The environmental road of the future:
Analysis of energy consumption and greenhouse gas emissions

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ABSTRACT

Road construction companies are aware of the strategic and universal issues associated with sustainable development and wish to make their own contribution to this collective effort, although the last decade has already seen a considerable number of environmental protection measures.

This paper describes the contribution made by road construction as for energy consumption and greenhouse gas emissions. The latter is the main issue for sustainable development. The principal road construction techniques are analyzed (hot asphalt mixes, bitumen emulsion technologies, concrete cement, in place or plant recycling, etc.). The different types of road pavement structure are examined and compared over a thirty year service life from cradle to grave.

The output of this study has driven us to develop an efficient tool to assist in quantifying sustainability in pavement projects. It can be used for research and development of tomorrow structures. Among the techniques, cold mix technologies and in place pavement recycling are promising.

As a last update, in a specific project analysis, the concept of an "ecologiciel" or software to evaluate various alternative solutions in respect of sustainability will be presented.

RÉSUMÉ

Les entreprises de construction routière sont conscientes des enjeux stratégiques et universels du développement durable. Elles souhaitent contribuer à cet effort collectif qui a déjà vu lors de la précédente décennie la mise en place de nombreuses mesures dans le domaine de la protection et la sauvegarde de l’environnement.

Cet article décrit la contribution de l’activité de construction routière en ce qui concerne la consommation d'énergie et l'émission de gaz à effet de serre. Les principales techniques routières sont analysées (enrobés à chaud, techniques à l’émulsion de bitume, béton de ciment, recyclage en place ou en centrale..). Les différents types de structures de chaussée routière sont analysés et comparés sur une durée de vie de 30 ans du « berceau à la tombe ».

Les résultats de cette étude nous ont conduit à développer un outil efficace pour quantifier les aspects du développement durable pour la sélection de structure de chaussée écologique. Parmi les techniques étudiées, les technologies de recyclage à froid ou de retraitement en place présentent les meilleurs scénarii.

Cet article évoquera le cas d’un projet particulier ainsi que les dernières évolutions d’un logiciel permettant l’évaluation de solutions alternatives plus soucieuses de l’environnement.

1.0 INTRODUCTION

In the framework of its policy of sustainable development, the Organisation for Economic Co-operation and Development (OECD) has set a priority for the first ten years of the 21st century on two actions: limiting the impact of industry on climate change and optimizing the management of natural resources.

Road construction companies are aware of the strategic and universal issues associated with sustainable development and wish to make their own contribution to this collective effort, although the last decade has already seen a considerable number of environmental protection measures.

This paper describes the contribution made by road construction in the area of energy consumption and greenhouse gas emissions. The latter is the main issue for sustainable development.

The principal road construction techniques are analyzed (hot asphalt mixes, bitumen emulsion technologies, concrete cement, in place or plant recycling, etc.). The different types of road pavement structure are examined and compared over a thirty year service life.

The entire production and construction process is taken into consideration, from the extraction of raw materials to the end of the pavement's service life, including the phases of materials manufacture, laying for the construction of a new pavement, and maintenance works during its anticipated service life.

The results are an efficient tool that assists in the selection of environmentally-friendly pavements. It can be used for research and development of tomorrow's structures. Among the techniques, cold mix technologies and in place pavement recycling are promising.

In order to illustrate the approach, a specific project is analyzed under this concept and an opening is done on the possibility of a software development to assist the decision process.

2.0 HYPOTHESES AND STUDY COMPONENTS

2.1 Hypotheses for structural design and traffic evolution.

The analyses involve the construction of a pavement and its maintenance over a service life of 30 years. Such a long service life is more in line with the spirit of sustainable development.

As the traffic has a key role in pavement design, the total cumulative Equivalent Single Axial Load (ESAL) is used for comparison.

The pavement structures have been determined on the basis of the AASHTO design guide (1993) (8).

All the new pavement structures have been studied on the basis of the same existing natural soil having a resilient modulus of 7500 psi or 50 MPa. The granular subgrade is a layer of 700 mm sand which are usually used for frost protection in Quebec. This layer has a resilient modulus of 15 000 psi or 100 MPa. Either rigid or flexible, the pavements layer lays down on

150 mm of granular base 0-20 mm. The structural coefficient and the other parameters are the one used by the Ministry of Transport of Quebec.

2.2 Environmental data

The data for the environmental analysis is provided by the relevant bodies or specialized agencies, Eurobitume for bitumen and Athena for cement and steel in the report for the Canadian Portland Cement Association, Swedish Environmental Institute, IVL, etc.

PRODUCT OR TECHNIQUE	Energy (MJ/t)	CO2 eq (kg/t)	Data from
Asphalt	4900	285	Eurobitume
Emulsion (60% residual asphalt)	3490	221	Eurobitume
Cement	4976	980	Athena & IVL
Crushed aggregates	40	10	Colas
Aggregates (pit-run)	30	2.5	Athena & IVL
Steel	25100	3540	Athena & IVL
Water	10	0.3	IVL
Fuel	36680	2765	IVL
Hot Mix Plant	275	22	IVL
Cold Mix Plant	14	1	IVL
Milling /Reclaiming	12	0.8	IVL
Cold in-place recycling	15	1.13	IVL
Laying down of HMA	9	0.6	IVL
Laying down of Cold Mix	6	0.4	IVL
Diamond grinding (m2 concrete slab)	79	5.7	IVL
Cement Concrete paving	2.2	2	IVL
Hauling tm/km	0.9	0.06	IVL

Table 1 : Typical energy consumption and GHG emissions for product and techniques

Pavement construction companies are mainly involved in the manufacture and laying of road construction materials, as shown in the diagram below.

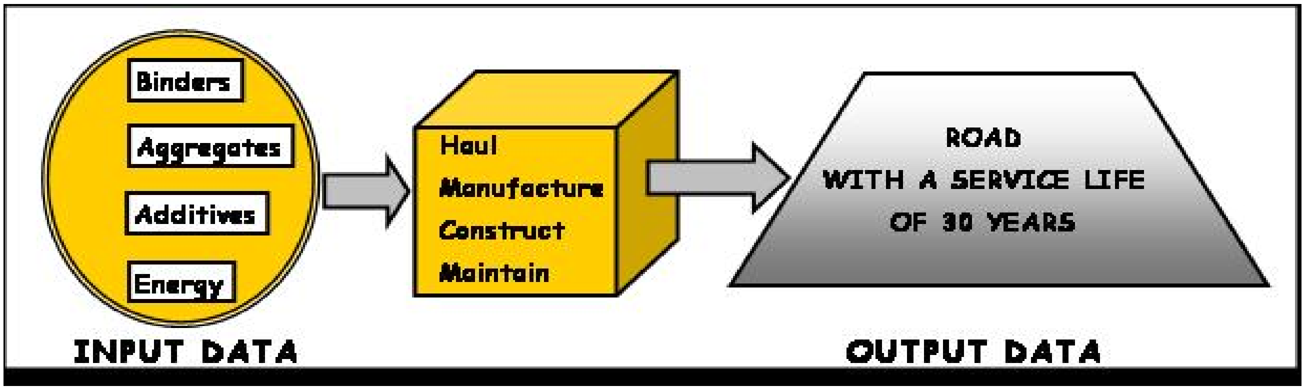

Figure 1: Construction of a road pavement

All the phases and stages of production, extraction, manufacture, transport, laying, etc. that are required to obtain a pavement with an acceptable level of service over the selected service life are therefore considered. The typical values set out the stages and transport distances are taken into account for a road pavement built in Quebec.

To manufacture one metric tonne of mix, the average distances considered are:

- 150 km between the refinery for bitumen production and the mixing plant,
- 150 km between the cement plant and the plant where the concrete is mixed,
- 800 km between the steel factory and the site,
- 5 km between the aggregate quarry and the manufacturing site.

And finally, an average 50 km is estimated for the distance between the manufacturing site and the construction site.

The major well known products, for which data exists, are selected. The data (energy and greenhouse gas emissions) for these products can be obtained from the references. Extreme values are removed, in order to select the ones which seem to be the subject of consensus.

This study will concentrate on energy consumption, materials consumption and greenhouse gas emissions during road construction and maintenance operations.

We shall deal with the different types of available techniques separately.

3.0 ENERGY CONSUMPTION

Energy consumption for the manufacture and laying is studied per metric tonne of manufactured and laid material, per m² of pavement structure built.

3.1 Energy consumption per metric tonne of material laid

Figure 2 shows the total amount of energy required to manufacture and lay one metric tonne of material from extraction of the raw materials to placement at the worksite. Energy is expressed in MJ per metric tonne of laid material.

Comments:

- *“Binders” are counted the energy consumed in order to extract and transport raw materials and manufacture binders (bitumen, cement, modified binder, etc.).*
- *“Aggregates” are counted the energy consumed in order to extract and manufacture aggregates at the quarry.*
- *“Manufacturing” is counted the energy consumed in order to manufacture mixes in a plant or production unit.*
- *“Hauling” is counted the energy consumed in order to transport the constituents and mixes from the plants where the constituents are manufactured to the worksite*
- *“Laying down” is counted the energy consumed in order to lay the material and perform the works.*
- *Cement concrete corresponds to undowelled concrete slab pavements.*
- *In the case of continuously reinforced concrete pavements also includes the reinforcement bars.*
- *As road materials, in particular bituminous mixtures, can be recycled, the energy contained in the binder used in the pavement is not considered as being lost.*
- *RAP refers to reclaimed asphalt pavement.*

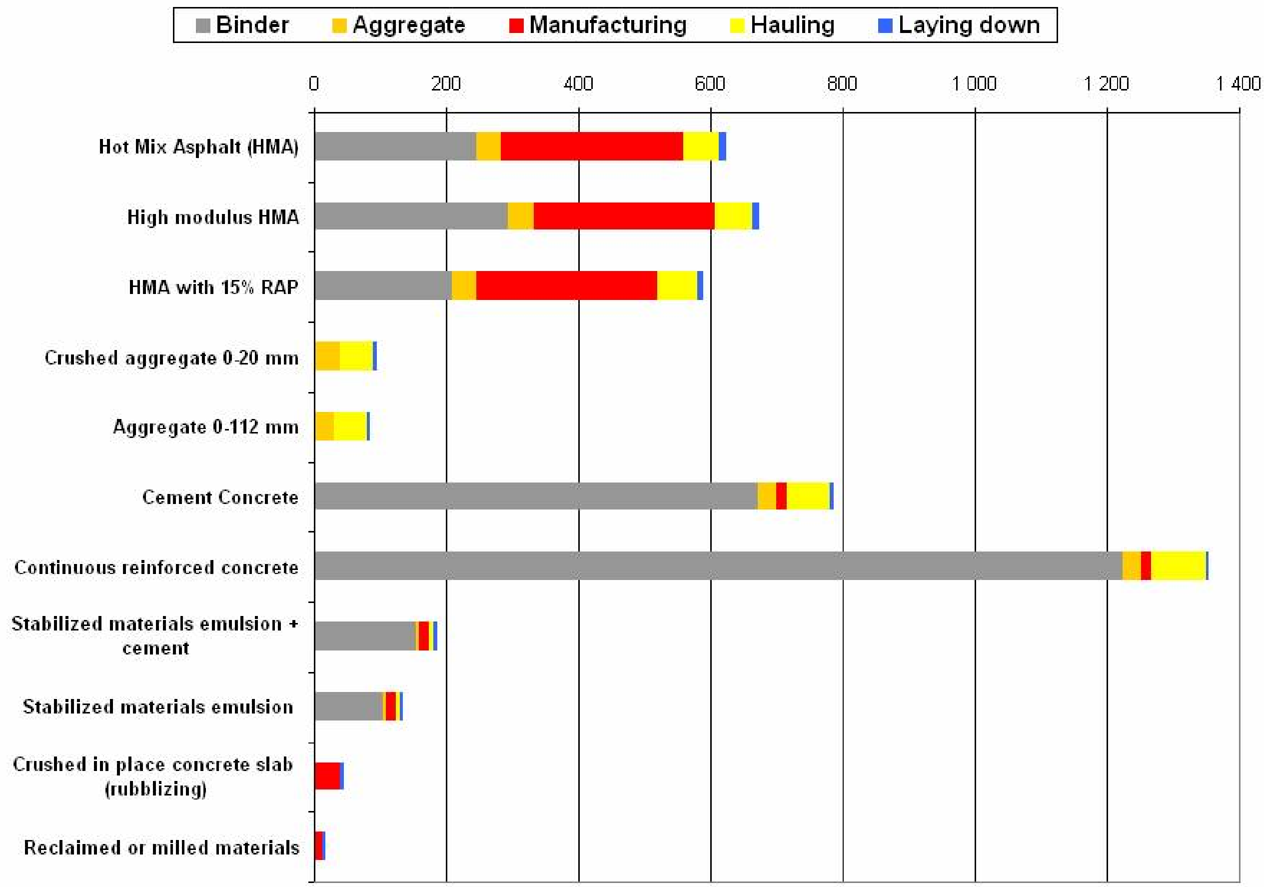

Figure 2: Energy consumption for the manufacture and laying of main road technologies

<u>Conclusion 1</u>

We can see that these technologies fall into five groups:

- Concrete cement: between 750 and 1,350, with an average value of 1000 MJ/t,
- Hot mixes, whether recycled or not: between 550 and 650, with an average value of 600 MJ/t
- Stabilized material in-place: between 150 and 200, with an average value of 175 MJ/t
- Granular foundation with an average of 80 MJ/t
- Materials issued from reclaiming, milling or rubblizing, with an average value of 40 MJ/t

3.2 Energy consumption for each type of structure (construction only)

In order to make an objective comparison, it seems necessary to take into account the real quantities of materials used for the construction of pavement structures with reference to traffic and the same bearing capacity of the existing ground.

Figure 3 shows the total energy consumption for each type of pavement as a function of the traffic (number of ESAL) for the following structure:

⇒ Type 1: Rigid pavement: concrete slab, short with dowel on a 150 mm granular base 0-20 mm

⇒ Type 2: Rigid pavement: continuous reinforced concrete slab on a 150 mm granular base 0-20 mm

⇒ Type 3: Flexible pavement: Hot mix asphalt on a 150 mm granular base 0-20 mm

⇒ Type 4: Rehabilitated flexible pavement: Reclaiming of 300 mm of existing structure, stabilisation with emulsion on 150 mm and hot mix asphalt.

⇒ Type 5: Rehabilitated flexible pavement: Reclaiming of 300 mm of existing structure, stabilisation with emulsion and cement on 150 mm and hot mix asphalt

⇒ Type 6: Rehabilitated rigid pavement into flexible pavement by rubblizing 200 mm of an existing concrete slab and new layers of hot mix asphalt.

Energy is expressed in MJ per m² of pavement structure.

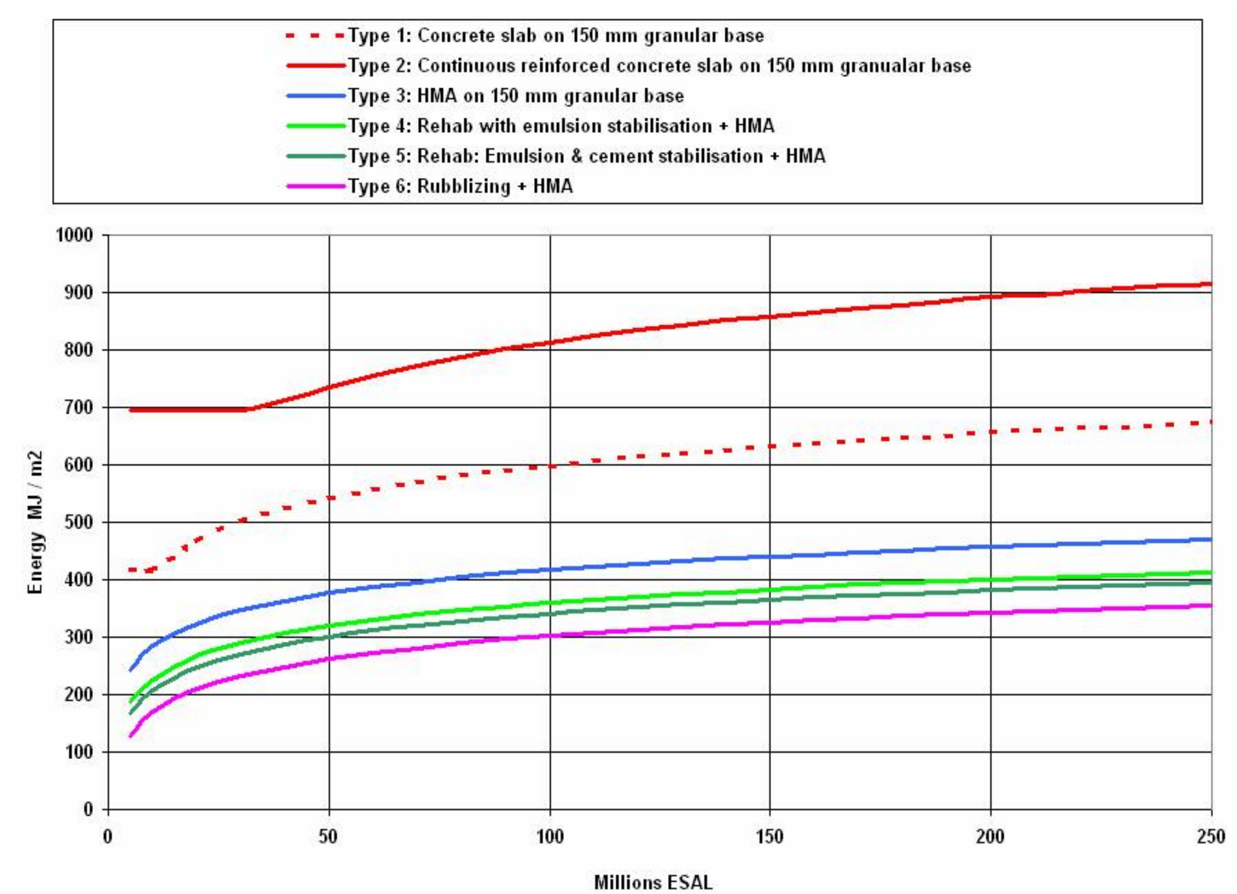

Figure 3: Energy consumption for pavement construction

Conclusion 2

We can see that when the products are included in techniques for an equivalent level of service, we have now only three groups:

- The new flexible pavement (type 3 HMA on 150 mm granular base) is taken as reference at a level of 1.0.
- The new rigid pavement which have an consumption of energy per m2 at a level 1.4 to 1.9 times their equivalent as flexible pavement
- The pavement which can be rehabilitated using reclaiming, stabilisation or rubblizing techniques and a new flexible pavement are at a level between 0.75 to 0.85.

3.3 Energy consumption for each type of structure taking account of maintenance

To allow an analysis over the life of the structure, we need to add the consumption of energy due to the maintenance requirements over a 30 years life span.

We have defined a maintenance schedule based on the schedule of maintenance of various pavement as expressed in "Le guide technique de conception et dimensionnement des chaussées" of SETRA LCPC in France (5), in the Highway design manual- Chapter 605.3 Life-Cycle Cost Analysis (LCCA) of Cal Trans, (6) and in the recommendations of the report on the benefits of new technologies prepared in December 2000 for the Ontario Department of Transportation (7).

Generally speaking, these agencies used a maintenance schedule such a new layer of HMA every 8 to 12 years on flexible pavement, and a surface overlay after 15 years and a partial reconstruction or reinforcement overlay after 28 years on rigid pavements.

We have considered the rehabilitated pavements as new flexible pavements as they are designed for the same life span.

The energy consumption for the maintenance during 30 years is of 161 MJ/m2 for the flexible pavement and 195 MJ/m2 for the rigid pavement.

Conclusion 3

When looking at the energy consumption for the maintenance during 30 years for an equivalent level of service, the results show a higher value for rigid structures at a level of 1.2 compared to flexible or rehabilitated structures.

4.0 GREENHOUSE GAS EMISSIONS

The main greenhouse gases (GHG) in the field of road construction are carbon dioxide (CO_2), nitrous oxide (N_2O) and methane (CH_4). As the contribution of these gases is not the same, their GWP (Greenhouse Warming Potential) must be expressed as a CO_2 equivalent. It is accepted that the GWP of N_2O is 310 and that of CH_4 is 21. That is to say that one kg of N_2O has as much effect as 310 kg of CO_2. Therefore, in order to be able to compare the GHG emission, all the effect of various gases have been reduced in CO_2 equivalent ($CO_{2\ eq}$)

GHG emissions are studied for a metric tonne of material manufactured and laid, and per m² of pavement structure.

4.1 GHG emissions per metric tonne of laid material

Figure 4 shows the GHG emissions for the manufacture of one metric tonne of material from extraction of the raw materials to laying on the worksite. GHG emissions are expressed in kg of $CO_{2\ eq}$ per metric tonne of material.

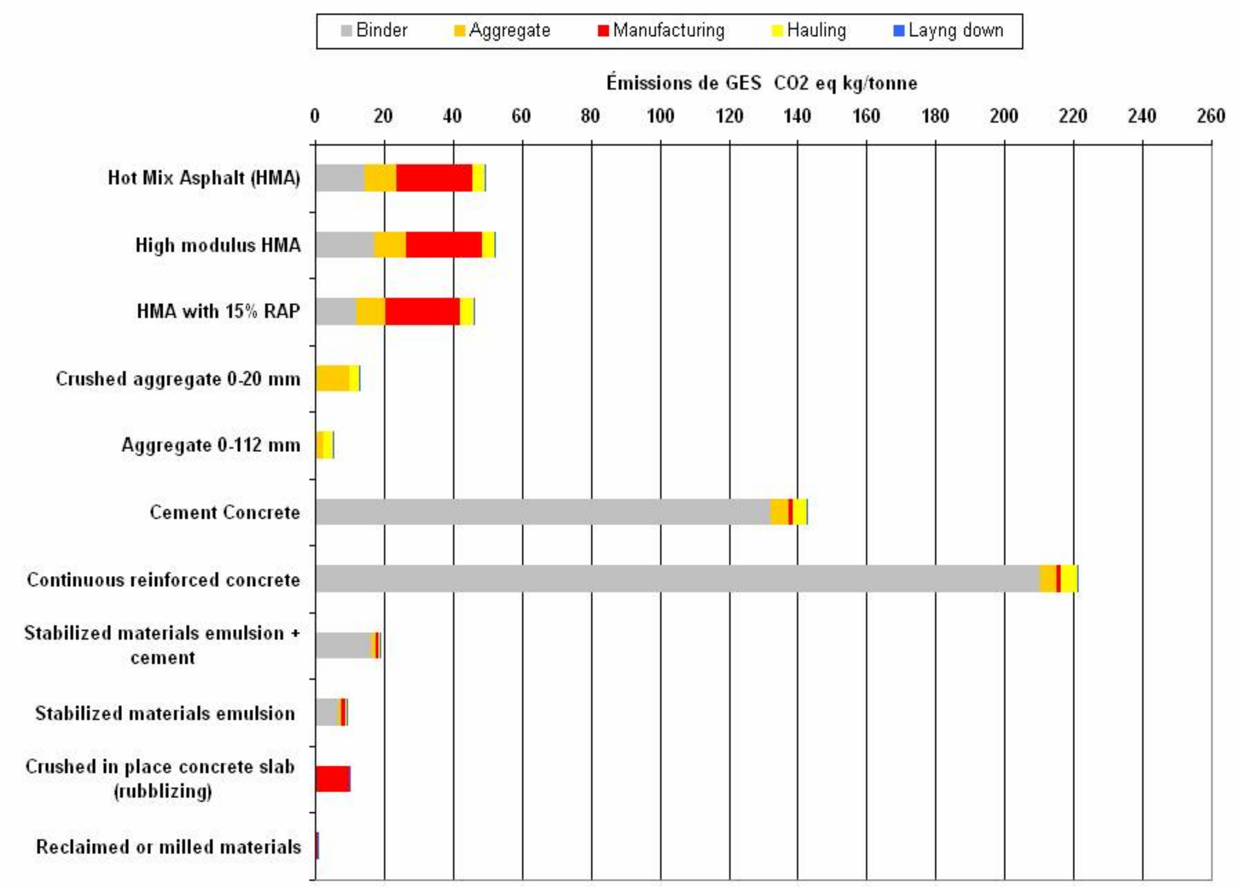

Figure 4: GHG emissions during manufacture and construction for the main road technologies

<u>Conclusion 5</u>

While five groups were identified in the analysis of energy consumption, only three are apparent for GHG emissions

- Cement concrete: 140 to 200 kg/t
- Hot mixes whether recycled or not: 45 to 50 kg/t
- Cold in-place recycling (bitumen emulsion or cement), “as dug” gravel, non treated aggregate base 5 to 20 kg/t,

4.2 GHG emissions for each type of structure without taking account of maintenance

As for energy consumption, in order to make an objective comparison, it seems necessary to take into account the quantities of materials used for the construction of pavement structures with reference to traffic and the bearing capacity of the existing ground.

The pavement structures and traffic levels are those described in paragraph 3.2 of this document.

Figure 5 gives the GHG emissions for one m² of new pavement without taking into account maintenance operations. GHG emissions are expressed in kg per m² of pavement structure.

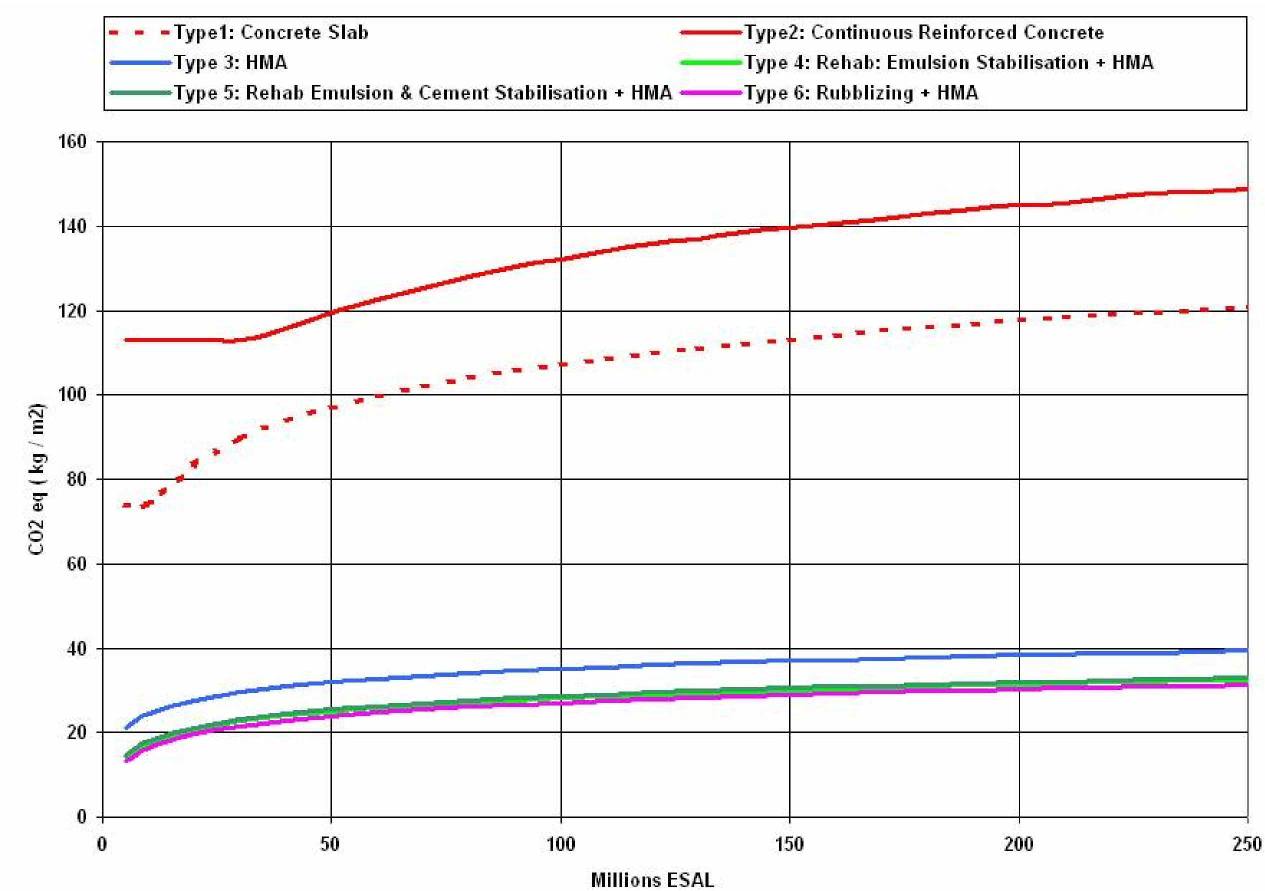

Figure 5: GHG emissions for the construction of pavement structures as a function of the traffic the pavement is expected to carry during its service life

<u>Conclusion 6</u>

We can see that when the products are included in techniques for an equivalent level of service, we have three groups:

- The new flexible pavement (Type 3 HMA on 150 mm granular base) is taken as reference at a level of 1.0.
- The new rigid pavement which has a value of GHG emissions per m2 at a level 3 to 4 times their equivalent as flexible pavement.

- The pavement which can be rehabilitated using reclaiming, stabilisation or rubblizing techniques and a new flexible pavement are at a level of 0.75.

In this case also, we can notice the advantage of recycling techniques.

4.3 GHG emissions for each type of structure taking maintenance into account

We have applied the same maintenance program over 30 years than the one described in paragraph 3.3 above. The GHG emissions for the maintenance during 30 years is of 12.9 kg of CO_{2eq} for the flexible pavement and 18.2 kg of CO_{2eq} the rigid pavement

Conclusion 7

When looking at the GHG emissions for the maintenance during 30 years for an equivalent level of service, the results show a higher value for rigid structures at a level of 1.4 compared to flexible or rehabilitated structures.

5.0 GENERAL CONCLUSIONS ON VARIOUS TECHNIQUES

The principal purpose of this study is to make an inventory of energy consumption and GHG emissions associated with road construction.

On the basis of a 30 year service life (which is in general more favourable to cement concrete structures), whatever the traffic and irrespective of whether construction alone or construction with maintenance is considered, the results obtained in the study lead to the following conclusions:

- For hot mix bituminous pavements, the two main processes responsible for GHG emissions are binder manufacture and mix manufacture. However in the case of cement pavements, the main processes that are responsible are cement manufacture and steel manufacture in the case of reinforced concrete.

- For new pavements, the most polluting structures are Continuous reinforced concrete pavements, and the least polluting are those using recycled asphalt pavement as part of the new HMA.

- For rehabilitation, in place recycling using asphalt emulsion with or without cement addition is a technique that consumes less energy and which contributes less to the greenhouse effect.

- For rehabilitation of rigid pavements, the rubblizing technique with a new HMA structure is by far a technique that consumes the least energy and which contributes the least to the greenhouse effect.

- This life cycle analysis of pavement structures shows the benefits of using bitumen emulsion and high modulus mixes. These techniques make it possible to manage and optimise energy consumption and reduce impacts on the greenhouse effect. Recycling saves materials and reduces transport.

6.0 AN EXAMPLE OF A POSSIBLE ANALYSIS: HIGHWAY 40 MONTREAL

Between 2003 and 2006, highway 40 In Montreal has been completely reconstructed using a continuous reinforced concrete slab. The project length was 16 km (2 x 3 lanes) from the interchange at Côte de Liesse to St-Charles Boulevard,
This part of the highway is one of the busiest road in Quebec and the design ESAL value over a 30 year life is evaluated to be 200,000 000 ESAL.

The chosen design is a 275 mm of Continuous Reinforced Concrete (CRC) slab on 96 km kilometres lane of 3.67 meters, for a total area of 352,320 square meter. As the slab is reinforced with 70 kg of steel per cubic meter, the total quantities required are 96,888 cubic meter of concrete and 6,782 tonnes of steel.

We will compare this CRC design with two other alternate design options with respect of the concept of sustainable development. The other alternate design options could have been a short concrete slab with dowel or a flexible pavement with high modulus HMA.

Design calculation for the same traffic (200,000,000 ESAL) gives the thickness for both alternate solutions in order to fulfil the same structural performance. For the short concrete slab we need a 325 mm thick slab and for the flexible HMA, we need 320 mm of high modulus HMA.

These alternate designs require the following quantities for the same 96 km-lanes project: 114,504 cubic meter of concrete in the short concrete slab alternate solution and 105,696 cubic meter or 270,580 tonnes of HMA for the flexible alternate solution.

The energy consumption and GHG emissions are detailed in the following table 2.

Composition of pavement materials in kg/tonne						
	Crushed aggregate	**Aggregate**	**Asphalt**	**Emulsion**	**Cement**	**Steel**
Continuous reinforced concrete	**410**	**410**	**0**	**0**	**135**	**28**
Cement Concrete	**410**	**410**	**0**	**0**	**135**	**0**
High modulus HMA	**940**	**0**	**60**	**0**	**0**	**0**

Energy consumption by tonne of material MJ./tonne						
	Binder	**Aggregate**	**Manufacturing**	**Hauling**	**Laying down**	**Total**
Continuous reinforced concrete	1 375	29	14	87	6	1 510
Cement Concrete	672	29	14	67	6	787
High modulus HMA	294	38	275	57	9	673

GHG Emissions CO2 eq kg/tonne						
	Binder	**Aggregate**	**Manufacturing**	**Hauling**	**Laying down**	**Total**
Continuous reinforced concrete	231.4	5.1	1.0	5.2	0.4	243.2
Cement Concrete	132.3	5.1	1.0	4.0	0.4	142.8
High modulus HMA	17.1	9.4	22.0	3.4	0.6	52.5

Table 2: Energy consumption and GHG emissions for product and techniques

Using the value for energy consumption and GHG emissions during construction according the three different techniques we obtain:

	Techniques used	Unit	Quantities	Total MJ MJ	Total CO2eq tonne
Project	Continuous reinforced concrete	m3	96 888	365 849 088	58 898
Alternate 1	Cement Concrete	m3	114 504	225 343 872	40 889
Alternate 2	High modulus HMA	tonne	270 580	182 100 340	14 205

Table 3: Total energy consumption and GHG emissions for the project and the alternates

From a sustainable development point of view, the project as constructed (CRC solution) has required 2 times more energy (the equivalent of 5 000,000 litters of fuel) and has generated 4.1 times more GHG or an extra 44,693 tonne of CO2 eq.

In its 2001 analyses for a 5 years policies on concrete pavement, the Ministry of Quebec has used the following maximum values for the materials; A cubic meter of concrete is valued at 170 $ per m3 and a tonne of HMA is valued at 65 $ par tonne. As there was no provision for CRC, we have adopted an average value for steel at 550 $ par tonne and the same value for concrete.

The cost of each solution is:

	Techniques used	Unit	Quantities	unit cost	Total Cost
Project	Continuous reinforced concrete	m3	96 888	208.50 $	20 201 148 $
Alternate 1	Cement Concrete	m3	114 504	170.00 $	19 465 680 $
Alternate 2	High modulus HMA	tonne	270 580	65.00 $	17 587 700 $

Table 4: Cost evaluation of the project and the alternates

Following the approach of a carbon tax as adopted this year by the province of British Columbia, the carbon tax is valued to 30$ per tonne in 2012.The average price for carbon on the European climate exchange in 2005 was closed to 21.5 euros or 35 $ per tonne

Choosing 30 $ per tonne the GHG emission of each techniques have an extra hidden cost to support the carbon tax.

Cost of GHG emission at 30$ per tonne of CO2 eq

	Techniques used	tonne CO2 eq	Extra cost for CO2 eq	% of Extra cost for CO2 eq
Project	Continuous reinforced concrete	58 898	1 766 940	8.7%
Alternate 1	Cement Concrete	40 889	1 226 670	6.3%
Alternate 2	High modulus HMA	14 205	426 150	2.4%

Table 5 : Cost of GHG of the project and the alternates

Therefore, the extra hidden cost represents 8.7 % of the cost for the design solution with continuous reinforced concrete compared to only 2.4% for the HMA solution.

7.0 A SOFTWARE TO HELP DECISION MAKERS

As the calculation may be tedious to represent the actual situation in a given area to integer the various parameters and conditions, the Colas group has developed a tool to help decision making. This software is known in Europe as the "ÉCOLOGICIEL".

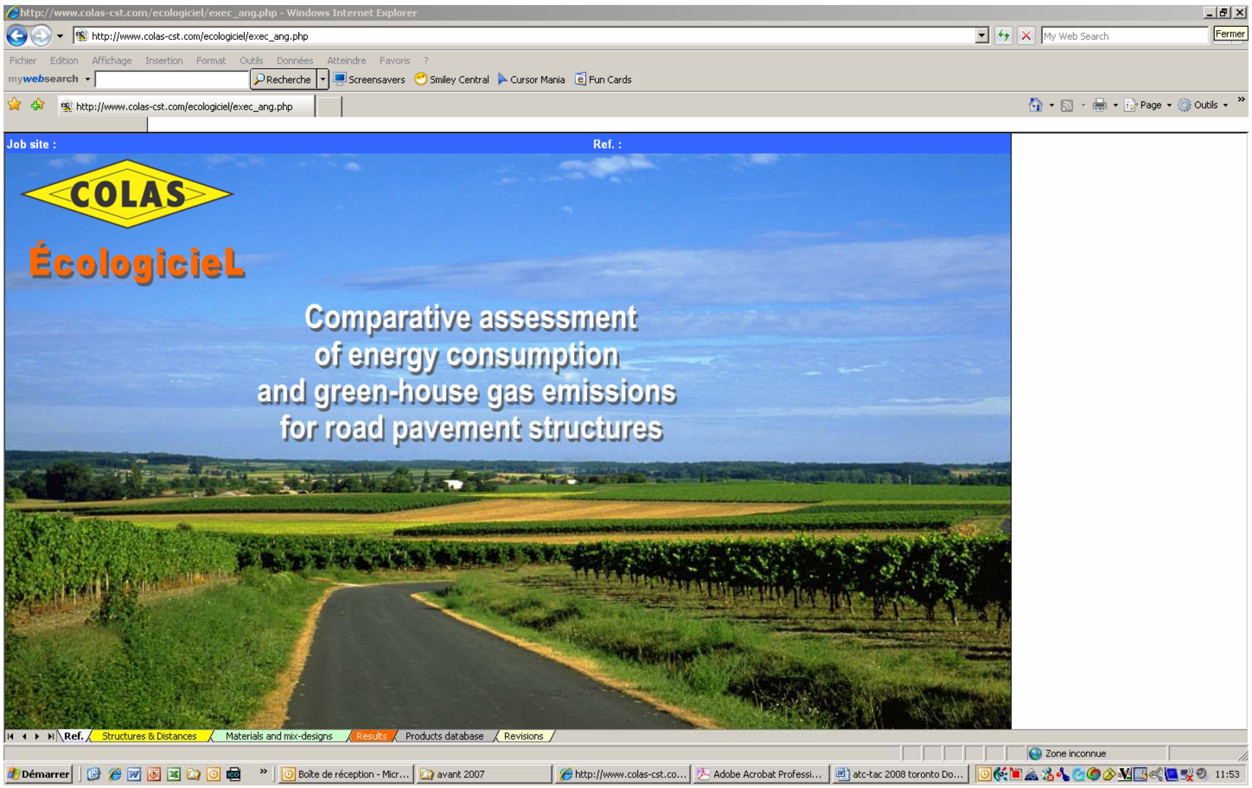

Figure 6: Opening window of the software

With this software, we are able to quantify energy and GHG emissions for various structures including the correction related to local parameters such as composition of the materials or distances. A special folder gives access to the parameters.

As an example 1, we can compare the 3 structures having the same structural performance:

1. 50 mm of HMA on 150 mm of cold in place recycling
2. 40 mm of HMA on 100 mm Asphalt Base Course
3. 40 mm of HMA on 60 mm Binder course on 150 mm crushed gravel 0-20mm

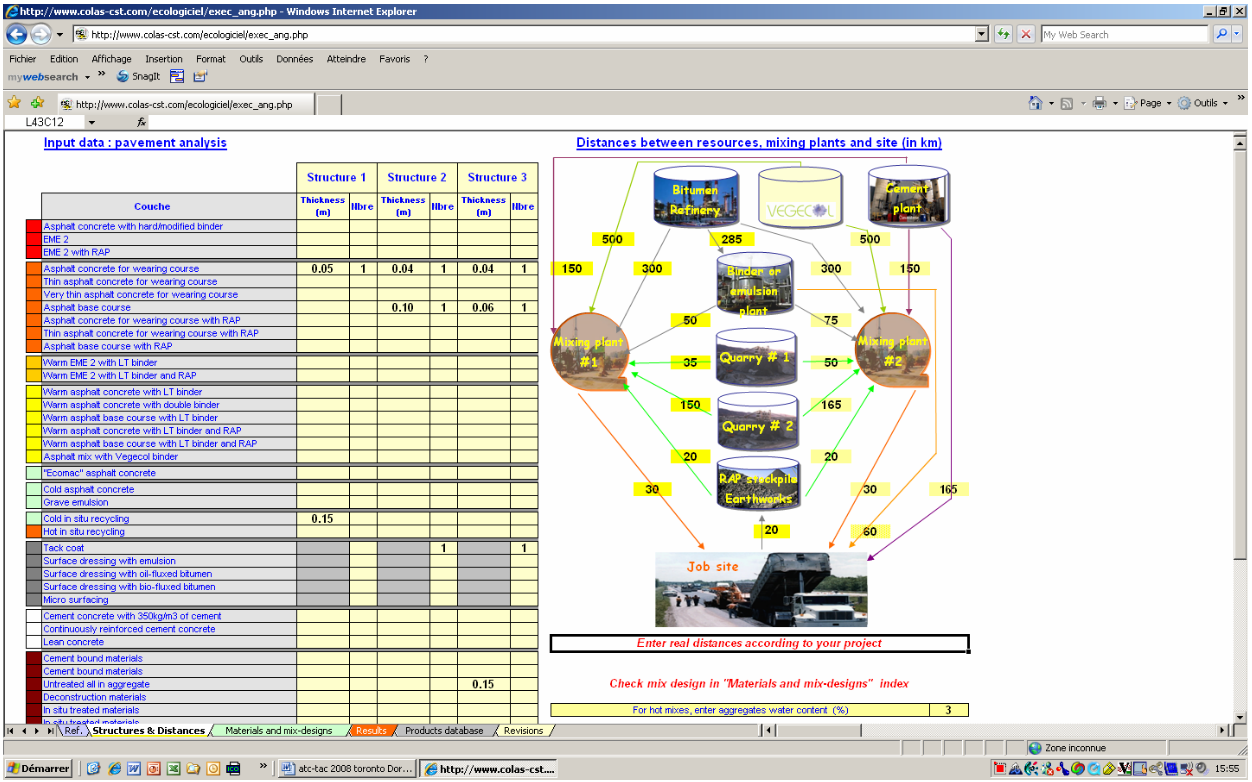

Figure 7: Worksheet for structures choices and parameters

For this example the results are as follows:

Structure	Binders	Aggregates	Mix manufacture	Transport	Laying	Total	Comparison / Base structure
Structure 1	69.8	7.4	32.5	13.4	2.7	**125.8**	
Structure 2	72.2	18.5	92.4	25.8	6.3	**215.1**	**+71.1%**
Structure 3	54.1	32.3	65.8	40.0	6.3	**198.5**	**+57.8%**

Table 6: Total energy consumption per pavement structure (MJ/m2)

For the GHG emissions:

Structure	Binders	Aggregates	Mix manufacture	Transport	Laying	Total	Comparison / Base structure
Structure 1	3.93	0.27	2.50	1.07	0.20	**7.97**	
Structure 2	4.24	0.67	7.11	2.06	0.48	**14.55**	**+82.7%**
Structure 3	3.17	1.17	5.06	3.20	0.48	**13.08**	**+64.2%**

Table 7: GHG emissions per pavement structure in CO_2 eq (kg/m2)

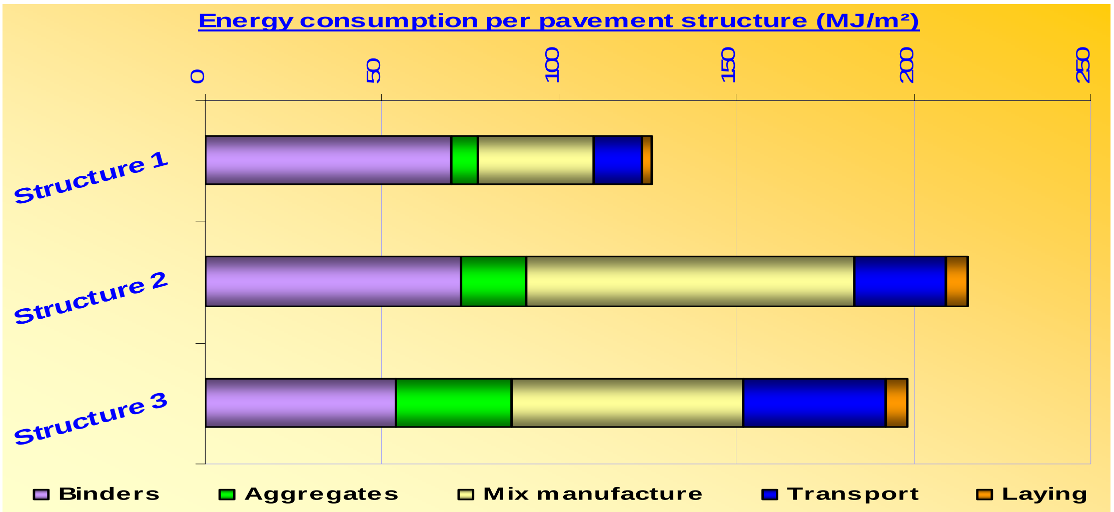

Figure 8: Graph of total energy consumption per pavement structure (MJ/m2)

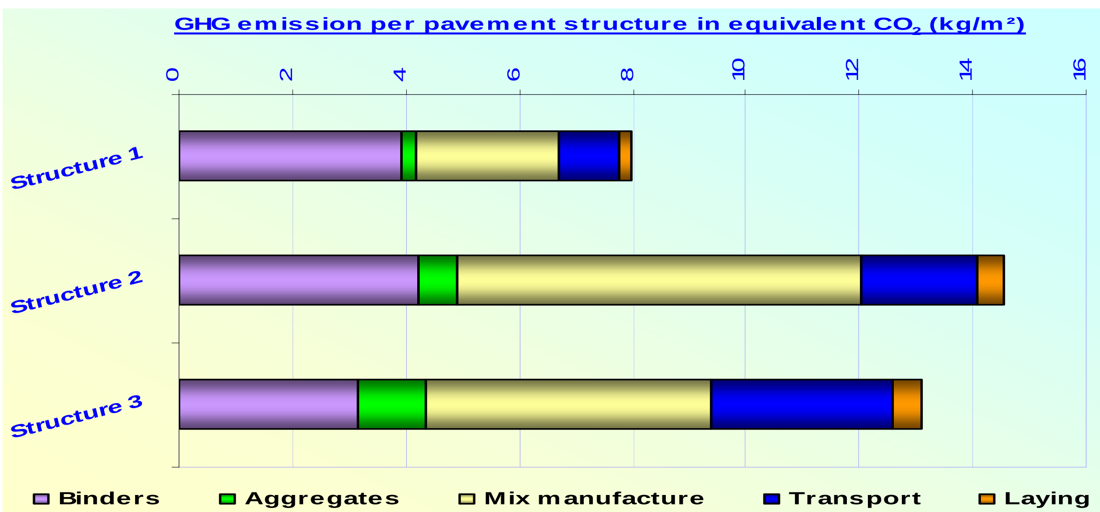

Figure 9: Graph for GHG emissions per pavement structure in CO2 eq (kg/m2)

This example shows that, compared to the structure using cold in place recycling techniques, the structure known as full depth pavement is emitting 87.4% more GHG, and the conventional flexible structure on gravel base is emitting 59.2% more GHG.

The same software can be used to compare the outputs of energy and GHG between various structure with recycled asphalt pavement and warm mix technologies:

1. Structure 1: 40 mm HMA on 100 mm ACB
2. Structure 2: 40 mm HMA with 15% RAP on 100 mm ACB with 25% RAP
3. Structure 3: 40 mm Surface warm mix with 15 % Rap on 100 mm warm mix base with 25% RAP.

For this example the results are as follows:

Structure	Binders	Aggregates	Mix manufacture	Transport	Laying	Total	Comparison / Base structure
Structure 1	72.2	18.5	92.4	25.8	6.3	**215.1**	
Structure 2	55.1	15.9	92.4	23.7	6.3	**193.4**	**-10.1%**
Structure 3	57.5	15.9	79.0	24.1	6.3	**182.9**	**-15.0%**

Table 8: Total energy consumption per pavement structure (MJ/m2)

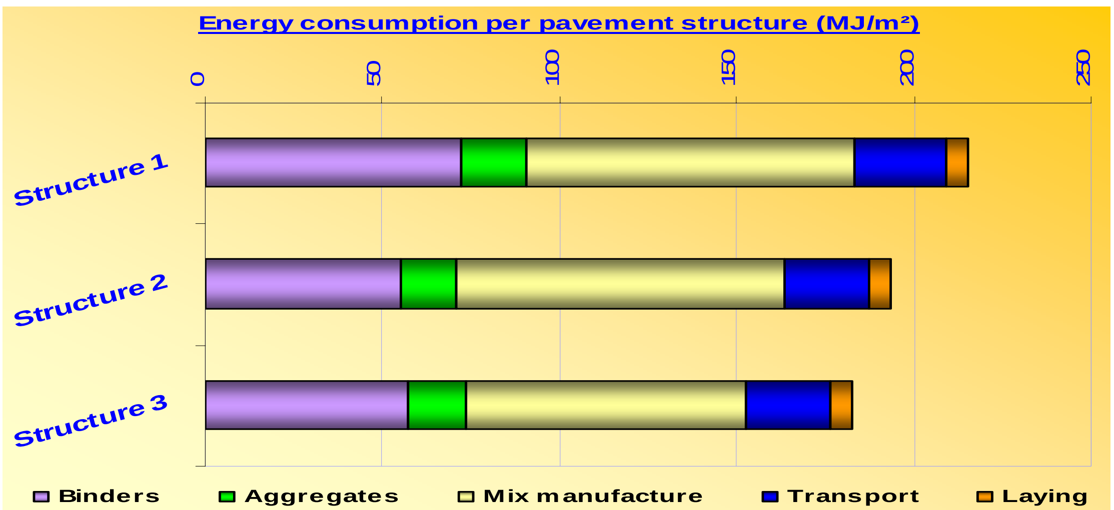

FIgure 10: Graph of total energy consumption per pavement structure (MJ/m2)

For the GHG emissions:

Structure	Binders	Aggregates	Mix manufacture	Transport	Laying	Total	Comparison / Base structure
Structure 1	4.24	0.67	7.11	2.06	0.48	**14.55**	
Structure 2	3.23	0.63	7.11	1.90	0.48	**13.35**	**-8.3%**
Structure 3	3.23	0.63	6.08	1.93	0.48	**12.35**	**-15.1%**

Table 9: GHG emissions per pavement structure in CO2 eq (kg/m2)

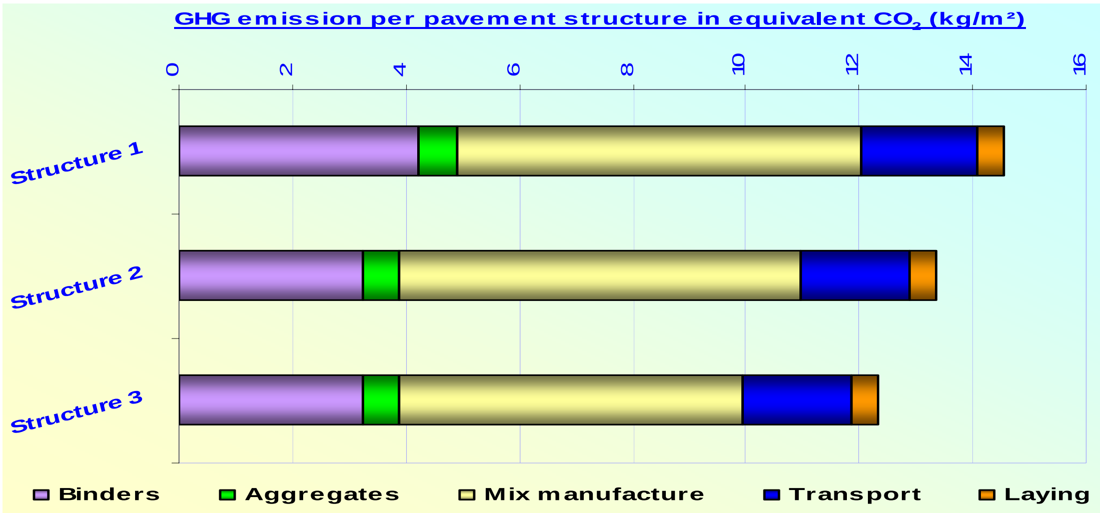

Figure 11 : Graph for GHG emissions per pavement structure in CO2 eq (kg/m2)

In this example we can quantify the gain in energy and GHG emission of solution using Rap and even more the one using the warm-mix technologies and RAP.

This software, still in a constant improvement can be considered as an important step towards the quantification of the sustainability of techniques, products and road projects.

8.0 CONCLUSIONS

Energy and GHG are increasing concerns in the concept of sustainable development. Roads construction and maintenance are not an exception. The choice of structures could not be longer influences only by the traditional cost evaluation. Quantifying the energy consumption and GHG emissions during construction and maintenance should become part of the economical equation for the best solution.

With this respect, recycling techniques are showing there importance in minimizing climatic impacts. From general data, we can easily start to discriminate solutions. However, a systematic analysis on a project basis can now be performed with the use of software such as “Ecologiciel”. These tools are at a preliminary developing stage and others are already on the drawing boards for new and more precise analysis.

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