Effectiveness of Selected Issues of Used Tyre Management in Poland

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Abstract

The study aimed to assess selected issues regarding used tyre management efficiency in Poland from 2008 to 2018, considering their generation, collection, recovery and accumulation per area based on European Union and national regulations. Within 11 years, over 5 million Mg of used tyres were introduced into the domestic market, exceeding the amount for 50 million registered vehicles. A significant process in tyre waste management was the recovery of 47% of tyres, almost entirely correlated with the total volume of tyres. Only the growth trend of the generated tyres was considered significant, and the rarely used indicator of the accumulation of used tyres per area exhibited an uneven accumulation of used tyres with the highest amount at 48.06 Mg km^{-2} in a region with a small area but a significant volume of waste tyres. Therefore, management of used tyres requires taking action in the country to optimise increasing waste collection and rational recovery in the context of further minimising environmental pressure and increasing the efficiency of their use, considering advanced technology.

Introduction

The development of the automotive industry worldwide favours the increasing demand for tyres and the formation of a significant number of used tyres, which are considered waste due to their quantity and durability. Moreover, tyres do not degrade in the natural environment for up to 100 years (Gronowicz and Kubiak 2007). Generally the disposal of used tyres and other polyisoprene based products are problems (Juma et al. 2006).

Hence, the tyre has become a waste on a global scale. Waste tyres arise as a result of the operation of vehicles and the dismantling of end-of-life vehicles. The main components of tyres are rubber, fillers, soot, steel, sulphur, zinc oxide, process oil, vulcanisation accelerators, and so on (Rofiqul et al. 2010). The related waste management includes collection, transport, treatment, and disposal including landfilling (Przydatek and Krok 2018). However, landfilling is the most popular method of waste disposal, which wastes the energy and material potential of used tyres and deteriorates the condition of the environment (Segre and Joekes 2000). Landfills pose a serious threat to the natural environment, fire-fighting, and habitats for insects and rodents (El-Naqa 2005).

To apply the waste hierarchy, European Union (EU) member states have been adopting measures to encourage solutions that minimise environmental impact (Pomberger et al. 2017). Therefore, on a global scale, all waste producers must be included in organised waste collection (Przydatek 2019). Such behaviour is to help protect natural resources and prevent environmental degradation (Gharfalkar et al. 2015). One of the most popular models in Europe in terms of improving used tyre management (and waste) considers optimisation and is based on extended production responsibility (Sienkiewicz et al. 2012; Gaska et al. 2018).

Every year, huge amounts of waste are generated worldwide, especially in the form of used tyres. In China alone, it has been estimated that around 20 million Mg of tyres will be generated in 2020 (Sun et al.

2016). The economy dealing with the alternative side of using waste is increasingly growing. Currently, the ideal solution for getting rid of used tyres is recycling or incineration (Directive 2000/53/EC). In the rubber waste industry, the tyre can also be used as a fuel, as a component of bituminous mass, and in the roofing and paving industries (Silvestravieiete and Sleinotaite-Budriene 2002; Hernandez-Olivares et al. 2002). Another way to manage used tyres is through retreading.

In 2013, the volume of used tyres in the EU reached 13.6 million Mg (Simić and Dabić-Ostojić 2017). The waste tyre management in the EU is regulated by the following legal acts: Council Directive 1999/31/EC, Directive End-of-Life Vehicle 2000/53/EC, and Directive Waste Incineration 2000/76/EC. Based on these acts, parts including tyres are required to be reused, recycled, or recovered, and the disposal of whole and shredded car tyres is prohibited. However, EU member states have the option of choosing a waste tyre management system considering the relevant fees and free market (Sienkiewicz et al. 2012).

The product life cycle, or more precisely the life cycle of the tyre, consists of intangible and tangible stages. The first stage includes design and construction. The second stage consists of three phases: manufacturing, use, and disposal of the used tyre. In all phases of the material cycle, the tyre harms the natural environment and human health and exhausts non-renewable resources. In contrast, Clauzade et al. (2010) and Torretta et al. (2015) found that all car tyre recycling/recovery methods provide environmental benefits.

Used tyres are remanufactured, recycled, or co-incinerated in cement plants as an alternative fuel. Used tyre recycling is an extremely difficult process due to the diversity of the raw material from which they are produced (Sienkiewicz et al 2012). Tires should be disposed to reduce their impact on the environment; through incineration which is the fastest and easiest discarding procedure (Machin et a. 2017).

The main reason for the need to neutralise waste is the development of civilisation and the improvement of the standard of living of society. As a result, waste and alternative technical solutions are increasingly generated.

According to the hierarchy of waste management, the prevention of waste is required. When this is impossible, it is necessary to act to ensure recovery and recycling and to prevent landfilling (COM 2005). Landfilling of used tyres is prohibited, except for bicycle tyres and tyres with an outer diameter greater than 1,400 mm (Act on waste 2012). A valuable element in the management of used tyres is energy recovery with their participation (Huang et al. 2012).

Unfortunately, many tyres are sometimes damaged or destroyed, so a possibility of recycling them in the recycling process must be found, giving them a new shape or function. Too much of this type of waste causes excessive accumulation, leaving recovery less likely. Rubber, steel, and textiles that are suitable for reuse or energy generation are eligible for recovery. Recycling with the use of used tyres, demonstrated in the course of recovery, aligns with environmental protection.

The study aims to assess the efficiency of selected issues in waste tyre management in Poland from 2008 to 2018, considering waste tyre generation, collection, recovery and mass accumulation per area.

Description of Examined Country

Poland is a country located in Central Europe. The country ranks 69th in terms of its area (312,696 km^2) and 36th in terms of world population and ninth in European population. In administrative terms, Poland is divided into three levels: voivodeship, district, and commune. The largest area of 35.579 km^2 is occupied by the Mazovian Voivodeship in the central part with the largest number of inhabitants, while the smallest area is 9.412 km^2 by the Opolskie Voivodeship, in the south - western part of the country (Przydatek 2020). The lowest average population density is in the voivodeships Podlaskie and Warmian-Masurian.

Used Tyre Management in the Country

In Poland, the used tyre collection system is implemented primarily by vehicle service stations and end-of-life vehicle dismantling stations (NWMP 2016). Used tyres can also be delivered by individuals to a selected vulcanisation plant. Depending on the selected place, used tyres can be returned for free or a fee. Used tyres can also be collected during selective waste collection as bulky waste (Skrzyniarz 2020). In contrast, certain taxes are levied in some countries, such as Denmark, Slovakia, and Croatia (Kaur et al. 2021). A significant supplement to the collection of used tyres includes selective waste collection points and waste management plants (Fig. 1). Despite Mazovian Voivodeship registering the most vehicles, the largest collection point for used tyres is in the Greater Poland Voivodeship (CRVD 2018).

Many tyre collection points exist in the country due to the ban on landfilling (waste code 16 01 03 – used tyres) (Regulation 2014). Sixty plants deal with the management of used tyres; few of them deal with comprehensive disposal or recycling of materials. In the Opolskie Voivodeship, an installation enables the co-combustion of used tyres. According to Wasilewski and Stelmach (2009), such a process is favoured by the significant calorific value of tyres with a value of 31.4 MJ kg^{-1}. One of the factors aimed at reducing the amount of waste generated both in Poland and the EU countries is the use of the waste hierarchy, including recycling, which reduces the effect of waste on the environment, the consumption of natural resources, and the costs (Eriksson et al. 2005).

Methods And Materials

Data acquisition was based on a questionnaire addressed to 16 individual Provincial Marshal Offices in Poland and included owner observations. Based on the annual data for 2008 to 2018, including the total sum and quantities of generated, collected and recovered tyres, an analysis was conducted that includes the determination of the mass accumulation indicator of tyres by area (division by country and voivodeship in Mg km^{-2}). The waste accumulation indicator by area was used in studies by Przydatek and Ciągło (2020) and Xiao et al. (2012). Generated waste tyres are primarily produced in vulcanisation plants, service points, and vehicle and dismantling stations for end-of-life vehicles (NWMP 2016).

According to Miliute-Plepiene and Plepys (2015), the number of studies considering waste accumulation indicators is increasing, which may result from the need to identify factors causing an increase in the mass of generated waste. In addition, based on Statistics Poland (2008–2018), the number of registered vehicles in Poland was determined. This number included motor vehicles, buses, lorries, special cars, tractor units, agricultural tractors, motorcycles, and mopeds.

A statistical analysis was also performed that included the maximum, minimum, and average. To determine the correlation relationship meeting the condition of the normal distribution for the data covering the total number of tyres, including those generated, collected, and recovered, the Pearson linear correlation coefficient method was used. When the condition of normal distribution was not met, Spearman's rank method was applied. The Spearman correlation coefficient R is a non-parametric equivalent of Pearson's coefficient. As with parametric correlation, the Spearman correlation coefficient R measures the strength of the correlation between variables. Non-parametric tests were used due to the lack of normality of the distribution of most of the analysed indicators following the results of the Shapiro-Wilk test ($p < 0.05$) (Przydatek and Kanownik 2019).

The non-parametric Mann-Kendall statistical test was chosen to test a series of numbers in terms of identifying an upward or downward trend that is not necessarily linear. Statistica 13 (StatSoft Poland, StatSoft, Inc., USA) was used for statistical analysis.

Used Tyre Quantity Analysis

The total volume of used tyres collected in Poland from 2008 to 2018, broken down by the 16 individual voivodeships, is listed in Table 1. The smallest mass of collected tyres was recorded in the north-eastern part of the country, specifically in the Podlaskie Voivodeship, whereas the highest was in the central-western region of Poland (Greater Poland Voivodeship, area 35.66 Mg km^{-2}). These values were respectively 42,067 Mg and 1,063,657 Mg. In contrast, the highest indicator of accumulation of used tyres at 48.06 Mg km^{-2} occurred in the southern part of central Poland (Świętokrzyskie Voivodeship, 15th in terms of size in the country – 562,848 Mg, whereas the lowest was 1.94 Mg km^{-2} in the north-eastern part of the country (Warmian-Masurian Voivodeship fourth position – 46,983 Mg) (Table 1). The total amount of tyres during the 11 analysed years ranged from 708.24 to 135,570 Mg with an average of 32,741 Mg (Table 2).

Table 1
Total amount of used tires divided into administration regions of Poland

Voivodeship	Amount of tires	Tire's accumulation
	Mg	Mg km^{-2}
Lower Silesia	116,813	5.86
Kuyavian-Pomeranian	175,155	9.75
Lublin	427,502	17.02
Lubusz	595,164	42.55
Łódz	327,739	17.99
Lesser Poland	348,935	22.98
Mazovian	234,703	6.60
Opole	446,564	47.45
Podkarpackie	548,455	30.73
Podlaskie	42,067	2.08
Pomeranian	109,527	5.98
Silesian	209,118	16.96
Świętokrzyskie	562,848	48.06
Warmian-Masurian	46,983	1.94
Greater Poland	1,063,657	35.66
West Pomeranian	159,434	6.96
Min	42,067	1.94
Max	1,063,657	48.06
Average	338,416	19.91

Table 2
Average amount of generated, collected and recovered used tires in Poland

Indicator	Average	Min	Max
Mg			
Amount of tires*	32,741	708.24	135,570
Collected*	14,295	73.16	80,197
Recovered*	16,060	0.50	58,401
Generated*	3,950	467.02	38,134
pcs.			
Vehicles**	52,471,172	43,389,232	62,570,032
*on the base data from voivodships			
** on the base data Statistics Poland			

In the analysed years, the accumulation indicator of collected tyres per unit area in the country ranged between 0.93 and 2.12 $Mg \cdot km^{-2}$ (Fig. 2). During this period, the lowest total amount of waste tyres was 292,277, but the highest was 663,935 (Fig. 3a). Moreover, the number of vehicles registered ranged from 43,389,232 to 62,570,032, which increased by as much as 19,180,800 (Fig. 3b). The highest number of vehicles (284,065,550) comprised motor vehicles and tractors (49.22%), but the lowest number (1,152,220) was for buses (0.20%). The extreme values for the accumulation rate and number of used tyres were recorded in 2009 and 2017 (Statistics Poland 2008–2018.

The variability of the indicated data was presented in Fig. 4, with recovered tyres at 47% and generated used tyres at the lowest share (11%; Fig. 5). However, the maximum values differ significantly in this respect. The highest value of 80,197 Mg occurred for collected tyres, excluding the total amount of tyres.

The average values of the collected and recovered tyres were 14,295 and 16,060 Mg, respectively, with a total amount of 32,741 Mg. For generated tyres, the average amount was the lowest at 3,950 Mg (Table 2).

The highest correlation value of 0.90 occurred between the total tyres amount and recovered tyres. The correlation value of 0.73 between the total number of tyres and collected tyres was high. The recovered tyres correlate with the collected tyres (0.43), which is a moderate correlation. The remaining relationships between the collected tyres and number of generated tyres, the total quantity of collected and generated tyres, and the recovered tyres did not exceed 0.4 (Table 3).

Table 3
Correlation between variability of amount generated, collected and recovered used tires

Tires	**Total amount**	**Recovered**	**Collected**	**Generated**
Total amount		*0,90*	*0,73*	*0,30*
Recovered	*0,90*		0,43	0,04
Collected	*0,73*	*0,43*		*0,38*
Generated	*0,30*	0,04	*0,38*	

[a]Italic value of statistics means that the relationship is statistically significant at $p < 0.05$

However, the trend study confirmed only a statistically significant increase in the generated tyres and a decrease in the collected tyres (Table 4).

Table 4
Time trends of generated and collected waste tires

Variable	**Trend**	**Probability (*p*)**
Collected tires	↓	*0,01*
Generated tires	↑	*0,02*

Discussion

The total amount of used tyres over 11 years in the country exceeded 5 million Mg with an average of 32,741 Mg, which confirms that this waste poses a serious problem in the area of environmental protection. According to Karaağaç et al. (2017), in Turkey, the annual amount of waste tyres is estimated at a higher level of 250,000 Mg. Similarly in Greece amount of collected waste tires exceeded 50,000 Mg (Panagiotidou and Tagaras 2005).

The ecotoxic effect of tyres on the environment during their life cycle results from the content of zinc, nickel, copper, lead, chromium, and copper (Piotrowska et al. 2019). Formela et al. (2016) demonstrated that the environmental impact of used tyres depends on their structure (i.e. traditional materials or natural rubber) (Uruburu et al. 2012).

- One of the important aspects of waste management is the prevention of waste. However, in the case of worn tyres, the prevention of their formation is limited for the sake of road safety in the scope of the required minimum tread height of a tyre. This indicates that the increase in the amount of used tyres depends on the number of vehicles in use. The average number of vehicles in the analysed period was over 1.5 times higher than the number of tyres collected. As the number of vehicles increases, so does the amount of tyres and their waste (Yadav and Tiwari 2017). Despite the successive increase in the number of vehicles, the largest amount of used tyres occurred in 2017. This result was observed in the central-western part of Poland, where the largest number of tyre collection points is located. De Figueiredo and Mayerle (2008) noted that the level of recycling of used tyres depends on the optimisation of the number and location of collection points. Despite the favourable results, however, the reuse of rubber as part of recycling in EU countries becomes problematic due to the declining demand for granules due to the economic crisis (Torretta et al. 2015). In contrast, Karaağaç et al. (2017) indicated that the demand for polymeric materials has been increasing in recent years in Turkey.

According to Skarbek and Michalski (2012), the solution for the rational management of used tyres is recovery and recycling. As part of the recycling process, waste tyres are used to produce bituminous mass, allowing lower costs concerning raw materials (Hsisheng et al. 1995). Ahn and Chen (2014) demonstrated that most tyres are not adequately managed by landfilling, among others, in ‘wild’ landfills. Moreover, Isse and Salem (2013) classified combustion as one of the most popular methods of tyre management, the side effect of which is the emission of pollutants into the atmosphere. According to Machin et al. (2017), uncontrolled combustion of used tyres generates 6% of pollution causing toxic fumes in the atmosphere and leading to water pollution through runoff. In Italy, about two-thirds of energy is produced on this basis (Torretta et al. 2015). The recovery of this energy is most often carried out by direct burning of tires (fragmented or whole) or in the pyrolysis process (Fig. 6), which is one of the effective processes of thermal conversion of waste with the calorific value of the pyrolytic liquid within the range of 41–44 MJ kg^{-1} (Williams 2013). One of the researcher (Godlewska 2017) showed that most often waste tires recovery means energy recovery.

In turn the recovery of used tyres in Poland was significant and amounted to 47%. This result indicates that the risk to the environment is minimised following the 4R principle (Mmereki et al. 2016). In Ecuador, Cecchin et al. (2019) found a lower level of used tyre recovery at 20%. It is important to reuse tyres by retreading. In this respect, Poland ranks seventh in the EU (ETRMA 2014). However, their share of generated tyres was low at 11%. In Lebanon, the highest production of waste tyres was observed in the third year of their use (Mrad and Sam 2020).

The collection of tyres is also important. In this case, the maximum value of collected tyres exceeded the recovery by over 20,000 Mg. However, the recovery of used tyres as waste in the form of recycling is considered significant by some researchers (Djadouni et al. 2018) because it considers the possibility of reducing energy consumption and limiting global warming.

An almost complete correlation relationship occurred between the total amount of tyres and their recovery. Despite this, this parameter indicated a significant growth trend, whereas tyre collection exhibited a significant decline. In addition, Rafique (2012) found that generated waste tyres increased in Poland. In turn Uruburu et al. (2012), presented a positive trend in Eastern Europe where the secondary use of rubber is increased for hardening roads with modified asphalt. Pastor et al. (2014) drew attention to the possibility of using waste tyres after disintegration as noise barriers, artificial barriers, and bales.

Przydatek and Ciągło (2020) considered the indicator of waste accumulation to the area as important. Hence, this indicator may help assess tyre management in terms of the selection of the location of treatment plants and the number of tyre waste collection points. The tyre accumulation indicator per country area in the analysed multiannual period reached the highest value of 2.12 Mg km^{-2}. The accumulation result of 48.06 Mg km^{-2} was higher with the amount exceeding 500,000 Mg in one of the smallest voivodeships in terms of area and the number of waste collection points. For comparison, the largest number of vehicles was registered in the largest voivodeship in Poland. The noticeable variability in the accumulation of used tyres should enable the selection of solutions conducive to rational management while minimising the negative effect of tyres on the environment under the current trends in such fields. According to Kaur et al. (2021), energy can be recovered from used tyres, which can help lower their environmental effects.

Conclusions

The analysis of the test results for the total amount of used tyres, including those generated, collected, and recovered in Poland, allowed for the formulation of the following conclusions:

- Under EU requirements and the hierarchy of waste management in the country, tyres were reused, recovered, and recycled.
- The significant average amount of used tyres, 32,741 Mg, confirms that this waste poses a potential problem in the area of environmental protection.
- The average number of vehicles in relation to the amount of used tyres, over 1.5 times higher, occurred with a noticeable growth trend of generated tyres.
- The greatest volume of used tyres occurred in 2017, despite the highest number of registered vehicles in 2018

and the significant amount of used tyres in the central-western part of the country with the largest number of tyre collection points.

- The tyre accumulation indicator per country area should be considered very helpful because it demonstrated a significant differentiation between the result achieved on the national scale at 2.12 Mg km^{-2} and the result achieved in one of the smallest voivodeships at 48.06 Mg km^{-2}. These results suggest the need to increase the number of points in other parts of the country that can accept used tyres (as part of a bulky waste collection).
- Recovery of used tyres at 47% exhibited a moderate correlation with the waste tyre collection, whereas the correlation with the total amount of tyres was almost complete, confirming the need to develop a selective collection of used tyres because of the decreased trend of collecting tyres.
- The desirable and at the same time effective direction of the utilization of used tires should be their efficient thermal conversion with energy recovery.

Declarations

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Ethics approval and consent to participate

Not applicable

Consent to Participate

Not applicable

Consent to Publish

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Competing Interests

Not applicable

Availability of data and materials

- The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request
- All data generated or analysed during this study are included in this published article (and its supplementary information files).

Author’s contribution

GP - cooperated on carried out research and prepared of research results, literature review, interpreted of the results and their discussed with conclusions, translated of the manuscript text into English, prepared of the manuscript for printing.

GB - prepared of a hypothesis, chosen of statistical methodology and tools, analysed of the results, including the statistical one, substantive verification of the work.

MJ - carried out research and the prepared development of the graphic part of the work.

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Figures

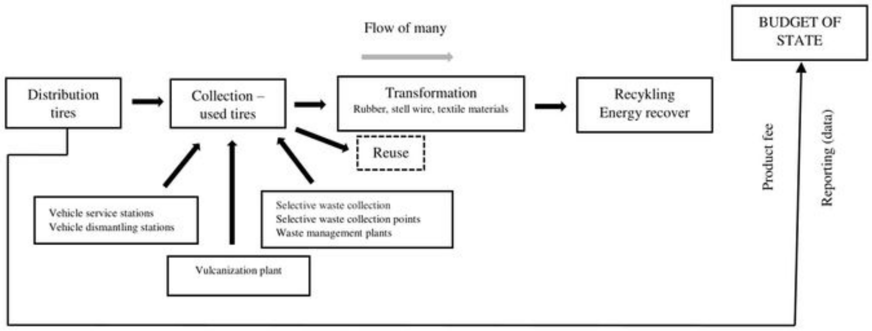

Figure 1

Diagram describing used tires management in Poland

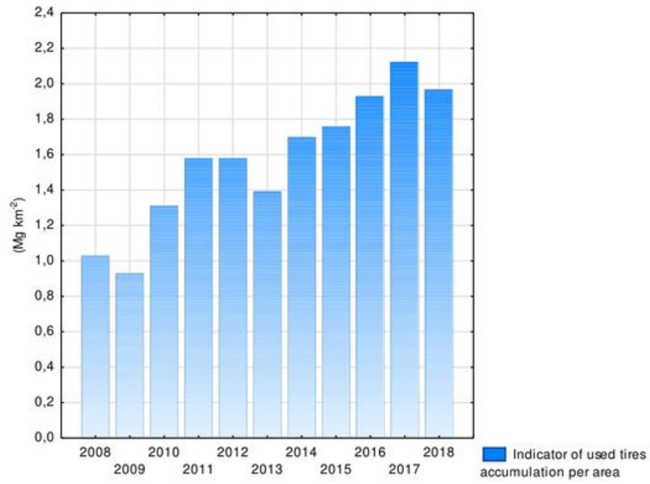

Figure 2

Indicator of used tires accumulation per area

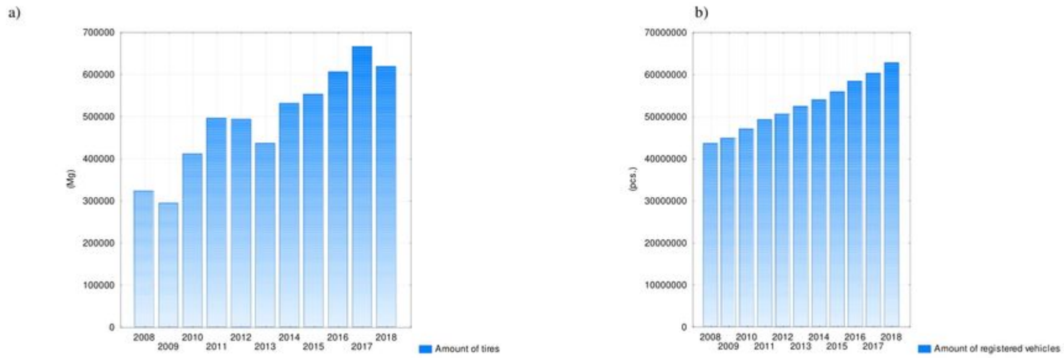

Figure 3

Amount of collected and used tires

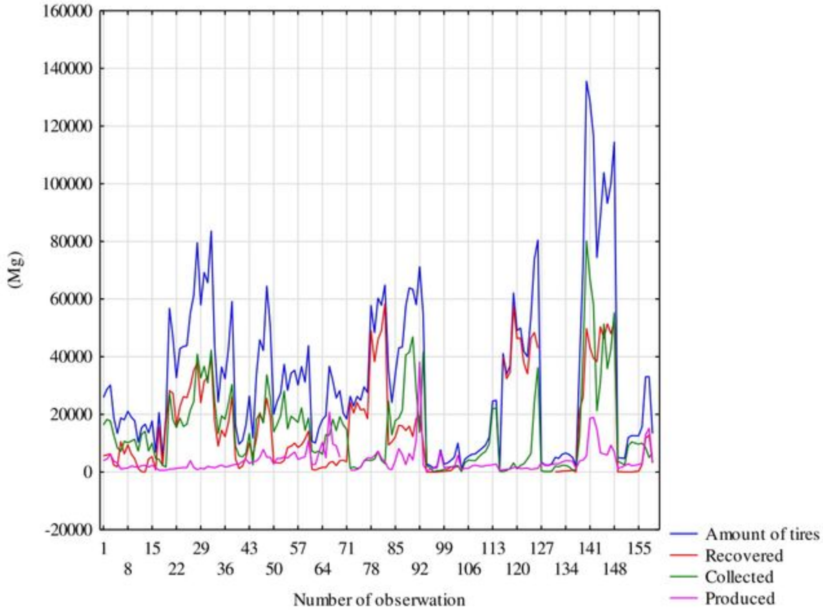

Figure 4

Linear variation in the value

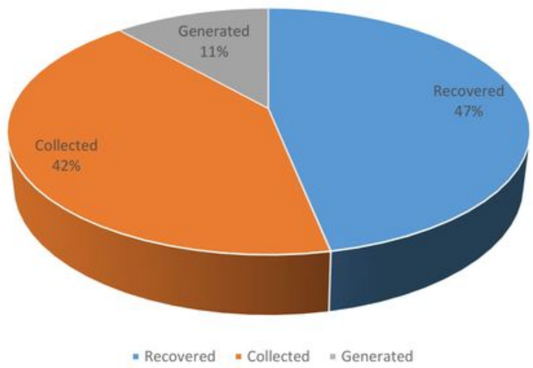

Figure 5

Share of individual processes used tires management

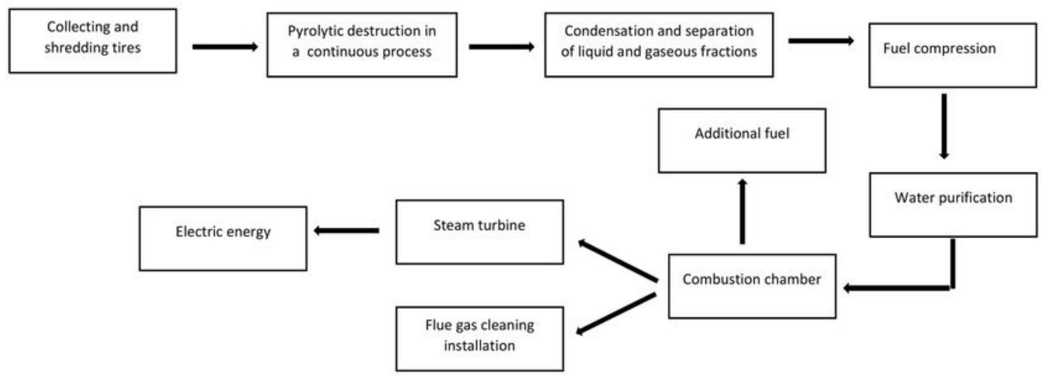

Figure 6

Process of recovery energy from used tires

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