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Research Paper

The Importance of Recycling Engine Vehicles Tires Waste in Terms of Natural Resources and the Environment

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ABSTRACT
Theautomotiveindustrycreatesenvironmentalproblemssuch as airpollutiondueto fuel consumption during vehicle life, maintenance operations, waste disposal, and end-of-life scrap disposal. Due to social and political pressures, the automotive sector is being forced to take greater responsibility for vehicle recycling. Recycling motor vehicle waste is a complex process for vehicle manufacturers and related sectors. Today, all materials from scrap vehicles can be technically recovered. In parallel with the increase in the number of motor vehicles, the problems associated with waste tires, the vast majority of which originate from vehicles used on roads, are rapidly increasing. While end-of-life vehicle tires are considered worthless waste, their storage and disposal also pose a significant environmental problem. Waste tires cause environmental and visual pollution and have negative impacts on living organisms and the environmental balance, including fire risks. One effective method used to solve these problems is to recycle and reuse waste tires in industrial applications or to use them in different sectors. In this study; The environmental pollution effects of waste tires, their prevention, the reduction of energy losses resulting from waste tire recyclingtechnologies, andthemeasuresthat can be takentopreventenvironmentalpollutionareexplained.

Keywords: *Environment, Waste Tire, Recycling, Reuse*

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I. Introduction

Today, anotherissuesynonymous with our age, such as communication, science, technology, and diseases, can be described as the depletion of natural resources and their impact on environmental pollution. Metals, widely used in various industrial sectors, are constantly depleting, as are other natural resources. Despite this huge demand and need for raw materials, limited raw material reserves are rapidly diminishing. Rising energy prices increase the cost of producing materials from raw materials. Necessary regulations must be implemented to ensure that these vehicles are scrapped for recycling. Due to social and political pressures, the automotive sector is being forced to take greater responsibility for vehicle recycling. This obligation and responsibility particularly encourages the economical recycling of materials such as seats and dashboards. The conservation of natural resources and environmental protection are among the benefits of the recycling industry. Waste vehicle tires, their environmental pollution effects, their prevention, technologies related to recycling, and reducing energy losses through import-based raw materials and recycling are also considered key solutions[1,2,3]**.**A vehicle tire, a cutting-edge technological product, has a ground contact area the size of a postcard for each tire. A pneumatic tire is a crucial element in road vehicles, forming the interface between the vehicle and the road, supporting the vehicle's weight, and controlling its direction and speed. Made of a combination of rubber, cord fabric, steel wires, and various chemicals, it is the most crucial component that maintains the vehicle's contact with the ground. The tread pattern on the tire wears down to a point where it becomes unusable with use. Worn tires reduce vehicle performance, increase fuel consumption, and, most importantly, negatively impact braking. Because tread depth is crucial for safe driving, tires should be checked regularly and replaced with new tires when the tread reaches a certain depth (at least 1.6 mm). Using tires with a tread depth below 1.6 mm is illegal in many countries because it poses a risk to life and property. Replacing tires with tread depth below this level is crucial for safety, as it becomes difficult for the tire to evacuate water and maintain traction, especially on wet surfaces[4,5].Materialrecycling has become a crucialprocessfortheworldand is referredto as "creativetransformation" bymanufacturers. Thedepletion of rawmaterialreserves, risingenergyprices, andwastepollutionnecessitatethereprocessingandreuse of materials. Today, governmentsareencouraging car manufacturerstodevelopplansfortheuse of 100% recyclablematerials, provided it is technicallyandeconomicallyfeasible. In Germany, approximately 22 millionoldtiresthataregeneratedannuallyandcannot be renewedareused in thecementindustry as a carbonaceousandenergy-carryingmaterial. Thecalorificvalue of an old tire is equivalentto 10 kg of coal. Harmfulsubstancesproducedduringexperimentsareretainedbythecement, andtheresidualgasesarelargelyfree of harmfulsubstances[1,2,4,5]. Theincreasingdemandfor motor vehicles has ledto a correspondingsurge in tire productionworldwide. Accordingtorecentestimates, over 1.5 billiontiresreachtheirend-of-life stageeachyear, generating a substantialvolume of non-degradablewaste. Duetotheircomplexcomposition, mainlynaturalandsyntheticrubber, carbonblack, steel, andtextilefibers, tiresareresistanttodecompositionandpresentsignificantenvironmentalchallengeswhendisposed of improperly. Traditionaldisposalmethodssuch as landfillingandopenburningarenolongerconsideredsustainableduetotheirdetrimentaleffects on landuse, airquality, andgroundwatercontamination[6].Theschematiccross-section of a tire is shown in Figure 1.

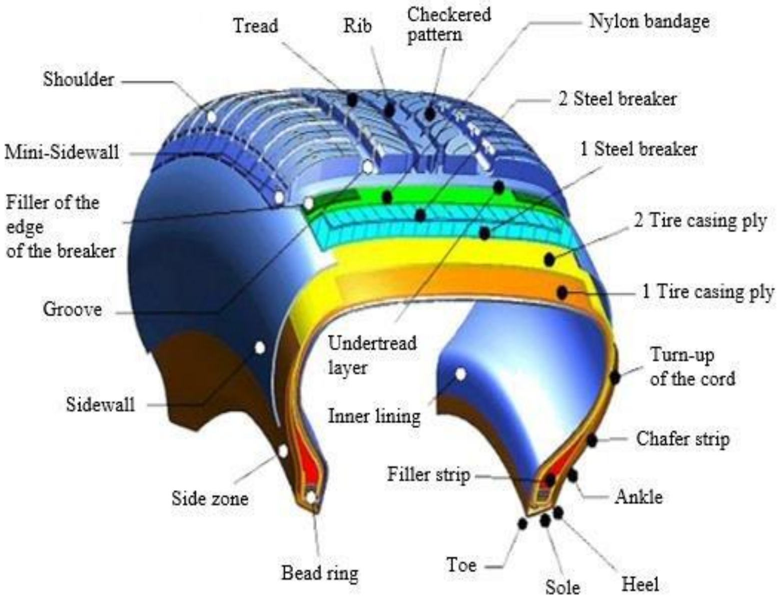

Figure 1. Components of a vehicle tire [4].

In Europe alone, 4.3 million passenger cars, vans and other light commercial vehicles were scrapped in 2023.The total weight of scrapped passenger cars, vans and other light commercial vehicles in the EU in 2023 was 5.0 million tons, of which 93.7% of parts and materials were reused and recovered, and 88.3% were reused and recycled[7].The increase in the global use of passenger cars, motorcycles, buses, trucks, and SUVs in recent years has required the production of large quantities of tires, which become a significant amount of waste that must be disposed of at the end of their useful life. New tire sales in Europe totaled 324 million units in 2020. In 2019, the total amount of end-of-life tires worldwide was determined to be approximately 30.9 million tons[5]. Figure 2 illustratestherecyclingandproductioncycle of usedtiresfor a vehicle.

Figure2. Life Cycle of a Tire, Recycling of RubberWastes as FuelandAdditives[9].

Approximately 85% of the rubber used as the primary raw material in the production of wheeled vehicle tires is used in the tire and automotive supply industries. Because tires are manufactured from highly durable, high-molecular polymers, natural and synthetic rubbers, they create waste that is difficult to decompose in the natural environment after use. Rubber is classified into two types: natural rubber and synthetic rubber. The vast majority of synthetic rubbers, which come in various forms, are composed of styrene-butadiene (SBR) and polybutadiene (PBR-CBR). Rubbers possess properties such as high flexibility and strength, low deformation and spreading, dynamic properties, easy processing and abrasion resistance, and resistance to polar liquids. Due to these properties, tires, which are essential components of vehicles, are produced in high volumes, and worn-out tires have become a major environmental problem. Incineration of used tires for energy production, chemical treatments to recover the rubber, and recycling of the steel in the tire all increase the cost of these processes. Recycling waste tires is possible and economically valuable, but the waste generated if not recycled is voluminous and hazardous. In many parts of the world, the amount of waste tires piled up without any legal regulations threatens human and environmental health. In industrialized countries, the annual volume of waste tires is equivalent to the size of a passenger car tire times the population. Disposing of waste tires in nature or burning them in the open air causes environmental pollution. The biggest danger posed by waste tires is that they cause uncontrolled fires. Once a tire fire starts, it is extremely difficult to control and extinguish due to the high heat and dense smoke it produces. The petrochemical content equivalent of an average tire is 9.5 liters of oil. Once a tire fire starts, it's extremely difficult to control and extinguish it due to the high heat and dense smoke it releases. The petrochemical content of an average tire is equivalent to 2 gallons of oil of oil. All smoke contains toxic chemicals, different types of smoke can vary in the proportions of individual toxic constituents and toxicant classes. However, there is enough similarity between smoke types to make comparisons useful. Each tire contains about 2 gallons of oil that is similar to heating oil. Therefore tire fire smoke is probably most like an uncontrolled oil fire. Tire fire smoke is particularly irritating probably inpart because sulfur dioxide is generated from the sulfur in tires. Due to their high oil content, tire fires can last for months, releasing toxic gases and polluting soil, groundwater, and surface water sources. Attempting to extinguish tire fires with foam or water creates even greater air, soil, and water pollution. Another danger is that waste tires create a suitable environment for insects and mosquitoes to live and reproduce, thus leading to the spread of mosquito-borne diseases. The dangers become even more pronounced when tire waste is stored separately from other waste. There is enough oxygen between all the tires to cause a fire. A pile fire in Winchester, Virginia, USA, lasted approximately nine months. Controlled burning of tires for disposal is not a suitable solution, as it releases tons of harmful compounds into the atmosphere. Substances released into the atmosphere as a black cloud during this combustion process include carbon black, volatile organic compounds, semi-volatile organic compounds, polycyclic hydrocarbons, oils, sulfur oxides, nitrogen oxides, nitrosamines, carbon oxides, and volatile particles. Also included are metals such as As, Cd, Cr, Pb, Zn, and Fe found in the burning materials. These pollutants, released into the atmosphere by burning, cause contamination of nearby soil and water, threatening the environment and living health. The residues left after a fire have the potential to contaminate the soil. The water used to extinguish fires can also cause pyrolysis and the formation of many hydrocarbons that can seep into the soil, creating a separate problem. These pollutants released into the atmosphere by fires cause contamination of nearby soil and water, threatening human health. Once a tire fire starts, it's extremely difficult to control and extinguish it due to the high heat and dense smoke it releases. The petrochemical content of an average tire is equivalent to 2 gallons of oil of oil. All smoke contains toxic chemicals, different types of smoke can vary in the proportions of individual toxic constituents and toxicant classes. However, there is enough similarity between smoke types to make comparisons useful. Each tire contains about 2 gallons of oil that is similar to heating oil. Therefore tire fire smoke is probably most like an uncontrolled oil fire. Tire fire smoke is particularly irritatingprobably inpartbecausesulfurdioxide is generatedfromthesulfur in tires[1,2,3,4,5,6,7,8].

Theeconomicimpact of tire waste extends beyond disposal costs. Improper tire storage creates fire hazards that have resulted in some of the most expensive environmental disasters in American history. The Winchester, Virginia tire fire of 1983 burned for nine months, requiring a Superfund cleanup operation that lasted nearly two decades and cost taxpayers millions of dollars. Modern tire recycling has transformed this waste stream into valuable resources. The recovery rate of 76% represents significant progress from the 1990s when less than 30% of waste tires were processed for beneficial uses. This improvement reflects both technological advancement in processing equipment and increased market demand for recycled tire products across multiple industries.In 1983, arsonists set fire to seven million tires in Winchester, Virginia, and these tires burned for nine months, contaminating nearby areas with lead and arsenic. The area was cleaned up under a Superfund project that ran from 1983 to 2002. In 1984, a pile of approximately four million tires, locally known as Mount Firestone, caught fire in Everett, Washington, and continued to burn for months because firefighters were unable to extinguish it. In 1989, a fire involving approximately 10 million tires started in Heyope (near Knighton, Powys, Wales) and smoldered for about 15 years[12]. Figure 3 shows an image related to tire fires and environmental pollution.

Figure3. Vehicle Tire Fires and Environmental Pollution

II. Rubber, Tire Recycling and Re-evaluation

Whiletherecycling of products that have reached the end of their lifespan has gained importance and come to the forefront in recent years, the situation is very different in the recycling of used tires. Since rubber is a valuable raw material, its recycling is as old as its production. While an average of 50% of rubber was recycled at the beginning of the 19th century, the abundance of oil, the production of synthetic rubber, and developments in tire technology negatively affected rubber recycling over time, and this rate decreased to 20% in the 1960s. In the 1990s, the recycling rate in the tire and rubber industry fell to 2%. As a result of the large decrease in the recycling rate, the number of tires directly thrown away has reached millions and even billions. By 2030, waste tire generation expects to reach 1.2 billion, for roughly 4 billion tires. It is estimated that the number of accumulated waste tires in EU member states is also around this figure. In recycling facilities, the thick wire portions of tires are first separated. These tires are then broken down into smaller pieces. Through grinding, the fiber(cloth) and remaining wire portions of the tires are separated. The resulting granulated tire pieces are then processed using various sieves to achieve the desired size. The resulting granulated tires are then marketed for use in rubber manufacturing, artificial turf, and rubber tile production. Mechanical crushing separates granulated rubber, steel, and textiles, while pyrolysis and other methods yield carbon black and aromatic oils. Reprocessing end-of-life tires through various industrial applications is one of the most effective ways to eliminate the problem of waste tires. These applications can be summarized in four different ways: direct reprocessing, re-retreading, thermal reprocessing, and raw material reprocessing[4,5,8,9,10,11].The values in Table 1 show that an average of 95% of waste tires are recycled. The global production of rubbers in 2016 has reached 26.9 million tons annually. The International Rubber Study Group (IRSG) also forecasted that the world's total rubber consumption would increase at an average of 2.8% per annum from 2017 to 2025. Currently, the main application of rubbers is tire manufacturing in different sizes from bicycles, and cars to large industrial vehicles. By 2030, it is estimated that 1.5 billion tires will be manufactured worldwide every year, of which 1.2 billion tires will be discarded annually[13]. Tires consist of three main products: rubber, steel fiber, andotherwastes, andtheirpercentagesaregiven in Table I.

Table 1. Averagecomposition of fuel-efficientpassenger car andtrucktyres [14].

Material	Passenger car tyre [wt%]	Truck tyre [wt%]
Natural rubber	21.2	37.1
Synthetic rubber	24.5	10.0
Process oil	4.4	0.8
Steel wire	10.8	21.1
Textile fibres	3.7	0.2
Carbon black	18.9	22.3
Silica	7.7	1.3
Antioxidants, antiozonants, curing system	8.7	7.2

2.1. Direct Assessment: The direct use of tires, as they are, in construction sites, as swings in playgrounds, and as ship buffers on piers. Other applications include tire reefs, creating fish habitats, and circulating tides and storm events underwater, allowing the tires to return to their natural habitat. A good example of direct assessment is the use of waste tires in the earthquake-resistant reinforcement of masonry structures. With this method, the steel mesh found in waste tires has been utilized as an earthquake-reinforcing material. Waste tires are economical because they are free, excluding transportation costs, and can be widely applied in rural and underdeveloped areas where masonry structures are concentrated.Figure 4 shows examples of the direct use of tires.

Figure 4.The Direct Useof TiresExamples.

2.2.Retreading (Recycling as Material): Waste tires can be re-treaded and used as tires. Retreaded tires are 50% cheaper than new tires. Retreaded tires are commonly used on aircraft and trucks. Retreaded tires meet the same safety and performance standards as new tires. The oil used in new tire production is preserved, providing economic benefits for both the seller and the manufacturer. These tires offer the same mileage as new tires while costing 50% less. Consequently, retreading used tires helps reduce the risk of burning tire piles. While retreading is the most environmentally friendly way to utilize used tires, they must be discarded when they become scrap. Ultimately, proper tire management is essential. Figure 5 shows an example of how waste tires can be retreaded and reused as tires.

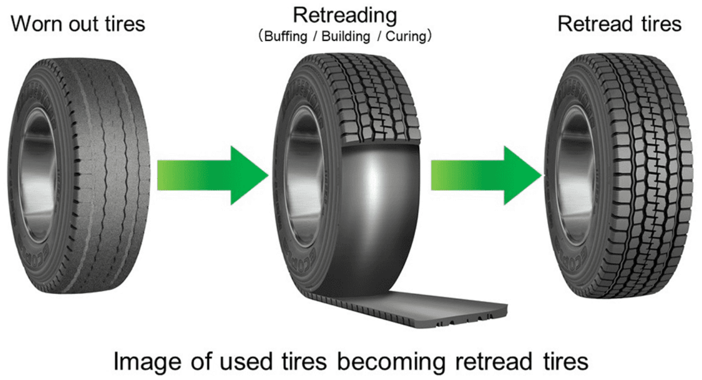

Figure 5.Wastetires can re-treadedandused as tires[15].

2.3.Rubber Granulation: Mechanical recycling is a widely adopted method for processing end-of-life tires (ELTs), focusing on the physical transformation of rubber into crumb or powdered form without altering its chemical structure. This approach not only diverts tires from landfills but also produces valuable materials for various applications. This process is achieved through the use of various shredding machines. Shredding can also be the first step in grinding and granulating whole tires. After the grinding process, the steel wires embedded in the tire are separated using magnetic separators. These steel wires allow for the production of steel that can be reused in construction materials. The resulting crumb rubber finds a wide range of applications across industries. It is commonly used in rubber-modified asphalt, enhancing the durability and flexibility of pavement surface layers. Other uses include flooring materials, mats, playground surfaces, athletic tracks, and molded rubber products like tiles and protective padding. Granulated rubber can be used in new tire production, shoe sole manufacturing, polyurethane foam production, panel manufacturing to reduce noise pollution from trains and traffic vehicles, road construction, embankment and ditch construction, sports and playground equipment, and port construction. The thermal treatment process, in general, pyrolysis of the waste tyres, has material recovery and non-polluting and capable of destroying most of the organic substances, which are harmful to human health. The thermal treatment process, in general, pyrolysis of the waste tyres, has material recovery and non-polluting and capable of destroying most of the organic substances, which are harmful to human health. Figure 6. Schematically shows the grinding and granulation of old tires[16].

Figure 6. Schematicallyshowsthegrindingandgranulation of oldtires[17].

2. 4. Thermal Recovery: In general, the thermal treatment combustion process, the volume of waste can be reduced by more than 90%, net energy producer. In 2017 in Europe, about 289 million tires were sold, which represents 20% of the world's tire production.Rubber has an energy value equivalent to high-quality coal. This fact poses a serious challenge for manufacturers, users and environmental authorities, tire recovery and recycling have become a valuable and growing resource in the last decade. Used tires have high calorific value (29–39 MJ/kg) and are made up of about 90% of organic materials, so they are an excellent source of fuel. Thermal recovery of waste tires is preferred over landfilling. In some incineration plants, tires are burned whole or in shredded form. The economics of converting tires into fuel depends on the tire being mixed into the incineration plant before re-refining. Plants that burn tires whole are more economical than those that burn them in shredded form. It is known to be used as a fuel in cement plants in Europe, the US, Canada, Japan, and Turkey. The remoteness of cement quarries and tire stacks from urban centers and their geographical location make them suitable for use as a fuel. In the US and Europe, it is used as a fuel in thermal power plants that generate electricity using heat and power generators. This incineration process releases toxic gases, which harms human health and creates environmental pollution. At a power plant in Germany, approximately 50,000 tons of tires are burned annually to generate electricity for central heating, nearby residences, and industry. The tires are burned at 1300°C, and the combustion process produces slag, dust high in zinc, and limestone. These products undergo further processing for recycling and reuse. The most common constituents of tires are natural rubber (14–27%), synthetic rubber (14–27%), fillers such as coal and silica (26–28%), plasticizers based on oils and resins (5–6%). In terms of elemental analysis, it is found that tires have sulfur (5–6%) and metals for reinforcement (16.5–25%) Other studies show that used tires have about 60% volatile matter, 30% fixed carbon, moisture contents less than 2% and about 7% of ash[18].

2.5. Recycling as Raw Material: In this method, the rubber, steel, and fibers that make up the tire are separated and reused as separate materials. Pyrolysis is another method used to convert old tires into fuel. For pyrolysis to occur, tires must be heated to between 500 and 60°C. Technically, pyrolysis is the process of breaking organic chemical bonds with heat. Tires pyrolyze into carbon black, gas, steel, and oil, which are then melted. A different process for pyrolysis and melting is defined for each product in different quantities. As the temperature increases, more gas is produced. When the temperature decreases, oil becomes the first fuel recovered. Steel is recovered in secondary melters and foundries. According to the Scrap Tire Management Council, one tire produces an average of 4 liters of oil, 3 kg of carbon black, 1.5 kg of gas, 1 kg of steel, and ash. The resulting oil and gas are reused as low-grade fuel. The steel is then reused. It is not an environmentally friendly method, as the process releases toxic gases that harm human health and cause environmental pollution. Figure 7 illustrates the thermal recovery process obtained by burning old tires, andTable 2 liststheareaswhereusedtires can be recycled.

Figure 7.Thermal Recovery Process of Burning Old Tires[19].

Table 2.Theareas of utilization of usedtires[18].

Utilization of UsedTires	
Direct Utilization (Reuse)	-Agriculture
	-Playground swing
	-Scaffolding
Utilization as Material (Material Preservation)	-Tire retreading
	-Converting rubber into granules.
Thermal Utilization (Energy Recovery)	-Cementplant
	-Heat plants
Raw Material Utilization (Raw Material Recovery)	-Oilsandgasessimilartopetroleum
	-Chemicals

The vast majority of waste tires are sent to municipal landfills or abandoned in the environment. Systematic efforts have been undertaken to collect, store, dispose of, and recycle waste tires, and tire recycling facilities have been established. Waste tires are also seen to be used, albeit in small amounts, on piers and boats. The use of waste tires as an alternative product in various industrial processes has largely mitigated the problems associated with waste tires in developed countries. The average calorific value of a used tire is between 28,000 kJ/kg and 35,000 kJ/kg, and the heat value of a waste tire is equivalent to approximately 10 kg of coal. In small amounts of waste tires is used as fuel in cement or brick production factories for cooking, but in these applications, the dust accumulated in the factories' chimney filters shortens their lifespan. Used tires, which have a high calorific value, can be burned in high-temperature furnaces to generate energy. Facilities such as cement factories and lime and gypsum factories use used tires as supplemental fuel. Used tires are recycled in various sizes, from whole tires to powdered ones. The rubber and fibers of the tire are separated by machinery, and the tire can be used in asphalt road construction and turf fields, while the tire cord fabric can be used as flooring and insulation in the furniture industry[8, 14, 15, 17, 20] as shown in Fig. 8.

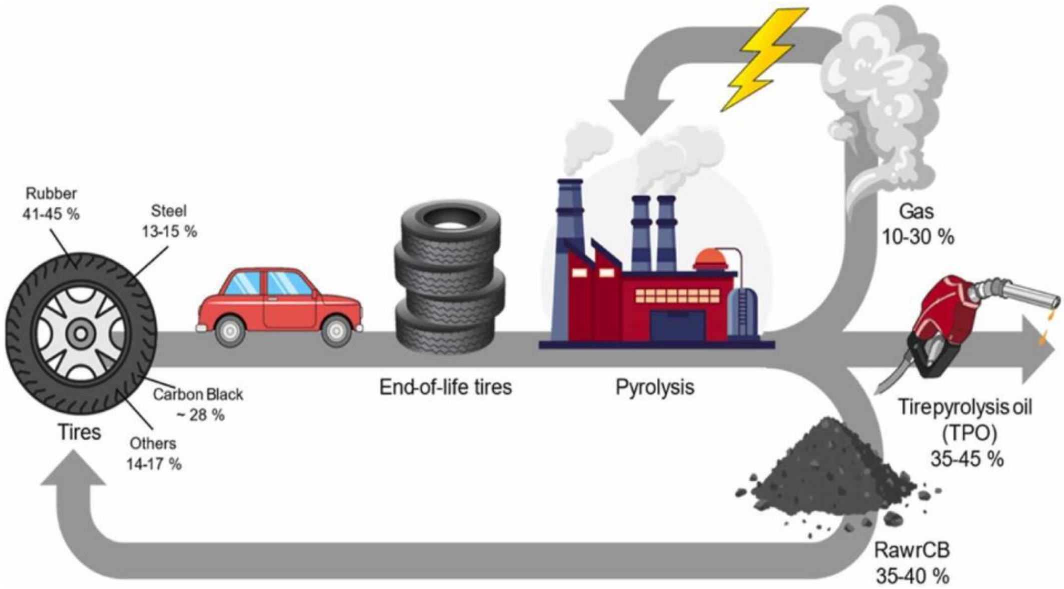

Fig. 8. Schematic representation of the ELT pyrolysis process[20].

III. Conclusion, Evaluation, and Recommendations

Thenewapproachtovehicleuse in theworldwideautomotiveindustrytoday is gearedtowardsplanning safer and more environmentally friendly products. To this end, various countries are supporting these efforts with new incentive mechanisms. While in previous years manufacturers concentrated on 0-60-100 km/h acceleration, maximum speed, and engine power to sell their cars, today new safety features, fuel economy, and car-environment interaction are emerging as new factors that customers consider when buying a car. The cars of the future will not only consist of largely recyclable parts but will also be designed to be easier to disassemble.The environmental problems caused by discarded tires can be significantly reduced by applying industrial treatments to used tires, reprocessing them, and using them in various industrial applications. In particular, some tires, especially those from buses, trucks, tractors, and construction machinery, can be retreaded after being removed from vehicles and made suitable for reuse.

• A collaborative effort is needed between tire manufacturers, sellers, users, and local governments for the healthy collection, storage, and disposal of waste tires.

• Since tire changes are carried out by service centers or tire dealers, the old tire should be taken back when a new one is given. Local governments should assist in the transfer of collected waste tires to regulated landfills, thus preventing the haphazard disposal of old tires in landfills or the environment.

• Since waste tires are economically valuable and recoverable, environmentally friendly methods should be chosen for tire recycling and reuse, and investors wishing to invest should be encouraged by the state.

• Projects should be undertaken to encourage creative ideas from universities, relevant institutions, designers, local governments, and the public regarding the reuse of waste tires, either whole or as separated products, and programs that improve environmental awareness should be organized.

• To fund efforts to collect, store, and dispose of waste tires, a tax could be imposed on tires. For each new tire sold, a symbolic waste tax of 0.1% of the sales price could be levied, and brochures and posters promoting social and environmental awareness could be distributed.

• • Environmentally conscious drivers and responsible vehicle use can lead to significant tire savings, while reduced maintenance and repair costs, decreased accident risk, and reduced traffic chaos can result in economic and social benefits exceeding expectations.

• Proper tire maintenance can extend tire life, saving energy and raw materials (half a barrel of crude oil for a truck tire) and reducing air pollution from production.

• Responsible driving will partially prevent the polluting effects of vehicles on the environment by resulting in lower fuel consumption, reduced exhaust fumes and refinery smoke, and less tire wear.

In conclusion, there are three fundamental principles for solid waste management worldwide. These principles are: minimizing waste generation, recovering waste, and disposing of waste without harming the environment. These processes, known as recovery, will protect our natural resources, save energy, increase economic contributions, reduce the amount of waste going to landfills, and represent an investment in the future. Considering fuel consumption, exhaust emissions, ergonomics, road and traffic safety, and the safety of life and property, these vehicles should be removed from traffic as soon as possible. The recycling of these vehicles, which are destined for scrap, should be processed taking into account their impact on the national economy and the environment.

Kaynaklar

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