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Logistics of recycling by the case of used car tyres in Poland

Abstract: *Waste generation is an intrinsic feature of economic activity, and its management is a problem dealt with by all societies and economies. The need for waste management arises from the necessity of saving resources, limiting space for waste deposition and limiting the contamination filtering from waste to the natural environment. The development of transported goods haulage and car transport all over the world generates one of the greatest, in terms of its weight, volume of waste, namely scrap tyres. It is estimated that more than 1.2 billion tonnes of scrap tyres are produced every year. The corresponding figure for the EU member states is 3.5 million tonnes, and for Poland - 200 thousand tonnes. High transportation and collection costs, and the fact that the transition period negotiated with the UE ended in 2014 are forcing the formation of an integrated domestic network that would deal with waste recovery and treatment.*
The purpose of the paper is to analyse the management system of scrap tyres in Poland in 2002-2014. The analysis refers to the required and attained recovery and recycling levels of scrap tyres. A regression equation has been used to present the trend of the number of recycled tyres (in thou tonnes). The analysis has been based on the data on waste management from the Ministry of the Environment, and Central Statistical Office (GUS) Ochrona środowiska 2015.
Keywords: *logistics, recycling, management of scrap tyres, sustainable development*

Introduction

Scrap tyres have become a growing global ecological problem that was attempted to be cured on a large scale by sinking tyres in the oceans, burying them in the sands of deserts, carrying them away to third world countries or collecting on thousands of either legal or illegal landfills. In the UE the issue started to be solved by introducing a ban on landfilling scrap tyres in Directive 1999/31/EC (Landfill Directive); in Poland the problem was addressed in the Act on waste of 27 April 2001 which introduced a ban on burying scrap tyres in landfills starting from 1 July 2003 and burying shredded tyres in landfills starting from 1 July 2006. The Act of 11 May 2001 on entrepreneurs' obligation in the scope of managing certain types of waste and product and deposit fees obliges manufacturers and importers to attain a specified level of recovery of tyres launched onto the Polish market. Directive 2000/53/CE on end-of-life vehicles, and the Act of 20 January 2005 on recycling end-of-life vehicles impose an obligation to dismantle and reuse tyres before scrapping them. It is banned to landfill scrap tyres, excluding bicycle tyres and tyres with an outside diameter above 1,400 mm (Article 5 of the Waste Act). Tyres

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from motorcars, delivery trucks and motor trucks are collected free of charge from: tyre service points, companies using cars, communes, all citizens and dismantling firms.

Sustainable development management

In the world today, economic development stands for a systematic change made as a result of quality-structural transformations in a given economy and is triggered off by the growth of productive forces ensuring an increase in production and consumption[2]. On the other hand, human and social development means a systematic improvement in people's living conditions, and a rise in social benefits and better access to them. A lack of harmony between the economic and social development leads to questioning the progressiveness of the whole process.

The condition of the natural environment influences economic structures both passively and actively. Passively, since the environmental factor limits those structures in terms of available resources, technologies and locations. Actively, as the natural environment becomes a factor producing more dynamic changes in those structures[3]. Therefore, technological restructuring is significant for the establishment of adequate relations between the economy and the environment.

The competitiveness of a region depends mainly on: its innovativeness, quality of labour force, ecological conditions and logistic links with the environment. The issues are directly connected with the ecological management of the environment, which should be understood as undertaking actions aimed at making territorial units, organisations, and subordinate people function in compliance with the set goal[4]. Such management is a process of making decisions, which, in turn, are mainly connected with[5]:

- establishing long-term strategic objectives and ways of their accomplishment;
- planning;
- establishing the scope of the subject and methods of control (compliance check of realised tasks);
- organising;
- managing people's behaviour to ensure an adequate impact on individual components of the ecosystem; and
- specific decisions that are forced by the internationalization and globalization of the management processes.

The above-listed information indicates that environmental management consists in managing the exploitation, protection and shaping of the environment towards sustainable development. It is realised both in a direct and indirect way, mainly in decision-making processes. That type of management is found in territorial networks and business units. Environmental management exists where envi-

[2] B. Poskrobko, *Zarządzanie środowiskiem*, PWE, Warsaw 2007, p. 27.
[3] J. Łunarski, *Zarządzanie środowiskiem*, Publishing House of Rzeszów University of Technology, Rzeszów 2002, p. 14.
[4] T. Borys, *Zarządzanie środowiskiem: gospodarka przestrzenna*, Publishing House of Oskar Lange Academy of Economics, Wrocław 2005, p. 40.
[5] B. Poskrobko, *Zarządzanie środowiskiem*…, op. cit., p. 35.

ronmental issues become integrated with organisation's general management. Environmental management exists in an organisation focused on generating profit if there is a system introduced in the form of such standards as EMAS or ISO 14000[6]. Consequently, an environmental management system should be understood as "a secluded and adequately organised part of the reality which is connected with the management of processes of exploitation, protection and shaping of the natural environment in the scope of a country, region, commune and an economic unit"[7].

Environmental protection especially consists in a rational development and management of the natural environment in accordance with the principles of sustainable development, and also in the prevention of contamination and restoring of the natural environment components. The last element is connected with the ecological balance which is defined as "a condition in which there is a balance between the mutual impact of human activities, wildlife conditions and habitat conditions that are created by inanimate nature"[8].

Maintaining the ecological balance is inevitable in the process of shaping the environment. That mainly refers to such an influence on the natural environment that is aimed at attaining the intended social and economic effects, and at the same time at preserving the natural balance. What is mainly indicated here is action focused on[9]:

- compensating for missing links in materials and energy cycles to increase the ecosystem productivity;
- reducing those elements of the system that have grown excessively as a consequence of human interference; and
- rehabilitating deteriorated systems by eliminating factors that cause environmental decay.

A very important issue in the sustainable development management is compensation, which should be perceived as a direction for environmental management. The environmental protection law treats it as an obligation imposed on an economic entity when there are negative changes produced in the natural environment that may be prevented[10]. In other words the exploitation of the environment is the manner and scope of using natural environment resources and values by a human. There are two types of environment exploitation[11]:

- direct, which conditions the survival of a human being; and
- indirect, which consists in using the components of the natural environment in economic activity processes, surface arrangement, exploitation of natural resources, or removing any negative impacts.

Environment exploitation is restricted by environment potential and capacity understood as the ability of the environment to shift anthropogenic and technogenic burdens. That ability is determined by the natural balance. On the other hand,

[6] T. Borys, *Zarządzanie środowiskiem*…, op. cit., p. 40.
[7] J. Łunarski, *Zarządzanie środowiskiem*…, op. cit., p. 21.
[8] Ibidem, p. 22.
[9] T. Borys, *Zarządzanie środowiskiem*…, op. cit., p. 42.
[10] Ibidem, p. 44.
[11] B. Poskrobko, *Zarządzanie środowiskiem*…, op. cit., p. 39.

the potential of the environment is seen as the natural resource stock of a certain structure and quality found in a given area.

Eco-innovation versus sustainable development

The slogan *sustainable development* is used by various organisations, offices and authorities all over the world[12, 13]. What is connected with the concept of sustainable development is sustainable entrepreneurship, sustainable land exploitation, sustainable education, and activities in the scope of environmental protection[14]. It is sometimes said that sustainable development can be a solution to the serious social problems of our times[15].

Guidance on sustainable development has been provided for years now, in practice since 1972 when Meadows acknowledged that the situation of world balance should be developed in such a way that the material needs of every single person on Earth were met and each person was given the same equal opportunities to accomplish their human needs[16]. Apart from that difficult-to-accomplish scenario, a real image of the future was also depicted. The economy should become cautious of the way it uses resources by stimulating their reuse, recycling and also by using renewable resources without limitation[17].

In 1980, the *World Conservation Strategy* was published. It presented a concept of using living resources more efficiently within sustainable development. The report pointed out the disruption of ecological processes and functions and a loss of natural resources (forests and farmland), especially in countries beyond the western culture, as an obstacle for sustainable development. It was said that, to make the development sustainable, one should take into account social and ecological functions, living and inanimate resources, and long- and short-term factors. The concept of sustainable development is associated with the Brundtland Commission (the World Commission on Environment and Development) founded in 1983. In 1987 the Commission published a document *Our Common Future*, in which it was stated that inequality is the biggest environmental issue in the world and is a fundamental problem for further growth[18]. It means that there is no ecology without equality and there is no equality without ecology.

Doubtless, what is directly connected with sustainable development is innovativeness, to be precise eco-innovations, or ecological innovations. Such types of innovation comprise all changes in technologies, organisational and management structures of a plant, enterprise, the economy or the whole country which mitigate or prevent a negative influence on the natural environment. The classification criteria of

[12] D. De Knecht, *Zrównoważony rozwój*, in: Innowacje, 25, 2008, 1-2.
[13] E. Kośmicki, *Zrównoważony rozwój w warunkach globalizacji gospodarki*, Białystok-Poznań, 2010, p. 455.
[14] E. Kośmicki, *Rozwój zrównoważony a globalne społeczeństwo ryzyka*, in: Edukacja dla bezpieczeństwa. Stan – Problemy – Perspektywy, Poznań, 2011, 159-185.
[15] http://www.un-documents.net/wced-ocf.htm.12.04.2017
[16] H. Ciążela, *Antycypacja idei rozwoju trwałego i zrównoważonego w koncepcji nowego humanizmu Aurelio Peccei*, in: Problemy Ekorozwoju, 2, 1, 2007, 59-67.
[17] Kośmicki E., *Zrównoważona konsumpcja a światowy system wyżywienia, in: Zrównoważona konsumpcja? Rozwój zachowań konsumentów w Polsce i Niemczech*, Heidelberg, 2011, 194-217.
[18] Kośmicki E., *Rozwój*…, op. cit., 14.

eco-innovativeness may vary. One of them can be assumed to be the field of activity, e.g. enterprises. Here eco-innovations can be divided into innovations encompassed in a product, service, production process, management and organisation[19]. Introducing ecological innovations in a product or service decreases or even eliminates environmental pollution. Therefore, ecological actions are necessary in the whole production process[20]. Each new proposal in the scope of designing and implementing a new product should be subject to verification from the viewpoint of the natural environment protection[21]. Depending on a component of the environmental sphere in the case of which the negative influence is becoming lower as a result of eco-innovations, we distinguish eco-innovations connected with the protection from air pollution (including combating climatic changes) and water and soil contamination, waste management and alternative energy sources.

A very important area of introducing ecological innovations is the production process, starting from the supply of materials, ending with the sale of goods. Each and every operation in the production process should be subject to an analysis with a view to its influence on the natural environment. The optimisation of the whole process from the perspective of the quantity and quality of waste is a very important development task. On entering into the European Union, Poland started to implement new requirements in the field, which triggered off a rise in ecological innovations. At present it is cheaper and easier to implement new technologies than look for ways of reducing contamination resulting from the application of the obsolete ones[22].

The majority of recent investments made by companies in Poland are investments in equipment and infrastructure (mainly buildings and machines), making up over 80% of outlays in total. Only about 8% of investments are aimed at financing research into new technologies, eco-technologies and eco-products. Meanwhile, what Poland needs now to be able to expand in the future are specific innovations[23].

The biggest Polish companies with yearly profit before tax of about 2.5 billion zlotys spend nearly 10 million zlotys per year on R&D. However, that amount is doubtless very low compared to the needs. To expand, companies should change their attitude towards eco-innovations, which are a way to attain sustainable development. Nonetheless, firms very often refuse to risk and develop their own technologies. The consumer-focused market does not facilitate innovations and the cooperation between business and science is still being established in Poland. Very often entrepreneurs fear the risk connected with financing innovations. One of the major risk factors is the cost of developing and implementing novel solutions and the fact that innovative eco-friendly technologies are not in high demand in Poland, hence it is not certain that an investment in the development of a new product will be a profitable one.

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[19] Pawłowski A., *Teoretyczne uwarunkowania rozwoju zrównoważonego*. Rocznik Ochrony Środowiska, Publishing House of Środkowo-Pomorskie Towarzystwo Naukowe Ochrony Środowiska, Koszalin, Vol. 11, 2009, 985-994.

[20] Szymańska A., *Nowoczesne technologie kołem zamachowym gospodarki*, Ecomenager, 2009, 11, 3.

[21] Kośmicki E., *Problem ochrony środowiska w przedsiębiorstwach międzynarodowych*, Ekonomia i Środowisko, 2, 2004, 141-158.

[22] E. Kośmicki, *Szanse zrównoważonego rozwoju Polski w obliczu globalizacji i członkostwa w Unii Europejskiej***,** Optimum. Studia Ekonomiczne, 1, 2006, 3-25.

[23] W. Janasz, K. Kozioł, *Determinanty działalności innowacyjnej przedsiębiorstw*, PWE, Warsaw 2007, p. 67.

Problems with introducing eco-innovations are also frequently connected with the tradition or the society's financial means. In many cases when a client doing shopping can choose between a more expensive innovative product and a traditional one but a few percent cheaper, s/he usually opts for the less costly option. There is still no developed market favourable to eco-innovations in Poland. Companies do not frequently find it necessary to develop new technologies, and since others do not do that either, there is no competition, and there is no such need or necessity. What Polish companies most often decide to do is to import known solutions from abroad because that does not result in a high financial risk. Entrepreneurs prefer to maintain their market position thanks to the high quality and relatively low price of goods and services rather than to retain it owing to their eco-innovativeness[24].

Companies need incentives and facilitations to cooperate with scientists more often. For a few years now there have been few targeted projects realised in Poland that consisted in creating new tailor-made solutions in cooperation with enterprises by scientists. The cooperation with the scientific milieu should be greatly enhanced by the Council of Ministers through introducing facilitations for and donations to ecoprojects with newly-established technologies focused on taking into account the principles of sustainable development[25].

The EU has launched a challenging plan of innovations in order to take up urgent actions on the regional, national and European levels. What it called for was to make all Europe a knowledge-based society open to eco-innovations. Moreover, it was also stressed that innovations should not fill people with anxiety but be positively viewed and, being facilitated, benefited all citizens[26]. The European Commission supported the establishment of innovation-friendly markets, based on the combination of innovations and adequate political instruments. The supreme goals were set to be: environmental protection, e-health, medicines, safety, power industry, transportation and logistics, and digital content.

Eco-innovations and their effects link all components of sustainable development. It means that they positively impact the natural environment and quality of life, and let companies increase production effectiveness. Eco-innovations also contribute to the economic growth and result in an improvement in the competitiveness of enterprises, not having a negative influence on the environment at the same time. In concepts of eco-development it is assumed the ecological arguments are superior to social and economic ones; on the other hand, in sustainable development concepts it is stressed that those components need to remain in balance.

Ecologistics

The range of negative factors that logistics can involve in relation to the natural environment is relatively wide. Logistics is one of the most energy-intensive functional areas in which both direct and indirect environmental aspects

[24] A. Marciniuk-Kluska, M. Kluska, *Ekologia i technika a rozwój innowacji*, Ekologia i Technika, XVI, 1, 2008, 23-26.
[25] L. Woźniak, B. Ziółkowski, *Zarządzanie ekoinnowacyjnością*, Ekopartner, Jakość Zarządzanie Środowisko, 2, 2010, 28-29.
[26] L.W. Zacher, *Trwały rozwój – utopia czy realna możliwość?,* Problemy Ekorozwoju, 3, 2, 2008, p. 63-68.

can be distinguished. Among the direct factors influencing the natural environment there are:

- production of waste and sewage, e.g. scrap tyres, motor oil, waste water from washing cars;
- contamination of soil and water, e.g. leaks during transport, from warehouses, through the terrain under landfill sites;
- exploitation of non-renewable energy sources, e.g. crude oil as fuel, electrical energy, thermal energy used in warehouses;
- road noise; and
- emission of harmful gases, e.g. NO_x, CO_2, soot.

Among factors influencing the natural environment indirectly there are:

- street congestion, e.g. traffic jams, delays in transport and deliveries;
- use of land surface, e.g. for warehouses, landfill sites, roads;
- water and soil contamination, e.g. as a result of road salt;
- exploitation of natural resources, e.g. plastic, metals from crude oil used in cars.

The main objective of ecologistics is the minimisation of negative factors impacting the environment in various stages, starting from design and production, through distribution and supply, ending with use and treatment. Therefore, the following environmental protection steps need to be taken:

- environmentally-friendly transport means, e.g. new tyres, low emissions intensity, possibly the lowest petrol consumption, environmentally-friendly lubricants and oils;
- transport means applying ecological concepts, e.g. vegetable-oil-driven vehicles;
- selection of optimal transport means, their number and frequency, e.g. given the size of packages, tyres;
- elimination of so-called empty journeys, planning the route, combining orders, contracts and shipments;
- linking the collection of, for instance, scrap tyres with waste sorting;
- optimisation of communication network and distances by, for instance, selecting locations, carriers and distribution centres;
- creation of main collection centres, e.g. collection centres of scrap tyres, recycling centres, waste sorting centres;
- rational use of storage space and capacity, e.g. stack shelving;
- construction of warehouses, double walls of containers, protection against overstocking in order to prevent leakage of liquids, gases.

Cargo traffic contributes most to excessive traffic on Polish roads. As a result of that phenomenon, there are many negative consequences perceptible to both societies and the natural environment. In order to prevent those adverse aftereffects some actions are taken to transfer part of the cargo flow from the heavy road transport to intermodal transport in which more than one transport means is used[27]. The most typical combination is road and rail transport. What facilitates the intermodal transport of cargo is the use of containers, motorcar bodies and

[27] *Wskaźniki zrównoważonego rozwoju*, GUS, 2014, p. 198.

semitrailers. The number of truck semitrailers (excluding tractor units) transported with and without cargo nearly tripled in 2014. Cargo transported in containers totalled 9.2 mill. tonnes, and rose nearly four times, compared to 2004. The average distance for transporting 1 tonne of cargo in containers was 359 kilometres. Between 2004 and 2014 the share of transport of large containers and trucks with cargo in transport by standard gauge rail (including wide gauge rail) successively rose from 0.8% to 3.9%. Despite steps taken for a few years now, the intermodal transport in Poland still constitutes a too low share in the market of cargo transportation[28].

Table 1. Impact of various transport means on natural environment

Transport means	Negative impact	Positive impact
Railway	Inflexible; Time-consuming; Limited by timetable; Dependent on railway routes; Transshipment frequently needed; Distortion of landscape by railway network;	Possibility of transporting large and heavy goods; Low environmental pollution; Exclusion from road traffic; Faster in long distances if handling is not needed; Low damage rate.
Truck	High environmental pollution; Use of large areas for the construction of roads; Delays in traffic, traffic jams; Limited capacity and weight of goods; Dependent on atmospheric conditions; Restricted traffic at weekends; Bans on the transportation of certain dangerous goods;	Flexible; Fast in short distances; Delivery straight to the chosen place; Short deliver time.

Source: Own work.

The development of road transport and excessive cargo traffic intensity is generating more and more used car tyres. The situation is becoming even more serious when we notice that that group of waste is one of the largest in terms of mass, especially in North America and Europe.

Analysis of the scrap tyre management system

The entry into force on 1 January 2002 of the so-called Product Act of 11 May 2001 on entrepreneurs' obligation in the scope of managing certain types of waste and product and deposit fees[29] started the development of t hescrap tyre management system in Poland. The ban on landfilling scrap tyres mainly referred to the biggest manufacturers of tyres operating at the time in the area of the whole country either through their own production plants in Poland or by importing new tyres to the country through their own companies established in Poland: Bridgestone, Continental, Goodyear, Michelin, Pirelli, who became the pioneers of the formation of the scrap tyre collection system. Tyre manufacturers concluded an agreement and opened a company called Centrum Utylizacji Opon, Organizacja Odzysku S.A. (CUO) in order to establish a nation-wide collection and transpor-

[28] Ibidem.
[29] Journal of Laws 2007 No 90, item 607, as amended.

tation system of scrap tyres and fulfil the obligations imposed on them under the so-called Product Act. In that period such systems were found on the Scandinavian peninsula, but the majority of European countries had not taken any steps in that scope yet. As a result of CUO's operation, the nation-wide collection system started to operate. To that end agreements with logistic companies were signed, collection started in, among others, tyre-service facilities, transportation centres and communes under agreements signed with recovery plants, tyre granulation plants and cement plants, which at present collect scrap tyres from all over the country. Despite stronger and stronger competition, CUO has maintained its leading market position, collecting all over the country and handing about 2/3 of all collected tyres for recovery.

About 3.5 mill. units of tyres (100 thousand tonnes) were sold in 2002 in Poland. The figure amounted to 5 mill. units in 2002-2005, which showed a slight upward tendency; a similar quantity of tyres is discarded every year. A significant rise in sales took place in 2006-2007, when the figure reached about 190 thousand tonnes, which was nearly twice as much as in 2002. In 2014 the volume of tyres launched onto the market was 234.3 thou tonnes - a rise of 5.5% compared with the preceding year.

From the point of view of environmental protection the biggest problem lies in tyres, which constitute between 60 and 70% of the rubber industry. A vast majority of tyres launched onto the domestic market, about 96%, are new products, while recapped used tyres make up approx. 4% of the total. Pursuant to the EU and Polish law, scrap tyres are treated as waste (Act of 27 April 2001 on waste). According to the regulation on waste catalogue, tyres are classified in group 16, subgroup 16 01 - end-of-life vehicles, under number 16 01 03 - scrap tyres. According to the Landfill Directive and Article 55 point 1 item 5 of the Waste Act, tyres cannot be stored in landfill sites, either in the form of whole or shredded tyres. Although rubber has been known for 170 years now - the first person to obtain it was an American, C. Goodyear, in 1839 - only an intensive development of the motor industry placed rubber goods, especially tyres, among the most serious environmental issues.

Table 2. Required recovery and recycling limits for scrap tyres in Poland in 2002-2014

Required level	2002	2003	2004	2005	2006	2007-2014
recovery	25%	35%	50%	60%	70%	75%
recycling	-	-	6%	9%	12%	15%

Source: Own work on the basis of the Act of 11 May 2001 on entrepreneurs' obligation in the scope of managing certain types of waste and product and deposit fees Journal of Laws 2007 No 90, item 607, as amended.

Since the implementation of the Act on entrepreneurs' obligation in the scope of managing certain types of waste, we have been observing an intensive development of the waste management system. The required recovery and recycling levels for scrap tyres in Poland in 2002-2014 are presented in table 2. The required recovery level in 2002 was 25%, which means that it was necessary to collect and

recover a quarter of the mass of new tyres launched onto the domestic market in a given year. In 2007, the recovery mass went up nearly six times within only six years, from 27.7 to 178.2 thou tonnes, and the recycling level was at 46.4 thou tonnes.

The required recovery level went up in subsequent years, attaining the target of 75% in 2007; such a target resulted from the fact that as a consequence of wearing, a tyre loses from 20% to 25% of its initial weight. Reaching the target recovery level for scrap tyres indicates that the number of new tyres launched in a given year is the same as the number of tyres subject to recovery. The target recycling level of 15% was calculated on the basis of the tyre industry capacity forecast for a given year in Poland.

In 2002-2008 the required recovery and recycling limits were attained, which is shown in table 3. Entrepreneurs were allowed to settle any surplus recorded in a given year, as the Act said, only in the subsequent calendar year, i.e. first the surplus from the preceding year was taken into account. In 2009 the attained recovery level fell to 74% (slightly below the required limit of 75%) and in the following years it went up and attained a record level of 96% in 2011. The situation was repeated in 2013, when the recorded recovery level again significantly dropped, as it was only 55.3% (while the limit was still 75%). In the relevant period the recycling levels were attained. However, just like in the case of the recovery level, the lowest recycled volumes were recorded in 2009 (19.8%) and 2013 (16%), which can be explained by the worsening economic situation.

Table 3. Attained recovery and recycling levels for scrap tyres in Poland in 2002-2014

Years	Attained level (in %)		Tyres (in thou tonnes) subject to	
	recovery	recycling	recovery	recycling
2002	27.5	0	27.7	0
2003	43.5	0	56.5	0
2004	58.9	11.5	88.7	17.3
2005	82.4	16.2	120.3	23.3
2006	91.3	19.7	167.5	36.0
2007	91.2	23.7	178.3	46.3
2008	82.2	22.0	151.6	42.4
2009	74.0	19.8	122.7	32.9
2010	82.1	36.6	160.3	71.3
2011	96.0	30.5	213.2	67.9
2012	84.2	23.7	184.2	51.9
2013	55.3	16.0	122.7	35.4
2014	81.6	26.4	178.5	57.7

Source: Own work on the basis of Central Statistical Office's statistical data *Ochrona środowiska*, and the data for 2003-2015 from the Ministry of Environment.

A repeatedly levelled charge that the required recovery and recycling levels for tyres are too high owing to the wealth of the Polish society, in which tyres are not changed every 2-3 seasons like in western countries, has been confirmed in

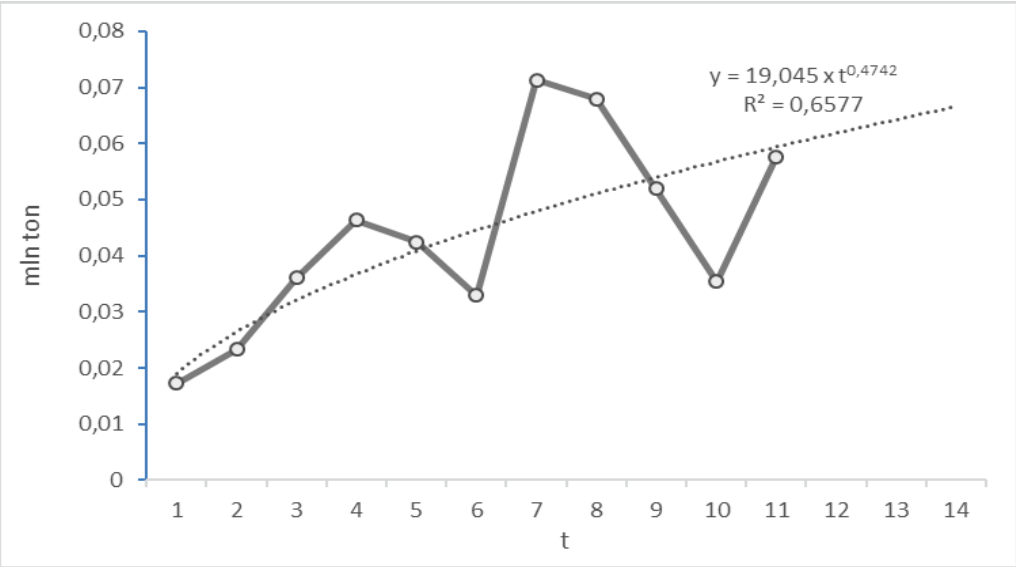
the recovery levels recorded in the years of a bad economic situation (2009 and 2013). The wear and tear of Polish tyres is higher than the standard 20-25%, and the surplus attained in the first years results from lower required recovery levels, tyres collected in landfill sites (which had not been recovered by 2002) and tyres from abroad. In 2014, the import of waste from EU member states to Poland amounted to 295 thou tonnes, including waste imported from Germany constituting as much as 42.6%, and waste from Lithuania and Slovakia – about 20% of total imported waste[30].

Table 4. Auxiliary calculations for determining the trend power function of tyres subject to recycling (in thou tonnes) in 2004-2014

Years	t	y_t	ln t	ln y_t	ln y_t * ln t	$(\ln t)^2$
2004	1	17.3	0	2.850707	0	0
2005	2	23.3	0.693147	3.148453	2.182342	0.480453
2006	3	36	1.098612	3.583519	3.936898	1.206949
2007	4	46.3	1.386294	3.835142	5.316636	1.921812
2008	5	42.4	1.609438	3.747148	6.030803	2.59029
2009	6	32.9	1.791759	3.493473	6.259463	3.210402
2010	7	71.3	1.94591	4.266896	8.302997	3.786566
2011	8	67.9	2.079442	4.218036	8.771159	4.324077
2012	9	51.9	2.197225	3.949319	8.67754	4.827796
2013	10	35.4	2.302585	3.566712	8.212657	5.301898
2014	11	57.7	2.397895	4.055257	9.724082	5.749902
Total	**66**	**482.4**	**17.50231**	**40.71466**	**67.41458**	**33.40015**

Source: Own work on the basis of Central Statistical Office's statistical data *Ochrona środowiska*, and the data for 2003-2015 from the Ministry of Environment.

In order to illustrate the development of the trend of tyres subject to recycling over time (in thou tonnes), it was assumed that the trend estimation is not linear. The linearization was carried out during the trend extraction with the method of least squares.



[30] *Ochrona Środowiska* 2015, p. 342, data from the Chief Inspectorate of Environmental Protection.

Graph 1. Trend power function of the number of tyres subject to recycling in mill. Tonnes

The general equation of the trend power function is as follows:

$$y_t = b \times t^a \qquad (1)$$

In order to change the equation into a linear form, it is necessary to find the logarithm of both sides of the equation with a natural logarithm:

$$\ln y_t = \ln b + a \times \ln t \qquad (2)$$

Then we substitute values by marking logarithms of variables with variables with (*):

$$\ln y_t = y_t^* \qquad (3)$$
$$\ln b = b^* \qquad (4)$$
$$\ln t = t^* \qquad (5)$$

And thus we come with a linear function:

$$y_t^* = a \times t^* + b^* \qquad (6)$$

Having taken into account the calculations presented in Table 4, the parameters of trend power function are as follows:

$$a = 0{,}4742 \qquad (7)$$
$$b = 19{,}045369 \qquad (8)$$

The equation of the trend power function describing the change in the number of tyres subject to recycling in 2004-2014 (graph 1) is as follows:

$$Y_t = 19{,}045369 \times t^{0{,}4742} \qquad (9)$$

The calculated coefficient of the regression equation, $a = 0{,}4742$, informs us that a rise of 1% in time resulted in a rise of 0.4742% in the number of tyres subject to recycling in the relevant period. Absolute term $b = 19{,}045369$ stands for the theoretical number of tyres subject to recycling in 2004.

Logistics of recycling and recovery of rubber goods

Scrap tyres are deemed to be the type of waste which, owing to its growing number, size and chemical composition, burden the natural environment most. Given their improved composition and construction, recycling scrap tyres is much more difficult and costly than other types of waste. Higher and higher customer expectations force tyre manufacturers to improve the functional value of their products, inter alia their resistance to mechanical damage, and to the exposure to

road conditions (water, temperature), which at the same time results in problems with the end-of-life processing.

Decisions about the possibility of recycling scrap tyres are made during the construction and technological design. Recycling can be included in various tyre life cycle phases:

- production - limiting the use of natural resources and waste production during the production process, lowering energy consumption in production processes,
- exploitation - prolonging the useful life of tyres: wear test and product servicing,
- end-of-life processing - recovering resources used and reintroducing them into the production process.

Among the environmentally-friendly conditions of the design stage there is the implementation of the 3R principle: reduce, reuse, recycle. Recycling-oriented tyre design takes into account the following factors: restricting the use of hazardous substances, concise and light construction, easy disassembly, and use of materials prone to recycling. On the other hand, recycling tyres in the end-of-life processing stage is connected with transporting scrap tyres, processing materials, and reusing the recovered resources.

An important problem in the scrap tyre management system is the cost of transporting and shredding tyres, especially the large industrial and agricultural ones, which significantly exceeds the cost of the environmental product tariff. The recovery and recycling requirements are not met in the case of agricultural and industrial tyres, and second-hand imported tyres. Entrepreneurs find it more profitable to pay a low environmental product tariff than organise the transport and shredding of tyres in the only shredding plant in Poland located in Przysieka Polska. The environmental product tariffs for post-consumed waste in 2012 were as follows:

- for retreaded tyres - 2.91 zl/kg;
- for new and old non-retreaded tyres - 11.62 zl/kg.

The transport costs of scrap tyres are mainly connected with the location of recovery and recycling facilities that are situated in the south, south-west and west of the country.

An entrepreneur is entitled to calculate the environmental product tariff for not recovering scrap tyres with the following formula:

$$OP_{recovery} = (P_O \times M_C - M_O) \times M_1 \times OP_1 / M_C \qquad (10)$$

where:

$OP_{recovery}$ – amount of tariff due in Polish zlotys;

P_O – recovery level required in a given year expressed in decimal fractions;

M_C – total weight in kg of all types of tyres launched by the entrepreneur in a given reference year in the territory of the country; M_O – total weight in kg of all types of tyres subject to recovery in a given reference year;

M_1 – weight in kg of tyres launched by the entrepreneur in a given reference year in the territory of the country;

OP_1 – environmental product tariff per unit for tyres in Polish zlotys.

The management of scrap tyres is an important economic and ecological issue. What is undertaken in that scope are multi-directional actions through which components and energy are restored and reused. Recycling consists in the secondary application of waste. In the case of rubber goods, there are three major ways to do that:

- material;
- chemical;
- energy.

Material recycling uses tyres directly or after their compaction, shredding or retreading. Shredded tyres are precious secondary raw material, the quality of which depends on a number of factors: method of shredding, type of rubber, size and shape of particles, density, and specific surface area. Individual rubber fractions: rubber fines and dust, can be added to new rubber compounds as organic filler, or a component in polymer and asphalt compositions[31]. About 20% of roads in the USA are covered with asphalt containing rubber granulate admixtures. The main obstacle for the use of rubber granulate in Europe is a resulting significant rise in construction costs (due to the high energy intensity of the granulate production process).

Regeneration of rubber is the oldest method of scrap tyre disposal in which the plastic properties of tyres are restored. In thermal regeneration, rubber is heated up to 175^{o}C for about 7 hours with water vapour. Other types of regeneration are mechanical and chemical.

The majority of scrap tyres, over 70%, are subject to energy recycling. In that process rubber is burned and thus heat emitted in the process is recovered. The caloric value of rubber goods is about 32 MJ/kg. What should be kept in mind is that rubber goods contain about 2% of sulphur, which is oxidised in the combustion process. Therefore, the furnaces should be equipped with fuel gas desulphurisation devices. Polish cement mills, CHP plants and systems in other sectors of economy use furnaces for used scrap tyre combustion. The disposal of scrap tyres in cement mills compared with material recycling is both ecologically more effective and less costly.

Tyre shredding, as a result of which 0.5 to 300 mm particles are created, is the basic process enabling further processing. About 4 mm-particle recovered material is used for sports fields, playgrounds and leisure areas. A product with a high degree of fragmentation, of less than 1 mm in diameter, is used as an additive to rubber mixes, as it substitutes rubber in floor panels, mats, doormats, car rubber mats, airless tyres in proms, rubbish containers and road safety elements.

End-of-life tyres are also applied to form so-called bumpers that protect watersides in ports, as a protection barrier on race tracks or in dangerous sites such as construction sites, and as protection and an organising element at landfill sites.

[31] W. Szlezyngier, Z.K. Brzozowski, *Tworzywa sztuczne, środki pomocnicze i specjalne zastosowanie polimerów,* Publishing House of Oświatowe FOSZE, Rzeszów 2012, p. 138.

Conclusions

Scrap rubber goods are qualified as waste that should be used industrially. However, the irreversibility of the vulcanisation process results in the need to apply a series of technological and organisational processes in order to recover the resources. The product made as a result is characterised by worse properties than the original material.

Tyre users' escalating requirements referring to the product resistance to mechanical damage, a long tyre exploitation period and adequate safety when driving regardless of atmospheric conditions on the road stand behind serious difficulties with end-of life tyre disposal. The resistance of a tyre resulting from the application of contemporary technologies and multilayer and multicomponent construction makes that type of waste an especially hard one to dispose of. The current scrap tyre management system in Poland should be deemed to be well developing, economically viable and well organised. The number of scrap tyres subject to various forms of recovery and recycling is increasing every year. Thanks to such an organisation of recovery, it is possible to monitor scrap tyre collection and transportation better.

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