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A global methodology for sustainable road - Application to the environmental assessment of French highway

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ABSTRACT

Road construction and maintenance have to be examined not only considering economical and technical factors as it is usually done, but also from an environmental point of view. In this area, natural aggregates as well as bitumen and cement are widely consumed and therefore constitute natural resources to be preserved. Road construction and maintenance processes have to be taken into account in terms of energy and materials consumption as well as emissions towards environment.

In order to perform a global road assessment including environmental approach, the Life Cycle Assessment (LCA) standard methodology proposes a general framework aiming at evaluating the environmental effects of any product, from cradle to grave. This methodology consists in defining a system and a functional unit (FU) to set a base of analysis. Then, the Life Cycle Inventory (LCI) step, consists in assessing flows inputs and outputs (i.e. consumptions and emissions) within the defined systems boundaries. Finally, the LCI can be completed by a Life Cycle Impact Assessment (LCIA) which evaluates potential environmental impacts using indicators. LCA has been widely applied to manufactured products, and also more recently applied to roads.

Road is typically a complex layered structure of different manufactured materials, each having its own life cycle. An overview of the existing LCI studies of road environmental assessment, lead the authors to the conclusions that LCA methodology cannot be directly applicable to road cases. Therefore, in this paper, a specific model, which is based on the LCA principle, called ERM/GRM (Elementary Road Modulus/Global Road Modulus), is presented. Together with the detailed description of this methodology, its application in a French highway as ERM pavement inventory is presented for highlighting the respective contribution of each kind of industrial process to road construction and maintenance and the role of maintenance work in total consumption and pollutant flows.

KEYWORDS

road, life cycle, inventory, assessment

1 INTRODUCTION

Because roads play a major role in society, road construction and maintenance have to be examined not only considering economical and technical factors as it is usually done, but also from an environmental point of view. In this area, natural aggregates as well as bitumen and cement are widely consumed and therefore constitute natural resources to be preserved. Vehicles traffic pollution has been extensively studied in the last decades in Europe [Boiteux 2001]. Besides, road construction and maintenance processes have to be taken into account in terms of energy and materials consumption as well as emissions towards environment. Both environmental pressures and effects can therefore be studied. For example, natural aggregate consumption for the French civil engineering sector reaches 200 million tons per year for roads alone, out of a total produced of 400 million tons [Michel 1997]. Besides, Life Cycle Assessment (LCA) is a well known standardised methodology [ISO 14040 1997] [ISO 14041 1998] [ISO 14042 2000] [ISO 14043 2000] proposing a general framework aiming at evaluating the environmental impacts of any product, from cradle to grave. LCA has been widely applied to manufactured products, and also applied to roads. Previous studies have been performed in order to propose LCI of typical roads (table 1). However, such studies on French roads [Ventura *et al.* 2003] [Ventura *et al.* 2004] showed that LCA could hardly be adapted as a prospective road life environmental analysis tool, including both structure and maintenance of the road with initial construction.

Hence this study is focused on a research concerning a specific global methodology, devoted, as a first step, to the analysis of road pavement environmental assessment. In this context, a literature survey was first done to analyse the pertinence of the existing LCA methodologies applied to roads. Then, a new developed methodology, called ERM/GRM (Elementary Road Modulus/Global Road Modulus) is presented. Finally, an application of the ERM for one French highway pavement environmental inventory during an analysed period of 30 years, including initial construction and maintenance is detailed and discussed.

2 ROADS AND LIFE CYCLE ASSESSMENT (LCA)

2.1 LCA principles

LCA is a standardised methodology proposing a general framework aiming at evaluating the environmental effects of any product, from cradle to grave. This method is mainly used for (i) comparing products giving similar service during their service life, (ii) highlighting parts of the products manufacturing processes that have major environmental impacts, in order to optimise their influence.

The LCA methodology first [ISO 14040] requires to describe the goal, scope of the study and to define a system and a functional unit (FU) to set a base of analysis. Then, the Life Cycle Inventory (LCI) step [ISO 14041], consists in assessing flows inputs and outputs (i.e. consumptions and emissions) within the defined systems boundaries. Finally, the LCI can be completed by a Life Cycle Impact Assessment (LCIA) step [ISO 14042 and 14043], which evaluates potential environmental impacts using indicators. Several literature studies have been focused on roads LCI and present environmental flows. An overview of hypotheses discussed in literature is given in next section.

2.2 Overview of LCA applied to case studies

Table 1 shows informations on existing road LCI studies. The authors and references deal with three main types of pavement materials (asphalt concrete, cement concrete and mixed) with differences between studied structures. Only references N°3, 6, 8 account for scenarios using recycled material: reclaimed asphalt pavement, blast furnace slag, and crushed concrete waste. Most of the studies consider a 1 km length road section. Cases N° 6, 8 base their analysis on a pavement surface unit. Except for case N°6, road maintenance works are taken into account during the analysed period. That latter varies from 30 years to 50 years. Studies N° 3, 5 consider road end of life, consisting of road demolition at the end of analysed period. It can be seen from this literature review, that the FU of a road LCI study requires many details (i) a length of road, (ii) a complete description of road structure (materials and geometrical configuration of layers), (iii) a period of analysis, and (iv) a description of maintenance policy. This FU implies to precise a lot of numerical values (length, width of road section; number and thickness of layers, materials properties…). Therefore, results of one case study cannot be generalized. Indeed, the change in one parameter value may involve important variations of environmental inputs and outputs ranges, especially because road products are responsible for huge amounts of flows. Furthermore, LCA methodology does not analyse interaction between the products and the territories where they are manufactured and used [Blanc 2000]. Avoiding territory seems difficult to conceive concerning roads, because they are built and remain inside a territory and technical scenarios often depend on territory specificity. Furthermore, LCI takes the product end of life into account, the principle of which is not in agreement with maintenance policies, planned to avoid road demolition, never occurring in France. Finally, from the analysis of these existing studies, it seems that LCI, which is rather a retrospective way of products environmental assessment, could hardly be adapted as a prospective road life environmental analysis tool, including maintenance. If roads environmental assessment is wished to be included in decision making processes, evaluation methodologies must be applicable to most cases, and a modelling tool becomes necessary. In this context, a new tool dedicated to roads, has been introduced in a previous study [Ventura *et al*. 2003].

N°	Analysed Road element	Analyse period	Maintenance works consideration	Analysed pavements	Recycling consideration	End of life consideration	Applied Method Phase	References
1	1 km of length	30 years	Yes	CRC, CS, AC, Semi-rigid,	No	No	LCI	[Chappat & Bilal 2003]
2	1 km of length	50 years	Yes	AC, CC	No	No	LCI	[Lundström *et al*. 1998]
3	1 km of length	50 years	Yes	AC	Yes	Yes	LCI	[Mroueh *et al*. 2000]
4	1 km of length	50 years	Yes	AC, CC	Yes	No	LCI	[Pontarollo *et al*. 2001]
5	1 km of length	30 years	Yes	CRC, CS, Mix, AC	No	Yes	LCI	[Peupurtier 2003]
6	1 m^2 of pavement	40 years	No	CRC	No	Yes	LCI	[Rouwette & Schuurmans 2001]
7	1 km of length	40 years	Yes	CC and AC	No	No	LCI	[Stripple 2001]
8	150x3.8 m^2	(*)	Yes	AC	Yes	No	LCA	[Ventura *et al*. 2004]

(*) This study is for a maintenance work of French road.
***CRC**: continuous reinforced concrete, **AC**: asphalt concrete, CC: cement concrete, CS: concrete slab.*

Table 1. Summary of existing road environmental assessment studies

2.3 Towards a new environmental road assessment method

According to the above discussion the developed tool (Figure 2) is based on: LCA methodology (figure 2 left side), whereas a specific geo-spatial model is proposed for the road (figure 2 right side). Geo-spatial modelling successively includes an Elementary Road Modulus (ERM) analysis and a Global Road Modulus (GRM) analysis. This tool separately considers road layers (each with a given life cycle either closed with demolition for upper layers or opened for lower layers) and road structure. Based on LCI, a chosen elementary road modulus (ERM) is developed to perform an inventory of the whole road structure including construction, exploitation and maintenance. The ERM is a modular road element resulting from traffic considerations and French level of service scenarios. It can be composed of different kinds of road pavement layers or earthwork, with various materials. Hence, road construction and maintenance techniques are modelled. The ERM is fully modular in order to be adapted to many

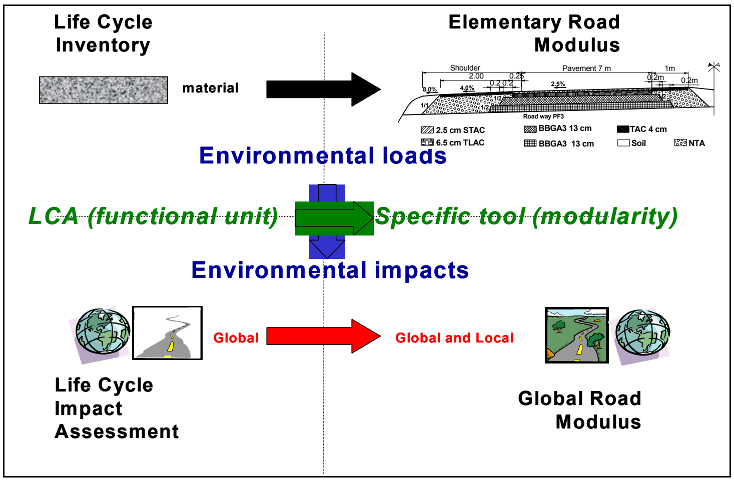


Figure 2: Principle of Road Modulus tool

different cases and, the investigated system includes : road initial construction, exploitation and maintenance. Each period is described through subsystems according to LCI methodology. Hence ERM leads to an environmental inventory of each subsystem input/output parameters. Once environmental loads are determined at the scale of the ERM (either pavement or earthwork at present), a second phase is applied: the Global Road Modulus model. LCIA methodology is considered and adapted to assess environmental impacts. Various kinds of GRM are in progress including indicators that both take into account global impacts and territory aspects. This future development, is not presented in this paper.

3 ERM MODELLING PRINCIPLES

3.1 ERM pavement model

3.1.1 System description

ERM inventory aims at calculating raw materials consumption, energy consumption and pollutant emissions from the following processes (i) raw materials manufacturing and transportation from the processing site to the road works site, (ii) road works equipment used during pavement construction and maintenance. Figure 3 presents the system boundaries of an ERM pavement. All subsystems inside the frame are included into environmental flows calculations. Flows induced by plasticizers, wastes storage and treatment, air entraining agents, and maintenance of equipments, are not included.

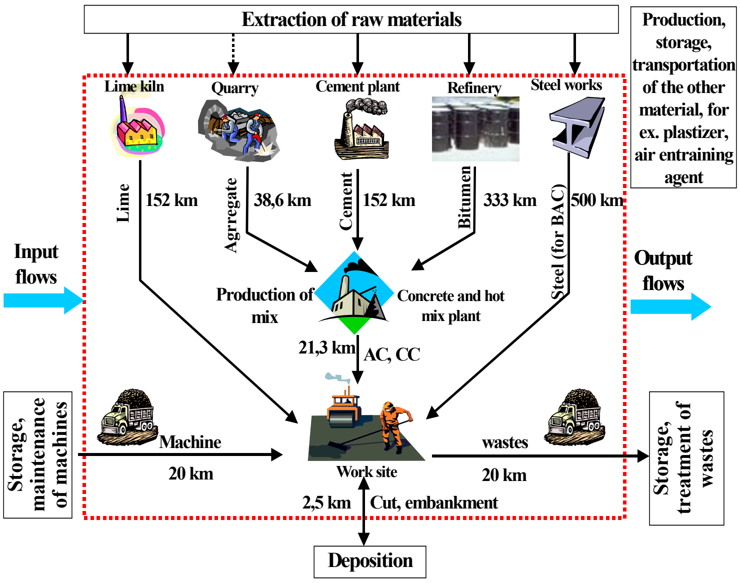


Figure 3. Boundaries and subsystem of the ERM pavement.

3.1.2 Inventory calculations

According to road service life, ERM allows to calculate environmental flows, for long periods of time. As literature available on LCI refers to specific dates, environmental data have to be updated and projected into the considered periods of time of the analysis (present and future). Thus, several assumptions have been set to perform such analysis (i) when several literature data sources were available, their trend with time was examined, (ii) when only one or few literature data sources were available, their time projection has been assumed to follow the Kyoto protocol that is, for the EU, a decrease of the emission of greenhouse gases by 8%, from year 1990 to 2010. Indeed, it is well known that during past periods, consumptions and emissions of many technologies and processes have been reduced. Such trend is then assumed to continue in the future. For years beyond 2010, trend was assumed to be constant and equal to the 2010 values. Figure 4 presents procedure of data harmonisation with time, with 1990 as the reference year. It has been necessary to identify and develop the

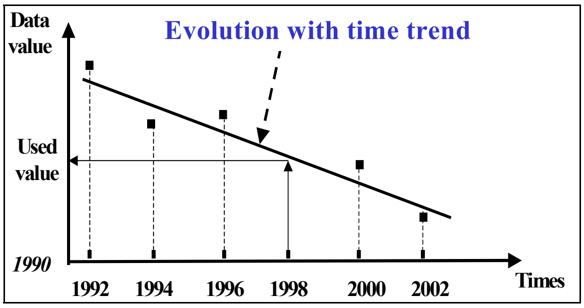


Figure 4. Time harmonisation of environmental data

inventory calculation method for each subsystem of figure 3. Figure 5 presents an example of this method in the case of road equipment engines. These engines are used both at the time of road construction and maintenance. Each equipment running in, has been analysed. Functioning periods of time of road works machines have been calculated from their technical capacities and from pavements characteristics. Total emissions were obtained from unit emissions factors of engines.

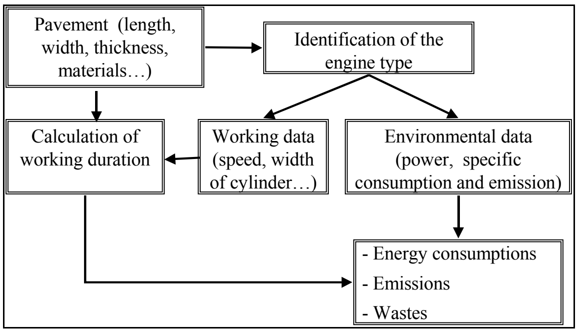
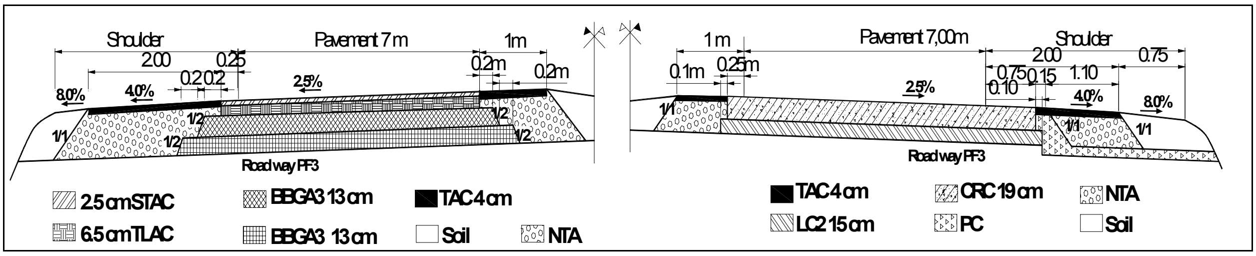


Figure 5. Example for the inventory calculation method- case of the construction engines

4. PRESENTATION OF TWO ERM PAVEMENT CASE STUDIES

4.1 ERM parameters description

An example of ERM application (figure 6) is presented for two different French highways sections of 1 km length, using either Asphalt Concrete (**AC**) pavement or Continuous Reinforced Concrete (**CRC**). Road structures are identified according to the French standard and the technical guidelines [SETRA-LCPC 1998], [LCPC-SETRA 1997] for traffic TC^6_{30} with 2000 heavy lorries by day, by slow lane and by direction. The light vehicles take 80 % of traffic composition, against 20% heavy vehicles; 90% of heavy vehicle are found on the slow lane.



(a) **AC** pavement (b) **CRC** pavement

BBGA3: bituminous-bound graded aggregate class 3, ***CRC****: continuous reinforced concrete, LC: Lean concrete, NTA: non treated aggregate, PC: porous concrete, STAC: super thin asphalt concrete, TAC: thin asphalt concrete, TLAC: thick layer asphalt concrete*

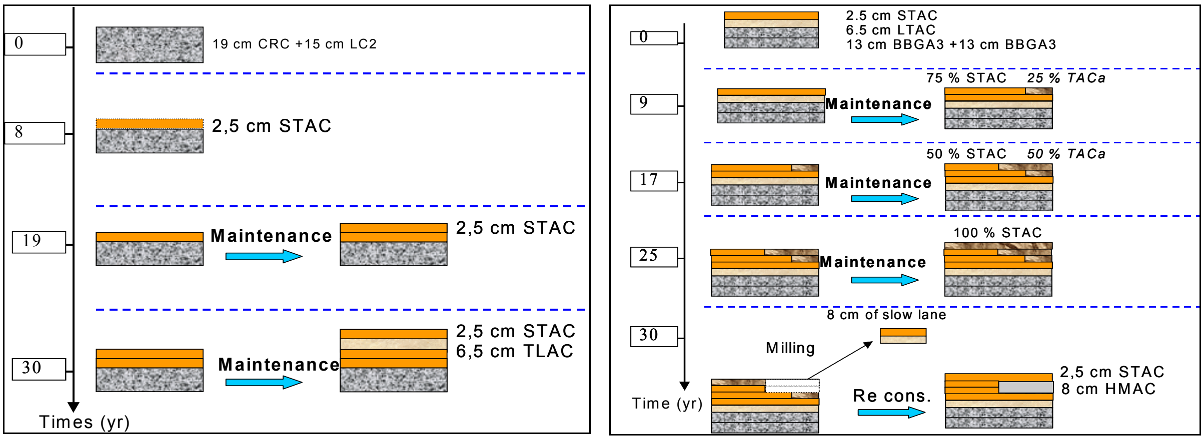
Figure 6. ERM geometrical parameters [SETRA-LCPC 1998]

Pavement materials used to calculate resources consumptions and emissions processes are presented in table 2. Environmental data concerning cements were taken from [St-Laurent cement 2003], [Lafarge Cement 2004], [Taiheiyo Cement Corporation 2003], [WBCSD 2002]. These data account for cements in general, and do not detail any particular product. They were assumed to correspond to a pure Portland cement, although in France, blended cements, that contain mineral additives and thus less clinker, are always used in concrete pavements. Scenarios clearly differentiating types of cements, should be considered in the future as it may influence results of environmental flows.

Materials	Composition (two lanes / 1 direction)
CRC (for CRC layer)	800 kg sand 0/5 + 440 kg gritting 5/10 (Ryolithe) + 585 kg gritting 10/20 (hard limestone) + 1.65 kg plasticizer + 0.06 kg air entraining agent + 325 kg cement CEM II/A32.5 + 145 l water. % of steel surface in relation to the concrete surface: 0.67 %
LC	860 kg sand 0/5 + 935 kg gritting 5/25 silicate -limestone + 1.25 kg plastizer + 0.025 kg entraining agent + 250 kg cement CEM II/A 32.5 + 170 l water.
STAC	Bitument content : 5.62%
TLAC	Bitument content : 5.2%
BBGA3	Bitument content : 4.35%

Table 2. CRC and AC pavement [SETRA-LCPC 1998] [LCPC-SETRA 1997] materials compositions

Roads service life, including maintenance operations, has been implemented in the ERM during a 30 years period of time. Figure 7 (a and b) shows expected maintenance operations for that period. The chosen road construction reference year is 1990, because all available literature data are almost between 1990 and 2002.



(a) **CRC** pavement (b) **AC** pavement

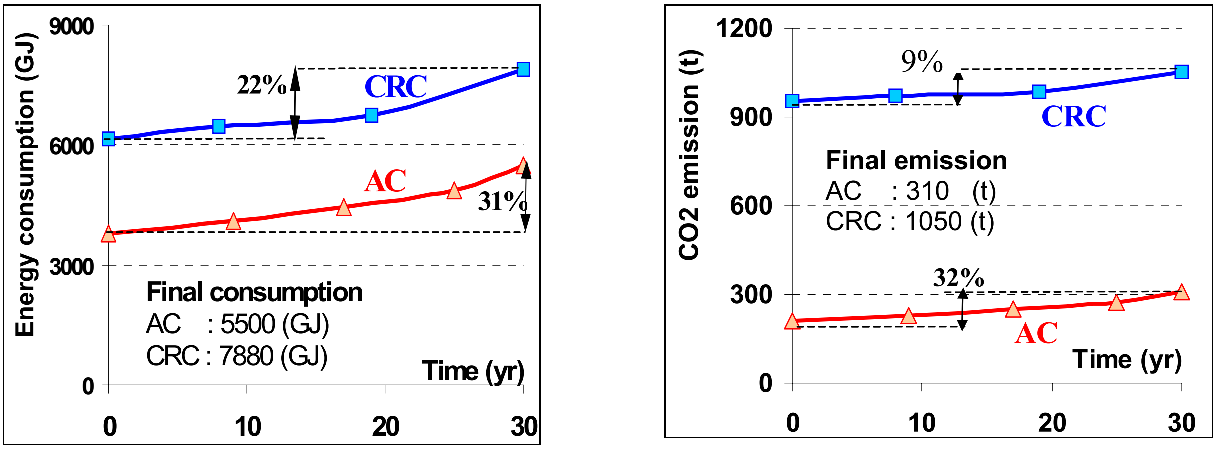
TACa: Thin asphalt concrete class a, HMAC: high modulus asphalt concrete

Figure 7. CRC and AC pavement maintenance description according to [Laurent 2004]

4.2 ERM pavement inventory results

The inventory calculations as well as all the emissions results cannot be detailed in this paper, they will be part of the PhD report of T. Hoang, that will be published in 2005. Hence, ERM inventory only includes: (i) raw materials (aggregates, bitumen, cement, steel) and energy consumptions, (ii) airborne emissions (CO, CO_2, CH_4, Volatil Organic Compounds, NO_x, N_2O, Particulate Matter (PM), SO_2), (iii) water emissions (Dissolved Organic Compounds, Oil(aq) Total nitrogen and Phenol), (iv) wastes (milled aggregates). This paper only presents energy consumptions, CO_2 emissions, and aggregates and bitumen consumptions as natural resources.

Figure 8a presents energy consumptions for both types of pavements. It shows that **CRC** pavement consumes more energy than **AC** pavement, while maintenance road works contribution to energy consumption respectively varies from 22% to 31% of total consumption. Figure 8b presents CO_2 emissions and exhibits a strong difference between both types of pavements. **AC** pavement requires one more maintenance operation than **CRC** pavement, during 30 years.



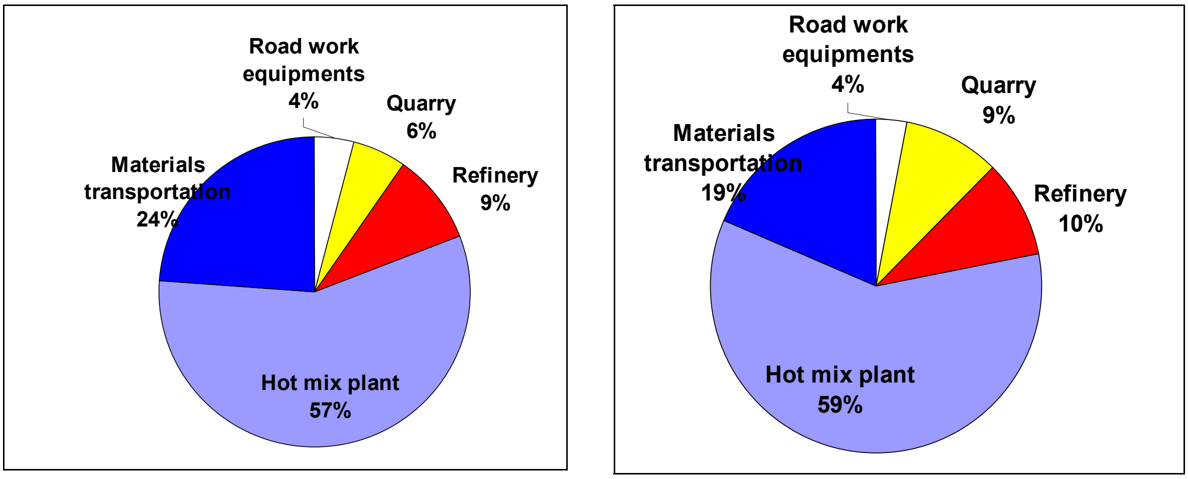
(a) Energy consumption **(b) CO_2 emission**

Figure 8. Energy and aggregates consumption for construction and maintenance works during 30 years

According to the studied scenarios, **CRC** pavement emits almost three times more CO_2 than **AC** pavement. For **CRC** pavement, contribution of maintenance work to total CO_2 emissions is only 9%, which is weak compared to the 32% contribution of **AC** pavement maintenance work. Besides, bitumen was not considered as feedstock energy as in other studies. For instance, according to [Pontarollo & Smith 2001], the primary energy of one cubic metre of asphalt incorporating 20 % Reclaimed Asphalt Pavement (RAP) is 1.62 GJ, while the corresponding feedstock energy is 4.48 GJ. Therefore, to include this amount of energy in the global balance leads to a change by a factor 2.8. This point is highly discussed between experts. According to [Consoli et al. 1993], "feedstock energy is important to be included if the feedstock is a commodity used as a source of fuel", and bitumen is not known to be used as a source of fuel. This possibility may become a reality in the future, and may thus induce specific processes that should then be also included in the system. The "bitumen feedstock energy" question cannot be considered as a simple question and deserves further investigations.

Furthermore, comparing figure 8a and 8b, it can be noticed that the time variations of energy consumption and CO_2 emissions are similar for **AC** pavement, and different for **CRC** pavement. In the case of **AC** pavements, this result is classical because most of CO_2 emissions usually come from combustion processes, which are the main used energy sources in the system. The contribution of electricity power is only 4 % of the total energy consumed by the system. In the **CRC** case, there is no simple relationship between energy consumption and CO_2. In that case, electricity power is also weak: 12 % of the total energy consumption.

AC pavement energy consumption and CO_2 emissions have been detailed by subsystem on figure 9a and 9b, the subsystem repartition is the same. Most of energy consumption and CO_2 emissions are due to the hot mix plant and transportation. Contribution of the quarry to CO_2 emissions is weaker compared to its contribution to energy consumption, because the main source of energy used is electricity power (53%) for that subsystem.

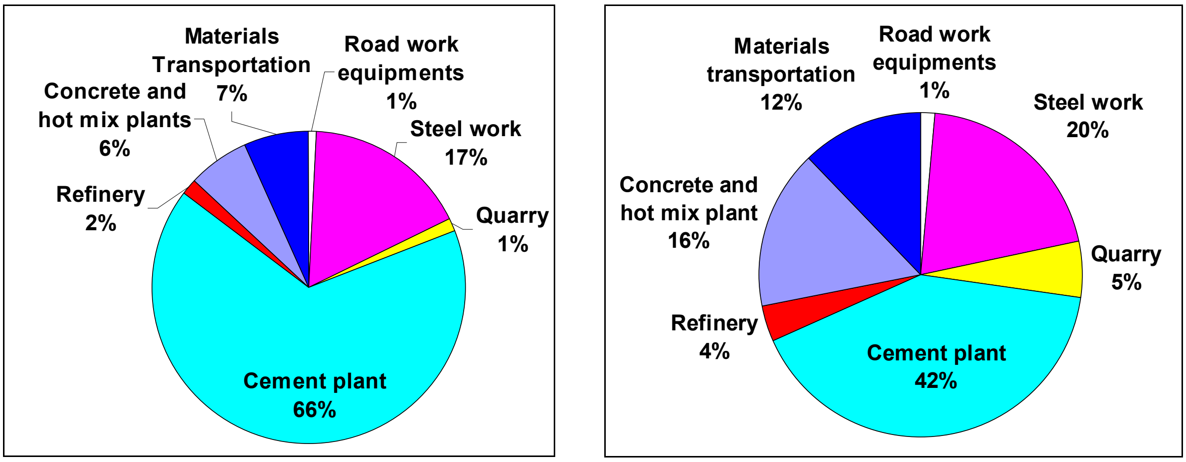


(a) CO_2 emissions (b) energy consumption

Figure 9. Subsystems contributions for AC pavement after 30 years

As for CO_2 emissions (figure 10a), the cement plant contribution to the global system is much higher: 66% of total CO_2. Indeed, in addition to combustion processes, CO_2 is also produced during chemical process of clinker production [Holcim 2004].

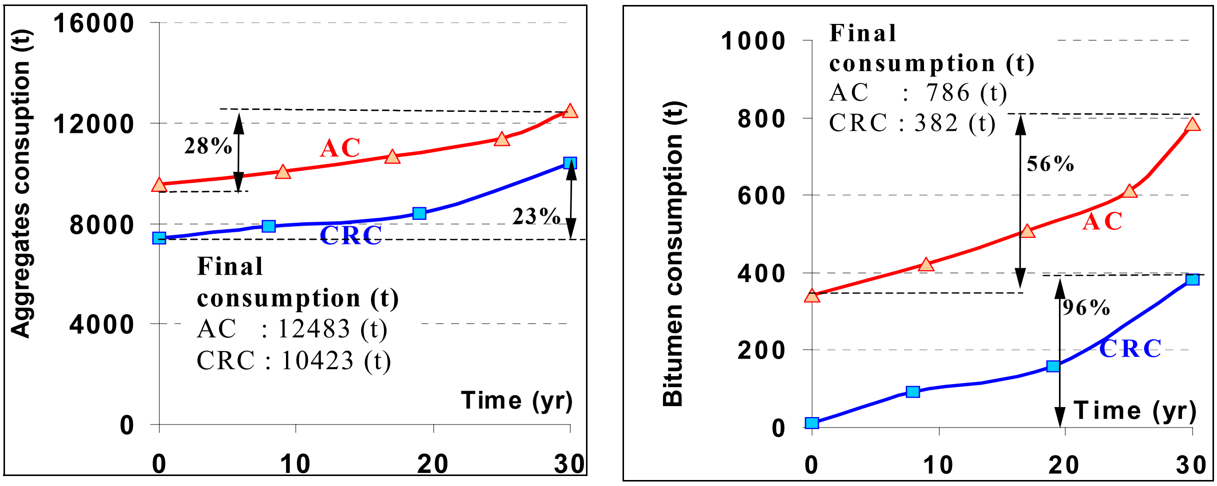
The same results are shown on figure 10a and 10b for **CRC** pavement. Cement plant, concrete and hot mix plants, steel manufacturing and materials transportation consume 90% of energy (figure 10b). The cement plant consumes the most with 42%.



(a) CO_2 emissions (b) energy consumption

Figure 10. Subsystems contributions for CRC pavement after 30 years

Figure 11a presents aggregates consumptions, which is greater for **AC** pavement than **CRC** pavement. This result is opposite to previous results [Ventura *et al*. 2003]. Some changes of the studied scenarios explain such a difference. In this previous paper, pavements structures and maintenance policies followed official French guidelines [SETRA-LCPC 1998]. Here, structures and maintenance have been changed to be more representative of real French conditions [Laurent 2004]. The wearing course of the **AC** pavement has been changed from 8 cm TLAC, to 6.5 cm TLAC + 2.5 cm STAC. Furthermore, the **CRC** pavement structure has also been modified: the cement concrete course is not covered by an asphalt concrete wearing course immediately after construction, but during the first maintenance operation after 8 years. These changes led to an increase of the total aggregates consumption for **AC** pavement and a decrease for **CRC** pavement. Contribution of maintenance works to the total aggregates consumptions is quite important: 23% for **CRC** pavement and 28 % for **AC** pavement. The **AC** pavement bitumen consumption (figure 11b), is logically greater than **CRC** pavement one. First, **AC** pavement requires bitumen during construction whereas **CRC** pavement does not. Secondly, **AC** pavement scenario needs one more maintenance operation than **CRC** pavement. The part of bitumen consumption for maintenance is very important even for **CRC** pavement (96%), because maintenance works always use asphalt to rebuilt surface layers.



(a) aggregates (b) bitumen

Figure 11. Aggregates and Bitumen consumption for road construction and maintenance after 30 years.

By the way, this difference between both studies shows that structures, constructions, and maintenance policies changes can reverse results and provides arguments to the necessity of elaborating a modular evaluation tool, including uncertainty analysis.

5. CONCLUSIONS AND PERSPECTIVES

A new tool for environmental evaluation dedicated to roads, has been developed. Based on LCA methodology, it is entirely modular, and applicable to many different scenarios of road structures construction and maintenance policies. This tool calculates environmental inputs and outputs flows, in a first phase called ERM, called ERM inventory, which has been detailed in this paper. ERM has been applied to two main types of heavy traffic French using **CRC** and **AC** pavements highways and a 30 years analysed period. They are analysed and give the inventory of the following flows: consumed materials (aggregates, bitumen, cement, steel), consumed energy, released airborne pollutants (CO, CO_2, CH_4, Volatil Organic Compounds, NO_x, N_2O, Particulate Matter, SO_2), and released water pollutants (Dissolved Organic Compounds, Oil(aq) Total nitrogen and Phenol). Only energy and raw materials consumptions, as well as CO_2 emission results are presented in this paper.

Energy consumption and CO_2 emissions results highlight that in the case of **CRC** pavement, cement and steel plants are the dominating subsystems. Besides, for the **AC** pavement, the contribution of the hot mix plant is found to be the most significant. Comparing both types of pavements, **CRC** energy consumption and CO_2 emissions are greater than **AC** (bitumen feedstock energy is not accounted for). This is primarily due to the concrete plant contribution that nearly consumes half of the total system's energy and releases extra CO_2 due to the chemical reactions of the elaborating process. Natural aggregates consumption of **AC** pavement is greater than the one of **CRC** pavement. AC pavement also uses more bitumen because it is the main binder used for this kind of pavement.

The presented results only concern chosen examples, and cannot be generalised. They are greatly linked to materials, equipments, and maintenance scenarios, and, as it has already been noticed, scenario changes may invert results. This points out the necessity of conducting uncertainty calculations.

The next step of the methodology is still to be done. It will consist in including other subsystems (electricity production, coal processing…). Relationships between road and the crossed territory are a part of the model still to develop in the form of GRM tool. Coupled to environmental evaluations, external costs are also in progress for a full analysis.

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