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LIFE CYCLE ASSESSMENT STUDY FOR NEW AND RECYCLED ASPHALT PAVEMENTS

BY

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Abstract. The paper is orientated towards the development of an unique frame of sustainable evaluation. It aims at pointing out the environmental impact of asphalt mixtures in a life cycle assessment (LCA) perspective and the importance of computer software as technology that facilitates this type of research. The analysis is based on the comparison between recycled *versus* traditional asphalt mixtures from the point of view of their ecological impact, expressed in kg CO_2e emissions/tonne of mixture. The technology used for evaluation is TRL (Transport Research Laboratory) software, asPECT (asphalt Pavement Embodied Carbon Tool) which analyses in a „cradle to site” perspective the asphalt mixtures following the LCA methodology procedures. Application of LCA methodology in roads engineering is useful for understanding the effects of highway construction processes on the environment. This highlights the benefits of recyclability process and advantages of their utilization. The present analysis results are previsionally and the research is limited due to the lack of real data and use of fictive information. The paper's originality consists in application of the life cycle impact assessment methodology, use of the affiliated computer software, original information for analysis and unique comparison results.

Key words: life cycle assessment; asphalt mixture composition; environmental impact; asPECT software.

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1. Introduction

The ecological impact of roads construction works can reflect the efficiency of the recycling process in comparison with a traditional process if we take into consideration the value of CO_2e emission. It is important to know the types and values of the energy used for the construction activities in order to understand the environmental impacts, to compare the processes and to take the right measures in order to limit the excesses.

The energy necessary for the process can be obtained from fossil fuel (gasoline or diesel), natural gas or new ecological energy sources. Most of them though create emissions that impact the environment by processes such as global warming (GWP), acidification (ACP), nutrient enrichment (NEP), photo-chemical smog formation (PSF), etc.

The impact of the construction works is determined by the energy necessary to manage the process, materials production, transportation and emissions added to the environment during each stage of the final product life cycle.

For the evaluation of energy we utilize the energetic value. This is a parameter used to compare materials and products in environmental terms. It represents the measure of the amount of energy consumed, in a “cradle-to-grave” process, from the extraction of raw materials to manufacturing processes, site exploitation and disposal. For the specific case presented in what follows the ”cradle-to-grave” process has been limited to ”cradle-to-site” due to the fact that the evaluation software asPECT, initial version limits the assessment. The ”cradle-to-site” process can be observed in Fig. 1 as the point between manufacturing and use phase.

In order to diminish the energy consumption and integrate into the sustainable development process, the transportation agencies have to select, for any infrastructure construction work, the materials with the lowest energy and water consumption, with minimum CO_2e emission during their life cycle, with minimal costs and traffic disturbance. Integration of all these factors represents criteria for selecting the most suitable pavement mixture for roads according to the Life Cycle Assessment (LCA) approach.

For a better understanding of the CO_2e emission notion must be mentioned that this represents a metric used to compare the emissions from various greenhouse gases (GHG) based upon their global warming potential (GWP). Carbon dioxide equivalents provide a standard of measurement against which can be valuated the impacts of releasing different GHG. Every GHG has a GWP which describes its effect on climate change relative to a similar amount of CO_2.

The ecological impact due to construction works is complex consisting not only in CO_2e emission but also (Ecolanes D4.1, 2007) the impact on environment (land occupancy, disruption of existing conditions and ecological equilibrium, change of landscape), raw materials exploitation impact (landscape degradation, use of technological equipment that generate chemical pollution, noise and vibrations, etc.), construction sites impact (occupancy of field surfaces, chemical and energetic pollution, disruption of community life, of flora and fauna, off-road and existent roads degradation), impact of infrastructure exploitation (chemical pollution, noise and vibrations).

The negative impact can be limited from ground levelling, grass planting on the new created ground areas in order to bring back the initial form, reuse of the excavated aggregates, use of the asphalt materials resulted from pavement demolition for recycling.

2. Life Cycle Assessment Methodology and Computer Software Applicability

2.1 Life Cycle Assessment Methodology

Life Cycle Assessment (LCA) methodology is a process with high applicability nowadays. Its definitions can be found in ISO 14044 standard and reflects the „consecutive and interrelated stages of a product system, from the acquisition of raw materials or generation of natural resources until its final elimination”. The system contains flows of inputs and outputs. The inputs represent the resources necessary to conduct a process and the outputs represent the emissions to different compartments as air, water or soil.

The methodology came to life around 1960 due to the fast exhaustion of fossil fuel and first was used in order to understand and evaluate the impact of energy consumption (Zhang *et.al*, 2006). Its development was towards the system approach, used for the evaluation of environmental consequences of a product, process or activity in a “cradle-to-grave” perspective. The cradle-to-grave process evaluates the whole life cycle of a product from raw materials extraction, materials production, manufacturing and use till final disposal (Fig. 1).

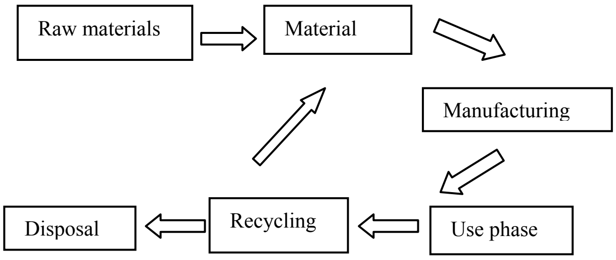


Fig. 1 – A product life cycle.

LCA methodology evaluates the environmental hotspots (Peris Mora, 2007) for a product or process. The analysis results are used for improving the environmental performance at every stage of a product life cycle.

Due to the methodology adaptability, currently it is applied in a wide diversity of areas such as: product development and improvement, strategic planning, public policy, marketing, etc.

The LCA for constructions evaluates the impact of a structure during its service life. Once the service life has been exhausted, the environmental impact is determined by the structure abandonment or disposal. Following disposal, materials may be totally or partially reused if the appropriate disposal techniques are applied (Yasantha Abeysundara, 2009).

This procedure is one of the main keys to sustainability, which will also find support in this paper.

The materials management consisting in reduction, reuse, recovery, etc., releases materials that were "temporary" part of the work. In this context, the materials that can be recovered during the disposal process confer to the engineering work the property of sustainability. The present research is focused on the advantages offered by the recyclability process at the structure end of life as component of sustainable development process.

The LCA takes into consideration the environmental impacts irreversibility in order to support and act in the direction of environment's capacity to recover.

In accordance with the sustainability process, the present research focused on finding a methodology and technology for measuring and comparing the environmental impact determined by roads asphalt pavements.

2.2 AsPECT Software Details and Application

During the last few years the researchers and institutes have developed several computer software that have the purpose to evaluate the environmental impacts of construction works by applying the LCA methodology (some examples GaBi 4, RealCost, HDM-4, aspect, etc.).

The present study was conducted using the TRL (Transport Research Laboratory) software, asPECT (asphalt Pavement Embodied Carbon Tool). This software was created alongside the Protocol for the Calculation of Life Cycle Greenhouse Gases Generated by Asphalt used in Highways and represents a calculation tool that can be used by producers of road materials, designers and contractors to calculate carbon dioxide equivalent (CO_2e) emissions associated with bitumen bound mixtures (Aspect Protocol & Guidance Book, 2009). Currently, asPECT software has two versions: first version which is a computer program based on Microsoft Excel and second version, starting from October 2010 with a new interface and applicability.

The software provides a framework which contains the necessary formulae, emissions factors and default data for the evaluation of CO_2e emissions of asphalt products. The environmental impacts results from raw materials processing, energy use, combustion process, chemical reactions, service provision and delivery, mixture processing at plant, site works with asphalt mixtures.

The software gathers information on the used materials, transportation procedures and mixing plant characteristics for the product evaluation and the CO_2e emission generated in order to obtain values per tonne for each life cycle phase and mixture in the project. The computer software has a three phases structure: materials, plants and projects.

3. Case Study on Assessment of Environmental Impact of New and Recycled Asphalt Mixtures and Technologies

Any construction work has a service life; for road structures the medium time period is of 15 years. During this time there is an optimum point from where the road structure starts to fail and a failure point establishing the moment in which the pavement needs to be replaced.

When the road structure is destroyed so that repairing works are useless, the layers replacement must be considered. This consists of milling the asphalt pavement at the upper layers according to the damaged area. Considering the layers deterioration value the milling depth will be established.

In this particular case will be milled the three asphalt layers of a road structure. The damaged asphalt pavement will be replaced with new mixtures.

The present study considered the layer replacing situation and consists in an example of asPECT software application to a complex project including the evaluation of a road pavement having a length of 1,000 m and a carriage wag of 7 m, using two evaluation alternatives namely

a) Alternative one, A_1: construction of a complete new pavement structure.

b) Alternative two, A_2: rehabilitation of an existing road, having the same pavement structure as that of alternative one, but where all the existing asphalt layers: BA 16, BAD 25 & AB 2, are realized with plant recycled mixture.

The research objective was to evaluate and compare the two asphalt mixtures alternatives from the environmental impact point of view, expressed in CO_2e emission and conclude on the advantages or disadvantages of one road structure type. For a proper analysis, the evaluation has considered the life cycle stages of asphalt products starting from sourcing raw materials through production to installation on site, in a ”cradle-to-site” procedure.

The analysis was facilitated due to the use of asPECT software, first version, which applies the LCA methodology.

The in-depth road structure consists of

a) wearing BA 16 – 4 cm;
b) binder BAD 25 – 6 cm;

c) asphaltic base course AB 2 – 10…15 cm;
d) foundation - ballast – 20 cm;
e) subgrade – 20 cm.

Alternative one (A_1) consisted in laying new mixtures based on traditional compositions: BA 16, BAD 25 and AB 2.

These asphalt mixtures are currently used by a local highway company, named S.C. CITADIN S.A. The materials structure for these compositions is reflected in Table 1.

Table 1
Traditional Asphalt Mixture Composition, [%]

No.	BA 16		BAD 25		AB 2	
1	Bitumen	6	Bitumen	4.5	Bitumen	4.2
2	Chippings 8-16	24.4	Chippings 16-25	23.9	Crushed gravel 16…25	17.2
3	Chippings 4-8	14.1	Chippings 8-16	23.9	Crushed gravel 8…16	14.4
4	Crushed sand	45.1	Chippings 4-8	9.4	Crushed gravel 4…8	19.2
5	Filler	10.4	Natural sand	17.2	Natural sand	19.2
6	–	–	Crushed sand	16.3	Crushed sand	19.2
7	–	–	Filler	4.8	Filler	6.6

Alternative two (A_2) consists in laying mixtures based on materials resulted from milled asphalt and included into new compositions (BA^r16, BAD^r 25 and AB^r 2). These compositions are based 75% on recycled material and low percentage of bitumen. The recycled mixtures composition can be seen in Table 2. The recycled mixtures composition is original.

Table 2
Recycled Asphalt Mixture Composition, [%]

No.	BA^r 16		BAD^r 25		AB^r 2	
1	BA 16	75	BAD 25	75	AB 2	75
2	Bitumen	2	Bitumen	1.2	Bitumen	1.5
3	Chippings 4-8	10	Chippings 4-8	5	Crushed gravel 4…8	6
4	Crushed sand	10	Chippings 8-16	10	Crushed gravel 8…16	9
5	Filler	3	Crushed sand	5	Crushed sand	6
6	–	–	Filler	3.8	Filler	2.5

After introducing these and other informations regarding the materials and plant operations into the software has been obtained a series of results. According to the detailed study and analysis, in Table 3 is presented the synthesis of the Environmental Impact expressed in kg of CO_2e/t as a result of the main phases of application of asPECT software to the first alternative (A_1).

Table 3

Alternative A_1 – Project Impact Summary, [%]

<table>
<tr><td colspan="4">Life Cycle Stages Summary Results</td></tr>
<tr><td colspan="4">Total project tonnage 4172</td></tr>
<tr><td>No.</td><td>Steps categoryies</td><td>Total kg CO₂e</td><td>kg CO₂e/t</td></tr>
<tr><td>Step 1-3</td><td>Material extraction and processing</td><td>169,479.378</td><td>40.623</td></tr>
<tr><td>Step 4</td><td>Transport to plant</td><td>58,473.89</td><td>14.016</td></tr>
<tr><td>Step 5</td><td>Asphalt production</td><td>30,203,973.334</td><td>7,239.687</td></tr>
<tr><td>Step 6</td><td>Transport to site</td><td>943.427</td><td>0.226</td></tr>
<tr><td>Step 7</td><td>Laying and Compacting</td><td>16,688.0</td><td>4</td></tr>
<tr><td colspan="2">Total</td><td>30,449,558.029</td><td>7,298.552</td></tr>
</table>

A similar environmental impact synthesis for A_2 (second alternative), using recycled asphalt, is presented in Table 4. In the two tables are considered the LCA stages, the total asphalt tonnage for the road structure and the final results as kg CO_2e emissions per total and per tonne of mixture.

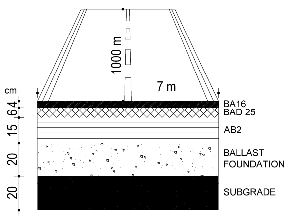
Table 4

Alternative A_2 – Project Impact Summary, [%]

<table>
<tr><td colspan="4">Life Cycle Stages Summary Results</td></tr>
<tr><td colspan="4">Total project tonnage 4,172</td></tr>
<tr><td>No.</td><td>Steps categoryies</td><td>Total kg CO₂e</td><td>kg CO₂e/t</td></tr>
<tr><td>Step 1…3</td><td>Material extraction and processing</td><td>88,100.025</td><td>21.117</td></tr>
<tr><td>Step 4</td><td>Transport to plant</td><td>28,451.482</td><td>6.82</td></tr>
<tr><td>Step 5</td><td>Asphalt production</td><td>18,123,940.137</td><td>4,344.185</td></tr>
<tr><td>Step 6</td><td>Transport to site</td><td>943.427</td><td>0.226</td></tr>
<tr><td>Step 7</td><td>Laying and Compacting</td><td>16,688.0</td><td>4</td></tr>
<tr><td colspan="2">Total</td><td>18,258,123.071</td><td>4,376.348</td></tr>
</table>

Table 5

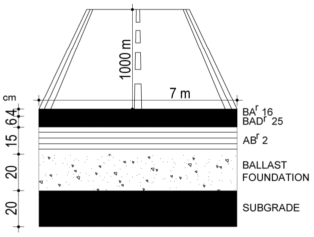
The Environmental Impact Assessment for Alternative A_1, Broken Down for Each Type of Mixture

<table>
<tr><td colspan="5">
</td></tr>
<tr><td>Layer</td><td>Layer thickness mm</td><td>Quantity of mixture, [t]</td><td>Consumption kg CO₂e/t</td><td>Total consumption kg CO₂e/km road, (7,000 m²)</td></tr>
<tr><td>BA 16</td><td>4</td><td>644</td><td>7,307.8</td><td>4,706,191</td></tr>
<tr><td>BAD 25</td><td>6</td><td>1,008</td><td>7,302.3</td><td>7,360,677</td></tr>
<tr><td>AB 2</td><td>15</td><td>2,520</td><td>7,294.7</td><td>18,382,680</td></tr>
<tr><td>Total</td><td>25</td><td>4,172</td><td>21,904.8</td><td>30,449,548</td></tr>
</table>

The synthesis of the final results regarding the environmental assessment for each of investigated alternatives can also be broken down for each asphalt layer as can be seen in Tables 5 and 6.

Table 6

The Environmental Iimpact Assessment for Alternative A_2, Broken Down for Each Type of Mixture



Layer	Layer thickness mm	Quantity of mixture, [t]	Consumption kg CO_2e/t	Total consumption kg CO_2e/km road, (7,000 m^2)
BA^r 16	4	644	4,372.9	2,816,143
BAD^r 25	6	1,008	4,370.2	4,405,148
AB^r 2	15	2,520	4,379.7	11,036,830
Total	25	4,172	13,122.8	18,258,121

The final comparative results of the environmental impact assessment for the investigated alternatives can be seen in Table 7.

Table 7

The Final Comparative Results of the Environmental Impact Assessment Expressed in kg CO_2e/t for the Investigated Pavements Emissions Alternatives A_1 and A_2

		Traditional pavement				Recycled pavement			
		Alternative, A_1				Alternative, A_2			
		BA 16	BAD 25	AB 2	Total	BA^r 16	BAD^r 25	AB^r 2	Total
Specific environmental impact for CO_2e as target assessment	kg CO_2e/t	7,307.8	7,302.3	7,294.7	21,904.8	4,372.9	4,370.2	4,379.7	13,122.8
	kg CO_2e/km	4,706,191	7,360,677	18,382,680	30,449,548	2,816,143	4,405,148	1,1036,830	18,258,121
Reduction of CO_2e due to the recycling process	kg CO_2e/t	–	–	–	–	2,934.9	2,932.1	2,915	8,782
	kg CO_2e/km	–	–	–	–	1,890,048	2,955,529	7,345,850	12,191,427

4. Conclusions

The sustainable development process allows the evaluation from ecological, economical and social point of view. The control of greenhouse gases emissions is a component of the ecological impact reduction. In this context, the assessment of environmental impacts associated with construction materials and technological processes is necessary as main component of sustainability process in constructions sector.

LCA methodology can be used as a tool for the evaluation of environmental friendly construction alternatives. The methodology is complex because the "cradle-to-grave" structure contains many stages and activities.

This methodology allows us to learn more about the environmental effects of a certain construction work or product. It's compulsory to consider during this type of analysis all the environmental effects resulted from the construction of a given structure, its service life, reuse and demolition. A great attention should pay the possibility to either recycle or recover materials or energy.

The analysis results reflect the benefits of technological change in the area of transport infrastructure. The new techniques and evaluation methods and computer software application facilitate the EIA (Environmental Impact Assessment). This study constitutes the support for asphalt recyclability process, for acquisition of new and improved equipments and computer software applicability.

Due to the fact that the asphalt mixtures compositions used in alternative A_1 are currently used in Romania, the research results might be exploited by local companies for transport infrastructure as an alternative to traditional asphalt mixtures.

The analysis results conclusion is that, by adopting the recycling technology for the existing deteriorated asphalt pavements, can be obtained significant reduction (40% for the current case) of CO_2e emission on the road projects.

The paper originality is based on the comparative evaluation of environmental impact for different asphalt pavements, the recycled asphalt mixtures composition and asPECT software applicability.

In order to develop this type of analysis and recyclability process, TRL (Transport Research Laboratory), UK, has created a new version of asPECT computer software starting from October 2010 with a new and improved interface. The new software will be used in further analysis of this research topic for more detailed results.

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STUDIUL ANALIZEI CICLULUI DE VIAŢĂ PENTRU ÎMBRĂCĂMINŢI ASFALTICE NOI ŞI RECICLATE

(Rezumat)

Lucrarea de faţă urmăreşte dezvoltarea unei scheme unice de evaluare sustenabilă în problema studiată. Prin aceasta se urmăreşte evidenţierea impactului de mediu al mixturilor asfaltice, observate în cadrul unei perspective de analiză a ciclului de viaţă şi a relevanţei rolului important reprezentat de softurile informatice ca tehnologie nouă ce facilitează acest tip de cercetare. Analiza se bazează pe o comparare a mixturilor asfaltice reciclate *versus* cele tradiţionale din punctul de vedere al

impactului lor ecologic. Acest impact este exprimat în kg de CO_2e/tona de mixtură. Tehnologia folosită pentru evaluare este softul implementat de TRL (Transport Research Laboratory), denumit asPECT (asphalt Pavement Embodied Carbon Tool), care realizează analize ale mixturilor asfaltice în cadrul unei structuri de la „naştere la amplasament" în conformitate cu procedurile metodologiei analizei ciclului de viaţă. Aplicarea metodologiei ciclului de viaţă în domeniul ingineriei drumurilor este utilă pentru înţelegerea efectelor procesului de construcţie a drumurilor asupra mediului. Prin aceasta pot fi evidenţiate beneficiile procesului reciclării şi avantajele rezultate din utilizarea sa. Rezultatele oferite de prezentul studiu sunt intermediare şi orientative datorită lipsei unor informaţii reale şi folosirii unor date fictive. Originalitatea cercetării constă în aplicarea metodologiei evaluării impactului ecologic pe parcursul ciclului de viaţă, aplicarea practică prin intermediul unui soft informatic precum şi folosirea unor date originale pentru analiză şi rezultate unice ale comparaţiilor efectuate.