Chapter

End-of-Life Tire Destination from a Life Cycle Assessment Perspective

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Abstract

Tires are complex materials manufactured from vulcanized rubber and various other reinforcing materials. One billion end-of-life tires (ELTs) are discarded annually, drawing attention from society. Options for their disposal include reuse, retreading, regeneration, co-processing, pyrolysis, and recycling; however, the ideal alternative has yet to be established. Life cycle assessment (LCA) has been used to quantify their impact and support the decision-making process, in order to determine the most beneficial alternative from an environmental standpoint. Scientific studies on LCA have been carried out on different continents, mainly Europe, Asia, and America. The aim of this chapter was to review studies on the life cycle assessment of end-of-life tire disposal. The main treatment and final destination options were reviewed as well as the most important limitations and aspects of the technologies studied. The most common form of disposal is recycling, with mechanical recycling for use in synthetic grass exhibiting the best environmental performance according to scientific research. Energy recovery also shows good performance, largely due to the emissions prevented through energy conversion. Co-processed and retreaded tires are regularly used for comparison but typically display poor environmental performance in relation to the first two alternatives.

Keywords: life cycle assessment, rubber, final destination, recycling, impacts, tire

1. Introduction

Approximately 1 billion unserviceable tires are discarded annually. The largest contributors are from the United States and the European Union, producing about 300 and 260 million, respectively [1–3]. Tires are a complex system containing 41% synthetic and natural rubber; up to 30 wt.% of additives such as silica and carbon black; 15 wt.% of reinforcing materials such as steel, polyester, and nylon; 6 wt.% of plasticizers and vulcanizing agents; and up to 2 wt.% of antiaging agents and other chemicals [4]. **Figure 1** shows the main components of a tire.

Selecting the final destination of tires requires significant knowledge and responsibility, since inappropriate disposal can result in a range of negative effects, including fires and the proliferation of mosquitoes. According to the waste hierarchy, there are several ways of disposing waste tires to mitigate environmental impacts, the most common being reuse, retreading, regeneration, co-processing, pyrolysis, and landfills [5, 6].

1.1 Reuse

Reuse involves using the whole tire or pieces of it to manufacture different rubber products for application in traffic and roadside barriers, the construction of parks and playgrounds, marine defense structures (dykes, wharfs, dams, and for coastal containment), channeling rainwater, artificial reefs, and biogas drainage [7, 8].

1.2 Reforming

Tire reforming can be achieved through three different processes, namely recapping, retreading, and remolding. All involve replacing one or more worn regions with crude rubber and submitting them to revulcanization to acquire the properties of a new tire. Recapping consists of replacing the tread, retreading replaces both the tread and its shoulder, and remolding, also known as bead-to-bead retreading, involves replacing the tread, shoulder, and entire sidewall surface [9, 10].

Reforming is an interesting strategy for used tire recovery, since it promotes savings in iron, rubber, and petroliferous resources and minimizes the problems associated with the disposal of used tires [11, 12]. Reforming is used primarily in the truck tire market, which can be retreaded three or four times [13, 14]. Retreading also provides energy savings because the energy required to manufacture a new tire is around 2.3 times greater than that needed for retreading [14, 15].

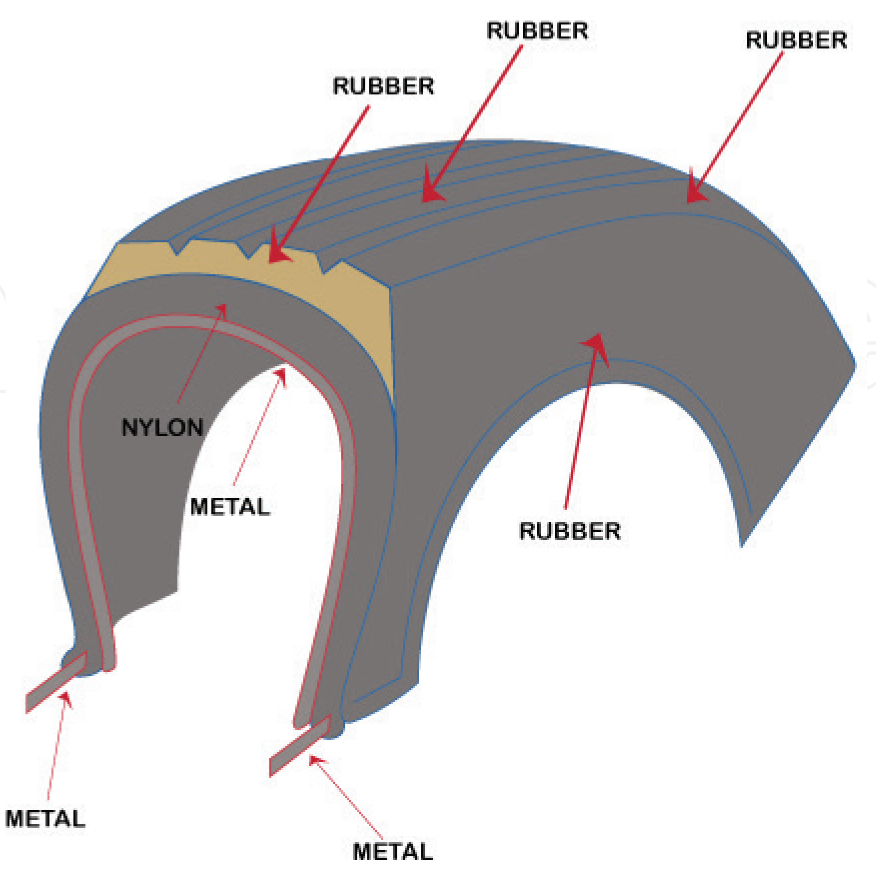

Figure 1.
Materials present in a tire.

1.3 Ground tire rubber

The presence of rubber and steel makes tire grinding a complex process. Rubber is an elastomeric material that requires special care, and steel has excellent mechanical properties, which hampers the molding process. Grinding can be carried out at ambient temperature, by ultrasound or cryogenically to produce small pieces of rubber for a variety of applications, including as a base for artificial grass pitches and playgrounds or an additive to asphalt [16, 17].

In grinding, vulcanized rubber is initially reduced to 7–10 cm particles that are placed into another grinder and processed at ambient temperature into smaller granules, removing steel (by magnetism) and fibers (using vibratory sieves and screens). Depending on the required product, additional processing (tertiary grinding) may be necessary to obtain even smaller particle sizes [17–19].

In grinding by ultrasound, whole tires are fed into a rotary grinder where ultrasound is generated, and the material is ground into 2 μm particles. The metal is removed by magnetic separators, and the final mixture consists of rubber and fabric [20, 21].

In cryogenic grinding, vulcanized rubber is first reduced to 50 mm particles in a mechanical pulverizer and then frozen at temperatures below −120°C in a cryogenic tunnel. The resulting rubber is fragile and can therefore be broken into small pieces in a mill. Metal and fibers are also removed, as occurs in mechanical grinding [18, 22–24].

1.4 Regeneration of tire rubber

In the case of regeneration, waste tires undergo chemical modification (degradation) in order to become more plastic, malleable, less viscous, and processable, that is, with properties similar to those of virgin rubber. Regeneration prompts the breaking of covalent carbon-carbon (C-C), carbon-sulfur (C-S), and sulfur-sulfur (S-S) bonds. If a number of C-C bonds are broken during the process, the main rubber chain may rupture, leading to serious structural disintegration [12].

The quality of products regenerated from waste tires varies according to their composition and the selectivity of the methods used in terms of the type and number of bonds to be broken. For regenerated waste to be deemed good quality, at least 70% of cross-linking must be carried out. It must also remain stable for at least 6 months and still be capable of being revulcanized at temperatures close to 170°C. Rubber regeneration can be carried out in the presence of a specific catalyst, which attacks the cross-linking points, or by applying enough energy to break these bonds. This process generally requires heat, chemical products, and mechanical energy. In principle, regeneration is used to obtain a product to replace virgin rubber with fewer technical requirements than the original product. Rubber is considered regenerated when it recovers its flow capacity and the characteristics of the original compound. Regenerated rubber can be used in carpets, furniture, asphalt mixtures, glues, and adhesives [25].

1.5 Co-processing in cement production kilns

Co-processing is defined as the use of waste materials to replace fuels and/or primary raw materials. Whole or ground tires are burned in a cement kiln to produce clinker, an intermediate product in cement manufacturing. The ash generated is not problematic because it is incorporated into the clinker, preventing the need for subsequent collection and treatment [16]. Silica and iron (contained in the tire) are used as secondary raw materials to replace sand and iron oxide in cement. The high temperatures (1500–1600°C) and oxidizing atmosphere in the cement production kiln allow complete combustion of the tire and almost total combustion of the volatile material produced during burning [7, 11].

The tires can be fed into the kiln whole or ground. Whole tires must be fed into the calcination zone of the kiln, while ground tires can be introduced into the burner zone [7, 20].

1.6 Co-processing in thermoelectric power stations

The use of fossil fuels (conventional power plants) in the form of coal, oil, and gas accounts for about 80% of the global energy demand [26, 27]. Nitrogen compounds and sulfur oxides produced by coal combustion have a significant effect on the environment and are responsible for acidification (acid formation) (HNO_3, H_2SO_4), increased ozone concentration at low altitudes, and high levels of particulate material [28, 29]. According to Singh et al. [30], using tires as a source material to generate energy in coal-fired power plants reduces NOx emissions and recovers the energy contained in the material. In this process, ground tires are combined with coal in the combustion unit to generate electrical energy. An important advantage of this process is that it lowers fossil fuel consumption [16]. Nevertheless, the energy conversion efficiency of power stations that use tires as raw material is 25–30% but far higher in conventional power stations. However, CO_2 emissions are around 23% lower when tires are used for energy generation [16].

1.7 Pyrolysis of tire rubber

Pyrolysis is a high-temperature chemical process that generates oil, gas, and carbon black. First, the tire is ground into 20 mm particles, fed into the pyrolytic reactor, and submitted to temperature (400–700°C) and pressure (0.01–0.04 MPa) conditions under which elastomers degrade. The products of the process consist of the following fractions: gaseous (hydrogen, methane, and carbonic oxides), liquid (water and oils), and residual solids (metals and dust) [16, 19].

An interesting process for the degradation of waste tires is thermolysis under pressure, which involves applying superheated steam and high pressure to obtain oligomers, gas, and liquid fuel. Used tires are placed into a preheating chamber (60–100°C), then fed into the reactor, and submitted to temperatures of 300–500°C and pressures of 1–1.2 atm. The resulting volatile hydrocarbons are removed and condensed, and the carbon residue is separated from the remaining metal [20, 31].

Another recycling technique for degrading tire rubber to obtain commercial products of interest is barodestruction, which is based on the pseudo-liquefaction of rubber at high pressure. Whole or ground tires are fed into the chamber at high pressure. The pseudo-liquefied rubber flows through the holes, and the nylon and metals are separated from the rubber. The metal is removed in the first step, and the rubber and nylon mixture is then passed through a grinder to separate the nylon. The gaseous emissions are treated using filters [20, 32].

1.8 Landfill disposal

This type of disposal consists of simply discarding tires in landfills, which is prohibited in Europe, according to Directive 2000/53/EU [33], and in countries such as Brazil [34]. In addition to shortening the useful life of the landfill, this practice impoverishes the soil, favors the proliferation of mosquitos, and makes the site prone to fires [7, 9, 15]. Fires caused by tires are difficult to extinguish. A tire

Authors and reference	Country	Impact method	Technology studied and/or process for end-of-life tires
Corti and Lombardi [18]	Italy	Ecopoint	• Combustion (waste-to-energy) • Substitution of fuel in cement clinker • Cryogenic pulverization • Mechanical pulverization
Ferrão, Ribeiro, Silva [15]	Portugal	Ecopoint	• Retreading • Recycling • Incineration (cement kiln) • Incineration (power plant) • Landfill
Li et al. [19]	China	Eco-indicator 99	• Ambient grinding • Devulcanization • Pyrolysis • Tire oil extraction
Clauzade et al. [7]	France	Not declared	• Recovery for retention basins • Tire recovery for infiltration basins • Mechanical recycling for steelworks • Mechanical Recycling in foundries application • Mechanical recycling for molded objects production • Mechanical recycling for synthetic turfs • Mechanical recycling for equestrian floors • Energy recovery for cement production • Energy recovery for urban heating
Fiksel et al. [16]	USA	Traci	• Cement production • Civil engineering • Incineration • Industrial boiler • Tire shredding and crumb production • Artificial turf • Molded products • Asphalt production • Retreading
Feraldi et al. [27]	USA	Traci	• Mechanical recycling • Energy recovery in co-incineration
Li et al. [35]	China	Eco-indicator 99	• Recycling to produce ground rubber
Sun et al. [36]	China	CML	• Recycling to produce reclaimed rubber
Ortíz-Rodriguez et al. [8]	Colombia	CML	• Reuse and retreading • Incineration • Grinding (recycling)

Table 1.
Summary of the studies assessed regarding LCA for waste tire rubber.

has around 75% of hollow space in relation to its entire volume, preventing these fires from being extinguished with water because the oxygen in this space feeds the fire. Additionally, the pyrolysis oil generated is a significant atmospheric, soil, and water pollutant [1, 2].

The most sustainable final destination for end-of-life tires is difficult to determine among the different possibilities available. The LCA tool has contributed to the decision-making process, requiring different technologies for each situation, region, and condition. As such, the aim of this chapter is to present studies that used LCA to investigate tire disposal options. Studies were reviewed by continent, and the environmental impact of each technology was evaluated.

The methodology used was divided into two stages. The first was to understand the different technologies applied for end-of-life tire disposal, and the second was to analyze life cycle studies that assessed these technologies in different parts of the world, including Europe, Asia, and America. To that end, a bibliographic review was conducted in different databases, such as ScienceDirect, Scopus, and Web of Science. The study selection criteria were directly related to the subject of the chapter, that is, end-of-life tire disposal based on life cycle assessment. The data from the selected articles are presented and summarized in **Table 1**.

2. Life cycle assessment of waste tire

2.1 General information on LCA

Life cycle assessment (LCA) can be used to quantify the impact of waste tire disposal and determine the most environmentally beneficial alternative for product manufacture and managing used products. LCA has also been applied to identify the most environmentally appropriate final destination for waste tires [3–7].

LCA can be applied to quantify the potential environmental impacts of a product and the resources used during its life cycle, including the acquisition of raw materials, production and use, and waste management. It can also be used to determine the best alternative for managing used products, encompassing their disposal, recycling, and reuse [37]. It is a broad assessment that considers all of the attributes or aspects of the natural environment, from human health to natural resources [38].

In order to standardize environmental management methodology, the International Organization for Standardization (ISO) developed the ISO 14.040 global standard [39], which defines the method for LCA application. An LCA study is divided into four phases: goal and scope definition, life cycle inventory (LCI) analysis, life cycle impact assessment (LCIA), and interpretation [40].

Defining the goal and scope includes establishing the motives for the study, the intended application, and target audience. The limits of the system under study are also described in this phase, in addition to defining the functional unit [40], which is a quantitative measure of the functions that the products (or services) perform. The results of the LCI provide information on the inputs (resources) and outputs (emissions) of the product during its life cycle in relation to the functional unit. The aim of the LCIA is to determine and evaluate the magnitude and significance of the potential environmental impacts of the system studied. In this stage, the functional units allow the relevant data to be compared. Inventory data are separated into midpoint [41] and endpoint (human health, ecosystem quality, and resource consumption) and converted into units via weighting factors for comparison [42]. Since the functional units have yet to be standardized, several names have been proposed, including Ecopoint unit. In this case, the values for each impact category are summed to produce a single value known as the Ecopoint, which corresponds to the environmental load of 1000 Europeans over a 1-year period [42, 43]. In the interpretation phase, the results of the previous stages are compared with the goal and scope in order to draw conclusions and provide recommendations [39].

In order to understand the state of the art, the papers developed in relation to the end-of-life tire destination that used the life cycle assessment were grouped by continents.

2.2 European LCA studies

Ferrão et al. [15] carried out an LCA of a new tire, whose life cycle phases were production, distribution, use, disposal, collection of the used tire, and recycling. The aim was to assess the impacts of a new tire during its life cycle as well as of four forms of recycling (recycling, retreading, fuel replacement, and energy generation) and disposal in a landfill. The Ecopoint approach was adopted, and the functional unit was a metric ton of used tires.

The results indicated that the most relevant phase in terms of environmental impacts was tire use. This was expected, since fossil fuels are the main fuel consumed during tire use and have a significant effect on the environment. Despite its impact, this phase is important in guaranteeing the safety of the vehicle, since the greater friction between the tire and the ground, the more secure the vehicle, but the more fuel it will consume [15].

Impacts resulting from landfill disposal are mainly related to the leaching of metals, stabilizers, flame retardants, and plasticizers, which are mixed with the rubber during tire manufacturing. Retreading is the most cost-efficient alternative in terms of the recovery of material and energy [11]. Although energy is consumed during retreading, consumption is 2.3 times greater when manufacturing a new tire. An important benefit of recycling is that it prevents the use of virgin material [15].

Burning whole tires to generate energy means they do not require grinding. However, a sophisticated burning system is needed to allow the use of high temperatures at specific points, and emissions must be kept within admissible limits [9]. Tire pyrolysis generates three products, namely, gas, oil, and carbon black. The energy potential of gas and oil (used to replace fuel) is similar to that of conventional products [44]. According to Van Beukering and Janssen [45], an important advantage of energy generation in cement kilns is that it does not produce solid residues and the sulfur emissions are not a significant problem because the sulfur generated is incorporated into the gypsum, which is added to the final product.

The results obtained in studies that applied LCA to analyze rubber recycling processes are detailed below. Corti and Lombardi [18] evaluated the following processes using LCA: mechanical pulverization, cryogenic pulverization, energy generation, and fuel replacement, the last applied in cement kilns. The functional unit was a metric ton of tires. The emissions generated were obtained via observations by the authors at different power plants, and average values were calculated. The only exception was the energy generation process, whose values were obtained from a thermodynamic model. The Ecopoint approach was adopted for the emission values.

Of the processes studied, cryogenic pulverization generated the most negative impacts due to its high water consumption when compared to the other processes. Other negative aspects include the greenhouse effect, eutrophication, and carcinogenic emissions (which were higher in cryogenic pulverization) [18].

The greenhouse effect, water consumption, and energy consumption were analyzed in greater detail. The impact on the greenhouse effect is assessed based on the equivalent CO_2 emissions into the atmosphere. According to Corti and Lombardi [18], cryogenic pulverization produces the poorest results, emitting around 450 kg of CO_2 equiv. per ton of tire processed. The energy generation process was the most beneficial because it consumes conventional materials, whereas fuel replacement showed no notable positive or negative influence on the greenhouse effect.

As previously mentioned, cryogenic pulverization displayed the most negative impact on water consumption, since it is high in the cryogenic step of this process. The energy recycling processes produced the best results, since water is not consumed to obtain energy.

In regard to energy consumption, cryogenic pulverization once again produced the worst results. As expected, much higher values were obtained in the two energy processes, given that they generate energy as opposed to consuming it.

Silvestraviciute and Karaliunaite [20] studied fuel replacement, mechanical pulverization, mechanical pulverization with ultrasound, thermolysis, and barodestruction recycling in terms of energy, atmospheric emissions, solid waste, and water consumption. The authors did not adopt a specific methodology for life cycle impact assessment, and only the values for each emission category were reported.

It can be concluded that the use of tires in the fuel replacement process is of significant interest in terms of energy; however, the emissions are similar to those produced using carbon as fuel [20]. In a study carried out by Corti and Lombardi [18], emission values were lower and negative, that is, the process did not result in new emissions. In the process studied by Corti and Lombardi [18], ground tires were added to the burner zone of the furnace, whereas Silvestraviciute and Karaliunaite [20] used whole tires added to the calcination zone. The advantage of the latter is the absence of the grinding step, since the whole tire is used; however, the drawback is that the metal is not recovered (during grinding, iron can be separated out and reused in another process).

In the process studied by Silvestraviciute and Karaliunaite [20], water consumption and solid waste generation were very low and not limiting factors. Gas and dust emissions are associated with fuel replacement and are zero or insignificant in the other processes.

Clauzade et al. [7] used LCA to assess used tire rubber as a substitute for different materials in a range of applications, including as a replacement for filler in retention dykes (concrete and polyethylene blocks) and infiltration (gravel substitute); as a filler at steelworks and foundries (to complement steel), in synthetic grass (instead of ethylene propylene diene copolymer–EPDM), at sports grounds (to replace sand), and in molded objects (instead of polyurethane); and as fuel for heating (coal substitute) and in cement plants (to replace fuel and raw materials). The study considered the transport of material from the generation center to the processing location, the impacts of the processes, and those prevented by the replacement. The authors concluded that reusing rubber as a filler for molded objects and synthetic grass provides the greatest environmental benefits. Additionally, the logistics of collection and transport is an important stage of the process.

2.3 Asian LCA studies

Li et al. [19] analyzed four processes for use in LCA: mechanical pulverization, regeneration, pyrolysis, and oil extraction. As in the studies mentioned above, the functional unit was 1 metric ton of tires. In accordance with Eco-indicator 99, disability-adjusted life years (DALY) were used to evaluate human health-associated impacts. The impact of one unit on this scale corresponds to the loss of 1 year of life. The unit used for ecosystem quality was the potentially disappeared fraction of species (PDF), in the form of $PDF^{*}m^{2*}yr$ (where m^2 is an area in square meters and yr, a year). An impact value of 1 for this unit indicates that all species within one square meter disappear over a year. For the resources category, the unit used was MJ of surplus energy, where an impact value of 1 indicates that an area previously used to extract resources requires 1 MJ of additional energy in order to be used again due to the decline in the natural resources available [46].

The following impacts were considered in the present study: ecotoxicity, acidification and nitrification, emission of carcinogenic materials, global warming potential, emissions of inorganic and organic materials harmful to human health, and the consumption of fossil fuels.

Global warming is caused primarily by the emission of CO_2, CO, N_2O, and CH_4. This study [19] found that only the oil extraction process caused negative effects. The processes that obtained the best environmental performance were mechanical pulverization and pyrolysis. The effects of the first three processes (mechanical pulverization, regeneration, and pyrolysis) are negligible when compared to oil extraction, which uses carbon as an energy source and generates large amounts of heavy metals.

The impacts assessed in the ecotoxicity category were those related to heavy metal and aromatic compound levels in the soil or air. Once again, oil extraction had the most negative impact because carbon is burned as an energy source.

In relation to fossil fuel consumption, all the processes obtained negative values because virgin material was not required, precluding the need for energy consumption during extraction. Even in oil extraction, fuel consumption is avoided, since the oil generated is an energy source [35].

The predominant management option in the Chinese end-of-life tire market is the production of ground rubber [35] for regeneration. In order to improve the environmental performance of ground rubber production, Li et al. [35] made a series of technical recommendations based on the Eco-indicator 99 method. The process consists of three main stages: ground rubber preparation, regeneration, and refining.

According to the authors [35], respiratory inorganics obtained the most severe results, that is, the highest relative contribution among the other impact categories assessed. With respect to regeneration, devulcanization was responsible for most of the environmental loads, corresponding to 66.2% of the total impact. Moreover, improvements in the flue gas treatment contributed to better performance. The use of renewable and clean energy can improve environmental performance by approximately 22%. These results could be used as a guide to reduce the environmental load when producing ground rubber from scrap tires. Moreover, increasing energy efficiency, improving environmental protection equipment, and using clean energy are effective measures to achieve this goal [35].

Still in regard to the Chinese tire market, Sun et al. [36] assessed the environmental impacts of radial tires for passenger vehicles. The authors used the CML method to analyze raw material extraction, tire production, use, and end of life. However, they considered only five out of eight impact categories, namely global warming potential (GWP), acidification potential (AP), photochemical oxidant creation potential (POCP), eutrophication potential (EP), and human toxicity potential (HTP), since these are easier to explain and based on direct emissions that are easy to correlate, in addition to being more important to tire production.

It was assumed that all end-of-life tires were collected and recycled and that, after separating the different tire components, the rubber was completely regenerated to replace synthetic rubber. This recovery and recycling process only showed negative impacts for GWP, EP, and HTP, meaning it prevents emissions as opposed to causing them. However, the main environmental impacts observed during the production of reclaimed rubber and waste treatment were for AP and POCP [36].

2.4 American LCA studies

Fiksel et al. [16] studied fuel replacement, energy generation, retreading, and mechanical grinding. The grinding process analyzed was aimed at the application of rubber in civil construction (as asphalt and a base for synthetic grass) and as a filler in new products. The authors found that using waste tires as raw material for synthetic grass is the most promising alternative, followed by energy recovery (co-processing in cement kilns and energy generation). However, the study was conducted in the United States, where the market for artificial grass is saturated, and, as such, they concluded that energy recovery is currently the most viable alternative.

Feraldi et al. [27] evaluated two final destinations for tires in the United States: grinding and energy recovery. The authors used the TRACI method and analyzed the future prospects for tire disposal considering changes in US energy matrix. The results identified grinding as the ideal final destination, given that energy recovery involves burning and emission of harmful compounds. With regard to future prospects, the authors concluded that the reduction in the impacts of each process would be negligible.

In Colombia, Ortíz-Rodríguez, Ocampo-Duque, and Duque-Salazar [8] used LCA to estimate the environmental impacts of three different alternatives for tires at the end of their useful lives in a case study at the Valle del Cauca Department. The first option was reuse and retreading, the second incineration, and the third grinding to obtain new products. CML-2001 was used to calculate the environmental impact indicators.

Grinding to manufacture flooring and rubber incineration in cement plants exhibited the best environmental results, largely because they prevent harmful effects by recovering the material. Comparison of the different waste tire recovery and disposal processes indicated that retreading and the production of multipart asphalt displayed the worst environmental performance. The performance categories used were global warming potential, ozone layer depletion, acidification, abiotic resource depletion, and photochemical ozone formation. The phases that most contributed to the recovery process were fuel consumption, initial synthetic rubber production, and conversion into liquid asphalt [8].

3. Summary of the studies evaluated

A comparison of the papers presented in **Table 1** shows that the studies are concentrated in Europe [7, 15, 18], the United States [16, 27], and China [19, 35, 36]. With respect to different forms of disposal, it is noteworthy that earlier studies describe a larger number of options, while current research focuses on comparing alternatives to recycling, as well as exploring different applications and recycling techniques [8, 35].

There is no consensus regarding the best impact method for tire recovery studies, although regional preferences are observed. European studies showed a preference for Ecopoint [15, 18], while American papers used only the TRACI method [16, 27], Chinese authors applied both Eco-indicator 99 and CML, and Colombian studies the CML [8, 19, 35, 36].

It is important to underscore that more LCA studies are needed to better understand the impacts of alternatives to traditional tire management, particularly when tires are submitted to new industrial processes, such as recycling [21, 47, 48].

4. Final considerations

End-of-life tire disposal was shown to be of great interest in Europe, Asia, and America, as a means of contributing to the decision-making process in selecting the best technological alternative from an environmental standpoint. Studies demonstrated that the best environmental performance, in general, was mechanical recycling for use in synthetic grass. The worst environmental performance was observed in co-processed and retreaded tires. There is no consensus regarding the best tire recovery method, although regional preferences are observed. European studies showed a preference for Ecopoint, while their American counterparts prefer Traci methodology for life cycle assessment.

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