Action 2.2

Environmental evaluation of recycling technologies of crumb rubber from ELTs in comparison with solutions such as landfill disposal and energy recovery

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With the contribution of

Contents

Introduction

The main aim of this work is to compare potential environmental impacts for the end life treatment of exhausted tyres. In particular, three processes are taken into account: mechanical pulverisation process (MPP), substitution of conventional fuel in the cement clink process and landfill disposal. Although the Legislative Decree 36/2006 prohibits the landfilling of end life of tyres (ELT), in the LCA analysis, it is anyway evaluated as reference scenario.

The processes are compared by means of Life Cycle Assessment (LCA) methodology, in order to consider both direct environmental effects, due the analysed processes, and indirect environmental effects, linked to the production processes of the manufactured input materials. The LCA study has been performed with GaBi v.6 software.

The present LCA study is based on data from literature and, after a bibliography analysis on the ELT management [1-2-3], a paper published by University of Florence [4] has been considered as reference. Anyway, the rubber powder recycling for asphalt applications will be investigated in the deliverable 2.3.

Goal and scope definition

The first phase of the LCA methodology is the goal and scope definition that consists of establishing the functional unit. The goal of this study is the comparison of different ELT managements: mechanical pulverization process (MPP), substitution of conventional fuel in cement clink and landfill disposal. The ELTs must not be considered as a waste, but as a resource, so an advantageous management should be devoted in improving the material and energy recovery. In material recovery, tyres are shredded and then ground to recover materials such as steel and rubber. Instead, in energy recovery, tyres are generally used in cement kilns or in furnaces as a fuel.

The functional unit is 1 ton of end of life tyres coming from both cars and trucks.

Mechanical Pulverisation Process

The production of pulverised tyres by means of the mechanical pulverisation process includes three steps of mechanical size reduction, as shown in Figure 1: grinding, crushing and pulverisation.

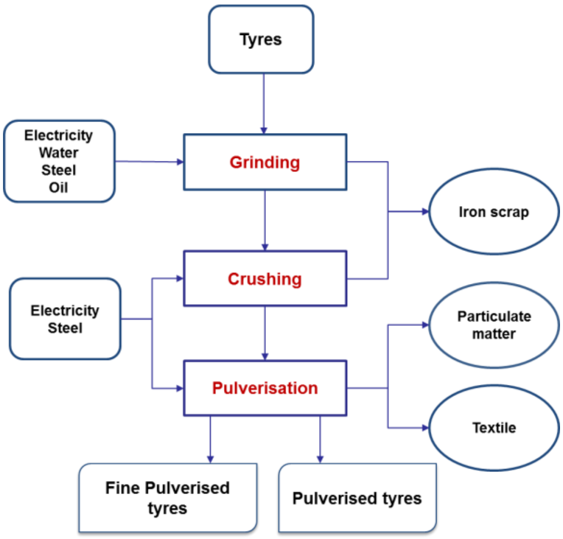

Figure 1 – Production of pulverised tyres by mechanical pulverisation process

The production of ground particles, about 7-10cm, takes place from tyres, electricity, water and oil. The first step is accompanied by the removal of the metallic fraction. The equipment is a double shaft grinder based on single knife elements.

The second step is the further grinding to a size of about 2 cm. The equipment that requires electric power is made of a fixed external cylinder equipped with blades and a rotating internal cylinder also with blades to crunching the inlet material. The grinding process produces dust which is removed using a suction system with fabric filters. Conveyer belts move the material from one step to the other, and magnetic belts are used for iron scrap separation.

The pulverisation of the tyre material to a size lower than 1 mm takes place in 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. For all three processes, the wear of the cutting blades can be significant and their periodic substitution is accounted for.

Substitution of conventional fuel in the cement clink process

This treatment consists of two steps: grinding and co-combustion, as shown in Figure 2.

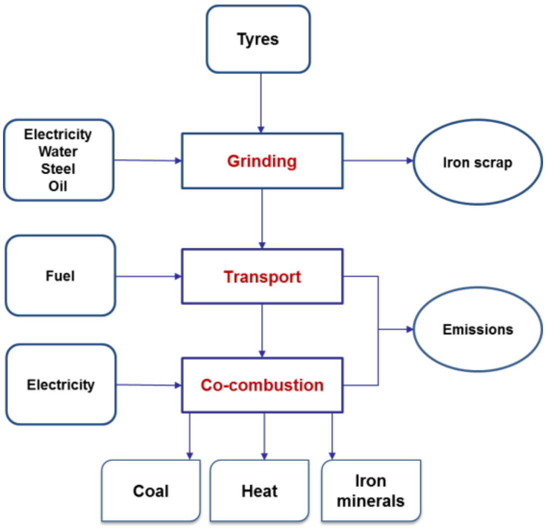

Figure 2 – Substitution of conventional fuel in the cement clink process

Shredded tyres replace part of the main fuel, coal that is still preferred to other fuels because it provides energy and raw material, with its ashes, for the cement production. The substitution rate can be calculated on the basis of the low heating value (LHV) of substituted coal and tyres. The iron content of the crushed tyres is used as iron mineral to improve the co-combustion process. As a matter of fact, in the cement conventional process, such a material is added, while in this case it is produced directly from the process itself, improving so the environmental impacts due to the material saving.

Landfill disposal

Landfill disposal of ELT is forbidden by Legislative Decree 36/2006. The tyre is made from materials that can be reused in new production processes. Thanks to the industrial processes of cutting and granulation of tires, it is possible to separate the different components: steel, textile and plastic. The possibility of landfill disposal is shown only to obtain a comparison with the other two processes, so it is used as a reference scenario.

Life Cycle Inventory (LCI)

According to the ISO14044, the inventory analysis requires that the process is represented as a system and also provides a quantitative description of all flows of materials and energy across the system boundary. Primary data have been collected with reference to Italian plants, considering average values on a significant observation period, generally one year.

Mechanical Pulverisation Process

As mentioned previously, the inputs and outputs of the mechanical pulverisation process have been estimated by existing plants.

The inputs to the grinding process are electricity, water, steel and oil and the outputs are ground tyres and iron scrap, as reported in Table 1.

Input	*Output*	*Amount*
Tyres		1000 kg
Electricity		170 MJ
Water		150 kg
Steel		0.230 kg
Oil		0.011 kg
	Ground tyres	966 kg
	Iron scrap	34 kg

Table 1 - Amounts of inputs and outputs for the grinding process

The Table 2 shows flows of input and output for the crushing process, referring to 1000 kg of input materials. The input to this second process is the output of the grinding process, so the amount should be referred to 966 kg.

Input	*Output*	*Amount*
Ground tyres		1000 kg
Electricity		573 MJ
Steel		0,010 kg
	Crushed Tyres 16 mm x 16 mm	750 kg
	Iron scrap	250 kg

Table 2 - Amounts of inputs and outputs for the crushing process

Similarly, the crushed tyres for the mechanical pulverisation process come from previous process but amounts of inputs and outputs in the Table 3 refer to 1000 kg.

Input	*Output*	*Amount*

Crushed tyres 16 mm x 16 mm		1000 kg
Electricity		513 MJ
Steel		0.278 kg
	Fine pulverized tyres (<0.7 mm)	630 kg
	Pulverized tyres (<2 mm)	310 kg
	Textile fibers	60 kg
	Particulate matter	263,920 mg

Table 3 - Amounts of inputs and outputs for the mechanical pulverisation process

The iron scrap from the grinding and crushing processes are removed and recycled. The fine pulverised tyres (<0.7 mm) are used for rubber asphalts.

The open-loop recycling has been evaluated with an economic allocation that determines the percentage recycled by means of the relationship between the price of the recycled material compared to that of the virgin material. In particular, for the metal part has been considered the value 0.37 as the ratio between the average price of recycled (www.scrapindex.com) and virgin material (LME).

Instead, for the fine pulverised tyres has been used the value 0.13 as the ratio between the average price of recycled (2010 data Ecopneus) and the average price of natural rubber (www.indexmundi.com).

In the present case study the pulverised tires (size between 0,7 and 2 mm) and textile fibers were sent to the landfill: this represents the worst case. In fact, it is possible to provide for these two flows recycling or energy recovery scenarios. For example, the tires pulverised are used as playground and sport surfaces, while the textile fibers can be burned to produce energy.

Substitution of conventional fuel in the cement clink process

The first step of the treatment is the grinding process and data from Table 1 can be used.

Then the ground material is to be transported for a distance ranging between 35 and 100 km from the grinding process plant to the cement production plant. Transportation has been considered only for this treatment line, in order to assess its contribution to the entire process.

The airborne emissions and the fuel consumption due to the transportation are referred to 1 ton of ground material. The electricity consumption has been estimated from the installed power and the equipment using rate.

The emissions, showed in

Emissions	*Amount [kg]*
SO_2	*4,33E+00*
NO_x	7,71E+01
NMVOC	1,19E+00
CH_4	2,60E+00
CO	3,46E-01
CO_2	1,49E+01
N_2O	7,79E-01
PM	6,71E-01
Cr	4,74E-04
Pb	2,19E-04

Table 4, have been evaluated with respect to the conventional fuel combustion and considering a 15% fuel substitution with rubber from the grinding process of tyres.

Table 4 – Emission factors for substitution of coal in the cement clink process

Concerning NO_x production, an average value between a decrement ranging from 15 to 30% has been considered.

Inlet and outlet data related to the entire process are summarized in the Table 5, where also shows the amount of saved coal and iron minerals due to the fact that the end of life tyres contains rubber and steel useful for improving the process setup.

Input	Output	Amount
Tyres		1000 kg
Diesel		6,05 kg
Electricity		6 MJ
Coal		-877 kg
Iron minerals		-250 kg
	Emissions	

Table 5 - Amounts of inputs and outputs for the use of ELTs in the cement clink

All input data, as electricity, diesel, coal, etc., have been retrieved from the database of GaBi.

Landfill disposal

The ELT landfill disposal cannot be actually a realistic solution because, as aforementioned, it is prohibited by law. In any case, such a scenario has been considered in order to have a reference solution to compare with the other end of life options.

Data have been collected on the basis of the average composition of tyres (Figure 3), coming both from cars (20-40%) and trucks (60-80%), and then representing the landfilling of such materials in the LCA software in accordance with the datasets already available in the database provided with the software.

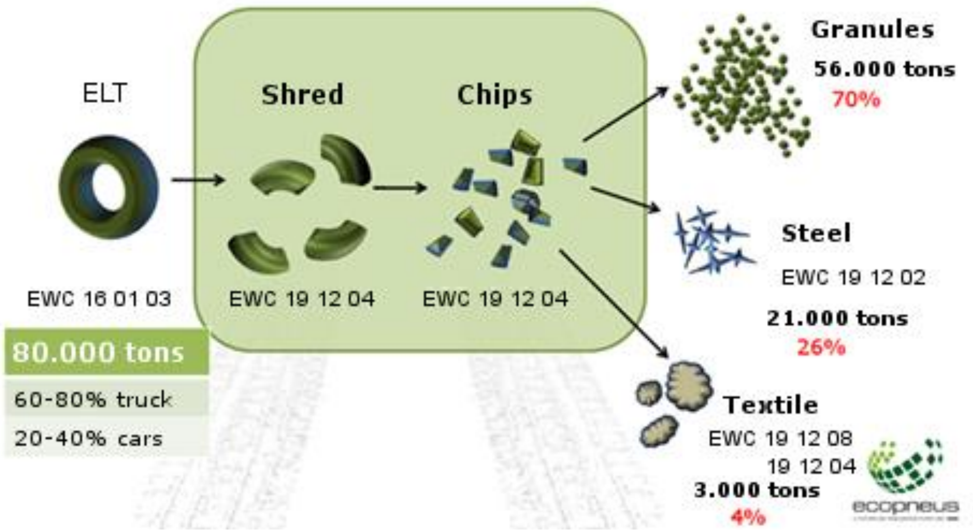

Figure 3 – End of Life Tyres composition

Life Cycle Impact Assessment

Data, collected during the Inventory Analysis phase, have been processed with the LCA software to estimate the environmental impacts. To this end, several models that correlate the inventory data to the environmental impacts can be used.

The environmental impact results for the CML2001 method (Nov. 09) and the total energy consumption impact are shown below:

- Global Warming Potential (GWP 100 years) [kg CO_2 eq.]
- Abiotic Depletion Potential (ADP elements) [kg Sb eq.]
- Abiotic Depletion Potential (ADP fossil) [MJ]
- Acidification Potential (AP) [kg SO_2 eq.]
- Eutrophication Potential (EP) [kg PO_4^{3-} eq.]
- Ozone Layer Depletion Potential (ODP) [kg R11 eq.]
- Photochemical Ozone Creation Potential (POCP) [kg C_2H_4 eq.]
- Human Toxicity Potential (HTP inf.) [kg DCB eq.]
- Freshwater Aquatic Ecotoxicity Potential (FAETP inf.) [kg DCB eq.]
- Marine Aquatic Ecotoxicity Pototential (MAETP inf.) [kg DCB eq.]
- Terrestric Ecotoxicity Potential (TETP inf.) [kg DCB eq.]
- Primary Energy Demand from renewable and non-renewable resources (PED) [MJ]

Results

All the results for each environmental impact are shown in Table 6.

	Landfill	MPP	Cement kiln
ADP elements [kg Sb eq.]	1,16E-05	-2,10E-05	5,57E-06
ADP fossil [MJ]	8,65E+02	-6,25E+03	-2,33E+04
AP [kg SO_2 eq.]	1,88E-01	1,31E-01	4,12E+01
EP [kg PO_4^{3-} eq.]	2,77E-01	1,12E-01	9,75E+00
FAETP [kg DCB eq.]	2,30E-01	-1,31E-01	-3,98E-01
GWP [kg CO_2 eq.]	1,64E+02	-5,97E+00	7,05E+01
HTP [kg DCB eq.]	1,88E+00	5,34E+00	8,49E+01
MAETP [kg DCB eq.]	5,90E+03	1,10E+04	-7,83E+03
ODP [kg R11 eq.]	3,04E-08	1,13E-07	2,13E-09
POCP [kg C_2H_4 eq.]	4,09E-02	-2,97E-02	2,19E+00
TETP [kg DCB eq.]	1,39E+00	1,39E+00	-2,77E-01
PED [MJ]	9,83E+02	-6,42E+03	-2,42E+04

Table 6 – Overview of the environmental impact assessment for each solution

Besides, an explanation of the main environmental categories is discussed in the following section.

Life Cycle Interpretation

The life cycle interpretation of the environmental results is one of the main phase of the LCA methodology. Below, the GWP and PED impacts are explained in detail since they are the most representative of the methodology. For the other impacts, a general explanation is provided while detailed graphs can be found in the Annex B.

Global Warming Potential (GWP)

The main environmental indicator GWP (Figure 4) shows that the landfill has a high environmental impact, mainly due to the disposal of textile fibers resulting from the ELT. Despite the negative contribution due to the emissions of the cement kiln that would impose an environmental load than the landfill, thanks to the recycling of the metal part and to the energy recovery for the partial replacement (approximately 15%) of the virgin material (coal), the balance is about half of the reference solution.

The best solution appears to be the mechanical pulverisation process because it values the recycling of metal and rubber powder (<0.7 mm), the latter used in the production of asphalt rubber.

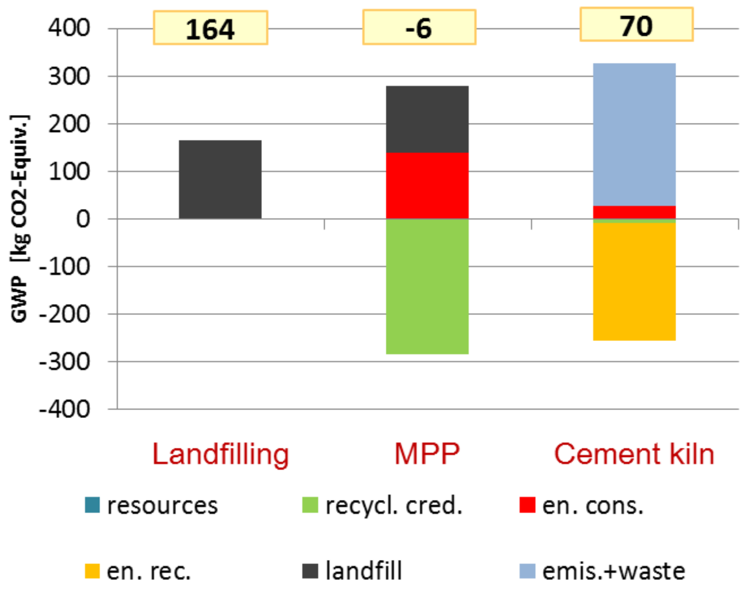

Figure 4 – GWP impact for each solution (landfill, MPP, Cement kiln)

Primary Energy Demand from renewable and non ren. resources (PED)

Figure 5 shows the PED impact for each evaluated solution in comparison with the reference scenario, the landfill disposal. The solution of the cement kiln has a negative impact due to energy credits from lower use of coal. The major influence in the case of the mechanical pulverisation process is due to the recycling of rubber, which allows the reduction of the production of raw material and allows obtaining an energy credit, whose value is intermediate between the reference solution, which is the worst and the solution of the energy recovery.

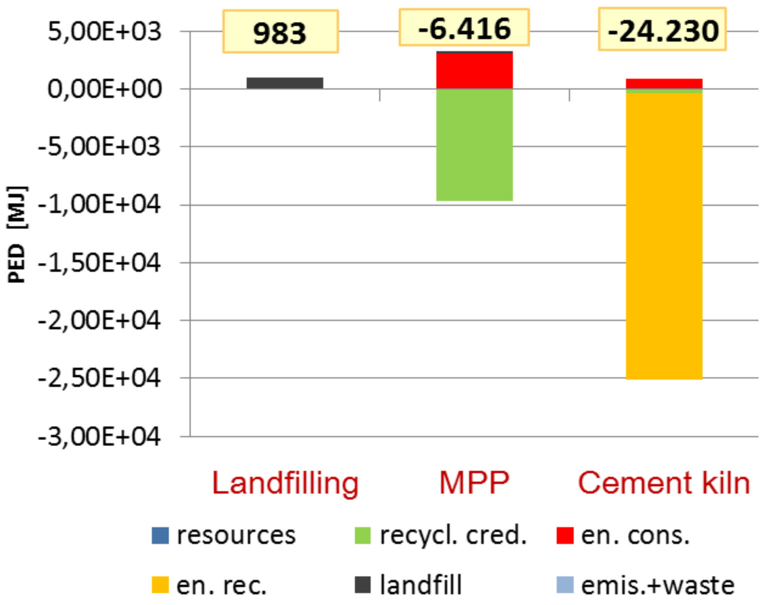

Figure 5 – PED impact for each solution (landfill, MPP, Cement kiln)

Other impacts

From the comparison with the landfill, the cement kiln shows clear environmental benefits related to energy recovery, for most of the impacts evaluated (ADP fossil, ODP, FAETP, MAETP and TETP). The electricity production adversely affects these impacts; however, the cement kiln has a positive balance due to credits related to energy recovery.

For impacts HTP, EP, POCP the cement kiln is the worst option because of the contribution due to air emissions.

The mechanical pulverisation process is a better alternative to the cement kiln, in particular as regards the impact ADP and POCP. The impacts MAETP and TETP penalize such solution because of the energy mix.

However, it should be noted that, for the mechanical pulverisation process, the worst case scenario has been taken into account, because both the rubber powder of size between 0,7 and 2 mm, both the textile fibers can be recycled for the realization of new products or recovered for energy production.

Conclusions

The LCA study has shown the benefits of environmental solutions for energy recovery and recycling in comparison with the landfill, especially focusing the attention on the two main environmental impacts, GWP and PED.

In particular, the recycling solution with production of rubber powder, which is the basic material for the realization of rubber asphalts, ensures a good environmental performance, especially considering the high volumes of ELT available. In conclusion, the two solutions described above turn out to be more advantageous compared to the landfill.

The environmental performances of the recycling solution could be improved more and more through a retreat of the rubber powder in order to increase the quantity of the material flow with the right size for the asphalt rubber application.

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