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Reuse scenarios of tires textile fibers: an environmental evaluation

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Abstract

End of Life Tires (ELT) constitute a major portion of End of life Vehicles (ELV). The treatment process of ELTs is primarily aimed at recovering steel and rubber, which jointly represent the main portion of the ELT material and are currently applied in different sectors. During the treatment of ELTs, other sub-products are generated in significant quantities (about 10-15% in weight), as textile fibers that currently are landfilled or used for energy recovery. The aim of this study is a comparative evaluation of the environmental impacts related to three different end of life scenarios for the textile fibers. In addition to landfilling and incineration, this study considers the possibility to reuse textile fibers as reinforcement in bituminous conglomerates. Results obtained through the Life Cycle Assessment study confirms that the reuse scenario leads to a relevant reduction of impacts in terms of Global Warming Potential. However, by considering other environmental metrics the reuse scenario is not always the less impactful one.

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Keywords: End of life tires; second life application, fiber material, environmental impact.

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1. Introduction

Nowadays, end of life vehicles (ELVs) constitute a massive waste source in Europe, even if ELV recycling is a priority of the European Union (EU) waste legislation, as underlined in the ELV Directive [1]. End-of-Life Tires (ELTs) constitute a relevant portion of ELV waste, more specifically “every year, about 3.4 million tons of old tires are disposed of in Europe, most being dumped or sent to landfill, in direct contravention of the EU rules banning landfilling of both whole and shredded tires.”[2,3,4]. Management of ELTs has become a critical problem worldwide

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due to the increasing number of vehicles circulating in the road network and to the crucial role that mobility has assumed in modern society development.

Since landfill disposal has been banned in most Countries, alternative final destinations have been sought, with the major effort dedicated in trying to exploit in the most efficient manner the high energy potential of ELTs [5]. The treatment and the recovery process of ELT is primarily aimed at recovering triturated rubber in various sizes and types, as well as steel fiber, which jointly represent the main portion of the ELT material [6,7,8]. Unlike rubber and steel that are currently being reused in various application fields, textiles represent a special waste (European Waste Catalogue – EWC code 19.12.08) to be disposed. Textile fiber represent about 10% by weight of the ELTs and every year, in Europe, about 320,000 tons per year of dirty fibrous material must be disposed as special waste. This results in negative impacts on the environment, economic losses and public costs. In Italy, in 2013, approximately 60% of dirty fibrous material collected by Ecopneus was sent to energy recovery in furnaces for the production of cement, 25% was used as fuel for electricity production while the remaining 15% is destined for disposal in landfills [9,10,11]. In this context, this study aims to investigate three different end of life scenarios of the textile fiber from an environmental point of view. In addition to the baseline scenarios (landfilling and energy recovery), commonly implemented in the Italian and European contexts, the use of the fiber in bituminous conglomerates is considered. The comparative evaluation is performed by using the standard Life Cycle Assessment (LCA)methodology [12], to demonstrate if and how much a reuse scenario for the textile fiber, positively influences on the reduction of environmental impacts related to ELTs[13].

After this introduction, the paper is structured as follows. Section 2 illustrates the characteristics of used tires, as well as the main state of the art researches related to reuse of ELTs and textile fiber. Section 3 details the three considered end of life scenarios with particular focus on the reuse of textile fiber in bituminous conglomerates. Section 4 presents the conducted LCA study and the discussion of the obtained results. Finally, Section 5 reports conclusions and future developments.

2. End of life tires characteristics and valorization

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

Regarding the constituent materials, 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 brief overview of this composition [3].

Table 1. Average composition of a tyre.

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

Each compound contributes to the particular characteristics of the tire, so as to promote longer life and a particular level of friction [14, 15]. The most common treatment for ELTs is the shredding in dedicated mills. The output of the treatment process is thus a shredded material of various sizes and types, depending on the intended uses: rubber chips or granules (about 70%), steel fiber (5-30%) and textile fiber (up to 10%).

2.1. Potential reuse scenarios for tire textile fiber

In Europe the law defines the legal framework and assigns the responsibility to organize the management chain of ELT to the producers (tire manufacturers and importers). The crucial steps are collection, sorting, transformation and recovery in authorized treatment companies. In recent years, progresses in the recovery of materials from ELTs have been done and currently the main application is energy recovery (as fuel in the cement kiln). The reuse of secondary raw materials is mostly exploited in civil engineering [16]: recycled rubber is reused in modified asphalt mixtures; additives for concrete; lightweight fillers in infrastructure; safety barriers, bumpers, artificial reefs, etc. Steel fibers from ELTs are sent to electric arc furnaces where they are used as secondary raw material by melting or to replace anthracite and coke as reducing elements of metal oxides. In addition, some studies have shown affordable use of steel fibers from ELTs as reinforcement in concrete [17].

The textile fiber, derived from the disposal of tires, it is until now classified as waste material. Textile fiber generally contains rubber impurities resulting from the shredding of the tire. The percentage of rubber present in the fibrous material varies from 5 to 20% by weight based on the treated type of tire. The research for the reuse of the textile fiber starts from the idea that it is necessary to separate the residual rubber component so as to obtain a "pure" material in order to reuse in an alternative application. Even in the scientific literature, it is hard to find information about the possible reuse of ELT textile fibers. In 2000-2001, Bignozzi and co-workers published some research papers on the use of ELT fibers for modified mortars [18]. 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 [19] investigated the use of waste textile fibers as reinforcing material for polypropylene (PP) used in the production of car bumpers.

3. Fiber end of life scenarios

In order to assess the advantages in terms of environmental impacts due to the reuse of the fibers, three different scenarios are compared: landfill, incineration and reuse as an additive in bituminous conglomerates. The following sub-sections describe the main characteristics of each scenario.

3.1. Landfill

The impacts resulting from the landfilling of tires, in particular of the textile fibers, are mainly due to the eco-toxicity associated with the leaching of metals [20], as well as from the leaching of different ingredients such as stabilizers, flame retardants, colorants, and plasticizers, which are mixed with rubber during compounding. After discarding tires in landfills, there is a high probability of leaching small molecular weight additives from the bulk to the surface and from surface to the environment, death of several species of advantageous bacteria in the soil [21]. Tires in landfills also occupy a large space and remain intact for decades. Moreover, when whole tires are buried they trap air and have a tendency to migrate to the top of the landfills, breaking the sanitary cap and increasing the instability of the sites [22].

3.2. Energy recovery techniques

Burning the textile material requires a relatively sophisticated high-temperature combustion facility to keep emissions within the allowed thresholds and the use of equipment capable of handling tires and feeding them into the combustion chamber [23]. Despite these requirements, converting textile fiber into fuel is fairly easy because of their high heating value, "clean" combustibility and easy handling (e.g., transportation, storage). The most widespread incineration processes include: (i) dedicated incineration, (ii) incineration in utility and industrial boilers, (iii) incineration in cement kilns and (iv) pyrolysis.

Amari et al. [24] estimated that the tire combustion process recovers only 37% of the energy embedded in new manufactured rubber tires, concluding that it is preferable to recycle rubber and textile fibers rather than use these waste materials as a fuel. Nevertheless, other authors, as Corti and Lombardi [25], argue that Waste to Energy

(WTE) technologies are environmentally preferable to mechanical recycling technologies, mainly due to the avoided use of conventional fuels for the generation of energy.

3.3. Second life application: conglomerates bituminous

The last considered scenario concerns the reuse of textile fibers as reinforcing material for bituminous conglomerates. The consumption of bituminous conglomerates at European level amounts to 325 million tons. This market segment represent a very large niche for ELT fibers uptake. ELT fibers might replace for instance more expensive reinforcements, as the cellulose fiber, reducing the use of virgin raw materials. This shall help to the realization of a closed loop lifecycle in line with European strategies that aim to promote the development of circular economy. The reuse of textile fibers requires a further separation of the rubber impurities from the fibrous material. **Fehler! Verweisquelle konnte nicht gefunden werden.**Fig. 1, Fig. 2 and Fig. 3 respectively show the fibrous material obtained after the traditional ELTs shredding, the clean fibers after the purification and the recovered rubber powder.

Fig. 1. Textile material

Fig. 2. Fiber

Fig. 3. Rubber

Before proceedings with the fiber reuse, the mechanical and chemical properties of the fiber have been studied to define the possible reuse scenarios. 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 in order to make the fiber usable in the current asphalt production process. This treatment compact the fiber into a pellets, increasing about 10 times the density. However it should be having a process temperature lower than the melting temperature (259°C). The process involves the use of lubricants waxes in order to decrease the temperatures reached during the passage in the matrices. In the case studied is used paraffin wax.

The use of recycled textile fibers as additive for bituminous conglomerates 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. Table 2 shows the relevant increase of deformation strength and of number of fracture cycles achievable by loading the conglomerate with only 0,3% in weight of fibers.

Table 2 – Asphalt properties

	Asphalt without fibers	Asphalt with fibers
% Bitumen	5.4	5.4
% Filler	6	8
Indirect tensile module [MPa]	4482	5212
Indirect Tensile Strength [MPa]	1.37	1.38

From Table 2 it is possible to note that the resistance are similar for the two type of asphalt and higher at 1.35 MPa limit fixed by the main tender dossier in Italy. On the other hand, the presence of the fibers determines an increase of the tensile modulus, which are higher about 15%.

4. Environmental life cycle evaluation

The goal of this study is to calculate the environmental impact of the fibre obtained at the end of the tire's life, in three different scenarios: landfill dispose, energy recovery with incineration, and reuse in bituminous conglomerates. The activity was carried out in collaboration with an Italian company (STECA company) authorised for the treatment of ELTs. The functional unit is defined as "dispose of the annual production of fibre in STECA".

The study is a "gate to gate" type, this means it refers only to a specific step of the life cycle of fibre. In particular, the study includes all the processes starting from the production of the fibre in STECA until its incineration or reuse in bituminous conglomerates or disposal in landfill. The system boundaries for three different scenarios, as well as the processes and activities included in the study are summarized in the following Fig. 4.

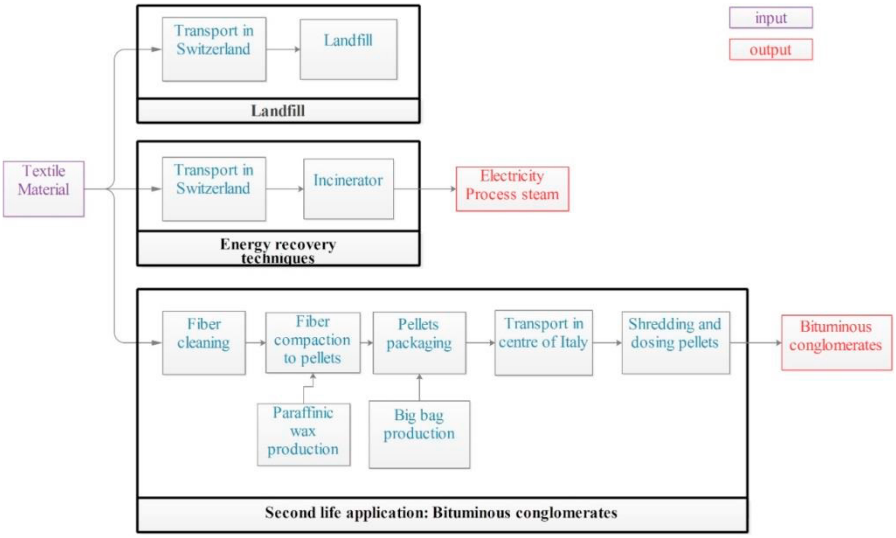

Fig. 4. System boundaries of three scenarios evaluated

Table 3 Components of different scenarios

Scenario	Input	Quantity	Unit
Landfill	Textile material	1.125	[ton/year]
	Euro 5 trucks load	23	[ton/travel]
	Distance	900	[km]
Energy recovery techniques	Textile material	1.125	[ton/year]
	Euro 5 trucks load	23	[ton/travel]
	Distance	900	[km]
Second life application: Bituminous conglomerates	Textile material	1.125	[ton/year]
	Clean fiber	787,5	[ton/year]
	Electricity of cleaning machine	640	[MWh/year]
	Electricity of compaction machine	200	[MWh/year]
	Paraffinic wax for pellets production	0.15	[kg wax/kg fiber]
	Polypropylene fibers for big bag production	340	[kg]
	Euro 5 trucks load	23	[ton/travel]
	Distance	300	[km]
	Electricity of shredding and dosing machine	378	[kWh/year]

The LCIA (Life Cycle Impact Assessment) method used for the calculation of the environmental impacts is the ReCiPe mid-point - Hierarchist (H) version – Europe [26]. Concerning the Life Cycle Inventory (LCI) phase, the data used for the inventory comply with the requirements imposed from ILCD. Most of the data used is data of "background", which means they have been communicated by the STECA company. The unit weight and the composition of “Big Bag” were obtained through a literature research. The production of wax paraffin for the realization of the pellets was obtained by consulting the "Professional" database of GaBi software. The inventory data are summarized in the following Table 3. In order to make possible the comparison, the inputs and outputs of the three considered scenarios have been “equalized”. This means that:

- in the “landfill” scenario, the impacts related to the production of energy, heat and the cellulose to be used in the bituminous conglomerate have been added to the global environmental balance;
- in the “energy recovery” scenario only the impacts related to the production of the cellulose to be used in the bituminous conglomerate have been added;
- in the “reuse” scenario the avoided impacts related to the production of the cellulose to be used in the bituminous conglomerate and the impacts related to the production of energy and heat have been added to the analysis.

Results obtained with the LCIA are shown in the Fig. 5, and Table 4.

Table 4 Value of the environmental impacts of each process in each scenario

Scenario	**Process**	**GWP [kg CO2 eq.]**	**Fossil depletion [kg oil eq]**	**Freshwater eutrophication [kg P eq]**	**Ozone depletion [kg CFC eq]**	**Particulate matter formation [kg PM10 eq]**	**Terrestrial acidification [kg SO2 eq]**
Reuse	Electricity generated	3,88E+05	3,51E+04	2,47E+00	1,93E-03	2,03E+02	5,29E+02
	Heat generated	3,24E+05	6,21E+04	7,90E+01	8,32E-07	4,15E+03	9,96E+03
	Transport	1,34E+05	3,20E+04	4,67E-01	6,70E-08	4,44E+01	1,09E+02
	Polypropylene fibers	6,90E+03	3,98E+03	8,36E-03	4,26E-08	3,33E+00	8,64E+00
	Wax Paraffin	1,11E+06	9,30E+05	2,22E+00	2,64E-06	6,80E+02	2,12E+03
	Electricity consumption	3,31E+06	7,20E+05	1,17E+01	7,68E-05	1,14E+03	3,35E+03
Energy Recovery	Cellulose	1,39E+06	2,36E+05	3,17E+02	3,26E-02	1,12E+02	3,23E+02
	Electricity generated	-1,71E+06	-2,79E+05	-5,77E+00	-2,62E-03	-6,25E+02	-1,72E+03
	Heat generated	-3,75E+05	-6,32E+04	-7,95E+01	-1,25E-05	-4,20E+03	-1,01E+04
	Transport	4,51E+05	1,08E+05	1,57E+00	2,26E-07	1,48E+02	3,65E+02
	Incineration	2,26E+07	1,77E+05	7,15E-01	2,56E-06	8,62E+03	1,98E+04
Landfill	Electricity generated	3,88E+05	3,51E+04	2,47E+00	1,93E-03	2,03E+02	5,29E+02
	Cellulose	1,39E+06	2,36E+05	3,17E+02	3,26E-02	1,12E+02	3,23E+02
	Heat generated	3,24E+05	6,21E+04	7,90E+01	8,32E-07	4,15E+03	9,96E+03
	Transport	4,99E+05	1,19E+05	1,74E+00	2,49E-07	1,65E+02	4,06E+02
	Landfill	7,57E+06	6,42E+04	7,84E+02	-9,09E-06	2,43E+03	8,64E+02

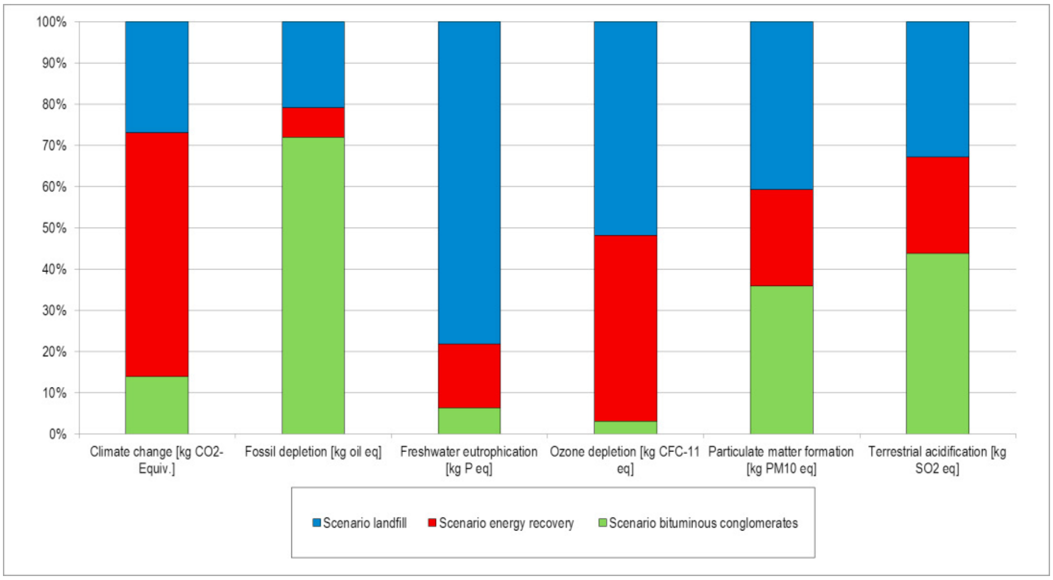

Fig. 5 Environmental impact of three different scenarios

Going into more details, reuse is the best scenario in terms of Global Warming Potential (GWP), while energy recovery scenario leads to very high impacts. This is mainly due to the incineration process (burning of plastic materials) that certainly cause relevant emissions in the air of potentially toxic substances that strongly contributes to the rise of the world temperature. The landfilling of plastic materials, instead, does not cause relevant emissions in the air, thus the influence on GWP is quite limited.

Considering the Fossil Depletion indicator, the situation is completely reversed. In this case, the most favorable end of life scenario is the energy recovery, because the incineration of the tire textile fibers allows saving fossil fuels (coal, oil, gas, etc.) commonly used for the generation of energy and/or heat. In the reuse scenario, the most of the impacts are related to the wax paraffin (produced by using fossil resources), needed to make the clean fibers reusable as reinforcement in bituminous conglomerates. In addition, the cleaning process and the subsequent compaction process in pellet consumes a very high quantity of electricity, thus indirectly causes the depletion of fossils. Regarding impacts related to the excess enrichment of nutrients in water (Freshwater Eutrophication indicator), reuse scenario is the most environmental friendly, while the other two scenarios are penalized by the production of cellulose and by the landfilling. However, as expected, it is not possible to univocally identify the less impactful scenario. Depending on the considered indicator the lower impacts have been obtained for the reuse or the energy recovery scenarios. Landfill scenario, which currently is the most common and the less expensive for the STECA company, can be never considered the most environmental friendly.

5. Conclusions

This paper presents a comparative environmental evaluation of three different end of life scenarios of the textile fiber recovered from ELTs. In the context of ELTs, the textile fibers, mainly composed by polyamide 6,6, is currently the univocal material that has not a closed loop lifecycle. The most common end of life scenarios for this material are landfill and incineration for energy recovery. In this study, also a reuse scenario (application as reinforcement in bituminous conglomerates) is considered. The LCA methodology has been used to perform the gate-to-gate environmental evaluations. The analysis considers all the processes and activities from the production of the textile fiber (obtained through the shredding of the ELTs) to the disposal or incineration or reuse of this material. According to the chosen impact categories, the bituminous conglomerates scenario, is the best solution to the disposal fibrous material problem. However, the analysis results show that both energy consumption and the use of the wax paraffin played a key role in terms of contributions to impacts and represented the highest process costs. From the results obtained are known as energy consumed and paraffin lead to high values of fossil depletion. Future developments will be mainly focused to reduce the wax paraffin and optimize the fiber compaction process in order to reduce the energy consumption. In addition, other closed loop scenarios (reuse in plastic compounds) could be considered to identify the best solution for the end of life management of the textile fiber recovered from ELTs.

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