LIFE CYCLE ASSESSMENT OF 9 RECOVERY METHODS FOR END-OF-LIFE TYRES

Reference document

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R&D Aliapur

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Using the present report

Aliapur asked PricewaterhouseCoopers Advisory's Sustainable Development Department to carry out an environmental assessment of the various recovery methods for end-of-life used tyres (ELT). The assessment was carried out by PricewaterhouseCoopers Advisory as part of the November 2008 commission.

The present document is a summary of the complete report, entitled, "Life Cycle Assessment of the various recovery methods for used tyres".

PwC Advisory assumes no responsibility in relation to any third party to whom the assessment may have been divulged or whom it may have reached; such persons shall take responsibility for the use of this report.

PwC Advisory and Aliapur remind the reader that the results presented in this assessment are based solely on the facts, circumstances and hypotheses reported during the assessment. If these facts, circumstances or hypotheses differ, the results are likely to change.

Furthermore, it is essential that the results be considered in their entirety, with regard to the hypotheses which have been made, and not separately.

Should you wish to have access to the full report, including the detailed results and comments from the critical review panel, please make a written request directly to Aliapur.

Document written with the assistance of

PRICEWATERHOUSECOOPERS ECOBILAN

SECTION I - Introduction

Aliapur was founded in 2002 by tyre manufacturers as a means of providing a collective response to the regulatory obligations in force in France with regard to the management of used tyres.

From 2004, Aliapur implemented a major industrial research programme to support the development and optimisation of long term, and diverse, recovery possibilities.

The recovery of used tyres is the result of these various types of research, and is now diversified into a wide range of methods:

- Re-use/retreading: extending the lifespan of tyres and delaying non reusable used tyre status
- Energy recovery in cement works or urban heating
- Material recycling of the carbon and iron in used tyres in steelworks or foundries
- Recovery in public works for the construction of drainage basins or retention basins
- Recovery of used tyre granulates in the manufacture of moulded objects, synthetic turf or equestrian floors

At a time when several used tyre recovery methods have achieved a certain maturity, Aliapur decided to carry out a comparative environmental evaluation of the various recovery alternatives.

In addition to comparing the different alternatives, this environmental evaluation aimed at identifying the strengths and weaknesses of each recovery method, and of the management of used tyres as a whole.

This evaluation was based on the Life Cycle Assessment approach and conformed to the methodological prescriptions developed in the ISO 14 040 and ISO 14 044 standards. It was carried out by PricewaterhouseCoopers Ecobilan, a consulting firm specialising in life cycle assessments, and was reviewed by a committee of European LCA experts and interested parties.

The study was conducted over an entire business year. The year 2008 was chosen as reference because it was representative of Aliapur's current and future activities (300,309 tonnes of tyres collected and recovered in 2008).

A few key figures:

- 140,000 collection orders in 2008 representing the 300,309 tonnes of collected tyres
- Collection made from 40,000 collection points throughout the country, and delivered to 90 sorting centres
- 11 transformation sites: grouping together and preparing recovery (shredding...)
- 27 recoverers, situated essentially in France, but also in Sweden (urban heating), Morocco (cement works) and Finland (public works).

Nine recovery methods that are representative of the field were studied:

- Four so-called “destructive” methods: cement works, foundries, steelworks and urban heating.
- Five “non destructive” recovery methods: retention basins, infiltration basins, moulded objects, synthetic turfs and equestrian floors.

An international critical review committee

An international committee composed of seven verifiers analysed the methodological choices and validity of both the data used and the results of the study.

- Henri Lecouls, Life Cycle Assessment expert and committee coordinator
- Jacky Bonnemains from the environmental association, “Robin des Bois”
- Guy Castelan from Plastics Europe
- Walter Klöpffer from the International Journal of Life Cycle Assessment
- Didier Laffaire from the ATILH (Technical Association for the Hydraulic Binders Industry)
- Lars-Gunnar Lindfors from IVL (Swedish Environmental Research Institute)
- Jean-Sébastien Thomas from the Arcelor Mittal Group

The critical review report, dated 21 November 2009, was published in its entirety in the full report of this assessment.

The comments made in the course of the critical review resulted in particular in:

- better distinguishing the destructive recovery methods from the non destructive methods
- presenting the references of the toxicology tests conducted by Aliapur
- doing a sensitivity analysis for the allocation of material energy
- better justifying the life spans of floors for sports use
- clarifying the foundry process model

Fundamental discussions also focused on the boundaries between systems, and, more particularly, on the end-of-life period for non destructive recovery of ELT.

SECTION II – The methodology

1. The system studied and the functional unit

The diagram below presents the various stages involved in the nine ELT recovery methods studied. They were all taken into account in this assessment. Also shown are the "traditional" products that ELT replace.

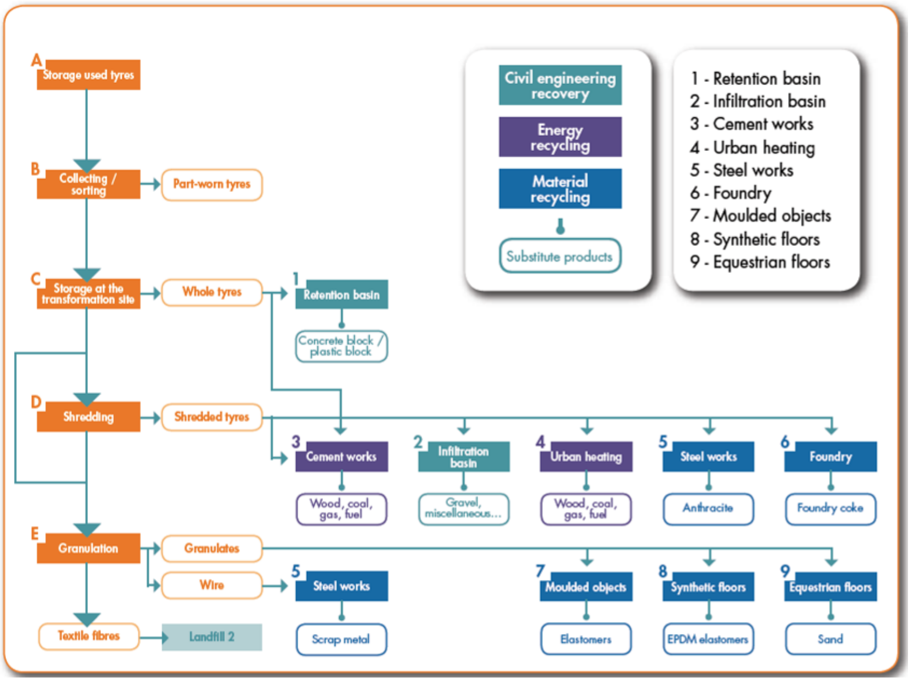

Figure 1: Diagram of the various ELT recovery methods studied

For all the recovery methods, **the environmental impact was calculated for a given provided service:**

"recovering one tonne of used, end-of-life used tyres from a collection point"

2. Eight characteristic environmental indicators

Eight indicators acknowledged in the field of Life Cycle Assessment were calculated. They form a set of indicators that are sufficiently complete to be able to satisfy the aims of the study:

- Total primary energy consumption
- Consumption of non renewable resources
- Water consumption
- Contribution to eutrophication[1]
- Emissions of greenhouse gas of fossil origin (direct, 100 years)

[1] The eutrophication of an aqueous milieu is characterised by the introduction of nutrients, in the form of nitrogen compounds or phosphates, for example, leading to a proliferation of algae and the asphyxia of the aquatic milieu.

- Tropospheric ozone formation[2]
- Acidifying gas emissions
- Generation of non dangerous waste

Assessment of the toxic and ecotoxic effects is presented in chapter 5 below.

3. Avoided impacts method

The assessment method was based on the methodological principles of Life Cycle Assessment and those that are used for reference in studies on household waste management.

The environmental review of the various ELT recovery methods was thus established for each environmental indicator by adding:

- The direct generated impacts by the stages needed for the recovery of the tyres: collection of the ELT, as well as the recovery stage in itself
- The avoided impacts through replacing the “traditional” products with ELT.

As the aim was to compare two solutions, one traditional method and one ELT-based alternative method, none of the stages that were identical for the two solutions being compared were taken into account given that they did not provide any differentiation.

As an example, in the case of cement works, using tyres as a replacement for traditional fuels makes it possible to:

- Avoid the extraction and preparation stages needed for these traditional fuels, the supply process for these traditional fuels and the shredding of solid fuels;
- Replace the fossil-origin CO2 emissions caused by the combustion of the traditional fuels with fossil-origin and biomass CO2 caused by the combustion of used tyres;
- Recover the steel contained in the ELT.

4. Allocation of the material energy contained in tyres

Used tyres contain material energy which is available for use in its thermal form, as expressed through its NCV (net calorific value). As this feedstock energy was initially obtained from the environment, it is necessary to determine to whom this consumption should be allocated.

End-of-life tyres have the status of waste according to the current regulations. In this study, it was considered that the consumption of feedstock energy should be attributed to those who transferred the tyre from a status of product to that of waste.

Used tyres thus have a very real potential – their NCV – which is considered to be free from the point of view of environmental accounting for the stages following this abandonment.

The critical review committee drew attention to the importance of choosing this allocation method, which necessarily had an influence on the results for the “total primary energy consumption” indicator. As a result, a sensitivity analysis was carried out, taking into account the following scenario: 50% of the feedstock energy consumption from the tyres was allocated to those abandoning the tyres, the remaining 50% to the ELT recovery method (see Section IV).

[2] Under certain climatic conditions, the atmospheric emissions of industries and transport can react in a complex manner with the effect of sun light, leading to the formation of photochemical smog. A chain of reactions involving volatile organic compounds and nitrogen oxides results in the formation of ozone, a super oxidising compound.

5. Evaluating toxic and eco-toxic impacts and other prior studies carried out by Aliapur

Evaluating the toxic and eco-toxic impacts of the sensitive stages of ELT recovery was done upstream of this study. Aliapur conducted a wide range of experiments with the aim of evaluating the toxic and eco-toxic impact that could be associated with certain key stages of the recovery methods for synthetic turf, retention basins and infiltration basins.

Rather than apply the toxicity and eco-toxicity indicators used in the context of life cycle assessments (which are usually not considered very solid) as a means of taking into account the potential toxicity or eco-toxicity associated with the various recovery methods studied, we decided it was more relevant to provide a reminder below of the main results of the experiments conducted by Aliapur. The critical review committee accepted this presentation of toxic and eco-toxic effects.

a) Synthetic turf

Aliapur carried out trials to evaluate ELT-based synthetic turf from the point of view of its leaching and emissions into the atmosphere:

- Leaching tests on complete (fibres, sand, glues and filling materials) synthetic turf systems (EPDM, ELT);
- Physical and chemical characterisation of the leachates;
- Eco-toxic tests on the leachates;
- Measurement of the emissions into the air of VOC and formaldehyde. In addition, these measurements made it possible to carry out INERIS health studies in accordance with several typical exposure scenarios.

The tested floors were comparable from the point of view of these various indicators and the eco-toxic tests that were carried out did not reveal any eco-toxicity in the leachates. VOC emissions were a little higher for EPDM surfaces than for those based on ELT.

A summary of this trial can be consulted at the following address:
http://www.aliapur.fr/media/files/RetD_new/Plaquette_gazon_synthetique.pdf

b) Retention basins and infiltration basins

Recovering ELT in retention basins has been the subject of many very advanced studies by Aliapur. These studies were conducted by the EEDEMS scientific group. They consist in carrying out *in situ* experiments with long term monitoring of leaching, chemical characterisation of the leachates and eco-toxicity tests (NF EN ISO 6341 daphnia test, NF EN ISO 17512-1 earthworm test, NF T90-375 algae test and the NF X31-201 barley test) on these same leachates. In order to reproduce the effects of regular watering of green spaces with this synthetic turf, tests were also conducted more in the long term on terrestrial plant species of the Ray Grass type.

None of these tests revealed any problems that could be assimilated with contamination of the water with which the ELT come into contact:

- From a physical and chemical characterisation point of view, the analysis of the results shows that the various substances that were screened for (metals, hydrocarbons, etc.) remained at concentrations lower than the threshold values for the legal references and less than the lower threshold values for the drinkability of water.

- The eco-toxic tests did not reveal any toxicity of the water in the retention basin in either the short or medium term.
- The tests conducted on the turf did not reveal any impact on germination or growth.

Additional information concerning these studies can be consulted at the following address:

http://www.aliapur.fr/modules/movie/scenes/home/index.php?fuseAction=page&rubric=MotsClesApplications&article=ApplicationsBassinsRetention&FUSEBOX_LANG=2

c) Equestrian floors

With regard to equestrian floors, measurement of the particles in the air took place in the course of tests carried out on ELT granulate-based equestrian floors; these measurements were made by means of a laser system.

These measurements made it possible to show that one of the main advantages of equestrian floors made from ELT granulates is that this type of floor produces less dust in the air than traditional floors made from sand (in addition, sand has a tendency to disintegrate under the effects of the hammering it receives from the horses' hooves, producing large amounts of dust and resulting in a frequent need for watering to prevent the formation of dust clouds).

6. Becoming end-of-life products

Fundamental discussions with the critical review committee focused on the boundaries of the studied systems, and, more particularly, on the end-of-life period for non destructive recovery of ELT.

The verifiers consider that the end-of-life period for non destructive recovery should have been taken into account. Furthermore, they believe that, as this has not been taken into account, the destructive recovery methods cannot be compared to the non destructive methods and that they should thus have been the subject of separate comparisons.

The authors of the study explain that the decision to not take into account the end-of-life period of the non destructive methods was based on the fact that:

- The functional unit focused on the recovery of one tonne of ELT and not on the destruction of one tonne of ELT;
- The accounting done in the context of the environmental studies on the management of household waste never takes into account the end-of-life step of non destructive recovery methods. The environmental assessment associated to the recycling of PET bottles in the form of polar fibers does not take into account the end-of-life step of polar fiber products. In this context, the recovery methods using incineration with energy recovery are compared to recycling recovery methods;
- Taking into account the end-of-life step, which would combine the dismantling/sorting operations and energy recovery from the tyres, would probably lead to improved results. The accounting option that was calculated thus corresponds to a conservative hypothesis.

The authors of the study are in agreement with the critical review committee on recommendations for a research programme to be set up, focusing on the end-of-life period for non destructive recovery methods.

SECTION III – Panorama of the results and conclusions

1. Existence of an environmental benefit for most of the studied recovery methods

Overall environmental review =

[Generated impacts by the stages necessary for the recovery of the ELT] – [Avoided impacts (replacing the "traditional" products with ELT)]

Environmental review / Indicators	Synthetic turf	Moulded object	Cement works	Steelworks	Urban heating	Equestrian floor	Retention basin	Infiltration basin	Foundry
Total primary energy consumption (in GJ)	-74	-63	-43	-54	-33	-4	-10	0(*)	-29(*)
Emissions of greenhouse gas of fossil origin (direct, 100 years) (in kg eq. CO_2)	-3,217	-2,703	-1,466	-672	-1,275	-342	-448	-11	-1,193(*)
Acidifying gas emissions (in g eq. SO_2)	-10,589	-20,425	-7,031	-2033	-1,499	-1,557	-1,083	18(*)	-4,115(*)
Emissions of gas contributing to the creation of tropospheric ozone (in g eq. ethylene)	-759	-204	-92	-193	1(*)	-156	-73	0(*)	-301(*)
Consumption of non renewable resources (in kg eq. antimony)	-33	-26	-21	-26	-17	-3	-4	0	-20(*)
Water consumption (in m^3)	-15	-41	-12	-2	0	-28	-1.3	0	-6(*)
Waste contributing to eutrophication (in g eq. PO_4)	-747	-1 838	-327	-77	-27	-270	14 (*)	21	-234(*)
Production of waste (in t)	-4	0	0	-1	-1	-29	-	0	-1(*)

(*) Non significant deviation when the overall result calculated is lower than the greater of the two following values: 10% of the total generated impacts, 10% of the total avoided impacts

Table 1 – Environmental review of the 9 recovery methods studied for 1 tonne of recovered ELT

The calculated environmental reviews show that with current technical conditions, almost all the recovery methods studied have environmental benefits, and this, regardless of the type of impact taken into consideration.

Comparing the results from the various recovery methods makes it possible to identify three main groups:

- The production of synthetic turf, the manufacture of moulded objects and cement works stand out as the most advantageous methods on the basis of the studied environmental indicators.
- Retention basins and infiltration basins are recovery methods for which the advantages remain relatively minimal.
- The other recovery methods have advantages situated at an intermediary level, between these two categories. Their advantages are more or less clear, depending on which indicators are taken into account.

Remark: Recovery in foundries is an emerging field. The data used in the present study were obtained from industrial trials that need to be confirmed. On the basis of the data currently available, the benefits generated by recovering ELT in foundries have been judged to be non significant.

In the particular of case of total primary energy consumption, the sensitivity analysis, which consisted in allocating half the material energy from the tyres to the recovery method, confirmed the robustness of the results for the recovery methods in synthetic turf, moulded objects, cement works, steelworks and urban heating. On the other hand, it resulted in the performances of the other recovery methods being put into perspective for this indicator (see Section IV, Chapter 2).

Generally speaking, the benefits provided by the recovery of ELT come from the effect of using ELT as substitutes for high energy-consumption materials, an effect from avoiding the production and transport of certain substituted materials when the life span of ELT products is greater than that of the products they replace, as well as the biomass fraction of used tyres.

2. Role played by the transport and preparation stages for ELT

Stages / Indicators	Impacts of the transport and preparation stages for ELT (for one tonne of ELT)	Avoided impacts for the different methods studied (for one tonne of ELT)							
		Synthetic turf	Moulded object	Cement works	Steelworks	Urban heating	Equestrian floor	Retention basin	Infiltration basin
Total primary energy consumption (in GJ)	0.5 to 3.2	-87	-66	-45	-55	-34	-9.5	-12	-1
Emissions of greenhouse gas of fossil origin (direct, 100 years) (in kg eq. CO_2)	44 to 95	-3,642	-2,794	-3,354	-2,406	-3,149	-544	-657	-68
Acidifying gas emissions (in g eq. SO_2)	257 to 630	-12,798	-20,961	-7,662	-2,486	-1,965	-2,880	-2,413	-301
Emissions of gas contributing to the creation of tropospheric ozone (in g eq. ethylene)	6 to 11.5	-807	-215	-102	-202	-9	-172	-101	-7
Consumption of non renewable resources (in kg eq. antimony)	0.2 to 0.5	-37	-26.5	-22	-26	-17.5	-4.4	-5.2	-0.4
Water consumption (in m^3)	0 to 0.6	-17	-41.2	-12	-2	0	-30	-1.5	-0.1
Waste contributing to eutrophication (in g eq. PO_4)	62 to 116	-984	-1 935	-443	-180	-134	-450	-298	-54
Production of waste (in t)	0 to 0.2	-4.5	-0.45	0	-1	-1	-29	- 1	0

Table 2 – Putting into perspective the generated impacts by the transport and preparation stages for ELT in relation to the avoided impacts through substitution for traditional products

As shown in the table above, the generated impacts by the common transport and preparation stages for ELT (collection and other stages such as transport, sorting, shredding,granulation) remain low relatively to the order of magnitude of the avoided impacts for the eight computed indicators.

3. Conclusions

The results obtained for the nine studied recovery methods show that it is always advantageous to invest in the stages upstream, represented by collection, sorting and shredding/granulation as a means of trying to recover the potential of used tyres.

A management policy for used tyres based on the combination of these different methods thus results in environmental benefits being produced.

Whilst approving this general conclusion, the critical review committee recommended that the end-of-life period of the non destructive recovery methods should be studied.

The obtained results also make it possible to put into perspective the hierarchy for waste mentioned in the context of the Directive 2008/98/EC concerning waste. It effectively appears that recycling methods do not systematically have better environmental review results than energy recovery methods.

4. Presentation in graph form of the environmental review results for the eight indicators and the nine methods studied

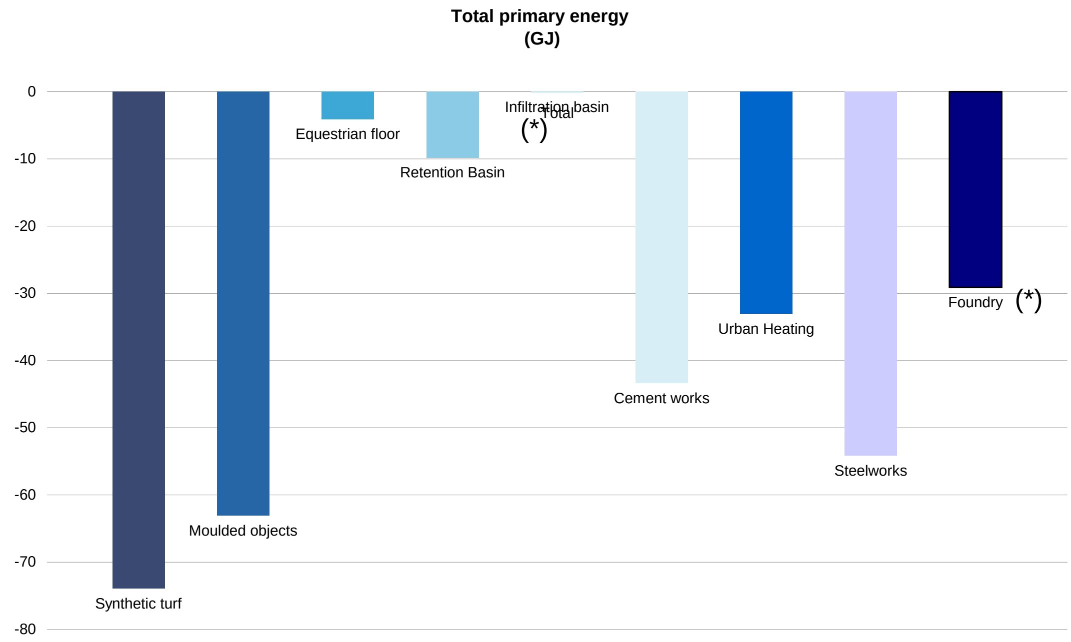

Figure 2: Environmental review results for total primary energy consumption (GJ/tonne of ELT)

(*) Non significant deviation less than 10% of the total: generated impacts by the recovery or avoided impacts

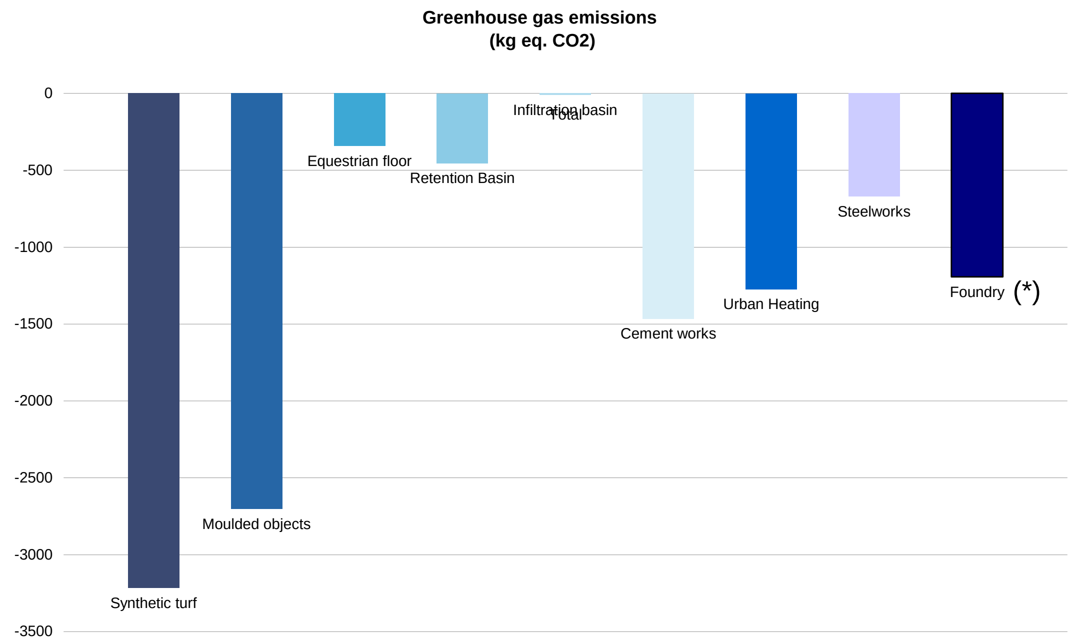

Figure 3: Environmental review results for greenhouse gas emissions (kg eq. CO_2/tonne of ELT)

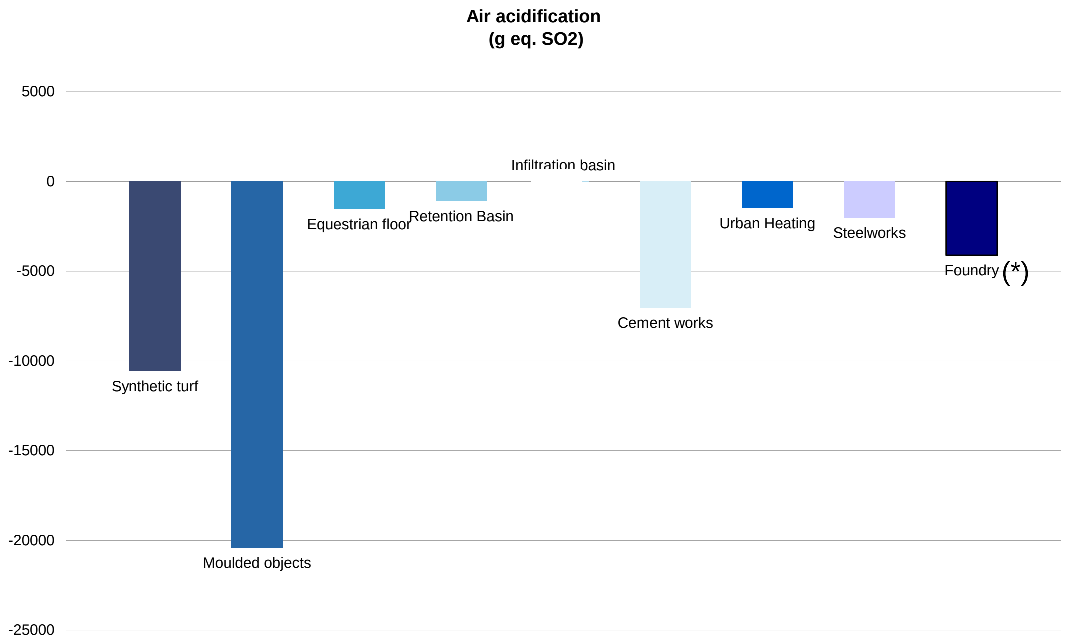

Figure 4: Environmental review results for acidifying gas emissions (kg eq. SO2/tonne of ELT)

(*) Non significant deviation less than 10% of the total: generated impacts by the recovery or avoided impacts

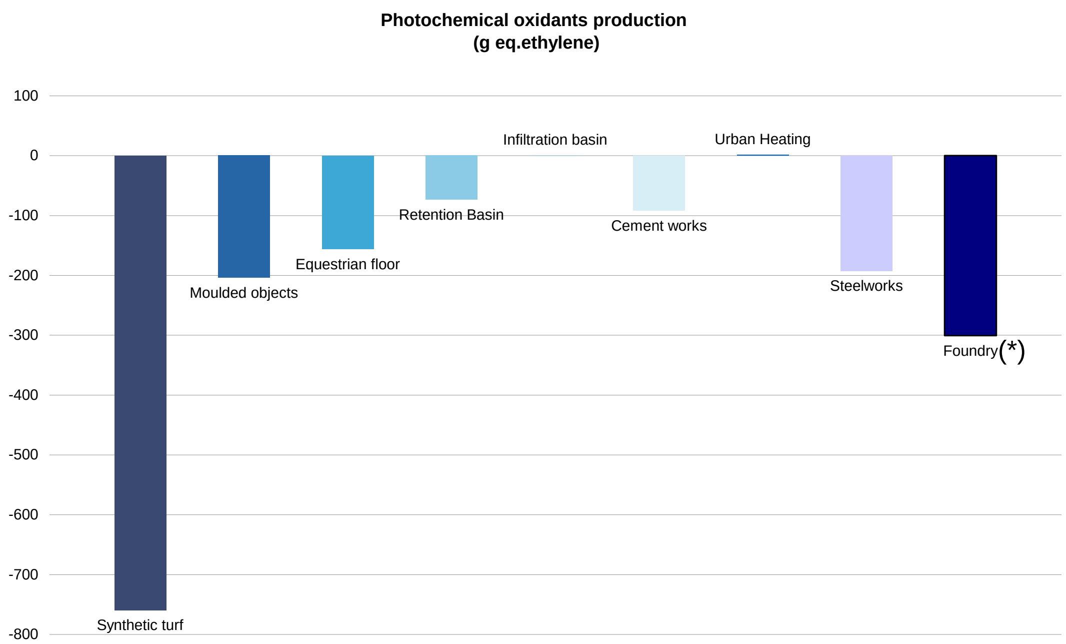

Figure 5: Environmental review results for emissions of gas contributing to the creation of tropospheric ozone (g eq. ethylene/tonne of ELT)

Consumption of non renewable resources

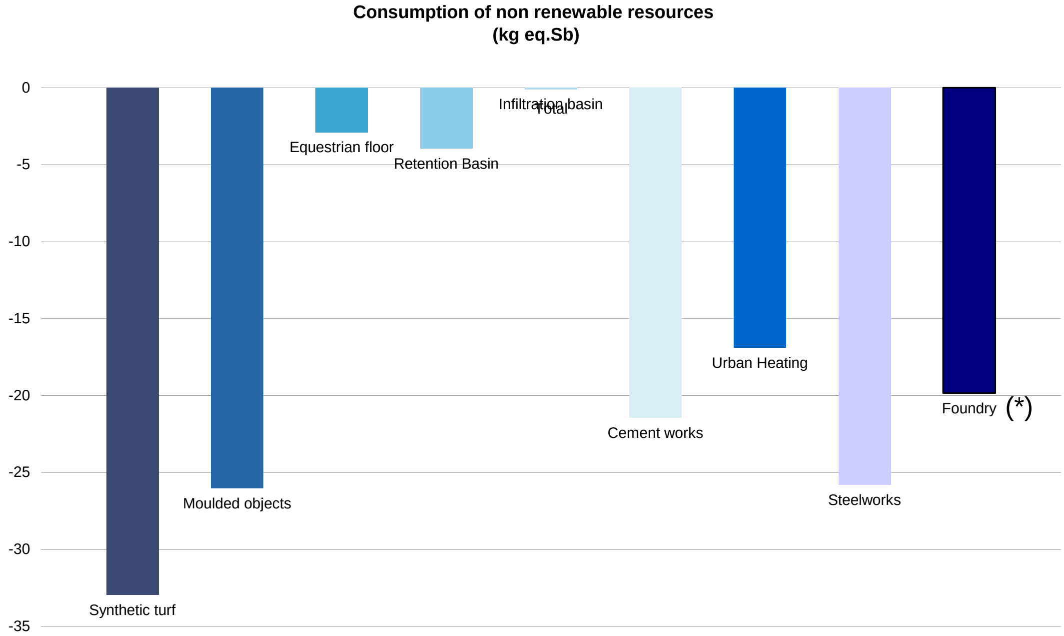

Figure 6: Environmental review results for the consumption of non renewable resources (kg eq. antimony/tonne of ELT)

(*) Non significant deviation less than 10% of the total: generated impacts by the recovery or avoided impacts

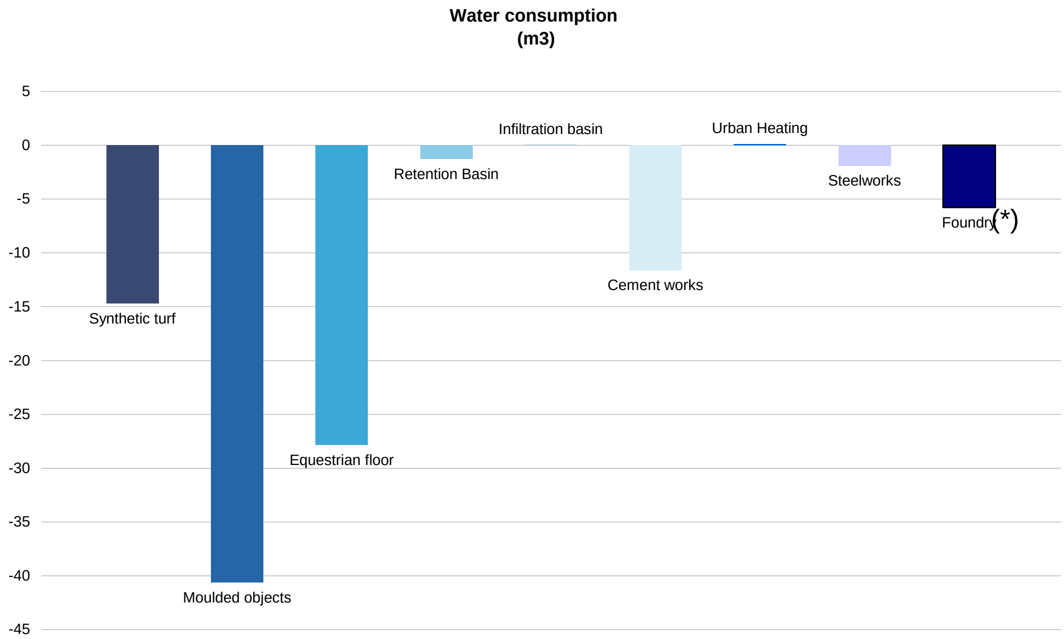

Figure 7: Environmental review results for water consumption (m^3 /tonne of ELT)

Waste contributing to eutrophication

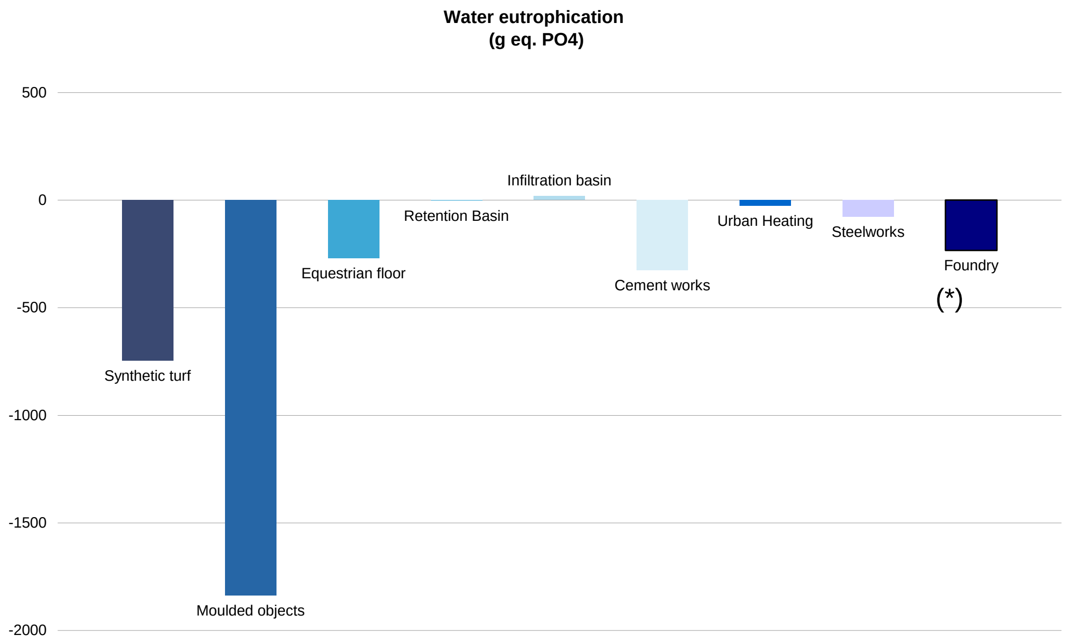

Figure 8: Environmental review results for waste contributing to eutrophication (g. eq. PO_4/tonne of ELT)

(*) Non significant deviation less than 10% of the total: generated impacts by the recovery or avoided impacts

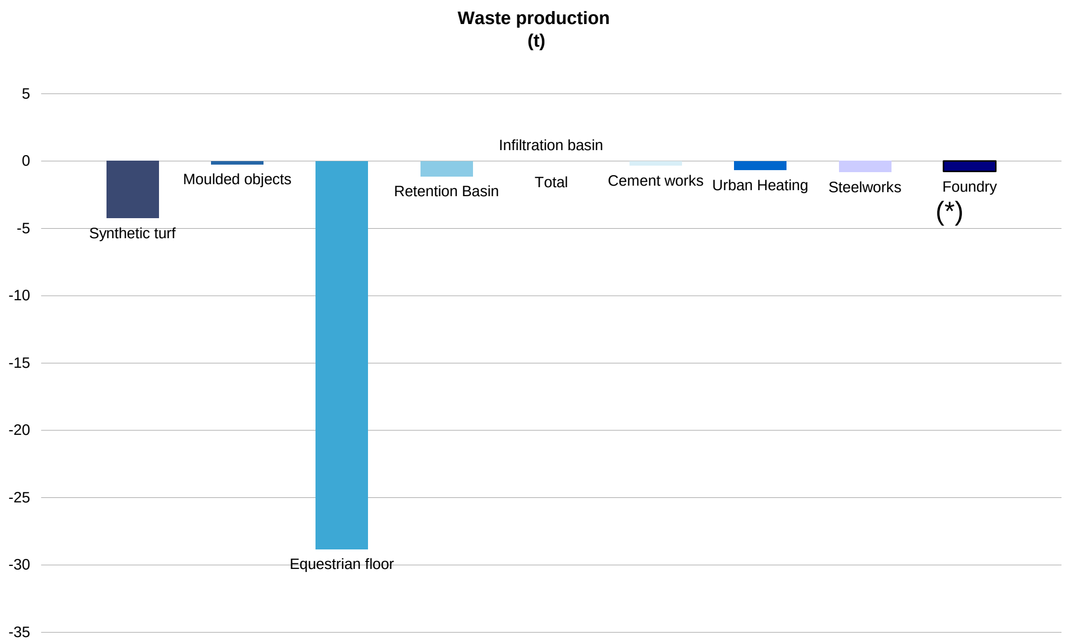

Figure 9: Environmental review results for total waste production (tonnes/tonne of ELT)

SECTION IV – For more details about the methodology

1. Substitution rates

Recovering ELT makes it possible to guarantee an alternative service for a supply that generally requires the consumption of traditional resources.

The information collected from the various contributors has thus made it possible to establish the substitution rate concerning each method.

ELT recovery method	**Substitution rate for an equivalent service and the same life span** ***1 tonne of ELT replaces:***	**Life span of the ELT-based product and the traditional product**
Retention basins	1.95 t of blocks of concrete or 0.3 t of blocks of polyethylene	Similar life span (20 years)
Infiltration basins	6 t of gravel	Similar life span (20 years)
Moulded objects	1 t of virgin polyurethane	Similar life spans
Synthetic turfs	0.5 t of virgin EPDM and 2 t of chalk	ELT: 10 years, EPDM: 4 years
Equestrian floors	44 t of sand	ELT: 10 years, sand: 3 years
Cement works	0.7 t of coke and 0.29 t of coal	NA Destructive methods
Urban heating	1.15 t of coal	
Steelworks	0.59 t of anthracite and 0.16 t of scrap metal	
Foundry	(1000 t of scrap metals + 9.5 t of coke + 1 t of ELT) replaces (1002 t of scrap metals + 10 t of coke)	

Table 3: Substitution rates for the various ELT recovery methods

NB: A football pitch uses around 150 tonnes of ELT granulates, an equestrian riding school around 30 tonnes, and a cement works can consume tens of thousands of tonnes a year.

2. Sensitivity analyses

Various sensitivity analyses were carried out in the context of this study in order to evaluate the incidence of certain technical choices, as well as the robustness of the results.

These analyses thus focused on the following aspects:

- allocation of the material energy from tyres
- the incidence of the choice of granulation technique (techniques currently used in France *versus* cryogenic granulation)

Other analyses, specific to a given recovery method, were also conducted. The information obtained is provided in the focus per recovery method presented in Section V.

a) Sensitivity analysis focusing on taking into account feedstock energy

In the context of this study, the feedstock energy contained in the tyres is calculated as being the responsibility of whoever passed the tyre from its status of product to that of waste, and not the responsibility of the ELT recovery method.

As shown in the table below, allocating half of the tyres' feedstock energy to the ELT recovery methods produces a change in the results for this indicator.

	Primary energy consumption (GJ/t)	
Recovery method	0% of ELT feedstock energy allocated to the recovery method	50 % of the ELT feedstock energy allocated to the recovery method
Synthetic turf	-74	-60
Moulded object	-63	-49
Equestrian floor	-4	10
Retention basin	-10	5
Infiltration basin	0	14
Cement works	-43	-28
Urban heating	-33	-18
Steelworks	-54	-40
Foundry	-29	-16

Table 4 – Results of the sensitivity analysis focusing on taking into account the feedstock energy of the tyres

This sensitivity analysis consisted in allocating half the feedstock energy from tyres to the ELT recovery method. It made it possible to confirm the solidity of the results obtained for the recovery methods for synthetic turf, moulded objects, cement works, steelworks and urban heating.

It also resulted in us putting into perspective the performances of the other recovery methods for the “primary energy consumption” indicator. This can be explained by the low energy-consuming nature of the traditional solutions being replaced, which use materials with a low, or zero, energy content (sand, gravel, concrete blocks).

b) Sensitivity analysis focusing on granulation process

Cryogenic granulation is not used in France: the sites at which this technology is available are located in Portugal. The Netherlands is also partially implementing this technology.

Through this complementary analysis, we hope to highlight the differences found at the environmental level between this granulation technique and those used in France (compression granulation and successive shredding granulation).

Scenario / **Indicators**	Reference scenario	Cryogenics
Total primary energy consumption (in GJ)	3	9
Emissions of greenhouse gas of fossil origin (direct, 100 years) (in kg eq. CO_2)	39	369
Emissions of acidifying gas (in g eq. SO_2)	243	2 031
Emissions of gas contributing to the creation of tropospheric ozone (in g eq. ethylene)	5.1	15.7
Consumption of non renewable resources (in kg eq. Sb)	0.3	2.5
Water consumption (in m^3)	0.66	9.40
Waste contributing to eutrophication (in g eq. PO_4)	23	115
Waste production (in t)	0.34	0.66

Table 5 – Comparison of the environmental generated impacts by the different granulation techniques

The results of this analysis are presented for the granulation stage only, with a reference flow of 1 tonne of tyres entering the granulation process. The reference scenario corresponds to the French distribution between the successive shredding and compression techniques.

It should be noted that this comparison does not take into account the differences in quality between the granulates produced.

The increase in impact between the successive shredding or compression techniques on the one hand, and the cryogenic granulation technique on the other is considerable.

This increase in impact comes essentially from the significant energy consumption at the level of the machines and for the production and transport of the liquid nitrogen needed for cryogenic shredding granulation.

3. Modelling the transport stages for used tyres

In-depth modelling work was carried out to characterise the transport stages for used tyres. Transporting ELT from their storage place to the recovery site is composed of the following stages:

- Collection of the used tyres from the storage sites and transport to the sorting centre: 40,000 collection points, around 90 sorting centres.
- Transfer of the ELT from the sorting centres to the transformation platforms (shredding / granulation). In most cases, the sorting and transformation are done on the same premises and this transfer is therefore not necessary.
- Transport of the ELT to the recovery sites. There are two possibilities:
  - the ELT are transported by road to the recovery sites
  - if the recovery will take place abroad (cement works, urban heating), the tyres transit first through transit hubs before being sent by boat and, when necessary, then by road to the recovery site.

The fuel consumption associated with each transport stage was calculated using the following formula:

Real consumption (in litres) =

$$\text{Distance} \times \frac{\text{full load consumption}}{100} \times \left[\frac{2}{3} + \frac{1}{3} \times \frac{\text{real load}}{\text{useful load}} + \text{empty return rate} \times \frac{2}{3} \right]$$

With regard to the collection stage from the storage sites to the sorting centres, systematic processing of the delivery slips for 2008 made it possible to:

- calculate the transport distance specific to each delivery slip
- form homogenous “transport categories” through analysis of the distribution of the tonnages collected and the kilometers travelled
- determine the values of the various modelling parameters

Once completed, the analyses revealed the need to establish sets of different data (tonnage transported, distance covered) for “skip” and “bulk” collections. On the contrary, it was not useful to distinguish the collections in terms of the type of tyre.

	Skip	Bulk
Total tonnage (t)	142,000	127,000
Distance (km)	77	74
Actual load transported (t)	4	1.4
Useful load (t)	12	3
Consumption per 100 km full load (L)	34	15
Empty return (conservative hypothesis)	100%	100%
Consumption per tonne (L)	9.5	12

Table 7: Modelling parameters for collections from storage sites to the sorting centres

Similarly, these parameters were determined for the other ELT transport stages.

SECTION V – For more details about each of the recovery methods

1. Focus on the transport stages

Given the logistic organisation needed for the management of used tyres, and the motivation shown by several of the interested parties for the environmental impact of transport, particularly the greenhouse effect, we wanted to evaluate the cumulated contribution of all the ELT transport stages for this indicator.

The transport stages taken into account for the calculations are as follows:

- Road transport of the tyres from the 40,000 collection points to the 90 sorting centres.
- Road transport of the ELT from the sorting centres to the transformation platforms (shredding / granulation).
- Transport from the sorting or transformation centres to the recovery sites in France (by road) and abroad (sea and road).

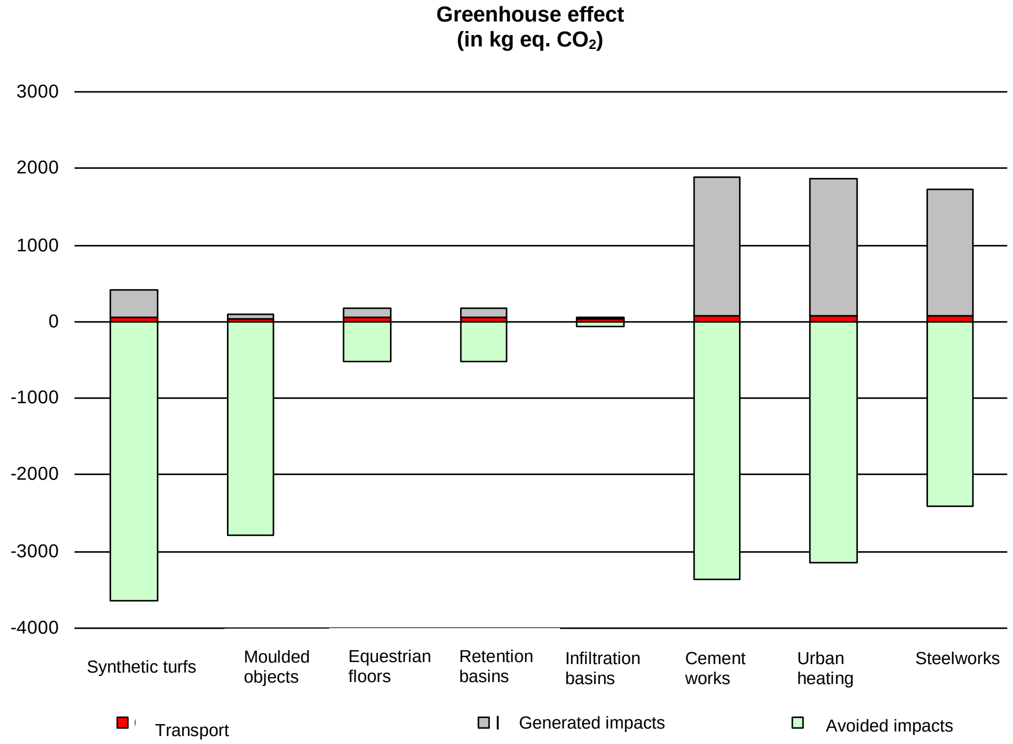

Figure 10: Greenhouse gas effect indicator- generated impacts, role played by the transport stages and avoided impacts for the various recovery methods studied

For most recovery methods, the results show that the transport stages play an environmental role (45 to 84 kg eq. CO_2/ tonne of ELT) that is secondary to the impacts generated by the recovery methods, and that the transport impacts are greatly inferior to the benefits generated by using tyres to replace traditional products.

2. Focus on the non destructive methods

Focus on synthetic turf

Scenarios / **Indicators**	Overall result	Generated impacts by the recovery		Avoided impacts (substitution effect)
		Total	*Including the transport and preparation stages*	
Total primary energy consumption (in GJ)	**-74**	13	*3*	-87
Emissions of greenhouse effect gas of fossil origin (direct, 100 years) (in kg eq. CO_2)	**-3,217**	425	*91*	-3,642
Emissions of acidifying gas (in g eq. SO_2)	**-10,589**	2,209	*536*	-12,798
Emissions of gas contributing to the creation of tropospheric ozone (in g eq. ethylene)	**-759**	48	*11*	-807
Consumption of non renewable resources (in kg eq. antimony)	**-33**	5	*0,5*	-37
Water consumption (in m^3)	**-15**	2	*0,6*	-17
Waste contributing to eutrophication (in g eq. PO_4)	**-747**	237	*97*	-984
Waste production (in t)	**-4,3**	0.2	*0.2*	-4.5

Synthetic turf is composed of a mat of synthetic grass into which is added a ballast bed of sand, covered with a layer of loose granulates.

The environmental results were established on the basis of the comparison of synthetic turf with a filling made of ELT granulates and a synthetic turf with a filling made of chalk and virgin EPDM granulates. At the level of the total life span of synthetic turf with ELT granulates, the substitution rate is 1 kg of ELT for 0.5 kg of virgin EPDM and 2 kg of chalk.

For all the indicators that we looked at, the overall results show that there are significant environmental benefits.

The transport and preparation stages play a role in the generated impacts by the recovery method, which remains secondary. The recovery stage itself (laying the synthetic turf with ELT granulates) plays the greatest role.

An analysis focusing on only the stages prior to recovery shows that:

- the transport stages (collection, transfer to shredding / granulation and to recovery) play a role of 60 to 80% in the indicators corresponding to emissions into the atmosphere (greenhouse effect, tropospheric ozone), emissions into water (eutrophication) or the exhaustion of non renewable resources. This can be explained by the consumption of fossil energy fuels in the transport systems.
- the granulation stage plays a role of 60 to 70% in water and energy consumption, and 100% of the production of non dangerous waste products.
- The sorting and shredding stages only play a very minor role in the environmental impacts of tyre recovery for synthetic turf.

Focus on moulded objects

Indicators / Scenarios[1]	Overall results	Generated impacts by the recovery		Avoided impacts (substitution effect)
		Total	*including transport and preparation stages*	
Total primary energy consumption (in GJ)	**-63**	3	*3*	-66
Emissions of greenhouse gas of fossil origin (direct, 100 years) (in kg eq. CO_2)	**-2.703**	91	*91*	-2.794
Emissions of acidifying gas (in g eq. SO_2)	**-20.425**	536	*536*	-20.961
Emissions of gas contributing to the creation of tropospheric ozone (in g eq. ethylene)	**-204**	11	*11*	-215
Consumption of non renewable resources (in kg eq. antimony)	**-26**	0.5	*0.5*	-26.5
Water consumption (in m^3)	**-40.6**	0.6	*0.6*	-41.2
Waste contributing to eutrophication (in g eq. PO_4)	**-1.838**	97	*97*	-1.935
Production of waste (in t)	**-0.25**	0.2	*0.2*	-0.45

[1] Warning: the stages identical to both of the solutions compared (in this case, the manufacturing stages) were not taken into account given that there is no differentiation in terms of the environmental result.

The environmental results were established on the basis of an ELT anti-vibration mat and an anti-vibration mat made of virgin polyurethane. The life span of both mats is the same and there is no difference in the manufacturing processes. The substitution rate taken into consideration is 1 kg of virgin polyurethane replaced by 1 kg of ELT granulates.

For all the indicators on which we focused, the overall results show that there are significant environmental benefits associated with the fact that there is no need for the production of virgin polyurethane, a process which is a stage with a relatively high impact.

The sensitivity analysis carried out with regard to the allocation of the feedstock energy from the ELT showed that the result was less positive for the field using ELT when half the feedstock energy from the tyres was allocated to it, even though the product nevertheless remained advantageous when compared to the virgin polyurethane sector.

Remark: the conclusions of the analysis focusing on the upstream recovery stages (transport and preparation) are similar to those established for synthetic turf.

Focus on equestrian floors

Scenarios[1] / **Indicators**	Overall results	Generated impacts by the recovery		Avoided impacts (substitution effect)
		Total	*including transport and preparation stages*	
Total primary energy consumption (in GJ)	**-4**	5.5	*3*	-9.5
Emissions of greenhouse gas of fossil origin (direct, 100 years) (in kg eq. CO_2)	**-342**	202	*91*	-544
Emissions of acidifying gas (in g eq. SO_2)	**-1,557**	1,323	*536*	-2,880
Emissions of gas contributing to the creation of tropospheric ozone (in g eq. ethylene)	**-156**	16	*11*	-172
Consumption of non renewable resources (in kg eq. antimony)	**-3**	1.5	*0.5*	-4.5
Water consumption (in m^3)	**-28**	2	*0.6*	-30
Waste contributing to eutrophication (in g eq. PO_4)	**-270**	180	*97*	-450
Production of waste (in t)	**-29**	0.4	*0.2*	-29

[1] Warning: the stages identical to both of the solutions compared (in this case, laying the support floor composed of a compacted layer of broken gravel) were not taken into account given that there is no differentiation in terms of the environmental result.

The environmental results for the "equestrian floor" recovery method were established from the comparison of an ELT equestrian floor with an equestrian floor made of the traditional sand.

A sand equestrian floor is different from an ELT equestrian floor in that it has a much shorter life span and is much thicker. For the life span of an equestrian floor made from ELT granulates (10 years), the substitution rate is 1 kg of ELT for 44 kg of sand. This calculation takes into account the renewal rate of 5% for the loose layer of ELT.
For all the indicators analysed, the overall result shows that there are environmental benefits for the ELT method, and that these advantages are more or less significant depending on the indicators.

This observation is particularly interesting given that ELT equestrian floors produce better performances than traditional sand floors in terms of dust emissions, as well as for the safety of the users.

The benefits come in great part from the fact that there is no need for sand production – extracting the sand from a quarry produces up to 70% of the avoided impacts with ELT, with the remaining 30% coming from the transport to the riding school.
In the particular case of the "total primary energy consumption" indicator, the sensitivity analysis carried out on the allocation of feedstock energy showed that the energy result was no longer positive for the ELT sector when half the feedstock energy from the tyres was allocated to this sector because of the low-energy-consuming nature of the traditional solution.

The sensitivity analysis for the life span of ELT equestrian floors consisted in comparing the scenario retained with one based on a life span of 20 years. The substitution rate was then 1 kg of ELT for 73 kg of sand, this producing an increase in the environmental benefits for the ELT recovery method.

Remark: the conclusions of the analysis focusing on the upstream recovery stages (transport and preparation) are similar to those established for synthetic turf.

Focus on retention basins

Scenarios[1] **Indicators**	Overall results	Generated impacts by the recovery		Avoided impacts (substitution effect)
		Total	*including transport and preparation stages*	
Total primary energy consumption (in GJ)	**-10**	3	*0,5*	-13
Emissions of greenhouse gas of fossil origin (direct, 100 years) (in kg eq. CO_2)	**-448**	209	*44*	-657
Emissions of acidifying gas (in g eq. SO_2)	**-1,083**	1,330	*257*	-2,413
Emissions of gas contributing to the creation of tropospheric ozone (in g eq. ethylene)	**-73**	28	*6*	-101
Consumption of non renewable resources (in kg eq. antimony)	**-4**	1,2	*0,2*	-5,2
Water consumption (in m^3)	**-1.3**	0.3	*0*	-1.6
Waste contributing to eutrophication (in g eq. PO_4)	**14 (*)**	312	*62*	-298
Production of waste (in t)	**- 1**	0	*0*	- 1

[1] Warning: the stages identical to both of the solutions compared (in this case, producing the drains, the geomembrane and the proofing complex) were not taken into account given that there is no differentiation in terms of the environmental result.

(*) Non significant deviation as less than 10% of the total of the generated impacts by the recovery

The environmental results were established from the comparison between the ELT recovery of whole tyres for the construction of retention basins, and solutions using traditional materials, such as blocks of concrete or plastic.

The results were calculated taking into account in particular the following data:

- The hypothesis made in this study was that of a substitution of 50% of the blocks of concrete and 50% of the blocks of plastic.
- The substitution rates were:
  - 1 kg of ELT for 2 kg of concrete in cases where the solution replaced is composed of blocks of concrete
  - 1 kg of ELT for 0.3 kg of polyethylene in cases where the solution replaced is composed of blocks of plastic
- The leaching impacts, taken into account for the recovery method, were deemed to be negligible for the traditional solutions.

The environmental results established for the indicators analysed show that there are environmental benefits for the recovery method, even though these benefits are nevertheless minimal for several indicators.

The benefits generated by replacing the blocks of concrete or plastic with ELT come mainly from the fact that using ELT removes the need to produce virgin polyethylene. The ELT solution is also more beneficial than concrete for all the indicators studied.

The results obtained and summarised above must nevertheless be put into perspective in the light of the two following points:

- The importance in terms of the benefits produced by the recovery of ELT in retention basins depends greatly on the respective proportions of concrete blocks and plastic blocks in the solution being replaced, with plastic blocks and concrete blocks producing very different impacts;
- Concerning energy consumption, the sensitivity analysis carried out shows that the results are not positive for the ELT sector when 50% of the feedstock energy from the tyres is allocated to the ELT sector. This can be explained by the low-energy-consuming nature of the traditional solution, which used materials with low energy content (mixture of concrete block and plastic block solutions).

Remark: the generated impacts by the recovery method come essentially from the implementation stage. This can be explained by the fact that the ELT void ratio (70%) is lower than that of the concrete blocks (100%), which thus implies the need for additional excavation work.

Focus on infiltration basins

Scenarios[1] / Indicators	Overall results	Generated impacts by the recovery: Total	Generated impacts by the recovery: *including transport and preparation stages*	Avoided impacts (substitution effect)
Total primary energy consumption (in GJ)	**0**(*)	1	*1*	-1
Emissions of greenhouse gas of fossil origin (direct, 100 years) (in kg eq. CO_2)	**-11**	57	*57*	-68
Emissions of acidifying gas (in g eq. SO_2)	**18**(*)	319	*319*	-301
Emissions of gas contributing to the creation of tropospheric ozone (in g eq. ethylene)	**0**(*)	7	*7*	-7
Consumption of non renewable resources (in kg eq. antimony)	**0**	0.3	*0.3*	-0.3
Water consumption (in m^3)	**0**	0.1	*0.1*	-0.1
Waste contributing to eutrophication (in g eq. PO_4)	**21**	75	*71*	-54
Production of waste (in t)	**0**	0	*0*	0

[1]Warning: the stages identical to both of the solutions compared were not taken into account given that there is no differentiation in terms of the environmental result.

(*) Non significant deviation as less than 10% of the total of the generated impacts by the recovery

The results come from the comparison between the sector using shredded ELT and the solution using natural gravel. The substitution was made on the basis of ratio of 1 kg of ELT for 6 kg of gravel.

The environmental results obtained for the indicators on which we focused show that there are environmental benefits for the recovery method, even if they are nevertheless minimal.

In the particular case of the “primary energy consumption” indicator, the sensitivity analysis carried out on the feedstock energy contained in the tyres shows that the energy benefit of the ELT recovery method in infiltration basins is not as strongly acquired as it depends on the choice of allocation for this energy.

The benefits generated by replacing the gravel with ELT come essentially from the substitution factor. The avoided impacts correspond essentially to the gravel production stage, whilst the fact of avoiding the transport stages for gravel supplies has very little influence on the avoided impacts obtained.

3. Focus on destructive methods

Focus on cement works

Indicators / Scenarios[1]	Overall results	Generated impacts by the recovery		Avoided impacts (substitution effect)
		Total	*including transport and preparation stages*	
Total primary energy consumption (in GJ)	**-43**	1	*1*	-44
Emissions of greenhouse gas of fossil origin (direct, 100 years) (in kg eq. CO_2)	**-1,466**	1 888	*95*	-3,354
Emissions of acidifying gas (in g eq. SO_2)	**-7,031**	630	*630*	-7,661
Emissions of gas contributing to the creation of tropospheric ozone (in g eq. ethylene)	**-92**	11	*11*	-103
Consumption of non renewable resources (in kg eq. antimony)	**-21**	0.5	*0.5*	-21.5
Water consumption (in m^3)	**-12**	0.2	*0.2*	-12
Waste contributing to eutrophication (in g eq. PO_4)	**-327**	116	*116*	-443
Production of waste (in t)	**0**	0	*0*	0

[1] Warning: the stages identical to both of the solutions compared were not taken into account given that there is no differentiation in terms of the environmental result.

The environmental results were established on the basis of the comparison between the energy recovery from ELT in cement works and the solutions using traditional fuels, such as petroleum coke and coal.

In order to interpret these results correctly, the following methodological points need to be taken into consideration:

- the substitution is calculated for an equivalent energy content
- the ELT replace a mix composed of 75% coke and 25% coal
- the only emissions for which a differential was calculated were CO_2 emissions; the other types of emission were taken as being equivalent for ELT and the solution they replaced, and were thus not taken into consideration in the review.

The environmental results obtained for the indicators studied show that there were significant environmental benefits for the recovery method. The biomass content of ELT, and the absence of extraction process with an environmental impact (as is the case for traditional fuels) are the origin of the environmental benefits calculated.

In the particular case of primary energy consumption, the sensitivity analysis carried out shows that the environmental results remain favourable for the ELT sector even when 50% of the feedstock energy contained in the tyres is allocated to it.

Part of the emissions of ELT comes from the carbon biomass[3], which does not contribute to the greenhouse effect indicator. This rule is coherent with the provisions of the regulations concerning the quantification of the CO_2 emissions declared as part of the greenhouse gas emission quota exchange system[4].

The emission factor taken into account for the ELT was thus around 60 t of CO_2/TJ *versus* more than 90 t of CO_2/TJ for coal or petroleum coke[5].

[3] Using used tyres as an alternative source of fuel, Reference values and characterisation protocols, Aliapur & PricewaterhouseCoopers, June 2009

[4] Decree dated 31 March 2008 concerning the verification and quantification of the emissions declared as part of the greenhouse gas emission quota exchange system

[5] It should be noted that in the context of the French National Quota Allocation Plan for the period 2008 to 2012, the State Department for Ecology, Energy, Sustainable Development and the Sea issued, on 10 December 2009, an updated version of the national derogation for determining the biomass fraction in ELT

Focus on urban heating

Scenarios[1] / Indicators	Overall results	Generated impacts by the recovery – Total	Generated impacts by the recovery – *including transport and preparation stages*	Avoided impacts (substitution effect)
Total primary energy consumption (in GJ)	**-33** **- 31** [2]	1	*1*	-34
Emissions of greenhouse gas of fossil origin (direct, 100 years) (in kg eq. CO_2)	**-1,275** **- 323** [2]	1,875	*82*	-3,150
Emissions of acidifying gas (in g eq. SO_2)	**-1,499** **- 555** [2]	466	*466*	-1,965
Emissions of gas contributing to the creation of tropospheric ozone (in g eq. ethylene)	**1** [(*)] **- 270** [2]	10	*10*	-9
Consumption of non renewable resources (in kg eq. antimony)	**-17**	0.5	*0.5*	-17.5
Water consumption (in m^3)	**0**	0.2	*0.2*	0
Waste contributing to eutrophication (in g eq. PO_4)	**-27**	107	*107*	-134
Production of waste (in t)	**-1**	0	*0*	-1

[1] Warning: the stages identical to both of the solutions compared were not taken into account given that there is no differentiation in terms of the environmental result.

[2] Overall results calculated with a scenario composed of 66% natural gas, 18% fuel and 16% coal

[(*)] Non significant deviation as less than 10% of the total of the generated impacts by the recovery

The environmental results were established from the comparison of the use of ELT for energy purposes in urban heating and the solutions using traditional fuels such as coal in the main scenario, as well as an energy mix composed of natural gas, fuel and coal, as part of the sensitivity analysis.

In order to interpret these results correctly, the following methodological points need to taken into consideration:

- the substitution is calculated for an equivalent energy content
- the main avoidance scenario is based on a traditional solution composed of 100% coal
- in a second stage, a sensitivity analysis was carried out on the basis of a mix composed of 66% natural gas, 18% fuel and 16% coal (an energy mix that is representative of the traditional fuels used in France).

For all the indicators on which we focused, with the exception of the gas contributing to the creation of tropospheric ozone, the environmental results obtained revealed environmental benefits, even if these benefits were more or less significant depending on the indicator taken into consideration.

For the total primary energy consumption indicator, the sensitivity analysis showed that the environmental results remained favourable for the ELT sector, even when 50% of the feedstock energy contained in the tyres was allocated to it.

The environmental benefits calculated come essentially from the biomass content of ELT and the absence of any extraction process with an environmental impact (unlike the traditional fuels that the ELT replace).

When the traditional method was modelled with an energy mix representative of the traditional fuels used in France, the benefits provided by the solution using ELT decreased considerably for greenhouse gas and acidifying gas emissions. This is essentially the result of the predominance of natural gas in the energy mix replaced, with the combustion emissions from natural gas in urban heating being of an order of magnitude very similar to that of tyres (60 t CO_2/TJ).

Focus on steelworks

Scenarios[1] / **Indicators**	Overall results	Generated impacts by the recovery – Total	Generated impacts by the recovery – *including transport and preparation stages*	Avoided impacts (substitution effect)
Total primary energy consumption (in GJ)	**-54**	1	*1*	-55
Emissions of greenhouse gas of fossil origin (direct, 100 years) (in kg eq. CO_2)	**-672**	1,735	*79*	-2,407
Emissions of acidifying gas (in g eq. SO_2)	**-2,033**	453	*452*	-2,486
Emissions of gas contributing to the creation of tropospheric ozone (in g eq. ethylene)	**-193**	10	*10*	-203
Consumption of non renewable resources (in kg eq. antimony)	**-26**	0.5	*0.5*	-26.5
Water consumption (in m^3)	**-2**	0.2	*0.2*	-2
Waste contributing to eutrophication (in g eq. PO_4)	**-77**	104	*104*	-181
Production of waste (in t)	**-1**	0	*0*	-1

[1] Warning: the stages identical to both of the solutions compared were not taken into account given that there is no differentiation in terms of the environmental result.

The environmental review of recovering ELT shred in steelworks was established on the basis of a comparison with the traditional solution of using anthracite for the same provided service. This recovery method is a destructive ELT recovery method. It has been considered that 1.7 kg of ELT can replace 1 kg of anthracite and 0.26 kg of scrap metal.

Nothing that is common to both solutions was taken into account in the evaluation. In this way, only CO2 emissions were considered to be differential between the use of ELT and the traditional solution.

For all the indicators analysed, the overall results show that there are environmental benefits, and that these benefits are more or less significant depending on the indicator considered.

With the exception of greenhouse gas emissions, the benefits generated by replacing anthracite with ELT come mainly from the fact of no longer having anthracite production to take into account or the recycling of scrap metals which is a relatively high-pollution stage. The fact of avoiding the transport stage for supplies of anthracite also provides a few additional benefits.

For the total primary energy consumption indicator, the sensitivity analysis carried out showed that the environmental results remain favourable for the ELT sector even when 50% of the feedstock energy contained in the tyres is allocated to it.

For the greenhouse gas emissions, the results are in favour of the ELT recovery method, even though the benefits are less significant than in the case of cement works. Although there is a biomass fraction in ELT, the substitution factor comes down more in favour of the anthracite than the ELT.

Focus on foundries

Indicators / Scenarios[1]	Overall results	Generated impacts by the recovery: Total	Generated impacts by the recovery: *including transport and preparation stages*	Avoided impacts (substitution effect)
Total primary energy consumption (in GJ)	**-29**(*)	2 191	*1*	-2 221
Emissions of greenhouse gas of fossil origin (direct, 100 years) (in kg eq. CO_2)	**-1,193**(*)	40,290	*79*	-41,483
Emissions of acidifying gas (in g eq. SO_2)	**-4,115**(*)	433,169	*452*	-437,284
Emissions of gas contributing to the creation of tropospheric ozone (in g eq. ethylene)	**-301**(*)	76,725	*10*	-77,026
Consumption of non renewable resources (in kg eq. antimony)	**-20**(*)	1,139	*0.5*	-1,159
Water consumption (in m^3)	**-6**(*)	1,310	*0.2*	-1,316
Waste contributing to eutrophication (in g eq. PO_4)	**-234**(*)	35,801	*104*	-36,035
Production of waste (in t)	**-1**(*)	166	*0*	-167

[1] Warning: the stages identical to both of the solutions compared were not taken into account given that there is no differentiation in terms of the environmental result.

(*)Non significant deviation as less than 10% of the total of the generated impacts by the recovery

The results above come from the comparison between using shredded ELT in foundries and using foundry coke for the same provided service. This recovery method is a destructive ELT recovery method. Life span is thus not a factor in the substitution evaluation.

Recovery in a foundry is an emerging field. The data used for the present study were thus obtained from the results of industrial trials and which therefore need to be confirmed.

Using ELT in foundries makes it possible on the one hand to provide carbon in replacement of the carbon traditionally provided by the coke and, on the other hand, to provide steel for the load used to produce the cast iron.

Introducing ELT into the load instead of part of the coke modifies the carburation rate of the coke (that is, the ratio between the quantity of carbon integrated into the cast iron as it exits the cupola, and the quantity of carbon initially contained in the coke) in relation to the carburation rate without ELT. The carburation rate for the coke without ELT is 1.17%. This figure is 0.94% when the quantity of ELT introduced corresponds to 1% of the load (scrap metal + coke + ELT). These percentages, though low, have a major influence on the cast iron manufacturing process.

As a result of the influence of the presence of ELT on the behaviour of the coke in the cupola, it cannot simply be considered that ELT are used in replacement of part of the coke and part of the scrap metal. It was thus considered that a load composed of 1000 kg of scrap metal, 95 kg of coke and 10 kg of ELT would be used to replace a load composed of 1002.35 kg of scrap metal and 100.5 kg of coke.

On the basis of the data currently available, it turns out from the various calculations that the differences highlighted are not significant, regardless of the indicator analysed.

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Association française de promotion des réseaux de chaleur et de froid ; « Données énergétiques pour les réseaux de chaleur en France » ; 2009

ATILH ; Approvisionnement moyen en combustibles traditionnels ; 2009

ATILH ; Mix moyen des combustibles meubles utilisés en cimenterie en France ; 2008

BP ; « BP Statistical review of world energy » ; Juin 2007

Cabinet Pierre Robin / BIO IS / ADEME/ Ville de Paris / Conseil Régional Rhône Alpes / Eurofield ; « Analyse de cycle de vie comparative d'un terrain de football en gazon naturel ou gazon synthétique » ; Novembre 2008

CSTB / ADEME / ALIAPUR / Sportingsols / Centre équestre de Vallet ; « Valorisation des pneumatiques usages dans la conception de nouveaux sols équestres » ; 2007

Eco-Emballages ; base de données WISARD™

Ecole Polytechnique Fédérale de Lausanne ; « Conception d'un système de stockage des eaux pluviales » ; Etudiants : Loïc Decrey, Guillaume Grandchamp, encadrant EPFL : Jérôme Payet, encadrant externe : Gilles Vialatte (Groupe Brunet) ; 2008

EEDEMS (Evaluation Environnementale Déchets, Matériaux, Sols pollués) ; « Caractéristiques et propriétés techniques des pneumatiques usagés dans le cadre d'utilisations en génie civil » ; 2005

World Energy Council ; « Survey of Energy resources 2007 » ; Septembre 2007

Other bibliographic sources used to model the traditional methods

Theme	**Stage**	**Source**
Production of electricity, European, French	Energy	Electricity Information 2007, IEA Statistics, International Energy Agency Pour les procédés de combustion: Laboratium fur Energiesysteme, ETH, 1996
Road transport	Transport	Laboratorium fur Energiesysteme ETH, Zurich, 1996
Sea transport	Transport	Laboratorium fur Energiesysteme ETH, Zurich, 1996
Production of liquid nitrogen	Granulation	Ecoinvent data Swiss Centre for LCI, EMPA-DU
Production of cement	Retention basin	Laboratorium fur Energiesysteme ETH, Zurich, 1996
Production of polyethylene (HDPE)	Retention basin	APME, 2005
Production of fibre glass	Retention basin	Data from a confidential site
Production of gravel	Infiltration basin	Laboratorium fur Energiesysteme ETH, Zurich, 1996
Production and combustion of diesel	Urban heating	Laboratorium fur Energiesysteme ETH, Zurich, 1996
Production and combustion of wood	Urban heating	Swiss Federal Office of Environment , Forest and Landscape (FOEL or BUWAL)
Production and combustion of natural gas	Urban heating Synthetic turf	Laboratorium fur Energiesysteme ETH, Zurich, 1996
Production of carbon black	Steelworks	ETH (Ökoinventare für Energiesysteme)
Production of coke	Foundry	Data from a confidential site
Production of polyurethane	Moulded objects Equestrian floors Synthetic turf	APME, 1999
Production of ethylene propylene diene (EPDM)	Synthetic turf	Confidential source (average of American sites 1990)
Production of sand	Synthetic turf Equestrian floors	Data from a French site
Production of styrene butadiene – Latex	Synthetic turf	IFP, Caoutchoucs synthétiques, procédés et données économiques.
Production of polypropylene	Synthetic turf	APME, 1999
Production of polyethylene (LDPE)	Synthetic turf	APME, 2005
Production of polyethylene terephthalate	Synthetic turf	APME, 2005
LPG: Production and Combustion	Synthetic turf	Danish Environmental Protection Agency, 1998

Theme	Stage	Source
Discharge of Class 2 waste	Synthetic turf Equestrian floors	Ecobilan
Production of chalk	Synthetic turf	Swiss Federal Office of Environment, Forests and Landscape (FOEFL or BUWAL)
Production of scrap metal	Foundry Steelworks Cement works	International Iron and Steel Institute - 2005

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