

Effectiveness of Selected Issues of Used Tyre Management in Poland

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Abstract

The study aimed to assess used tyre management efficiency in Poland from 2008 to 2018, considering their recovery based on EU and national regulations. Within 11 years, over 5 million Mg of used tyres were introduced to the domestic market, exceeding 50 million registered vehicles. A significant process in tyre waste management was the recovery of 47% of tyres, which was almost fully correlated with the total amount of tyres. Only the growth trend of the manufactured tyres was considered significant, and the rarely used indicator of the accumulation of used tyres per area showed an uneven accumulation of worn tyres with the highest amount of 48.06 Mg km⁻² in a region with a small area but significant volume of tyres. Therefore, management of used tyres requires taking actions that optimise increasing waste collection and rational recovery in the context of the further minimisation of environmental pressure and increasing the efficiency of their use, taking into account the 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). Tyres 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 waste tyre management in Poland from 2008 to 2018 while considering their rational recovery.

Description of examined country

Poland is a country located in Central Europe. The country ranks 69th in terms of its area (312,696 km²) 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 km² is occupied by the Mazovian Voivodeship in the central part with the largest number of inhabitants, while the smallest area is 9.412 km² by the Opolskie Voivodeship, in the south - western part of the country (Przydatek 2020). The lowest average population density is in the voivodships 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). A significant supplement to the collection of used tyres is selective waste collection points and waste management plants. The largest number of collection points for used tyres is located in the Greater Poland Voivodeship, despite the registration of the largest number of vehicles in the Mazovian 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

The acquisition of data was based on a questionnaire addressed to 16 individual Provincial Marshal Offices in Poland and owner observations. Based on the data from annual for the years 2008 to 2018 that include the total sum and sums of the quantities of tyres whose were generated, collected, recovered, an analysis was conducted that includes the determination of the mass accumulation indicator of tyres by area of the country and individual provinces. The waste accumulation indicator for area was used in the studies by Przydatek and Ciągło (2020) and Xiao et al. (2012). Generated tires are mainly produced in vulcanization plants, service points, vehicles 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. The obtained data constituted the basis for the assessment of the efficiency of used tyre management.

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).

A flow chart (i.e. a line chart for cases) and a cluster analysis were used to explain the detection of the structure of the data, considering the hierarchical agglomeration method, allowing the determination of the tree hierarchy of elements of the analysed set. 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 lists of volume of used tyres collected in Poland from 2008 to 2018, broken down by the 16 individual provinces was showed 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 $42,067 \text{ Mg}$ and $1,063,657 \text{ Mg}$. 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) with a total weight of tyres of $562,848 \text{ Mg}$, whereas the lowest was 1.94 Mg km^{-2} in the north-eastern part of the country (Warmian-Masurian Voivodeship fourth position) ($46,983 \text{ Mg}$) (Tab.1).

The total amount of tyres during the 11 analysed years ranged from 708.24 to $135,570 \text{ Mg}$ with an average of $32,741 \text{ Mg}$ (Tab. 2). The highest amount of collected tyres occurred in 2017, while vehicles in the following 2018 (Fig. 1).

The accumulation indicator of collected tyres per country area in the analysed years ranged between 1.94 and $2.12 \text{ Mg}\cdot\text{km}^{-2}$. In turn, the number of vehicles registered in the analysed period was from $43,389,232$ to $62,570,032$ which was an increase of as much as $19,180,800$. The extreme values for both the number of tyres and the rate of accumulation of worn tyres were recorded in 2008 and 2017 (Fig. 1).

The variability of the indicated indicators is presented in Figures 2 with the dominance of waste recovery at the level of 47% (Fig. 3). However, the maximum values differ significantly in this respect. The highest

value of 80,197 Mg occurred in the case of collected tyres.

The average values of collected and recovered tyres were respectively 14,295 and 16,060 Mg. In case of the generated tyres average amount was the lowest amounted to 3,950 Mg (Tab. 2), similarly share of 11% (Fig. 3). 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 (Tab. 3).

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

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, used tyres are used in the production of

bituminous mass, which allows lower costs concerning raw materials (Hsisheng et al. 1995). Ahn and Chen (2014) demonstrated that most tyres are not properly managed by landfilling, among others on '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. 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. 4), 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).

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 full correlation relationship occurred between the total amount of tyres and their recovery. However, the share of generated tyres was low at 11%. Despite this, this parameter indicated a significant growth trend, but tyre collection exhibited a significant decline. 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 surface 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 voivodships 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 that are conducive to rational management while minimising the negative effect of tyres on the environment in accordance with the new trends in such field.

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 worn tyres, over 1.5 times higher, occurred with a noticeable growth trend of generated tyres.
- The tyre accumulation index per country area was 2.12 Mg km⁻² at achieved by 48.06 Mg km⁻² in one of the smallest Voivodeship in Poland.
- The largest amount of used tyres occurred in 2017, despite the successive increase in the number of vehicles in the central - western part of the country with the largest number of tyre collection points.
- Recovery of used tyres at the level of 47% exhibited a moderate correlation with the collection, whereas the correlation with the total amount of tyres was almost full.
- The desirable and at the same time effective direction of the utilization of used tires in domestic conditions 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, selectioned of statistical methodology and tools, analyzed 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.

References

1. Act of December 14, 2012 on waste (Journal of Laws of 2013, item 21, as amended)
2. Ahn I-S, Cheng L (2014) Tire derived aggregate for retaining wall backfill under earthquake loading. *Constr Build Mater* 57:105–116
3. Cecchin A, Lamour M, Davis MJM, Polit DJ (2019) End-of-life product management as a resilience driver for developing countries: A policy experiment for used tires in Ecuador. <https://doi.org/10.1111/jiec.12861>
4. Clauzade C, Osset P, Hugrel C, Chappert A, Durande M, Palluau M (2010) Life cycle assessment of nine recovery methods for end-of-life tyres. *Int J Life Cycle Assess* 15:883–892
5. COM (2005) – Commission of the European Communities – Communication from the Commission to the Council, the European Parliament, the European Economic and Social Committee and the Committee of the Regions. Taking Sustainable use of Resources Forward: A Thematic Strategy on the Prevention and Recycling of Waste, Brussels 21.12.2005, 666
6. Council Directive 1999/31/EC of 26 April 1999 on the landfill of waste
7. CRVD-Central Register of Vehicles and Drivers 2018, <http://www.cepik.gov.pl/> accessed 14.02.2021 (in Polish)
8. Directive (2000) 53/EC of the European Parliament and of the Council of 18 September 2000 on end-of life vehicles -. Commission Statements
9. Directive 2000/76/EC of the European Parliament and of the Council of 4 December 2000 on the incineration of waste

10. Djadouni H, Trouzine H, Correia AG, Da Silva Miranda TF (2018) Life cycle assessment of retaining wall backfilled with shredded tires. *The International Journal of Life Cycle Assessment* 24:581–589
11. El-Naqa A (2005) Environmental impact assessment using rapid impact assessment matrix (RIAM) for Russeifa landfill, Jordan. *Environ Geol* 47:632–639
12. Eriksson O, Carlsson Reich M, Frostell B, Björklund A, Assefa G, Sundqvist JO, Granath J, Baky A, Thyselius L (2005) Municipal solid waste management from a systems perspective. *J Cleaner Prod* 13(3):241–252
13. ETRMA European Tyre Rubber Manufactures Association, 2014 European tyre rubber industry - Statistic <https://greentire.it/en/> accessed 17.02.2021
14. Figueiredo JN, Mayerle SF (2008) Designing minimum-cost recycling collection networks with required throughput. *Transp Res Part E* 44:731–752
15. Formela K, Hejna A, Piszczyk A, Saeb MR, Colom X (2016) Processing and structure-property relationship of natural rubber /wheat bran biocomposites. *Cellulose* 23:3157–3175
16. Gaska K, Generowicz A, Zimoch I, Ciuła J (2018) A GIS based graph oriented algorithmic model for poly-optimization of waste management system doi: 10. 21307/ACEE- 2018-061
17. Gharfalkar M, Campbell C, Ali Z, Hillier G (2015) Analysis of waste hierarchy in the European waste directive 2008/98/EC, *Waste management*, 39, 305–313
18. Godlewska J (2017) Recovery and Recycling of Waste Tires in Poland. *Procedia Eng* 182:229–234
19. Gronowicz J, Kubiak T (2007) Recykling zużytych opon samochodowych. *Problemy Eksploatacji* 2-2007:5–18 (in Polish)
20. Hernandez-Olivares F, Barluenga G, Bollati M, Witoszek B (2002) Static and dynamic behavior of recycled tire rubber-filled concrete. *Cem Concr Res* 32(10):1587–1596
21. Hsisheng T, Serio MA, Wójtowicz MA, Bassilakis R, Solomon PR (1995) Reprocessing of used tires into activated carbon and other products. *Ind Eng Chem Res* 34:9, 3102–3111
22. Huang J, Li G, He W, Xu J, Wang H, Yang L (2012) Energy Analysis of Tire Life Cycle. *Automotive Engineering* 34(3):277–281
23. Isse CA, Salem G (2013) Utilization of recycled crumb rubber as fine aggregates in concrete mix design. *Utilization of recycled crumb rubber as fine aggregates in concrete mix design. Constr Build Mater* 42(42):48–52 48–52.
24. Juma M, Korenova Z, Markos J, Annus J, Jelemensky L (2006) Pyrolysis and combustion of Scrap tyre. *Petroleum Coal* 48(1):15–26
25. Karaağaç B, Kalkan EM, Deniz V (2017) End of life tyre management: Turkey case. *J Mater Cycles Waste Manage* 19:577–584
26. Machin EB, Pedroso DT, de Carvalho JA (2017) Energetic valorization of waste tires, *Renewable and Sustainable Energy Reviews*, Volume 68, Part 1, Pages 306–315
27. Miliute-Plepiene J, Plepys A (2015) Does food sorting prevents and improves sorting of household waste? A case in Sweden. *J Clean Prod* 101:182–192

28. Mmerek D, Machola B, Mokokwe K (2016) Status of waste tires and management practice in Botswana. *J Air Waste Manag Assoc* 69:Issue 10
29. NWMP - The National Waste Management Plan 2022 adopted by the Council of Ministers by the resolution No. 88 of July 1, 2016 accessed 16 April 2021
30. Panagiotidou S, Tagaras G (2005) End-of-life tire recovery: the Thessaloniki initiative. *Managing Closed-Loop Supply Chains* pp 183–193
31. Pastor JM, García LD, Quintana S, Peña J (2014) Glass reinforced concrete panels containing recycled tyres: Evaluation of the acoustic properties of for their use as sound barriers. *Constr Build Mater* 54:541–549
32. Piotrowska K, Kruszelnicka W, Bałdowska-Witos P (2019) Assessment of the Environmental Impact of a Car Tire throughout Its Lifecycle Using the LCA Method. *Materials* 12(24):4177
33. Pomberger R, Sarc R, Lorber KE (2017) Dynamic visualisation of municipal waste management performance in the EU using Ternary Diagram method. *Waste Manag* 61:558–571
34. Przydatek G (2019) Factors of Changes in Waste Management in a Mountain Region of Southern Poland, *Journal of Ecological Engineering*, Volume 20, Issue 5, May 2019, pages 86–96
35. Przydatek G (2020) Analysis of effectiveness of changes in waste management in Poland. *Environ Sci Pollut Res* 27:25766–25773
36. Przydatek G, Ciągło K (2020) Factors of variability in the accumulation of waste in a mountain region of southern Poland. *Environmental Monitoring and Assessment*, Volume 192, Article number: 153
37. Przydatek G, Kanownik W (2019) Impact of small municipal solid waste landfill on groundwater quality. *Environ Monit Assess* 191(3):169
38. Przydatek G, Krok R (2018) Wybrane elementy gospodarki odpadami w przedsiębiorstwie komunikacji publiczne. *Zeszyty Naukowe Państwowej Wyższej Szkoły Zawodowej im Witelona w Legnicy* 29:299–308 (in Polish)
39. Regulation of the Minister of the Environment of 9 December 2014 on the waste catalog (Journal of Laws of 2014, item 1923)
40. Rofiqul Islam M, Parveen M, Haniu H, Islam Sarker MR (2010) Innovation in Pyrolysis Technology for Management of Scrap Tire: a Solution of Energy and Environment. *International Journal of Environmental Science and Development*, Vol. 1, No. 1, April 2010 ISSN:2010 – 0264
41. Segre N, Joekes I (2000) Use of tire rubber particles as addition to cement paste. *Cem Concr Res* 30(9):1421–1425
42. Sienkiewicz M, Kucińska-Lipka J, Janik H, Balas A (2012) Progress in used tyres management in the European Union: A review. *Waste Manag* 32(10):1742–1751
43. Silvestravieiete I, Sleinotaite-Budriene L (2002) Possibility to use scrap tires as an alternative fuel in cement industry environmental research. *Eng Manage* 3(21):38–48
44. Simić V, Dabić-Ostojić S (2017) Used tire management: an overview, Part II. 3rd Logistic Conference Belgrad Serbia 25–27 May 2017

45. Skarbek A, Michalski R (2012) Energy use of waste from end of life vehicles. *Archives of Waste Management Environmental Protection* 14(1):27–32
46. Statistics Poland (2008–2018) <https://bdl.stat.gov.pl> accessed 21.01.2021
47. Sun X, Liu J, Lu B (2016) Life cycle assessment of Chinese radial passenger vehicle tire. *The International Journal of Life Cycle Assessment* 21:1749–1758
48. Torretta V, Rada EC, Ragazzi M, Trulli E, Istrate IA, Cioca LI (2015) Treatment and disposal of tyres: Two EU approaches. A review. *Waste Management* 45 (2015) 152–160
49. Uruburu A, Ponce-Cueto E, Cobo-Benita JR, Ordieres-Mere J (2012) The new challenges of end-of-life tyres management systems: a Spanish case study. *Waste Manag.* doi:10.1016/j.wasman.2012.09.006
50. Wasilewski R, Stelmach S (2009) Odzysk energii w przemysłowych procesach spalania i współspalania zużytych opon samochodowych. *Archives of waste management* 11(2):63–72 (in Polish)
51. Williams PT (2013) Pyrolysis of waste tyres: a review, *Waste management*, vol. 33, pp. 1714–1728
52. Xiao J, Xie H, Zhang C (2012) Investigation on building waste and reclaim in Wenchuan earthquake disaster area. *Resour Conserv Recycl* 61:109–117
53. Yadav JS, Tiwari SK (2017) The impact of end-of-life tires on the mechanical properties of fine-grained soil: A Review. *Environ Dev Sustain* 21:485–568

Tables

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
Łódź	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 waste 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	0.05	58,401
Generated	3,950	467.02	38,134
pcs.			
Vehicles	52,471,172	43,389,232	62,570,032

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

Tires	Total amount	Recovered	Collected	Produced
Total amount		<i>0,90</i>	<i>0,73</i>	<i>0,30</i>
Recovered	<i>0,90</i>		<i>0,43</i>	<i>0,04</i>
Collected	<i>0,73</i>	<i>0,43</i>		<i>0,38</i>
Generated	<i>0,30</i>	<i>0,04</i>	<i>0,38</i>	

^aItalic value of statistics means that the relationship is statistically significant at $p < 0.05$

Table 4 Time trends of generated and collected tires

Variable	Trend	Probability (p)
Collected tires	↓	<i>0,01</i>
Generated tires	↑	<i>0,02</i>

Figures

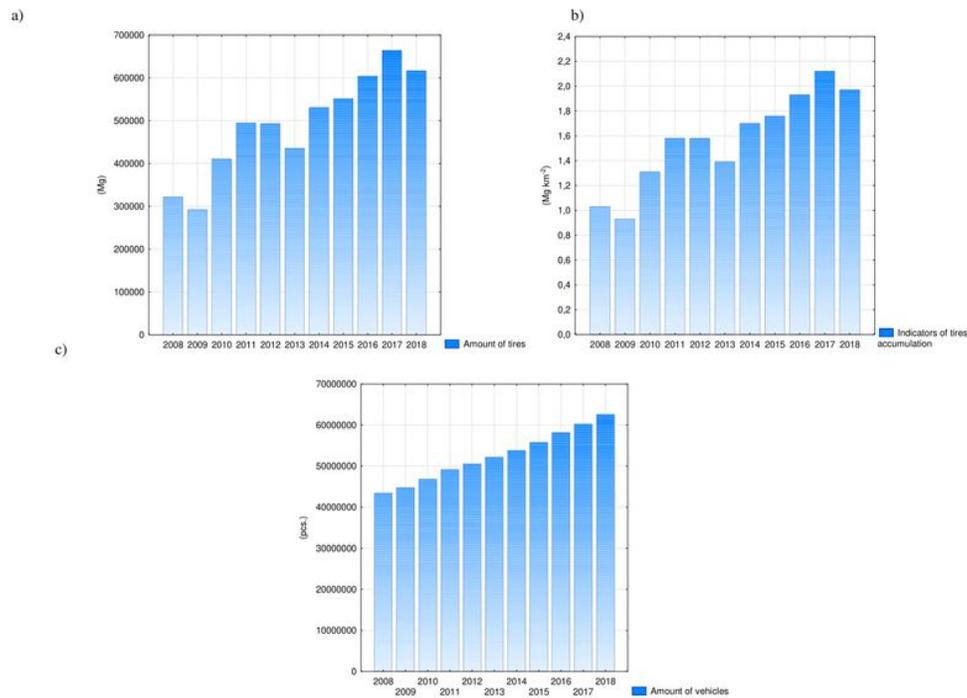


Figure 1

The data of amount

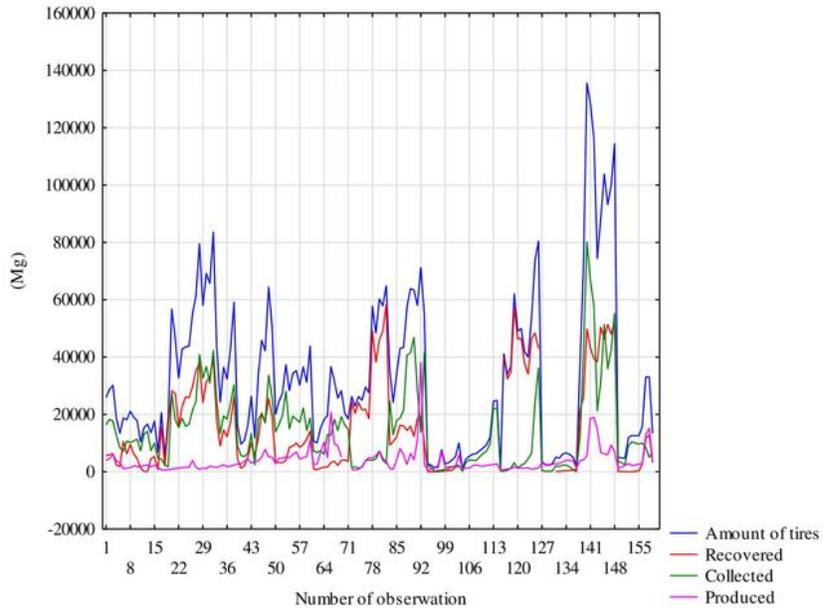


Figure 2

Linear variation in the value

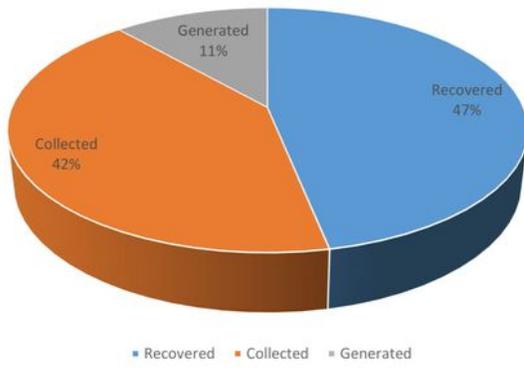


Figure 3

Share of individual processes

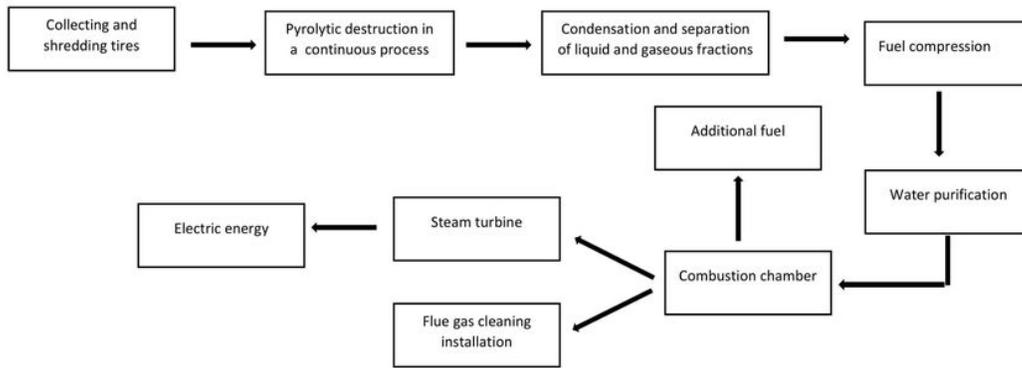


Figure 4

Effective solution of used tires management