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Sustainable Logistics of End-of-life Vehicles – Trends in Europe

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Abstract

Purpose of the article: In the article we have focused on the trends determining the development of reverse logistics of end-of-life vehicles in selected European countries. The analysis concentrates on quantity of end-of-life vehicles which are especially interesting for reverse logistics because of their fitness for recovery or reuse. End-of-life products contain fully valuable elements which, according to the idea of sustainable use of resources, should be recovered. Accordingly, reverse logistics aims at protecting natural resources and the environment through reintroduction of processed waste materials into the economic cycle as valuable products and materials.
Methodology/methods: The aim of the article was achieved on the basis of a critical analysis of subject literature and the analysis of statistical data. In the article the method of descriptive and mathematical statistics and dynamic analysis were used. The 2006–2014 years were analyzed. The data come from the data base of the Eurostat, the statistical office of the European Union. The following variables were taken into account: the amount of end-of-life vehicles (in tonnes and in number of cars), reuse level (in tonnes), recovery level (in tonnes), and recycling level (in tonnes). The analysis was based on a t-Student test for two average values of dependent samples, sign test and the Wilcoxon signed rank test. In order to see if the reverse logistics actions implemented in European countries were effective, the analysis compares the average values of individual variables from the year 2014 and 2006. Measurements were done for the same countries on the same element of population. The chain indexes and the average change tempo for specified variables were calculated. The similarity of the formation of specified variables in each year was compared on the basis of the index of similarity structures.
Scientific aim: The scientific aim of the article is to identify the basic trends determining the development of reverse logistics of end-of-life vehicles in selected European countries (Belgium, Bulgaria, Czech Republic, Denmark, Germany, Estonia, Greece, Spain, France, Italy, Cyprus, Latvia, Lithuania, Luxembourg, Hungary, The Netherlands, Austria, Poland, Portugal, Slovakia, Finland, United Kingdom, Norway). These trends are reflected in the amount of end-of-life vehicles designed for reuse, recovery and recycling.
Findings: With respect to their total or partial processing, end-of-life vehicles are handled according to the 3R principle (reduce, reuse, and recycle) in order to promote the concept of sustainable development. Unfortunately, the number of end-of-life vehicles in Europe is increasing which is a result of the growing economy and society's wealth. Also the ecological awareness of the producers and consumers is rising which is reflected in the increased number of end-of-life vehicles put through reuse, recovery and recycling processes. The analyzed period shows an average annual increase in the reuse, recovery and recycling indexes in most of the

discussed countries. Therefore, we can speak of an increasing ecological efficiency of sustainable logistics of end-of-life vehicles.
Conclusions: Sustainable logistics allows to recover value from used products. End-of-life products contain materials of full value that should be recovered, which undoubtedly fosters sustainable use of resources. European countries vary according to both the effort and the result of the end-of-life vehicles recovery which is due to economic, legal and cultural circumstances. But research shows the existence of positive trends in the realization of reuse, recovery and recycling processes of end-of-life vehicles. These tendencies should delineate further activities in this area.

Keywords: sustainable development, sustainable logistics, end-of-life vehicle, recovery, reuse, recycling

JEL Classification: F64, M20, Q56

Introduction

Proper functioning of enterprises is determined through such criteria as revenue, costs, quality and price of the product. In opposition to economic goals are tasks connected with the reduction of environmental impact of basic activities and building society's welfare. Considering the fact that customers do not base their decisions solely on price and quality, but also on the environmental impact of the product, offering a product which is developed with economic, social and environmental norms and requirements is becoming the basic task of contemporary businesses (Bąk-Sokołowska, 2015). Following profitability alone turned out to be insufficient in the evaluation of a business because it functions in more dimensions than just economic (Grzegorzewska-Ramocka, 2009). When engaging in pro-ecological undertakings, businesses should make informed decisions on the scope and direction of the activities as well as the expected results (Nitkiewicz, 2013). Apart from securing their own existence, businesses should also aim at preserving natural resources for future generations (Krzywda, Krzywda, 2014). This breeds the need for the integration of the concept of sustainable development with management. The complementarity of both fields will be maintained by sustainable logistics which includes the principle of sustainable development in the functioning of a logistic system.

Sustainable logistics proves especially beneficial where there are products composed of many elements, such as end-of-life vehicles, which can undergo different recovery paths. Contrary to other used products such as household appliances and small electronic devices, the number of end-of-life vehicles can be monitored through the vehicle registration systems (Yano *et al.*, 2014). It is necessary to promote the recycling of end-of-life vehicles due to the anticipated increase in the production and use of cars (Sakai *et al.*, 2014). The analysis of generated and recovered quantities of end-of-life vehicles is crucial to monitor the realization of the sustainable development principles in the logistic waste management system.

1. Sustainable logistics and sustainable supply chain in context of management of end-of-live vehicles

Following the principles of sustainable development in logistics stems from the multiplicity of goals of a logistic system. Businesses' main focus is their development. But they are also expected to follow environmental and social norms. Lasting economic success is only possible if a company responds to the needs of people and respects the environment in its activities. Therefore, a sustainable business activity is expressed through efficient and economical use of resources, identification and reduction of risk and respecting the needs of the society (Schmidt, 2010).

Sustainable logistics is an important element of corporate sustainable strategy (Schmidt, 2010), and the sustainable growth determines non-financial areas of generating the value of businesses (Kościelniak, 2016). In this context, sustainable logistics is realized on the level of a company. With respect to the whole net of cooperating businesses, the concept of sustainable development is discussed on the level of a supply chain where the sustainable development concept is realized at every stage of manufacturing, i.e. from the first to the last of the product's life cycles (Sundarakani *et al.*, 2010). The principle of sustainable supply chains is the integration of the management of resources, operations, information in order to maximize revenue and society's wealth, as well as reduce the environmental impact (Leszczyńska, 2014).

The environmental aspect of sustainable development is particularly important due to the fact that most customers are interested

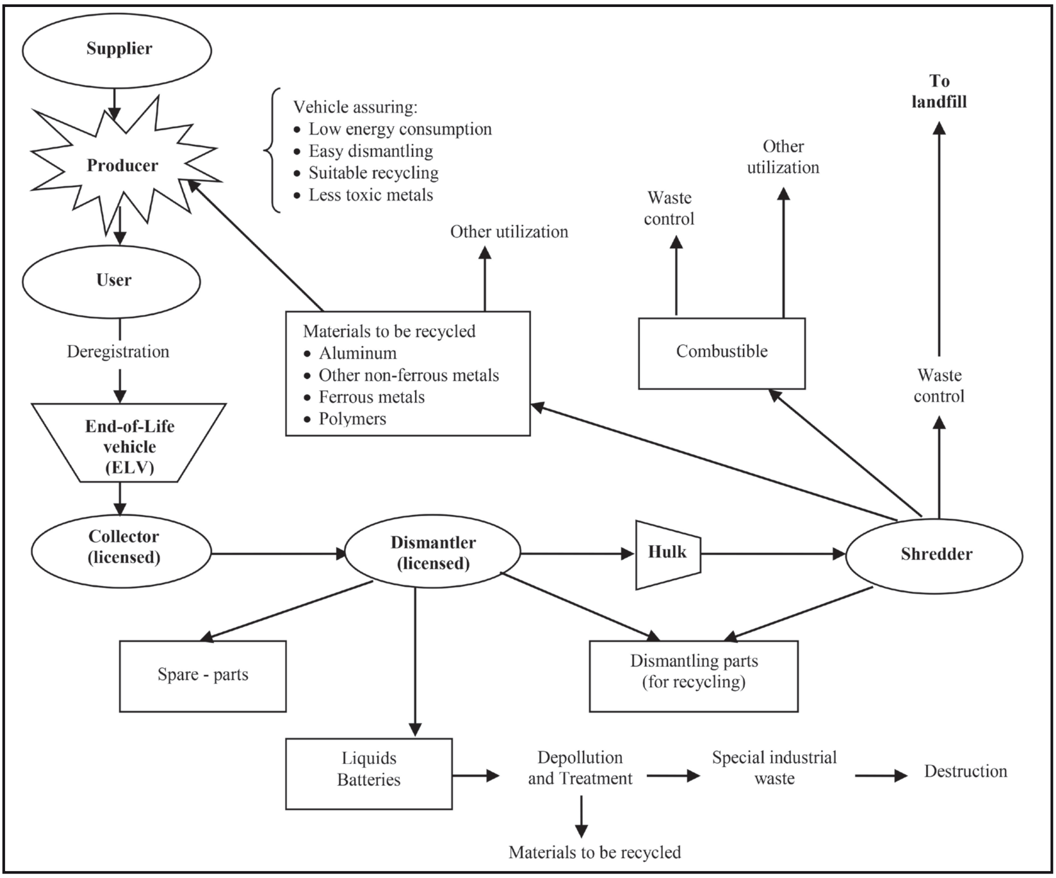

Figure 1. Major steps for ELV recycling according to the E.U. directive.
Source: Kanari et al., 2003.

in the environmental impact of the products they buy (Straube, Doch, 2011). Introducing ecological issues into company's operation and planning does not make it ecologically sustainable. The results of these activities do (Bretzke, 2011).

Used cars are categorized as multi-component consumer products (van Schaik, Reuter, 2004). Because of their physical and chemical properties, they are particularly apt to be recovered and reintroduced into the economic system, which preserves resources. A car engine is composed of about 1000 parts and contains 40 different materials (Gruden, 2003). The processing of end-of-life vehicles falls into the following phases: (1) initial treatment to remove most of the dangerous components, especially batteries, oils, cooling fluids; (2) disassembly of the elements which can be reused or recycled; (3) shredding where the car's body is divided into elements of different sizes that can be later segregated into individual fractions (Fonseca *et al.*, 2013). It is clear, then, that reuse and recycling are processes which can contribute to the reduction of waste from end-of-life vehicles. These processes are realized by multiple entities (Figure 1) which realize different functions (Figure 2), especially: vehicle owners, producers and dealers who run disassembly stations, entities collecting used cars, shredding businesses, specialized

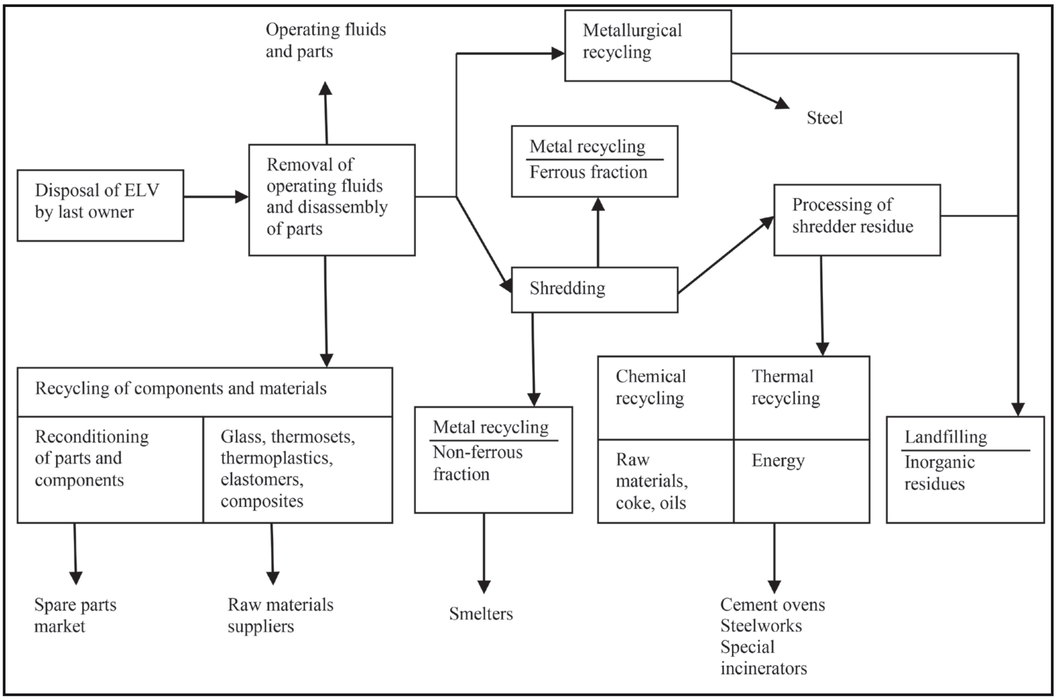

Figure 2. Recycling of end-of-life vehicles. Source: Bellmann, Khare, 2000.

recycling facilities and public administration (Chamier-Gliszczyński, 2011; Ahn *et al.*, 2005).

Generally speaking, sustainable logistics, and sustainable supply chain in particular, realizes processes connected with the production, transport and utilization of end-of-life vehicles. Decisions connected with these activities influence the environmental impact and the costs of the functioning of the system by determining the following three aspects: the localization of facilities (strategic level), the designation of the used products (tactical level), and the selection of the materials and services providers (operational level) (Quariguasi Frota Neto *et al.*, 2008).

The flows of end-of-life products are of cascade character, which necessitates additional logistic operations in terms of the handling of material and energy streams (Taskhiri *et al.*, 2016). Each of the entities realizing these processes will pursue the optimization of its benefits and losses. That is why it is so important to create a supply chain with a clearly defined rules of the distribution of profits and losses among the entities (van Lier *et al.*, 2016). It is worth remembering that the accessibility of functioning supply chains to entities translates into the readiness of the country for the global market (Ekici *et al.*, 2016). Moreover, due to the intensification of pro-ecological activities in logistic systems, their goal was redefined from the reduction of costs to the minimization of costs and environmental impact (Quariguasi Frota Neto *et al.*, 2008). European directive 2000/53/CE concerning the management of end-of-life vehicles bids car producers to minimize car waste and maximize reuse and recycling. For this reason they need to know the factors determining the development of recovery, including recycling (Millet *et al.*, 2012). At the very stage of car design, the producers should address the questions of the reduction of dangerous materials, broader use of refrigerants which have a lesser influence on global warming, and the preparation and distribution of information on disassembly with regard to recycling (Hiratsuka *et al.*, 2014). A properly realized removal and disassembly will contribute not only to the reduction of the environmental impact of used vehicles, but also to the reintroduction of resources and materials from recycling which is a way of preserving natural resources (Alwaeli, 2016). The following activities are undertaken in order to improve the indexes of recovery and recycling (Kamińska *et al.*, 2008):

1. Reducing the number of materials used in the production of cars.
2. Using recyclable materials.
3. Labelling materials in the production phase to make their identification and recycling easier.
4. Developing a manual of a car's disassembly.

What is more, processing steel waste, including vehicle waste and scrap metal recovery consumes 75% less energy and has a lower air pollutants emission than processing of iron ore (Sicińska, 2014). This makes steel processing environmentally friendly, which should encourage to continuously increase the indexes of recovery and recycling of end-of-life vehicles.

Collecting and processing waste and recyclable materials, including end-of-life vehicles has a big practical meaning. Waste management is often seen as an obligation and all activities are planned so that they meet legal norms (Bogh *et al.*, 2014). Implementation of the sustainable logistics concept into the functioning of a business does more than that. It guarantees an economically and ecologically efficient flow of materials in closed economic cycles.

2. Research Purpose and Methods

We analyzed the quantities of end-of-life vehicles. Due to their physical and chemical properties and the danger they pose to the environment, used cars are a special object of reverse logistics. The goal of the article is to identify changes in terms of the quantity of end-of-life vehicles designed for reuse, recovery and recycling in selected European countries. We posed the following research questions:

1. With what measures is it possible to assess the functioning of sustainable logistics of end-of-life vehicles?
2. Are the changes in terms of the highlighted measures in the selected European countries positive?
3. Do we observe significant changes in the level of the measures over a period of time in the selected European countries?

Considering the concept of a logistic system, the main goal of sustainable logistics is to improve the economic and ecological efficiency of the supply chain of end-of-life vehicles. The article concentrates on the measure of ecological efficiency which in the context of end-of-life vehicles can be understood as the effect of putting used cars through processes allowing for their reintroduction into the economic cycle as products of full value or materials. In this situation the general measure of efficiency can be defined as the relationship of the number of reused, recovered and recycled end-of-life vehicles to the number of produced vehicles. In order to assess the general ecological efficiency of the sustainable logistics of end-of-life vehicles, the following indexes were used:

1. Reuse index – to assess the reuse of end-of-life vehicles:

$$I_{Reuse} = Q_{Ruse}/Q_{Gen} \quad (1)$$

where:

I_{Reuse} reuse index,
Q_{Gen} end-of-life vehicles generated,
Q_{Reuse} waste reused.

2. Recovery index – to assess the recovery of end-of-life vehicles:

$$I_{Recovery} = Q_{Recovery}/Q_{Gen} \quad (2)$$

where:

$I_{Recovery}$ recovery index,
$Q_{Recovery}$ end-of-life vehicles recovered.

3. Recycling index – to assess the recycling of end-of-life vehicles:

$$I_{Recycle} = Q_{Recycle}/Q_{Gen} \quad (3)$$

where:

$I_{Recycle}$ recycling index,
$Q_{Recycle}$ end-of-life vehicles recycled.

The numbers of generated, reused, recovered and recycled end-of-life vehicles can be seen as the partial measures of ecological efficiency in terms of sustainable logistics. The following measures corresponding to the specified measures were determined:

1. WGENT – The amount of end-of-life vehicles (in tonnes)
2. WGENN – The amount of end-of-life vehicles (in number of cars).
3. REUSE – Reuse level of end-of-life vehicles (in tonnes).
4. RECOV – Recovery level of end-of-life vehicles (in tonnes).
5. RECYC – Recycling level of end-of-life vehicles (in tonnes).

The analysis used data from the Eurostat (Eurostat, 2016), the statistical office of the European Union covering the period 2006–2014. Based on the accessibility and completeness of data, the following countries were singled out for analysis: Belgium, Bulgaria, the Czech Republic, Denmark, Germany, Estonia, Greece, Spain, France, Italy, Cyprus, Latvia, Lithuania, Luxembourg, Hungary, the Netherlands, Austria, Poland, Portugal, Romania, Slovakia, Finland, the United Kingdom, Norway.

The dynamics in the amount of end-of-life vehicles were examined with the use of simple dynamics indexes such as chain indexes and the average change tempo. It was also checked if the year 2014 showed significant changes in the numbers of end-of-life vehicles (generated, reused, recovered and recycled) in comparison to the year 2006. In order to do that, we looked at the average values of individual variables in the year 2014 and compared with their average levels in 2006. The measurements were all done on the same group of countries. We investigated the differences between the level of a variable from the years 2014 and 2006 with help of Student's t test for two averages for dependent variables, signs tests and Wilcoxon's rank test. Student's t test assumes that the population has a normal distribution. Signs and Wilcoxon's tests do not require the assumption about the normal distribution. We assumed the null hypothesis of null difference between the average level of a given variable in the year 2014 and the average level of this variable in the year 2006, and an alternative hypothesis that the difference between the averages is positive in the case of the quantity of waste in general and of quantities reused and recycled. It was checked, therefore, if over the period of the analyzed 9 years there are any negative or positive tendencies in the number of end-of-life vehicles in terms of both the general waste quantity and the quantity reused and recycled.

3. Results

In order to evaluate the efficiency of the sustainable logistics of end-of-life vehicles we calculated the reuse, recovery and recycling indexes. The values of the indexes are shown in Tables 1–3.

The highest reuse indexes in 2014 are observed in Lithuania, Cyprus, Hungary, the Netherlands, Spain, Estonia and Belgium, while in 2006 they were highest in Lithuania, the Netherlands, Belgium, Norway and France. Unfortunately, the values of indexes in these countries differed significantly, especially in Estonia, Cyprus, Latvia and Norway which reveals significant fluctuations of the index over individual years. The most stable

Table 1. Reuse index (in %).

Countries	Years								
	2006	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**
Belgium	19.1	19.7	19.4	17.3	17.6	13.7	12.9	14.9	16.6
Bulgaria	3.9	3.1	3.0	1.0	0.7	0.8	1.0	1.7	2.1
Czech Republic	2.6	2.6	2.8	2.7	2.7	2.7	2.7	2.7	2.7
Denmark	11.1	10.6	13.1	10.9	14.7	15.5	12.4	14.8	15.2
Germany	6.3	6.7	6.1	3.5	7.8	6.5	5.6	4.2	4.0
Estonia	–	–	6.0	3.0	4.9	8.1	7.6	7.3	16.7
Greece	2.6	2.5	8.8	15.0	19.0	19.8	21.2	22.0	–
Spain	9.0	3.9	4.5	13.0	13.2	13.3	13.3	14.8	17.4
France	14.0	14.0	14.0	6.7	9.7	8.7	8.0	11.8	10.2
Italy	9.8	12.5	12.6	13.8	10.1	14.4	9.7	12.0	7.7
Cyprus	5.9	10.4	12.1	33.0	16.8	16.2	17.8	17.4	31.3
Latvia	11.8	4.0	5.8	9.0	12.7	8.1	4.4	5.6	5.4
Lithuania	42.5	31.7	29.7	31.4	26.3	29.2	29.2	30.2	33.7
Luxembourg	0.0	11.6	6.9	5.3	4.8	5.4	3.9	1.8	1.6
Hungary	7.4	13.3	14.8	10.4	14.3	11.6	11.6	16.6	27.0
Netherlands	22.0	22.7	24.5	23.7	24.5	23.5	24.1	23.8	24.1
Austria	3.9	4.8	4.6	4.3	4.5	5.3	5.2	6.1	5.3
Poland	11.3	12.3	13.7	11.1	10.6	9.0	10.0	10.4	10.4
Portugal	0.6	1.5	1.2	5.2	3.9	3.8	3.5	3.5	4.1
Romania	1.3	12.0	8.5	5.9	3.8	4.7	6.5	5.7	3.5
Slovakia	3.9	2.3	4.4	2.4	2.6	2.0	1.2	1.4	2.1
Finland	9.1	11.0	11.0	11.0	10.4	10.4	10.4	10.4	5.6
United Kingdom	1.3	1.3	1.8	2.1	1.8	2.0	1.9	2.1	2.2
Norway	15.9	17.7	12.0	5.0	6.7	3.9	11.8	8.0	6.9

Source: Author's own study.

values of the index in the analyzed period were observed in the Czech Republic and the Netherlands.

The value of the recovery indexes exceeded 80% in the majority of the analyzed countries. The highest recovery level was observed in Germany, Austria, Bulgaria, Luxembourg and Slovakia. Over the discussed period, the recovery indexes have stable levels and there is an average annual increase in the relationship between the recovered and generated end-of-life vehicles. An annual average decrease under 2% is observed in Estonia, Greece and Hungary. A slightly bigger downward rate was only recorded in Cyprus where the average decrease in analysed period reached 3,9%.

Recycling indexes behave similarly to recovery indexes which leads to the conclusion that recycling is a recovery process. The steepest annual average increase in the recycling index was observed in Norway (3,7%). The biggest decrease, on the other hand, took place in Cyprus (3,9%).

In order to complete the analysis with respect to the general assessment of the efficiency of sustainable logistics of end-of-life vehicles, we examined the change dynamics

Table 2. Recovery index (in %).

Countries	Years								
	2006	2007	2008	2009	2010	2011	2012	2013	2014
Belgium	70.9	70.4	70.8	73.2	73.7	76.9	80.1	78.0	77.6
Bulgaria	83.4	89.6	83.7	88.2	88.6	91.7	90.3	92.4	92.9
Czech Republic	82.5	82.5	83.2	83.6	83.6	83.6	83.6	83.6	83.6
Denmark	68.9	70.6	69.8	71.4	76.0	77.4	80.2	71.9	70.9
Germany	83.3	83.7	86.8	83.1	98.4	101.7	100.7	99.5	97.4
Estonia	82.5	82.2	86.7	84.4	73.4	70.8	77.5	79.1	71.7
Greece	79.7	81.7	76.9	72.4	67.5	67.9	69.1	69.5	–
Spain	75.0	81.2	81.2	73.0	72.5	74.1	74.9	76.7	76.1
France	67.0	67.5	67.4	75.4	72.2	76.1	79.0	77.5	81.1
Italy	63.0	70.7	74.5	70.8	75.3	70.9	72.5	70.8	77.4
Cyprus	80.7	73.0	67.7	59.9	70.1	70.4	69.1	69.1	58.9
Latvia	74.2	86.9	83.0	77.1	73.4	77.8	93.5	87.0	87.0
Lithuania	50.0	55.0	55.5	54.3	62.2	58.2	60.9	62.2	60.7
Luxembourg	85.8	73.5	77.8	79.9	83.1	85.4	91.0	92.8	93.4
Hungary	74.1	69.5	69.6	67.3	72.5	74.6	74.6	75.1	68.7
Netherlands	63.1	62.7	61.1	61.5	70.9	72.7	72.0	72.1	71.8
Austria	81.9	81.4	91.5	91.8	92.0	92.3	89.0	90.6	90.9
Poland	74.5	64.7	66.4	76.9	79.2	82.5	82.8	79.8	77.6
Portugal	85.6	84.2	86.0	81.7	82.9	84.2	84.1	87.0	88.6
Romania	78.9	73.7	78.0	79.4	81.7	82.1	79.7	81.7	85.0
Slovakia	79.8	84.3	84.4	87.2	87.6	92.5	89.9	92.3	93.9
Finland	73.6	69.9	69.9	70.3	84.6	84.6	84.6	84.6	91.7
United Kingdom	81.0	83.1	82.0	81.5	83.8	83.6	86.2	86.8	88.5
Norway	67.6	65.4	70.7	80.9	88.0	89.4	82.0	86.7	90.6

Source: Author's own study.

of partial measures. Table 4 presents the annual average tempo of change in the amount of generated end-life-vehicles and the amount of vehicles put through individual recovery processes.

In the 2006–2014 period in the majority of countries there was an annual average increase in the amount of end-of-life vehicles expressed both in tones and the number of cars. The increase was biggest in Finland and on Cyprus. A relatively stable level of generated end-of-life vehicles is observed in Belgium, Germany, the Netherlands and the United Kingdom. The analysis of change in the number of end-of-life vehicles put through disposal processes in the 2006–2014 period yielded following results:

- The biggest annual average increase in the amount of reused end-of-life vehicles was observed on Cyprus and in Portugal (the increase was also high in Greece, but only in the 2006–2013 period), the biggest annual decrease, on the other hand, in Italy and Norway (and Luxembourg – in the 2007–2014 period).
- The highest annual average increase in the amount of recovered end-of-life vehicles characterized Finland and Cyprus,

Table 3. Recycling index (in %).

Countries	Years								
	2006	2007	2008	2009	2010	2011	2012	2013	2014
Belgium	70.9	70.4	70.8	73.2	73.7	76.9	80.1	78.0	77.6
Bulgaria	83.4	89.6	83.7	88.2	88.6	91.7	90.3	92.4	92.9
Czech Republic	82.5	82.5	83.2	83.6	83.6	83.6	83.6	83.6	83.6
Denmark	68.9	70.6	69.8	71.4	76.0	77.4	80.2	71.9	70.9
Germany	83.3	83.7	86.8	83.1	98.4	101.7	100.7	99.5	97.4
Estonia	82.5	82.2	86.7	84.4	73.4	70.8	77.5	79.1	71.7
Greece	79.7	81.7	76.9	72.4	67.5	67.9	69.1	69.5	–
Spain	75.0	81.2	81.2	73.0	72.5	74.1	74.9	76.7	76.1
France	67.0	67.5	67.4	75.4	72.2	76.1	79.0	77.5	81.1
Italy	63.0	70.7	74.5	70.8	75.3	70.9	72.5	70.8	77.4
Cyprus	80.7	73.0	67.7	59.9	70.1	70.4	69.1	69.1	58.9
Latvia	74.2	86.9	83.0	77.1	73.4	77.8	93.5	87.0	87.0
Lithuania	50.0	55.0	55.5	54.3	62.2	58.2	60.9	62.2	60.7
Luxembourg	85.8	73.5	77.8	79.9	83.1	85.4	91.0	92.8	93.4
Hungary	74.1	69.5	69.6	67.3	72.5	74.6	74.6	75.1	68.7
Netherlands	63.1	62.7	61.1	61.5	70.9	72.7	72.0	72.1	71.8
Austria	81.9	81.4	91.5	91.8	92.0	92.3	89.0	90.6	90.9
Poland	74.5	64.7	66.4	76.9	79.2	82.5	82.8	79.8	77.6
Portugal	85.6	84.2	86.0	81.7	82.9	84.2	84.1	87.0	88.6
Romania	78.9	73.7	78.0	79.4	81.7	82.1	79.7	81.7	85.0
Slovakia	79.8	84.3	84.4	87.2	87.6	92.5	89.9	92.3	93.9
Finland	73.6	69.9	69.9	70.3	84.6	84.6	84.6	84.6	91.7
United Kingdom	81.0	83.1	82.0	81.5	83.8	83.6	86.2	86.8	88.5
Norway	67.6	65.4	70.7	80.9	88.0	89.4	82.0	86.7	90.6

Source: Author's own study.

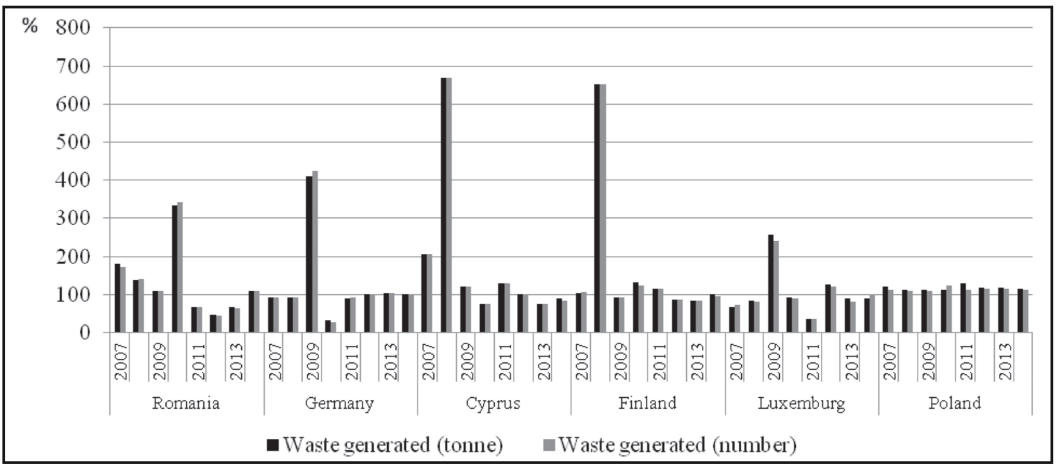

Figure 3. Chain indexes for generated end-of-life vehicles in the chosen countries.
Source: Author's own study.

Table 4. Annual average rate of change.

Countries	Variables				
	Waste generated (tonne)	Waste generated (number)	Reuse	Recovery	Recycling
Belgium	0.71%	–0.41%	–1.05%	1.86%	1.43%
Bulgaria	7.79%	7.56%	0.12%	9.26%	9.94%
Czech Republic	12.39%	11.17%	12.93%	12.58%	12.61%
Denmark	2.24%	0.27%	6.30%	2.59%	2.64%
Germany	1.41%	0.31%	–4.09%	3.42%	2.18%
Estonia	5.73%	3.67%	22.41%**	3.89%	3.62%
Greece	19.14%*	13.69%	61.59%*	16.83%*	16.19%*
Spain	–1.87%	–3.39%	6.59%	–1.69%	–1.94%
France	3.65%	1.94%	–0.35%	6.16%	5.53%
Italy	–3.89%	–5.82%	–6.70%	–1.37%	–1.17%
Cyprus	35.56%	34.66%	67.06%	30.33%	29.87%
Latvia	5.95%	4.97%	–3.89%	8.08%	8.04%
Lithuania	11.37%	10.11%	8.18%	14.12%	15.26%
Luxembourg	–8.40%	–9.31%	–27.52%***	–7.42%	–8.40%
Hungary	–2.04%	–3.88%	15.21%	–2.97%	–3.89%
Netherlands	1.09%	–0.25%	2.24%	2.74%	1.40%
Austria	–3.23%	–4.60%	0.40%	–1.96%	–2.52%
Poland	17.86%	14.78%	16.67%	18.46%	18.18%
Portugal	17.94%	16.45%	51.53%	18.45%	17.56%
Romania	10.13%	8.94%	24.25%	11.15%	10.98%
Slovakia	9.56%	8.61%	1.16%	11.82%	11.80%
Finland	27.94%	25.93%	20.46%	31.49%	28.75%
United Kingdom	1.28%	1.33%	8.03%	2.42%	2.06%
Norway	5.17%	3.61%	–5.26%	9.08%	6.83%

**The 2006–2014 years were analysed. **The 2008–2014 years were analysed. ***The 2007–2014 years were analysed.*

Source: Author's own study.

the most significant decrease, on the other hand, took place in Luxembourg.

- The biggest annual average increase in the amount of recycled end-of-life vehicles was observed in Cyprus and Finland, the biggest annual decrease, on the other hand, in Luxembourg.

Changes in the amount of reused, recovered and recycled end-of-life vehicles come from the change in the amount of generated end-of-life vehicles. Since the amount of generated end-of-life vehicles vary significantly in the analyzed countries over the 2006–2014 period, we carried out the change dynamics on the basis of chain indexes for six countries with the highest level of the variability coefficient (Figure 3).

The most stable changes in the amount of generated end-of-life vehicles on the year-to-year basis are observed in Poland. The strongest fluctuations, on the other hand, were recorded in Cyprus and Finland, especially

Table 5. The Student's t test for interrelated samples for variables determining the level of waste generated, reused, recovered and recycled end-of-life vehicles in selected European countries.

A pair of variables	Difference	t value	p value
WGENT/2014 & WGENT/ 2006	31502.170	1.250717	0.223612
WGENN/2014 & WGENN/ 2006	8038.958	0.272895	0.787369
REUSE/2014 & REUSE/ 2006	3348.500	0.914347	0.370021
RECOV/2014 & RECOV/ 2006	48734.7100*	2.491710*	0.020363*
RECYC/2014 & RECYC/ 2006	40720.460*	2.349902*	0.027731*

**Difference statistically significant at a significance level of 0,05.*

Source: Author's own study.

Table 6. Sign test and Wilcoxon's test for variables determining the level of waste generated, reused, recovered and recycled in selected European countries.

A pair of variables	Sign test			Wilcoxon's test		
	v<V	Z'	p value	T	Z	p value
WGENT/2014 & WGENT/ 2006	20.83333	2.653614	0.007963*	56.00000	2.685714	0.007238*
WGENN/2014 & WGENN/ 2006	29.16667	1.837117	0.066193	79.00000	2.028571	0.042503*
REUSE/2014 & REUSE/ 2006	25.00000	2.245366	0.024745*	85.00000	1.857143	0.063292
RECOV/2014 & RECOV/ 2006	20.83333	2.653614	0.007963*	48.00000	2.914286	0.003565*
RECYC/2014 & RECYC/ 2006	20.83333	2.653614	0.007963*	51.00000	2.828571	0.004676*

v<V – percent of the number of variables for which the difference is negative, Z' – critical value of sign test, p – p-value for the tests.
T – critical value of Wilcoxon's test for group size n≤25, Z – critical value of Wilcoxon's test for group size n>25.

in the 2007–2009 period – the amount of generated end-of-life vehicles in the year 2008 exceeded significantly the levels form 2007 and 2009. And in Germany the number of end-of-life vehicles in 2009 went up steeply in comparison to the previous year.

In order to see if the differences in the amount of generated, recovered, reused and recycled end-of-life vehicles in 2014 in the analyzed countries were serious in comparison to the year 2006, we juxtaposed the average levels of individual variables from 2014 with the average levels they reached in 2006. The analysis was based on the same countries which means it was the same element of the population. Hence we used the Student's t test for dependent samples. The results are shown in Table 5.

It may be assumed, therefore, that the average amount of recovered and recycled end-of-life vehicles was higher in 2014 than in 2006. The amount of generated and reused end-of-life vehicles look different, though, as their average level in 2014 was similar to the one from 2006. We can conclude, therefore, that the amount of both generated and recovered end-of-life vehicles is constant. In their level, all variables show positive tendencies.

Slightly different results were yielded by the sign test and Wilcoxon's test which are a non-parametric alternative to the Student's t test for bind variables (Table 6). These tests are used to determine the significance of differences between two dependent samples where there is no assumption about the normal distribution of differences.

In the case of the sign test and Wilcoxon's test the hypothesis about equal distributions for all variables, which is why we can say that the differences between averages are statistically significant. The test confirm positive tendencies in terms of the numbers of reused, recovered and recycled end-of-life vehicles, and inform us of a major increase in the amount of generated end-of-life vehicles in 2014 in comparison to 2006.

4. Discussions

When we analyze the rates of reuse, recovery and recycling indexes, we can speak of positive trends. Considering the fact that end--of-life vehicles contain parts and materials which can be recovered, it seems legitimate to carry out a separate analysis on them. The variety of parts and materials that end-of-life vehicles are built of results in a wide range of activities and processes and a variety of entities engaged in sustainable logistics. Therefore, the analyses require the quantities of: liquids, tires, oil filters, other materials arising from depollution (excluding fuel), metal components, large plastic parts, glass, other arising from dismantling, batteries and accumulators, catalysts, ferrous scrap (steel) from shredding, non-ferrous materials (aluminum, copper, zinc, lead, etc.) from shredding, shredder light fraction (SLF), other materials arising from shredding. This type of waste is generated in the processes connected with dismantling, depollution and shredding. Another reason why reuse, recovery and recycling rates are high is the fact that it is not just the currently collected end-of-life vehicles that undergo these processes, but the stored ones as well. Future analysis should also embrace the relationships between the numbers of accumulated end-of-life vehicles and the numbers of recovered vehicles.

5. Conclusion

Recovering the value from used products, including cars, and redirecting it to the economic cycle is becoming necessary for the contemporary economies. The environmental impact of production and consumption processes makes businesses increasingly responsible for their products in their post-consumer phase. Return flows are realized by multiplicity of entities which often differ in terms of their goals. That is why return processes are controlled by sustainable logistics. End-of-life vehicles are composed of numerous parts which makes them interesting for sustainable logistics which aims at profitability and efficiency of all activities connected with the recovery of end-of-life vehicles.

In most analyzed European countries the changes in the quantities of end-of-life vehicles in relation to the methods of their recovery are positive. Recovery, including recycling, is the preferred method. All countries show the level of recycling equal or higher than 50%, and in the majority of the countries the level is higher than 70%. Moreover, in the period 2006–2014 there is an average annual increase in both the level of recycling and the quantity of waste undergoing this process. Annual average decreases in this respect are slight and do not exceed 9%. Unfortunately, the number of generated end-life-vehicles is also increasing which is caused by legal, economic and social factors. The number of end-of-life vehicles will continue to increase along with the growth of economy and society's wealth. The discussed countries show similar tendencies. In the analyzed group of countries we observed a significant increase in the number of generated end-of-life vehicles in 2014 in comparison to 2006. We can speak of a positive change, though, as the number of recycled, recovered and reused end-of-life vehicles in 2014 were significantly higher than in the year 2006. This tells us that the European policy on end-of-life vehicles is correct.

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