

OEM participation in remanufacturing remains small, but there are encouraging signs that OEMs are taking a greater interest in remanufacturing and re-use because of the opportunities afforded by remanufacturing to increase profits and to gain feedback on failure modes and durability. In the United States, OEMs account for less than 5% of remanufacturing activity. Independent third parties makeup the majority of the 73,000 US remanufacturing firms [50]. The percentage of automotive remanufacturing undertaken by carmakers in Europe is also likely to be small. Nonetheless, remanufacturing by car companies is occurring. Volvo Cars' exchange system for remanufactured parts is one example. Through this system Volvo remanufactures used parts (obtained from dealers) to the same quality as new parts. Over 2000 different components, from gearboxes to consoles, are remanufactured in this manner and sold to consumers with a full warranty [51]. Remanufactured engines are also used by one OEM as replacements for under-warranty engines, resulting in considerable cost savings [48]. BMW also remanufactures 15,000 engines each year at its Landshut plant [33,46]. But, while the company supports component re-use in secondary markets, it does not do so in new cars [28]. Companies such as Mercedes-Benz and Ford currently harvest and sell spare parts as well. Notably, Ford has done so by buying salvage yards in North America and Europe [2].

There remain at least four obstacles to the widespread adoption of remanufacturing. Firstly, most products that currently arrive at the end of their life were not designed to be recycled or remanufactured [52]. Secondly, there has been an explosion in the number of car models over the past two decades [48]. This has lead to the production of fewer vehicles of each model. The result is that remanufacturers are less able to take advantages of economies of scale. Their ability to meet stringent supply requirements for just-in-time production processes is also diminished.

Third, there is significant supply chain uncertainty associated with remanufacturing and re-use, including: the supply of remanufacturable parts, the quality of the returned parts and variable processing times [2,48]. As a result, remanufacturers are forced to keep large inventories to mitigate against such variability. Yet, some of this uncertainty is likely to decrease in the future. Analysis of experiential data in addition to advances in technology such as electronic data logs will allow a more expedient and accurate assessment of the quality of returned parts. BMW is already moving in this direction. The new BMW 7 Series contains an on-board computer which constantly monitors component wear and alerts the driver when action is required [33].

Finally, alternate recovery methods are becoming more financially attractive. The development of sophisticated post-shredder technology is increasing the economic feasibility of recycling and energy recovery [49]. The ELV Directive could hasten this process.

Thus some carmakers are becoming progressively more involved in the business of collecting and selling used parts.

Similarly, a few companies are also taking the next step of rejuvenating these 'in-house' and selling them as remanufactured components. But it is too early to tell whether recent actions constitute the beginning of an enduring swing toward greater levels of re-use and remanufacture.

4.4. Expectation 4: increased levels of recycling of ELV materials

Ideally, annual ELV recycling rates, published at EU, national or company-wide levels would provide solid evidence as to whether or not ELV recycling has increased as a result of regulation. In the absence of such data, it is possible to gauge progress by assessing the level of R&D and innovation in recycling technologies.

There is mounting evidence that innovation in recycling is occurring. It is being driven by high recycling rate requirements in both the ELV Directive and the Waste Electrical and Electronic Equipment Directive. End-of-pipe recycling solutions are needed as vehicles already in use will reach their end of life by 2006. Hence, BMW has been working on recycling of pyrotechnic components (such as airbags and belt tensioners) in addition to new, automatic sorting techniques for plastics, metals and shredder residues [33]. Volkswagen has designed a new separation and recycling process, known as the VW-SiCon Process [53]. Not surprisingly, recent efforts have focused on extraction and recycling of polypropylene as it comprises the largest fraction of automotive plastics [54]. Yet there are exceptions. For instance, Dupont is developing technology to recycle nylon composites to produce resin that is "essentially equivalent" to virgin nylon [55]. Processes for disposing off plastics with brominated flame retardants are also being tested [56]. A wide variety of additional methods are being developed to sort and recycle plastics as well [57].

The automotive industry need only attain a 5–10% improvement in the rate of re-use and recycling to meet the 2006 recycling target of 80% set out in the ELV Directive. Current data are insufficient to assess whether carmakers are on track to reach this goal. What is clear is that one or both of the following will need to take place in order to reach the 2015 target of 95% recovery: (i) a dramatic increase in the recovery of plastic, rubber, glass and other non-metallic materials, and (ii) a movement away from these materials toward more easily recycled materials such as aluminium. Notably, the 2015 recovery target may be partially achieved through increased rates of energy recovery. This is detailed in Fig. 2. Still, the variety of recycling innovations taking place points toward an improved ability to recycle current materials on a commercial scale in the not too distant future. This, in combination with a modest increase in the level of re-use and remanufacturing may make it feasible to reach the 2006 target.

4.5. Expectation 5: increased level of publicly available information

The ELV Directive requires that producers use material coding standards, which allow identification of the various materials during dismantling. It also requires that information on the treatment of end-of-life vehicles and progress with regard to re-use, recycling and recovery be provided to prospective vehicle buyers. Is such information being provided?

Information available to vehicle recovery operators does appear to be improving. The International Dismantling Information System ('IDIS') and the International Material Data System ('IMDS') are two key automotive initiatives aimed at improving data collection and dissemination. The IDIS database and associated software are produced by the IDIS 2 Consortium, which consists of 24 carmakers. IDIS enables the identification of component materials to improve the efficient treatment of end-of-life vehicles. The database currently lists around 44,000 car components for 888 vehicle models from 24 car manufacturers. The 40 brands referenced in IDIS represent more than 95% of the current automotive European market, as well as all the major manufacturers from Japan, Korea and the United States [58]. Car companies are currently undertaking the significant process of gathering the required information from their suppliers and updating this information for distribution to those involved in end-of-life vehicle recovery. Auto parts suppliers also use another database, the IMDS to catalogue the composition of car parts (including their surface coatings). IMDS was developed by a number of European carmakers, though North American and Asian manufacturers have since embraced the system [59].

Coding standards are also being instituted to enable identification of components that are suitable for recovery, re-use and recycling [20,23]. The European Council for Automotive R&D (EUCAR) is currently working with its members to collect information on ELV treatment systems as well [20].

Car manufacturers are also making some efforts to communicate a vehicle's environmental performance to the customer. As noted above, Volvo has been providing Environmental Product Declarations (EPDs), verified by Lloyd's Register Quality Assurance, for a number of their vehicles since 1998. EPDs are seen as a potentially useful tool for communication of a product's environmental impact and may form part of an integrated European Product Policy according to the European Commission's Integrated Product Policy (IPP) white paper [60]. However, in order for EPDs to be useful and credible they require verification and standardisation of approach across the industry [61]. This remains to be accomplished.

In general, it appears that car manufacturers are improving industry's access to information on vehicle disassembly and recovery. Further effort is needed to provide the same level of information to car buyers. Consumers face a deficit of accurate, comprehensive and easily available information pertaining to the ecological impact of their potential purchase. This lack of verified data hinders the ability of a consumer to purchase a vehicle that is environmentally friendly.

5. Conclusion

ELV legislation is having a discernible effect on numerous '*end-of-pipe*' solutions such as innovation in recycling methods and shredder residue separation techniques. These new technologies are likely to be used to recycle material from a broad range of industries and particularly from white-goods, which are already processed in shredders alongside automobile hulks. However, *end-of-life design* considerations are not a high priority for car manufacturers. Economic imperatives and a drive toward customisation remain the key motivations in automotive design. Furthermore, eco-design efforts may be restricted by the delayed payback associated with long vehicle lifetimes and the fact that innovations in end-of-pipe recycling technologies will be required to process older cars regardless of design changes. This raises the possibility that car manufacturers might get locked-in to sub-optimal solutions that favour recycling over remanufacture and re-use.

Nonetheless, there are some important impacts of ELV legislation on design, particularly on material choice. There are strong indications that ELV legislation is leading to a reduction in toxic substance use. Numerous life cycle design tools, indicators and processes focused on improved material use are being utilised in the design process. Carmakers are reducing the number of different plastics being used in order to improve recyclability. It is also likely that ELV legislation will increase the use of aluminium, in part due to its ability to be easily recycled. Though the ELV Directive does not specify targets for the use of recyclates in vehicles there is evidence that recyclates are increasingly being used in car parts, albeit at low total volumes. There also appears to be a focus on increasing the proportion of materials that can be recycled or downcycled, rather than on the quality of recyclate.

The impact of ELV legislation on design for re-use and remanufacturing is limited. Embracing remanufacturing requires significant changes to organisational processes and an approach to design that incorporates remanufactured parts. Remanufacturing is likely to only be economically attractive to carmakers if they are able to share directly in the profits. To capture such benefits carmakers will need to actively participate in the remanufacture of their own parts or develop close financial and operational ties with existing remanufacturing organisations. At least initially, most remanufacturing activity will continue to be limited to the provision of replacement parts for existing vehicles.

There is evidence that the ELV Directive is resulting in improved collection and dissemination of data that enables efficient material and part identification. Some initiatives to communicate a vehicle's environmental performance to the customer are also appearing. However, in order for these to be useful to the end consumer such information will need to be available and standardised across models and brands.

Policy instruments can influence the choice of innovation path and "may work as 'selection devices' by constraining some innovative options while providing incentives to pursue other innovation solutions" [8]. In the case of the automotive industry the interplay of legislative and economic factors has led to an increased emphasis on recycling and hazardous substance removal. The resultant innovation may be sufficient to reach ELV Directive targets and may also have spill-over benefits to other industries. The next step toward sustainable vehicle management lies in increasing the levels of re-use and remanufacturing.

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