Re-Road *End of life strategies of asphalt pavements*

Environmental Performance of Reclaimed Asphalt – Final Report

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SEVENTH FRAMEWORK PROGRAMME

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Re-road – End of life strategies of asphalt pavements

WP3

D3.5 Final report - Environmental performance of RA

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List of abbreviations

Asphalt fumes	Gases, vapors and aerosols emitted from heated asphalt
BSM	Benzene soluble matter: the amount/fraction of particle matter from asphalt fumes soluble in toluene.
GWP	Global Warming Potential
HSA	High Specification Aggregates
LCA	Life Cycle Assessment
MSS	Sample name (in the risk assessment model) to denote pavement constructed using material from a mixed source stockpile.
ODP	Ozone Depletion Potential
PAH	Polycyclic Aromatic Hydrocarbons
PAH-16	16 PAH compounds listed as priority pollutants by the US Environmental Protection Agency.
PMB	Polymer Modified Bitumen
RA	Reclaimed Asphalt
Ref Mix 1	Sample name (in the risk assessment model) to denote pavement constructed using SMA with 0% RA.
Ref Mix 2	Sample name (in the risk assessment model) to denote pavement constructed using SMA with 15% RA.
Ref Mix 3	Sample name (in the risk assessment model) to denote pavement constructed using SMA with 30% RA.
SMA	Stone Mastic Asphalt
SVOC	Semi Volatile Organic Compounds
Stockpile	Sample name (in the risk assessment model) to denote pavement constructed using material from a mixed source stockpiles.
Storbit	Sample name (in the risk assessment model) to denote pavement constructed using a mixture with 50% RA and a rejuvenator called Storbit
TCA	Sample name (in the risk assessment model) to denote pavement constructed using a tar containing RA material.
TSM	Toluene soluble matter: the amount/fraction of particle matter from asphalt fumes soluble in toluene.
VOC	Volatile Organic Compounds
WP	Work Package

1 Introduction

The Re-Road project focussed on recycling asphalt at the highest level. This has been achieved through optimising recovery processes, plant, mixture designs and understanding performance. There was also a need to understand the environmental performance of recycled asphalt, a material that has already spent many years as part of a highway structure, and any risks that this may pose. Furthermore, there was a need to realise the environmental perspective for recycling asphalt in the first place; the benefits it could yield and how these benefits measure up to other environmentally-focussed initiatives in the asphalt industry.

Recycling asphalt was already an established practice before the Re-Road project commenced. However, there were questions as to whether it was being recycled to the most beneficial applications, with much ending up in unbound applications such farm tracks or fill.

1.1 Overview of Re-Road WP3

The main objective of the work package (WP) 3 research program was to develop and improve tools that can be used to assess and characterize the environmental performance of the use of reclaimed asphalt (RA) and to identify and assess environmental benefits and burdens rising from the different stages of an asphalt pavement's life cycle (Figure 1-1).

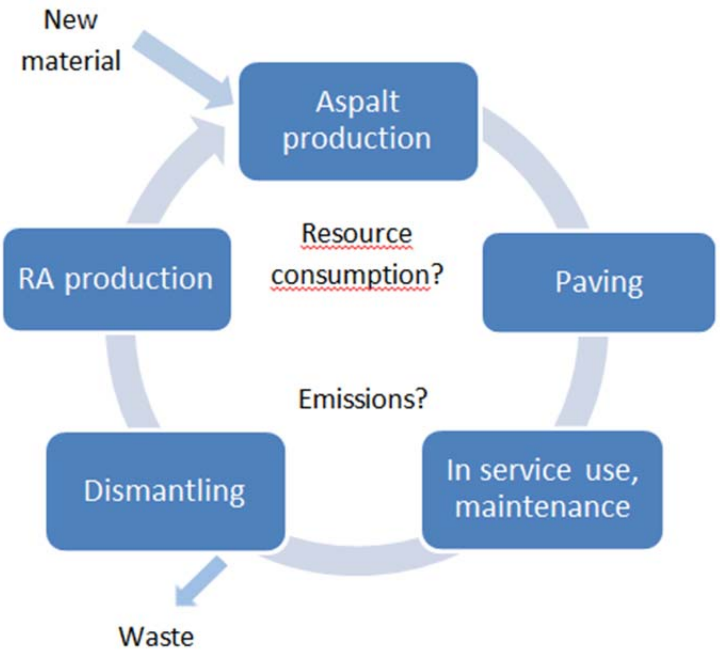

Figure 1-1. The asphalt pavement's lifecycle can be divided into the following four stages: i) asphalt production from new raw materials; ii) paving and in service use (including maintenance); iii) dismantling of the asphalt and iv) production of RA-material (crushing, sieving etc).

The research work conducted within WP3 has been organised in two subtasks:

- Subtask 3.1 Risk Assessment of RA
- Subtask 3.2 Life Cycle Assessment of RA

To allow the Re-road partners to conduct a risk assessment and life cycle analysis of pavements incorporating RA (relevant to all European partners) it was first necessary to obtain an accurate overview of the road construction practices employed across Europe. Hence, a survey was performed (using questionnaires and performing interviews) for the purpose of informing the subsequent analytical tasks. The results and conclusions of this work can be found in Deliverable 3.1 *State of the Art on Risk Assessment and Life Cycle Analysis of Reclaimed Asphalt* [1].

In deliverable 3.2 *Guide on Testing Methods for Environmental Characterisation* the various stages that require consideration was identified and test methods and field experiments capable of characterizing the crucial chemical and physical features were proposed and discussed.

In the deliverables D3.3 *Environmental Risk Assessment on the Use of Reclaimed Asphalt* [2] and D3.4 *Life Cycle Assessment of Reclaimed Asphalt* [3] the modelling work is presented in full details together with information on the data collected from literature, lab- and field experiments. This report summarises the main findings of these two assessments and provides an integrated evaluation of the results.

1.2 Partners/Authors

The following partners and authors contributed to the experimental studies, modelling work and the discussions of the results presented:

- <u>Partners</u>:
  - Swedish Geotechnical Institute, (SGI), Sweden.
  - Transport Research Laboratory, TRL Limited, (TRL), United Kingdom.
  - University College Dublin, National University of Ireland, Dublin (NUID UCD), Ireland.
  - Centrum Dopravniho Vyzkumu, (CDV), (in English: Transport Research Centre), Czech Republic.
  - The University of Nottingham, (UNOTT), United Kingdom
  - Danish Road Institute, (DRI), Denmark.

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- Aoife Quinn, NUID UCD
- Roman Ličbinský, CDV
- Jiří Huzlík, CDV
- Vilma Jandová, CDV

Additionally, the technical staff conducting the experiments at the participating laboratories is acknowledged.

1.3 Scope of the report

For RA to be successfully reused in high value recycling applications, such as reuse in new asphalt surfaces, it is necessary to ensure that the environmental characteristics of the material are fully understood. This, however, is a not an easy task as there are multiple processes involved and the quantification of these is quite difficult. The objective of this document is to summarise the Risk Assessment and Life Cycle Assessment work carried out within Re-Road WP3.

2 Risk assessment of RA

In all road construction work there exists an element of risk of environmental damage. This is an inevitable result of the construction process, but it is important to ensure that the level of risk remains within an acceptable range. The use of RA within asphalt surface layers presents many advantages with respect to material use and sustainability. However, there exists a perception that by using RA in surface courses, there is an increased risk of environmental damage. This raises a number of questions, including:

- Is there an increased risk of contaminants leaching by having the recycled materials closer to the surface (and infiltrating water)?
- Does the recycling process, including stockpiling of the materials, present any environmental hazards?
- What are the most likely pathways for contaminants that can lead to health issues (airborne, waterborne, other)?

A risk assessment of the road construction cycle represents a valuable tool in attempting to answer these questions. If the level of risk can be quantified, then informed decisions can be made about the process. This includes relative assessment of the risk associated with using recycled materials relative to that associated with using virgin materials.

2.1 Effect on groundwater quality

There are considered to be three potential sources of contamination associated with reclaimed asphalt:

- Contaminants in the bitumen, additives and aggregates;
- Contaminants which build up on the surface of the road during its previous pavement life/lives;
- Contaminants which build up during the life of the newly laid pavement containing RA.

These contaminants may then be available for leaching into road runoff or water infiltrating the road surface or they can be blown from the surface by wind.

In assessing the potential effect on groundwater, a leaching model was developed that incorporates data from the leaching tests reported in the Re-Road Deliverable D1.6 "Test Methods for Environmental Characterization of Reclaimed Asphalt" [4].

2.1.1 Modelling approach

A probabilistic modelling approach was undertaken to assess the effect of RA on water quality (full details are available in deliverable 3.3 [2]). This was utilised as it allowed discussion of the key question of material variability often associated with using recycled materials. The method employed was a Monte Carlo simulation approach. A standard pavement was identified and deterministic parameters were identified (e.g. pavement length and width). Normal distributions were assigned to variable parameters such as pavement depth, density and leaching behaviour. The pavements were then subjected to 18 years of rainfall data, based on the rainfall data set associated with Dublin Airport from 1990-2008. The mean annual rainfall in this area is 760mm and has ranged from 624mm to 1104mm.

The leaching characteristics of the pavement were based on data obtained from percolation tests [6] and measurements on total content (mg/kg) of the individual compounds belonging to the group of the 16 polycyclic aromatic hydrocarbons (PAH) listed as priority pollutants by US Environmental Protection Agency (PAH-16). Using this information a leaching model was developed and 20,000 simulations were conducted for a range of pavement types. These included:

- Pavement constructed using stone mastic asphalt (SMA) with 0% RA (Ref Mix 1);
- Pavement constructed using SMA with 15% RA (Ref Mix 2);
- Pavement constructed using SMA with 30% RA (Ref Mix 3);
- Pavement constructed using a mixture with 50% RA and a rejuvenator (Storbit);
- Pavement constructed using a tar containing RA material (TCA);
- Two pavements constructed using material from mixed source stockpiles (MSS and Stockpile).

Further details on these pavement constructions can be found in Deliverable D3.3 and information about the RA materials is given in

Table 2-1. For the particular cases of the pavement using the TCA, MSS and Stockpile materials, the pavement is in effect modelled as an unbound material. No fresh bitumen is added to the mix; the intention is to use these materials for comparison with the bound recycled materials.

Table 2-1 Materials included in the leaching model and their content of PAHs.

Sample name	Description	Sum of PAH-16
Ref. mix 1	Re-Road reference material – an 11.2mm stone mastic asphalt containing 0% RA	1.0[a] - 1.4[b]
Ref. mix 2	Re-Road reference material – an 11.2mm stone mastic asphalt containing 15% RA (RA=from stockpile in Germany; porous asphalt, polymer modified bitumen (PMB))	0.7[a] – 1.0[b]
Ref. mix 3	Re-Road reference material – an 11.2mm stone mastic asphalt containing 30% RA (RA=from stockpile in Germany; porous asphalt, PMB)	0.6[a] - 1.3[b]
Storbit	New asphalt mix, containing 50% RA and the rejuvenator Storbit. (RA= origin unknown).	5.5[a] - 9.1[b]
TCA	Sample taken from a mixed source stockpile (containing tar-RA) in Sweden. RA-aggregates <10mm. The origin of the tar-RA is unknown.	126[a] – 530[b]
MSS	Sample taken from a mixed source stockpile in Ireland. Origin of RA is unknown. The maximum particle size is 20mm.	23[a] – 57[b]
Stockpile	Sampled taken from mixed source stockpile in Czech Republic. RA = origin unknown.	7.2[a] – 41[b]

[a]Analysis of PAHs made on <4mm grain size; see Table 7.2 in Deliverable 1.6 of Re-Road [4].

[b]Analysis of PAHs made on <1mm grain size; see Table 3.4 in Deliverable 1.6 of Re-Road [4].

2.1.2 Input data

A sample of the leaching characteristics used for the modelling is shown below in Figure 2-1. The data presented in the figure corresponds to naphthalene leaching from the TCA sample, as determined using the percolation test [1]. Similar curves are available for each material, describing the release of all PAHs and selected heavy metals; these curves are used to characterise the release rate of these contaminants.

Equations are then developed for each contaminant describing the mass of contaminant released per kg of sample tested. This data is then transformed to allow for a number of differences between the way the material is used in the test and the way it is used in the pavement. These include:

- Different particle size distributions between test materials and road materials;
- Variation in the road construction (particularly with respect to depth and density of the constructed pavement);
- Allowing the modeller to describe the contaminant released per surface area of pavement instead of per kg of sample;
- Allowing for increased variability within the RA by specifying higher standard deviations in the leaching behaviour.

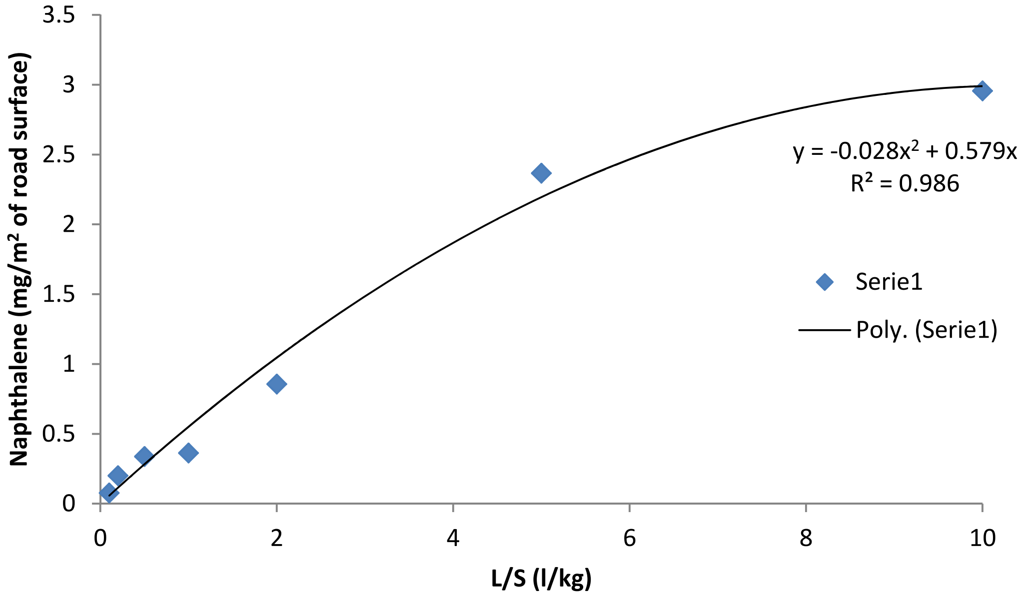

Figure 2-1 Leaching behaviour of naphthalene as determined using the TCA material in the percolation test

2.1.3 Results

The results of the probabilistic modelling are in the form of a probability distribution and these can be calculated for various scenarios for a range of PAHs. In each case the results correspond to 1 year of rainfall and 2 graphs are presented: a frequency distribution and a cumulative distribution of quantity leached per square meter of road area. Sample values are shown in the Figure 2-2 below; full details are available in Deliverable D3.3 [2].

2.1.3.1 PAH leaching after 1 year

Leaching from the pavement over a period of 1 year was modelled using the chosen rainfall data. A sample of the data is presented below in Figure 2-2, where the expected leaching of phenanthrene is presented. Similar distributions are available in D3.3 for all other PAHs. Based on these distributions a number of observations may be made:

- For the Re-Road reference mixes with 0%, 15% and 30% RA, the quantities of phenanthrene leached are far below what is observed for the TCA and MSS materials;
- There is no clear difference between any of the Re-Road reference mixtures, suggesting that there is no increased risk associated with using the material in surface courses;
- Similar trends were observed for all PAHs. The highest concentration of individual PAHs was always associated with either the MSS or TCA material.

Leaching levels associated with the reference mixtures were always significantly below these values.

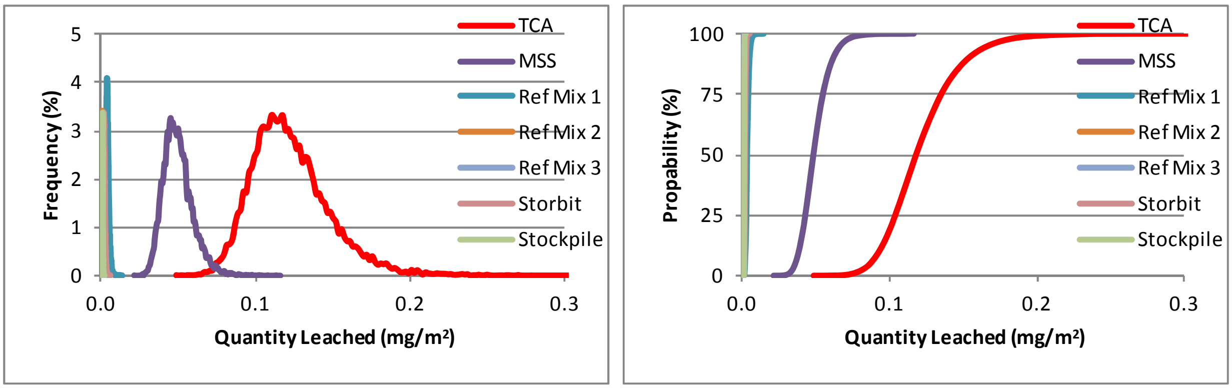

Figure 2-2 Sample leaching behaviour – phenanthrene leaching from various pavement surfaces after 1 years rainfall (figures of the other PAHs studied can be found in deliverable 3.3 [2]).

2.1.3.2 Summary Statistics

Based on the Monte Carlo simulations, it was also possible to produce a range of summary statistics that describe the results of the model. A range of distributions were produced for PAH leaching levels based on a typical pavement road construction. While the data does describe the range of values produced, it does not allow useful comparison with water quality guidelines. The data presented in Table 2-2 represents a summary of the data from the risk assessment model. The values represent an upper 95% fractile of the distributions presented in the figures such as Figure 2-2 above, i.e. a value with a 5% chance of being exceeded. This data is then converted to PAH concentration in water, by making use of the pavement area and volume of infiltrating water, both of which are already known.

Based on the values shown in Table 2-2, a number of comparisons can be made, both with groundwater limits and contamination levels associated with regular trafficking effects. An extract of the groundwater limits used in Ireland are presented in

Table 2-3 [7].Some conclusions include:
The levels of leaching associated with the Re-Road reference mixtures are significantly below the guideline values presented in

- Table 2-3. These materials will not exceed the EPA guideline values under any circumstances.

The highest leaching levels were associated with the tar containing RA, supporting supporting that restrictions are required on its use in road construction. It should be should be noted that the data presented in Table 2-2 does not exceed the EPA groundwater guidelines [7], but for the case of naphthalene it approaches the limiting value as listed in

- Table 2-3. As such, a prudent approach would be to conduct a site-specific risk assessment (including testing of total and leachable amounts of PAHs) before any re-use of tar-containing RA in road construction.
- In all cases the levels of leaching associated with the Re-Road reference mixtures is below that associated with wash-off of contaminants from road traffic.

It should be noted that the leaching model assumes no degradation, sorption or dilution of emitted PAHs reaching subsoil or groundwater. In practice this is not the case, meaning that the model used is very conservative.

Table 2-2 Summary of 95% fractile of leaching distributions after one year of exposure

	Concentration (μg/l)						
	TCA	**MSS**	**Ref Mix 1**	**Ref Mix 2**	**Ref Mix 3**	**Storbit**	**Stockpile**
Naphthalene	0.811	0.009	0.014	0.013	0.011	0.010	0.007
Fluorene	0.1429	0.1216	0.0082	0.0003	0.0003	0.0013	0.0005
Acenaphthene	0.1151	0.3271	0.0050	0.0002	0.0001	0.0009	0.0005
Acenaphthylene	0.0712	0.0372	0.0027	0.0002	0.0002	0.0005	0.0001
Anthracene	0.0249	0.0265	0.0032	0.0001	0.0001	0.0004	0.0001
Phenanthrene	0.2278	0.0918	0.0079	0.0003	0.0002	0.0039	0.0014
Fluoranthene	0.1429	0.1216	0.0082	0.0003	0.0003	0.0013	0.0005
Pyrene	0.0117	0.0142	0.0003	0.0000	0.0000	0.0003	0.0003
Benzo(a)anthracene	0.0004	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Chrysene	0.0003	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Benzo(b,k)fluoranthene	0.0006	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000
Benzo(a)pyrene	0.0005	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000
Indeno(1,2,3-cd)pyrene	0.0003	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000
Dibenzo(a,h)anthracene	0.0003	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000
Benzo(g,h,i)perylene	0.0003	0.0001	0.0002	0.0000	0.0000	0.0000	0.0001

Table 2-3 PAH interim guideline values [7]

Parameter	Interim Guideline Value
Naphthalene	1.0 µg/l
Anthracene	10000 µg/l
Fluoranthene	1.0 µg/l
Benzo(b,k)fluoranthene	0.5 µg/l
Benzo(a)pyrene	0.01 µg/l
Indeno(1,2,3-cd)pyrene	0.05 µg/l
Benzo(g,h,i)perylene	0.05 µg/l

2.2 *Effect on air quality*

The health hazard related to airborne bitumen fume generation is primarily relevant for paving crews while there is little opportunity for exposure related to asphalt plant workers. Exposures to asphalt fume have declined since the 1970's and is normally below occupational threshold limits [8]. Recycling of RA and introduction of additives can potentially create new exposures and health concerns. The complex chemical composition of asphalt fumes and the high variability in exposure makes the occupational assessment of bitumen fume susceptible to large variability in magnitude and constituent for a variety of influencing factors, including:

- Climate, (wind speed and direction, temperature etc.);
- Work tasks (paving, screeding, raking, rolling etc.);
- Ambient environment;
- Asphalt application (type, source, temperature, engineering controls etc.);
- Sampling device (type, rate, duration etc.);
- Metric under examination (toluene soluble matter (TSM), benzene soluble matter (BSM), volatile organic compounds (VOC), semi volatile organic compounds (SVOC) etc.).

This high variability in occupational exposure can mask significant changes in emissions and makes it very difficult to relate quality and quantity of bitumen fumes to the quality of RA, binder and binder additives. In order to correctly assess the influence of these parameters, laboratory test methods performed under controlled conditions can be of great value. Such experiments were therefore conducted, using a laboratory bituminous mixtures fume generator, making it possible to isolate and identify the impact of RA and asphalt binders on both quality and quantity of emitted bitumen fumes [4]. By making use of a sequential mixing protocol it was further possible to relate these emissions to specific parts of the RA recycling cycle e.g. paving or asphalt plant. The obtained data can either be used as input for risk assessment of critical parts of the life cycle (paving activities) or as input for life cycle assessments (LCAs).

Hot mix asphalt data from the fume generator (mixing temperature 145°C) was compared with field data on emissions collected from the literature (full details and references are given in deliverable 3.3 [2]). The comparison showed that the laboratory data reproduces the decline in bitumen fume emissions with the progression of the recycling cycle due to depletion of VOCs and SVOCs [2]. However, the mixing protocol was found to underestimate the emissions of bitumen fumes. This is particularly pronounced for the parts of the mixing protocol that aim to reproduce mixing activities; emissions were underestimated by at least a factor of 50. This is a drawback since mixing activities are the main opportunities of emissions and a dominating source in relation to health hazards. The underestimation of emissions may also give false representation of the quality of bitumen fumes in the latter parts of the mixing protocol (representing paving activities) since it may underestimate the depletion of specific VOCs or SVOCs. Furthermore, the laboratory bituminous mixtures fume generator and the mixing protocol is not sensitive enough to allow the identification of specific, and from the risk assessment point of view, important substances such as PAH and BSM in the latter part of the mixing protocol (paving activities).

Despite these difficulties the fume generator has yielded some interesting results. Addition of uncontaminated RA in the hot mix asphalt process does not seem to increase the total emissions or the quality of bitumen fumes in any significant way. Data on emissions from mixes containing tar contaminated RA shows that these types of mixes are more emissive, especially for PAH; this is also in agreement with earlier findings [9]. In addition, tar contaminated RA is also more emissive for benzene soluble matter BSM. Both PAH and BSM are important parameters in relation to health risks. The effect is pronounced even for mixes with a rather limited contamination of PAH at approx. 300 mg/kg (PAH-16). Data on the recycling of PmB RA and use of added modified binder (SBS PmB 25/55-55A used in Re-Road WP 5 - Performance modelling of RA) indicate an increase in the emission of BSM compared to added pure paraffinic binder (35/50 pen-grade). This increase is conspicuous and indicates that occupational exposure limit values might be exceeded although the uncertainty of the method is still too large for the latter to be ensured. Only two different types of binders were tested and these findings need to be confirmed by testing on an expanded set of binder qualities. Further investigations are also needed to clarify the reason for this behaviour. Re-Road experimental data indicate that RA can be a source of airborne organic contaminants to the hot mix asphalt plant process. The extent to which these will be emitted at the plant stack will depend on the removal efficiency in the plant process and how RA is introduced in the asphalt plant.

The laboratory bituminous mixtures fume generator is an important tool to relate quality and quantity of bitumen fumes to the quality of RA, binder and binder additives but still has flaws and should be developed. More calibration of laboratory test data with measurements in the field is needed. Preferably the same set of materials should be tested both in the laboratory and in the field. The possibilities of modifying the method so that emissions related to mixing activities are higher should be investigated. There is also need of a laboratory method that can estimate the emissions of fumes during in situ hot recycling of asphalt pavements.

Field studies on RA particle release to the environment during cold milling operations showed that emissions could tentatively be grouped into three different categories

a) Low release of RA: below 0.01 kg/m2 of milled surface (0.01 % of milled RA mass). This release can be achieved with ambitious sweeping actions and at favourable weather conditions (low wind speed < 4 m/s)

b) Medium release of RA: up to 0.05 kg/m2 of milled surface (0.05% of milled RA mass). This release is normally achieved with moderate sweeping actions and at normal weather conditions (wind speed < 8 m/s)

c) High release of RA: above 0.5 kg/m2 of milled surface (0.5% of milled RA mass). This release is achieved with failing sweeping actions or substantial involuntary or accidental spillage or conscious dumping and at extreme weather conditions (wind speed > 10 m/s).

2.3 Conclusions

Resulting from the Risk Assessment conducted in Deliverable D3.3, a number of concluding remarks were made:

Remarks related to the leaching of contaminants:

- The use of RA within bound pavement mixtures resulted in no increase in environmental risk. Bituminous bound mixtures containing 0%, 15%, 30% and 50% RA all produced similarly low levels of leaching, significantly below the groundwater limit values for contaminants such as PAH and heavy metals.
- There was no clear pattern discernible that could be considered to apply across all PAH compounds. If a material was leaching low quantities of lighter PAHs, this did not mean that the behaviour would also be observed for the heavier PAHs. In this context, it is recommended that future risk assessments should include all of the 16 EPA priority PAH.
- The highest leaching levels were associated with the tar containing RA, supporting the practice of restricting its use in road construction. Re-use of tar-containing RA in road construction should be preceded by site-specific risk assessment and testing of total and leachable amounts of PAHs.
- The variability of the leaching associated with RA was not found to be significant.
- It should be noted that the leaching model assumes no degradation, sorption or dilution of PAHs. This means that the model used is very conservative.
- A stockpile experiment was conducted and showed that it is possible to observe appreciable levels of leaching associated with water infiltrating stockpiles of RA. The risk associated with storing RA, with high levels of contaminants (e.g. PAH-16), outdoors appears high, and consideration should

be given towards the impact of the leaching water on its receiving environments.

Remarks related to the emissions to air:

- The laboratory asphalt fume generator gives valuable input to both LCA and risk assessment.
- The total emission of asphalt fumes during plant hot recycling (measured as total organic carbon) does not change substantially due to addition of uncontaminated RA.
- Laboratory data on the quality of fumes (e.g. PAH and BSM content, both of which are critical substances with respect to health risks), changes in relation to both binder and RA quality.
  Tar contaminated RA is more emissive by orders of magnitude exceeding occupational limit values for BSM at paving activities.
  The use of a modified binder (SBS-modified) indicates a pronounced increase in the emission of BSM compared to a pure paraffinic binder. Only two different types of binders were tested and these findings need to be confirmed by testing on an expanded set of binder qualities. Further investigations are also needed to clarify the reason for this behaviour.
- There is a need for further development and calibration of the laboratory fume generator and emission protocols to improve its sensitivity for emissions related to paving activities and its consistency with field data. There is also need of a laboratory method that can estimate the emissions of fumes during in situ hot recycling of asphalt pavements.

Remarks related to emission of particles during cold milling:

- The loss of RA-particles during cold milling of pavements is low and substantially lower than the loss caused by surface wear from studded tires with the exception of failing sweeping operations or extreme weather.

3 Life cycle assessment of RA

The life cycle assessment (LCA) study [3] focussed on the environmental basis for recycling asphalt and how it measured up against other environmentally-focussed initiatives in the asphalt industry. Also within the scope of the study, it was possible to investigate specific parts of the life cycle that could be optimised in order to enhance benefit realisation, or negate any particular negative effects that may be associated with RA use. The research answered questions including those listed below:

- What are the benefits of recycling asphalt?
- What is the additional benefit of recycling surface course back into new surface course?
- How does the toxicity of reclaimed asphalt compare to that of virgin aggregates and bitumen?
- How do the benefits of recycling compare to those of warm mix asphalt?
- By how much does moisture in RA diminish the benefits of recycling?
- How significant is durability in relation to recycled mixtures?

3.1 *Impact assessment*

Undertaking a life cycle assessment (LCA) was the most appropriate way to establish the necessary framework to answer these questions on an equitable, transparent basis. The life cycle assessment could also make use of the abundant data that had been generated by past research and some of the new data that would be generated in the course of the Re-Road project. The LCA software “SimaPro” was used to facilitate the assessment[1], with generic datasets selected for transport, energy use and some materials selected from the integrated Ecoinvent database[2].

A range of ten impacts were assessed in the LCA, these are briefly summarised in Table 3-1. These were selected to meet the EN 15804:2012 standard on the *Sustainability of Construction Works* and were supplemented with four categories to assess toxicity.

[1] SimaPro: http://www.pre-sustainability.com/simapro-lca-software

[2] EcoInvent v2: http://www.ecoinvent.ch/

Table 3-1 Impact categories assessed

Impact category	Unit	Brief description
Abiotic depletion	kg Sb eq	The depletion of “non-living” finite natural resources.
Acidification	kg SO2 eq	Results in lowering the pH of water courses.
Eutrophication	kg PO4--- eq	Nutrient enrichment of water courses.
Global warming (GWP100)	kg CO2 eq	Leads to climate change effects.
Ozone layer depletion (ODP)	kg CFC-11 eq	A reduction of stratospheric ozone leads to a proliferation of UV rays at the Earth’s surface.
Human toxicity	kg 1,4-DB eq	These four impact categories assess the potential toxicity levels associated with chemical compounds on humans and organisms in the fresh water, marine and terrestrial environments respectively.
Fresh water aquatic ecotoxicity	kg 1,4-DB eq	
Marine aquatic ecotoxicity	kg 1,4-DB eq	
Terrestrial ecotoxicity	kg 1,4-DB eq	
Photochemical oxidation	kg C2H4 eq	Photochemical oxidation results in summer smog production in the troposphere.

3.2 Results

Some of the key results are presented in this section. Each of the analyses uses a baseline of “virgin material” (conventional hot mix stone mastic asphalt) against which a series of additional scenarios are presented that are subtle variations on the first. Figure 3-1 demonstrates the reduced impact associated with recycling to sub base (unbound), a single bound course at 15% and 30% and to all courses (“high recycling; 30% to each bound layer and 50% to the sub base).

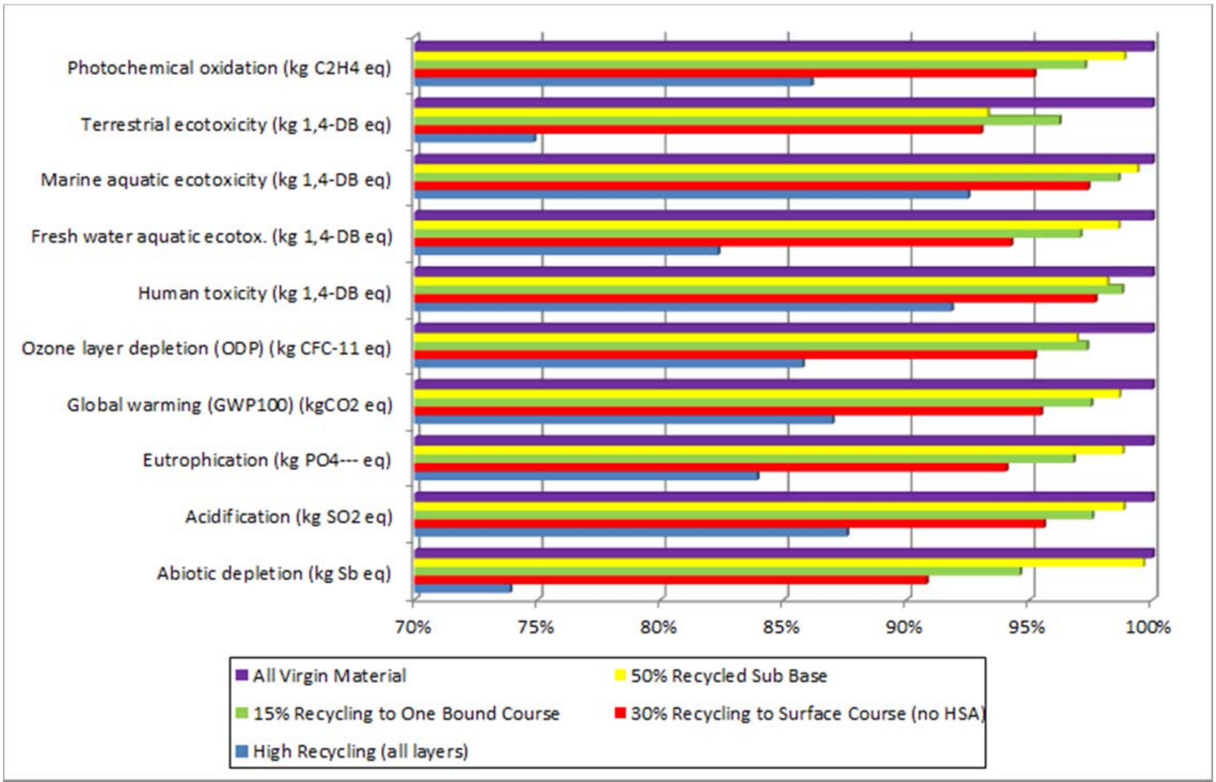

Figure 3-1 Varying recycling routes and rates

The disparity of sources of high specification aggregates with the required skid resistance properties to be placed in the surface course is investigated in Figure 3-2. Here the conventional hot mix asphalt in the surface course contains high specification aggregates (HSA) that have undergone an additional journey from source to plant of 900 km by boat and some additional processing due to their hardness. The journey by boat was selected to be representative of journeys undertaken by HSA across Europe e.g. from Norway to Denmark or Northern Ireland to South-East England. Other types of journey are investigated in D3.4 [3]. Two further scenarios are presented that investigate 30% recycling of the course containing HSA (which displaces some of the requirement to use fresh HSA) and another scenario that recycles an equivalent amount of asphalt to a base or binder course that does not require the use of HSA. A tangible additional benefit is associated with preserving asphalt containing HSA to the surface course.

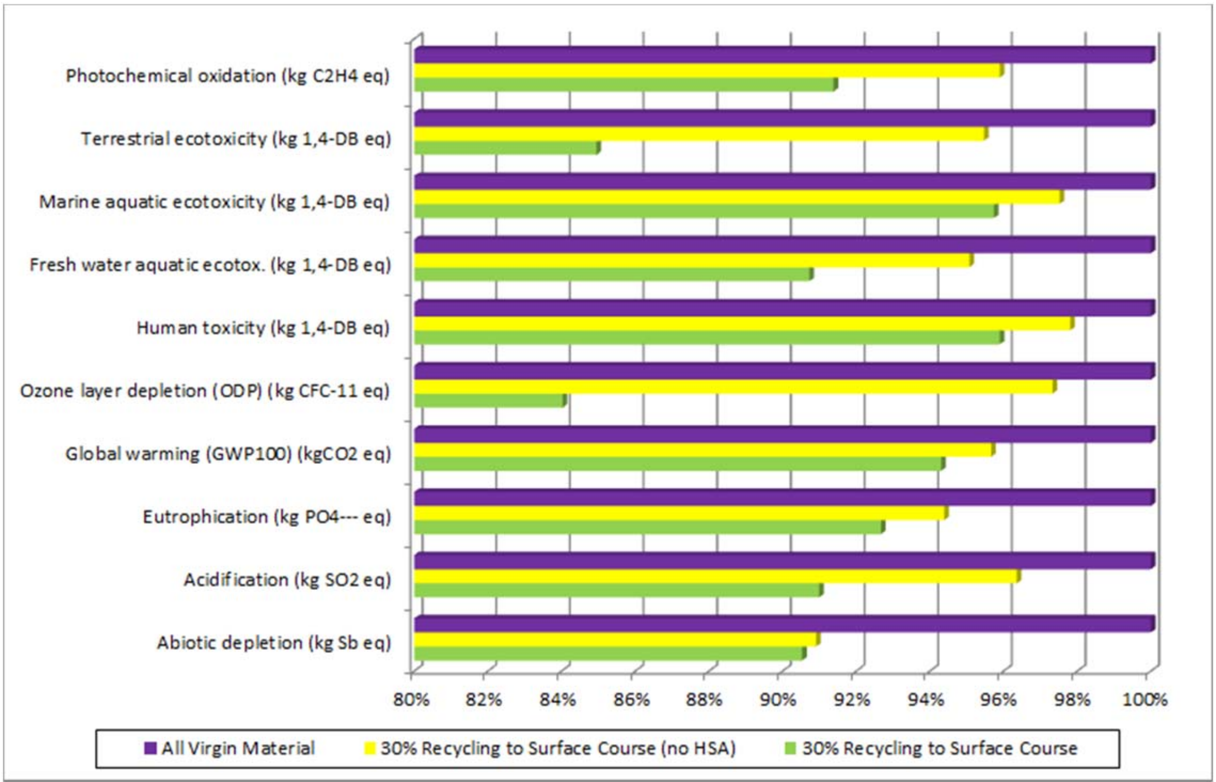

Figure 3-2 Assessing the additional benefits of recycling to the surface course

Warm mixing of asphalt mixtures (at 130°C as opposed to 165°C) is another environmentally-focussed initiative that is currently gaining more traction across Europe (and is very prominent in the United States). Figure 3-3 compares the environmental credentials of warm mixing to a low recycling scenario (with just 15% recycled to bound layers). Additives are also commonly used to facilitate warm mixing; a further scenario shows the impact of warm mixing using a synthetic (Fischer-Tropsch) wax additive.

RA sometimes contains excessive moisture when compared to virgin aggregates that has to be driven off in the plant dryer before it can be incorporated into new mixtures. The moisture can arise during its previous lifetime and as a result of typical storage situations (exposed stockpiles). This particular factor is reflected in the results displayed in Figure 3-4.

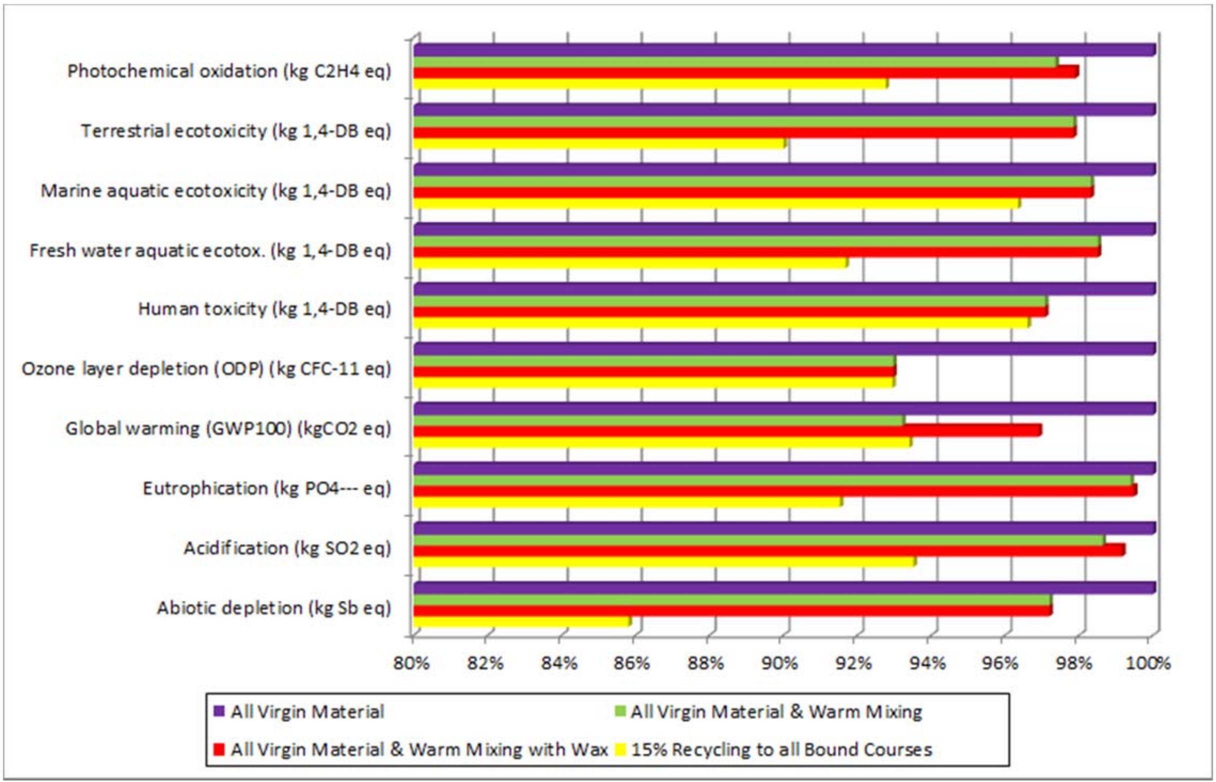

Figure 3-3 Comparing warm mixing and recycling

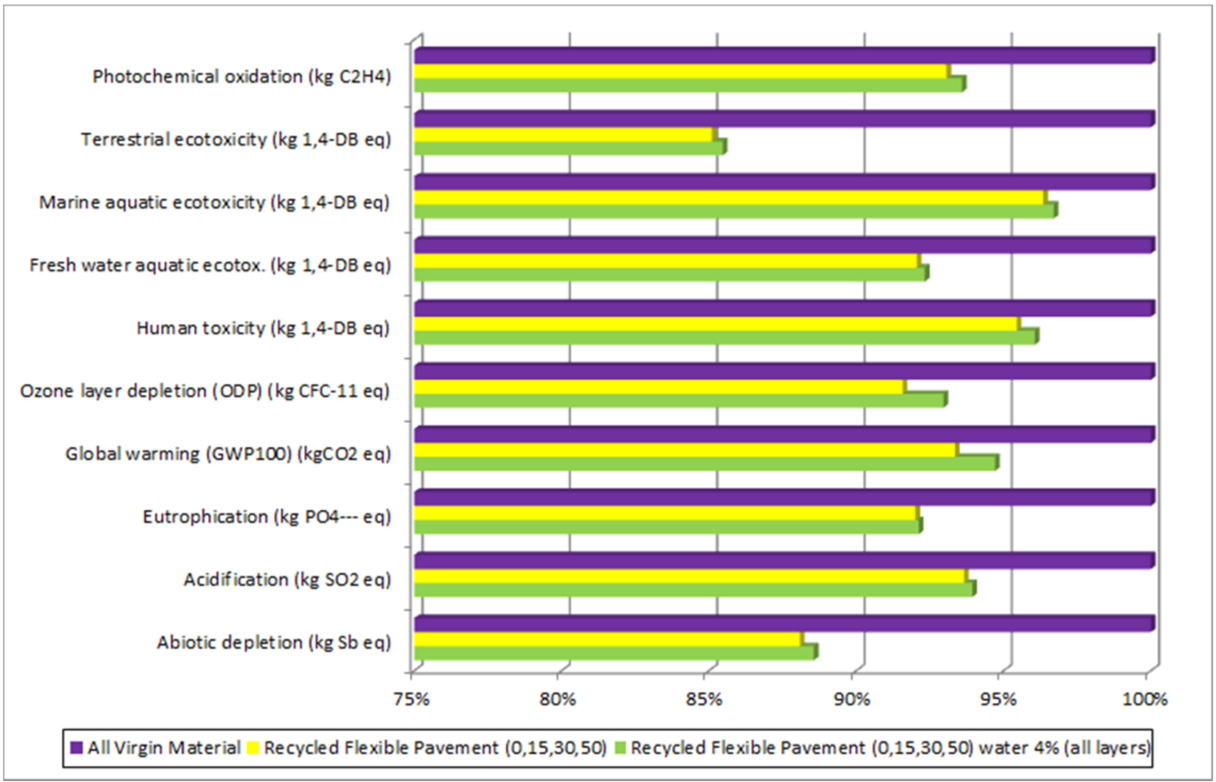

Figure 3-4 Evaluating the effects of excess moisture in RA

The durability of asphalt mixtures remains one of the “biggest unknown quantities” in pavement design since variable durability can result from any of a number of factors of which recycled content may be one. The results of Re-Road and other past studies are inconclusive as to whether RA content is really factor in enhancing or diminishing the durability of pavement courses. However, the resultant effect of variable durability in terms of environmental performance is indicated in Figure 3-5.

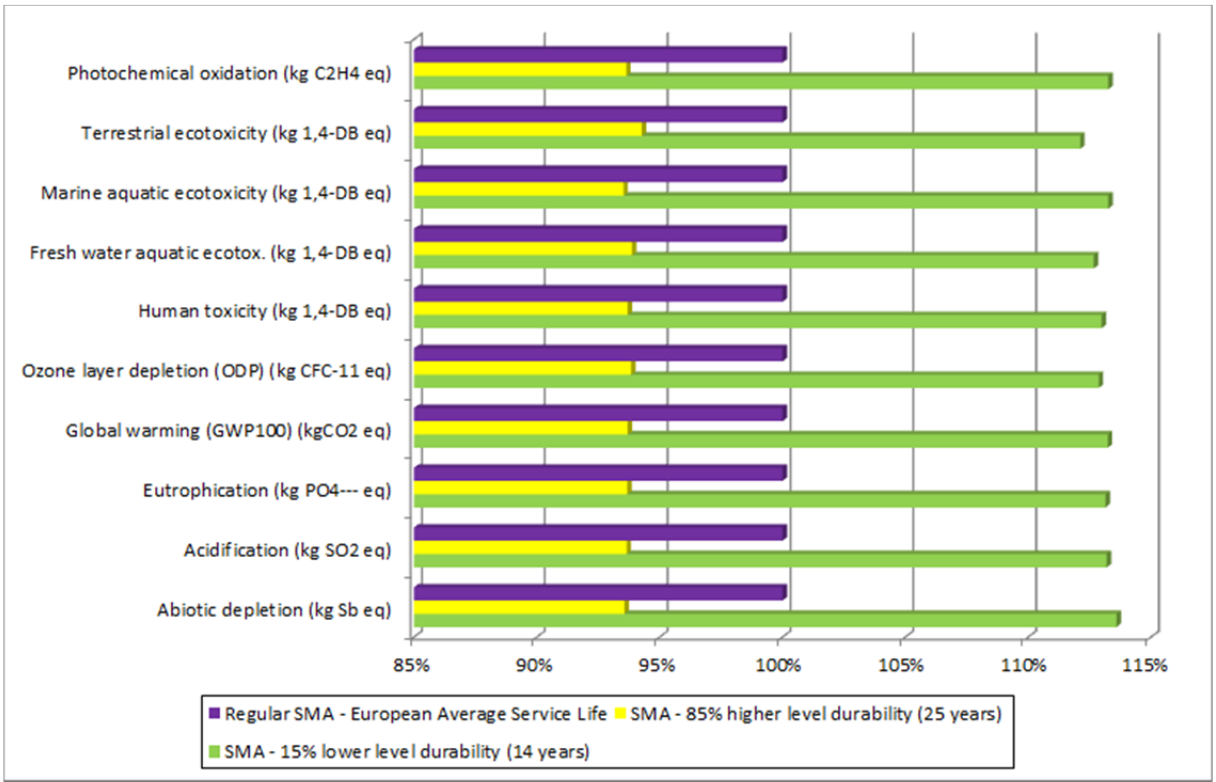

Figure 3-5 Evaluating the effects of variable durability

3.3 Conclusions

The results of the LCA demonstrate that, above all, recycling to a bound course was significantly more environmentally advantageous than recycling to an unbound course. Appreciable extra benefit can be realised if high specification aggregates are preserved in their original application by surface-to-surface course recycling, due to the quarries that produce these specialised aggregates being widely spaced (hence requiring large transport distances for the aggregates). The moisture content that is sometimes present in reclaimed asphalt only mildly counteracts the recycling benefits.

The results indicate that low level recycling (just 15% to bound courses) is significantly more environmentally beneficial than warm mixing, from the perspective that it achieves bigger impact reductions across more impact categories, this effect is accentuated if the additives used to facilitate warm mixing are included in the analysis.

The LCA also suggested that the toxic effects of organic compounds that experiments have shown to be present in the leachates and vapours arising from reclaimed asphalt materials are not that significant. However, the risk assessment that has also been conducted as part of Re-Road (Deliverable 3.3) is likely to be the best source of information regarding these potential toxic or harmful compounds.

4 Integrated evaluation

4.1 Determining the significance of toxic and harmful compounds using different methodologies

Interestingly, the combined approach to environmental assessment used in Re-Road produced some useful synergies in terms of the results obtained. The risk assessment and the LCA both attempted to assess the potential significance of certain waterborne contaminants present in RA (organic and inorganic) in terms of their impact on human health. This was one of the main foci of the risk assessment, which applied a probabilistic simulation approach to assess risk using primary data obtained from lab- and field experiments. An attempt was also made to assess a range of toxicity impacts (considering human, marine, fresh water and terrestrial environments) in the LCA, using secondary data from peer-reviewed sources and the CML impact assessment methodology, developed by the University of Leiden, Netherlands [10].

At the time of analysing the LCA results in Deliverable 3.4, some questions were raised over the validity of the results arising from the toxicity impact categories, given that it took very high concentrations of contaminants to show any type of significance in the results in relation to in situ leaching. However, the results obtained have been validated by those of the risk assessment, given the fact that observed contaminant concentrations arising from bound pavement materials in the risk assessment were well below water quality guideline values for all pollutants even in the case where tar contaminated RA was recycled.

Only in relation to the case of stockpiled material field tests did the concentrations exceed the recommended groundwater guidelines [7] (for zinc, fluoranthene and benzo[b]fluoranthene only). This was somewhat mirrored in the LCA, when the results of a peer reviewed batch study are modelled and the magnitude of the fresh water aquatic ecotoxicity impact is seen to be very sensitive to varying PAH concentrations. The concentrations of inorganic chemicals such as zinc could not be considered by the LCA since they were not covered by the peer reviewed study.

Om the contrary, the risk assessment and the LCA came to different conclusions regarding the potential significance of airborne emissions in terms of their impact on human health. The LCA suggested that the toxic effects of emissions of organic compounds to air in plant hot mix recycling of reclaimed asphalt materials are not that significant, while the risk assessment showed that the quality of RA and of binders have a significant impact on the quality of generated fumes. Laboratory data combined with field data strongly indicate that occupational exposure limit values for paving activities are exceeded at hot mix recycling of tar contaminated RA. In addition, the laboratory data indicated that the quality and type of added binders in the plant recycling process may also have a significant impact on the quality of fumes. Only two different added binders, one SBS-modified binder and one pure paraffinic binder, were tested and these findings need to be confirmed by testing on an expanded set of binder qualities. Further investigations are also needed to clarify the reason for this behaviour.

5 Facilitating implementation

The central objective at the heart of the Re-Road project is to develop knowledge and innovative technologies for enhanced end of life strategies for asphalt road infrastructure. From an environmental perspective, this involved tasks such as:

- Identifying and quantifying any increased environmental risk associated with having the recycled materials closer to the surface.
- Assessing the overall environmental performance of the recycling process
- Determining the most appropriate material management route for reclaimed asphalt and the relative benefits of the alternative routes.
- Exploring the relative performance of environmentally-focussed asphalt initiatives.
- Determining how product level factors and refinements can influence environmental performance

As can be seen from the conclusions presented above, the use of RA in asphalt surface courses was largely seen as being of positive benefit. However the experience of the partners in the project to date has also allowed for some suggestions to be made for future work. These would include:

- Further development of test methods that better represent the leaching process associated with materials used in pavements. Many of the leaching test methods available have originally been defined for soils or wastes, and the use of these methods for pavement engineering does raise uncertainty on how to use the results. Guidance on key issues such as preparation methods and testing of bituminous mixtures would add significant value to the tests and could form the basis for future risk assessments.
- Further development and calibration of the laboratory fume generator and emission protocols to improve its sensitivity for emissions to air related to paving activities and its consistency with field data.
- A life cycle costing with the same parameters of the LCA; the economic perspective could be vital with regards to elevating recycling rates, particularly since bitumen is a crude oil derivative and its prices are directly dependent on the price of oil.
- Durability assessments that produce robust lifetime data for all types of asphalt mixtures (recycled, warm, half-warm and cold), since these are critical to making an informed analysis of the environmental credentials of any material.
- Consideration should be given to the potential impacts of infrastructure and plant that facilitates the asphalt recycling process including covered bays for RA storage and additional feed lines (conveyors and dryers) that are sometimes retrofitted to existing asphalt plant to handle higher quantities of RA.
- Research that considers in-service wearing of the surface course and the fate and potential impacts associated with the particulates generated.

6 References

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[5] CEN ISO/TS 21268-2:2009 “Soil quality – Leaching procedures for subsequent chemical and ecotoxicological testing of soil and soil materials – Part 2: Batch test using a liquid to soil ratio of 10l/kg dry matter (ISO/TS21268-2:2007)”.

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[7] Environmental Protection Agency Ireland (2003). *Towards Setting Guideline Values for the Protection of Groundwater in Ireland*. Environmental Protection Agency, Ireland.

[8] European Asphalt Pavement Association (2007). *Environmental guidelines on best available techniques (BAT) for the production of asphalt paving mixes*.

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[10] Institute of Environmental Sciences, University of Leiden: Handbook on impact categories "CML 2001”. Leiden, The Netherlands, 2002.

re-road.fehrl.org

THE RE-ROAD PROJECT aims to develop knowledge and innovative technologies for enhanced end of life strategies for asphalt road infrastructures. Such a strategy has an important impact on the energy efficiency and the environmental footprint of the European transport system and fits within the life-cycle thinking which is being introduced in waste policy at European level. It leads to reduction of the need for new raw materials, prevents the creation of waste and the occupation of landfills and consequently minimizes the need to transport these materials to and from the work site and hence reducing energy, pollution including CO_2-emissions.

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EUROPEAN COMMISSION DG RESEARCH
A FP7 Collaborative Project
WORK PROGRAMME Sustainable Surface Transport
SST.2007.1.2.2 End of life strategies for vehicles/vessels and infrastructures

WORK PACKAGES

WP 1 Sampling and Characterization of RA
Virginie Mouillet

WP 2 Impact of RA quality and characteristics on mix design and performance of asphalt containing RA
Konrad Mollenhauer

WP 3 Environmental performance of RA
Anja Enell

WP 4 RA processing and RA management at the mixing plant
Erik Nielsen

WP 5 Performance modelling of RA
Sabine Werkmeister

RA = Reclaimed asphalt