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Guide for using suitable eco-balance tools to evaluate the environmental compatibility of cold recycling

Final report

Deliverable D5.2

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CEDR Call2012: Recycling: Road construction in a post-fossil fuel society

CoRePaSol

Characterization of Advanced Cold-Recycled Bitumen Stabilized Pavement Solutions

Guide for using suitable eco-balance tools to evaluate the environmental compatibility of cold recycling

Final report

Deliverable D5.2

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CONTENT

Executive summary

Assessment of material or structure eco-balance has gained increased importance during last 10-15 years. There are different actions, projects or working teams involved in topics like environmental compatibility and environmental sustainability of structures and structural materials. It is even one of the fundamental areas which have to be assessed for structural materials according to the European Construction Product Regulation which has a status of legal requirements since 1 July 2013 and additionally to previous Construction Product Directive includes requirements on sustainability, especially sustainable use of natural resources including aspects of environmental compatibility. This is further supported by ongoing European actions toward Green Public Procurement where beside standard criteria like price also environmental aspects will be more and more important. From this point of view it is necessary to be able measure and interpret carbon footprint or release of emissions which are produced by cold recycling techniques. Additionally it is important for the industry as well as for the public authorities (administrators, infrastructure owners etc.) to be able to compare different technical solutions not only in terms of total investments or technical parameters, but also in terms of their effect to the environment, which are applicable for pavement rehabilitation. In this respect then solutions should be used for road construction or rehabilitation which are well-balanced in all of the mentioned aspects, i.e. techniques should be preferred which provide sound technical solutions with a good cost-benefit ratio (securing value for money) and limit any impacts on the environment.

The original intention of CoRePaSol project was to seek for suitable tool applicable for calculating eco-balance between the existing professional applications which can be found on the market. Preferably it was expected to create a suitable synergy with the tool developed within CEREAL project. This idea nevertheless so far failed since the Carbon Road Map software tool developed by CEREAL is still not available for public use. Additionally it was found that cold recycling techniques could not be simple included. Especially, if the intention was to show effects of different combinations of machinery used for cold recycling technologies. In the second step it was analyzed if there could be easier solution to include effectively cold recycling techniques to British asPECT software tool. Even this was finally not decided as a most suitable way and finally the project team started to structure available technical data in a way to create own simple calculation tool. This Excel-based application is able to compare different technical solutions of performing cold recycling. It is linked to a detailed database of machinery data. Special attention has been paid do describe as good as possible the daily snapshot of a regular cold recycling procedure. Material data, mainly of bitumen and cement, are taken from existing life-cycle inventories.

This report explains the importance of eco-balance (carbon-footprint) calculations and stresses the difference of older or new machines used in cold recycling – especially with respect to fulfill tough requirements with respect to allowed emissions produced by engines (actually TIER 4 final/EPA IV final standard in EU and the USA). Further detailed analyses of selected available carbon-footprint/LCA calculation tools are summarized in a separate chapter. In this respect it was the intention of the project team to point out some of the

strengths and weaknesses of each of the analyzed software tools and recommend what should be included in a tool which would allow also calculation of cold recycling.

Finally in chapter 5 the principles of the Excel-based calculation tool developed within CoRePaSol are summarized and key dialog boxes shown. To make the benefit and application of the tool more clearly to the reader, chapter 6 includes calculations for hypothetical construction site which can be rehabilitated by different ways of cold recycling. In several tables the input data as well as receiving outputs of the calculations are shown and described to demonstrate the overall idea of this calculation tool. It is even shown how impact of different generations of a construction machine (recycler) can be interpreted with respect to the impact such recycler has to the environment. Gained results and conclusions have to be always put in relation to economic values to demonstrate the possible effects. It is mainly important to describe the practical use for decision on suitable recycling technique and have the opportunity to compare different approaches from environmental point of view (public sector perspective) as well as to compare the influence of selected generations of machinery and its contribution to emission release (more private sector perspective). The most important conclusion is nevertheless the ration of material-based and machinery-based emissions, which could additionally demonstrate the benefit of cold recycling.

In the future it might be of recommendation to identify additional possibilities how the developed tool and existing data could be used by professional calculators. With respect to the public authorities it might be of importance if different approaches could be compared, i.e. cold recycling with new surface layer vs. mill and fill etc. This was not further followed within CoRePaSol since it was not the objective of the activities and tasks proposed and delivered to CEDR.

1 Introduction

Within CoRePaSol it had been decided to identify or to work in parallel on a simple and basic Excel-driven calculation tool for carbon footprint assessment of cold recycled mixes with particular integration of engine related emissions of CO_2 CO, NO_x, HC and particle matters (PM). In this respect recyclers of different type and engine generation were included and filled with relevant data. The target was to answer the question what amelioration in terms of emissions should be possible with machines fulfilling the newest emission standards given in EU and in the USA in comparison to older emission standards. It was not the project objective to fully enter and develop complex carbon footprint software or eco-balance calculator since it was planned to find a solution within existing software tools. Nevertheless the area of cold recycled mixes seems to be very specific and none of the existing tools or calculators and even not CEREAL project could offer a suitable solution.

2 Cooperation with ERA-Net project CEREAL

With regard to optimized synergies and interaction between different ERA-Net Road project teams, it was in terms of eco-balance and carbon footprint the first set target of CoRePaSol project team to cooperate wherever possible. In the field of eco-balance and especially for calculation of green-house gas (GHG) emissions within WP5 there was an ERA-Net project "CEREAL" – CO_2 Emission Reduction In Road Lifecycles - running in parallel (2011-2013). Already during the proposal phases of CoRePaSol the first contacts had been established signalizing the intention to use the CO_2-Calculator "Carbon road map" that was in progress and under development within this project.

To do a carbon footprint calculation for cold recycling processes means to take into account all major emission sources. Major parts of emissions are contributed by construction material similar to hot mix asphalt, by asphalt mixes themselves and by construction machinery used on site. Specifics have to be understood with respect to the more preferred in-situ technique, which constitutes some difference to hot mix asphalt. Further it is necessary to clearly define, that each new used material on site does have its own carbon footprint. There are different proven calculators available that could handle the material issue and give correct numbers. Cold recycling is in first place an in-situ applied process. Comparatively, only very little amount of new material is incorporated in the road rehabilitation, e.g. hydraulic and bituminous binders, gravel or fines and a new top layer. Existing tools like Dubocalc, AggRegain or asPECT couldn't easily being used or adopted as they would not offer a ready to use solution to the given problem. None of these calculators were able to answer the question what the usage of machines on jobsite would contribute to the total carbon footprint of the cold recycling process.

It was expected that the ERA-Net Road project CEREAL would offer a solution to take machines and their CO_2 emissions into account. It was designed as Excel-based software with open architecture. That means that new process models, new machines, new material can be added by every user. Once it can provide the relevant emission information the internal database will be able to assist with calculation of the new processes. Unfortunately, the CEREAL project team encountered difficulties with the implementation of the software solution which lead to a severe delay in their schedule. This delay became that important that within the CoRePaSol project a principal decision had to been taken if it would be possible to wait for a solution without endangering the set objectives of CoRePaSol project itself to get any additional delay. In order to minimize risks, the project team decided to work in parallel on a simple calculation of CO_2 emissions for a real job site in Ireland (which had been monitored and used within the project) without doing software development. When the first test versions of Carbon road map were available a lot more problems were found during implementation of cold recycling process. To solve these problems would have meant to get additional and massive support of CEREAL project team. This was not possible due to the massive delay and none resources left to help this cooperation being more beneficial. Finally, up to date the Carbon road map software is not released officially, nor is the instruction manual. Nevertheless the intension of the CoRePaSol team is further follow the software and later – even after CoRePaSol project is finished to seek for possible solution or suitable interface with CEREAL project.

Another issue arose from the point of machine specific emissions. European Union as other states in the world did major progress in limitation of emissions of construction machineries. Beside the emissions of CO_2 there had been introduced major limitations to carbon monoxide CO, NO_x, HC and fine particle matters in the last years. This legislation is known as TIER4 interim /EPA IV interim and TIER 4 final/EPA IV final standard. It is within EU covered and forced by the directive 97/68/EC. Most certainly, this does help to reduce the named emissions significantly. Neither the Carbon Road Map Software that had been developed within CEREAL nor any other software tool was able to quantify this beneficial effect.

3 Assessment of existing CO_2 tools for road structures

In this chapter, advantages and disadvantages of nine existing CO_2 calculation procedures (and appropriate tools) are described and evaluated more in detail. These tools are used in road infrastructure within Europe and they are compared with results obtained from real in-situ conditions and with experiences of many experts. In total, 16 calculation tools (i.e. software applications) were described. Nine of them were chosen for additional detailed assessment. The goal was to evaluate the usability of one of these tools for cold recycled techniques eco-balance assessment, or to define requirements for future creating of own-developed basic calculator, which would be mainly based on following expectations:

- Not requiring large amount of data, which are closed in a black-box, but it will be possible to add more data (in principle, the more data the more accuracy → i.e. open architecture tool).
- Use of experience and already obtained data for more precise calculation of relevant results in the field of pavement recycling techniques.
- Pre-defined maintenance measures and scripts based on current functional technologies (with the possibility of adding or modifying more scenarios/measures).
- Inclusion of the whole life cycle of a pavement (ideal final target), but it will be focused mainly on the principles of maintenance and differences in every single maintenance scenario and set of corresponding measures.
- Inclusion of pavement equipment and special objects (i.e. bridges, tunnels, security and control equipment, etc.).
- Use principles of the existing maintenance and operation models, with respect to their application and usual usage in different countries.
- Ability to use such tool for calculations of the total carbon footprint for projects all over Europe – comparison of same techniques based on same principles in different part of the continent.
- Not considering the dependence of road characteristics (horizontal or vertical alignment parameters, road category and carriageway parameters).

Based on the proceeded assessment of current data and information, it is possible to resume, that:

- Current software tools can be mostly described as closed application, it means their calculation approach is a black-box architecture.
- Assessed software tools require large amount of data and are relatively complex.
- Existing software tools which were evaluated are mostly focused on new pavement/road structures and they don't consider the complex maintenance with respect to life-cycle assessments.
- European models have in general a problem with presentation of simple and clear results; in comparison to that US models are significantly more effective in this respect.
- European models include considerable amount of useful data, sometimes it might be maybe advantageous to structure them better.

- In case of DuboCalc tool it includes (unfortunately) detailed information only about the status and common practice in Denmark.
- In case of asPECT and ROAD RES these tools include (unfortunately) detailed information only about the situation in Great Britain and Scandinavian countries.

Table 1: Overview of evaluated carbon footprint/LCA tools applicable to asphalt pavements

Software name	Advantages (+)	Disadvantages (-)
RoadMap CEREAL	+ accessibility of the database + open architecture	- not yet available due to technical problems - did not calculate deeply with recycling techniques
asPECT (UK)	+ accessibility of the database	- needs large amount of data
AfwegingsModel Wegen (NL)	+ transparent and simple + includes maintenance the possibility to use updated data	- impossible to add data into existing database
AggRegain / ESRSA (UK)	+ accessibility of the database	- needs large amount of input detailed data
ROAD-RES (DK)	+ good methodological structure	- needs large amount of input detailed data
DuboCalc (NL)	+ complexity of the database	- non-transparent process of results calculation
JouleSave (EU)	+ includes the effect of interaction between the roadway and traffic load	- needs detailed knowledge of roadway design parameters
GreenDOT (US)	+ good design and ergonometrics	- applicable in the US
PaLATE (US)	+ good design/structure and ergonometrics	- applicable in the US
WLCO2T (UK)	+ useful database based on Price Book (UK)	

From 11 identified existing software programs suitable potentially for eco-balance assessment the following software tools were evaluated:

- Road Map of CEREAL project
- asPECT
- Afwegingsmodel wegen
- AggRegain CO2e emissions estimator tool (ESRSA)
- ROAD-RES
- DuboCalc
- JouleSave
- GreenDOT
- PaLATE
- WLCO2T
- SEVE
- CHANGER

Remaining five identified software tools were assessed only concisely. These tools are Ecologiciel (Colas); CO2NSTRUCT; LCI Model; HDM-4 and VETO.

3.1 Summary results of realized analyses

RoadMap (CEREAL project tool)

The tool was analysed, nevertheless it has been identified that there is no functional and proven release available. Mainly with respect to the focus on cold recycling techniques.

asPECT (asphalt Pavement Embodied Carbon Tool)

This software takes into account the impact of CO_2 which was generated during construction and maintenance of a pavement structure. It includes CO_2 emissions related to transport of input materials, paving, maintenance and final demolition (removal). The CO_2 sources which are considered include energetic consumption, combustion process, chemical reactions and transport of materials.

It is suitable to use following positive aspects of this software in case that in the future there will be endeavour to develop a new LCA or carbon footprint tool:

- calculation of results for different construction project phases;
- detailed standard of environmental database – enables to distinguish CO_2 according to its origin (input materials, energy, transport, equipment).

The following negative aspects of this software should be avoided in case of developing a new LCA or carbon footprint tool:

- too much detailed database doesn't enable to use a program for approximate tentative assessment (i.e. it is necessary to insert large number of specific technical data to successfully proceed the calculation) – in the new software a multilevel system depending on the amount and expertise of available data should be preferred;
- software is defined only for flexible pavements – the new tool shouldn't neglect rigid pavements or composite pavement structures

AfwegingsModel Wegen (AMW 1.1)

CROW software is an objective and transparent model, in which the user has the possibility of the choice among different structures types – asphalt, concrete, paved roadway. The first purpose of the software tool is to establish characteristics for single types of roadway cover. Other purpose is to enable the choice of suitable cover, respectively to choice a strategy of maintenance, based on assessment of environmental, financial and other criteria.

It is suitable to use following positive aspects of this software in case that in the future there will be endeavour to develop a new LCA or carbon footprint tool:

- usability for both asphalt and concrete structures;
- defining of characteristics during construction/maintenance/reconstruction (i.e. usability for the whole lifecycle);
- possibility to safe input and output data into separate files, which enables its reusability. Ideal is an export into MS Excel file.

The following negative aspects of this software should be avoided in case of developing a new LCA or carbon footprint tool:

- impossibility to edit and modify existing database – the data are not fix, there is no possibility to correct it for particular conditions (for example the distance between a construction site and an asphalt plant). But it is suitable to mark clearly the modified data, as “user modified”;

- software is not very user friendly. The software layout doesn’t enable a simple assessment of differences/similarities between single layers of a pavement. For any software, which will be made in the future, it is necessary to define a consistent appearance, clarity and the possibility to compare results.

ROAD-RES

This Danish software tool follows two basic objectives. It performs a comparison of environmental impacts and consumption of sources for different lifecycle phases with basic materials and residue from waste incineration. It assesses and compares two available methods for determination of waste incineration residue, namely it is dump disposal or use of a material in road construction.

It is suitable to use following positive aspects of this software in case that in the future there will be endeavour to develop a new LCA or carbon footprint tool:

- EDIP97 is a default LCA method in ROAD-RES. It is possible to replace this model by another LCA method, for example Eco-indicator 95, Eco-indicator 99 or CML 2001;
- detailed focus on the demolition phase – i.e. it is possible to authentically model a demolition of a construction including the area recovery.

The following negative aspects of this software should be avoided in case of developing a new LCA or carbon footprint tool:

- complicated for user, non-transparent;
- it requires an additional software (C++/PARADOX database system).

DuboCalc

The software is not intended for optimization and determination of environmental impacts in the area of road construction (in its original version). Today the software is used mainly for comparing offers of contractors with the focus on the area of environmental impacts. Due to this, the software is designed as closed, without the possibility to get free access to the database and the software itself. Also the transparency might be better. It doesn’t take into account the maintenance and lifecycle is pre-defined for Dutch specifics.

It is suitable to use following positive aspects of this software in case that in the future there will be endeavour to develop a new LCA or carbon footprint tool:

- basic principles, calculation and data principles – software is user friendly, LCA methodology is suitable and includes useful databases. It is recommended in the future to copy these elements into any new made software for the purpose of LCA calculations, including the methodology.

The following negative aspects of this software should be avoided in case of developing a new LCA or carbon footprint tool:

- the tool doesn’t consider maintenance in appropriate extent – software focuses on new constructions/reconstructions, but from the point of view of maintenance it lack complexity;

- non-transparent calculation which is caused by the “black-box” design of the software. Repeatability and verifiability of the data is complicated;
- use of old data – no always it must be a problem. After verifying, the data can be used for the new developed software.

JouleSave

This calculation tool is a supplementary module of MX software (Inroads software), which is intended for designing the road alignments. This fact determines its limitation for relatively close user’s group using the MX software. At the same time it is true, that from the point of view of road design CO_2 emissions (generated during the life cycle) are as good as neglecting factor, which has a very low effect on the final road design.

It is suitable to use following positive aspects of this software in case that in the future there will be endeavour to develop a new LCA or carbon footprint tool:

- possibility of a very detailed analysis – it is possible to determine emissions of the expected traffic loading. This can be however calculated also by other suitable software tools, which has connectivity to MX software. With respect to the tool which is searched for cold recycled mixes and their applications in pavement rehabilitation, this is an aspect which is more linked to transport engineering and the relation to road characteristics rather than the life cycle analysis of a pavement structure. In this connection there is only a very small intersection.

The following negative aspects of this software should be avoided in case of developing a new LCA or carbon footprint tool:

- limited by the MX software;
- detailed understanding of pavement design principles is a presumption.

GreenDOT (Greenhouse Gas Calculator for State Department of Transportation)

It is suitable to use following positive aspects of this software in case that in the future there will be endeavour to develop a new LCA or carbon footprint tool:

- the software has a good design and is user friendly.

The following negative aspects of this software should be avoided in case of developing a new LCA or carbon footprint tool:

- it is complicated to obtain most of the input data;
- the tool is applicable only for relations and conditions given by the U.S. market.

paLATE (Pavement LCA Tool for Environmental and Economic Effects)

This software tool is intended for calculation of environmental and economic impacts of roads within a LCA.

It is suitable to use following positive aspects of this software in case that in the future there will be endeavour to develop a new LCA or carbon footprint tool:

- the software has a good design and is user friendly;
- good and use-oriented structure of particular emission data sources (material production, pavement structure, transport, maintenance) and good adjustment

according to used materials (soils, unbound layers, bituminous materials, hydraulically bound layers).

The following negative aspects of this software should be avoided in case of developing a new LCA or carbon footprint tool:

- due to source data the tool is applicable only for U.S. conditions.

WLCO2T

It is suitable to use following positive aspects of this software in case that in the future there will be endeavour to develop a new LCA or carbon footprint tool:

- good source data from the UK (Highway Agency+CESSM3 Carbon and Price Book)
- possibility of inserting and editing data (i.e. also databases or calculation methods

Note: Complex software analysis was not done.

SEVE

Not evaluated – it was not possible to get free access to this software.

CHANGER

Not evaluated – it was not possible to get free access to this software.

Ecologiciel (Colas, France)

This software tool can be identified as a first one designed purely for the assessment of CO_2 impacts (carbon footprint) in the field of road construction. It is software tool developed originally by COLAS company for comparison of applicable technologies. COLAS was later one of the participants in the development of SEVE software tool. This tool was not analysed because of no accessibility and the fact that most of the software is only in French.

CO_2NSTRUCT

This tool is a web application, which quantifies direct and indirect emissions of simple actions or building projects (elements). This is done in a kind of database and each of the assessed actions is then allocated to particular process stakeholders. It is the first software, which uses GHG quantification and their allocation in the life cycle, nevertheless in the existing form it is according to the so far done evaluation to all intents and purposes useless.

LCI Model

This software focuses only on CO_2 emissions of building materials; it does not cover the construction and maintenance phases. It is in fact a real inventory and forms a part of more complex software AggRegain.

HDM-4

This software tool was originally not designed as a life cycle calculator and it provides more functionalities related to evaluation and decision on the best solution of a road to be constructed in terms of investment criteria. From the viewpoint of operation and maintenance HDM-4 contains software modules which compare and assess different scenario of maintenance actions. The tool is based on MS Excel and in general focuses primarily on user stages of road structure lifetime. It is officially used for the decision of public investors and administrators with support of World Bank which identifies this tool as official one to be used if road alignment alternatives should be compared and assessed and financed by World Bank or International Monetary Fund.

VETO

This tool was developed in Sweden and it is limited to calculations of regular daily traffic fuel consumption based on known pavement surface parameters like IRI or texture (macrotexture etc.). This software application does not calculate seamlessly the whole construction phase of a road project.

4 Comment on technical development

With regard to the development of engine related CO_2-emissions it is in every operators and contractors interest to reduce this emission. CO_2 emissions are produced proportionally with any quantity of burned diesel fuel. Fuel costs are a major component of variable costs to any fleet of construction machinery. Every measure that helps cutting down fuel consumption aiming at lower costs does at once help to reduce CO_2 emission. Because of this simple and direct proportional conjunction the fuel consumption of newer machine generations drops. Even if newer machines are equipped with more powerful engines, these machines are more effective in using one quantity of fuel. For instance, the latest generation of road recycler will consume less liter diesel per recycled square meter (m^2) than any older generation. The same principal is valid for any construction machinery used on job site.

The introduction of EPA IIIB and later on EPA IV emission standard in European Union helps to reduce any emission from diesel engines in construction machinery significantly as the following graph illustrates.

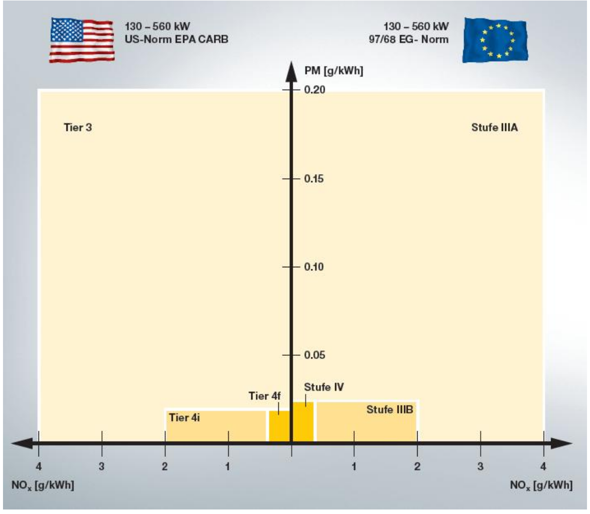

Figure 1: Actual emission requirements on diesel engines in EU and the US

On the other hand this standard is a major driver for important progresses in engine development and emission control. Any construction machinery OEM did and does face huge challenges in fulfilling the standards.

The diesel engine manufacturers offer different solutions to achieve this goal. Basically, every diesel engine is complemented by its own exhaust after treatment solution where often three important components can be found:

a) Diesel particle filter (DPF) which helps to reduce particle matter and can be actively or passively regenerated. This technique does often come with an additional diesel oxidation catalytic.
b) Selective catalytic reduction which helps to reduce NO_x by injecting Ammoniac (NH_3) into the exhaust fumes and leading to a chemical reaction producing N_2 and H_2O instead of NO_x.

c) Diesel engine internal measurements, e.g. Exhaust Gas Recirculation (EGR) that does help to reduce undesired particles in the exhaust by recirculating it for a second combustion.

Of course, this exhaust after treatment systems have to be integrated in new construction machines additionally, hitting all limits in given space. Finally, these efforts result in a drastic reduction of emissions but also in significantly higher costs for diesel engines and thus environmental friendly construction machines according to the latest state of the art. The following graph shows a scheme of a typical exhaust treatment system fulfilling Tier 4f / EPA IV specifications.

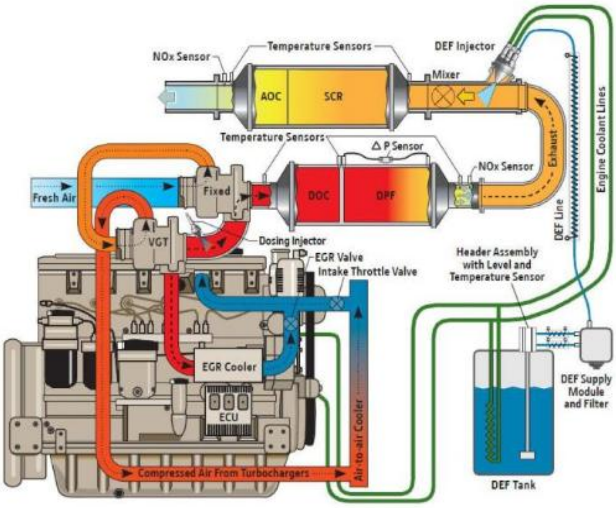

Figure 2: Example by John Deere™

5 Excel-driven calculation tool – alternative development of CoRePaSol

Based on previous activities done at the Czech Technical University in Prague under the support of Wirtgen GmbH, a basic calculation MS Excel tool has been developed. The tool is designed to calculate the emission impact of the road structure rehabilitation. By inserting minimal amount of input data, user easily gets a basic comparison of cold recycling techniques or variations that are possible to be used. Application mainly consists on data and calculations related to cold recycling techniques and its alternatives for flexible pavement rehabilitation depending on preference, how cold recycling should be performed – in-situ or in-plant by using suitable mobile mixing plant – and which binders should be used. Included methods were chosen regarding to current trends in pavement engineering and also with respect to reach promised objectives of CoRePaSol project work package. The calculation tool cannot be understood as a professional software for carbon footprint assessment since it was developed as a proxy because of the absence of applicability of existing tools as presented earlier in this report. It should help in term of this project to show environmental advantages of cold recycling techniques, whereas the principles might by adaptable in the future to any existing professional software.

The MS Excel-based tool calculates approximate costs of the road rehabilitation and carbon footprint. Calculation outputs can be used to find and support the most environmental compatible and friendly cold recycling technique to be suitable for the planned rehabilitation. This approach might be important and supportive to road administrators, local authorities or ministries of transportation. The results from this first version of a simple calculator will encourage further development of a suitable more complex tool to be applicable not only to contractors and the public road administration, but to the industry as such. The very basic MS Excel calculation tool was developed and practical case studies assessed.

There are stochastic methods used for calculating the total CO_2 and air polluting emissions (CO_2 – Carbon dioxide, NO_x – Nitrogen oxides, HC – Hydrocarbons, CO – Carbon monoxide, PM – Particulate Matters) for several rehabilitation technologies and their technological variants. The calculation tool consists of machinery database including real-time data, observed and measured on job site. Existing database can be freely supplemented by any additional type of used recycler, paver, compactor etc. Based on personal experience from the praxis and available information from the Wirtgen Group (machinery producer of recyclers, cold milling machines, pavers, rollers, crushers, asphalt plants), a day snapshot for the key machine (recycler) was created. Day snapshot describes usual working day activities on the job site, (CENIA 2013).

Four main activities/time sections have been identified:

1. Cold crank (engine starting, heating up);
2. Net operation time (recycling);
3. Technical breaks (e.g. waiting for the connection of other machines in the defined and used machinery set);
4. Engine switched off (checking the machine – liquids, milling drum, safety, refuelling, filling water/cement tank).

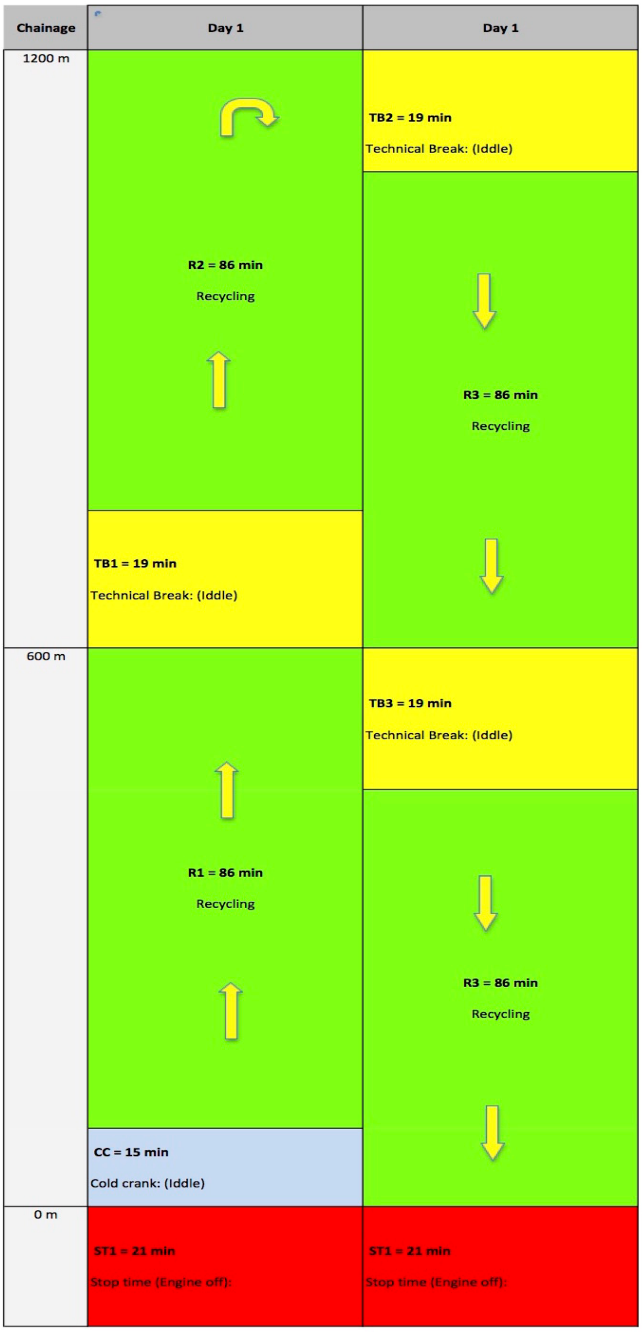

Figure 3: Day snapshot for a standard recycler

Following calculation summarize times necessary to finish the scope of work of a recycler for a standard working day.

Recycling:	**342** min
Stop time (Engine off):	**42** min
Cold crank: (Iddle)	**15** min
Technical Break: (Iddle)	**57** min
total	**456 min**

After the day snapshot was created and other missing times and data were gathered, the analysis of the time distribution (recycling, engine off time, cold crank, technical break) was done. The result from the analyses led to creation of the calculation formula for the excel basis tool. This formula was after small modification universally used also to other machines usually used during cold recycling techniques.

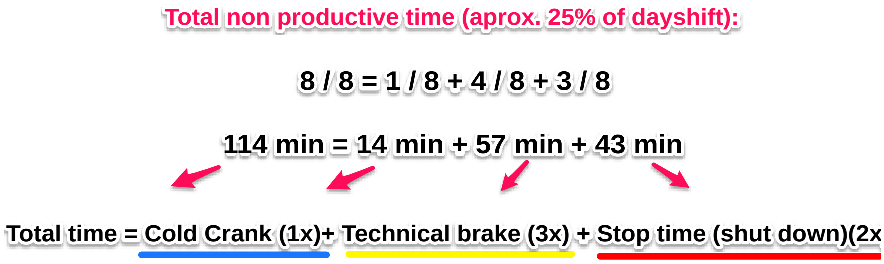

Figure 4: Time distribution and basic assumptions – recycler

Once the basic calculation assumptions for the tool were agreed between involved partners (CTU and Wirtgen), the work on calculation tool started. Following figures shows the first design and ideas of the calculation tool. Once user will insert the basic specification of the rehabilited road, then choosing of the prefered way of rehabilitation follows, (Snizek et al. 2014b).

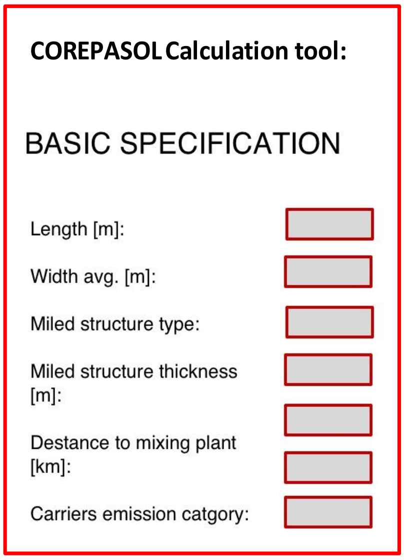

Figure 5: Inserting basic specification

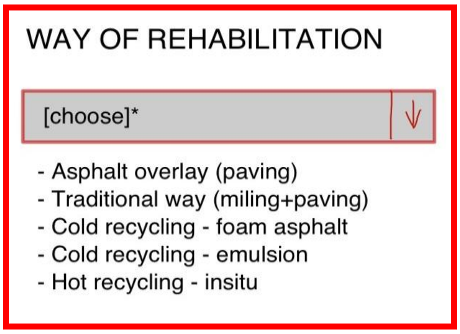

Figure 6: Selection of the rehabilitation option

On the Figure 6 of calculation tool design, there are also other rehabilitation methods included. But in fact only cold recycling techniques and its variants are described in detail. It was not the intention to include methods to the calculation, because it would be extremely demanding and out of scope of this research project. Once rehabilitation method would be chosen, next step leads to the choice of machinery used for the planned job site. Machines can be chosen from the basic database.

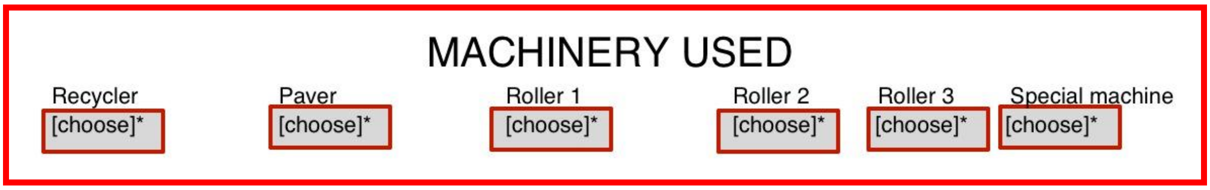

Figure 7: Choosing machinery used

After the machinery is chosen, the final table with basic economic and environmental parameters for possible methods is shown by the proposed simple Excel calculation tool. Results for each rehabilitation method should consist of following parameters: total costs, NO_x, HC, CO, CO_2 and particulate matter (PM).

OPTIMAL WAY

No.	Way of rehabilitation	Machinery	↓ Price	↓NOx.	↓HC+NOx.	↓CO.	↓PM.	↓Energy
1.	Cold recycling - asphalt foam	Wirtgen xx	€					
2.	Cold recycling - emulzion	Wirtgen xx	€					
3.	Traditional way.	Wirtgen xx	€					

Figure 8: Table for quick comparison of possible technologies and assessed parameters which can be compared

Despite of the fact that the software development of any tool has never been the aim of the CoRePaSol project, it was possible to invent a suitable alternative which has potential for further improvements. Unfortunately even if it was possible to develop basic MS Excel calculation tool, it had never reached the design showed above (Fig. 5-8) and transformation to the easy intuitive use and more friendly designed professional software application with multiple uses.

However, the development of the basic calculation tool was finished and the pilot as well as couple of other rehabilitation projects could be evaluated with this tool.

6 Pilot project – working example

Theoretically defined pilot project described in this report presents an asphalt pavement, which can be reconstructed by the technological option of cold recycling or by the use of standard recycling techniques. The aim of this sub-chapter is to demonstrate the process of comparing the amount of CO_2 produced in the material production (hydraulic and bituminous binders used to stabilize the cold recycled mixes) and CO_2 produced by the machinery during the actual implementation of the reconstruction, (Chehovits 2012).

In order to present the result a hypothetic pilot project was chosen with the following input parameters shown in Table 2.

Table 2: Basic project data

Type of road	Asphalt pavement outside municipal area
Length:	1,200 m
Width:	4.75 m
Rehabilitation depth:	150 mm

Individual technologies include various combinations of the following binders in a defined quantity.

Table 3: The content of binders in mixtures

Binders	Content (% by mass of the mix)
Foamed bitumen	2.5
Bituminous emulsion (C60B7)	3.5
Water	3.0
Cement CEM II 32.5 R	1.0

Table 4: Basic data of materials (production)

Mix component	Density (t/m^3)	CO_2 (kg/t)	Data source
Water	1.00	0.30	IVL
Cement CEM II 32.5 R	1.25	980	IVL
Bituminous emulsion (C60B7)	1.00	221	Eurobitume
Foamed bitumen	1.10	285	Eurobitume

Table 5: Basic data of fuel (production and consumption)

Substance	Density (t/m^3)	CO_2 (kg/l)	Data source
Diesel – refining	0.84	0.26	Afteroilev
Diesel – consumption	0.84	2.66	Czech Ministry of Environment

It is considered that for certain conditions during the reconstruction, any of the following reconstruction techniques or cold recycling technology can be used.

Table 6: Technology of the road reconstruction (Snizek et al 2014a, Valentin 2009)

1	CR – foamed bitumen, pre-spread cement
2	CR – foamed bitumen, cement slurry
3	CR – bitumen emulsion, pre-spread cement
4	CR – bitumen emulsion, cement slurry
5	CR – foamed bitumen
6	CR – bitumen emulsion
7	REC – pre-spread cement
8	REC – cement slurry
9	Pulverization

NOTE: CR = cold recycling, REC = recycling

Pulverization – should be understood as a very seldom-single used technique only applicable to roads with light traffic. This technique can be used in combination with other mentioned techniques together with pre-spread material (fines, aggregate). In reality it is not a typical recycling technique.

Cold-in place recycling is carried out by machines, comprising mainly of standard equipment used in construction processes (rollers, graders, cement spreader, water and asphalt tankers, etc.). Besides the standard construction machines, part of the set is also formed by special machines, mainly recyclers and cement slurry mixer. The assembly can also involve some specially equipped types of milling machines, which can replace the recycler for certain projects. The largest number of machines is needed for the implementation of road reconstruction in the case of cold-in recycling with foamed bitumen and pre-spread cement. The table below shows the average fuel consumption data corresponding with the construction machines.

Table 7: Average fuel consumption of machines in the project (l/m^2) and related CO2 by machines

Construction machine	Fuel	Consumption (l/m^2)	CO_2 (t/m^2)*
Binding agent spreader	diesel	0.0022	6.502E-06
Water tanker	diesel	0.0046	1.356E-05
Bitumen tanker	diesel	0.0052	1.520E-05
Recycler (WR 240i)	diesel	0.0788	2.302E-04
Padfoot compactor	diesel	0.0077	2.276E-05
Vibratory compactor	diesel	0.0077	2.276E-05
Grader	diesel	0.0109	3.204E-05
Tandem roller	diesel	0.0077	2.276E-05
Static roller	diesel	0.0070	2.071E-05

Fuel consumption and CO_2 emissions are calculated on the basis of work done and the fuel consumption per working day (day snapshot) and the amount of emissions per the same time period.

The amount of CO_2 produced per 1m^2 of surface project is bound primarily to fuel consumption, in this case diesel. For the pilot project values are resumed in Table 7. The Table 8 below summarizes the total amount of CO_2 produced and consumed quantity of fuel for each machine within the pilot project (cold-in place recycling with foamed bitumen and cement).

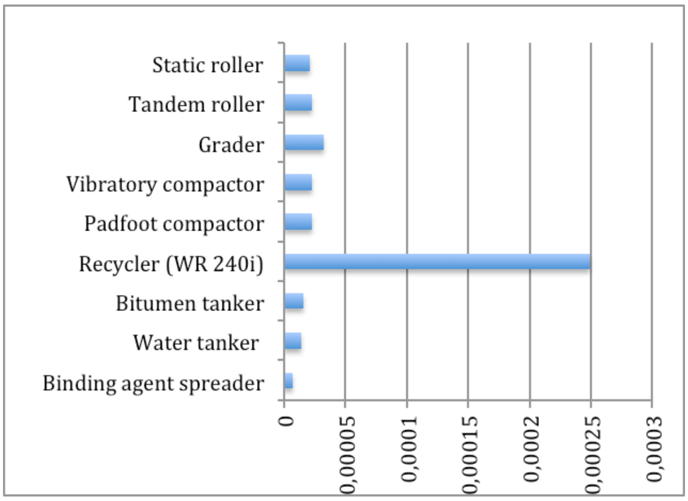

Figure 9: Average CO_2 production by machines (t/m^2)

Table 8: Total CO_2 produced and consumed fuel on the pilot project

Construction machine	Consumption of fuel (l)*	Produced CO_2 (t)
Binding agent spreader	12.69	0.0371
Water tanker	26.48	0.0773
Bitumen tanker	29.69	0.0867
Recycler (WR 240i)	449.37	1.3121
Padfoot compactor	44.44	0.1298
Vibratory compactor	44.44	0.1298
Grader	62.56	0.1827
Tandem roller	44.44	0.1298
Static roller	40.44	0.1181
TOTAL	**755**	**2.20**

** Fuel consumption is calculated on the basis of work done and the fuel consumption per working day (day snapshot).*

The recycler, as well as any other machine in the set can be replaced with another machine having the same capabilities. Following such modification, of course, the fuel consumption and CO_2 production varies. In order to maximise efficiency and workload on jobsite the machine specification should match the project specification. In the case of recyclers it is recommended to carefully choose their working width depending on the total project working width. The table below compares alternative recyclers for assembly machines, (Snizek et al 2012) and the consequence of an unfavourable choice.

Table 9: Alternative recyclers for the project

Construction machine	Consumption fuel (l)	Produced CO_2 (t)
Recycler (WR 200, 3rd)	517.36	1.5107
Recycler (WR 200i, 4rd)	486,32	1.4201
Recycler (WR 2400, 1st)	396.15	1.1568
Recycler (WR 2500S, 2nd)	362.15	1.0575

Although the recycler WR 200i is the most environmental-friendly one from the four selected machines, it operates with narrow swath while the desired width of the recycled pavement is larger. Therefore, when comparing with other three machines the WR 200i and also WR 200 must execute 3 runs while the other two only 2 runs.

Table 10: Average fuel consumption and CO_2 production of alternative recyclers

Construction machine	Average fuel consumption (l/h)*	Average CO_2 production (t/h)*
Recycler (WR 200, 3rd)	50	0.1511
Recycler (WR 200i, 4rd)	47	0.1420
Recycler (WR 2400, 1st)	67	0.2024
Recycler (WR 2500S, 2nd)	70	0.2115

** The calculation of CO_2 emissions and fuel consumption is based on the work done and the amount of emissions per day snapshot.*

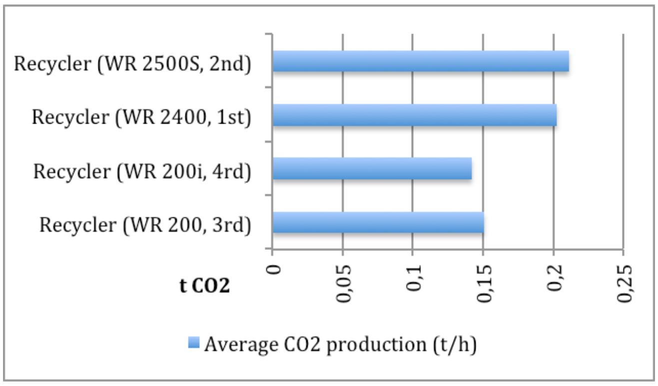

Figure 10: Average CO_2 production of alternative recyclers on project

Despite the fact that construction machinery significantly contributes to the production of CO_2 during the road reconstruction, the largest producer of CO_2 is the industrial production of subsequently incorporated materials (hydraulic and bituminous binders in particular). Table 11 presents total CO_2 production during the manufacture of each incorporated material used in various combinations within the defined pavement rehabilitation methods. Percentage of weight presents mass of material (its content) in the newly build-in mixture. Values are calculated by the MS-Excel calculation tool. Sources of unit reference figures and fixed parameters are show under the table.

Table 11: Total production of CO_2 during the production of materials in the pilot project (t/m^2)

Construction machine	% weight in the mixture	CO_2 (t)
[1]Water	3.0	0.05
[2]Cement CEM II 32.5 R	1.0	104.15
[3]Cement slurry	4.0	127.07
[4]Bituminous emulsion (60 %)	3.5	28.64
[5]Foamed bitumen	2.5	36.94

Reference data sources: 1-IVL; 2-Athena & IVL; 3-Athena & IVL; 4-Eurobitume; 5-Eurobitume

The table below gives a general overview of available technological options with a focus on the production of CO_2 by machines and from material manufacturing. The table also includes the estimated quantity produced per m^2 of the project with the implemented technology.

Table 12: Technological variants focusing on CO_2 – material and machines

Technology of rehabilitation	CO_2 (t) (kg/m^2)	CO_2 (t) Total
1 CR – foamed bit., pre-spread cement	6.60	37.63
2 CR – foamed bit., cement slurry	6.53	37.24
3 CR – bit. emulsion, pre-spread cement	6.80	38.78
4 CR – bit. emulsion, cement slurry	6.82	38.87
5 CR – foamed bitumen	2.93	16.68
6 CR – bitumen emulsion	3.13	17.82
7 R – pre-spread cement	3.98	22.66
8 R – cement slurry	4.01	22.87
9 Pulverization	0.28	1.60

Data source: OptiRec software application (calculation based on data from machine producer and European emission standards)

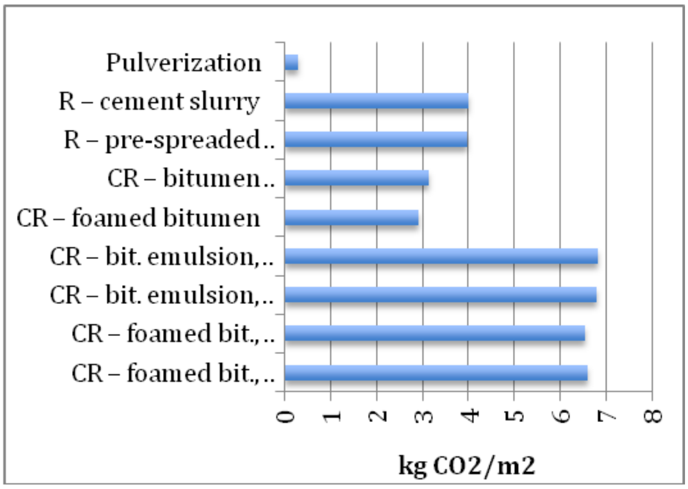

Figure 12: Overview of project's total CO_2 /m^2 for each technology including material and machines

The final part of this chapter is devoted to the proof of a minimum share of CO_2 production by construction machines involved in the road reconstruction. Following Fig. 22 and Fig. 23 CO_2 emissions produced by the whole set of machines used for the technology are within 5-10 % of the total amount of CO_2 produced. The remaining major amount is produced during the production and processing of the incorporated material, (CENIA 2013).

Table 13: Technological variants and source of CO_2

Technology of rehabilitation	CO_2 (t) material	CO_2 (t) machines
1 CR – foamed bit., pre-spread cement	35.86	1.78

2 CR – foamed bit., cement slurry	35.69	1.55
3 CR – bit. emulsion, pre-spread cement	37.14	1.63
4 CR – bit. emulsion, cement slurry	36.97	1.90
5 CR – foamed bitumen	15.03	1.65
6 CR – bitumen emulsion	16.31	1.51
7 R – pre-spread cement	20.85	1.81
8 R – cement slurry	20.68	2.19
9 Pulverization	00.02	1.58

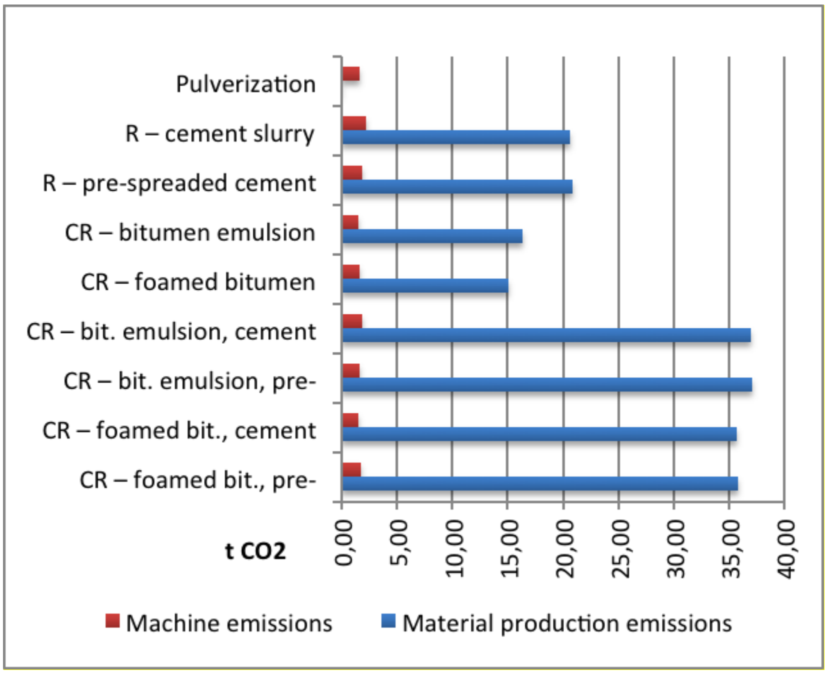

Figure 13: Technological options and sources of CO_2

7 Conclusions related to pilot project calculations

It can be concluded that in the case of road reconstruction with one of the cold in-place recycling techniques 90-95 % of emissions are generated during the production process of used construction materials, mainly the binders, where the crucial part of CO_2 is emitted. The influence of used construction equipment for road reconstruction remains in minority, reaching about 5-10 %.

The society should therefore seek primarily to eliminate just the emissions from the production and processing of building materials, and to maximize support for the use of once used and incorporated materials.

Recycled materials are often underestimated, although their quality can be often higher than the quality of newly produced mixtures and materials.

In this relation if going to answer the question of the impact of construction machinery on CO_2 emissions during cold recycling process as key emitter the recycler can be identified. Since cold-in place recycling runs complete recycling passage arrangement (up to 9 machines in some extremes), an important role is played by the recycler's working width in relation to the width of the reconstructed pavement. If possible, it is advisable to choose recycler with an appropriate working width in order to minimize number of crossovers during the road reconstruction and the grip of recyclers used to its maximum efficiency. In this way the emission and economic influences of the machinery will be significantly reduced.

It is necessary to follow up even the actions which are planned by the EAPA Task Group on Carbon Footprint, where one of the objectives is to create a generic example of Environmental Footprint Declaration (EPD) for European asphalt mix. It is expected that the EPD later could be used as a benchmark for all European nations and companies acting on the European market. The EPD and the Product Category Rules (PCR), which will be developed, should respect existing standards. It is only necessary to coordinate this action with any actions done by CEDR or by CEN TC 227/WG6 and with the activities within the EU-project "Ecolabel".

8 Acknowledgement

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