Life cycle assessment of waste tyre treatments: Material recycling vs. co-incineration in cement kilns

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1. Executive summary

This life cycle assessment study investigates two European end-of-life treatment options for used tyres including processing of tyres for material recycling (main scenarios use rubber as infill material in third-generation artificial turf) and co-incineration of tyres in cement kilns. Thus, the study intends to estimate the environmental impacts of processing tyres for material recycling in comparison with incineration of tyres. The main focus in terms of material recycling is on the use of waste tyres as infill in modern artificial-turf football pitches but applications of cryogenic powder rubber are also considered.

The study was commissioned by Genan (tyre recycler), and carried out by FORCE Technology. It has been reviewed by a critical-review panel. The composition of the panel and the critical review statement can be found in Appendix 5.

This is a comparative LCA intended for public disclosure and the LCA is expected to be used as a decision-support tool. It contains all elements described as compulsory in the ISO standards for life cycle assessment (ISO 14040:2006 and ISO 14044:2006).

The overall scope of the LCA study is the comparison of the potential environmental impacts of the following two end-of-life treatment scenarios for whole tyres:

1) Processing of tyres for material recycling at Genan's recycling facilities. This option implies the following applications for the main recycled tyre components:

a. The recycled rubber is used in applications, where it replaces different materials, which would otherwise be used for the given applications. To represent this, the major use as an infill material in modern, third-generation artificial turf fields is modelled. The results of the main recycling scenarios in this report are therefore applicable for that use only. However, the report includes a discussion about the comparability with other rubber applications;

b. Steel is separated as a steel scrap fraction, which is re-melted for production of new steel;

c. A residual fraction, mainly consisting of synthetic fibers and rubber, is separated and used as secondary fuel in cement kilns.

2) Use of tyres as secondary fuel (co-incineration) in cement production. This process involves:

a. Energy recovery of the combustible component of tyres (rubber, fibers);
b. Utilization of the tyres steel component as a source of iron, substituting other sources of iron in the cement process.

Additional scenarios for cryogenic powder rubber

An additional two secondary scenarios are included for the application of tyre-derived rubber. These two scenarios are applicable for the fine rubber granulate powder from a cryogenic production line, where the rubber granulate is further processed in a cryogenic process. The produced rubber powder is very fine and relatively uniform. It is of a particularly high quality and therefore has more high value applications in comparison with the ambient rubber granulate, which is not further processed. Examples of common applications include the use in new tyres and other industrial products [Genan, 2019]. Little documented information is available about the use of the rubber material in these applications due to producer confidentiality concerns. Therefore, the two cryogenic rubber scenarios rely on the prerequisites described in the following:

1. The cryogenic rubber is used in applications where it replaces carbon black in a ratio of 1:1 by weight. It is assumed that there are no impacts related to the use stage and that final disposal is by incineration.
2. The cryogenic rubber is used in applications where it replaces synthetic rubber in a ratio of 1:1 by weight. It is assumed that there are no impacts related to the use stage and that final disposal is by incineration.

These two scenarios differ from the main material recycling scenario in two ways. First, the production includes an extra processing step (the cryogenic process) and secondly they differ w.r.t the rubber applications, which are as described above.

Functional unit and system boundary overview

The functional unit is defined as **the treatment of one tonne of tyres** in Europe. The overall system boundaries are shown separately for the material recycling and the co-incineration methods in Figures 1.a and 1.b below.

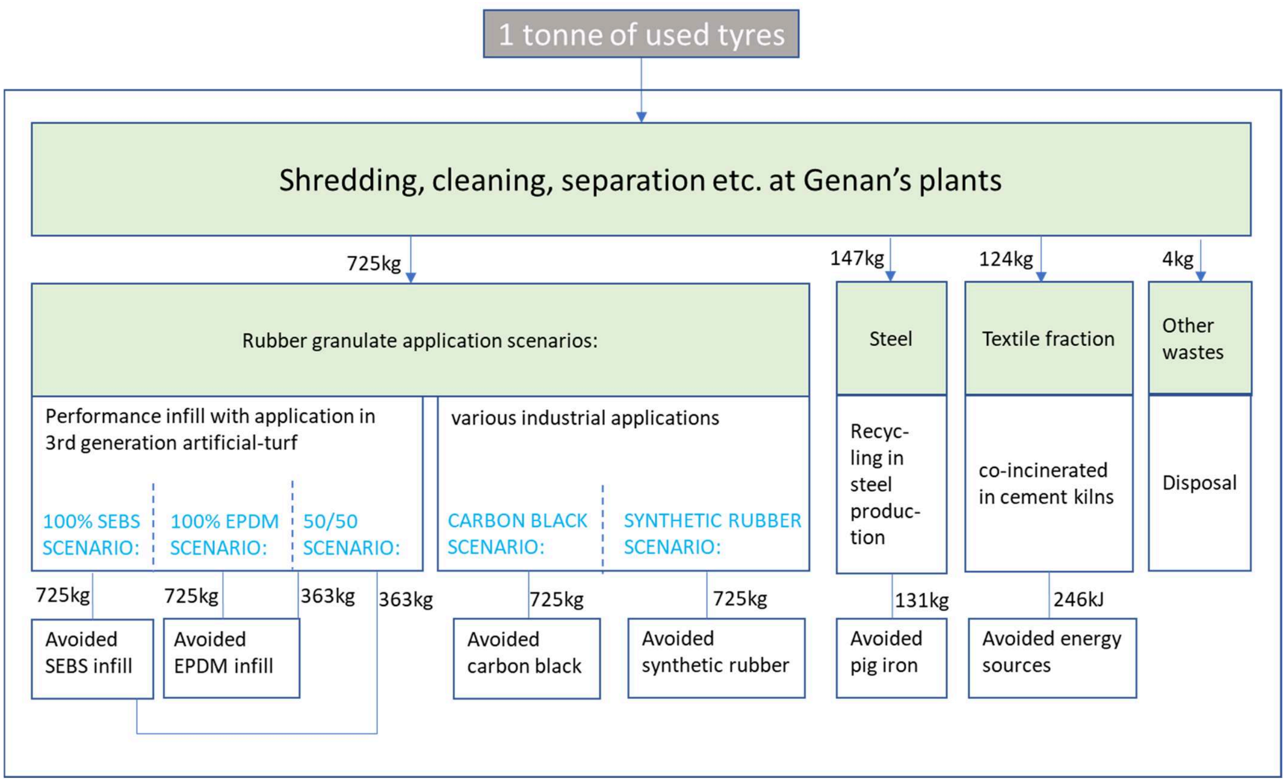

Figure 1.a System boundaries for material recycling methods. All infills are incinerated after dismantling of artificial turfs. (SEBS is styrene ethene butene styrene copolymer, EPDM is ethylene propylene diene monomer)

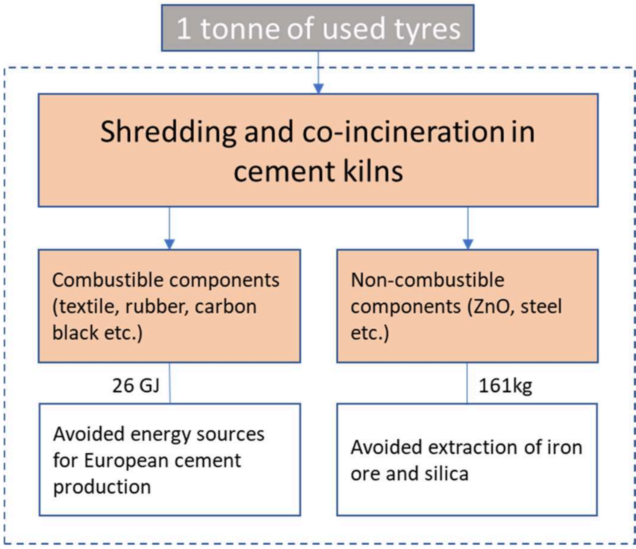

Figure 1.b System boundaries for co-incineration method

Main results – material recycling for infill vs. co-incineration

The potential environmental impacts identified in an LCA are assessed by calculating the results for a broad range of impact categories. The impact categories investigated in the project are those included in the results in table 1 below. The corresponding characterization and normalization factors applied are EF 2.0.

The total results for each of the modelled scenarios are represented in Table 1 below. Numbers in green indicate that the value is lower than the corresponding value for the co-incineration scenario.

Table 1. Total life cycle results of material recycling (rubber used for infill) vs. co-incineration (green figures in the material recycling scenario indicate that the impacts are lower than the corresponding impact category in the co-incineration scenario).

IMPACT CATEGORY	Co-incineration	Material recycling (SEBS infill)	Material recycling (EPDM infill)	Material recycling (50/50 infill)
Climate change fossil (kg CO2-eq.)	-197	**-838**	**-972**	**-905**
Acidification terrestrial and freshwater (Mole of H+ eq.)	-0.801	**-2.61**	**-3.08**	**-2.84**
Eutrophication freshwater (kg P eq.)	-0.0039	0.000867	**-0.0136**	**-0.00635**
Eutrophication marine (kg N eq.)	-0.237	**-0.552**	**-0.648**	**-0.6**
Eutrophication terrestrial (Mole of N eq.)	-2.69	**-6.08**	**-9.48**	**-7.78**
Ozone depletion [kg CFC-11 eq.]	-3.37E-06	2.84E-06	-2.07E-6	3.83E-07
Photochemical ozone formation (kg NMVOC eq.)	-0.656	**-1.79**	**-2.12**	**-1.95**
Ionising radiation (kBq U235 eq.)	-3.15	**-204**	**-228**	**-216**
Respiratory inorganics (Disease incidences)	-4.38E-06	**-2.18E-05**	**-2.60E-05**	**-2.39E-05**
Ecotoxicity freshwater (CTUe)	26.6	**-8.59E+01**	**-1.35E+02**	**-110**
Cancer - human health (CTUh)	-1.46E-06	**-5.74E-06**	**-6.04E-06**	**-5.89E-06**
Non-cancer human health effects (CTUh)	4.99E-05	0.000103	9.10E-05	9.70E-05
Land Use (Pt)	-5.90E+02	**-4.18E+03**	**-5.18E+03**	**-4.68E+03**
Ressource use, energy carriers (MJ)	-1.02E+04	**-3.12E+04**	**-3.39E+04**	**-3.25E+04**
Ressource use, mineral and metals (kg Sb eq.)	-0.0000299	**-1.45E-04**	**-0.0501**	**-0.0251**
Water scarcity (m^3 world equiv.)	-12.6	**-8.18E+01**	**-8.62E+01**	**-84**

When comparing the material recycling scenarios (rubber used as performance infill) with each other, then the table above shows that all environmental impact categories are better when 100% EPDM[1] performance infill is replaced in comparison with the scenario where 100% SEBS[2] performance infill is replaced. However, for most of the impact categories the results are in the same order of magnitude. The 50/50% SEBS/EPDM infill scenario is, naturally, an average of the two other scenarios.

[1] Ethylene propylene diene monomer
[2] Styrene ethene butene styrene copolymer

The table also shows that material recycling has a lower impact in 14 out of 16 impact categories compared with co-incineration when the replacement infill scenarios are 100% EPDM or 50/50 SEBS/EPDM. The two exceptions are ozone depletion and non-cancer human health effects. The impact category for non-cancer human health effect is associated with a large degree of uncertainty in the underlying LCA method as is also the case for all the human and ecotoxicity impact categories. The results are similar when the replacement infill scenario is 100% SEBS except for the impact category eutrophication, which in this case is lower when the tyre treatment route is co-incineration. That means, that when the scenario is 100% SEBS, then only 13 out of 16 impact categories are lower for material recycling in comparison with co-incineration.

The potential climate change impact category is 76-80% lower in the material recycling system compared with the co-incineration system. Expressed in another way, the potential climate change benefit from the material recycling (infill) is 4.3 - 4.9 times greater in comparison with the potential benefit from the co-incineration of used tyres. The most favorable climate change results are obtained in the 100% EPDM scenario and the 50/50% EPDM/SEBS scenario is again in the middle of the two other infill scenarios.

While the material infill recycling treatment is better than co-incineration for most impacts, the co-incineration system also has net-negative values in most categories, which means that both treatment systems lead to significant savings in potential environmental impacts.

Normalization of main results – material recycling for infill vs. co-incineration

With the aim to further scrutinize and discuss the magnitude of the overall findings the results are normalized. It is noted, however, that normalization is not an integral part of the results and is according to ISO 14040 only an additional optional value judgement based on the LCA results. One of the reasons for this is that normalization factors are relatively uncertain.

Figure 2 below shows the normalized impacts for the material recycling method using rubber as infill (100% infill scenarios) in comparison with the co-incineration treatment method for used tyres. Here it is noted, that the least robust environmental impact categories are left out with the aim that the interpretation focuses on those impacts, which can be assessed with a higher degree of certainty.

For most impact categories the normalized impacts for the co-incineration system are higher than the normalized impacts for the material recycling system (infill) and for most impact categories it is a notable difference. One exception is ozone depletion, where the impacts are so small that they do not show in the graph. For the 100% SEBS infill scenario another exception applies for eutrophication freshwater, where the contribution to this impact is so small that it does not show in the graph.

The normalized values for climate change are the largest (most negative) and the savings on climate change in the material recycling system corresponds to more than 0.1 global persons contribution to climate change during one year for all material recycling performance infill scenarios. In comparison the co-incineration system saves less than 0.03 person equivalents in the climate change category.

It should be noted that the scale in Figure 2 below shows net-negative values !

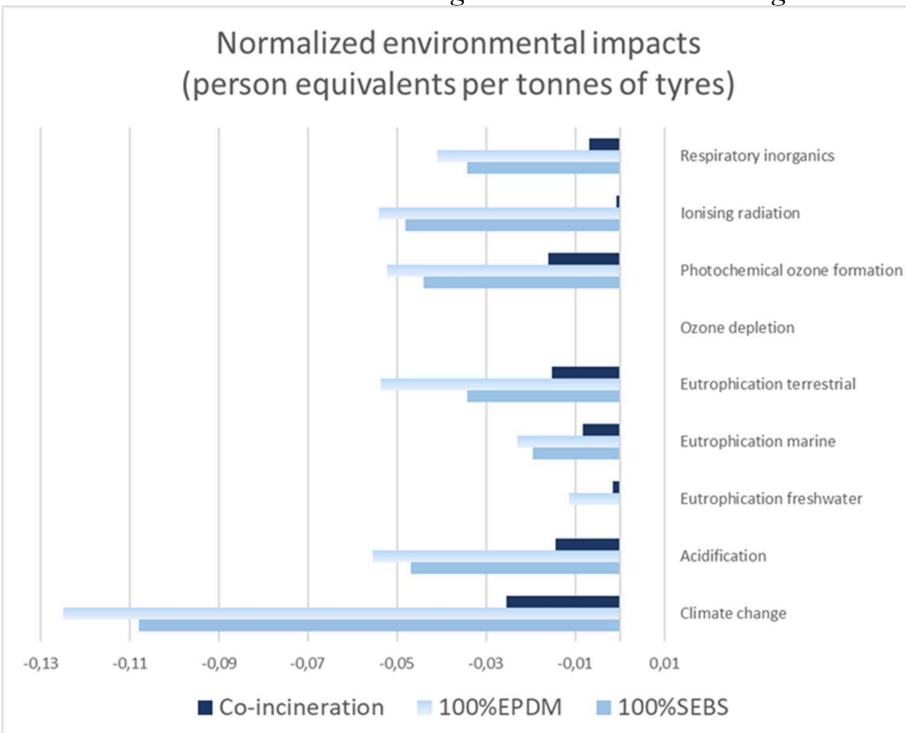

Figure 2. Normalized potential environmental impacts from different treatment options of one tonne of tyres – application of recycled rubber as infill

Results of cryogenic rubber scenarios:

For the tyre material recycling, where the recycled rubber in the form of cryogenic powder rubber replaces either carbon black or synthetic rubber, the results shows that material recycling has the lowest impact in 7-10 out of 16 impact categories in comparison with the co-incineration tyre treatment method. The potential climate change impact from the cryogenic scenarios is 7-10 times lower than when the tyres are treated with the co-incineration method.

Normalization of the results of the cryogenic rubber scenarios:

With the aim to further scrutinize and discuss the magnitude of the overall findings the results are normalized. It is noted, however, that normalization is not an integral part of the results and is according to ISO 14040 only an LCA step. One of the reasons for this is that normalization factors are relatively uncertain.

The normalized results of the cryogenic scenarios are shown in Figure 3 below. The impact category, which shows the greatest (net-negative) contribution to the person equivalents is climate change and, for the scenario where carbon black is replaced, also respiratory inorganics. For both cryogenic scenarios, the contribution to climate changes is 7-10 times lower in comparison with the co-incineration treatment method.

It should be noted that the scale in Figure 3 *below shows net-negative values !*

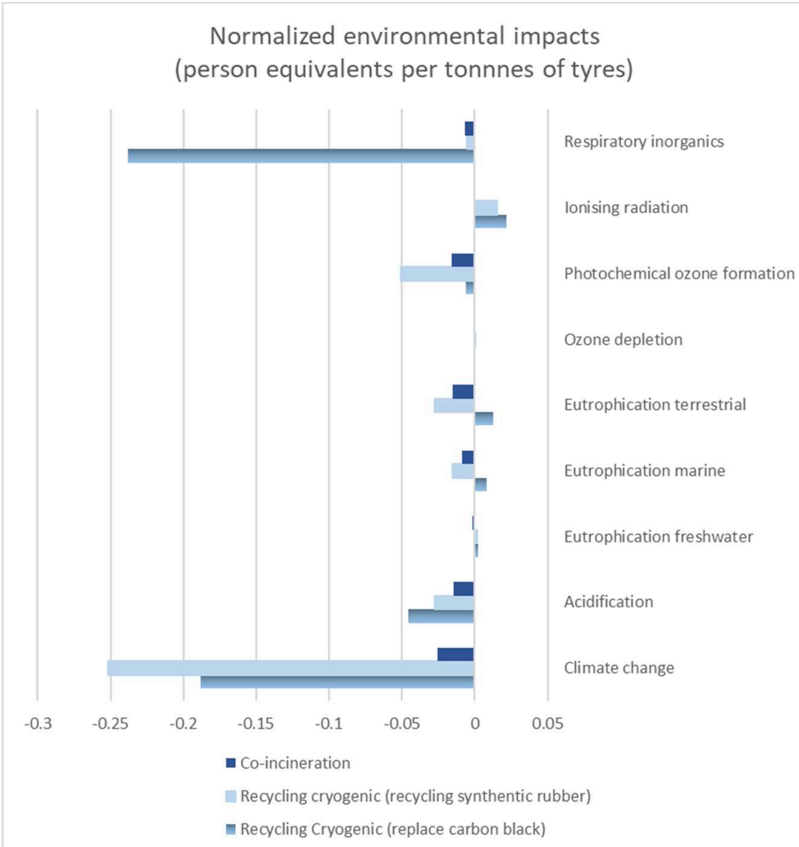

Figure 3. Normalized potential environmental impacts from different treatment options of one tonne of tyres – applications of recycled cryogenic rubber

Main assumptions

As in any LCA, the quantification of environmental impacts relies on a number of qualified assumptions, which must be transparently communicated in the LCA report. This is an inherent part of an LCA, and it is common that conclusions are highly dependent on some of those assumptions. In order to check the robustness of the conclusions, the most important assumptions are tested in a sensitivity analysis. In this LCA several assumptions were made in the favor of the co-incineration treatment method for used tyres. The reason for this is to ensure that material recycling is not unduly favored over co-incineration as the study commissioner Genan material-recycle tyres. These assumptions can thus be considered to be conservative. The main conservative assumptions made in this LCA (in favor of co-incineration) are:

- The assumption that recycled tyre rubber from Genan replaces virgin infills in a ratio of 1:1 on a weight basis: This assumption is considered to be conservative mainly because of the following aspects:
    - The refill quantity required for maintenance of the fields during the life time of the fields is in reality expected to be greater for virgin infills due to the higher content of rubber in End of Life Tyres (ELT) rubber infill
    - The life time of the fields may in reality be longer for ELT rubber in comparison with virgin infill, due to quality characteristics

- No recycling is assumed for any of the infill materials at the end-of-life of the artificial sports turfs. Based on the information gathered in this study, the authors consider it more likely that ELT infill will be recycled into valuable applications in comparison with virgin infills. This is particularly relevant when considering the environmental implications in the longer run as recycling may be expected to become more widespread.

- The share of waste fuels used for co-incineration influences the assumed replacement of fuels in the co-incineration treatment method. The replacement of waste fuels is a key assumption, which in this study is based on a European average. For this reason, a sensitivity assessment was carried out. This showed, that if the share of waste fuels were higher, then the potential environmental impacts from the co-incineration treatment method would generally also be higher. This is the case in Germany, where they have a large cement production sector. In this context it is highlighted, however, that some European countries also have a lower share of waste fuel inputs in comparison with the European average. For details about which fuels were assumed to be replaced see Table 14 the second column.

The sensitivity assessment includes calculations for a scenario, where landfilling of infill materials are assumed at the end-of-life. The ratio of primary iron sources for steel production and for co-incineration was also tested in the sensitivity analysis.

None of the sensitivity assessments carried out changes the overall conclusions in the LCA study and thus the sensitivity assessment demonstrates that the influence of the assumptions on the results is not decisive. The majority of the results are consistently in favor of the material recycling method, where the rubber is used as performance infill for artificial-turf football pitches, when compared with co-incineration of the used tyres. Two exceptions are ozone depletion and non-cancer human health effects which are lower for co-incineration. In the SEBS infill scenario the eutrophication freshwater is also lower for co-incineration.