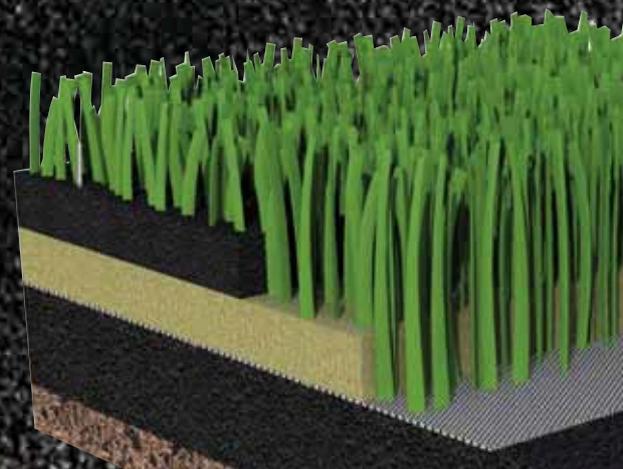


Comparative life cycle assessment of two options for waste tyre treatment: material recycling vs. co-incineration in cement kilns

Executive summary





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Executive summary

This life cycle assessment (LCA) study investigates two treatment options for used tyres: material recycling where rubber granulate from all tyres is used partly for modification of asphalt and bitumen and partly for infill in artificial turf and co-incineration where all tyres are incinerated in cement kilns. The study compares nine different environmental impact categories for each treatment option, and it concludes that in all nine impact categories material recycling as an end-of-life treatment option for tyres provides a larger environmental benefit than co-incineration. The difference between the two options is judged to be significant in most impact categories, the only exception being that the reduction in consumption of iron ore is similar for the two end-of-life routes. The results demonstrate that applications of used tyres substituting virgin rubber and using rubber's properties are environmentally superior to co-incineration.

Two methodological variants of LCA, the consequential approach and the attributional approach, were used in parallel. The consequential approach was used as the baseline scenario for both treatment options. The results as presented in the report refer to one tonne of used tyres as the functional unit. Taking total annual tyre generation of Germany of 650,000 tonnes per year as an example, the difference between the two treatment options corresponds to e.g. 70,000 person equivalents with respect to global warming potential, 103,000 person equivalents with respect to energy demand, and 96,000 person equivalents with respect to acidification. There are also savings in the other environmental impacts categories examined (no trade-offs), and calculations based on the attributional approach to LCA show even larger benefits from recycling.

The baseline scenario assumes that used tyres would eventually be replaced by fossil fuels (coal and lignite) in cement kilns. Cement kilns already use fossil fuel and waste for incineration, and in the event that the tyre component is replaced by waste, the material recycling option provides even further environmental benefit.

The study has been commissioned by the Danish waste tyre handling company of Genan Business & Development A/S and carried out by a team from the Copenhagen Resource Institute, FORCE Technology (Denmark), and the German IFEU Institute in Heidelberg. It was carried out according to the ISO standards 14040 and 14044 and was peer reviewed by an independent, international team of three experts led by Gaiker, a Spanish Technology Centre.

Background

The waste hierarchy presented in the EU Waste Directive provides a rule of thumb for the priority treatment of waste. The hierarchy identifies as a general rule material recycling as being better for the environment than energy recovery and pinpoints landfilling as the most environmentally damaging end-of-life option. A wide array of waste streams such as used tyres, animal fat and meal, textiles, waste from the wood and paper industry, or plastics were landfilled in many EU Member States just a decade ago. An EU ban on the landfilling of tyres, which entered into force in 2006, has sparked a debate on which of the alternative treatment options for used tyres is the most environmentally beneficial.

When comparing the benefits of incineration with those of recycling of waste, it is difficult to draw a definitive cross-sector conclusion. A number of LCAs have been carried out in recent years to compare incineration in cement kilns to recycling of different waste streams, including paper, sewage sludge, waste oils, and plastics. These studies indicate that if the recycling process has a relatively high energy and/or material demand, and the recycled material does not substitute a valuable virgin material sufficiently, it is likely that a cement kiln is more environmentally effective.

Life cycle assessment method

LCA is a methodology used to identify the environmental impacts related to a product, service or system from a holistic standpoint that incorporates all known potential environmental impacts and follows the product, service or system from "cradle to grave". The life cycle includes all known processes in the stages of extraction of raw materials, production, use and disposal. This type of holistic analysis has gained increasing interest within the EU and "life cycle thinking" has become an integral part of many strategies and regulations within waste management.

The LCA method is described in the ISO standards 14040 and 14044. An LCA study consists of four phases (figure A). The main purposes of the goal and scope definition phase are to clarify the purpose of the study, what it can and cannot be used for, the product system studied and its boundaries. In the inventory analysis phase, data on the inputs and outputs of the processes included in the system are collected or calculated. On the basis of this inventory, the potential environmental impacts are assessed and finally the results are interpreted. Carrying out an LCA is by definition an iterative process.

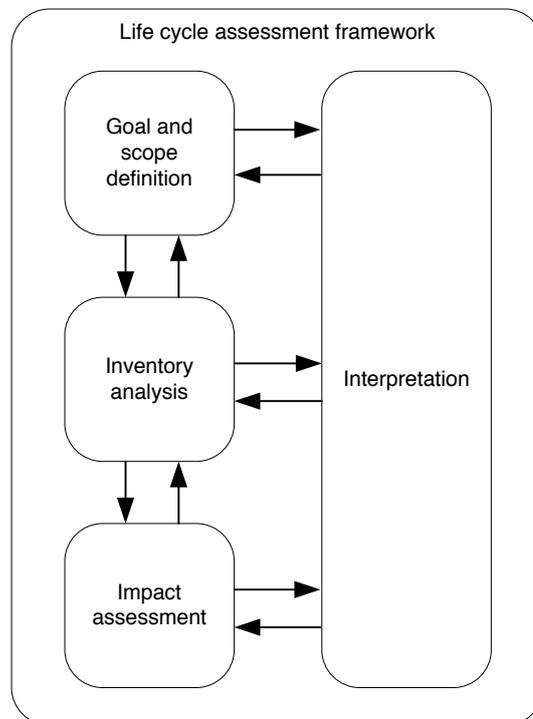


Figure A. Phases of an LCA (ISO, 2006)

LCA is increasingly being used as a decision-support tool, and the application of the method has shifted from scenarios examining the current situation to those examining the consequences of change. The former is called "attributorial" LCA and includes average data on each unit process within the whole life cycle. The latter, called "consequential" LCA, focuses on examining all known consequences of a change, including unit processes that are significantly affected by the change, irrespective of whether they are within or outside the life cycle.

The practical application of LCA may be placed along a continuum from strictly consequential to strictly attributorial, and both approaches are accepted within the ISO LCA standards. The consequential approach is best suited for studies comparing two products or processes. Since the present study is a comparative LCA, the consequential approach has been the primary focus. The attributorial approach is, however, still practiced internationally, also for comparative studies. In order to gain a wider acceptance of the results of this study, the attributorial approach has been used in parallel as a

control. Detailed information on the two approaches and a discussion of the differences in results are included in the study.

Scope of study

This study compares co-incineration of tyres as a source of energy and iron in cement kilns with recycling of tyres for use as an ingredient in rubber asphalt (fine fraction < 1.4 mm) and for use as an infill in artificial turf (> 1.4 mm) (figure B). In the material recycling process, the tyres are shredded and the textile and steel fractions are separated. The remaining rubber is granulated before use in modified bitumen for asphalt and as an infill. The textile fraction is incinerated in a cement kiln and the steel fraction is recycled. By recycling, several processes such as production of synthetic rubber are avoided.

In the co-incineration process, whole or shredded tyres are fed into the cement kiln and incinerated. This not only provides a source of energy, but iron from the steel component of tyres also contributes to the process. By co-incineration, energy production from other fuels and extraction of iron ore are avoided.

A change from co-incineration to recycling implies an increased demand for other fuels and iron ore in the co-incineration route, whereas the emissions occurring from incineration of tyres are avoided.

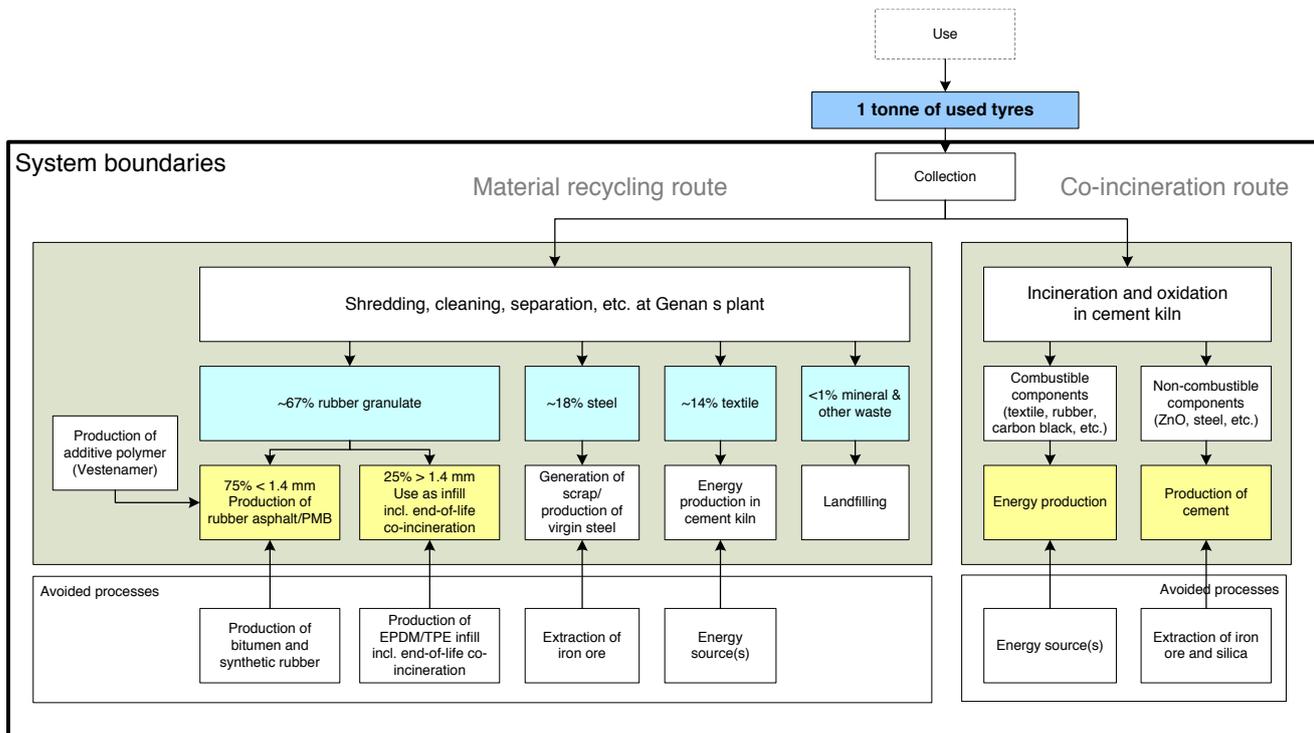


Figure B. The studied system and its boundaries

Two scenarios were investigated; a short-term (2010) scenario, which among other things uses current technology and energy sources, and a long-term scenario (2020), which uses projections of technology, energy sources, treatment volumes and effects of scale. The geographical scope of the study is Europe, which is modelled using a representative recycling plant and a cement kiln situated in Germany.

LCA is a holistic methodology that allows the investigation of environmental impacts and resource use caused by each of the processes that are part of the two tyre treatment options. LCA takes into account the substitution of other materials (bitumen, polymer) that would be used in rubber asphalt and as an infill if the tyres were not recycled, or the energy sources that would be used in a cement kiln if tyres were not used as a fuel.

The environmental impacts identified in an LCA are assessed by calculating the results for a broad range of impact categories. The results are always expressed as *potential* impacts since the *actual* impact from, for example, emissions of CO₂, can only be quantified exactly if and when it actually happens. In this study, the environmental impact categories covered are:

- Global warming potential expressed in kg CO₂-equivalents. Greenhouse gases such as carbon dioxide and methane can cause climate change.
- Acidification potential expressed as g SO₂-equivalents. Acids and compounds that can be converted to acids emitted to the atmosphere can cause regional damage to ecosystems as a result of acid rain.
- Nutrifaction potential in water expressed as g PO₄-equivalents. Nitrogen and phosphor can lead to nutrient enrichment of ecosystems. In water, this entails increased algae growth which can eventually result in damaged ecosystems.
- Nutrifaction potential in soil expressed as g PO₄-equivalents. Nitrogen and phosphor can lead to nutrient enrichment of ecosystems. In soil, this may entail that low-nutrient eco-systems disappear.
- Toxicity potential (carcinogenic risk) expressed as mg arsenic equivalents. Chemical substances can cause cancer in humans and animals.
- Toxicity potential (acute human toxicity: PM10¹) expressed as g PM10-equivalents. Small dust particles can cause respiratory diseases.
- Photochemical ozone creation potential expressed as g ethylene equivalents. Solvents and other volatile organic compounds react with nitrous oxides and form smog which is detrimental to human health as well as ecosystems.

Furthermore, two indicators are used to describe the use of resources:

- Cumulative energy demand (balance of fossil fuel use) expressed in GJ.
- Non-energy resource depletion expressed in kg of iron ore (since only iron is of significant relevance in this study).

The impact within each category is calculated for both recycling and co-incineration using information on the inputs and outputs of each process included in the analysed system. All impacts are expressed per tonne of tyres.

Results

The results for the long-term scenario using the consequential approach are shown below (Table A). It is noted that the calculation excludes the environmental impacts from production and use of tyres, which are equal for both systems. The negative values, found for both treatment routes, thus indicate that impacts are avoided or – in other words – that both treatment options provide benefits for the environment. Hence, larger negative values are better in environmental terms.

It is obvious from Table A that material recycling gives larger benefits for the environment than co-incineration in all examined impact categories. The differences are very large in important impact categories such as global warming potential, energy demand and acidification. However, the difference is insignificant with respect to mineral resource (iron ore) consumption, and for impact categories such as nutrifaction the difference is virtually without importance as can be seen from the results in Figure C. Where uncertainties are known to exist, they have been subject to a thorough uncertainty analysis.

¹ Particulate matter with a diameter of less than 10 micrometers

Table A. Results from the short and long-term scenarios using the consequential approach

Impact category (units per tonne of tyres)	Short term		Long term	
	Co- incineration	Material recycling	Co- incineration	Material recycling
Global warming potential (kg CO ₂ -eq.)	-796	-1922	-792	-1892
Fossil fuel (GJ)	-27	-50	-27	-49
Iron ore (kg)	-398	-400	-398	-399
Acidification potential (g SO ₂ -eq.)	-1561	-6804	-1555	-6744
Nutrication potential, soil (g PO ₄ -eq.)	-103	-411	-103	-420
Nutrication potential, water (g PO ₄ -eq.)	-0.001	-18	0.0003	-19
Carcinogenic risk potential (mg As-eq.)	-26	-1255	-26	-1235
PM10 (g PM10-eq.)	-1999	-5871	-1995	-5875
Photochemical ozone creation potential (g ethylene-eq.)	-49	-4737	-49	-4740

There are no significant differences between the short and long-term analyses across the nine impact categories. It appears that the benefits from recycling will be reduced slightly, by less than 5%, over the next 10 years, but this change is probably not larger than the general uncertainty of the results. The results for co-incineration only change marginally from the short-term to the long-term scenario, and these changes are also seen as insignificant. Therefore, the main conclusion from the baseline scenarios is that material recycling appears as the better treatment option in both the short and the long term. The finding is consistent, since there are no trade-offs in any of the examined impact categories. Furthermore, changes in production with respect to the distribution on granulate sizes would not alter the main conclusions.

The two figures below (figures C and D) graphically summarise the results of the comparison. The units used are *person equivalents*, expressing total impact of the treatment of one tonne of tyres relative to the impact caused by one person in one year. For global warming, the reference is emissions per capita in Western Europe, whereas Germany is used as a reference for the remaining impact categories.

Figure C shows that all impact indicators are, to different degrees, in favour of recycling, except the iron ore resources indicator, which gives almost identical results for co-incineration and material recycling. With respect to nutrication potential in water it can be seen that the savings for both treatment options are without any practical importance.

Figure D shows the net difference between co-incineration and recycling. Note that negative values mean net environmental benefits. The figure shows that the differences in most impact categories are significant, and that the results are consistent in both the short and long-term scenarios.

The results indicate the magnitude of the savings if tyres are subjected to recycling instead of co-incineration. Disregarding mineral resource use and nutrication potential in water, where recycling has a negligible advantage, the results show that between 0.07 and 0.31 person equivalents are saved per tonne of tyres being recycled and not incinerated. If the 650,000 tonnes of waste tyres generated each year in Germany are subjected to recycling instead of incineration it would result in annual potential savings of between 40,000 and 200,000 person equivalents, again depending on impact category.

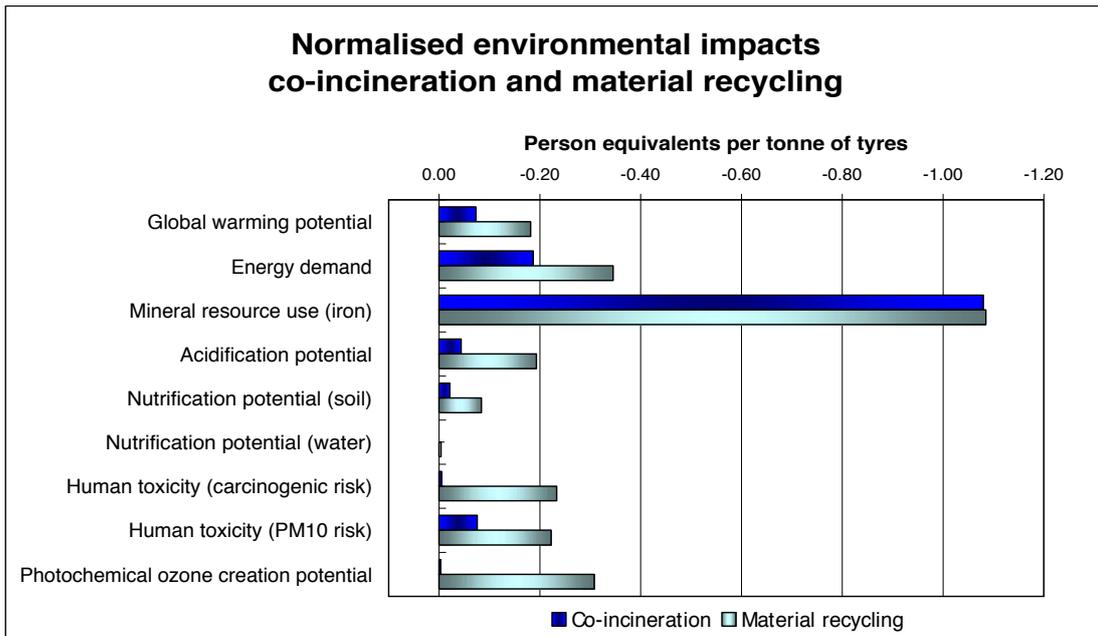


Figure C. Potential environmental savings from co-incineration and recycling in person equivalents per tonne of tyres (short-term, consequential approach)

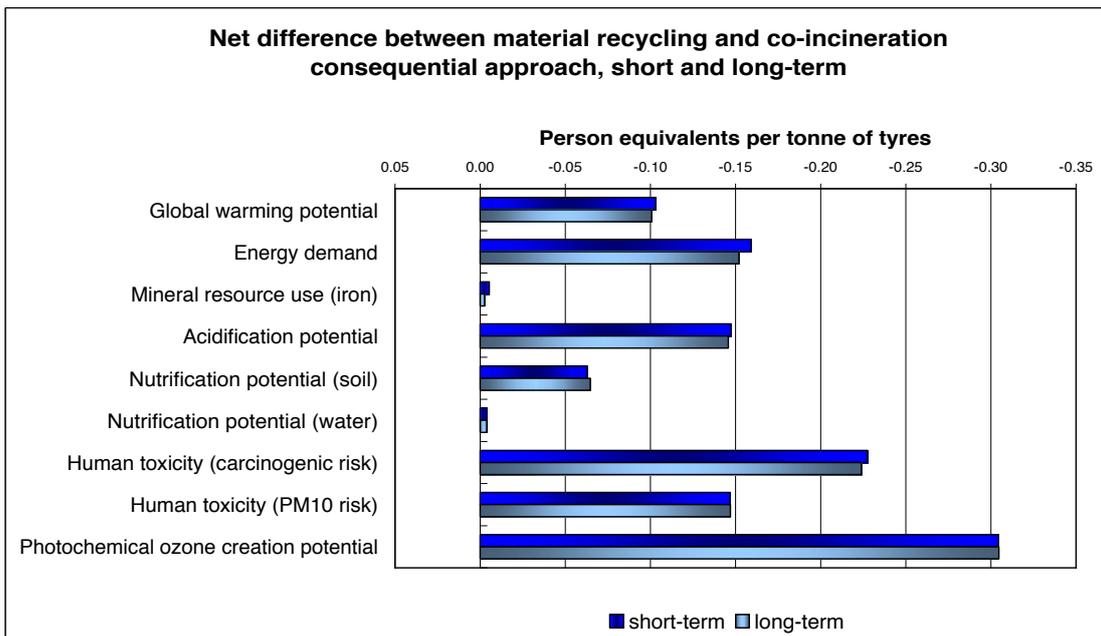


Figure D. Savings from material recycling instead of co-incineration in person equivalents per tonne of tyres

Main assumptions

As in any LCA, the quantification of environmental impacts is only possible by making a series of qualified assumptions. 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 to the assumptions made, the assumptions are presented transparently and the most important ones have been tested thoroughly parameter by parameter in a sensitivity analysis.

A previous study for Genan showed that the results are applicable to wet-processing for making rubber asphalt, but they are not fully consistent for dry processing, because sand or gravel and not bitumen are substituted (Villanueva *et. al*, 2008). This finding is not changed by the present study.

Another important assumption is related to modelling of the energy source substituted by used tyres in cement kilns. In the previous study it was assumed that coal is substituted in the short term and lignite in the long term, thereby giving less benefits for co-incineration. In the present study, we have assumed that 50/50 of hard coal and lignite are substituted in both the short and long term, and therefore there are only small differences between the scenarios.

Substitution of waste is not as beneficial as substitution of coal and lignite in the cement co-incineration route, and it will therefore make recycling stand out even better as a treatment option. If on a short-term basis using the consequential approach scrap tyres are completely substituted by animal meal or waste plastics as a fuel in cement kilns, it is estimated that 2.6 tonnes of CO₂-equivalents are saved per tonne of scrap tyres in the recycling scenario compared to the co-incineration scenario. In a country like Germany where 650,000 tonnes of scrap tyres are generated every year, the full consequence of such a substitution would amount to an estimated yearly Global Warming Potential effect of 1,690,000 tonnes of CO₂-equivalents, equal to the total greenhouse gas emissions of approximately 155,000 Germans.

A sensitivity analysis showed that the overall benefits from material recycling only depend on the size of the granulate fractions to a limited extent. Thus, the benefits in global warming potential vary from 1,684 to 2,034 kg CO₂-equivalents per tonne of tyres, if the fine fraction is between 25% and 100% of the output. Most of the other environmental impacts examined in the study show a similar picture. In comparison, co-incineration only gives a benefit of about 800 kg CO₂-equivalents per tonne, and the main reason for this difference is that both the fine and the slightly coarser fraction are used in applications where they substitute virgin polymers. The main reason that the fine fraction gives relatively higher benefit is that more virgin rubber is substituted, when the granulate is used in asphalt than in the use as an infill.

This study is largely based on German and Danish data. However, an analysis of the sensitivity of the results to geography-dependent processes has proved that the results can be considered robust and valid at a European level.

When it comes to the use of LCA approaches, the two methodology variants, *consequential* and *attributorial*, have been tested in parallel. The consequential approach has been chosen for the baseline scenario, and the conclusions presented above refer to this scenario. However, the calculations based on the attributorial approach proved to be even more beneficial to recycling.

The differences observed in the results underline the advantage of using a broad scope when carrying out comparative LCAs. In such cases, covering both approaches ensures that the results can be compared and analysed from both sides of the basic discussion of which approach is the better – consequential or attributorial. The results in the present study show that the same conclusions are reached in both approaches, and this evidently adds to the credibility of the study and the robustness of the results.

