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Abstract: Nowadays, waste is something that every country can handle in terms of disposing of it, storing it, or reusing it. However, waste is not only municipal waste but also other raw materials that wear out over time, and their primary purpose in life is over. The ideal case for such waste is its recycling and reuse in other forms. Preventing waste is the best way to recycle, but its life cycle needs to be addressed if waste is produced. The economic model of the current society is primarily linear so far. We extract natural resources and take them to the other side of the world, where products are made from them. These are distributed to other corners of the world, where consumers buy, use and throw them away. This is how waste is created and raw materials in the form of products end up in landfills, incinerators, or thrown in the wild. However, according to the institute, the circular model should, in addition to a stable economy, also ensure a healthy environment. This specific area of waste is under-discussed across society compared to plastics, where more emphasis is placed on recycling and reuse. The presented manuscript concerns the worst kind of waste, namely end-of-life tyres. Despite this, there are companies in Slovakia that are looking for innovative ways to evaluate this type of waste and are dedicated to traditional recycling methods. The number of fast-paced used tyres is increasing nowadays, which also adapts to the lifestyle of everyday life.

1 Introduction

Over 6 million tons of end-of-life automobile waste are produced annually worldwide, of which approximately 5 million tons are recycled [1]. In percentage terms, 87 percent of the total vehicle waste is recycled after the end of its useful life [2]. Among the EU countries, France is the largest producer of waste in this area, closely followed by the United Kingdom and Italy. These three countries produced just over 1 million tons of waste in 2018. For comparison, Slovakia produces only 38 000 tons of end-of-life vehicles per year [3].

The upcoming Figure 1 offers a graphical treatment of the European Union's recycling capacity from 1992 to 2019.

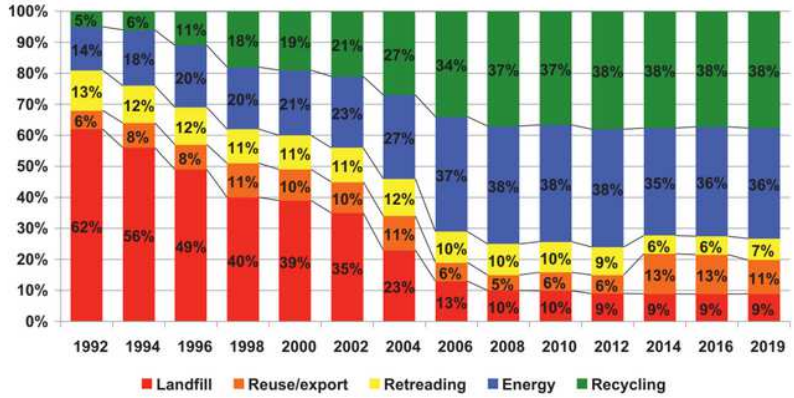

Figure 1 EU Recycling capacity (1992-2019) [3]

The share of landfilling is slowly disappearing in the European Union, and its percentage decreased from 62% in 1992 to 9% in 2019. The reuse share reached its lowest point in 2008 when its value was around 5%. On the contrary, in 2019, we can note an increase in the reuse of waste tires to a value of 9%. Retreading as a possible way of using waste tires has decreased within the EU to 7%. On the contrary, waste tyres' share of energy and material recovery is very close in percentage values from 1992 to 2019 [4]. The newly built plant near our neighbours in Hungary is worth mentioning, which also deals with the issue mentioned above of processing used tyres. The new plant in the Hungarian refinery Zala z recycles 10% of all used tires in Hungary. Behind this plant are the oil, gas, and petrochemical group MOL, whose portfolio includes the Slovak refinery Slovnaft. The construction of the plant cost 8.5 million euros [4]. The plant aims to produce so-called rubber asphalt from used tyres. It is an unusual composition of asphalt and granulated mixture from waste tyres. MOL developed this new production technology in cooperation with Pannonian University. Chemically stabilized rubber asphalt was patented in 2009, and later in 2014, it was awarded the ecological product trademark. The technology patented by the MOL company allows rubber asphalt to be transported, stored, and later used so that it can be produced in bulk, and at the same time, its use can be outside the place of its production [5].

On the other hand, rubber asphalt produced in the USA is produced directly at the site of road construction, as it must be used within a few hours. Due to the extraction of rubber particles. The mentioned plant can produce up to 20,000 tons of rubber asphalt annually. This production covers almost 10% to 15% of the domestic demand for asphalt [6]. Hungary can thus ensure the construction of nearly 200 kilometres of the two-lane road by recycling half a million used tyres. The conditions for expanding rubber-asphalt routes are favourable, as rubber-asphalt has excellent adhesion to mineral substrates. This reduces the probability of potholes, and its higher load capacity compared to traditional asphalt minimises the possibility of ruts on the road [5].

In the world, one of the cheapest and at the same time the simplest ways, which is burning used tyres, is often used. From an ecological point of view, this method is very unfriendly to the environment. When used tires are burned, oxidation reactions occur, where many of the tyres that burn turn into carbon oxides and soot. Substances such as butadiene, styrene, aliphatic and aromatic hydrocarbons, benzene, toluene, and phenylacetylene are released into the air [6,7]. Simply put, heavy metals are released into the air, which negatively impacts the environment. Despite these facts, this method of recycling tires is used in many countries worldwide. The result of the tire combustion process is fuel (Figure 2).

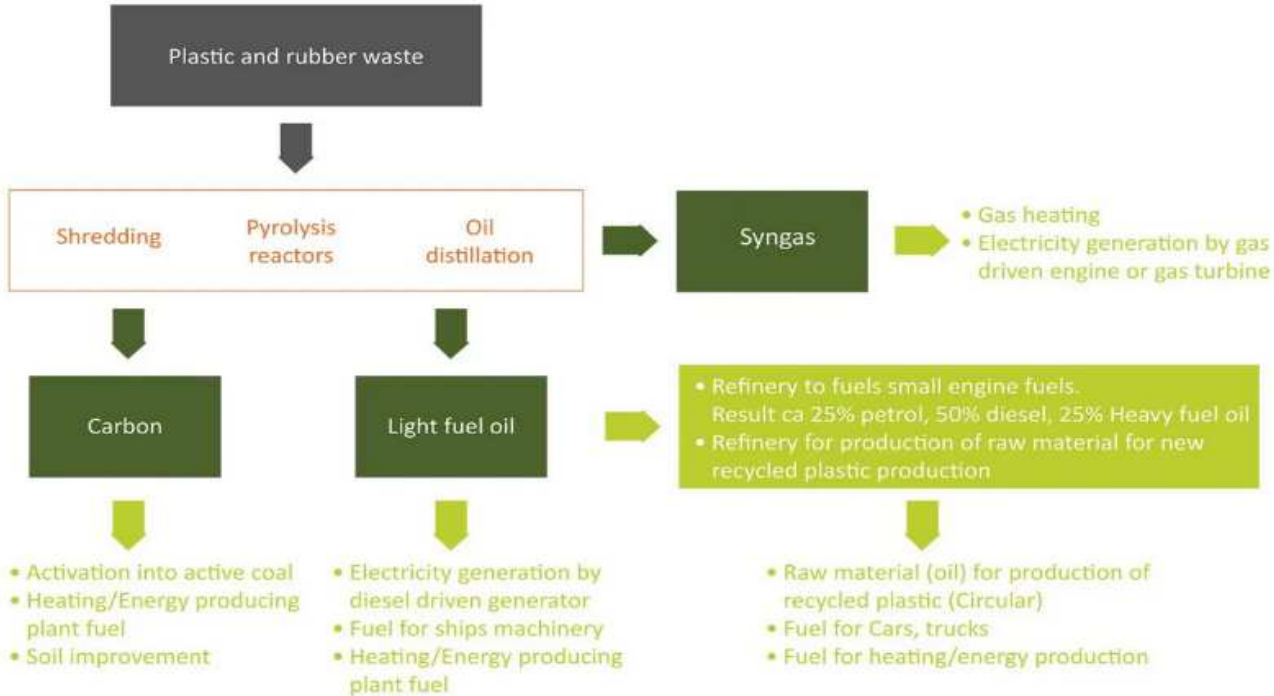

Figure 2 Process of waste tyres and plastics management [4,7]

To illustrate, if we burn 700 kg of used tyres, thanks to the burning, we will get a secondary processing product, which is fuel, but on the other hand, we will produce 720 kg of toxins and soot [6]. In Finland, it provides recycling of used tires with an innovative method that is friendly to the environment [6]. In 2007, the company developed dry pyrolysis technology. Compared to classic pyrolysis, which is very popular in the EU, dry pyrolysis does not

produce any excess emissions [4,5]. As the company's homepage states, their advantage over classic pyrolysis is that no cooling or heating cycles occur during their production, and no emissions are released into the air during processing, as the show takes place through closed processes (without a chimney). The resulting product of recycling is pyrolysis oil. Around 10,000 tons of old tyres are processed annually in this Finnish company [4]. The innovative method of using tyres consists of a modified thermal decomposition process - pyrolysis. The essence is to heat the recycled material at a high temperature without access to oxygen [7]. Under specific pressure conditions, high temperature breaks down tyres into individual components, such as oil, carbon, or gas. Pyrolysis oil made from rubber can be used for heating in industrial furnaces or converted into diesel or gasoline in refineries.

2 The waste tyres characterization

The input material is not only old tyres but also various plastics, which are either crushed on a crushing machine or sent to a pyrolysis reactor, where, thanks to pyrolysis, we obtain synthesis gas, which is suitable for gas heating or the production of electricity with a gas engine or turbines. The mentioned pyrolysis oil can even be used as fuel for ship engines or vegetable fuel producing heating energy [5,6]. The basic goal of the proper functioning of every enterprise is to ensure safety and health protection at work in the human-machine-environment system [5]. Despite implementing all available measures to increase safety and health protection and conscious compliance with the organization's occupational health and safety policy by employees, it does not exclude the emergence of an undesirable situation that leads to occupational accidents. If such an undesirable situation occurs, it is necessary to proceed according to the valid legislation [4]. Safety and health protection at work can be defined as the state of the workplace, which ensures that in compliance with rules such as technological procedures, safety regulations, etc., a situation will not arise that would endanger the health of workers [6]. To create safe work, in which the protection of the worker's health must be observed, it is required to develop and implement a system of measures such as legislative, economic, social, organizational, technical, health, and education [7]. We consider waste tyres, rubber scraps, and rubber waste as input to the recycling process. The annual capacity for the plant is 15,000 tons/year [4]. As an output from the recycling process, the mentioned three forms are rubber granulate, metal component, and textile component, which can be seen in Figure 3.

Figure 3 The Material Outputs from Recycling [4]

For truck tyres, in addition to chopping, the bead ropes are removed, and the tyre is cut into smaller parts. Passenger car tyres are somewhat simpler, as they can be chopped and crushed. The result of crushing, magnetic and pneumatic separation is rubber granulate, which has different fractions [5].

3 The future of waste tyres

Not all products are suitable for natural renewal, and just-worn tyres are a typical example. Ambition in this direction must be set against what is possible in the context of current technologies with a certain expansion of market demand. In other words, although our ambition may be fully circular, there will still be many areas of products in which full circulation will be unattainable [4,7].

Figure 4 describes the principle of understanding circular economy or circular economy. The circular economy model aims to preserve the value of products and materials as long as possible to minimize waste and use new resources [8]. Within the framework of the graphic expression of the circular economy of waste tires model, the input raw material is the tyre, which consists of components, followed by the design and production. After production, the distribution by companies dedicated to the sale of tyres to the consumer market begins [9]. After a certain time, the tire wears out, i.e. the end of its useful life [8,10]. At this moment, the tyre represents waste, intended for collection and subsequent recycling, where the output of the recycling process is a new type of raw material - granulate.

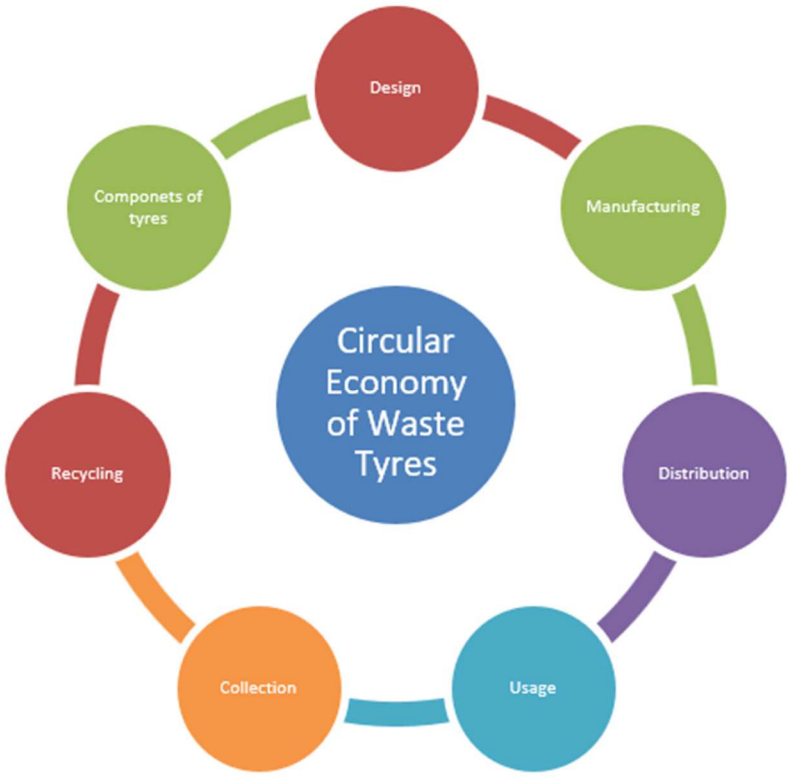

Figure 4 Circular Economy cycle [Authors own processed]

4 Conclusions

The 2030 Agenda for Sustainable Development, approved in September 2015 by the UN General Assembly, also belongs to the circular economy [11]. The 2030 Agenda represents the most complex set of priorities of a global nature, the goal of which is to achieve sustainable development [8,11]. Transformation, integration, and universality are its key principles. The 2030 Agenda includes 17 Sustainable Development Goals (SDGs), which are processed into 169 related sub-goals. The main ambition of these goals is to guide the structural political, economic and social transformation of individual countries of the world, where the Slovak Republic has also signed up to implement Agenda 2030. Agenda 2030 connects three dimensions of sustainable development: economic, social, and environmental. The goal of Agenda 2030 in Slovakia is to get closer to Green Slovakia through several strategic documents [6,12].

The potential of waste tyres is also very significant with the circular economy or the circular economy, as waste can be recycled and offers various possibilities for processing and subsequent use, whether it is the production of granules, alternative fuel, or the production of rubber asphalt. This area provides a large number of options for secondary processing of material and its subsequent transformation into various innovative forms of products originating from waste tyres.

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