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The Economic and Ecological Impacts of Dismantling End-of-Life Vehicles in Romania

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Abstract: In a global market characterized by the trend of saving non-renewable resources, recycling has become one of the key factors that alleviates the rarity of resources and preserves existing ones. One of the largest industries that consumes natural resources is the automotive industry. This includes not only resource consumption but also the environmental effects of each new unit produced in this industry. As a result, recycling end-of-life vehicles has become an increasingly obvious and widespread concern. This paper proposes a preliminary analysis of the dismantling/recycling activities in Romania compared to other economies (e.g., USA). It aims to determine the impact that dismantling end-of-life vehicles has, according to the legislation in the field, on the economy and the environment. In order to obtain a complete picture, it is obvious that further research is needed.

Keywords: Auto recycling policy; end-of-life vehicles (ELVs), automobile shredder residue (ASR), dismantling; recycling economy; environment

1. Introduction

In a world preoccupied by environmental issues and recycling, the auto industry and the vehicles involved in everyday traffic generate a sum of debates, controversies, and, usually in the end, a lot of actions. In this context, end-of-life vehicle (ELV) recycling is encouraged by a multitude of factors, primarily economic and technological, and also the social and ecological aspects of today world. Thus, the auto industry is trying to go along with this new way of doing business and is moving towards sustainable waste management.

The purpose of this paper is to clearly analyze the available information on the Romanian market in order to improve the understanding on the nature and extent of any environmental and economic impacts caused by end-of-life vehicles (ELVs). In a market that is characterized by a large number of ELVs, such as the Romanian market, we can already assume that ELVs are one of the most highly recycled consumer products. The auto dismantlers remove all components that have economic value. However, because of the continuing trend towards newer, more reliable cars, and not to forget electric cars with long warranty periods, this may be an industry that, in the medium term, will register significant declines [1]. The information in this paper is based on previous discussions with owners of different Romanian auto dismantling companies and data provided by the Romanian Automotive Register. Accordingly, this paper deals with factors associated with ELVs, which have been considered by others [2], to pose potential environmental dangers. The novelty of this paper lies in the fact that very few have investigated this topic in Romania.

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Essentially, ELVs are motor vehicles that have reached the end of their useful lives, and they are considered waste. ELVs are vehicles that are either old and are not able to function according to the manufacturer conditions or they are heavily damaged following an accident. All ELVs are removed, or in the process of being removed, from circulation and, of course, deregistered. There are two categories of vehicles that can be included in ELVs:

- M1—all vehicles designed for passenger transportation with less than 8 + 1 seats, and
- N1—all vehicles designed for goods transportation, less than 3.5 t maximum load.

Because many different materials can be obtained from ELVs, like ferrous metals (71%), glass (3%), plastics (8%), fluides (2%), rubber (5%), nonferrous metals (7%), and others (4%), they are considered more of a valuable resource than waste [3–5]. The current auto recycling industry is not an old one, as it is just 75 years old at the international level [6]. Basic marketing facts and figures prove that the auto recycling industry is a vital, market-driven industry. Every year, over 25 million tons of materials are recycled from ELVs, and automobiles are the most recycled goods in the world today [6]. According to auto recycling statistics, more than 80% of a car can be recycled [7], and the remaining 20% that cannot be recycled is labelled as "auto shredder residue" (ASR). In this category, ferrous and nonferrous metal pieces, dirt, glass, fabric, paper, wood, rubber, and plastic are included. There is worldwide concern in decreasing the percentage of ASR because around 5.5 million tons of ASR is discarded at landfills every year [8].

As an alternative to tire landfill disposal, there are a few sustainable and cost-effective measures. Steam gasification of scrap tires was investigated by Molino et al. [9], which transforms scrap tire carbons into highly pure, activated carbons using a three-step treatment [10]. An interesting way of using recycled materials from ELVs, thus removing pollutants from the environment, is to use waste scrap tires as adsorbents and in microbial immobilization in order to enhance the bio-removal of volatile organic compounds (VOCs) from contaminated water [11].

The automotive sector has already proven their strong commitment towards reducing the ecological impact of the production and use of vehicles [12]. According to the European Automobile Manufacturers' Association (ACEA), the automotive industry is not only concerned about reducing waste but also to contribute to the modern approach of a circular economy [13]. The definition provided by Europa.eu states that "The circular economy is a model of production and consumption, which involves sharing, leasing, reusing, repairing, refurbishing, and recycling existing materials and products as long as possible. In this way, the life cycle of products is extended. In practice, it implies reducing waste to a minimum. When a product reaches the end of its life, its materials are kept within the economy wherever possible. These can be productively used again and again, thereby creating further value" [14]. This is exactly what characterizes the trends in the automotive industry nowadays.

Starting from the fact that the automobile sector generates about 5% of the total industrial waste, and that ELVs are an important source of hazardous substances, it is self-evident that recycling is an important concern to specialists. As a result, there is rather extensive literature in this research sector. Simic carried out an extensive review on ELV recycling (a total of 35 journal papers), dividing the works into three major categories: vehicle recycling practices (13 papers), legislation (17 papers), and remanufacturing and materials recycling (5 papers). He outlined the fact that recycling and recovery of ELVs should be regarded as the most important components of environmental policies and sustainable development worldwide [15].

Kumar and Sutherland [16] carried out an overview of the studies on the vehicle recovery infrastructure. They concluded that the mathematical models available have several limitations generated by economic aspects not fully understood or discussed like material flows, economic transactions and market factors, and last but not least, inadequate or missing government policies.

Ilgin and Gupta [17], concluded in their paper based on the reviewed papers on product recovery and manufacturing that more studies are needed. The papers on vehicles life cycle, disposal and ELV, and on their impact on environment, were also reviewed by Mayyas et al. [18]. Also, Go et al. [19] realized a review on ELVs, recycling, disassembly methods and their connections with other fields. Nakano and Shibahara [4] presented the methods used for ELVs recycling and their impact on environment through a comparative assessment on green gas emissions.

Case-by-case analysis, concerning the practices in vehicle recycling field, were conducted by Daljmin and De Jong [20] in the case of the European Union, Kim et al [21], Joung et al [22]—for Korea, Sakkas and Manios [23]—for Greece, Nakajima and Vanderburf [24]—for of Germany, Forton et al. [25], Edwards et al. [26]—for UK, Chen and Zhang [27], Wang and Chen [28], Gan and Luo [29]— for China, Cheng et al. [30]—for Taiwan, Altay et al. [31]—for Turkey, and Hiratsuka et al [32]—for Japan, and Lin et al., for small island of Kinmen [33] Comparative analyzes were conducted by Zameri and Blount [34], between EU, US, Japan, and Australia.

The problems faced by the EU in the automotive sector i.e., abandonment of cars, pollution, and waste have led to the adoption and application of appropriate legislation: Directive 2000/53/EC. The directive's influence on cars' abandonment has been studied by Smith et al [35]. The reduction of pollution through innovations in the field was the subject of econometric analysis studies by Nicolli et al. [36] and by Mazzanti and Zoboli [37]. Gerrard and Kandlikar [38] notice that the effect of the implementation of the directive on some EU member states brought about changes to the material composition of the new vehicles. Questionnaires were used to analyze the specific UK case by Smith and Crotty [39], and that of Germany by Blume and Walther [40]. Santini et al. [41] concluded in their paper that the structural weakness of Italian municipal solid waste incinerators (MSWI) has led to the failure to meet targets for recovery rate in Italy. Ferrao and Amaral [3] realized a model for economics of dismantling and shredding activities, after a short analysis of industry and brief overview of legislation, namely Directive 2000/53/EC. They concluded that are more to do in this regard, and a better cooperation between car manufacturers and dismantlers is desirable. Anyway, there was an increase in ELV articles and use of ESA tools, that also coincided with the introduction of EU regulation [42].

A comparison of legislation in the field was made by several authors: EU vs Japan, by Kanari et al [43], Sakai et al [44]; US vs EU vs Japan, by Gesing [45]; Japan vs Korea and China, by Che et al [46], and Japan vs China, by Zhao and Chen [47].

Both in European and the Japanese legislation relay on the extended producer responsibility (EPR) principle. Manomaivibool [48] made a comparison from this principle perspective between UK's and Sweden's effectiveness of management of ELVs. Wilts et al [49] concluded that EU ELV Directive, by setting quotas for recycling under EPR action, is not the best solution especially for precious metals, and they proposed an international covenant as a policy instrument.

Sakai et al. [50] made a comparative study on recycling systems of ELVs for EU and Japan, tracking issues such as ELV recycling flow, ELV management methods, properties of ASR, direction of ASR management, and the effectiveness of ASR, life cycle assessment and ASR recycling methods, and the direction of ELV. The paper compiled the date on ELV recycling system and spotted the similarities and differences among them.

2. Methods and Materials

2.1. Context and Scope of the Study

In order to present an ELV recycling image as complete as possible our research focused on several aspects of the field, which combine to form a comprehensive image. We started from realizing a comparative analysis of the recycling regulation and of the differences between the recycling flows in different countries, in order to set the stage for the detailed analysis.

We analyzed, determined and calculated the auto market share and ELV generation. We looked at the Recycling Industry and Used Parts market in the USA, as a basis, and extrapolated the data on the Romanian market.

Finally, in order to evaluate the economic and environmental impact of the dismantling and parts re-use activity we started by modeling the dismantling of an average vehicle and extended the findings to the total Romanian market.

2.2. Recycling Regulations and Process Flow

2.2.1. Recycling Regulations

In a world increasingly concerned with environmental protection, it is normal that automobiles, and in particular ELV, to be subject to the challenges of an appropriate legislative framework. Legislation in this field differs from country to country, from one continent to another, but common elements are found everywhere. While there is specific ELV legislation in the European Union, and in Japan, Korea, and China, in USA, for example, the recycling of ELV is subject to environmental protection laws.

In the Table 1 we can observe these differences between ELV management systems, either based on legislation, or based on market mechanisms and environmental regulations [50].

Table 1. Different end-of-life vehicle (ELV) management systems.

	ELV Management System	**Background of the Management System**
EU	Law/Directive 2005/53/EC (2000)	Measures for increasing automobile shredder residue (ASR) Measures for abandoned automobiles Environmental measures of dismantling sites
Romania	Law/Directive 2005/53/EC (2000) Law 212/2015 regarding ELV management "Rabla" governmental program	Measures for abandoned automobiles Environmental measures of dismantling sites, uses of resources, Bonuses for electric new cars bought
Japan	Law for Recycling of ELV (2005)	Lack of final disposal sites Illegal dumping of ASR Effective use of resources
Koreea	Law Act for Resource Recycling of Electrical/Electronic Equipment and Vehicles (2008)	Measures for ELVs Effective use of resources Management of information on ELVs
China	Law ELV Recycling Regulations (2001) Automotive Products Recycling Technology Policy (2006)	Measures for illegal assembly Effective use of resources Measures for recycling economy
USA	Related Law Resource Conservation Recovery Act, Clean Air Act, etc.	Strict implementation of regulations Environmental conservation measures associated with ELV recycling

Source: adapted after Sakai et al, 2014.

There have been concerns at EU level regarding about the environmental protection starting with the 1970s, but a coherent policy in this area appeared only after the Single European Act, and especially after the Maastricht Treaty. ELVs have benefited from special legislation since 2000, when Directive 2000/53/EC was adopted. This directive aims to manage and control waste from cars (both creation and disposal) and, more importantly, to make simple people as well as those involved in this field become more aware of the result of their actions on the environment. The instruments considered are reuse, recycling and collection of ELVs and their components. The principles underpinning the directive are:

- The subsidiary principle: the legislation applied in each Member State should be adopted at national level; and
- the extended producer responsibility principle: the car manufacturer and importers should bear the cost of recycling.

Additionally, member states have to meet the recycling targets that are set by the Directive, namely: Reuse and recovery of 85% on mass basis and reuse and recycling of 80% by 2006 and reuse and recovery of 95% on mass basis, and reuse and recycling of 85% by 2015.

These targets mean that less than 15% and respectively 5% are the desirable rates for final disposal. It is important to mention that is not sufficient to recycle just the metals, but also plastics, rubber and others, to meet these targets. There is also a requirement for producers that for all the cars produced after 2003, the majority of components should not contain lead, mercury, cadmium, or hexavalent chromium. In order to achieve these aims and to adapt to changing realities of our lives, the EU-Directive 2000/53/EC had been revised, amended and modified 8 times until now, the latest one revision being in 2017.

In Japan, as showed in the Table 1, the ELVs management system is based on Law for Recycling of ELV (2005). Concerns in this area date back to the early 1990s. In 1993 the Basic Environment Act was adopted, setting the basis for Japan's environmental policies. In 2000 a new piece of legislation that laid the foundations for a society whose functioning has an ever-lesser impact on the environment was adopted—the Basis Act on Establishing a Sound Material-Cycle Society. The principle that this type of society is working on is the priority for the cyclical use of circulative resources of reuse, recycling, and energy recovery [32]. Just as in the European legislation, in the Japanese one we can find the extended producer responsibility principle. Responsibility for recycling rests not only with producers but also with consumers. As far as ELV are concerned, their management has been enforced ELV Recycling Act in 2005. There have been several issues that led to a need to take action in this regard, among which we can recall the shortage of final disposal sites, the need to prevent illegal dumping, and unsounded treatment of ELV, as a consequence of steel scrap market fluctuations [50].

However, the treatment of ELV is under the strict jurisdiction of Waste Management and Public Cleansing Act. As showed by the Waste Management and Public Cleansing Act vehicles producers and importers are responsible for:

- Destruction of fluorocarbons used as the refrigerant in air conditioners;
- recycling of gas generators used for airbags and seat-belt pretensioners; and
- recycling and energy recovery of automobile shredder residue (ASR), using the recycling fee paid by vehicle owners when they purchase a new vehicle [32].

Unlike the cases outlined above, in the USA, ELV recycling operates autonomously based on the market mechanism [50]. The professional automotive recycling industry, represented by ARA, is the one that took initiative and actions in ELVs recycling field. Although there is no integrated management system, the emphasis is placed on elements considered hazardous, like dioxins, furans, polycyclic aromatic hydrocarbons, greenhouse gases, and hexavalent chromium and mercury. ELVs recycling programs are monitored thorough the environmental laws. Relevant regulations in the field are the Resource Conservation and Recovery Act (RCRA), the Clean Air Act (CAA), and the Clean Water Act (CWA), along with state governments own regulations.

If we are referring exclusively to the Romanian automotive market, in 2018 were registered 6,450,750 vehicles, which, considering the total population of the country, gives us a ratio of 1 to 3, meaning 1 out of every 3 Romanians have a car.

The cars can be categorized in six major time related categories, as shown in the Table 2:

Table 2. Romanian Auto Park by car age (2018).

Car Age	Number of Vehicles Registered	% in Total
Btw 0–2 yr	235,704	3.65%
Btw 3–5 yr	302,856	4.69%
Btw 6–10 yr	796,394	12.35%
Btw 11–15 yr	2,080,113	32.25%
Btw 16–20 yr	1,658,730	25.72%
Over 20 yr	1,376,953	21.34%
Total	**6,450,750**	**100%**

Source: data processed after www.drpciv.ro/news-and-media/statistica [51].

It can be observed that the main category of used cars is represented by the cars between the ages of 11 and 15 years, which form 32.25% of the total number of registered cars in Romania. There are 3,035,683 cars over 16 years old, compared with 3,415,067 automobiles considered "newer" cars, so 47.06% of Romanian vehicles could be included in the ELVs category. Concerning the types of the cars registered in Romania, in 2018, according to fuel type, we have 2,890,563 diesel powered cars and 3,534,103 gas powered cars. [51].

A noticeable increase in the Romanian auto market can be observed in the first nine months of 2019. The registration of new cars increased with 124,049 units, +16.37%, compared with the same period of the previous year. The first registration of the secondhand cars in Romania reached in the first nine months of 2019, 329,231 units—a decrease of 5.1% compared with the same period of previous year. This decrease of the registration of used cars in Romania was due to the fact that the amount of the Rabla Vouchers was increased and subsequently more people preferred to buy new cars, using the discount offered by government. The statement above is supported by the Romanians buyers' choices of new car brands, as it follows:

- DACIA (part of RENAULT NISSAN GROUP, manufactured in Romania) sold 37,115 units in 2019, representing an increase of 26.65% compared with the same period of 2018;
- RENAULT (manufactured in Romania) sold 10,705 units in 2019, representing an increase of 16.01% compared with the same period of 2018;
- SKODA sold 9596 units in 2019, representing an increase of 10.12% compared with the same period of 2018;
- FORD (manufactured in Romania) sold 9219 units in 2019, representing an increase of 22.84% compared with the same period of 2018; and
- VOLKSWAGEN sold 8525 units in 2019, representing an increase of 0.85% compared with the same period of 2018 [52].

We can observe the Romanians' preference for cars for which it is easy to find spare parts in auto dismantling shops and for cars produced in Romania.

2.2.2. Process Flow

From a geographic perspective, besides focusing on select countries from the European Union we also included data from Japan because Japanese national auto and recycling industries is more mature than the European one, and indicates future development directions.

After analyzing the ELVs recycling flows in EU, Japan and Romania we observed that are no major differences between this three auto recycling systems. In the adapted Figures 1 and 2 we are presenting the general ELV recycling flow in EU, Japan and Romania, using the framework offered by Vermeulen et al. 2011, Sakai et al. 2014, and Yoshida and Hiratsuka 2014 [32,50,53], and added the results from Romanian dismantling market based on significant data collected and processed in the field.

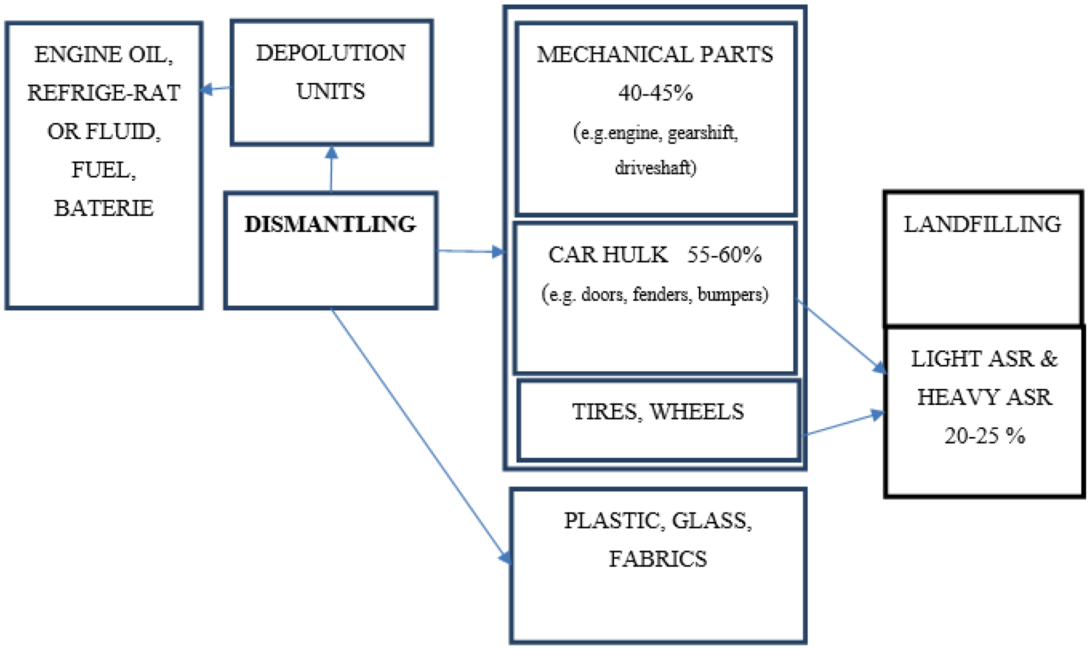

Figure 1. ELV recycling flow in Romania and EU. (Source: adapted after Vermeulen et al. 2011, Sakai et al. 2014).

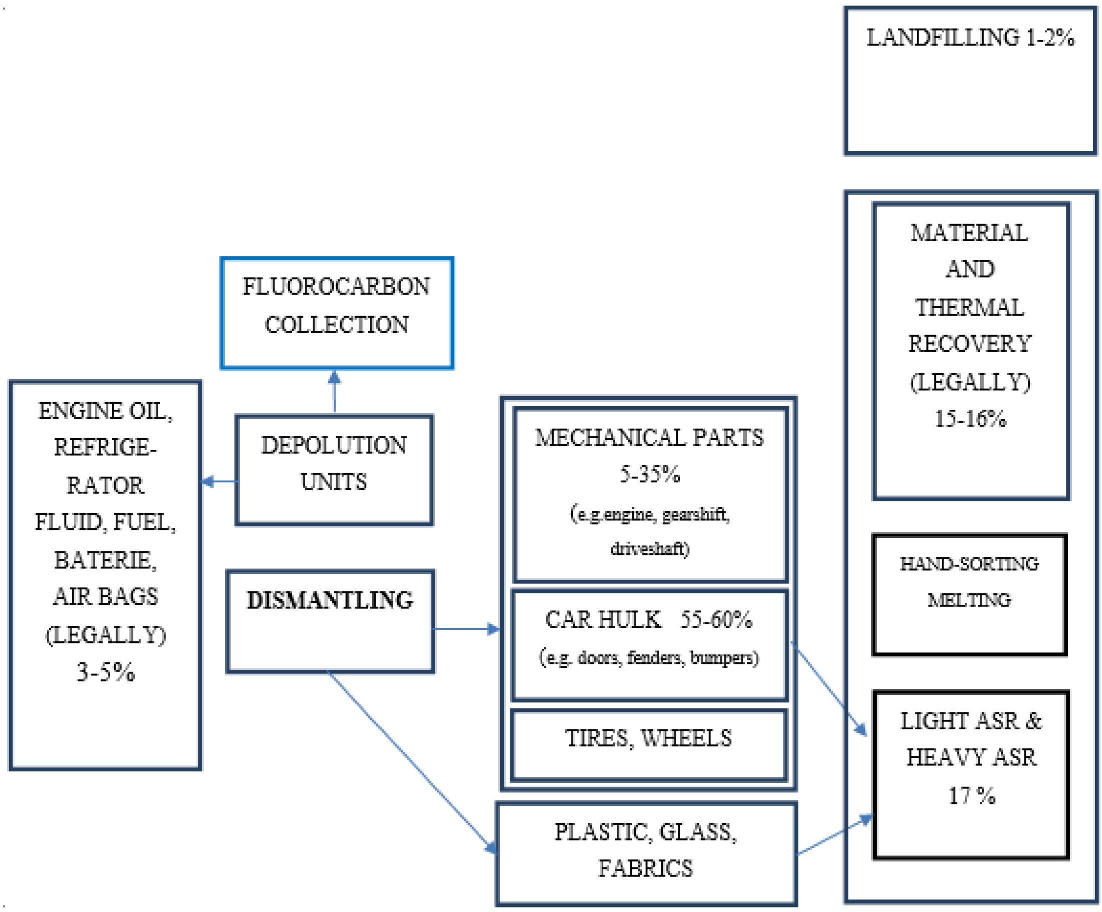

Figure 2. ELV recycling flow in Japan. (Source: adapted after Yoshida and Hiratsuka 2012; Sakai et al. 2014).

The recycling process of an ELV usually starts with the car being brought to the dismantling operator; in some cases the ELVs are bought by these operators in order to reuse or resell the functioning parts of the car. The car is dismantled into separate categories. First the components that are considered most polluting are taken out: engine oil, fuel, refrigerant gases, and car battery. They are delivered to special recycling units that are also handling the storage until they are properly disposed. After that the mechanical parts (engine, gearbox, turbine, suspension system, injectors etc.), car hulk (separated by parts: Doors, bumpers, stops, etc), tires, plastic, glass, and fabrics are collected. After dismantling of the car, the total weight of the vehicle is about 55%–70% of the original weight in EU and Japan [50]. What is left after dismantling is put into shredders and finally separated by air classifier into ASR light and ASR heavy. In the EU, and subsequent in Romania, the ASR represents around 12%–32%, and all is landfilled. Additionally, in Romania, tires taken from an ELV cannot be reused and for the plastic, glass and fabrics collected every dismantling operator must have an agreement with a collector unit, usually for a fee of around 500 euro per year. Air bags also cannot be resold, and they go straight to landfill all over in EU. On the other side, in Japan the Law for the Recycling of End of Life Vehicles, dictates a more profound recycling of ASR, through melting furnaces and secondary stage recycling. This way they managed to drop the percentage of ASR that is landfilled to 1%–2% of the total ELV mass [32,50].

2.3. Market Analysis

The auto recycling industry is inextricably linked to the overall auto industry and any discussion or analysis needs to start from there. Because of its specific characteristics the auto industry is both the source of its input and the destination of its output, and the reuse of auto parts has no other option than to move more or less in sync with the vehicle park. The ELVs are the only source of the re-use spare parts and the users of these parts are the vehicles approaching ELV status, as well as the ones that need to be fixed after an accident, and most likely in the second half of their life, when they are no longer under full CASCO insurance and the investment in new parts makes less economic sense.

Considering this aspect, we have decided to anchor our analysis on two main data points and the period between them. The first data point is the year 2010, when the world car population has surpassed the 1 billion mark for the first time, reaching the amount of 1017 million registered vehicles [54]. The second data point was the year 2016, because it is the most recent year from which reported economic data was widely available. By this year the world car population has reached 1.32 billion vehicles, after a compounded annual growth of 4.48% [55]. Several industry researches forecast car ownership to reach 2.4 billion by 2050 [56].

As we stated above, the selected analyzed countries, EU, Japan and USA, are countries with a mature market and also, they represent a large diversity of geographical regions with slightly different perspectives on dismantling of ELVs. The vehicle ownership and the estimated generation of ELVs are listed in Table 3.

We have extended the analysis performed by Sachai et al for Romania as follows: Data for automobile ownership was extracted from the Romanian Institute for Statistics and the Deregistered Vehicles [57,58] were calculated by subtracting the number of owned automobiles at the end of a 2010 from the sum of newly sold automobiles in the same year and the number of owned automobiles at the end of 2009. Data for ELV is based on official reporting regarding compliance with the EU Directive 2000/53/EC.

The global generation of ELVs was estimated at 40 million accounting for 4% of total automobile ownership. The deregistered automobiles include, in addition to ELVs (deregistered car that undergo treatment/recycling through appropriate processes within the country), exported used cars, and unregistered cars used within private sites and cars illegally dumped as waste. The generation of ELVs depends on the number of deregistered automobiles, while the latter is related to the number of registration and the life duration of automobiles. It is likely that in several countries, including Romania, the difference between the deregistered cars and the ELVs leads to significantly higher increases in the car dismantling activity based on imported used cars. As a result of this the ELVs statistics by themselves are not sufficient to paint a clear picture of the area we have analyzed, so we extended the analysis in several directions.

Table 3. Global and country estimates of car ownership and ELVs.

Country	Automobile Ownership (Units)	Deregistered Vehicles (units/year)	ELVs (units/year)
USA	239,811,984	20,419,898	12,000,000
Japan	75,361,876	4,080,000	2,960,000
EU	271,319,000	14,077,000	7,823,211
Germany	45,261,188	2,570,137	500,193
Italy	41,649,877	1,835,293	1,610,137
France	37,744,000	2,002,669	1,583,283
UK	35,478,652	1,810,571	1,157,438
Spain	27,750,000	996,718	839,637
Global total	1,016,763,420	115,805,275	40,176,051
Romania	**4,139,701**	**235,173**	**190,790**

Source: adapted after Sachai et al., 2014.

We started by looking at the ELVs evolution in EU countries between 2010 and 2016, based on EU reporting data, as shown in Table 4. The countries encompassing close to 70% of the total EU car ownership and the overall EU show a decrease of 20%–30% of ELV generation over this 7-year period, with some yearly fluctuation but a clear trend. By comparison, in Japan the analyzed data show a decrease with 31% through 2000 and 2016, from 4.2 million units of ELVs to 2.9 million units ELVs [50,59].

Table 4. End-of-life ehicles generation (number of vehicles/year).

	2010	2011	2012	2013	2014	2015	2016	CAGR *	Δ%(2010–2016)
EU	7,383,000	6,789,000	6,286,000	6,234,000	6,150,000	5,983,000	6,007,000	−3.38%	−18.64%
Germany	500,193	466,160	476,601	500,322	512,163	473,386	412,801	−3.15%	−17.47%
France	1,583,283	1,515,432	1,209,477	1,115,280	1,084,766	1,016,326	1,046,083	−6.67%	−33.93%
Italy	1,246,546	952,461	902,611	876,052	853,584	958,245	978,960	−3.95%	−21.47%
UK	1,157,438	1,220,873	1,163,123	1,149,459	1,106,846	995,527	1,103,050	−0.80%	−4.70%
Romania	**190,790**	**128,839**	**57,950**	**37,989**	**42,138**	**41,886**	**41,886**	**−22.33%**	**−78.05%**

Source: own calculation based on data from https://ec.europa.eu/eurostat/web/waste/key-waste-streams/elvs. * CAGR (compounded annual growth rate).

In the same time, until 2015, Romania has experienced a much stronger drop of 78% in yearly ELV generation, from more than 190,000 to close to 40,000 vehicles. This significant drop is explainable by the improving age characteristic of the Romanian auto park, in itself a result of a combination of import restrictions for old age vehicles, through the First Registration tax, and the "Rabla" program [60,61], which, between the years of 2010 and 2016 lead to the deregistration and recycling of 436,107 vehicles, 10.5% of the auto park in 2010. In these conditions, even though the Romanian auto park grew faster than the global one, with a compounded growth rate of 4.76% per year and reached more than 5.4 million cars registered in 2016, less than 1% of these become ELVs every year (0.8% in 2015), as opposed to 4.6% in 2010.

This is even clearer when we look at specific annual numbers. In 2010, out of the 235,173 deregistered vehicles, 183,625 were recycled as scrap metal through the RABLA program. Because Romania's exports of used cars are insignificant and can be considered 0, the remaining 51,548 deregistered vehicles were, in the vast majority, disassembled and sold as parts. In 2016, deducting the 25,905 RABLA program vehicles from the total of 79,174 deregistered vehicles we obtain a number of disassembled cars in the same magnitude, of 53,269. Based on these results and considering the car ownership increase trend, we can safely assume that the Romanian national auto park currently generates between 55,000 and 60,000 cars for disassembly per year.

The other component of the dismantling industry comes from imported cars, and here the estimation becomes very difficult. Within the European Union there is no way to track the intra-community exports and limited reporting requirements. As a result, the 2018 European Commission report regarding the Assessment of the implementation of the Directive 53/2000 estimated that more than 4 million cars per year fall into the category "vehicles of unknown whereabouts", compared to around 6 to 7 million ELVs treated in compliance with the ELV Directive and reported to Eurostat. In 2014 the difference between the de-registered vehicles in the EU and the reported ELVs and the extra-community exports was 4.66 million, out of which 4%–5% represent stolen cars [62]. At this moment is impossible to estimate how much of this amount was imported to Romania and disassembled.

2.4. Recycling Industry and Used Parts Market in the US

Another way to estimate an annual volume of re-usage in the auto industry is to try to perform a top-down calculation on the recycling industry. We started by looking at the recycling industry in the USA, because the extensive network of industry association makes for a wealth of data available.

The most important aspect in this analysis is the split between the reuse and the recycling activities. According to Directive 2005/53/EC (2000) for the EU countries, Law for Recycling of ELV (2005) for Japan and for USA, Related Law Resource Conservation Recovery Act, the reuse and recycling ratio should be between 90%–95% [50]. Typically, the recycling part is conducted by the scrap metal companies and it represent the destination for the cars of 15+ years, while the parts yards process cars typically in the 7–15 years old category. There is however an overlap, as the hulk of the car, after being stripped of re-usable parts, is delivered by the parts yards to the same scrap metal yards for processing. The disassembly process is quite extensive, from a typical 1200 kg disassembled ELV only about 300 kg is being scrapped, but the overlap is there nonetheless.

The automotive recycling industry employs over 140,000 people in the United States at more than 9000 locations around the country, generates $32 billion in sales nationwide, and supplies around 37 percent of all ferrous metal to blast furnaces and smelters across of all USA.

Every ton of new steel made from scrap steel conserves 1.1 tons of iron core, 0.6 tons of coal, and 50 kg of limestone. In addition to conserving natural resources, automotive recycling plays an important role in reducing air and water pollution, and solid waste generation. Each year the industry collects and reuses or recycles an estimated 30 million liters of gasoline and diesel fuel, 90 million liters of motor oil, 30 million liters of engine coolant, 20 million liters of windshield washer fluid and 96% of all lead batteries [63].

The recovered and reused spare parts further the ecological and economic advantages of the recycling activity, annually about 850,000 engines and 1 million transmissions being remanufactured and sold. This industry is estimated by IBISWorld at $5 billion in 2018, about 15% of the entire recycling industry, and it employs over 19,000 people in 2753 business. The Used Spare Parts industry, including the specialized stores, has generated a profit of more than $160 million in 2018 and has been growing at an annual rate of 1.1% in the past 5 years. This growth is expected to continue and even increase in the future years [56]. The average car age in the US is 11.6 years and 10.7 years in Europe. By 2021, IHS Markit estimates there will be 81 million vehicles over the age of 16 on the road in the US, and holding the relationship constant, it is estimated that Europe will have approximately 90 million cars over the age 16 by the same year. This indicates a strong demand for replacing parts for older age cars worldwide in the coming years and a continuation of the growth trend of the industry [56].

2.5. Romanian Recycling and Disassembly Industry

The Romanian market is much more opaque and harder to analyze because of the complete lack of industry association and sparse reporting. The Romanian Association for Auto Disassembly, ANSDAR ("Asociatia Nationala a Societatilor de Dezmembrare Auto") was established in 2004 and has become a full member of EGARA, the European umbrella association for the national associations of automotive recyclers in Europe, in the same year. However, the Association is no longer active, and the last information consolidated by ANSDAR indicated a number of 80 dismantling yards in Romania, processing approximately 20,000 cars per year in 2009, and another 30,000 cars being fully disassembled by un-licensed yards. No other information is available for the later years [64]. An analysis of the industry statistical data offers similar vague information. The Romanian CAEN code ("Clasificarea Activitatilor din Economia Nationala") for the dismantling activity, 3831 and 3832, also include the scrap yard activities and selective waste collection. In 2016 the biggest 100 companies in these industries employed 6175 people and realized a total turnover of 900 million EUR, as shown in Table 5. After assessing the activity of each of these companies one by one we concluded that the biggest dismantling yards realized a turnover of close to 8o million EUR in 2016, about 9% of the total recycling industry. Using an average value of spare parts generated of 3600 EUR (detailed in the following section), this turnover indicates a number of 22,000 cars dismantled and sold.

Table 5. Top 100 companies in Recycling Industries in Romania.

Activity	Number	Turnover 2016		Employees
		Million RON	Million €	
Selective waste collection	68	2290.31	508.96	3895
Scrap metal yards	22	1403.42	311.87	1822
Spare parts yards	10	355.38	78.97	458
TOTAL	100	4049.11	899.80	6175

Source: Oficiul National al Registrului Comertului.

However, this result was less than useful in our effort to estimate the total amount of dismantled cars in Romania. Several discussions with companies in this industry led us to the conclusion that there is a large number of small size dismantling yards, which completely distorts the overall weight of the turnover. In addition, the unlicensed operators realize a significant proportion of the dismantling activity, with only partial or even lacking official reporting. The empirical estimations of the companies' managers, based on their personal expertise but limited data, indicated a market size of 60,000–80,000 vehicles processed yearly.

Because the estimation of the market based on the last numbers figures consolidated by the ANSDAR [64] (50,000 cars dismantled in 2009) and the 4.76% annual growth rate of the Romanian auto park, points towards a current amount of 70,000 cars dismantled in the present, we have decided to use the amount in the rest of the analysis. While it is clear that the lack of precision is also transmitted to the total results, the figure will nonetheless be useful in presenting the order of magnitude of the economic and environmental results of this activity.

3. Results

Auto Disassembly Economic and Environmental Analysis

In order to evaluate the economic and environmental impact of the dismantling and parts re-use activity we started by modeling the dismantling of an average vehicle. We used an Opel Astra H model 2010, as it is, in the opinion of the industry actors, the car closes to both the average (as price and weight of parts) and median (as number of cars) vehicle being disassembled in Romanian part yards.

The parts generated by the disassemble process can be divided into 3 main groups—parts that are recycled by delivery to specialized collection points, (batteries, windshield, airbags, tires, etc.), parts that cannot be sold to population as they represent safety features of the car (and need to be replaced with new parts (fuel tank, center pillar, brakes system, steering system, dash board, etc.) and regular spare parts, which were lumped in the biggest assemblies they can be sold into. While there are cases in which for instance an engine is deconstructed and sold by component parts, especially when part of it has been damaged, the economic and environmental result are similar to the sale of the complete engine. We calculated the clients' economic benefit as the difference between the average price of a new part (original or aftermarket) and the average price of a used part, and the environmental benefit as the decrease in the carbon footprint of the new parts not acquired, in kg of CO2 equivalent. In these calculations we used a net conversion of 5.6 tons CO2 equivalent/steel and 43.7 tons CO2 equivalent/aluminum. We took into consideration the fact that each ton of used parts could have generated a decrease in carbon footprint of 1.5 tons for steel or 8.1 tons for aluminum if they would have been scrapped. The car's hulk was included only in the environmental analysis, and a CO2 footprint of 1.5 tons per ton of material was used [65].

As it shown in the Table 6, the analysis indicates a total economic benefit of 10,800 EUR, split amongst the buyers of the used parts, which are thus offered an alternative to buying new, much more expensive parts, and a decrease of carbon footprint by 3.7 tons of CO2 equivalent for each disassembled vehicle. This analysis does not consider the economic benefit for the used parts yard and the workplaces created and also does not consider the environmental benefit resulted from the recovery of plastic, glass, rubber, and rare metals which vary significantly depending on the type of vehicle being dismantled and its specifications.

Table 6. Environmental and economic impact of used parts sale—Opel Astra H 2010.

Part	No.	Weight (kg)	Price (€)	New Part Price (€)	CO2 Footprint (kg)	Benefit (€)
Front end assembly	1	20	100	400	112	300
Spoiler	1		100	500		400
Grille	1		20	100		80
Front fender	2	5	35	100	56	130
Back fender	2	25	100	400	280	600
Front hood	1	15	80	250	84	170
Back hood	1	30	100	400	168	300
Door	4	25	30	250	560	880
Roof	1	20	100	100	112	-
Hood hinge	8	0.1	10	30	4	160
Door window regulator (Al)	1	0.2	20	100	9	80
Windshield washer assembly	1	3	50	150	131	100
Engine	1	80	400	2,000	448	1,600
Turbocharger	1	5	200	500	28	300
Fuel injection system	4	0.3	50	200	7	600
Fuel pump	1	5	100	500	28	400
Fan clutch	1	5	200	450	28	250
Pressure plate	1	1	20	70	6	50

Table 6. *Cont.*

Part	No.	Weight (kg)	Price (€)	New Part Price (€)	CO2 Footprint (kg)	Benefit (€)
Torque convertor	1	0.2	30	150	1	120
Clutch disk	1	0.5	30	80	3	50
Torsion bar	1	2	20	50	11	30
Alternator	1	4	100	300	22	200
Starter motor	1	2	40	150	11	110
Axle shaft	2	10	100	300	112	400
Air conditioner	1	4	100	400	22	300
Radiator (Al)	1	4	50	100	175	50
Entertainment display	1		100	300		200
Lamps	2		50	100		100
Mirrors	2		30	50		40
Wheels (set)	1	40	100	600	224	500
Diverse sensors	1		300	900		600
Catalyzer (Al)	2	7.5	150	1,000	656	1,700
Car Hulk (to scrap metal)	1	300			450	
Total					3,748	10,800

Source: Industry experts.

For example, the research performed by the Worcester Polytechnic Institute [65] concluded that the auto recycling yards in the state of Massachusetts, process 165,000 cars per year, more than 2 times the amount estimated through our study and obtain a carbon footprint reduction of 2.2 million tons CO2 equivalent, more than 8 times the amount calculated by us, through a superior re-use of all available parts. It is also important to note that Massachusetts is one of the smallest US states, with a population of just 6.8 million people, basically just one third of Romania.

Because we were forced to use approximations and we also tried to realize the calculations on the low end of all benefits, these amounts are basis amounts and should be considered only as indicative of scale and magnitude. Further research is recommended in reaching a more concrete result, but, because of the conditions of the industry, with a lack of industry association and vague and limited activity reporting, this would be possible only based either on a wide collaboration with the main economic operators or through a concentrated effort made together with the Romanian Institute of Statistics [66].

4. Discussions

Bearing in mind Romanian automobile recycling industry we find it difficult to believe that Romania could reach the suggested target of 95% of reuse and recovery by European Commission Directive 2005/53/EC (2000).

The ELV waste flow in Romania is not a very clear one due to a lack of communication between dismantling companies, manufacturers, waste disposal companies and, not least, the authorities. In Romania most dismantlers care more about the money value of the parts, despite the reuse or recycle value, and as a consequence, the parts with a lower demands or lower value end up as landfill. Another issue is the price of some new raw materials that can be way lower than the price of recycled ones. The higher price of recycled materials is due to low processing volume, which cause higher unit costs.

Looking at the technical challenges of ELV dismantling process we observed that the older ELVs are not designed for disassembly, or destructive disassembly. The dismantling companies have to deal with problems regarding toxic, nonrenewable, rare, expensive, strategic materials, and also, they have to consider the fact that some materials cannot be easily identified and therefore cannot be properly recycled. Maintaining a safe working environment during is a must for all these companies and is a priority for them to preserve a sound dismantling environment. These can be obtained throughout modernization and automation of dismantling activities, in particular, and modernization of dismantling industry, in general.

Even though the recycling activity is seen as full of good intents, the dismantling process can generate secondary pollution. Conducting a thorough environment monitoring could be a solution of this challenge.

Moreover, for the challenges regarding collection of ELVs we identify the following: Reliable collection of scrap cars, prevention of illegal dumping and avoidance of illegal use of ELVs, all those can be improved with the help of a more firm and concise involvement of governmental institutions.

We identified five phases in the ELV process in Romania: Collection—done by licensed authorized companies; depollution—removal of hazardous substances; dismantling—removal of valuable of auto parts (engine and gear box); shredding—realized by shredding plant for crushing and disposal of remaining ASR that unrecyclable.

In this paper, we focused on general aspects of dismantling ELVs, but for further study we acknowledged the opportunity to expand our study with other strategies for vehicle recycling such as the use of rubber from tires, non-ferrous metals (aluminum), plastics, glass, and textiles. The use of all elements mentioned above in construction has been successfully implemented worldwide [67].

- Rubber from scrap tires can be used as heat sink for foundation, road surface, asphalt, and rubberized asphalt for highways, garden mulch, carpet underlay, crash barriers and flood defenses, roof tiles, and other fine aggregates replacement in traditional cementations materials. [5,67] Torreto et all [5] is considering the treatment and disposal of tires in Romania and Italy. Even though at the European level there are no explicit regulation for tires management, in Romania is used "principle of producer responsibility", endorsing the collecting of used tires up to 80% of any tires that is placed on the market [5].
- Non-ferrous metals such as aluminum obtain from body and rim parts, wheels and engine, can be used in roofing sheet or aluminum cladding.
- Plastics meaning polyurethane foam, polyester and other PVC fabrics can be used in thermal and acoustic insulation, piping, drainage mats for green roof, etc.
- Glass and fiber glass resulting from windscreen and under-bonnet component can be found in building products such as paving tiles, concrete blocks, roof canopy, carpet glues, and thermal insulation.
- Textiles such as cloth, nylon, vinyl, linen, cotton, and blanket are being used for thermal and acoustic insulation [67].

In order to reach the target of ELV recycling rate suggested by European Commission it is important to use and implement appropriate techniques in ASR recycling and is also important to be the ones that has the least environmental impact.

5. Conclusions

Based on the analysis described above and extending the individual benefits to the estimated amount of 70,000 dismantled vehicles, we can conclude that the auto dismantling industry in Romania generates an economic benefit for the population of approximately 750 million EUR (10,800 EUR x 70,000 cars) and a carbon footprint reduction of 260,000 tons CO2 equivalent. While these amounts are quite impressive, we have to consider both the ambitious target of the European Directive 53/2000, described in this paper and also that the examples from the more mature markets (USA and Japan) show that there still is significant growth potential here.

Currently, as described in this paper, the main used parts recycled from the dismantling of an average car reach only a weight of around 614 kg, which is only 49% of the total weight of an Opel Astra H, far below the 85% target set by the European Union. The average for the recycled parts is now about 17.60 EUR and 6.1 kg of CO_2 footprint per each kilogram. If we consider the remaining 460 kg needed to be recycled per car in order to reach the E.U. Target and assume economic and environmental benefits of only 50% of the averages benefits, as we have no clear visibility of the components remaining to be recycled, we obtain another 4000 EUR and 1400 kg of CO_2 equivalent footprint reduction.

Also considering the recycling activity in USA and the age of the auto park in Europe and Romania, we can infer a total ELV generation of up to 100,000 vehicles per year in the near future. This would raise the total economic benefit for the population to 1.48 billion EUR and a carbon footprint reduction of more than 500,000 tons CO_2 equivalent, showing a potential of almost doubling the economic and environmental benefits.

Our research has confirmed both the high importance of the auto parts recycling industry in Romania and its potential for further growth, supporting therefor the idea that state attention and support should be more focused on it. The industry could benefit from measures aimed at improving productivity and at implementing or even developing new recycling technologies, both areas that require substantial resources, usually outside the possibilities of regular industry actors.

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