Management of the end-of-life of light and heavy vehicles in the U.S.: comparison with the European union in a circular economy perspective — Source link

Michael Saidani, Alissa Kendall, Bernard Yannou, Yann Leroy ...+1 more authors

Institutions: Université Paris-Saclay, University of California, Davis

Published on: 17 Jul 2019 - Journal of Material Cycles and Waste Management (Springer Japan)

Topics: European union, Circular economy, Extended producer responsibility, Benchmarking and Automotive industry

Management of the end-of-life of light and heavy vehicles in the U.S.: comparison with the European union in a circular economy perspective

Michael Saidani, Alissa Kendall, Bernard Yannou, Yann Leroy, François Cluzel

To cite this article: Saidani, M., Kendall, A., Yannou, B. et al. Management of the end-of-life of light and heavy vehicles in the U.S.: comparison with the European union in a circular economy perspective. J Mater Cycles Waste Manag (2019). https://doi.org/10.1007/s10163-019-00897-3

MANAGEMENT OF THE END-OF-LIFE OF LIGHT AND HEAVY VEHICLES IN THE U.S.: COMPARISON WITH THE EUROPEAN UNION IN A CIRCULAR ECONOMY PERSPECTIVE

Authors: Michael Saidani[1], Alissa Kendall[2], Bernard Yannou[1], Yann Leroy[1], François Cluzel[1]

[1]Laboratoire Genie Industriel, CentraleSupélec, Université Paris-Saclay, France

[2]Department of Civil and Environmental Engineering, University of California-Davis, USA

Contact author: michael.saidani@centralesupelec.fr

Published in: Journal of Material Cycles and Waste Management, on July 17, 2019.

Abstract: In a context of transition towards a more circular economy (CE), this study undertakes an analysis of the appropriate transfers and applications of best managerial practices, regulations and know-how from the automotive sector to the heavy vehicle one, as well as from the European Union (EU) to the United States of America (U.S.), and *vice versa*. While the EU appears to be a few steps ahead of policy activity regarding the management of end-of-life automotive vehicles (Directive 2000/53/EC and Extended Producer Responsibility principles), the U.S. heavy vehicle industry presents several aspirational industrial practices, including the collaboration between end-of-life actors, supporting parts remanufacturing and facilitating reuse. New empirical findings and lessons learned from both geographical regions are combined with previous analyses to develop a benchmarking template of commendable CE practices. Against this background, the findings open on the remaining challenges and circular economy opportunities for both regions, as well as for emerging and newly industrialized countries whose automotive markets are growing fast.

Key words: Circular economy, end-of-life management, end-of-life vehicles, best practices, recycling, policy making, extended producer responsibility.

Word count: 6,700 words excluding appendix, tables, and references.

INTRODUCTION

BACKGROUND AND MOTIVATION

End-of-Life Vehicles (ELVs) are one of the most valuable sources of secondary raw materials [1-2]. As the unidirectional model of production, so called linear economy, is unsustainable, a move towards a circular economy (CE) is becoming increasingly important, and the point of interest for many scholars, industrial practitioners and policymakers [3-4]. A CE is an economic system supporting a more sustainable management of resources throughout the life cycle of systems and is characterized by closed loops, promoting activities such as maintenance, sharing, leasing, reuse, remanufacturing and recycling [5]. In fact, a CE aims to retain the highest utility and value of products, materials, and resources at all times, to minimize the generation of waste [6]. However, despite the potential sustainable – economic, environmental, and social – benefits that more circular practices could bring, the challenges to both businesses and policymakers are diverse [7]. To accelerate the transition to a circular economy, Members States of the European Union (EU), as well as other countries such as China [8-9], are deploying a broad range of policy instruments [10]. Proper end-of-life collection and policy are indeed key enablers to establish and optimize a circular supply chain [11]. For instance, regulations must prohibit illegal waste collection channels, inappropriate disposal, and enable manufacturers in collaboration with recycling facilities to recycle both their own as well as competitors' products.

Yet, there is currently no specific policy framework regulating the end-of-life (EoL) management of heavy vehicles. Also, a review of the published literature shows that the EoL management of heavy-duty and off-road (HDOR) vehicles in the U.S. is, as in the European Union (EU), a research topic still barely explored in the scientific literature [12]. This gap in research, along with lagging policies and regulations for considering light and heavy-duty vehicles EoL in the U.S. has not gone unnoticed by relevant industry stakeholders. According to the CEO of the U.S. Automotive Recyclers Association [13]: "Different countries are on different parts of the path related to end-of-life management of vehicles. By looking at how other countries deal with their industry, one can choose some parts of the path that are desirable and try to avoid some of the paths that are unpleasant."

It is with that perspective that this research undertakes an analysis of the appropriate transfers and applications of best practices, regulations and know-how from one industrial sector (e.g., the automotive sector) to another (e.g., the HDOR vehicles sector) and from a geographic region (e.g., the EU) to another (e.g., the U.S.), and *vice versa*. It examines some suitable practices (e.g., the extended producer responsibility), challenges (e.g., an underground economy), and potential solutions (e.g., data standardization for after-sales services) in a context of CE transition. In addition, from a research perspective, the complexity of these two industries, plus their considerable environmental and economic impacts, make it particularly relevant to figure out how to implement circular practices. On this topic, a first short perspective note has been published in 2018 [14]. Yet, due to the size restrictions (perspective note limited to 1,500 words with a maximum of 5 references), even if it a convenient format to communicate rapidly on new research results, the content was not sufficiently detailed or practical from a managerial perspective for industrialists, and scientifically sound for researchers working on the circular economy implementation.

In the present and more comprehensive piece of work, the relevance of the juxtaposition of the U.S. and the EU situations is first justified. Then, after exposing the research methodology, an overview of the main findings, analyzing similarities and differences through the lens of policymaking and business practices in the management of EoL vehicles, is presented and summarized (tables 1 and 2). In particular, the actual regulatory framework, plus tangible and advisable industrial practices are revealed through a closer look at a comparison between the State of California in the U.S. and France in the EU. Against this background, a practical benchmarking template of commendable CE practices is proposed and discussed, considering feedbacks from diverse stakeholders after communication of this template to involved actors in the automotive and heavy vehicle industries. Finally, remaining challenges and CE opportunities are given for the U.S., the EU, and also for emerging countries and newly industrialized countries – e.g., BRIC countries (Brazil, Russia, India and China) – whose automotive markets are growing fast [1].

END-OF-LIFE VEHICLES IN THE U.S. AND IN THE EU

The U.S. and the European automotive markets are similar in terms of number of vehicles, but those vehicles vary with respect to size and age. Automobile ownership worldwide has exceeded 1 billion since 2010. The U.S. and the EU account for 50% of this total number, each having respectively 240 million and 270 million vehicles in circulation [15-16]. Also, the number of annual deregistered automobiles (20 million in the U.S. and 14 million in the EU) [17-18] is of the same order of magnitude, as well as the number of annual end-of-life vehicles (ELVs) officially recovered (12 million in the U.S. and 6.5 million in the EU) [19-20]. In the heavy vehicle industry, around 1 million HDOR vehicles are reaching their end-of-life in Europe each year [12].

Regarding the end-of-life management and processing of light-duty vehicles, as in Europe, the state-of-the-art American authorized treatment facilities (ATFs) handle properly and very efficiently the decontamination (i.e., the depollution), dismantling and shredding processes, according to State of California Auto Dismantlers Association (SCADA) [21]: “Vehicle fluids and other regulated materials are extracted and properly recycled. Recovered parts are then sold to repair other cars at a savings of up to 80% over the cost of new parts. Recyclable materials are sent to a processor and manufactured into new products.” While the American and European vehicle fleets and associated recycling industries share many commonalities, the vehicles that comprise these fleets are quite different. The average ELV in France weighs 1,040 kg and is 17.5 years old, while the average ELV in California is 1,700 kg and 15.6 years old [22].

RESEARCH METHODOLOGY

RESEARCH CONTEXT AND FRAMEWORK

In a context of transition towards a CE, this study – extending the geographical scope of the analysis done in the EU [12] – is motivated and made possible by a research collaboration during the academic year 2017-2018 between two universities, the University of California-Davis in the U.S. and the Université Paris-Saclay in France, supported by the Franco-American Fulbright Commission.

Actually, the first extensive investigation on the application of CE principles and practices into the HDOR vehicles sector has been conducted in the EU [12]. A multi-method approach was applied for data collection, combining different information sources grouped as desk-based and field-based research. The impacts of regulations, business models, and emerging technologies were notably analysed for CE performance. The results were rooted in the suggested CE building block framework of the Ellen MacArthur Foundation [23]. The passenger cars or automotive sector was considered as the reference one, as extended legislation and practices are already available and applied. On one hand, the automotive sector encompasses on-road engine vehicles weighing less than 3.5 metric tons. On the other hand, HDOR vehicles are composed of two categories, namely heavy-duty vehicles, which are mainly trucks, and non-road mobile machinery, including agricultural and construction machinery. HDOR vehicles have a gross vehicle weight rating or aggregate trailer mass higher than 3.5 metric tons.

To develop the present comparison between the U.S. and the EU, an updated literature review as well as new industrial field investigations were done in the U.S. with the aim of providing supplementary insights to the initial questions raised by the study undertaken in the EU [12]. These questions include: (i) to what extent is CE achieved and implemented in the automotive and HDOR vehicles sectors, (ii) what industrial practices and regulations are prevalent and supportive of CE goals, (iii) what are the key challenges both regions have to deal with for an enhanced CE of vehicles, and (iv) how could the U.S. could learn from best practices implemented in the EU, and *vice versa*?

MATERIALS AND METHODS

The materials and methods deployed for this study include a simplified version of the research methodology used for the analysis in the EU [12], applying both desk-based and field-based research:

- Here the desk-based research comprises an update of the published literature (until April 2019), industrial reports, and current regulations in the U.S., using combinations of the following keywords in academic and industrial databases [12]: {end-of-life management, heavy vehicles, heavy-duty and off-road vehicles, automotive, recycling, remanufacturing, recovery, regulations, extended producer responsibility, shredders, United States of America, USA, U.S., American, California}.
- The field-based research was through (i) on-site visits, and interviews with non-governmental organizations (e.g., the Automotive Recyclers Association, the National Stewardship Action Council, the Californian Product Stewardship Council) and industrialists (e.g., Caterpillar, Holt of California) actively involved in the automotive or HDOR industries, as well as (ii) through the attendance at one seminar indirectly related to the subject at the Institute of Transportation Studies within the University of California-Davis.

HETEROGENEITY OF CIRCULAR ECONOMY ENABLERS

REGULATORY FRAMEWORKS

While the American and European analogy in ELVs is noteworthy in terms of number of vehicles, the primary difference between these two regions lies in their regulatory frameworks. In the

EU, automobile recycling targets are established under the ELV Directive 2000/53/EC [24], which, since 2015, sets a minimum of 85% for reuse plus recycling and 95% for reuse plus recovery, as detailed in Table 1. European automotive manufacturers and importers are responsible for recycling costs based on the principle of Extended Producer Responsibility (EPR). The EPR, also known as product stewardship, is a principle requiring that producers have the responsibility (i.e., to organize, and to pay in some European countries) for the collection, treatment and recycling of waste arising from their products at end of life. Producers shall also ensure the take-back (free of charge) of end-of-life vehicles and provide information about the proper dismantling of such vehicles in the EU [25].

By providing a robust framework of requirements for collection and recycling, the EPR has already moved entire industries – like the automotive sector in the EU – towards a more circular economy, as opposed to a more limited company-by-company approach [26]. Another complementary key requirement is to issue a certificate of destruction (CoD) which is a condition for deregistration of the end-of life vehicle. The link between the vehicle registration system and the waste management system is important to steer the ELVs into the authorized treatment facilities (ATFs). In addition, shredder installations within these ATFs for light vehicles fall under the scope of the European Waste Framework Directive [27] and Industrial Emissions Directive [28], which imply that these ATFs shall apply best available techniques (BAT).

Arora et al. [1] also conducted a comparison of ELV management systems between different countries worldwide at a macro level (e.g., comparing the ELV laws in the EU, Japan, Korea or Taiwan). In accordance with their study, a proper ELV Directive integrated within the framework of the EPR scheme is a key enabler to succeed in controlling the number or the fate (e.g., proper treatment in ATFs) of vehicles reaching their end-of-life. As a result, the EoL processing of the automotive sector is increasingly streamlined and well-organised in the EU. Note that this European Directive concerns only the automotive sector, and thus the EoL management of HDOR vehicles is more uncertain and poorly controlled. Indeed, to date, there is no overall end-of-life regulations concerning the HDOR industry in the EU. The end-of-life management of HDOR vehicles is still a marginal and barely structured activity in Europe [12].

In contrast, in the U.S., there are neither specific national regulations, such as EPR, nor quantitative recycling targets for the disposal of light- or heavy-duty vehicles. The result is inconsistent States regulations. The recycling of ELVs is only managed under existing and cross-sector regulations on environmental protection [29]. Also, contrary to the EU, no parties are particularly specified or responsible for implementing EoL activities or providing recycling infrastructures in the U.S. Legislation is, as such, a key action lever to enter EoL vehicles into appropriate circularity loops, in addition to an appropriate vehicle registration system to prevent the illegal treatment and disposal of end-of-life vehicles. The European experience has demonstrated the viability and success of law-making to encourage the reuse of automotive parts, through its associated remanufacturing and recycling markets. The latest European example in this regard can be found in France: in line with the EU action plan for the circular economy [30], the French environmental ministry introduced a legislation, which became active in 2017, mandating that automotive repair shops should offer customers, whenever possible, the choice between spare parts coming from CE loops – i.e., parts that can be reused in their existing state or after remanufacturing - and originally manufactured parts

On this basis, some organizations in the U.S. – such as the National Stewardship Action Council (NSAC) and the Automotive Recyclers Association (ARA) – are working to make progress with legislation and to change attitudes progressively towards more responsible and sustainable practices. The NSAC, founded in 2015 as an affiliate of the California Product Stewardship Council, is acting in speeding up the process of creating new laws to both support the EPR and provide a CE in the U.S. Yet, according to the NSAC Executive Director, in 2018, no new legislation related to the end-of-life management of light- or heavy-duty vehicles is under development in the U.S. or in California. In fact, the NSAC needs active industry participation and involvement – e.g., from both automotive producers and recycling facilities – before beginning or considering legislative proceedings, like working on a bill setting up an EPR for the automotive market. In addition, the CEO of the ARA, confirms that the 2018 U.S. political administration is not really pledging for new environmental regulations and automakers still fear that the use of second-hand parts from CE loops will lower their economic benefits [13]. Nevertheless, the ARA is still advocating in front of U.S. Congress members – to take the regulation process forward. Also, because proper education appears to be another key action lever to close-the-loop, the ARA University in the U.S. has developed the first eLearning Center that delivers best practices for the automotive recycling industry, including courses such as dismantler training, as well as parts upgrading or sales specialized training, to achieve a sound end-of-life management of salvaged vehicles.

INDUSTRIAL AND MARKETING ACTION LEVERS

Meanwhile, when political actions are neither proactive nor supportive, closing-the-loop of the automotive industry has to be motivated by other considerations, such as economic ones. For instance, the embracement of circular practices – such as product as a service, product life extension, preventive maintenance, recovery and recycling, just to name a few – by automotive manufacturers could generate $400-600 billion of potential additional revenue for them by 2030 worldwide [31], thus making the adoption of CE practices a very profitable activity in the automotive market. This possible additional revenue for automotive producers takes into account extensive repair and reuse activities in the automotive industry, plus after-sales services such as (preventive) maintenance, as well as sales of second-hand spare parts, embracing as such a wide range of CE strategies. Even if some automakers in the U.S. are starting slowly to collaborate with recycling automotive third parties, the ARA notices a lack of clear and committed support to parts reutilization from automotive OEMs. The two main challenges are to: (i) make U.S. automakers aware of economic opportunities offered by circular practices, and (ii) to assist them in their transition towards more circular businesses, e.g., by disseminating best industrial practices and their associated benefits. In the EU, the positive net value of the collected end-of-life vehicles is high enough in most countries (mainly where producers are actually paying recycling fees, e.g., in Netherlands) to finance collection and treatment operations thanks to take-back schemes organized by a collaboration between recycling centers and producers [32]. Note that the effort and costs of end-of-life operations (applying BAT to ensure high-quality recycling), are expected to be more and more expensive over the next years, due to, e.g., new materials in vehicles (such as carbon fibre reinforced plastics which are hardly recyclable), the increasing equipment levels (e.g., complex electronics, air conditioning systems) in cars, as well the expansion of the electric vehicle market (where the dismantling and recycling of traction batteries add extra costs).

In the meantime, the U.S. automotive industry could take inspiration not only from European automotive actors but also from their own heavy-duty and off-road industry, as explained hereafter.

In the absence of a regulatory framework addressing the EoL management of their fleet [33], HDOR vehicles producers, aware of the remaining value of their used equipments, are proposing a growing number of remanufactured HDOR equipment along with new products as a part of their aftermarket product offering. Indeed, many HDOR producers recognize the value of remanufacturing, and an estimated 200-300 firms are remanufacturing HDOR equipment in the US [34]. For example, the largest HDOR equipment company, Caterpillar, is leading the way by producing both new and remanufactured HDOR equipment in the US and worldwide, through a wide network of collaborators to ensure circular supply chain through reverse logistics. In fact, Caterpillar's remanufacturing programme took back annually around 2.2 million EoL units for remanufacturing, representing (i) 73,000 tons of materials, including 50,000 tons of iron; (ii) 6,000 different remanufactured products such as engines, fuel systems, and tyres. Incentives such as a deposit scheme and voluntary take-back of products ensure that large quantities of parts are returned to Caterpillar [12]. For instance, at a regional level, the company Holt of California is the authorized distributor for Caterpillar, putting back on the market remanufactured parts in cooperation with local stakeholders and customers.

In Europe, a similar story can be told but in the light-duty sector. The French automaker Renault has developed collaborations with third parties to ensure an efficient reverse supply chain supporting closed-loop reuse, remanufacturing and recycling of end-of-life vehicles, both to comply with the ELV Directive 2000/53/EC and to achieve sustainable profits. Operating a network of 350 dismantlers that have disassembled more than 110,000 vehicles in 2016, Renault is working with INDRA Engineering, a pioneer in automotive recycling, and Suez Environment, a specialist in global waste management. Similarly, a joint venture named Encory has been launched in September 2016 between the German automaker, BMW Group, and ALBA Group to enhance reverse logistics, supporting therefore the reuse and remanufacturing of used automotive parts, both to meet the requirements of the ELV Directive, and to achieve more economic profits. In the U.S., the State of California is already trying to develop and implement sound practices in terms of ELVs management. As INDRA Engineering operating in France [12], the SCADA operates state-of-the-art and licensed recycling facilities that take responsibility for recycling and disposing of ELVs using environmentally responsible practices, as well as selling used vehicle parts [21]. In line with increasingly strict emissions regulations, the State of California Vehicle Retirement Program proposes a scrapping premium offer (up to $1,500) as a catalyst for retiring old vehicles from the road to enter into proper and authorized end-of-life channels. In the present case of financial incentives to foster *a priori* more sustainable behaviours, it should always be analysed and discussed if a scrapping premium offer is deployed a means to promote better recycling or to promote sales of new vehicles. One may argue that if the amount of money offered as a scrapping premium is too high, functioning vehicles might be abandoned and scrapped too early, which would decrease the average lifespan of the vehicles, accelerate the products cycles, and contradict the concept of a sustainable circular economy.

HOMOGENEITY OF REMAINING CHALLENGES

AN UNDERGROUND ECONOMY

Even if an increasing number of CE-related initiatives are noticed, both regions could perform better from a CE perspective. For instance, in France – with more than 1,650 authorized treatment facilities (ATFs) and 60 licensed shredders – 1.1 million ELVs are properly and legally recovered by ATFs over the 1.8 million produced each year, according to the ADEME [35] (figures from the year 2014) and the Oeko-Institute [36]. This means that around 0.7 million of ELVs are lost in illegal recycling channels on a yearly basis (in 2014) in France. Similarly, in California – with around 1,100 auto dismantlers licensed by the California Department of Motor Vehicles – 1.2 million vehicles reach annually the end of their useful lives, among which 30% are being processed through unlicensed dismantlers [21]. Actually, despite their differing political commitment to ELVs management, the U.S. and the EU are facing similar challenges to achieve an augmented circularity of their used or retired vehicles within closed-loop systems.

As illustrated with the numbers above, the gap between deregistered cars and ELVs entering in ATFs is not negligible. Significantly, the SCADA identifies and blames an "underground economy" of unregulated dismantlers that do not have the same environmental regulatory requirements, insurance, reporting and documentation obligations, and tax liability as required for licensed dismantlers. This unfair trading and competition leads many licensed operators out of business. For instance, in California, the number of licensed dismantlers has declined from 1,236 to 1,072 in five years, between 2011 and 2016. To tackle this issue, SCADA urges for better cooperation between key stakeholders in the automotive industry in California, including the Department of Motor Vehicles, the Board of Equalization, the Vehicle Registration Authority, and the California Environmental Protection Agency. Likewise, the 1,650 ATFs distributed in the French territory fail in collecting every ELV. As a result, tons of ELVs leak from European end-of-life channels, to be exported to Eastern Europe or North Africa where infrastructures to handle, dismantle and recycle ELVs are underdeveloped, which is a significant challenge that needs to be addressed.

As such, Sakai et al. [15] suggested that "a global consensus on the rules for ELV management systems and on their operation at an international level" should be required. Similarly, focusing on e-wastes produced in Europe, Palmeira et al. [35] showed that the poor management of growing amounts of e-wastes has given rise to illegal international trading of such wastes, resulting in environmental harm, unsafe working conditions, and loss of economic opportunities for the EU. To combat the illegal market, potential solutions are exposed concluding that the best mean to defeat this unfair trade is to implement an enhanced and operational take-back system.

TOWARDS A DATA STANDARDIZATION ON SPARE PARTS

Another obstacle for a better circularity of parts and materials from ELVs is the inconsistent access to standardized, understandable and usable data, on spare parts to manage their proper and effective reuse or repair, for all players in the automotive industry whether in the EU or in the U.S.. Particularly, the access to the OEMs' information on vehicle parts is essential for automotive recycling businesses to put back on the market the right parts at the right prices. The European Commission has already pinpointed this challenge, stating that "information on all parts of the vehicle shall be made available in a database easily accessible to independent operators" [36]. In a CE perspective and to reach a sustainable management of ELVs' parts, this information is of utmost importance due to the increasing complexity of vehicles, including the growing number of parts, electronic components, and composite materials. In the EU, manufacturers shall provide access to the vehicle repair and dismantling information, but they may charge a fee for accessing such data [37]. International manufacturers fulfil this obligation through the International Dismantling Information System (IDIS) [38]. Yet, according to discussion with a manager from INDRA state-of-the-art recycling centers in France [39], these requirements are not systematically implemented into practices and the IDIS does not consider the practical needs of the dismantlers (e.g., lack of useful and pragmatic information to guide the operators when disassembling an ELV).

While the HDOR actors have already realized this issue and are actually implementing measures in this regard both in the EU and in the U.S., the ARA advocates for similar actions within the U.S. automotive sector, whether by regulations setting or by cooperation between OEMs and end-of-life third parties. Taking the lead, the Heavy Duty (HD) Distribution Association and HD Manufacturer Association are creating product data standards for the HDOR aftermarket, involving manufacturers, distributors, data system providers, and maintenance centers [40]. Thus, by standardizing and streamlining aftermarket product data, the communication about product and system attributes will be improved across the HD aftermarket, resulting in getting the right part more effectively for end-customers and fostering remanufacturing and reuse of components, which are actually critical elements for advancing the shift towards a more circular economy. A comparison table of best practices and main remaining challenges in the EoL management of light- and heavy-duty vehicles for both regions, as a summary of previous sections, is given in Table 2.

BENCKMARKING TEMPLATE OF COMMENDABLE CIRCULAR ECONOMY PRACTICES

DESCRIPTION OF THE TEMPLATE

In order to spread best CE practices faster and in an operational way for industrial players, a both synthesized and practical benchmarking template has been developed. The Joint Research Center (JRC) [41] defined best environmental management practices (BEMPs) as the techniques, measures or actions implemented by the organisations of a given sector which are the most advanced in terms of environmental performance in areas such as energy and resource efficiency, emissions, or supply chain management. Similarly, here, a best circular economy practice can be defined as a commendable activity, action, strategy or technique deployed in an industrial sector in line with the CE principles, as defined in the introduction [5-6], which contributes significantly to the circularity performance of systems (e.g., through resource conservation, waste reduction) and can serve as an example or inspiration source for other stakeholders of a same or other industrial sector. In their report, the JRC provides an overview of BEMPs in the automotive manufacturing sector, with a focus on the manufacturing and end-of-life vehicle handling stages [41]. It includes general best practices for remanufacturing components, as well as BEMPs for the handling of end-of-life vehicles, including ELVs collection (component and material take-back networks) and ELVs treatment (enhanced depollution of vehicles, and general best practices for plastic and composite parts). As such, it aims to be a source of inspiration and guidance for any company of the sector wishing to improve its environmental performance.

In a complementary manner, in a CE perspective, and at a time when industrial actors are not systematically aware, do not have access or time to read over full academic researches or complete reports, the proposed template of best CE practices aims to disseminate appropriate industrial practices to catalyze the CE transition in both the automotive industry and the heavy vehicle industry. The proposed template includes inspiring and state-of-the-art industrial strategies as well as business examples, combining commendable practices found in the U.S. and in the EU. By providing sound information on CE implementation, we argue the diffusion and dissemination of good practices can create a right incentive to increase circularity performance. For instance, this template can help identify the available and effective action levers to close-the-loop on valuable components, as well as to support the implementation of CE projects at different and complementary levels. Indeed, it could be used as strategic roadmap towards the CE, to position relatively to competitors, to motivate and inspire further circular strategies, to define quantitate objectives of circularity, to communicate internally or externally about sustainability, to raise awareness of employees or to train workforce (e.g., engineers, designers) on the CE principles.

These best circular practices are presented through several industrial examples. They are organized according to the four building blocks of the CE defined by the Ellen MacArthur Foundation (namely, (i) circular product design, (ii) new business models, (iii) reverse cycles, (iv) favourable system conditions) [23] and in line with lifecycle thinking and systemic approach (considering most of the stakeholders of these industries, i.e., extractive industry, suppliers, designers, makers, distributors, retailers, users, after-sale services, end-of-life centers). Notably, some quantitative impacts of circular practices on the three pillars of sustainability (i.e., economic, environmental, and social) are given. Here are the sample of companies and OEMs from which best CE practices have been taken, gathering the different industries of light-duty, heavy-duty, on-road and off-road vehicles, so that the commendable circular design and business practices in these industrial sectors can be learned from one another:

- For the automotive industry (e.g., cars), examples of best circular practices are taken from French automaker Renault and its collaborative network, including INDRA Automotive Recycling.
- For the heavy-duty vehicles (e.g., trucks) industry: Volvo Trucks, and DAF.
- For the construction equipments, agricultural machineries and off-road vehicles (e.g., excavators or tractors) industry: Caterpillar, Liebherr, Komatsu, and John Deere.
- For the handling vehicles (e.g., forklifts) industry: Fenwick-Linde, Manitou, and Toyota Material Handling.

The practical two-page benchmarking template is available in Appendix A.

DISSEMINATION OF THE TEMPLATE

Contacted companies and industrialists

The benchmarking template of best CE practices, detailed in the previous sub-section, has been disseminated to diverse stakeholders of the light and heavy vehicle industries, both in the U.S. and in the EU. Feedbacks from several of them are discussed hereafter.

First, major companies to contact, in order to disseminate and get feedback on this template, have been identified through the following rankings:

- Top 12 world's construction equipment manufacturers, in decreasing order, based on sales volume [42]: Caterpillar (USA); Komatsu (Japan); Volvo Construction Equipment (Sweden); Hitachi Construction Equipment (Japan); Liebherr (Germany); Sany (China); Zoomlion (China); Terex (USA); Doosan (South Korea); John Deere (USA); XCMG (China); JCB (UK); […] Manitou (France ~25th).
- Top 7 truck manufacturers, in decreasing order, based on worldwide revenue [43]: Daimler AG Trucks (Mercedes-Benz, Freightliner, etc.); Volvo Trucks; Paccar Trucks (Kenworth); MAN Trucks; Scania Trucks; DAF; Iveco.
- Top 10 automotive manufacturers, in decreasing order, by motor vehicle production [44]: Toyota; Volkswagen Group; Hyundai / Kia; General Motors; Ford; Nissan; Fiat Chrysler; Renault; Groupe PSA.

Then, the method used to find out relevant contact persons, and industrialists within these companies, was an Internet search on Google and LinkedIn, based on the following keywords (both in English and French): {Company Name AND Circular Economy; Company Name AND Sustainability; Company Name AND Corporate Social responsibility (CSR); Company Name AND Sustainable Development Director}

Finally, once a relevant and potentially interested industrialist has been identified, and the information contact found, an email was sent to this industrialist, explaining the purpose of such a document and asking for some constructive feedback on it.

Industrial feedbacks

In all, the template has been sent and shared to twenty-two industrialists (including sustainable development managers, environment engineers, business development managers, corporate social responsibility managers, etc.) from automotive and HDOR vehicles companies listed in Table 3. A positive and constructive feedback were received from five of them, in addition to the comments of the managers from Liebherr Machines Bulle and Manitou Reman, and with whom two more advanced industrial case studies have been conducted [45].

For instance, the head of responsible business unit from Scania confirmed it is a "very interesting research topic and great initiative to summarize best practice" and indicated this document will be shared internally to the appropriate persons. According to the Remanufacturing

Manager from Manitou, such template is very useful to push forward the sustainable development actions undertaken by the CSR department, to inspire the design and engineering department at developing more circular products, as well as to help defining realistic targets and proper action plans (including resources and budgets) to achieve these objectives.

Here is the insightful and illustrative feedback from the Parts & Services Manager at Volvo Construction Equipment France (translated from French): “The topics covered in your template are almost all covered at Volvo CE with more or less maturity. Within the parts and services department, we are currently working on a "1st life", "2nd life", "3rd life" and "4th life" approach considering the entire lifetime of a machine, with associated adaptive offers for the customers. Finally, the total cost of ownership is an aspect that we are also working on but with some difficulties because it depends on many parameters, including the type of machine and the type of application (which are much more diverse in our industry).”

Last but not least, here is the valuable critical feedback from the Director Environment and Innovation at Volvo Trucks Sweden: “The template works well as a “checklist” and inspiration. It was a very good overview and shows well the different aspects and opportunities. However, I missed a couple of interesting aspects such as circular metric (how to measure circularity), sensors and similar (how to better understand usage for better re-use and recycling) and content knowledge (know what materials you have in your truck/machine). We are right now involved in research projects regarding e.g., circular metric. In that project we also try to understand the sustainability aspects of circularity.” The insights provided by these feedbacks are further discussed in the next section of this article.

DISCUSSION

INSPIRATIONS FROM BEST CIRCULAR ECONOMY PRACTICES IN BOTH REGIONS

All in all, each region and these two industrial sectors can learn from one another to a certain extent by sharing their best political, industrial and business practices in a CE perspective, and by implementing them through e.g., benchmarking, joint venture, international cooperation, and/or regulatory framework. Joint ventures and cooperation between producers and end-of-life actors are indeed effective approaches for activities where economic drivers exist, and profits are possible. However, for activities without immediate or sufficient economic drivers (e.g., design for dismantlability, depollution, recycling of shredder light fraction), cooperation would not be sufficient, and an additional regulatory framework would be necessary.

Discussing the role that an EPR plays in the EU attempt to move towards a more CE, Kunz et al. [26] found that despite the positive results in EPR so far (in implementing some aspects of circular economy), a number of challenges remains and has to be addressed, including how to ensure proper enforcement of recycling standards, as well as incentives for fostering design for recyclability, and the need for harmonized legislation and coordination between all stakeholders. As such, to move towards a truly circular eco-system in both automotive and HDOR industries, we highlight the importance not only of a proper regulatory framework (e.g., in the EU for the automotive sector) but also of a common vision and shared commitment between all industrial actors concerned in the (re)use of automotive parts and HDOR equipment. Eventually, as stated by the director environment and innovation at Volvo Trucks Sweden, the use of existing or the new development of appropriate CE indicators [46-47] is a key to monitor this CE transition while ensuring sustainable benefits.

MANAGING THE CE IN THE LIGHT AND HEAVY VEHICLE INDUSTRIES WORLDWIDE

Both the heavy vehicle industry globally and the automotive sector in the U.S. could take inspiration from the different and complementary regulations that drive and monitor a sound end-of-life management of cars in the EU. Also, the automotive industry can be inspired by some commendable CE practices implemented in the HDOR sector. For instance, while the retreading of tyres is well-established in the heavy vehicle industry, this commendable practice from a CE perspective is less popular in the automotive sector.

Actually, connecting a worldwide understanding in the end-of-life management of vehicles is an important milestone to unlock the great potential of an operational and sustainable CE [7]. Furthermore, newly industrialized countries – such as China or India – where the number of vehicles reaching their end-of-life will soon outnumber the European or American figures should be a focus of research and advocacy for improving ELV management and CE. In this light, we also believe it is of utmost significance for them to anticipate and to take inspiration from the best existing practices in both the EU and the U.S., so as to innovate towards even more effective management. An interesting line of future research would be to investigate how can some of the best circular economy practices implemented in the EU or in the U.S. be transferred to newly industrialized countries such to India and China, considering how these countries are different in terms of regulatory framework, standard of living, economic wealth, repair and recycling infrastructure (where the informal sector might be dominant), and mobility structure (e.g., tuk-tuks, motorcycles).

In this line, Lishan et al. [48] recently addressed this important and yet under-explored issue by analyzing the environmental and economic performances of remanufactured operations performed on one HDOR equipment (a loading machine) in China. Specifically, this study compared the environmental and economic benefits between two remanufacturing scenarios and the business-as-usual case, with empirical data indicating significant environmental gains from remanufacturing, which may encourage greater use of this process in future. Similarly, India is actually facing an important motorization growth with more than 200 million motorized vehicles registered in 2017, which will lead to a humongous quantity of end-of-life vehicles to handle in the next few years [1]. As such, Arora et al. have developed an ELV management framework including the proposition of a business model for improving the sustainability of the end-of-life management of vehicles in India. The purpose is to anticipate and solve issues such as “the lack of standard operating procedures, ambiguity in deregistration of vehicles, and poorly informed consumer practices that prevent an effective and sustainable ELV management”.

CONCLUSION AND PERSPECTIVES

The aim of this present work was to analyze and support the possible transfer of commendable circular economy practices from one industrial sector to another one. The best CE practices and remaining challenges of the automotive and heavy vehicle industries – which share some similarities (e.g., components, materials) but have also their own specificities (e.g., regulations, marketing practices) – have been put in parallel through the four building blocks of a circular economy. In this line, a practical benchmarking template has been developed and disseminated to key industrial players of the heavy vehicle industry. Also, two geographical regions – the U.S. and the EU – have been compared in regard to their management of end-of-life vehicles.

To conclude and open up on promising perspective for future work, it has been found that a CE of vehicles in the EU is mainly driven and stimulated by the ELV directive 2000/53/EC including the EPR principle, forcing industrial automakers to cooperate with end-of-life third parties to meet the mandatory recovery, reuse and recycling targets, as well as to comply with the end-of-life treatment obligations. In contrast, progress towards an augmented circularity of vehicles in the U.S. is pushed less consistently by individual actors and associations advocating for a circular economy.

While the EU appears to be a few steps ahead of policy activity regarding the management of ELVs (but only for the automotive sector), the U.S. HDOR sector presents some aspirational industrial practices, e.g., collaboration between HDOR aftermarket actors or the Caterpillar example, supporting parts remanufacturing and facilitating reuse.

To extend the discussion against this background, it can be interesting for future research to study how two more separate industrial sectors can learn from one another in their transition towards a more CE. For instance, to what extent the research contributions and industrial practices that support the CE in the automotive and heavy vehicle sectors could be transferable or adapted to other sectors that are facing similar challenges in the management of their end-of-life fleet, such as the aircraft industry. In other words, how the aircraft industry could benefit from the approaches, methods and tools developed in the automotive or heavy vehicle industries that seem commendable in a CE transition, and *vice versa*. Actually, while neglected for a long time, the end-of-life stage of the aircraft's life cycle has come into greater focus in recent years [49-50] as a consequence of: the increasing number of aircrafts which are reaching the end of their working life; the important added value components and materials that can be recovered; the trend in the transportation sector which goes to legislation in terms of EPR scheme. Also, similarly to the heavy vehicle industry, there is presently no specific regulation which regulates the treatment of worn-out aircrafts, and the research on the fate of end-of-life aircrafts is quite recent [51].

ACKNOWLEDGEMENTS

The authors would like to acknowledge the support of the Fulbright Commission and the Institute of International Education to make possible this study through a research collaboration between the University of California-Davis, in the U.S., and CentraleSupélec, Université Paris-Saclay, in France. The authors also thank all the industrialists who not only took the time to go over or experiment our proposed benchmarking template but also provided insightful comments on it. Last but nor least, the authors would like to thank the two reviewers for their insightful comments and valuable suggestions, including complementary information and additional relevant references that have been analyzed and incorporated, to augment the quality and content of this research work.

REFERENCES

[1] Arora N, Bakshi SK, Bhattacharjya S (2019) Framework for sustainable management of end-of-life vehicles management in India. Journal of Material Cycles and Waste Management, 21:79–97.

[2] Rosa P, Terzi S (2018) Improving end of life vehicle's management practices: An economic assessment through system dynamics. Journal of Cleaner Production, 184: 520–536.

[3] Matthews JA, Tan, H, Hu M (2018) Moving to Circular Economy in China: Transforming Industrial Parks into Eco-Industrial Parks. California Management Review, 60:157–181.

[4] Bocken NM, Olivetti EA, Cullen JM, Potting J, Lifset R (2017) Taking the circularity to the next level: A special issue on the circular economy. Journal of Industrial Ecology, 21:476–482.

[5] Geisendorf S, Pietrulla F (2017) The circular economy and circular economic concepts—a literature analysis and redefinition. Thunderbird International Business Review, 2017, 1–12.

[6] Kirchherr J, Reike D, Hekkert M (2017) Conceptualizing the circular economy: An analysis of 114 definitions. Resources, Conservation and Recycling, 127, 221-232.

[7] Esposito M, Terence T, Soufani K (2018) Introducing a Circular Economy: New Thinking with New Managerial and Policy Implications. California Management Review, 60:5–19.

[8] McDowall W, Geng Y, Huang B, Barteková E, Bleischwitz R, Türkeli S, Doménech T (2017) Circular economy policies in China and Europe. Journal of Industrial Ecology, 21:651–661.

[9] Liu L, Liang Y, Song Q, et al. (2017) A review of waste prevention through 3R under the concept of circular economy in China. J Mater Cycles Waste Manag, 19:1314.

[10] Slavík J, Remr J, Vejchodská E (2018) Relevance of selected measures in transition to a circular economy: the case of the Czech Republic. Detritus, 1:144–155.

[11] Buruzs A, Tomas A (2017) A Review on the Outlook of the Circular Economy in the Automotive Industry. International Journal of Environmental and Ecological Engineering, 11: 6. [12] Saidani M, Yannou B, Leroy Y, Cluzel F (2018) Heavy vehicles on the road towards the circular economy: Analysis and comparison with the automotive industry. Resources, Conservation and Recycling, 135:108-122.

[13] Wilson M (2017) Key to the concept – Automotive manufacturers must embrace parts reuse because it is key to the industry's circular economy. Recycling Today, August 31, 2017. Accessed 15 Jan 2019: http://www.recyclingtoday.com/article/automotive-parts-reuse

[14] Saidani M, Kendall A, Yannou B, Leroy Y, Cluzel F (2018) What about the circular economy of vehicles in the U.S.? An extension of the analysis done in the EU by Saidani et al. (2017). Resources, Conservation and Recycling, 136:287–288

[15] Sakai S, Yoshida H, Hiratsuka J. et al. (2014) An international comparative study of end-of-life vehicle (ELV) recycling systems. Journal of Material Cycles and Waste Management, 16:1–20.

[16] ACEA-European Automotive Manufacturers Association (2017) Statistics – Vehicles in use. Accessed 15 Jan 2019: http://www.acea.be/statistics/tag/category/vehicles-in-use

[17] Bento AM, Roth KD, Zuo Y (2013) Vehicle Lifetime Trends and Scrappage Behavior in the U.S. Used Car Market. Accessed 15 Jan 2019: http://dx.doi.org/10.2139/ssrn.2262593

[18] USDoT-US Department of Transportation (2017) National Transportation Statistics. Accessed 15 Jan 2019: https://www.rita.dot.gov/bts/sites/rita.dot.gov.bts/files/publications/national_transportation_statistics/index.html

[19] Statista (2017) Motor Vehicle Production. Accessed 15 Jan 2019: https://www.statista.com/topics/975/motor-vehicle-production

[20] Eurostat (2019) End-of-life vehicles (ELVs) Key Waste Streams. Accessed 15 Apr 2019: https://ec.europa.eu/eurostat/web/waste/key-waste-streams/elvs

[21] SCADA-State of California Auto Dismantlers Association (2017) The Underground Economy: Report & Recommendations. Accessed 15 Jan 2019: https://www.dtsc.ca.gov/GetInvolved/ReviewPanel/upload/SCADA-DTSC-IRP-Ltr-1-16-dskv1.pdf

[22] Statista (2017) US Light Vehicle Average Curb Weight. Accessed 15 Jan 2019: https://www.statista.com/statistics/660493/us-light-duty-vehicle-average-curb-weight

[23] Ellen MacArthur Foundation (2013) Towards the circular economy – Economic and business rationale for an accelerated transition. Report, Cowes, Isle of Wight, UK.

[24] Directive 2000/53/EC of the European Parliament and of the Council of 18 September 2000 on end-of life vehicles. Official Journal of the European Communities (21 October 2000).

[25] Directive 2005/64/EC of the European Parliament and of the Council of 26 October 2005 on the type-approval of motor vehicles with regard to their reusability, recyclability and recoverability.

[26] Kunz N, Mayers K, Van Wassenhove, LN (2018) Stakeholder Views on Extended Producer Responsibility and the Circular Economy. California Management Review, 60:45–70.

[27] Directive 2008/98/EC of the European Parliament and of the Council of 19 November 2008 on waste and repealing certain Directives.

[28] Directive 2010/75/EU of the European Parliament and of the Council of 24 November 2010 on industrial emissions (integrated pollution prevention and control)

[29] Konz R (2009) The End-of-Life Vehicle (ELV) Directive: The Road to Responsible Disposal. Minn. J. Int'l L., 18:43.

[30] European Commission (2015) Closing the loop – An EU action plan for the Circular Economy. The Circular Economy Package Proposal. Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. Brussels, Belgium.

[31] Accenture (2016) Automotive's Latest Model: Redefining Competitiveness through the Circular Economy. Accessed 15 Jan 2019: https://www.accenture.com/us-en/insight-redefining-competitiveness-through-circular-economy

[32] Delmas MA, Cuerel Burbano V (2011) The Drivers of Greenwashing. California Management Review, 54:64–87.

[33] DoT CA (2017) What are the rules and regulations for truckers in California? Accessed 15 Jan 2019: http://www.dot.ca.gov/hq/paffairs/faq/faq32.htm

[34] USITC (2013) The USITC Remanufacturing Report: Key Findings, Observations, and Insights. The 2013 Remanufacturing Industry Roundtable, April 11, 2013.

[28] ADEME (2016) Chiffres clefs et évolution des taux de réutilisation, recyclage/valorisation des VHU. JUIN –DD'16, Montreuil, France, October 2016.

[29] Oeko-Institute (2017) Assessment of the implementation of Directive 2000/53/EU on end-of-life vehicles (the ELV Directive) with emphasis on the end of life vehicles of unknown whereabouts. Report, Chapter 3.2, December 2017

[35] Palmeira VN, Guarda GF, Kitajima LFW (2018) Illegal international trade of e-waste – Europe. Detritus, 1:48–56.

[36] Article 6 of EU Regulation No. 566/2011.

[37] Regulation (EC) No 715/2007 of the European Parliament and of the Council of 20 June 2007 on type approval of motor vehicles with respect to emissions from light passenger and commercial vehicles (Euro 5 and Euro 6) and on access to vehicle repair and maintenance information

[38] International Dismantling Information System (2019). Accessed 15 Apr 2019: http://www.idis2.com/index.php?action=home&language=english

[39] INDRA Automobile Recycling, 2019. Accessed 15 Apr 2019: http://www.indra.fr/en/recycling_engineering.html

[40] HDDA (2017) Product Standards for Heavy-Duty Aftermarket in Development. Accessed 15 Jan 2019: http://autocare.org/Who-We-Are/Segments/HDDA/HDDA--Heavy-Duty.html

[41] Gaudillat PF, Antonopoulos IS, Dri M, Traverso M, Canfora P (2017) Best Environmental Management Practice for the Car Manufacturing Sector, JRC Science for Policy Report.

[42] USUBC (2015) Top 50 manufacturers of construction machinery. Accessed 15 Jan 2019: http://www.usubc.org/files/Zeppelin_top_50_manufacturer_%20construction%20machinery.pdf

[43] Statista (2018) Worldwide leading truck manufacturers based on production figures. Accessed 15 Jan 2019: https://www.statista.com/statistics/270293/worldwide-leading-truck-manufacturers-based-on-production-figures

[44] Wikipedia (2018) List of manufacturers by motor vehicle production. Accessed 15 Jan 2019: https://en.wikipedia.org/wiki/List_of_manufacturers_by_motor_vehicle_production

[45] Saidani M (2018) Monitoring and advancing the circular economy transition : Circularity indicators and tools applied to the heavy vehicle industry. PhD Thesis, Industrial Engineering. CentraleSupélec, Université Paris-Saclay.

[46] Saidani M, Yannou B, Leroy Y, Cluzel F, Kendall A (2019) A taxonomy of circular economy indicators. Journal of Cleaner Production, 207:542–559.

[47] Moriguchi Y (2007) Material flow indicators to measure progress toward a sound material-cycle society. J Mater Cycles Waste Manag, 9: 112.

[48] Lishan X, et al. (2018) Comparative life cycle assessment of manufactured and remanufactured loading machines in China. Resources, Conservation and Recycling, 131:225–234.

[49] Ribeiro JS, Gomes JO (2015) Proposed Framework for End-of-life Aircraft Recycling. Procedia CIRP, 26:311–316.

[50] MORE AERO (2019) Modularized Aircraft Recycling by Development and Testing of a Mobile Recycling Unit for the Aerospace Sector. Accessed 15 Apr 2019: https://www.süderelbe.hamburg/en/aircraftrecycling.html

[51] Keivanpour S, Kadi DA, Mascle C (2015) End of life aircrafts recovery and green supply chain: a conceptual framework for addressing opportunities and challenges. Management Research Review, 38:1098–1124.

[52] European Remanufacturing Network (2015) Remanufacturing Market Study, for Horizon 2020. Chapter 9: Heavy-Duty and Off-Road equipment, November 2015.

[53] US International Trade Commission (2012) Remanufactured Goods: An Overview of the U.S. and Global Industries, Markets, and Trade. Chapter 4: Heavy-Duty and Off-Road (HDOR) Equipment, Investigation No. 332-525, USITC Publication 4356, October 2012. [54] Acute Market Reports (2017) Global Automotive Parts remanufacturing Market Size, Market Share, Application Analysis, Regional Outlook, Growth Trends, Key Players, Competitive Strategies and Forecasts, 2017 to 2025 Report September 2017.

[55] Weiland FW (2014) European remanufacturing of heavy-duty and off-road vehicle components (including tyres): a hidden giant? FWJ Consulting, May 2014.

[56] Snodgress D (2012) Sustainable development – Our focus & commitment. Cat Reman, September 2012.

[57] Ellen MacArthur Foundation (2015) The Circular Economy Applied to the Automotive Industry. Accessed 15 Apr 2019: http://www.ellenmacarthurfoundation.org/circular-economy/interactive-diagram/the-circular-economy-applied-to-the-automotive-industry

[58] Volvo Group (2015) The Volvo Group Annual and Sustainability Report 2015. Report, pp. 22.

[59] Volvo Truck Corporation (2012) Disassembly instructions, complete vehicle. Service Information, Volvo Truck Corporation, Göteborg, Sweden, 2012.

[60] Toyota (2016) Vehicle Recycling. Accessed 15 Apr 2019: https://www.toyota-europe.com/world-of-toyota/feel/environment/better-earth/recycle
https://global.toyota/en/sustainability/report/vehicle-recycling/

[61] Manitou Group (2016) Handling your world. Annual Report 2015. May 2016.

LIST OF TABLES

TABLE 1 – COMPARISON OF ELV REGULATIONS (AUTOMOTIVE SECTOR ONLY) BETWEEN THE EU AND THE U.S.

Geographical scope	European Union (EU)	United States of America (U.S.)
Key figures	– EU (2010s average): Automobile ownership: 270 million [15-16]; Deregistered automobiles: 14 million; Number of ELVs managed: 6.5 million. Production of 20 million of new cars in 2016. Average vehicle age in use: 11.5 years (same in the U.S.) [20]. – France (2014): Average weight of ELV: 1040 kg; Average lifespan: 17.5 years; 1684 ATFs, 61 licensed shredders; 1.1 million ELVs properly and legally recovered by ATFs (Authorized Treatment Facilities) over the 1.8 million produced and lost in illegal recycling channels [28].	– U.S. (2010s average): Automobile ownership (2010): 240 million [15-19]; Deregistered automobiles: 20 million; Number of ELVs managed: 12 million. Production of 12 million of new cars in 2016. In the US, from 297 licensed shredders in 2014 to 274 ones reported in 2016 [17-18]. – California (2010s average): Average weight of ELV = 1700 kg; Average lifetime for passenger cars: 15.6 years; 1.2 million vehicles reached the end of their useful lives in 2017. 1,100 auto dismantlers under licensed. Yet, an estimated 30% of all ELVs are being processed through unlicensed and unregulated dismantlers [18-19].
Key points of EoL regulations for the automotive industry	– ELV Directive 2000/53/EC targets M1, i.e. 4-wheeled vehicles with seating capacity of nine or less, including passenger vehicles, and N1, i.e. freight vehicle with maximum load capacity under 3,500 kg [24]. – Strict recycling targets are established in the EU: since 2015 a minimum of 85% for reuse plus recycling, 95% for reuse plus recovery [25]. – In the EU, parties responsible for recycling costs include automotive manufacturers and importers (and finally users) based on the principle of EPR [26].	– No national regulation exists for the disposal of automotive waste. Instead, individual States are free to adopt inconsistent regulations. Without regulated treatment procedures, ELV disposal facilities in many States are free to irresponsibly dispose of ELV waste that does not create potential revenue [29]. – No specific recycling goals nor recovery targets in the US. – Rather, in the US, no parties are particularly specified or responsible for recycling costs.

To cite this article: Saidani, M., Kendall, A., Yannou, B. et al. Management of the end-of-life of light and heavy vehicles in the U.S.: comparison with the European union in a circular economy perspective. J Mater Cycles Waste Manag (2019). https://doi.org/10.1007/s10163-019-00897-3

TABLE 2 – END-OF-LIFE MANAGEMENT OF HEAVY- AND LIGHT-DUTY VEHICLES IN THE EU AND THE U.S.

Industrial sector	Heavy-duty & off-road (HDOR) vehicles		Light-duty vehicles (automotive sector)	
Geographical scope	European Union (EU)	United States of America (U.S.)	EU	U.S.
Reman. market (i.e. revenue generated by annual sales of reman. parts)	European HDOR remanufacturing market corresponds to 3.7 billion euros in annual sales in 2013 [52].	U.S. market for remanufactured HDOR equipment: $4.5 billion in 2009 to $6.8 billion in 2011 [53].	European automotive reman. market is estimated to be worth 5.7 billion euros in 2013 [54].	U.S. market for remanufacturing cars has generated a revenue of $5.0 billion in 2017 [54].
Regulations	No specific regulatory framework for the EoL management. Waste Framework Directive 2008/98/EC applies [27].	Same with left. Regulations regarding imports and exports.	European Directives ELV 2000/53/EC and 2005/64/EC [24]. Waste Framework Directive 2008/98/EC applies	No specific national regulation [29]. More details in Table 1.
	High focus on emissions regulations with increasingly strict pollution standard to meet for manufacturers and users to maintain their system up-to-date and compliant over time.			
Exports of used vehicles	Eastern Europe and North Africa, where there is a lack of infrastructures, knowledge and skills to handle properly the ELVs.	EPA (Environmental Protection Agency) requirements for importing and exporting vehicles and engines such as a Certificate of Conformity.	Eastern Europe and North Africa, where there is a lack of proper infrastructures, knowledge and skills to handle properly the ELVs.	Vast majority of U.S. exports of used vehicles parts are to FTA (Free Trade Agreements) partners, mainly to Mexico where they are often remanufactured and shipped back to the US.
Associations (e.g. collaborations and lobbying)	Less developed than in the US. More disparate. Few experts involved such as Cider Engineering.	A lot of associations/networks involved (see below), related to trucks parts, aftermarket services.	In France: INDRA and its network of recycling facilities, connected to OEMs (e.g., Renault) [39].	ARA (Automotive Recyclers Association) at a national level. In California: SCADA, similar to INDRA.
Examples of commendable circular economy practices (see further examples in Appendix A)	Remanufacturing offers and services, with more HDOR remanufactured spare parts than in the automotive sector. Here are other examples of sustainable circular practices: - substance restrictions on hazardous materials; - eco-design (e.g., design for easy disassembly); - dismantling manual available for most of Volvo's trucks; - retreading of HDOR tyres [55].	Remanufacturing offers and services (e.g., Caterpillar [56]). Willing of establishing product information and data standards for the heavy-duty aftermarket supply chain, involving e.g. the HDDA (Heavy Duty Distribution Association), (HDMA) Heavy Duty Manufacturers Association, and the International Truck Parts Association in North America for both the U.S and Canada [40].	Transparent collaborative network. Well-established dismantling and systematic recycling procedures within the ATFs, propelled by the ELV Directive [24] and EPR [26]. French law active since 2017 mandating that workshops should offer customers the choice between spare parts from the circular economy (i.e. used or reman parts) and newly produced parts.	Selling used vehicle parts under Standard Industrial classification. SCADA established the industry's premier certification program within the US to foster an enhanced ELVs management. 2017 California Cash for Clunkers Vehicle as a scrapping premium incentive. ARA University: premier online training resource of the professional automotive recycling industry [13].
Remaining challenges and areas for improvement	Implementation of regulatory framework for EoL management. Better control of exports. Enhanced collaborations between end-of-life stakeholders. Issue of monitoring the heavy equipments during their usage (for preventive maintenance and traceability).		Thriving underground economy of unlicensed and unregulated dismantlers. Unfair competition between authorized treatment facilities (ATFs) and unlicensed or illegal operators that have the same access to salvaged vehicles than ATFs who comply and have to pay extra costs (e.g. operating taxes).	

TABLE 3 – INDUSTRIAL FEEDBACKS

The template has been shared with relevant industrialists from the following companies *(feedback from companies in **bold** are discussed in this article)*				
Caterpillar	Daimler Trucks	JCB India	John Deere	Komatsu
Liebherr	**Manitou**	PSA France	Renault	Renault Trucks
Toyota France	**Scania**	VI Conseils	**Volvo CE**	**Volvo Trucks**