CEDR Transnational Road Research Programme
Call 2013: Energy Efficiency

funded by Austria, Germany,
the Netherlands, Norway, Slovenia and UK

Conférence Européenne des Directeurs des Routes
Conference of European Directors of Roads

EDGAR
Evaluation and Decision Process for Greener Asphalt Roads

Guidance document on the sustainability assessment of bituminous materials and technologies

Deliverable 2.2
October, 2015

Project Coordinator:
BRRC – Belgian Road Research Centre

Project Partners:
EPFL – Ecole Polytechnique Fédérale de Lausanne
TRL – Transport Research Laboratory
NTNU – Technical University Trondheim

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Due date of deliverable: 15/08/2015
Actual submission date: 31/10/2015

Start date of project: 16/04/2014 End date of project: 15/04/2016

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Version: 0.1, 10/2015

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Executive summary

The principal aim of the EDGAR project is to bridge the gap between innovation in the bituminous materials sector and adoption of the new technologies[1] by national road administrations (NRAs). It aims to do this by providing road authorities with an assessment methodology that places sustainability information on the new technologies at their fingertips, enabling them to make informed decisions, by building an evidence base, and gaining re-assurance to facilitate quick adoption of the technologies that provide the biggest advances towards sustainability for the highways sector and society as a whole.

This document details the approach taken to developing a sustainability assessment process for novel bituminous technologies, and the resultant methodology for NRAs to use. The methodology is formulated in a six-step process; starting with NRAs raising concerns over a technology and ending with them enabled to make an informed decision over its use. The methodology provides assistance for NRAs at each key juncture, from identifying concerns, selecting the indicators to assess, performing the assessment, and evaluating the results with the assistance of weighting methodologies and conventional asphalt baselines. The process can be repeated as more evidence is generated that relates to use of a technology, allowing the decision maker to become more informed.

The methodology draws on two previous deliverables from this project. The findings of Deliverable 1.1 (D1.1) are used to formulate a 'matrix of considerations' to assist NRAs in identifying sustainability issues in relation to certain families of asphalt products e.g. durability (the issue) in relation to cold mix asphalts (the family of products). Considerations might not necessarily always arise from a negative perspective, but might also be raised to prove a positive claim (e.g. the reduced global warming potential of warm-mix asphalts). Deliverable 2.1 was concerned with setting the scope for the assessment methodology. A few specifications for the methodology were defined in Deliverable 2.1 (D2.1): that it would consider the full life cycle of asphalt, in order to take into account durability issues, and would complement the Environmental Product Declaration (EPD) process, but not be too data or time intensive for NRAs to undertake. A wide range of sustainability indicators were reviewed and considered for application. Some indicators were discounted at this stage but the final 'basket' of eleven indicators was not completely finalised. Final selection is described in this report, using the life cycle assessment (LCA) process of 'normalisation'. The final basket of indicators aligns with the three spheres of sustainability: environment, economy and society.

To measure each indicator, an appropriate methodology was recommended from a review of closely related initiatives or available standards, acknowledging the extensive pool of valuable research that has already been conducted in relation to the sustainability assessment of highway products, whether or not the work was specifically branded as such. In relation to some indicators, the pool of available methodologies was extensive and for others the choice was very limited. To assess recyclability a bespoke indicator had to be developed. All methodologies were selected or devised to be used by assessing against a conventional asphalt baseline. The final step in development of the methodology was to apply multiple attribute decision making, a type of multiple criteria decision analysis, to assist NRAs in analysing the outputs from assessments. The methodology will be demonstrated in Deliverable 3.1 (D3.1) using three test cases.

[1] In the context of this report, 'technology' is used as a broad sense to cover materials and processes related to the application of bituminous products on the highway network.

1 Introduction

1.1 Background

A way forward for the EDGAR methodology was outlined in previous deliverable D2.1 (Wayman & Peeling, 2015). It was decided that the methodology should be life-cycle based and extend beyond ‘cradle-to-gate’, in order to include some appraisal of durability of the products being assessed, and their influence on the use-phase impacts of the road. Furthermore, it was concluded that any methodology developed should appraise social and economic aspects of bituminous materials alongside the environmental, in order to fully meet the requirements of the ‘sustainability’ agenda. D2.1 explored some of the boundaries for sustainability assessment of bituminous materials, through a review of the relevant standards and the advances that the highways sector has already made in the area. It also examined the relevance of Environmental Product Declarations (EPDs) in devising such a process. It was concluded that the EDGAR methodology should complement the EPD process rather than provide an alternative to it. Figure 1-1 proposes how this could be achieved.

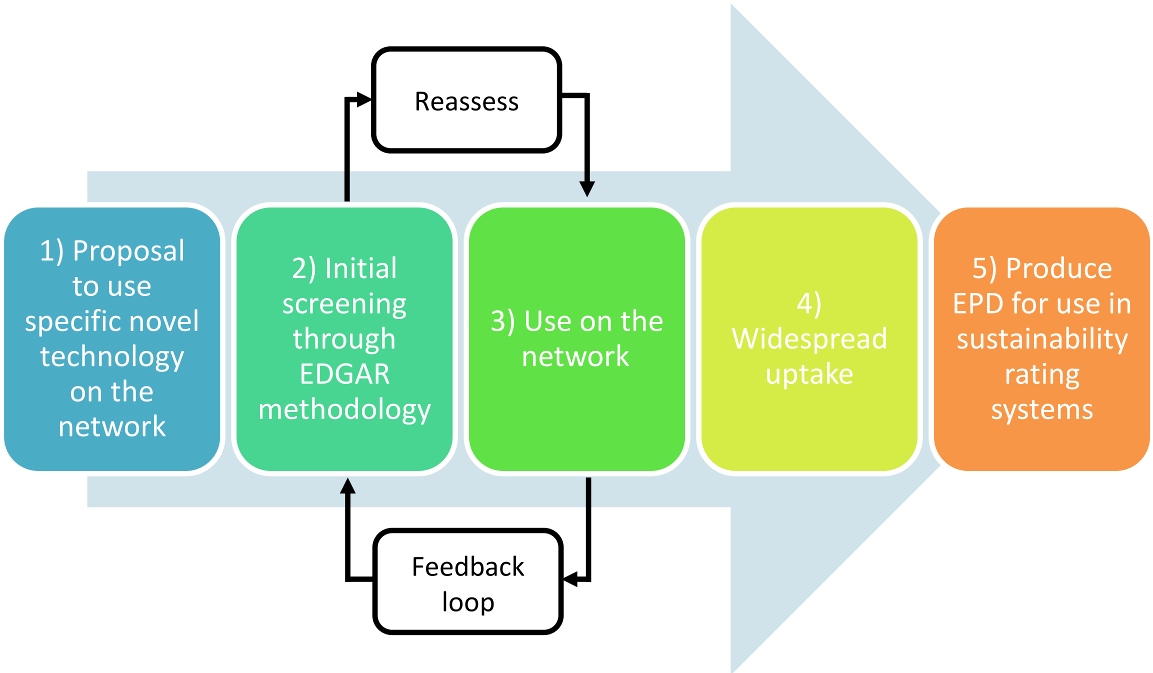

Figure 1-1: The EDGAR methodology in EPD context

It is envisaged that the EDGAR methodology will be more streamlined than the in-depth assessment of 24 indicators that creating an EPD requires, and will therefore provide a means for novel bituminous products to be ‘screened’ before use on the network and more readily adopted. The EPD process can then be undertaken once materials have reached widespread application. Regarding impact assessment for EDGAR, available sets of sustainability impact indicators were considered for their relevance to the bituminous materials sector. A set of indicators for assessing novel bituminous materials and technologies was proposed, covering the environmental, social and economic spheres of sustainability.

1.2 Aim of the report

This report, Deliverable 2.2 (D2.2), follows directly on from D2.1 and recommends a methodology for NRAs to use to assess technologies prior to their use on the road network. The processes used to arrive at the final methodology are presented in this report:

- Identification of environmental indicators with particular relevance to asphalt and downplaying those that have little significance in order to arrive at a more manageable final 'basket of indicators';
- Synthesis of alerts and research gaps from D1.1, to create a 'considerations matrix' that provides NRAs with an indication of where knowledge may be insufficient surrounding the use of a particular technology or concerns may exist;
- Identification and recommendation of appropriate methodologies to assess each indicator in the basket;
- Application of user preference weighting to the final set of methodologies to account for confidence in the data sources used and further assist the decision-maker;
- Development of the framework and processes to demonstrate how NRAs might wish to use the methodology.

2 The proposed EDGAR methodological framework

2.1 Decision making context

The EDGAR project addresses a specific context for NRAs: when novel bituminous materials are proposed to be used on the network. Figure 2-1 suggests a decision making context in which it might be used.

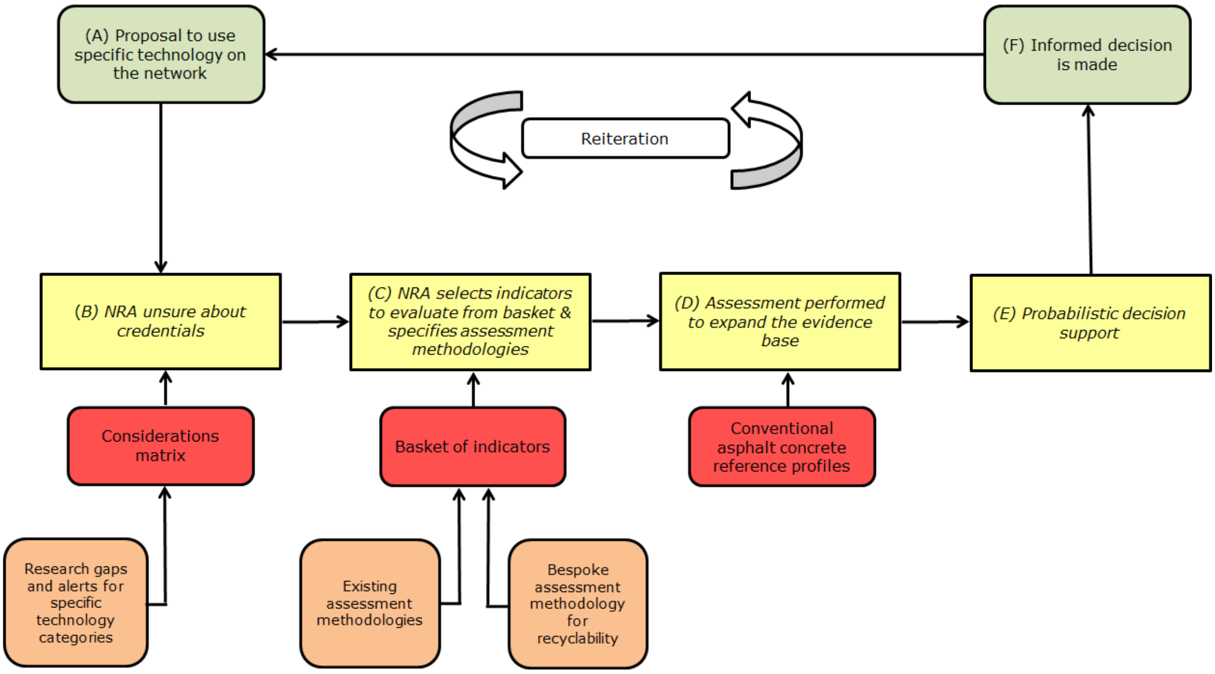

Figure 2-1: Decision making context and decision support from EDGAR

The steps in the process are described in more detail below:

Step A – Proposal to use the novel material on the network

An application is made by a contractor to use a new technology on the network. At this stage the product (and its constituent materials, where applicable) has already been CE marked by the manufacturer and a Declaration of Performance (DoP) drawn up to contain information about its performance in relation to the essential characteristics defined within the harmonised technical specifications. The DoP covers aspects related to the Basic Requirements for Construction Works (BRCW; Construction Products Regulation (574/2014)) including mechanical resistance, stability and safety in case of fire.

Step B – NRAs unsure about the material or technologies' credentials

From a sustainability perspective, decision maker(s) in the NRAs are not fully confident about using a new technology on the network, or would like the evidence base supporting the material to be expanded in order to inform the decision-making process. The current evidence base might be lacking since it does not address perceived risks associated with use of the technology on the road network (whether environmental, social or economic), or does not make the advantages clear enough.

A ‘matrix of considerations’, produced from a synthesis of research supporting the adoption different types of technology on highways in D1.1, will assist NRAs to identify areas where the evidence base might be lacking for specific families of technology. See Section 4.1 for the matrix.

Step C – NRA selects indicators to evaluate from the basket and specifies the assessment methodologies

A basket of eleven indicators has been arrived at through evaluation in D2.1 and through the process of normalisation, described later in Section 3. The basket has been compiled to address the main sustainability concerns associated with the application of bituminous technologies on the network, across their full life cycle. Based on the list of considerations identified in Step B, the NRA will select the indicators that they would like to be measured. For each indicator a methodology has been suggested later in Section 4.2. This would need to be specified by the NRA as the selected assessment methodology. The assessment process can be streamlined according to the level of confidence that already exists in use of the family of materials: the number of indicators selected might be just one or two for established families of asphalt technologies, or a greater number if the technology is more emerging.

Step D – Assessment performed to expand the evidence base

The NRA might require the product manufacturer or contractor to augment the evidence base, or it may wish to do this in-house, or commission an independent third party to conduct the assessment, such as a test house or independent research organisation.

It is recommended that a ‘control’ is assessed in all cases; this would typically be conventional hot mix asphalt in widespread use such as asphalt concrete, if the proposed technology is a material, or conventional plant if the technology is targeted at a process improvement. This will give a point of reference on which to base relative comparisons of performance.

Step E – Probabilistic decision support

Having been provided with the results, the NRA can insert the results into the decision support framework that is described in more detail in Section 5, to make the results obtained more manageable and comparable.

Step F – Informed decision is made

The decision support framework will assist the NRA in making a final decision over use of the technology on the network.

The assessment process does not necessarily conclude after a single iteration of steps A-F. A repeat of the cycle can be conducted if the evidence base is still insufficient after one loop, or more evidence in relation to the technology becomes available.

3 Finalising the basket of environmental indicators

Priorities of the EDGAR methodology are to (i) focus on bituminous technologies and (ii) not be too data or time intensive. D2.1 identified a potential basket of indicators that could be applied to bituminous technologies and these are reproduced in Table 3-1. However, it was thought desirable to reduce the number of environmental indicators for the aforementioned reasons. The process used to do this was a commonly used life cycle assessment (LCA) technique called 'normalisation'.

Table 3-1: Likely composition of the indicator set for the EDGAR methodology from D2.1

Environmental	Social	Economic
Based on normalisation, 2-4 indicators from: • Resource depletion (abiotic) • Resource depletion (fossil fuels) • Global Warming Potential (GWP) • Ozone Depletion Potential (ODP) • Acidification potential (AP) • Eutrophication potential (EP) • Formation potential of tropospheric ozone (POCP)	• Health & safety for road users (possibly incorporating 'noise') • Health & safety for road workers (incorporating 'toxicity') • Responsible sourcing	• Financial cost • Traffic congestion
• Performance (durability)		

Alongside the indicators in Table 3-1, it is important to take into account performance (durability) in product assessment, since a product might perform exceptionally on cradle-to-gate, but disintegrate within a very short time once placed on the road. Assessing only on a cradle-to-gate or cradle-to-site basis would not pick this up. Performance has the potential to influence each of the three spheres of sustainability, given the direct relationship between durability, material replacement rates and number of required maintenance interventions.

3.1 Normalisation process

The LCA process of normalisation is described in an extract from the *Handbook on LCA* (ILCD, 2010) presented in Box 3-1.

In normalisation, the indicator results for the different midpoint level impact categories or endpoint level damages are expressed relative to a common reference, by dividing the indicator results by the respective reference value. As reference values typically the impact or damage results of the total annual territorial elementary flows in a country, region, or continent, or globally (or per average citizen, i.e. per capita) are used. These reference impact or damage results are termed "normalisation basis". The normalisation basis is calculated from the inventory for each of the impact categories or damages in the same way as the impact indicators or damages of the analysed system (e.g. product) are calculated from its life cycle inventory: For midpoint level results the normalisation basis is the overall potential impact, calculated from the annual inventory of elementary flows. For endpoint level results the normalisation basis is the overall damage to the areas of protection.

To ease communication (and quality checks) across studies, it is recommended to use as normalisation basis the elementary flow inventory per capita in the selected country/region/globally per year.

The decision whether to use global data or data for a specific country, region or continent shall be made during the initial scope definition and shall be justified along the following considerations:

- *Where are the supported decisions be made (Situations A, B), or where is the reference of the accounting (Situation C)?*
- *Relevance for the intended application(s) and target audience of the LCI/LCA study.*
- *Sufficiently complete availability of inventory data for the chosen country, region or globally, and with a sufficiently similar completeness of all impact categories / areas of protection considered in the LCI/LCA study.*
- *The elementary flows of the normalisation basis have to be appropriate for use with the LCIA method used for the LCI/LCA study, i.e. are classified and characterised as are those of the analysed system.*
- *Compatibility with the midpoint impact categories or category endpoints, as applied, and with the set of weighting factors to be subsequently applied, if any (see below).*

The year of the normalisation basis should be the latest year for which reliable data are available. The chosen normalisation basis should not be changed later on in the study, unless it has to be extended if in the course of the study a non-default impact category has been additionally included.

Box 3-1: Extract from the Handbook on LCA on normalisation

The basic process is also summarised in Figure 3-1.

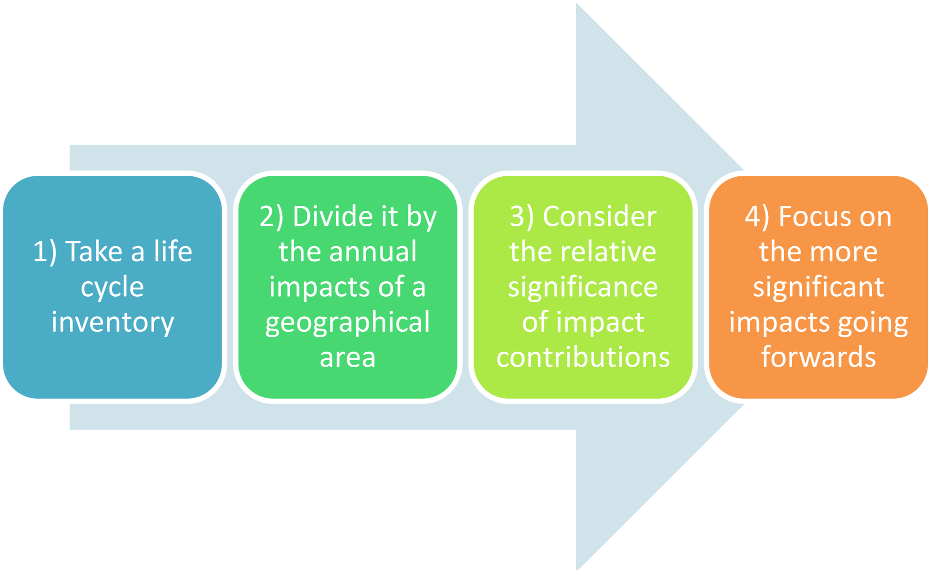

Figure 3-1: The basic process of normalisation

Environmental Product Declarations (EPDs) for asphalt are essentially life cycle inventories of 'standard' asphalt originating from different countries. A number of EPDs were identified in the course of producing D2.1 and afterwards, these are as follows:

- PE International EPDs from Germany in 1999 for base course, binder course, mastic asphalt, SMA and wearing course (Federal Ministry for Environment, Nature Conservation, Construction and Nuclear Safety, 2013);
- ACCIONA Infraestructuras EPD from Spain in 2013 for the N340 road (Acciona, 2013);
- Office des Asphaltes EPD from France in 2009 for a hot mix asphalt pavement and waterproofing asphalt (Federation of French Road Building Industry, 2014);
- Foreningen Asfalt og veirservice EPD from Norway in 2009 for asphalt gravel (Norwegian EPD Foundation, 2011);
- BAM Wegen EPD from the Netherlands in 2009 for asphalt concrete (SBK, 2012).

Five of these ten EPDs were selected as a representative sample set of life cycle inventories for the normalisation process (Step 1 in Figure 3-1). These were the German binder course EPD, the French hot mix asphalt EPD and the three EPDs from Spain, Norway and the Netherlands. The EPDs had to be translated and then the data from each EPD was tabulated. A set of annualised impact data: 'West Europe 1995' (CML, 2010) was selected to normalise the datasets. Within this data source the 'category totals (summary)' spreadsheet was used which contains impact categories (e.g. acidification) and figures for reference situations.

Step 2 was to divide the EPD asphalt datasets with the corresponding impact category data from the annualised dataset, resulting in a unitless number. This normalises the scale of the impact to the total impact across Western Europe, i.e. the figure obtained becomes a measure of the contribution of one tonne of asphalt to the overall impact across the geographical area used. The scale of impacts, largest to smallest, was ranked for each of the five EPDs. The results of this step are presented in Annex A.

Normalisation was only applied to the impact assessment indicators that were common to at least four of the five EPDs. These were:

- Acidification of air and water
- Destruction of the stratospheric ozone layer
- Global warming potential
- Eutrophication
- Photochemical oxidant formation

After normalisation, two of these indicators - eutrophication and destruction of the stratospheric ozone layer - were on a scale of 1,000 – 100,000 less than the other three indicators measured. It was therefore decided to discard these indicators at this stage and focus on the other three: acidification, global warming potential and photochemical chemical oxidant formation, which seemed to be more significant for bituminous products. Table 3-1 could therefore be modified to Table 3-2.

Table 3-2: Modified composition of the indicator set for the EDGAR methodology

Environmental	Social	Economic
• Resource depletion (abiotic) • Resource depletion (fossil fuels) • Global Warming Potential (GWP) • Acidification potential (AP) • Formation potential of tropospheric ozone (POCP)	• Health & safety for road users (possibly incorporating 'noise') • Health & safety for road workers (incorporating 'toxicity') • Responsible sourcing	• Financial cost • Traffic congestion
• Performance (durability)		

4 Identifying methods to address specific concerns

4.1 Compiling a matrix of considerations

A so called 'matrix of considerations' was produced to highlight the key sustainability aspects that relate to different families of bituminous technologies. The considerations identified originated from alerts/research gaps highlighted in Deliverable 1.1, where the following sustainability criteria were considered:

- Global warming potential
- Use of resources for energy
- Use of materials for resources
- Air pollution
- Health & safety
- Financial cost
- Recyclability
- Performance

Based on the findings of D1.1, and the normalisation described in Section 3.1, the list above was modified slightly and added to, to arrive at the eleven criteria below in Table 4-1. 'Air pollution' covers the AP and POCP impact categories resultant from normalisation. When measured, these eleven criteria were thought to comprehensively evaluate the sustainability of bituminous technologies in a highway context.

Table 4-1: Sustainability criteria applicable to bituminous materials in highway pavements

Original criterion from D1.1	Final indicator
Global warming potential	Global warming potential
Use of energy resources	
Use of materials for resources	Depletion of resources & waste management
Pollution	Air pollution
	Leaching potential
Health & safety	Noise
	Skid resistance
Financial cost	Financial cost
Recyclability	Recyclability
Performance	Performance (durability)
(not included)	Responsible sourcing
(not included)	Traffic congestion

Three indicators were added to the final basket that were not previously covered in D1.1: leaching potential, responsible sourcing and traffic congestion. Assessing the leaching potential of materials that will be in situ within the road structure for many years and, in some cases, exposed directly to precipitation and percolation through the structure is an important environmental consideration. Responsible sourcing was included to bring more of a social dimension to the overall basket of indicators, considering material supply chains locally, nationally and internationally. Finally, traffic congestion was thought to be an important factor to evaluate, in order to consider the impact on user journeys during maintenance, mainly from an economic perspective, but perhaps also with some environmental implications. According to the findings of D1.1, global warming potential and use of energy resources could be streamlined into one indicator, since the trend in both criteria were usually found to be identical for bituminous materials, given that the global warming potential of bituminous materials was directly linked to direct combustion of fuels and little else. Finally, the 'health & safety' criterion was defined to be more directly applicable to bituminous materials, to consider noise and skid resistance. Descriptions of the selected indicators are provided in Table 4-2.

Table 4-2: Further description of the selected indicators

Indicator	Description
Global warming potential	Evaluating the contribution to climate change of the technology in material terms (cradle-to-gate) or its 'in use' effect
Depletion of resources & waste management	Assessing the overall 'material balance' of a tonne of asphalt, considering primary and secondary materials, and waste
Air pollution	Assessing pollution potential on the basis of air pollution (non-CO_2 emissions), evaluating acidification and photochemical oxidation potentials
Leaching potential	Assessing pollution potential on the basis of leaching potential to groundwater
Noise	A health & safety consideration for road users and road neighbours related to surface characteristics
Skid resistance	A health & safety consideration for road users related to surface characteristics
Financial cost	In life cycle cost (LCC) terms, measured as net present value
Recyclability	Assessing the potential for the valuable properties of asphalt's constituents to be retained into the next lifetime
Performance (durability)	Using a selection of test methods to assess different characteristics of bituminous materials that relate directly to how long it will last in the pavement structure
Responsible sourcing	Evaluating social aspects related to the supply of constituent materials
Traffic congestion	Social aspects related to installation of the material at the road site and the consequences for road users

To produce the matrix of considerations, the research gaps and alerts identified in D1.1 were re-visited and supplemented for the indicators in the basket that had not already been considered. A more fundamental consideration of positive claims was also conducted. The final matrix of considerations to be used in Step B of the EDGAR methodology is presented in Table 4-3.

Table 4-3: Matrix of considerations

Technologies / Applicable sustainability indicator(s)	Global warming potential	Depletion of resources & waste management	Air pollution	Leaching potential	Noise	Skid resistance	Financial cost	Recyclability	Performance (durability)	Responsible sourcing	Traffic congestion
Warm and half-warm asphalt technologies											
Foam	◆ green	◆ blue	◆ green	◆ blue	◆ blue	◆ blue	◆ orange	◆ blue	◆ orange	◆ blue	◆ green
Organic additives	◆ orange	◆ blue	◆ green	◆ orange	◆ blue	◆ blue	◆ orange	◆ orange	◆ orange	◆ orange	◆ green
Chemical additives	◆ orange	◆ blue	◆ green	◆ orange	◆ blue	◆ blue	◆ orange	◆ orange	◆ orange	◆ orange	◆ green
Cold and semi-cold asphalt technologies											
Emulsion	◆ green	◆ blue	◆ green	◆ blue	◆ blue	◆ blue	◆ orange	◆ blue	◆ orange	◆ blue	◆ green
Foam	◆ green	◆ blue	◆ green	◆ blue	◆ blue	◆ blue	◆ orange	◆ blue	◆ orange	◆ blue	◆ green
Asphalt recycling											
Plant	◆ green	◆ green	◆ green	◆ blue	◆ orange	◆ orange	◆ green	◆ blue	◆ orange	◆ green	◆ orange
In situ	◆ green	◆ green	◆ green	◆ blue	◆ orange	◆ orange	◆ green	◆ blue	◆ orange	◆ green	◆ orange
Secondary and open-loop recycled materials											
Steel slag	◆ orange	◆ green	◆ blue	◆ orange	◆ orange	◆ green	◆ green	◆ orange	◆ orange	◆ green	◆ orange
Fly ash	◆ orange	◆ green	◆ blue	◆ orange	◆ blue	◆ blue	◆ green	◆ orange	◆ orange	◆ green	◆ orange
Crumb rubber	◆ orange	◆ green	◆ red	◆ orange	◆ green	◆ blue	◆ green	◆ orange	◆ orange	◆ green	◆ orange
Shredded roofing	◆ orange	◆ green	◆ red	◆ orange	◆ orange	◆ orange	◆ green	◆ orange	◆ orange	◆ green	◆ orange
Crushed glass	◆ orange	◆ green	◆ blue	◆ orange	◆ orange	◆ red	◆ green	◆ blue	◆ orange	◆ green	◆ orange
Alternative and modified binders											
Bio-binders	◆ orange	◆ blue	◆ orange	◆ orange	◆ blue	◆ blue	◆ orange	◆ orange	◆ orange	◆ orange	◆ orange
Sulphur	◆ green	◆ blue	◆ red	◆ orange	◆ blue	◆ blue	◆ orange	◆ orange	◆ orange	◆ orange	◆ orange
PMB	◆ orange	◆ blue	◆ blue	◆ blue	◆ green	◆ blue	◆ orange	◆ orange	◆ green	◆ blue	◆ green

Table 4.3 (cont.): Matrix of considerations

Technologies / Applicable sustainability indicator(s)	Global warming potential	Depletion of resources & waste management	Air pollution	Leaching potential	Noise	Skid resistance	Financial cost	Recyclability	Performance (durability)	Responsible sourcing	Traffic congestion
Additives											
Anti-stripping agents	◆ (green)	◆ (blue)	◆ (blue)	◆ (orange)	◆ (blue)	◆ (orange)	◆ (orange)	◆ (blue)	◆ (green)	◆ (orange)	◆ (green)
Pigments	◆ (blue)	◆ (blue)	◆ (blue)	◆ (orange)	◆ (blue)	◆ (blue)	◆ (orange)	◆ (orange)	◆ (orange)	◆ (orange)	◆ (orange)
Fibres	◆ (blue)	◆ (blue)	◆ (blue)	◆ (blue)	◆ (blue)	◆ (orange)	◆ (blue)	◆ (blue)	◆ (green)	◆ (orange)	◆ (green)
Rejuvenators	◆ (orange)	◆ (green)	◆ (orange)	◆ (orange)	◆ (blue)	◆ (blue)	◆ (orange)	◆ (orange)	◆ (orange)	◆ (orange)	◆ (orange)

4.2 Using the matrix

The matrix highlights pre-existing 'considerations' regarding the evidence bases of certain families of bituminous technologies. Gaps in the evidence base that have been determined against each family of technologies are marked with an orange symbol (◆). If a clear negative has been identified then a red symbol is used (◆). Potential positive claims are indicated with a green symbol (◆). If the anticipated impact is unknown or neutral then a blue symbol is used (◆). The matrix should never be used to 'tally-up' positive, negative and neutral symbols; it should only be used as a decision aid to assist NRAs in deciding where the case for using a particular technology may be formed.

If an NRA is presented with a proposal to use a new technology then the NRA can raise its own concerns with the evidence base or refer to the matrix to be prompted in this respect (Step B in Figure 2-1). Each consideration raised has a related indicator that can be measured to enhance the evidence base associated with the technology. Once the matrix has been consulted then the NRA specifies the indicator(s) that it would like to have measured (Step C). For technologies that are a small step from the conventional (e.g. an elevated recycling rate), just one or two indicators might be selected for measurement; for a more fundamental step change then a more extensive investigation to measure several indicators would be warranted. The next section describes the methodologies that have been identified to measure each indicator.

For example, take a chemically modified asphalt. The product contains a chemical previously unused in asphalt that is claimed to facilitate half-warm mixing in binder and base courses. The NRA is keen to adopt low-temperature asphalts wherever possible but feels the new technology is not yet proven. The NRA consults the matrix of considerations (Table 4-3) to decide where it should request further evidence to be provided in order to allay any reservations. The matrix indicates the following:

- A positive effect (◆) should be associated with use of the chemical additive in relation to 'air pollution' and 'traffic congestion'.
- A neutral effect (◆) is anticipated to be observed in relation to 'depletion of resources and waste management', 'noise' and 'skid resistance'.
- The current evidence is inconclusive (◆) in relation to 'global warming potential', 'leaching potential', 'financial cost', 'recyclability', 'performance (durability)' and 'responsible sourcing'. Each of these elements is very specific to the individual product and cannot be informed by past studies with any degree of accuracy.

Where the current evidence is inconclusive, the NRA may require further evidence to be provided to evaluate these indicators quantitatively. In this case it should proceed to specify the methodologies it wishes to see used to measure the indicators, and decide who should measure them (the product manufacturer, contractor, someone in-house or an independent research organisation or test house). The methodologies selected may be the EDGAR recommended methodologies or alternatives that are preferred by the NRA. Where a positive effect is expected, the NRA may also choose to evaluate these indicators to reinforce the case for use of the product on the network.

4.3 Methodology review and selection

Each indicator in the basket would need to be assessed using an appropriate methodology in order to enable NRAs to perform Step D in the assessment process. Towards this end, a review was embarked on to identify potential methods of assessment ('methodologies') against each indicator. The following considerations were explored during the identification process:

a) Brief overview – describing the methodology and who developed it.
b) Input parameters and data requirements – the data required prior to the assessment commencing.
c) Timescale for data collection – the hours, days or weeks to gather the data required to perform an assessment.
d) Applicable life cycle steps – whether the life cycle is cradle-to-gate, cradle-to-grave, or otherwise streamlined. Are the applicable life cycle stages adequately covered?
e) Ease of assessment and knowledge required – what level of expert knowledge required to complete the assessment?
f) Geographical applicability – if the method was developed for an area other than Europe, could it still be adapted for use in Europe or is it universal?
g) Freely available or available at cost?
h) Format of results – are the results qualitative or quantitative?
i) Ability to differentiate between asphalt mixtures – one of the most important criteria, since any selected method has to demonstrate the benefits or drawbacks of the new technology over the status quo.
j) Key advantages and shortcomings – how can the key points be summarised?

The outcome of the review is presented in a separate document: EDGAR_methodologies_review.xlsx. The findings of the review allowed a methodology (or methodologies) to be recommended to measure each indicator. The recommended methodologies are presented in the 'dashboard' in Figure 4-1.

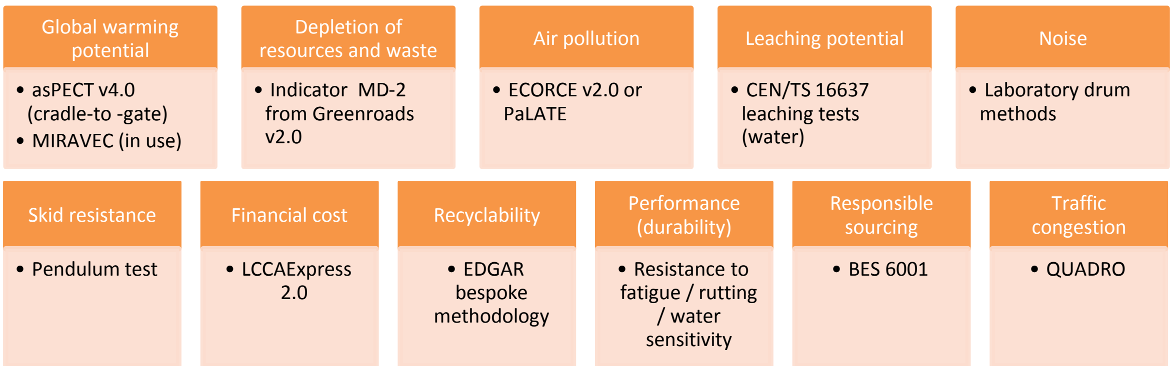

Figure 4-1: The EDGAR methodology 'dashboard'

Some additional justification for the choice of methodology against each indicator is presented in Table 4-4. Having undertaken the wider review, it became clear that some characteristics of the methods might be particularly significant to end users, and therefore helped to inform decision-making regarding the final recommended methodologies. The characteristics that were thought to be of particular importance were as follows:

- Material focussed – the methods selected should be able to differentiate between different types of asphalt, based on the subtleties of mixture design, component material characteristics, production and performance.
- Quantitative – ideally the method would result in a quantitative result that is not ambiguous for the decision-maker, and can be easily utilised in user preference modelling.

- Quick and convenient – since the main objective of EDGAR is to 'screen' materials, any method selected should not be too involved or laborious, and therefore produce relatively quick results.
- Cost effective – in order to facilitate take-up of the EDGAR methodology across Europe it was anticipated that NRAs would ideally not wish to pay significant amounts to access the chosen methodologies.

Table 4-4: Additional justification for methodology selection

Indicator	Recommended methodology	Material focussed?	Quantitative?	Quick?	Free?	Main reason(s) for selection
Global warming potential	asPECT v4.0 (cradle-to -gate)	✓	✓		✓	An established method that offers the most granularity in results with regards to specific characteristics of asphalt mixtures, their production and CO_2e quantification. Can be universally applied with country-specific emissions factors.
	MIRAVEC (in use phase impacts)	✓	✓			The only tool identified that can equate macro-texture and road roughness (which need to be measured elsewhere at cost) of pavement materials to CO_2e. Developed in a previous CEDR (road ERA-net) programme.
Depletion of resources & waste management	Indicator MD-2 from Greenroads v2.0	✓	✓	✓		Few tools are actually dedicated to measuring recycled & recovered content, however, this method (path 2) is directly applicable to highway materials. Access to manual available at minimal cost.
Air pollution	ECORCE v2.0 or PaLATE	✓	✓		✓	Once this tool is made universal in terms of datasets then it will provide the best alternative to commercially available LCA software for measuring AP, POCP etc. Until that time PaLATE provides a viable alternative.
Leaching potential	CEN/TS 16637 leaching tests	✓	✓	✓		A standardised European method devised specifically for testing construction material monoliths (e.g. asphalt blocks).
Noise	Laboratory drum methods	✓	✓	✓		Most noise measurements need a full scale trial section. The drum method can be performed in the laboratory with good accuracy and cut down the cost and time requirement.
Skid resistance	Pendulum test	✓	✓	✓		A standardised European method devised specifically for testing road and airfield surface characteristics.
Financial cost	LCCAExpress 2.0	✓	✓	✓	✓	A straightforward and accurate costing method with dedicated software, devised specifically for highways.

Indicator	Selected methodology	Material focussed?	Quantitative?	Quick?	Free?	Main reason(s) for selection
Recyclability	EDGAR bespoke methodology	✓		✓	✓	In the absence of other tools, a methodology was devised specifically to measure recyclability of asphalt materials. Not quantitative.
Performance (durability)	Resistance to fatigue	✓	✓	✓		All well-established standardised European methods that can be performed routinely in laboratories. The method(s) should be selected based on the specific concerns with the materials.
	Resistance to rutting	✓	✓	✓		
	Water sensitivity	✓	✓	✓		
	Stiffness	✓	✓	✓		
Responsible sourcing	BES 6001	✓		✓	✓	The only standardised method that could be identified to specifically measure several elements of responsible sourcing. A points based system so outputs not strictly quantitative.
Traffic congestion	QUADRO	✓	✓	✓		Modelling traffic flows requires dedicated software that is only available at (small) cost. QUADRO is a proven application to measure cost and CO_2e implications of traffic management scenarios, hour-by-hour.

4.4 Reference material comparison

All eleven indicators have been selected on the basis that any assessments will be made by comparing the technology with an appropriate reference material or life-cycle activity. There is no one ‘reference’ asphalt; the reference should be selected on a case-by-case basis. A few examples would be as follows:

- The technology is a lower-temperature asphalt. Compare it to the conventional hot mix asphalt that it is anticipated to replace.
- The technology is asphalt containing a secondary material as an aggregate or binder replacement. Compare it to the conventional hot mix asphalt with primary material e.g. an asphalt concrete mixture.
- The technology is a novel process e.g. *in situ* patching. Compare it to the processes in the conventional asphalt life cycle that it is designed to replace, in this case hot mix asphalt production, transport to site, preparation of the substrate, and laying and compaction.

Making a relative comparison with a reference material also means that there is no absolute requirement to convert the non-metric units that result from some tools (e.g. LCCAExpress 2.0 provides results in US Dollars per mile).

4.5 Signposting

Figure 4-2 signposts to a location where additional information on each recommended methodology can be found.

Global warming potential	• asPECT v4.0 • MIRAVEC
Depletion of resourecs and waste management	• Greenroads v2.0
Air pollution	• ECORCE v2.0 or PaLATE
Leaching potential	• 16637 Part 1 and 16637 Part 2
Noise	• Vehicle-Pavement interaction • Asphalt Pavement Texture and Noise
Skid resistance	• Pendulum test
Financial cost	• LCCAExpress 2.0
Recyclability	• EDGAR bespoke methodology
Performance	• Fatigue • Rutting • Water sensitivity • Stiffness
Responsible sourcing	• BES 6001
Traffic congestion	• QUADRO

Figure 4-2: Signposting to further information on selected methodologies

5 User preference – alternatives ranking

Once the various criteria (basket of indicators) and the methods used in order to assess the alternatives according to the selected criteria have been selected, a decision support methodology has to be defined. This methodology should be able to consider user preferences.

In a first phase, the various alternatives (i.e. green technologies) have to be assessed according to the indicators that are summarized in Table 5-1. The output format of the selected indicators can be diverse as some indicators are qualitative (recyclability, responsible sourcing) and some other quantitative. Besides, the boundaries for the evaluation process according to a given indicator can also vary:

- Some indicators concern the whole life cycle of the product (for example: climate change, depletion of resources & waste management, air pollution…).
- Some indicators concern only a specific stage of the products lifecycle (for example: noise, mechanical performance, traffic congestion…).

The evaluation of the various alternatives according to the selected indicator permits to create a table of performance that will be further used for the decision process methodology.

Table 5-1: Format of output data from each recommended methodology

Indicator	Selected methodology	Output format	Comments
Global warming potential	asPECT v4.0 (cradle-to -gate)	kgCO_2e per tonne of asphalt	
	MIRAVEC (in use phase impacts)	CO_2 in tonnes	Some investigation required to isolate the roughness and macro texture effects from others considered.
Depletion of resources & waste management	Indicator MD-2 from Greenroads v2.0	1 point. 8% recycled 2 points 18% recycled 3 points. 28% recycled 4 points. 38% recycled 5 points. 48% recycled	
Air pollution	ECORCE v2.0 or PaLATE	Emissions per tonne of asphalt	
Leaching potential	CEN/TS 16637 leaching tests	mg pollutant / m^2 surface area	
Noise	Laboratory drum methods	Close-proximity (CPX) dB Statistical pass-by (SPB) dB	
Skid	Pendulum test	Pendulum test value (PTV)	

resistance			
Financial cost	LCCAExpress 2.0	$/mile	Could be converted to €/km or left 'as is' for relative comparison
Recyclability	EDGAR bespoke methodology	A score 0-100	
Performance (durability)	Resistance to fatigue	ε_6 microstrain	
	Resistance to rutting	mm at rate µm/cycle	
	Water sensitivity	ITSR %	
	Stiffness	GPa	
Responsible sourcing	BES 6001	Points system or Excellent / Very Good / Good / Pass	
Traffic congestion	QUADRO	User costs (£) per traffic management scenario	Per m^2 results / per hour results can be extracted if required.

Based on the selected indicators, an evaluation and decision support methodology has been defined. This methodology should aim at ranking the various alternatives and help in the decision process, this also by integrating some probabilistic aspects.

The methodology developed comprises four independent levels that are roughly summarised in Figure 5-1, each bringing its own contribution to the decision making process.

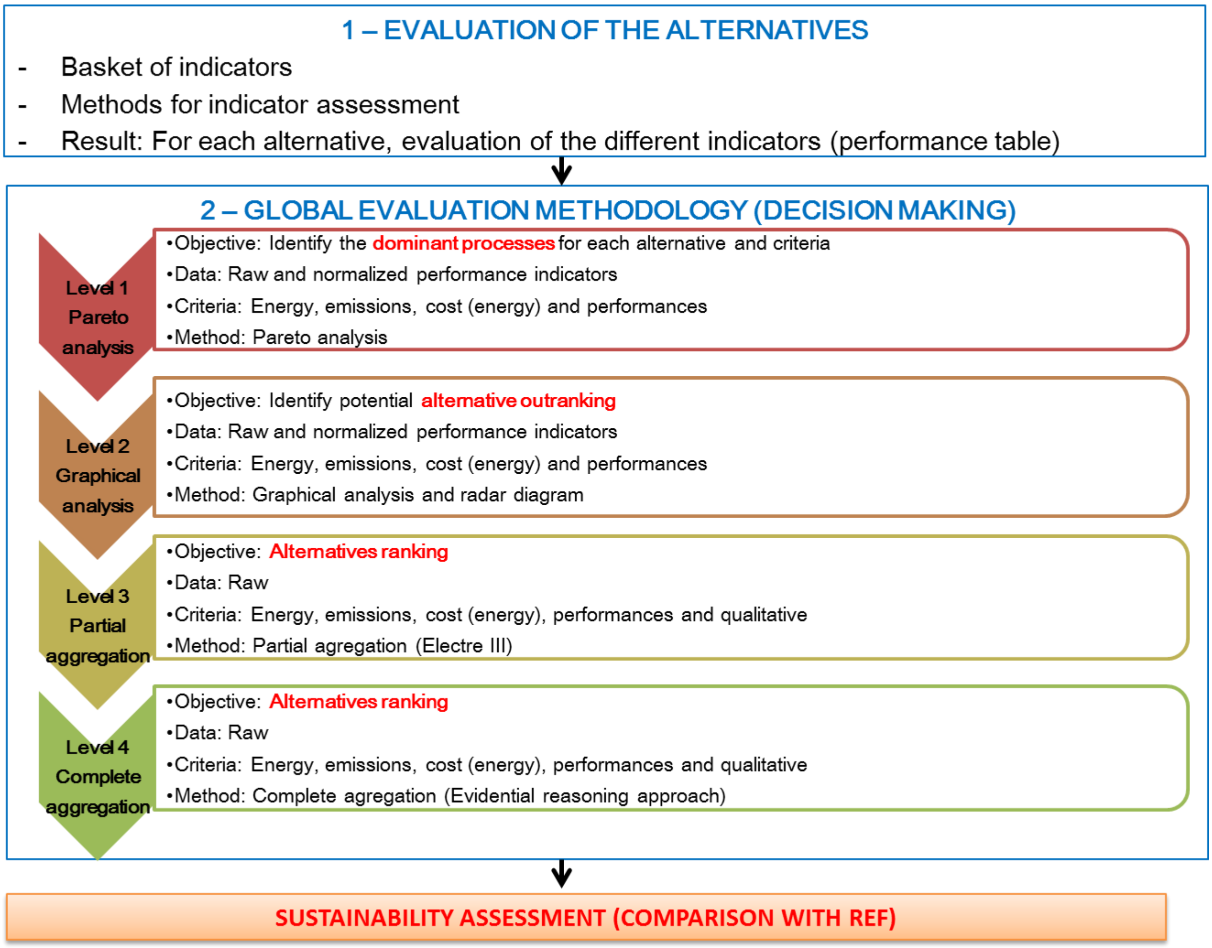

Figure 5-1: Overview of the global evaluation methodology

In the first level, a Pareto representation is used to identify the dominant processes over the lifespan of each alternative. This first level does not aim at comparing the various alternatives, but focuses on the LCI phases of the alternatives. The performances and other qualitative criteria are not considered at this first evaluation stage. Even if this first step does not permit to assist in the decision process, some interesting information regarding the effect of each separate life cycle stage is provided. By highlighting the dominant processes, one can better allocate the efforts in gathering data by focusing on the most important life cycle stages.

A first comparison of the alternatives is conducted at the second evaluation level. To achieve this, various graphical analyses are used in order to highlight the potential outranking alternatives. In these first two levels, raw data are used, without any treatment or weighing. This means also that only quantitative indicators can be taken into account at the second evaluation level.

User preferences and qualitative criteria are introduced at the third analysis level, through the introduction of multi-attribute decision making (MADM) methodologies. There are two major “families” of MADM methods, namely partial and complete aggregation, each having their own distinct advantages and properties. There is no perfect MADM method; the choice of method depends on the type of problem to be solved. Thus, existing methods applied in MADM domains were selected for implementation in the specific context of asphalt mixture evaluation. Besides the quantitative criteria considered in the first two levels, the various qualitative criteria are considered from the third evaluation level.

In the third evaluation level, a partial aggregation method using pseudo-criteria is proposed. The favoured option in this respect was the ELECTRE III method, which has been widely used in the environmental domain (Maystre *et al*., 1994a). This method presents the particular property of considering various outranking degrees by comparison of two alternatives meaning that a slight difference for a given indicator does not necessarily mean a better performance. Threshold values have to be defined in order to distinguish the various outranking degrees. The MADM method applied also has the particularity that it does not allow compensation between criteria for a given alternative and the equality between two alternatives can be the result of a given evaluation process.

The fourth evaluation level uses an algorithm derived from the Evidential Reasoning (ER) approach. This consists of a complete aggregation method, based on the Dempster-Shafer theory, but modified for application in framework of MADM (Yang and Singh, 1994). The fourth evaluation level is also the most complex, but it allows the model to take into account the occurrence probability of a given performance (for instance: 80 % confidence that the performance is "good" and 20 % that the performance is "average"). Data unknown is also considered in the ER approach applied, meaning that it is not compulsory to evaluate all the criteria for a given alternative. In case a performance is not available, then the confidence degree in the final evaluation will be lower. Finally, as for every complete aggregation method, the utility of each alternative is calculated and the ranking determined according to some transfer function.

The final methodology proposed is based on the work carried out by (Bueche, 2011).

6 Conclusions & recommendations

It was decided that enhancing the evidence base in a targeted manner was a necessary step to improve confidence amongst road authorities to use novel bituminous technologies on the road network. Innovation in the bituminous materials sector has always been healthy, with a wide-range of technologies coming to market that address all elements of the asphalt life-cycle. Uptake of these technologies has rarely reached potential capacity, partly because NRA's have been unable to fully appraise the risks associated with full-scale deployment on the network. Furthermore the shift towards more sustainable practice now often features within the strategic approaches of NRAs, but the claims surrounding the use of novel technologies are often unfounded, or indeed unexplored, hence informed decision-making with sustainability-related issues cannot take place.

The EDGAR project set out to address some of the deficiencies in the evidence-base surrounding the use of novel technologies and provide a framework for informed decision-making with regards to their sustainability attributes. The first objective was to understand the other relevant information sources already available to NRAs. Environmental Product Declarations (EPDs) were determined to be environmental profiles produced for products that were already well established, providing information on materials for use in 'green' building rating systems, by means of an often lengthy assessment process. A process needed to be developed that could complement EPDs, to quickly screen out any unsustainable products before any wide scale deployment was even considered. The range of impacts considered by EPDs on the one hand could be streamlined, since EDGAR would look at only one product category; bituminous materials, but on the other hand could be supplemented to investigate social and economic considerations and make a more rounded 'sustainability assessment'. The LCA technique of normalisation was used to identify the most significant impact categories to asphalt. A basket of eleven indicators that would sit at the heart of the EDGAR methodology resulted.

The second objective was to identify appropriate methodologies that could be used to measure each indicator in the basket. One of the foremost considerations in this process was not to 'reinvent the wheel' in relation to methodologies, since such effort in past research has already been dedicated to the development process. Instead the task focussed on selecting and signposting the most applicable from the range already available, with due consideration given to time, cost, scope and repeatability, and perhaps most importantly the ability to differentiate one bituminous technology from another; the novel from the conventional, and to consider the life cycle stages of a highway that are really affected by the choice of asphalt. Alongside the basket of indicators, a multi-attribute decision making (MADM) approach has been proposed to assist the decision-maker in interpreting the results arising from different indicators. This part of the methodology will be fully demonstrated in EDGAR Deliverable 3.1.

The framework that resulted included a six-step process for NRAs to follow when considering a novel technology, commencing with raising concerns, selecting appropriate indicators from the basket to be measured, utilising the results with the assistance of user-preference modelling and making a final decision concerning use of the technology. Use of the methodology will be demonstrated in WP3 with three case studies.

7 Acknowledgement

The research presented in this report/paper/deliverable was carried out as part of the CEDR Transnational Road Research Programme Call 2013. The funding for the research was provided by the national road administrations of Austria, Germany, Netherlands, Norway, Slovenia and UK.

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Annex A: Results of normalisation

Results for the five EPDs and the designated impact categories.

Indicators of the impact assessment	Unit	1) PE International EPD from Germany for binder course (1999)	2) ACCIONA Infraestructuras EPD from Spain for the N340 road (2013)	3) Office des Asphaltes EPD from France for a hot mix asphalt pavement (2009)	4) Foreningen Asfalt og veirservice EPD From Norway for asphalt gravel (2009)	5) BAM Wegen EPD from the Netherlands for asphalt concrete (2009)	West Europe 1995' Annualised impact data
Acidification potential of soil and water	kg SO2 equiv.	0.2187	385.1	3.28E-03	0.486	2.38E-01	2.7E+10
Depletion potential of the stratospheric ozone layer	kg CFC-11 equiv.	5.73E-08	-	7.34E-08	2.71E-05	1.03E-05	8.7E+07
Global warming potential	kg CO2-equiv.	74.94	103800	6.24E-01	56	4.79E+01	4.9E+12
Eutrophication potential	kg phosphate equiv.	0.02293	46.77	4.57E-04	0.092	4.43E-02	1.3E+10
Formation potential of tropospheric ozone	kg ethene equiv.	0.1655	94.39	7.74E-04	1.80E-02	8.80E-03	8.2E+09
Applicable life-cycle stages		*A1-A3*	*A5-B5*	*A1-C4*	*A1-A5*	*A1-C4*	*n/a*

Normalisation results for the five EPDs and the designated impact categories.

Indicators of the impact assessment	1) PE International EPD from Germany for binder course (1999)	2) ACCIONA Infraestructuras EPD from Spain for the N340 road (2013)	3) Office des Asphaltes EPD from France for a hot mix asphalt pavement (2009)	4) Foreningen Asfalt og veirservice EPD From Norway for asphalt gravel (2009)	5) BAM Wegen EPD from the Netherlands for asphalt concrete (2009)
Acidification potential of soil and water	7.99515E-12	1.40783E-08	1.20E-13	1.7767E-11	8.70E-12
Depletion potential of the stratospheric ozone layer	6.59E-16	-	8.44E-16	3.11E-13	1.18E-13
Global warming potential	1.53465E-11	2.12566E-08	1.28E-13	1.14679E-11	9.81E-12
Eutrophication potential	1.78834E-12	3.64765E-09	3.56E-14	7.17519E-12	3.46E-12
Formation potential of tropospheric ozone	2.00814E-11	1.14531E-08	9.39E-14	2.18E-12	1.07E-12
Applicable life-cycle stages	*A1-A3*	*A5-B5*	*A1-C4*	*A1-A5*	*A1-C4*

Ranking of normalisation results for each EPD and impact category with an average rank provided.

Impact Categories		1) PE International EPD from Germany for binder course (1999)	2) ACCIONA Infraestructuras EPD from Spain for the N340 road (2013)	3) Office des Asphaltes EPD from France for a hot mix asphalt pavement (2009)	4) Foreningen Asfalt og veirservice EPD From Norway for asphalt gravel (2009)	5) BAM Wegen EPD from the Netherlands for asphalt concrete (2009)	Average Rank
1	**Acidification potential of soil and water (kg SO_2 equiv.)**	3	2	2	1	2	2.0
2	**Depletion potential of the stratospheric ozone layer (kg CFC-11 equiv.)**	5	-	5	5	5	5.0
3	**Global warming potential (kg CO_2 equiv.)**	2	1	1	2	1	1.4
4	**Eutrophication potential (kg phosphate equiv.)**	4	4	4	3	3	3.6
5	**Photochemical oxidant formation (kg ethene equiv.)**	1	3	3	4	4	3.0

Annex B: Methodology review

Available in separate Excel sheet, with file name: EDGAR_methodologies_review.xlsx

Annex C: Bespoke recyclability methodology

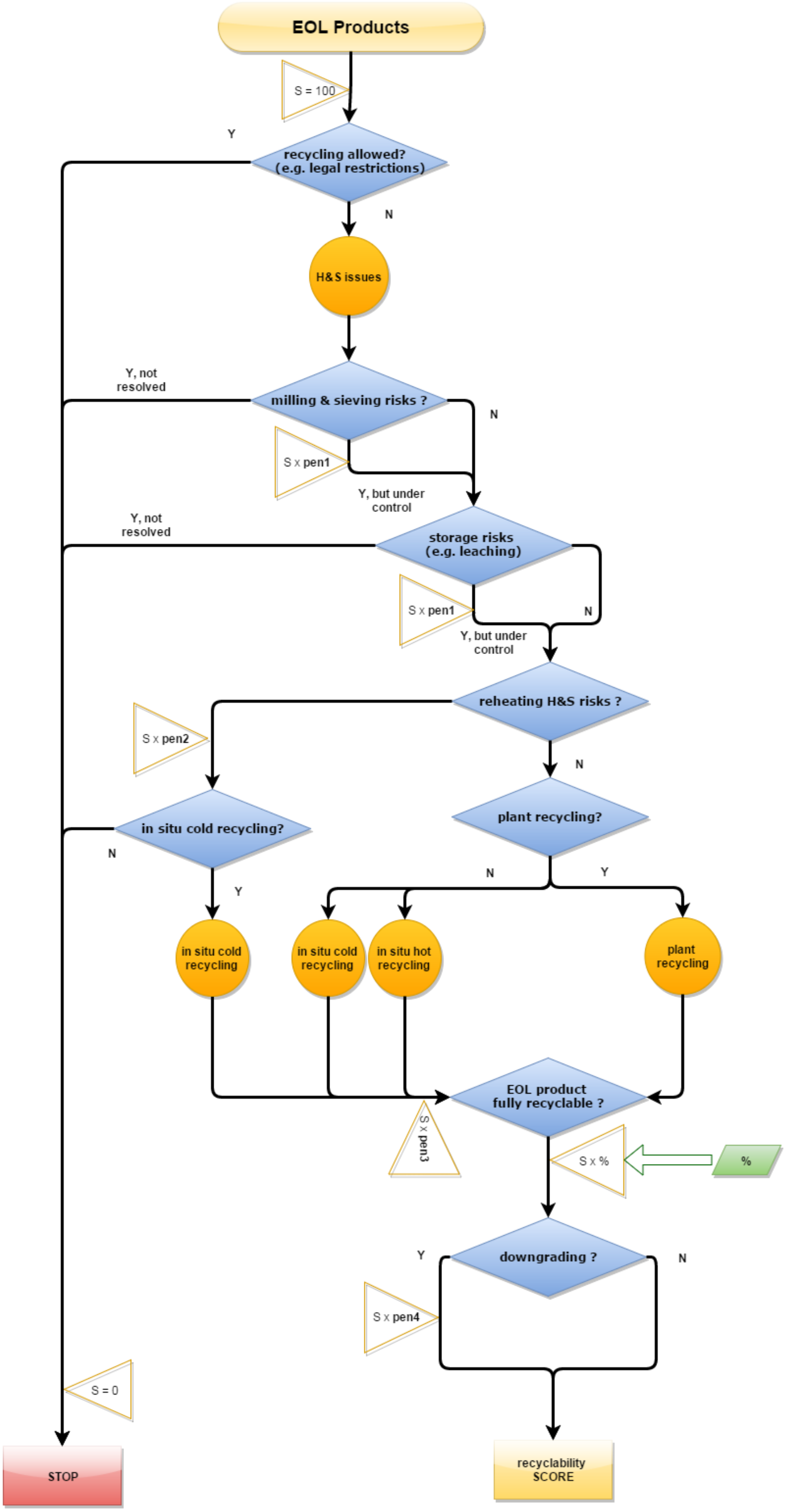

Figure C-1: Flowchart of the recyclability methodology