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Environmental analysis of different end of life scenarios of tires textile fibers

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Abstract

End-of-Life Tires (ELT) are one of the main source of waste in End of Life Vehicles (ELVs). Textile fibers represent about 10% in weight of the ELT and every year, in Europe, about 320,000 tons of dirty fibrous material must be disposed as special waste. Studies show that the fibrous material can be used in second life applications, reducing the environmental impacts of tires disposal, but none of these researches quantitatively evaluate the achievable benefits. This study presents a comparative evaluation of the environmental impacts of the tires considering different scenarios for the end of life of the textile fibers material.

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Keywords: " End of life tires; environmental impact; second application."

1. Introduction

About 9 million end-of-life vehicles (ELV) for year are recycled in the EU countries, and even if this value has strongly increased after 2000, yet approximately 15% of ELV materials are still considered waste and generally goes to landfills. Currently only thirteen Member States over 27 met the 85% target of ELV materials re-use/recovery while the European environmental legislation on this matter [1] requires the reduction of this waste to a maximum of 5% by January 2015. To reach this ambitious goal, all the sector operators (producers, distributors, dismantlers, etc.) must be committed and are encouraged to improve: a) the treatment of end-of-life vehicles, b) the development of methods for re-using, recycling and recovering end-of-life vehicles and their components, c) sustainable circular economic models for recovery and recycling of ELV waste.

End-of-Life Tires (ELT) are one of the main source of waste in ELVs. The global tire output is estimated in 1.5 billion units/year and subsequently just as many will fall into the category of ELTs. In Europe, today the amount of ELT that needs to be processed is 2.6 million tons/year, 95% of which may go for recovery of reusable material (39%) or energy recovery (37%) [2,3,4]

In Italy every year about 35 million tires (400,000 tons) from cars, two-wheelers, trucks, industrial agricultural vehicles, arrive at the end of their life; around 20,000 tons still finish to landfill [5].

Over the last 20 years recovery rates for ELT have dramatically increased in Europe mainly thanks to Extended Producer Responsibility (EPR) schemes that are one of the main economic instruments to implement the waste hierarchy (COM(2011) 571). At the same time the cost of recycling to the consumer has decreased due to advent of better recovery approaches and technologies.

ELT may be source of several valuable secondary raw materials. The output of the treatment process of ELT is shredded material of various sizes and types, depending on the intended uses: rubber chips or granules (70%), steel fibres (5-30%) and textile fiber (up to 15%). Unlike rubber and steel that are currently being reused in various application fields, textiles represent a special waste (CER code 19.12.08) to be disposed. In 2013, approximately 60% of dirty fibrous material collected by Ecopneus was sent to energy recovery in

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furnaces for the production of cement, 25% was used as fuel for electricity production while the remaining 15% is destined for disposal in landfills [3].

Textile fibers represent about 10% by weight of the end-of-life tires (ELT) and every year, in Europe, about 320,000 tons of dirty fibrous material must be disposed as special waste. This results in negative impacts on the environment, in terms of GHG emissions and pollution, economic losses and public costs.

This study presents a comparative evaluation of the environmental impacts of the tires considering different scenarios for the end of life of the textile fiber material. In particular it has been demonstrated that it's possible use the fibrous material and the related changes in the disposing process of tires.

2. Context of research

In Italy the law defines the legal framework and assigns the responsibility to the producers (tire manufacturers and importers) to organize the management chain of ELT. The crucial steps are collection, sorting, transformation and recovery in authorized treatment companies. The treatment and the recovery process of ELT is primarily aimed at recovering of triturated rubber in various sizes and types, which represents the main portion of the ELT material. During the treatment of tires, other two sub-products are generated in significant quantities, namely steel and textile fibers.

In recent years, progresses in the recovery of ELT have been done; currently the main markets for recycling are energy recovery (as fuel in the cement kiln) and the recovery of as secondary raw material. One of the sectors in which recycled rubber is mostly exploited is civil engineering [6]: modified asphalt mixtures; additives for concrete; lightweight fillers in infrastructure; safety barriers, bumpers, artificial reefs, etc. Currently steel fibers from waste tires are sent to electric arc furnaces where it is used as secondary raw material by melting or to replace anthracite and coke as reducing elements of metal oxides. However, growing the interest towards sustainable building in smart cities, some studies have shown affordable use of steel fibers from waste tires as reinforcement in concrete [7].

As regards the recovery of textile fibers, the main problem for recycling is the contamination of rubber that does not allow to obtain a pure product, economically and qualitatively usable. This cleaning practice is not usually adopted because there is not yet a market that justifies the effort and resources required for that. Moreover, there is a lack of available information on the characteristics of the textile fiber that composes the ELT that does not allow to identify suitable sectors for reuse. The main consequence is that both ELT treatment companies and end-users are discouraged to invest in fibers recycling; thus, the dirty fiber is landfilled or goes for thermal utilization (waste incineration plants or cement production furnaces). Even in the scientific literature, it is hard to find information about the possible reuse of ELT fibers. In 2000-2001, Bignozzi and co-workers published some research papers on the use of ELT fibers for modified mortars [8, 9]. The fibers, mainly consisting of a blend of polyester, rayon and nylon fibers, have yielded positive results by improving the mechanical properties of the mortar, but the solution did not achieve market success due to economic reasons. Czvikovszky [10] investigated the use of waste textile fibers as reinforcing material for polypropylene (PP) used in the production of car bumpers. Even in this case the fibers have given positive results giving the modified PP a greater resistance to bending, increasing the modulus of elasticity and acceptable impact strength compared to conventional PP. Those works are the basis of further R&D activities that have been carried out by Steca and his coworkers in the past few years. The evolution of processing technologies, know-how and innovative ideas allowed to overcome all the major drawbacks and to pave the way for ELT fibers recycling.

Fiber modified compounds can create a huge added-value for plastic producers. The mixing of ELT fibers may require only partial modifications to existing extruders and so minor investments that will be soon recovered by higher profitability; in fact, the value of items can be higher because of their greater mechanical strength and durability. This makes the modified compound of considerable technical-economical interest for manufacturing of a wide range of plastic products, such as: carters, automotive components, containers, pallets and so on.

The value of roads and infrastructures realized with the new modified asphalts will be much higher because of longer lifetime (we can estimate a life time of the pavement of about 6-7 years compared to 5-6 current). Besides, the better performance makes the new conglomerates applicable to very different climatic conditions and therefore ensures a wider market and replication across the EU. The new asphalt will be extremely appealing for construction companies for their mechanical properties and will tremendously reduce the public procurement costs of roads and infrastructures rehabilitation and maintenance.

3. Used tires characteristics and valorization

The article shows how reducing the landfill material is possible to reduce the impacts of the end of life tire (ELT). It is therefore necessary to define how to use the waste material in the second raw material, demonstrating the sustainable reuse of recycled fibers in two promising applications: reinforced plastic compounds and bituminous mix for new asphalts. In both cases the use of recycled ELT fibres will reduce the pressure on primary raw materials and enhance the use of alternative compounds. This will reduce the overall GHG emissions, pollutants and environmental pressure due to land occupation and extraction of non-renewable raw materials. Enhancing ELT materials recycling and promoting economically affordable models will also help to stimulate the ongoing ELT recovery market, will prevent further illegal dumping and will encourage the reclamation of existing stocks. Through the use of Life Cycle Assessment, methodology it is possible assess the impacts of a product (in this case of ELT) during the entire the life cycle, from cradle to grave[11]. Results of recently conducted LCA studies demonstrate that under present conditions, the substitution of traditional materials by ELT derived materials (rubber and steel) proved to be environmentally positive in most of the scenarios considered. It is expected that, through the LCA analysis, will be possible to demonstrate that the second use of the fibers coming from the disposal of ELT will reduce the negative impact on the environment and human health.

3.1. Properties of tire waste and reuse

Tires have a mixed composition of carbon black, elastomer compounds, steel cord, fibers, in addition to several other organic and inorganic components. Table 1 shows a view of this composition [12].

Table 1. Average composition of a tyre.

Ingredient	Passenger Car	Lorry	Off The Road
Rubber/Elastomers	47%	45%	47%
Carbon Black	21.5%	22%	22%
Metal	16.5%	23%	12%
Textile	5.5%	3%	10%
Zinc Oxide	1%	2%	2%
Other	8.5%	5%	7%

Tires are made up of four main parts as follows: the tread – designed for contact with the ground and to ensure the proper friction; the carcass – the structural part of the tire on which the tread is vulcanized; the shoulder – minimizes the effects of irregularities of the terrain and transfers the load due to braking and oversteering under acceleration; the heels – to fit the casing to the rim.

Each compound contributes to the particular characteristics of the tire, so as to promote longer life and a particular level of friction [13, 14]. An untreated gum is relatively weak and soft. To give the crude rubber robustness and elasticity, it has to be vulcanized in order to create bonds between the molecules. The rubber thus becomes resistant to abrasion and water, as well as unresponsive to exposure to chemicals, heat and electricity. Another consequence of these treatments is the high resistance to the action of microorganisms, which take more than 100 years before being able to destroy the tires, thus making it unreasonable to dispose of tires in landfills.

An ‘‘end-of life tire’’, ELT, means that the tire has ceased to perform its original function, that is, to complete the wheel of a vehicle to enable mobility in a safe condition. This does not mean that the material the tire is made from can be immediately recycled and be reinserted into industrial production to produce other useful products.

The word ‘‘used tire’’ is more generic. In fact it indicates that the tire is not new and has been used. There are two cases: the used tire is not a form of waste

a. when it is re-used as it is;

b. when it can be reconstructed and is not abandoned or sent for recovery or disposal; the used tire is form of a waste (ELT)

a. when it is neither reusable nor reconstructable;

b. when it is abandoned or is sent for recovery or disposal;

ELTs are a special kind of waste. The main producers of ELTs are mechanical workshops where clients buy new tires and leave the old ones. When it is decided that the used tire is neither reusable nor reconstructable, it is discarded and the recovery process is started through industry consortiums. Other manufacturers of ELTs are vehicle breakers who take the vehicle for demolition, together with its tires. Here the quality of the used tires is assessed, which may in turn be considered suitable for recovery, as in the previous case, as a special waste to be crafted or for commercial activities.

In practice, in compliance with the regulations, the used tire should be managed as special waste. However, in recent years, and until the collection and recycling of ELTs became more common, many tires were accumulated in various forms and in particular in and around urban areas. The reasons are varied and currently it is estimated that in EU about two million tons of ELTs yearly are stored more or less legitimately or even abandoned [12]. Those that have been abandoned on public land fall between the need for ‘‘municipal waste’’. Thus it is still widely regarded that ELTs belong to both categories (special and municipal waste).

3.2. Fiber tires applications

Part of the research was responsible for analyzing the possible scenarios application of the fiber coming from the ELT disposal. The mechanical characteristics of the fiber materials have been studied in order to understand its properties and define the possible for reuse. The analyses showed that the fiber mainly consists of polyamide 6,6. Then, for its use as reinforcement, it will be necessary to use a matrix having a process temperature lower than melting temperature 259°C.

Various scenarios for fiber reutilization have been investigated. Some preliminary experimental tests were carried out in order to evaluate the response of materials reinforced or modified with ELT fibers. The results revealed that the most promising applications for the transfer of technology in the industrial sector are the compound in plastic and modified asphalts. These two sectors have given very interesting results not only in terms of mechanical properties improvement but also in terms of cost efficiency. Concerning the use of recycled fiber in plastic compounds, the tests carried out during the research phase showed a significant increase of molded plastic materials in impact strength and higher deformation resistance (Table 2). The table shows that the PP compound loaded by 20% of fiber has lower elastic module and the maximum deformation is 12% compared to 700% of the neat (conventional) compound. Remarkably, the 20% load with fiber is rather low.

Table 2. Results of mechanical deformation tests on PP compounds reinforced with the ELT recycled fibre

	Maximum stress [MPa]	Maximum deformation [%]	Young module [MPa]

	Ave	SD	Ave	SD	Ave	SD
Neat	28.72	1.2	712	111	1465	54
20%	23.92	1.91	12.22	2.1	1305	64

In the field of bituminous conglomerates, the use of recycled textile fibers as an additive showed a significant increase of the values of tensile modulus and of fatigue strength (6-7 times higher than the standard conglomerates) and therefore of the useful lifetime of the pavement.

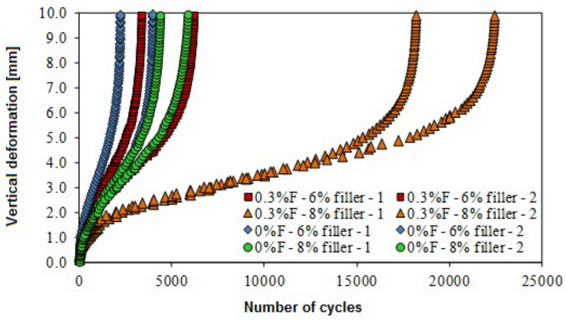

Figure 1. Results of mechanical deformation tests on conventional bituminous conglomerates.

The Figure 1 show the tremendous increase of deformation strength and of number of fracture cycles achievable by loading the conglomerate with only 0,3% in weight of fibers. The suitable combination of fibers and filler, which helps the dispersion of the fibers, further contributes to the fatigue resistance.

3.3. Environmental analysis: the LCA methodology

In addition to the definition of sustainable development, given from the Brundtland report, other definitions could be highlighted. For example, in 1991, the International Union for Conservation of Nature has defined sustainable development as that ‘‘improving the quality of human life while living within the carrying capacity of supporting ecosystems’’[15]. In 1996, the American Society of Civil Engineers has defined it as ‘‘the challenge of meeting human needs for natural resources, industrial products, energy, food, transportation, shelter, and effective waste management while conserving and protecting environmental quality and the natural resource base essential for future development’’ [16].

As a way to address these concerns, the Life Cycle Assessment (LCA) methodologies have been proposed. The primary goal is to evaluate a product or service throughout its life, considering the direct and indirect impacts. The ISO 14040 [17] Standard divides the process of Life Cycle Assessment in four phases: (1) The goal and scope definition;

(2) Inventory analysis; (3) Impact assessment; (4) Interpretation. After the definition of the aim and scope of the study that ‘‘shall be clearly defined and shall be consistent with the intended application’’[18], the main work is the development of an inventory in which all significant environmental burdens during the lifetime of the product or process are collected and quantified, followed by an assessment of impacts that are presented in order to allow its comparison or further analysis. The Life Cycle Inventory (LCI) includes different sub-steps such as raw materials extraction, transportation, production, consumption and waste disposal.

The impact assessment phase, defined as a technical process, quantitative and/or qualitative, to characterize and evaluate the effects of the flows identified in the previous phase, consists of the systematic evaluation of impacts, namely the determination of the potential contribution of the product for the categories of environmental impact, such as global warming, acidification, among others. The life cycle of a pavement is divided into five phases: (1) raw materials and production, (2) construction, (3) use, (4) maintenance, (5) end of life.

4. Choosing between alternatives: use of LCA

The use of the fibrous material obtained by the disposal of ELT, causes different impacts on both the life and disposal process of the tire. The choice of the different recovery technologies is based on various criteria. Life Cycle Assessment (LCA) in recent years has had most of the applications [19, 20]. The boundary conditions need to be clearly defined, taking into account that they vary significantly depending on the particular economic and social contexts. This definition is an necessary for the technique to be efficient and provide reliable results. In a LCA application, the usual approach is to consider the daily load of ELTs from a collection point as a functional unit. Then, once the boundary conditions and the alternative solutions for the recovery have been defined, the tool is developed considering various aspects, such as the total primary energy consumption, the consumption of non-renewable resources, the water consumption, the contribution to eutrophication, the emission of greenhouse gases of fossil origin, the emission of acidifying gases, the creation of a tropospheric ozone, and the production of non-dangerous waste [21]. The environmental impacts of the solution should be evaluated considering both the results of the LCA and the costs of the different operating scenarios.

The analysis of the scenarios has seen, among the various activities, related to the collection of data / information to achieve the LCA, both of the current process (AS-IS) that the new process (TO-BE) by inserting a new machinery to accomplish the cleaning and compaction of the textile fibers. The activity was carried out in collaboration with the STECA company and were identified the main constraints and system boundaries. The plant AS-IS consists of three main steps of processing which results in the complete grinding of the tires. The first step is the production of ground particles about 7–10 cm accompanied by the removal of the metallic fraction. The equipment is a double shaft grinder based on single knife elements. Other inputs to the sub-system are electricity, water and oil. The second step is the further grinding to a size of about 2 cm. The equipment is made of a fixed external cylinder equipped with blades and a rotating internal cylinder also with blades, that fit the ones on the external cylinder, thus crunching the inlet material. Electrical power is required to drive the equipment. A suction system equipped with fabric filters is also present, to remove the dust, produced during the grinding phases. In order to move the material from one step to the other conveyer belts are present, and magnetic belts are used for iron scrap separation. The last step is the pulverization and separation of the tire material to a size lower than 1 mm, and takes place in a machinery based on a fixed and a rotating disk, equipped with blades and between which a pneumatic transport system is used, equipped with a fan and a cyclone. Figure 2 shows the current process of STECA disposing.

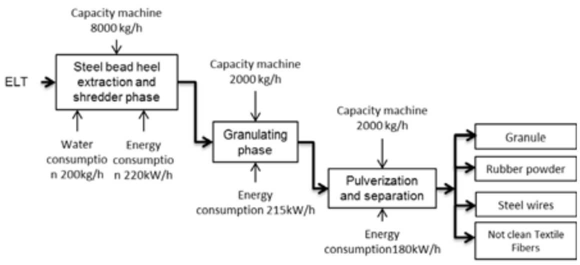

Figure 2 - Disposal process AS-IS

The company operates in 2 working shifts, reaching about 29,000 kg of disposal ELT for daily. The Table 3 shows the daily input and output of the analyzed system.

Table 3- Input –Output ELT as-is process

	Input	Output
ELT (kg/day)	29140	
Energy (kW/day)	800	
Granule (kg)		19790
Rubber powder (kg)		1000
Steel wires (kg)		2350
Not clean Textile Fibers (kg)		6000

The textile fiber commonly extracted, extracted from the As-Is (Not clean Textile Fibers) process has variable percentages of 40-60% in weight of rubber residuals.

Given that the product has like present outlet the dump, it needs to consider that a processing of tires of 9.000 t/year (annual production of Steca), involves an extraction of textile fiber of 5% of the volume, increased further of 5% of rubber from the residual. In essence it's necessary pay the double to dispose of the waste material with several problems; economic and environmental. The use of a new machine allows to completely clean, any residual of rubber component on the fiber, reducing the contamination of rubber to below 1%. As previously underlined, on the working of 9.000 t/year one will obtain a separation of textile fiber not treated of 900 t/year, where it will be recovered about 450 t/year of rubber, which will be destined to the raw material production inside the production cycle (Figure 3). In this case through the new process it is possible to clean 6000 kg/day of landfill material, recovering 3000 kg/day of rubber powder, and producing 3000 kg/day of textile fibers clean. In addition, once treated the textile fiber is compacted automatically in the cleaning circuit and made excellently suitable for use as a second raw material (compound plastic and / or asphalt), thus excluding the landfill. Using the centrifugal force principle, the new machine is able to ensure a good cleaning of the canvas without having to use additional chemicals that should be worsen the environmental emission. The Table 4 - Input – Output ELT to-be processshows the daily input and output for the TO-BE process.

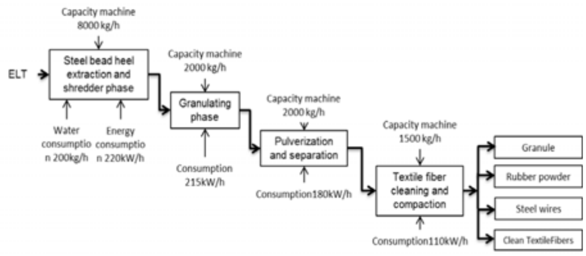

Figure 3 – Disposal process TO-BE

Table 4 - Input –Output ELT to-be process

	Input	Output
ELT (kg/day)	29140	
Energy (kW/day)	1190	
Granule (kg)		19790
Rubber powder (kg)		4000
Steel wires (kg)		2350
Clean Textile Fibers (kg)		3000

The main objective of this LCA analysis is the evaluation of the environmental impact of the different scenario of textile fibers of the ELT, by comparing the different plants manufacturing described above. The following assumptions have been considered:

- The amount of ELT processed is the same both for the process that AS-IS - TO-BE;
- In the impacts assessment of the TO-BE process has been analyzing the life cycle of the process whit the machine necessary to clean the fiber;
- The life time considered for the entire system is 15 years in the Country Italy, and the energy demand in this lifetime for the user considered, is indicate in table 3 and 4;
- As a model for the impact evaluation, the Recipe End point (H) methodology was applied.

The environmental impact evaluation of the two different plants manufacturing have been calculated by the support of the SimaPro 8 LCA tool and Ecoinvent 3.0 as database. The results are shown in the following Figure 4.

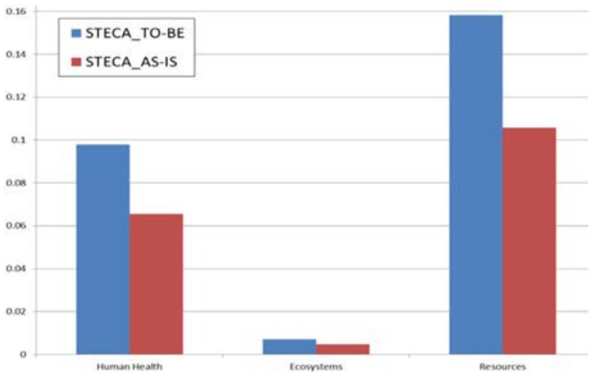

Figure 4- Normalization impact of the different plant configurations.

The use of the new machine added into the TO-BE production cycle, increases of the environmental impacts due to higher consumption of energy and the impact of the life cycle of the machine to clean the fiber.

In parallel, also an environmental analysis of the different waste scenario of ELT. In particular has been comparison the case where the fibrous material ends up in landfills, the case where ends up in the waste incineration plant and the case in which it is cleaned up and used in the plastic compound or asphalts. The comparison, presented in Figure 5, has shown that in this case, the highest impact in environmental terms is related to the scenario AS-IS, in which the fibrous material ends up in landfills or incineration.

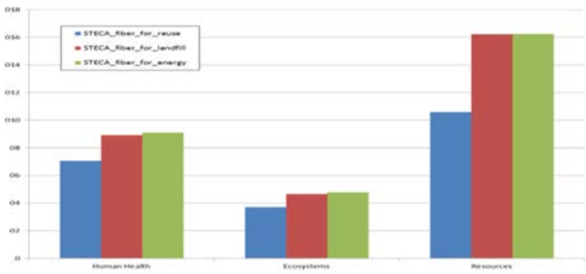

Figure 5 – Normalization environmental impact of different waste scenarios of the fibers

It is possible to observe that, considering the three indicators of the Figure 5, the minimum environmental impact is associated to the scenario with fiber for reuse. For the calculation the three different scenarios of the fibrous material end of life, were also considered the impacts due to the different processes production (AS-IS, TO-BE).

5. Conclusion

This document shows the trend of the environmental impacts of ELT considering different end of life scenarios of the fibrous material. The analysis considers various end of life scenarios; landfill, incineration and reuse, showing the different impacts. It has also demonstrated the technical feasibility of reusing the textile fiber as secondary raw material in asphalt and plastic compounds. However, such applications provide a degree of cleaning of the fiber higher than that destined for landfill or incineration. It was therefore analyzed the new process of disposal of the tires considering the level of cleanliness required of the fiber (TO-BE process). The analyzes show a global reduction of impacts in the case of re-use of the fibrous material. Subsequent analysis will consider the cost benefit analysis, and the evaluation to insert the canvas resulting from the disposal of ELT on the market.

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