LCA OF ROADS ALTERNATIVE MATERIALS IN VARIOUS RECYCLING SCENARIOS

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ABSTRACT

Large quantities of wastes are produced in road and metallurgical industries and their recycling in roads allows saving non-renewable natural resources, reducing waste storage or landfilling and promoting local economies. Usually, the processes of materials production (primary production) are assessed by LCA practitioners and their production for recycling purposes (secondary production) is taken into account only through their processing and their transport phases. The phases of life cycle corresponding to stockpiling and use in the pavements and then potential release of pollutants to water are in general considered to have no impact counted in LCA. The data come from available standard leaching tests (as shown in http://ofrir2.ifsttar.fr) and pollution of water is controlled by regulations as it is the main reason for not using waste in France due to potential release of pollutants to water. This paper presents an approach for the environmental impact assessment of alternative materials, dealing with emission of pollutants to water during their life cycle phases in roads, mainly, stockpiling, recycling or landfilling. Different scenarios are then investigated using life cycle assessment to compare the variations of both toxicity and ecotoxicity indicators used in LCA. A comparison with the material processing on the industrial sites is also proposed to discuss the indicator range results and to think about the opportunity to add these sub-systems to road LCA tools.

INTRODUCTION

Society produces today a large volume of industrial wastes whereas their continuous increase requires strategies to recover and recycle these materials since their disposal by landfilling is limited by decreasing availability of space, and increasing cost of disposal. Recently in France, significant decisions for sustainable development have been taken, especially after French Grenelle 1 and 2 laws *(1,2)* that have provided for the incentive to recycle alternative materials locally. Recycling provides hence a number of benefits and LCA is actually improved to assess resources saving. It allows to: conserve natural resources, reduce waste volumes, lower materials construction cost, reduce transport demand, while energy consumption has to be assessed as well as other impacts of these materials during their life cycle.

Regarding pavements LCA framework this paper deals with alternative materials assessment, including their leaching properties and associated impacts when subjected to rainfall. Several indicators are therefore calculated at the material scale or at the road scale, to set the range of possible toxic and ecotoxic effects. These effects are highlighted focusing on materials processing (quarrying, milling), materials transport, materials stockpiling, materials landfilling and materials use in pavement layers. The range of impacts obtained according to various life cycle scenarios including recycling/landfilling and natural aggregates (or sand) use is investigated in order to clarify the necessity of taking into account the leaching of pollutants from alternative materials to water when proposing LCA models. As the available data are scarce to assess these broad questions for one material along its whole life cycle, and because we had no idea of the value of some indicators for some scenarios, several materials and their partial LCI data were considered, just to point out the issues of this topic and if it is valuable to go on with release of pollutants from alternative materials to water, actually not implemented in LCA for the use phase.

CLASSICAL LCA WITH LITERATURE DATA

Available LCI Data for LCA Considering Alternative Materials for Roads

Based on SETAC guidelines *(3)*, LCA typically involves one or both of the following objectives:

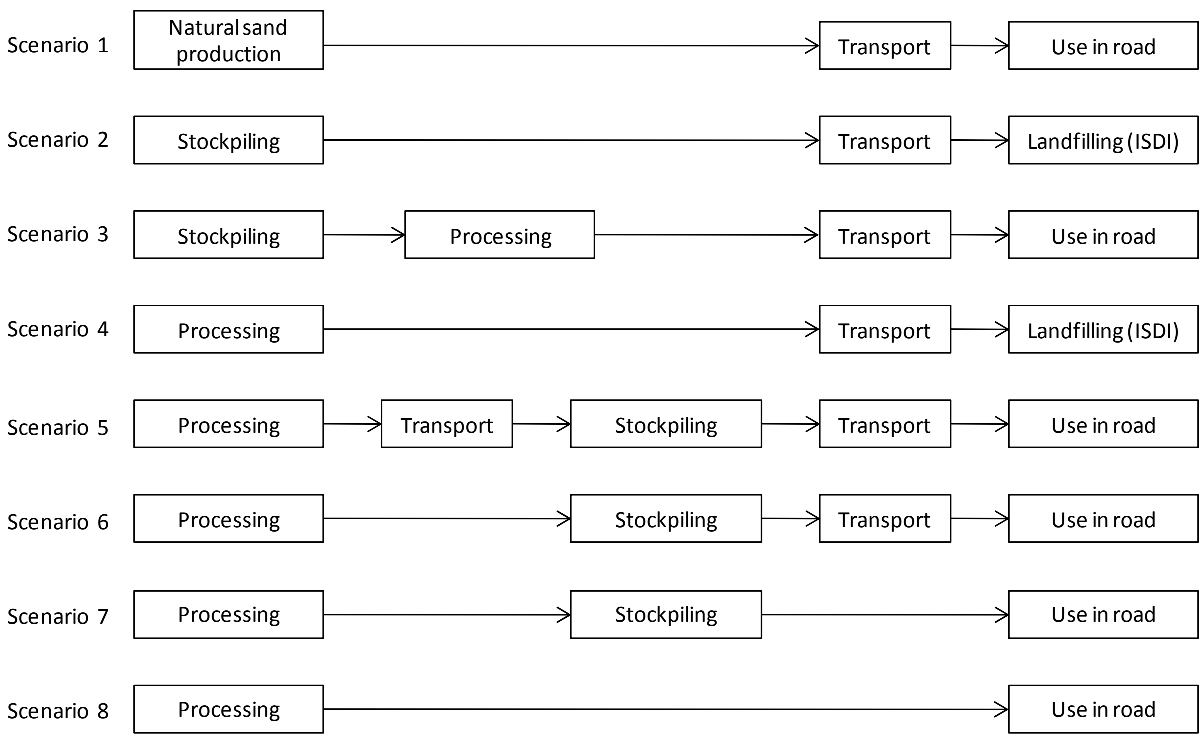
- Compare products (or processes). In that case, chosen systems only include materials, processes and life cycle steps, that may induce differences between compared products (or processes) ;
- Provide environmental information (for public and/or private organizations). Here, chosen systems may be much wider.

According to some authors, LCA is also a diagnosis tool that enables to improve the global environmental profile of any system considered. It may be decomposed into successive levels that depend upon the authors: 1) system description, 2) elementary process, 3) flux calculations, 4) build the appropriate model, 5) analyze and interpret the results and do the report. The system usually gathers all the elementary processes (sub-systems) that are defined as the "smallest unit of the system" with inputs and outputs related to the industrial operation of interest *(4)*.

Then, to improve data collection related to the stock phase and road use, a literature LCI survey was performed within the national project called OFRIR (acronym of Observatoire Français des Ressources dans les InfRastructures de génie civil). This project, funded by ADEME (French governmental agency), was developed with INERIS and the CEREMA laboratories, that is, a wide panel of practitioners and researchers. OFRIR gathered experts in the field of roads and LCA to collect environmental data on materials, LCI data and road LCA results and practice. This project, providing a database (http://ofrir2.ifsttar.fr *(5)*), was developed to check alternative materials properties for use, regulations and standards and their LCA practice. The web site *(5)* is presenting namely a detailed state of the art on LCI of alternative materials and leaching properties knowledge. It also revealed, concerning the literature overview performed at the international scale on alternative materials, that quite no data are currently available for the impacts of pollutant emissions from alternative materials during use and stockpiling phases.

Scenarios Considering Alternative Materials

Several combinations of subsystems could provide various road scenarios to assess. They include alternative materials use in road (use phase), stockpiling (temporary stocks) and landfilling (called ISDI in France). Figure 1 indicates the possible scenarios of interest and how they can be compared to other life cycle parts: i.e. to the resources processing and transport. Then depending on the field data available that involve various alternative materials this panel of scenario is investigated in this study to set the basic knowledge on this topic.



Scenario 1: elementary phases (sub-systems) for natural sand; scenarios 2 and 3: elementary phases for industrial wastes; scenarios 4, 5, 6, 7 and 8: elementary phases for road wastes

Figure 1: The different scenarios for alternative materials use or not in roads.

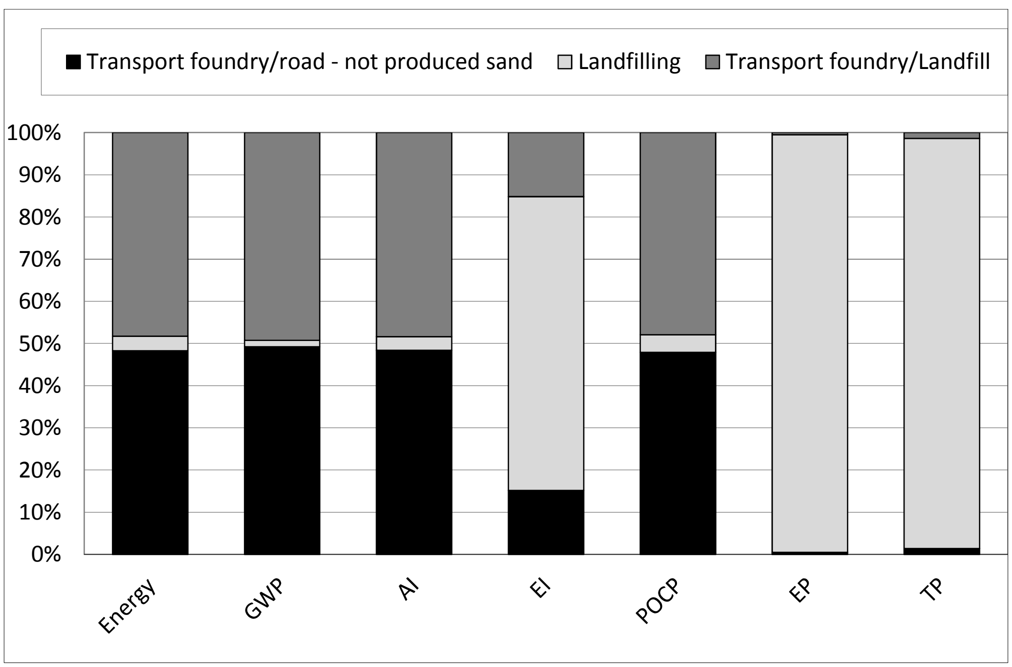
Setting the Pertinence of the Indicators with a Case Study Using Foundry Sand (FS)

According to the scenario of Figure 1, a case study with foundry sand is first considered to highlight the actual situation of alternative materials LCA in terms of impacts pertinence. Data from a field experiment are analyzed to assess the transport and resources saving/consumption. This case study shows classical LCA and does not take into account the use phase in the road, namely release of pollutants from alternative materials when in contact with water. It is based on published data *(18)*.

The case study considers the new plan of the secondary road under rehabilitation (RN 80), which involved the movement of 135,000 m^3 of earth, including 35,000 m^3 of crushed rock. More than 17,000 tons of waste foundry sands were treated with the hydraulic binder (cement) to constitute the sub-base layer to a thickness of 46 cm. The layout was as half-road or full width according to zones. The bituminous cover is a total of 18 cm thick: 10 cm of high modulus asphalt (EME), 6cm of bituminous concrete with high modulus (BBME) and 2.5 cm of very thin bituminous concrete (BBTM). This structure studied here considers only 3,000 tons and was based on sizing hypotheses accounts for the nature of the sands treated with hydraulic binders and the mechanical class of the material (class 4) constituting it to achieve minimal bearing capacity required (PF3, AR1, modulus>120 MPa). The treatment with hydraulic binder is a means to achieve the required performance with the calculated road size. The calculations proposed take into account the paving phase and the equipment working for this purpose.

Waste foundry sands present a gap-grading analysis close to 0/2 mm with more than 80% as fines (<0.5 mm). They are relatively homogenous across the samples. The addition of clays (kaolin, bentonite) in the manufacture of moulds results in a high burned clay content as revealed by the methylene blue test [VBS; French standard NF EN 933-9]. Values ranged from 0.3 to 0.8 g of methylene bleu absorbed per 1 kg of 0/2mm sand. The water content gave highly variable results because of the high content of fines and their storage conditions: outdoors and not covered. Water content got up to 20%, but was generally around 12 to 13%. The foundry sand material properties as calculated here (with sand from foundry plant in Autun, France) allow for its use in road layer.

LCA was performed using *Ecoinvent* database *(7)* and CML indicators with classical hypotheses for alternative resources (no impact for processing, stock and use) and plotted. Figure 2 shows in % the comparison of transport from foundry to road, from foundry to landfill and landfilling alone.



GWP: Global Warming Potential; EI: Eutrophisation Index; AP: Acidification Potential; POCP: Photochemical Ozone Creation Potential; TP: Toxic Potential; EP: Ecotoxic Potential

Figure 2: Comparisons of scenarios for FS life cycle (RN80 case) with *Ecoinvent*.

As shown on Figure 2, landfilling exhibits significant Eutrophication (EI), Ecotoxic potential (EP) and Toxic (TP) impacts, showing that it is sound to consider these impacts for mitigation. Hence, this validated that release of pollutants from alternative materials to water for landfilling is important to study for further investigation on alternative materials. Further, Table 1 highlights in details the main results of the foundry sand (FS) road section: transport, landfilling and natural sand elaboration for the studied section of road RN 80. The results reveal the importance of transport for this resource when compared to unproduced natural sand. Finally, FS recycling seems interesting to use in a road layer replacing raw natural sand considering these sub-systems. Landfilling is very impacting if we consider TP and EP values.

Table 1: Comparisons of Impacts Range for Various Scenarios of RN 80 (3,000 tons of FS used)

Indicators	Units	Transport of FS (30km)	Landfilling of FS	Total Landfilling+ Transport of FS (30km)	Unproduced Natural Sand[1]
Energy	MJ	39225	942	40167	180
GWP	kg Eq CO_2	2737.5	28.77	2766.3	7.26
EP	kg Eq 1.4 DCB	325.50 E+03	2.17E+07	2.20E+07	5.04E+03
TP	kg Eq 1.4 DCB	245.6	5700	5945.6	6.9

[1] Unproduced natural sand: LCI for natural sand production

LCA WITH NEW DATA INCLUDING ALTERNATIVE MATERIALS

Impacts Calculation and Release to Water Tests Performed

The calculation of impact indicators is performed in accordance with an ecodesign tool (http://ecorcem.ifsttar.fr), according to a model explained in a previous work by Sayagh *(8)*, is described as:

$$Ind_j = \sum_{i=0}^{i} \alpha_{ij} \times C_{ij} \times m_i \quad (1)$$

Where:

Ind_j, indicator associated with impact category j; m_i, mass of inventory flow i (kg) corresponding to release of pollutants to water ; C_{ij}, contribution coefficient of inventory flow i to impact category j; and α_{ij}: classification coefficient (from Goedkoop, 2001 *(9)*). Each indicator is expressed in specific units per kilograms or tons. The contribution coefficients selected from the literature and implemented for the impact calculations, based on Equation (1), and the chosen impact categories (and indicators) derived from classical LCA comprise all references given in *(8) :*

Energy consumption: the specific energy consumption of each piece of equipment; Global Warming Potential (GWP), from IPCC *(10)*,

Toxic and Ecotoxic Potentials (TP and EP), from Huijbregts *(11)*.

Figure 3 shows the various tests performed to characterize water release and toxic and eco toxic effects as rainwater may leach chemicals elements from alternative material either during handling and stockpiling before recycling or due to infiltration through the pavement surface containing recycled materials. Analyses of raw materials were conducted at the laboratory to determine the presence of various compounds and elements with hazardous characteristics. The leaching of heavy metals and polycyclic aromatic hydrocarbons (PAH) from asphalt materials and pavement has been investigated.

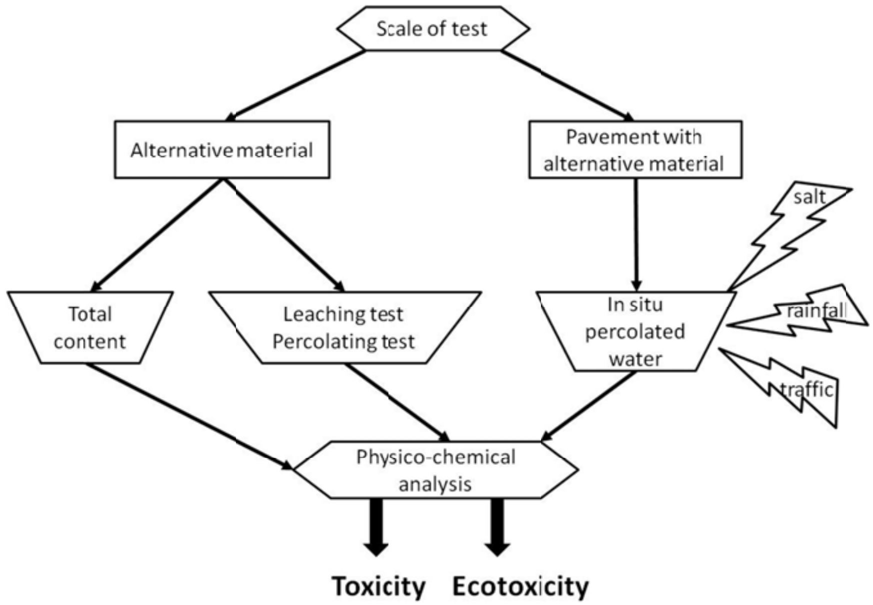


Figure 3: Experimental data collection at various scales –materials and pavements.

The leaching tests were done on crushed aggregates according to both NF X 31-210 (3x16 hours) *(12)* and NF EN 12457-2 (24 hours) *(13)*. The test consists of extractions of the material at liquid on solid ratio (L/S) equal to 10 by specific mixing. The percolation test is column extraction test that runs in up-flow mode. Seven eluate fractions were collected within the range of L/S 0.1-10 L/kg according to CEN TS 14405 *(14)*. In both tests, the leachant is demineralized water and the particle size is smaller than 4 mm. The percolating tests are performed on the milled aggregates directly without any additional preparation.

Materials Studied

The alternative materials investigated were municipal solid waste incinerator (MSWI), milled recycled asphalt pavement (milled RAP), foundry sand (FS) and blast furnace slag (BFS). The pavements assessed were a section of RN76 (a national French heavy traffic road in a rainy area) (RN76) made of asphalt without reclaimed asphalt pavement RAP (RN76 0% RAP) and another section of RN76 made of asphalt containing 20% of RAP (RN 76 20% RAP).

<u>Natural Aggregates *(15)*</u>:
Aggregates are produced with respect to their potential use, so as to match the required grading and thereby ensure marketability. Rock hardness is one of the geological properties that lead to a raw material classification, provided aggregate use properties are determined through laboratory testing. As regards the environment and depending on the types of operations performed, a quarry site is capable of generating various impacts as a result of raw material transformation. Such impacts are directly correlated with electricity consumption, emission releases into the air and water, and waste production, all of which are assumed to represent total environmental impacts. A previous article intended to describe a methodology capable of quantifying environmental loads at the scale of a quarry site for 3 different rock types *(14)*. The upstream process incorporated for the LCA of aggregate production is located in the extraction area inside the quarry, while the downstream process was the washing plant. The shortest representative period of production plant operations was found to be one week. The

obvious production unit to adopt, as regards economic considerations, was per ton of processed aggregates for a given grading sold, according to a scenario identified as a grading set obtained at the plant outlet.

Processed RAP aggregates *(16)*:
The industry has provided an LCI in France for processed aggregates, including crushing and cribling phases. It is given in Table 3. The system associated with this LCI is including upstream energy just like in the quarried natural aggregates. Hence as shown the energy spent by ton is close for natural aggregates *(15)* and processed RAP *(16)*.

Processed BFS aggregates *(17)*:
This study focused on the environmental assessment of several grading for Blast Furnace Slag (BFS) aggregates, in considering two production scenarios at a single site. Devoted to just one BFS site and implementing the method based on mass flows within the site, the principles of this assessment depend on whether aggregate paths are adapted to modeling the paths of any aggregate production process *(17)*.

Milled RAP aggregates *(18)*:
RN 76 RAP considered herein is produced of demolition of an old pavement (one lane of 3.5m width) using a milling equipment of 1.5 m width. Then the milling machine is considered to produce either RAP at the size required for direct recycling (milling speed of 10 m/mn) (Milled RAP -Table 2) or that will be stocked and crushed before use (milling speed of 31 m/mn). Consumption for the milling equipment are expressed as a function of the milling duration for a given layer thickness. No upstream energy linked to energy production is taken into account in *(18)* data that are only linked to the milling machine consumption

Foundry Sand *(18)*:
Foundry sand consists primarily of clean, uniformly sized, high-quality silica sand or lake sand that is bonded to form moulds and cores for ferrous (iron and steel) and nonferrous (copper, aluminum, brass) metal castings due to its thermal conductivity. In foundry, the sand is reused several times by regeneration. When it can no longer be reused in foundry process, it is removed from the foundry and qualified as waste foundry sand (FS). Then it is tested, analyzed and stockpiled and starts another life.

EP and TP Calculations for Alternative Materials Stockpiling and Use in Roads

As described on Figure 3, two scales of tests were investigated: material scale (alternative materials) and pavement scale (pavements containing alternative materials). Table 2 presents resulting impacts considering directly leaching and percolation results at the laboratory and in situ. The scenario names of the second column define the subsystems concerned by the calculation. It is indeed a first step into modelling that gives orders of magnitudes. The results show that for toxicity potential (TP) and eco-toxicity potential (EP), the maximal values are obtained for leaching tests performed on powder. Hence as the release depends on the higher exchange surfaces between the crushed materials and the water, we can consider that they are the upper limit that can be reached for TP and EP as regards leachates. The TP results obtained for 0% RAP and 20% RAP (milled from RN76 and used in the new pavement) in situ are so low that it can be concluded that they are not significant. In Table 2, the release of pollutants from alternative materials in roads to water does not include winter-maintenance effects due to salt. Only RAP effects are investigated (winter periods were removed), and cumulated leachates from the road pavement are considered. As expected, percolating gives lower release than leaching (about 10 times less). This shows the sensitivity of indicators like EP and TP to various scenarios and materials. Finally the value of EP for a one year in situ follow up is close to percolation test results on aggregates.

Table 2: EP and TP Values Obtained for Different Scenarios Studies by Ton of Material

kg éq. 1.4 DCB	**Scenario**	**Type of Test**	**MSWI Aggregates *(5)***	**Milled RN76 RAP Aggregates *(16)***	**RN80 *(19)* FS**	**RN76 *(16)* 0% RAP**	**RN 76 *(16)* 20% RAP**
TP	Stock potential (lab test)	Leaching (powder)	3.02	9.42	0.043		
		Percolating (aggregates)		0.31			
	Use (1 year)	In situ (pavement)				0.049	0.028
EP	Stock potential (lab test)	Leaching (powder)	490.11	748.00	546.66		
		Percolating (aggregates)		50.60			
	Use (1year)	In situ (pavement)				72.1	71.5

EP and TP calculations for Materials Processing

Table 3 gives the indicators results considering French case and data used for different materials processes. Hence, detailed calculations were evaluated before considering any of the upstream processes tied to: 1) indirect impacts of electricity production deriving from nuclear plants and explosives production; 2) indirect impacts of fuel production in the case of BFS and milled RAP.

Table 3: Comparisons of Impacts Range for Indicators for 1 ton of Materials

Indicators	**Units**	**Quarried Natural Aggregates *(15)* – with Upstream Energy**	**Processed RAP *(16)*-with Upstream Energy**	**Processed BFS *(17)*-Without Upstream Energy**	**Milled RAP *(16)*-Without Upstream Energy**
Energy	MJ	48.5	47.4	15.6	18.9
GWP	kg Eq CO_2	2.2	2.6	1.5	1.5
TP	kg Eq 1.4 DCB	0.21	1.59	0.12	0.18
EP	kg Eq 1.4 DCB	48.8	323	26.5	33

Comparing Table 3 and Table 2 reveals that the range of EP variations is very important and dependent upon the energy mix introduced in the database as upstream process (Table 3). Further investigation is in progress on alternative materials to better check the range of EP and TP and therefore introduce in the LCI database more complete life cycle phases.

CONCLUSIONS

This study investigated extended scenarios to characterize alternative materials use and assess them along road life cycle. This idea led to consider the impacts of their use and stockpiling phases. In addition their processing phase is examined as well, although usually not considered in general LCA tools, but indeed considered by road LCA practitioners in France. We thought before this study that completing the life cycle assessment with stockpiling and use subsystems may improve the comparisons between classical solutions and recycling solutions.

The study was then devoted to propose a method based on a wide data collection focused on leaching of pollutants to water from several alternative materials, allowing such assessment. Hence the indicators classically used in LCA were first investigated considering a road made with FS (RN80). Landfilling ecotoxicity and toxicity were found very high: EP of 2.17 E+07 and TP of 5700. These 2 indicators were then chosen for the study to assess recycling, which is the basic variant of landfilling. For the first road case investigated (RN80) that consider foundry sand, simulations with *Ecoinvent* showed that the highest impacts values of the whole studied sub-systems in the paper (see Figure 1) were those of landfilling according to *Ecoinvent* database.

For all the selected alternative materials, for which available leaching data are known, calculation was performed for EP (ranging from 50.6 to 400) and TP (ranging from 0.0028 to 9.42) to think how to assess stockpiling and use scenario. The alternative materials processing were also assessed for other materials (natural aggregates, RAP, BFS. The latter EP (26.5 to 323) and TP (0.12 to 1.59) exhibit moderate impacts when compared to landfilling just like stock and use phases. As for road use and stock phases, additional data should be collected to increase the set of results using this methodology and to refine the model giving stockpiling and long life use impacts. The international literature does not give such kind of results for this purpose (LCA of stockpiling and use phase) to our knowledge. Local data are still collected to increase our database on the topic.

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