Proceedings of 7th Transport Research Arena TRA 2018, April 16-19, 2018, Vienna, Austria

A methodology to facilitate the implementation of new sustainable technologies for greener asphalt roads

De Visscher Joëlle [a], Anastasio Sara [b], Bueche Nicolas [c], Hoff Inge [b], Maeck Johan [a], Vanelstraete Ann [a], Vansteenkiste Stefan [a], Wayman Matthew [d]

[a] *Belgian Road Research Centre, Woluwedal 42, B-1200 Brussels, Belgium*
[b] *Norwegian University of Science and Technology, Høgskoleringen 7A, Trondheim 7491, Norway*
[c] *École Polytechnique Fédérale de Lausanne EPFL, Laboratoire des voies de circulation LAVOC, 1015 Lausanne, Switzerland*
[d] *Transport Research Laboratory, Crowthorne House, Nine Mile Ride, Wokingham, Berkshire, RG40 4JA, United Kingdom*

Abstract

The adoption of new sustainable technologies by National Road Administrations (NRAs) throughout Europe is often a slow and difficult process. The set of potentially relevant sustainability indicators which need to be considered from a life cycle perspective is wide and NRAs are often confronted with a large amount of missing or uncertain data. The EDGAR project (Evaluation and Decision process for Greener Asphalt Roads), funded by the CEDR (Conference of European Directors of Roads) Transnational Road Research Program Call 2013 ‘Energy Efficiency’, developed a methodology to facilitate quicker adoption of the technologies that offer the greatest sustainability benefits for the road sector and the society as a whole. EDGAR proposed a reduced basket of sustainability indicators specifically designed for asphalt materials and directly relevant to NRAs. A methodology was then devised to quantify these indicators, using either existing or new tools, and to implement the results in a Multiple Attribute Decision Making Model to make a balanced and well informed decision.

Keywords: sustainability, asphalt, road construction, Green Public Procurement

1. Introduction

1.1. Context

Reduction of energy consumption is a major challenge and responsibility for the road construction industry, not only because of the rising prices of fossil fuels, but especially because of the ecological impact of the associated emission of CO_2 and other greenhouse gases. The overall aim of the CEDR (Conference of European Directors of Roads) Transnational Road Research Program “Energy Efficiency” was therefore to develop concepts and methodologies for road construction and operation with reduced energy use.

Asphalt is known to be a highly sustainable road construction material. Its most important asset is recyclability: a mixture with reclaimed asphalt (RA) has a significantly smaller environmental impact than a mixture with only virgin materials, mainly because the embedded carbon footprint of the materials (bitumen and aggregates) can be discounted over the successive lifecycles. Besides recycling, there is a broad range of other innovative technologies on offer in the asphalt sector. All of these technologies aim at reducing CO_2 emissions, the use of energy and primary nonrenewable materials, and to extend the lifetime of the pavement. Consequently, they all have the potential of further improving asphalts sustainability. An overview of the most common families of potentially ‘green’ technologies is given in Table 1. This generic categorization of technologies was based upon existing knowledge and a literature review done by the EDGAR project team.

Table 1: Overview of the most common families of ‘green’ technologies

Family of technologies	Sub categories
Warm and half-warm asphalt technologies	Foam based
	Using organic additives
	Using chemical additives
Cold and semi-cold asphalt technologies	Emulsion based
	Foam based
Asphalt recycling	Plant recycling
	In situ recycling
Secondary and open-loop recycled materials	Steel slag
	Fly ash
	Crumb rubber
	Shredded roofing
	Crushed glass
Alternative and Modified binders	Vegetal or bio-binders
	Sulphur modified/extended binders
	PMB (Polymer modified bitumen)
Additives	Anti-stripping agents
	Pigments for coloured asphalt
	Fibres
	Rejuvenators

Road authorities play a major role in the advancement of new green technologies and materials, as they can favour the most sustainable solutions in their procurement criteria and procedures. Therefore, they need to have at their disposal correct information, data, assessment tools and methodologies to decide which of the alternative solutions offers the greatest benefits to the environment, the economy and the society as a whole.

1.2. Problem statement

The adoption of innovative asphalt technologies by National Road Administrations (NRAs) is often a slow and difficult process; one of the reasons is that it is not easy for a NRA to evaluate the true sustainability. The problems they are confronted with are as follows:

- Firstly, the set of potentially relevant sustainability indicators (environmental, social and economic) is diverse and therefore the assessment of all indicators is difficult and time consuming.
- As seen in Table 1, the impacts of some of these innovations are not confined to the material or mixture level and therefore, a cradle-to-gate evaluation will not be sufficient. The whole life cycle needs to be considered.
- The relative importance of the various indicators needs to be balanced in an objective way. Otherwise it is difficult to justify why a particular technology is preferred to another alternative.
- And finally, there is still a large amount of uncertain or missing data regarding some of these technologies (e.g. the carbon footprint of some additives).

1.3. The EDGAR project

The EDGAR project (Evaluation and Decision process for Greener Asphalt Roads), funded by the CEDR Transnational Road Research Program Call 2013 'Energy Efficiency', developed a methodology which makes sustainability information on new technologies more easily accessible for decision makers. This facilitates quicker adoption of the technologies offering the greatest sustainability benefits.

The methodology proposed is intended to be practical and applicable on short term by NRAs. Hence, it focusses on the essential data and sustainability criteria for the specific case of a bituminous material or technology, without being excessively data intensive and time consuming. It is intended to be transparent and flexible, in a way that it can be further refined and tailored to the specific needs of NRAs and to new insights and developments.

EDGAR was a 2-year project carried out by a consortium of four partners:

- BRRC – Belgian Road Research Centre (Belgium) – Project leader
- TRL – Transport Research Laboratory (United Kingdom)
- EPFL – Ecole Polytechnique Fédérale de Lausanne (Switzerland)
- NTNU – Technical University Trondheim (Norway)

The project was concluded in November 2016. This paper describes the approach, the main findings and finally, the conclusions and perspectives. More details about the project and its deliverables are available at the project website (www.ntnu.edu/edgar).

2. Project approach

It is important to acknowledge that, besides reduction of energy consumption and CO_2 emissions, there are other issues that need to be considered in the evaluation of asphalt materials and technologies:

1. There are other environmental impacts to be considered besides GWP (Global Warming Potential), such as AP (Acidification Potential) or ADP (Abiotic Depletion Potential) of fossil fuels. These are described in the European norm EN 15804, which defines the core rules for preparing Environmental Product Declarations (EPDs) for construction products.
2. For sustainability, additional aspects related to socio-economic factors need to be considered. Road authorities have to balance environmental considerations against social and economic considerations, as the safety and wellbeing of road workers, road users and residents is crucial and financial means are limited.
3. A long term vision requires the consideration of the environmental, social and economic impacts from a life cycle perspective, including all stages from cradle-to-grave or cradle-to-cradle and the benefits and loads beyond the end-of-life (EoL). Such a long term perspective is only possible when the performance of the bituminous mixture is known. Adequate performance and durability shall be required at all times, as the expected lifetime is a parameter with a heavy weight in any type of life cycle assessment (LCA).

As explained in the introduction, one of the main assets of bituminous mixtures in terms of sustainability is that they are highly recyclable. This results in high material efficiency and a huge reduction in energy consumption and CO_2 emissions. A primary consideration is thus to ensure that the future recyclability of asphalt is not compromised by allowing new technologies or the use of additives or other novel materials in the production or paving of bituminous mixtures. Therefore, a simple and easy-to-use tool was devised to quantify the potential for future recyclability. The basic idea is that, when the recyclability potential is zero or very low, further assessment is unnecessary and the technology shall be rejected.

A complete cradle-to-cradle assessment of a bituminous mixture depends on the expected lifetime, which in turn depends on a variety of other factors, like performance characteristics of the material, construction quality, traffic use, climate and maintenance schemes. This implies many uncertainties, which will have an impact on the reliability of the final outcome of any sustainability assessment. The approach followed in the EDGAR project was to rely on performance related characteristics, rather than on lifetime predictions. Performance related characteristics of the bituminous material, such as resistance to rutting and fatigue resistance, are closely correlated to the expected lifetime and they are easily accessible by NRAs in an early stage. Either these data are already available as a result of the initial type testing (ITT) phase of the bituminous mixture, or the NRA can demand the performance testing to be done.

With these considerations in mind, the following approach was followed by the project team:

- To obtain an overview of existing knowledge on the sustainability aspects of asphalt technologies, the most important families of technologies, as defined in table 1, were reviewed. Particular attention was given to knowledge gaps that obstruct a correct and complete life cycle assessment, and on potential risks or alerts NRAs should be aware of. This is further discussed in section 3 of this paper.
- Starting from an extensive list of sustainability indicators used in the construction industry, the list was narrowed down to a limited set of indicators. This process is described in section 4. Given the importance of recyclability and performance, as explained above, these two characteristics shall be contained within the basket of indicators. A flowchart was designed to assess the recyclability potential and attribute a score for recyclability. Existing tools or new tools for the assessment of the selected indicators were evaluated on the basis of different criteria and compared.
- Having determined the essential sustainability indicators, Multiple Attribute Decision Making (MADM) methods were proposed to aid in the assessment of the overall sustainability of a specific technology, in comparison to other alternative solutions or to a known reference. Section 5 describes these methods and section 6 briefly discusses the application in a case study.

This approach allowed optimum use of data and information and tools already available in the context of sustainability. It leaves a high degree of flexibility and transferability across countries and regions, because each NRA can decide which tools it prefers to assess the selected indicators and they can attribute weights, depending on the relevance of each indicator in the context of the project or application. Also, this approach allows addition of new indicators or omission of others if new insights or new priorities should arise in the future years.

3. Review of materials and technologies for bituminous mixtures

For each of the families of technologies in Table 1, existing information and data regarding the impact on sustainability was reviewed and summarized in a report (De Visscher et al, 2015). The review confirmed that there are still many knowledge gaps, despite the fact that some of these technologies have already been in use for many years. Information remains very general, the reliability is often debatable and the boundaries of the system to which the data apply are not always well defined. Moreover, sustainability information is often limited to one stage in the life cycle where the most notable gains can be demonstrated (usually the production stage). NRAs and other users should be aware that these gains can be partly or totally lost in another stage.

Regarding the main sustainability indicators, the following general conclusions were drawn:

- Global warming potential (GWP), a relative measure of the amount of heat trapped in the atmosphere by greenhouse gases such as CO_2, is generally acknowledged as the most important impact category. It is mainly attributed to extraction/production of raw materials, drying/heating and transport. For the processes of drying/heating and transport, GWP can be estimated or measured fairly well. However, for the extraction/production of constituent materials (especially additives), information is often missing.
- For the use of resources for energy, the findings are similar as for GWP. This is logical, since GWP is largely due to the combustion of fossil resources for drying, heating and transport. Therefore, there is a strong correlation between GWP and the use of resources for energy for bituminous materials.

- In case of bituminous materials, the resources for materials which are used over the life cycle are mainly the constituents of the mixture itself. There is of course a significant positive impact from the use of reclaimed asphalt (RA) and secondary materials. The use of RA is particularly beneficial, since it does not only save aggregates from primary sources, but also bitumen. However, the use of material resources for the production of special additives is rarely documented or considered, which often portrays an incomplete picture with regards to the overall sustainability of the product.
- Air pollution can be studied by emission measurements in the plant or at the worksite. This is a good and objective way of investigating the air pollution associated with the production and construction stages. However, it is hard to find information on the air pollution associated with the production/extraction of the constituent materials or the processing of secondary materials.
- Health and safety issues are rarely discussed, probably because it is difficult to demonstrate them. Some studies did measure the exposure of workers to air pollutants, dust and various chemical substances, but results were mostly below the detection limits (which is a good result).
- The financial cost is reasonably well documented, but the impact of a specific technology is variable depending on many factors, such as the size of the plant, the amount of bituminous mixture produced and the evolution of the prices of materials and energy over time. NRAs need to estimate the cost over the entire life cycle, which also depends on maintenance needs, the estimated lifetime and a discount rate, used to determine the present value of future cash expenditure. This information is not always readily available.
- It is usually claimed that recyclability will not be affected by the material or technology used. However, one has to be extremely cautious with the use of some additives which may imply future risks (particularly health risks) during recycling. Also, there may be several levels of recyclability, depending on cold or hot recycling, the possible recycling rates, downgrading of the RA, etc. Recyclability is never considered in such depth.
- Performance is well studied for many techniques (e.g. for the use of RA), thanks to the performance based test methods that are now standard in Europe (wheel tracking tests, water sensitivity tests, fatigue tests, etc.). The fact that the use of RA is possible without a loss of performance is generally acknowledged, but one should remain aware that this requires a correct mix design and handling/storage procedures for the RA, in order to control the risks and uncertainties associated with heterogeneity and variability of the RA characteristics.

For the continuation of the project, it was concluded that the sustainability criteria on which the methodology will be based shall not be too detailed, since the literature shows that it would be very hard and nearly impossible for NRAs to fill in all the required detailed information with reliable data. Besides the report, a further output of this review was the so-called ‘matrix of considerations’ (Wayman et al, 2015b). This matrix shows for each of the considered families of technologies and for each of the considered sustainability criteria where the concerns are situated and what type of additional evidence a NRA may wish to acquire or demand from producers or material suppliers to make an informed decision regarding the use of the product.

4. Sustainability indicators relevant to the bituminous materials life cycle

Following the project approach and the conclusions of the previous review, it was decided to seek for a manageable set of indicators, which are relevant to bituminous mixtures and measurable or quantifiable by NRAs. These should include the main aspects of sustainability and thus allow to make a fair overall assessment.

4.1. Environmental indicators within the scope of EN 15804

The European standard EN 15804 sets the rules for producing EPDs (Environmental Product Declarations) for construction products. It covers 24 indicators, not all of them being of relevance or significant to bituminous materials. To narrow down the set of potential indicators to a limited set containing only the most significant ones, a technique was used called ‘normalisation’ (EC-JRC, 2010). This is a commonly used technique in Life Cycle Assessment, allowing to assess the significance of indicators for a given product or service. The process consists of taking an impact indicator result and dividing it by a reference value, typically the annual impact for a geographical area. Indicators with an insignificant contribution to the total annual impact for the area are then discarded. This process was applied to bituminous mixtures (Wayman et al, 2015b). Therefore, impact indicator results were retrieved from existing EPDs of standard bituminous mixtures, representing 5 European countries (Germany, France, Spain, Norway and the Netherlands), and these were divided by the total annual impact for Western Europe. Following this process, only the following environmental impact indicators were retained:

- Global Warming Potential (GWP)
- Acidification Potential (AP)
- Photochemical Ozone Creation Potential (POCP)
- Abiotic Resource Depletion Potential (AOP)

4.2. Indicators beyond the scope of EN 15804

EN 15804 covers only environmental indicators, while the EDGAR methodology aims to evaluate bituminous materials and technologies against all 3 facets of sustainability: environmental, social and economic. A review was done of various norms and standards related to social and economic performance indicators used within the construction industry (Wayman et al, 2015a). Those with a potential relevance to bituminous technologies were discussed in more detail, but for most of these indicators, it seems difficult to evaluate the significance of the impact of a given bituminous technology. Another important consideration in the selection of socio-economic indicators is the availability of tools and methods to measure or assess these indicators. Indicators that can't be assessed by NRAs are presently of little use to the EDGAR methodology. As a conclusion of the review of all potential socio-economic indicators, only the following were retained:

- pavement noise
- health and safety of road users and workers
- responsible sourcing
- traffic congestion
- life cycle cost (= financial cost in a life cycle perspective)

4.3. The EDGAR basket of indicators

Once the most relevant environmental and socio-economic indicators in relation to bituminous materials and technologies were selected, the completeness of the basket was verified by checking the retained indicators against the 'EU Green Public Procurement Criteria for Road Design, Construction and Maintenance' (EC-SWD, 2016). This document describes the most significant environmental impacts to be assessed in the green public procurement process of a road (on voluntary basis). Pavement noise and traffic congestion are among the key environmental impacts defined by the EC document, which is in line with the selection made by the EDGAR project. Rolling resistance is also one of the key environmental impacts for the EC, since decreasing rolling resistance has an impact during the whole service life stage of the road. EDGAR did not consider rolling resistance as a separate indicator, but it is considered implicitly in the GWP indicator since the effect of reducing rolling resistance is mainly a reduction of CO_2 emissions in the use stage. This is however an approach that could be reconsidered. By defining rolling resistance as a separate indicator, its importance could be more clearly defined.

The final 'basket' of indicators (Table 2) thus comprises eleven indicators covering environmental, socio-economic and performance aspects. 'Health and safety of road users and workers' was in the specific case of EDGAR converted into skid resistance, since this is in this case the only quantifiable safety characteristic which is directly dictated by the selection of the bituminous material (for a surface course).

Each of these indicators can be assessed by various existing tools or methods. The EDGAR framework does not specify methods or tools to use, realising that different NRAs will have their own preferences where methods are concerned. However, it was undertaken to recommend some methodologies based on an extensive review and criteria deemed particularly pertinent (degree of material-focus, quantitative or qualitative, speed of assessment and cost of assessment) (Wayman et al, 2015b).

Table 2: Basket of indicators

Indicator	Description
Global warming potential	The contribution to climate change of the technology in material terms
Depletion of resources	Primary resource depletion
Air pollution	Pollution potential on the basis of air pollution (non-CO_2 emissions), evaluating acidification and photochemical ozone creation potentials
Leaching potential	Pollution potential on the basis of leaching potential to groundwater
Noise	A health consideration for road users and residents related to surface characteristics
Recyclability	The potential for the valuable properties of asphalt to be retained into the next lifecycle
Skid resistance	A health & safety consideration for road users related to surface characteristics
Responsible sourcing	Evaluating social aspects related to the supply of constituent materials
Financial cost	In life cycle cost (LCC) terms, measured as net present value
Traffic congestion	Social aspects related to paving at the road site and the consequences for road users
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

5. Decision support

Once the selected set of sustainability indicators have been assessed, a decision support methodology is required in order to evaluate and compare various alternatives and assist NRAs in the decision making process. Existing Multi-attribute Decision Making (MADM) methods applied in other domains were selected for implementation in the specific context of EDGAR. This was based on previous work carried out by Bueche (2011). The input to the MADM process consists of the data generated for each selected criterion (i.e. assessment of the basket of indicators previously discussed). These various data form the ‘input matrix’, which is fed into the decision making process, leading to an evaluation and ranking of the alternatives. The decision making process is a four-level process, in which each level is more complex than the previous, but provides more information. MADM methodologies are introduced only in the third and fourth levels, with the introduction of user preferences. An overview of the evaluation methodology is proposed in Figure 1, each specific level being detailed below.

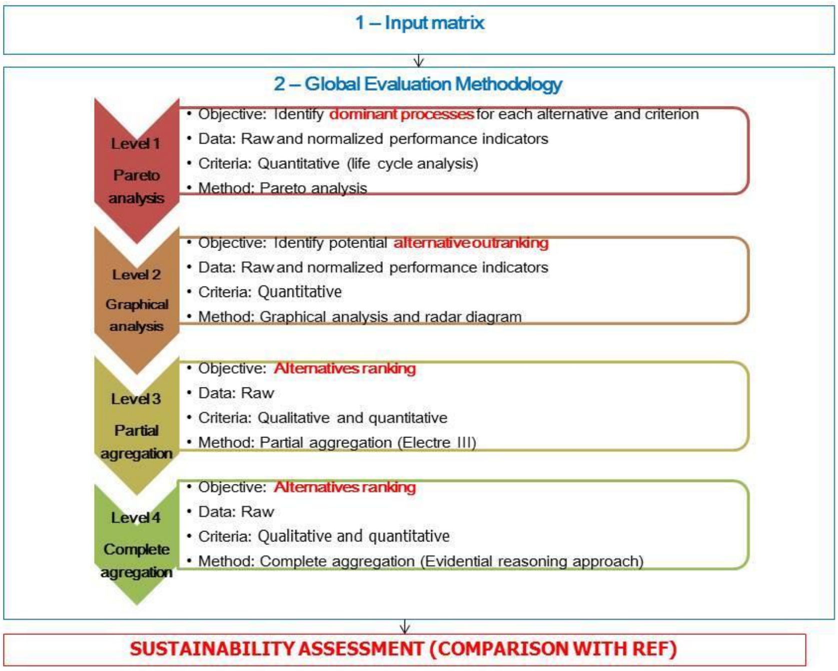

Figure 1: Process followed in EDGAR for comparison of alternative solutions with a reference (REF)

level 1: A Pareto representation is used to identify the dominant processes for each criterion over the lifespan of the asphalt mixture. This first level does not compare the various alternatives directly, but focuses on the different life cycle phases and reveals the dominant processes.

level 2: A first comparison of the alternatives is conducted. To achieve this, various graphical analyses are used, permitting to highlight the potential outranking alternatives. In the first two levels, raw data are used without any treatment or weighting. Only in the exceptional case where one of the alternatives would outrank the others on all the criteria, a final decision could be made at this level.

level 3: In the third level, a partial aggregation method using pseudo-criteria is proposed. The favoured method in this respect was the ELECTRE III method that presents the particular property of considering various outranking degrees by pairwise comparison of two alternatives.

level 4: The fourth evaluation level uses an algorithm derived from the Evidential Reasoning approach, modified for application in the framework of MADM. The fourth evaluation level is the most complex, but it allows the user to take into account the uncertainty of input data and data unknown.

These four levels have been implemented in an Excel spreadsheet, which allows users to perform the assessment once the input matrix has been introduced. For the 3rd and 4th level, the tool also expects the user to introduce weighting coefficients, expressing the importance attributed by the user to each individual criterion. This user preference depends on the application and obviously, could change the solution ranking.

6. Case study

In the final phase of the project, the methodology was demonstrated through a practical case study (Bueche et al. 2016). Besides demonstrating how the methodology works, the case study showed the difficulties encountered in obtaining data and the critical points of the methodology. This helps to evaluate how the methodology could be refined and improved for future use by NRAs. The case study considered five different alternative solutions for paving the surface course of a road section:

1 Hot mix asphalt (HMA) (= reference profile)
2 Warm mix asphalt (WMA)
3 Warm mix asphalt with reclaimed asphalt (WMA + RA)
4 Cold in-place recycling (CIR, emulsion based)
5 Hot mix asphalt with steel slag (HMA + steel slag)

The data are partly based on test sections constructed on a road in the Flanders region in 2009, as part of a research project on WMA technologies (De Visscher et al, 2010). The sections with HMA and the WMA (using a synthetic wax) were used to provide some of the data and conditions for cases 1 and 2. The other three cases were not applied on the test sections and therefore, much of the data related to these cases was collected from literature and other sources. The cold in-place recycling (CIR) alternative was especially challenging, since this alternative is very different from the others due to the high recycling rate, the in-place production, the specific equipment used on site and the lack of accurate data on performance characteristics. For more details on the conditions and assumptions regarding the different cases, refer to Bueche et al. (2016).

The most important conclusions drawn from this case study were:

- The Excel-based software tool for MADM allows the user to perform the evaluation and thereby gain appraisal of the impact of the various indicators.
- It is not a simple task to find reliable and accurate data for all indicators. This is a finding in common to any type of sustainability assessment tool. Even though the EDGAR methodology strived to a small number of indicators, it was still time consuming to collect the input data.
- In this particular case study, some of the indicators such as responsible sourcing or skid resistance did not play a role in the ranking of the alternatives, because there was no or little variation in these indicators from one alternative to another. However, this doesn’t mean that these indicators are not important in general. For example, if two alternatives would be provided by two different companies, one of which is very much concerned with responsible sourcing, the indicator ‘responsible sourcing’ should be able to make a difference.
- The user of the MADM tool shall still have sufficient expertise in the field of bituminous materials and remain critical towards the outcome. For example, in this particular case study, the CIR solution ranked as the best solution. However, CIR as such is rarely used. Because of its high sensitivity to surface raveling, it is

always protected by a slurry seal or a thin surface course. Hence, it was not correct to consider CIR as a viable alternative, without accounting for the impact of the protective overlay.
- The case study showed that for some indicators, such as GWP and air pollution, the use stage has an overwhelming contribution. This shows that an NRA should take all possible measures to decrease the impact of the use stage. If the option of selecting a type of asphalt surface course with a low rolling resistance is available, this option shall be considered because the impact on GWP and air pollution over the whole life cycle would probably be dominant.
- In this MADM tool, the use of weighting factors is necessary to account for user preferences and the use of threshold values to account for data uncertainties and the significance of differences. The final ranking of the solutions depends on these parameters, but small changes in these parameters should not completely overturn the ranking. Therefore, a sensitivity analysis is needed to check the stability or robustness of the solution.

As a final remark, this example only demonstrates the functionality of the methodology for one particular case study. More test cases for different types of projects with various loading and climate conditions are needed to improve and fine tune the methodology.

7. Rounding up the EDGAR methodology

Figure 2 presents the methodological framework. It is a process, commencing with NRAs raising concerns over a specific technology (B), selecting appropriate indicators from the basket to be measured (C), utilising the appropriate tools to quantify or measure these indicators (D) and finally, making an informed decision with the support of MADM methods (E). This process can be iteratively repeated whenever new or more reliable data become available (e.g. through trial sections), to increase evidence and consequently gain confidence in the decisions made. The EDGAR 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. Using the ‘Considerations matrix’ and baseline data for a standard reference material would streamline the process. The user can then focus on assessing the indicators of concern and default to the reference data for the remaining indicators.

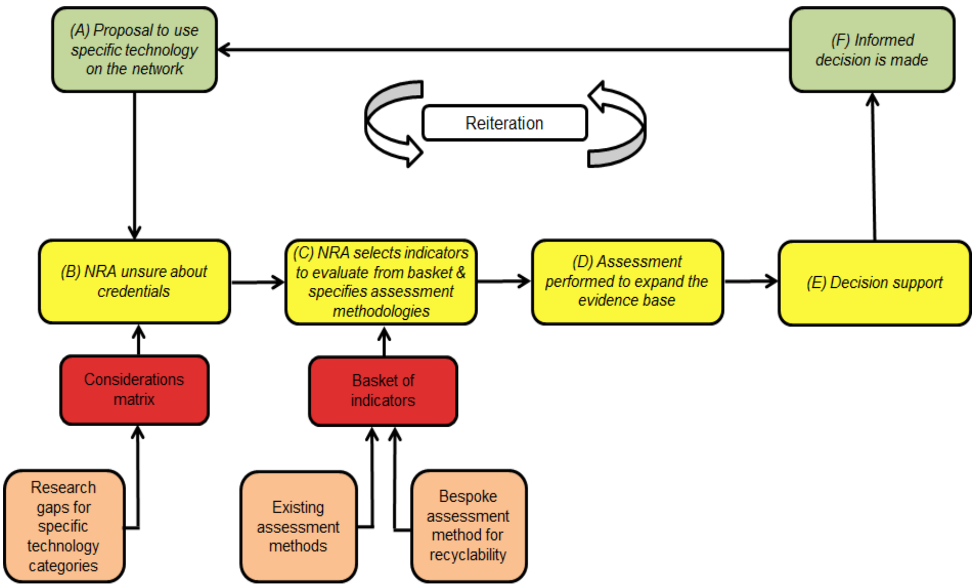

Figure 2: Decision making context and decision support from EDGAR

8. General conclusions and perspectives

The EDGAR project focused on the development of a methodology to assess the sustainability of bituminous mixtures and technologies, considering environmental, social and economic aspects from a life cycle perspective. The methodology is intended for NRAs, to enable them to make informed decisions within a limited time scale and with limited effort, on the basis of a manageable set of sustainability indicators. The indicators were selected for significance and relevance to bituminous mixtures. One of these indicators is recyclability, for which a simple and quick tool was devised to determine a score. The methodology is presented as a six-step process for NRAs to follow when considering a novel technology (see Figure 2). Use of the methodology and the MADM tool was demonstrated in the final stage of the project in a case study.

Such a methodology will allow enhancement of the evidence base in a targeted manner and improve confidence amongst road authorities to use novel bituminous technologies on the road network. The MADM tool can also be used to facilitate communication with contractors and the public. Indeed, it can be used to compare different proposals in a tender and helps justifying some decisions. This will allow for a faster and smoother implementation of new sustainable technologies and hence, help to bridge the gap between the development of novel technologies and their adoption on the road network.

Future work on this methodology should be driven by experience and feedback from the end-users, which are in first instance the NRAs. Some ideas for further improvements and developments are:

- In this project, performance was characterized by rutting resistance, water sensitivity and fatigue (the last one being less relevant for a surface course). The set of performance indicators could be expanded to include also ravelling resistance and thermal or reflective cracking resistance, depending on the type of course (base, binder or surface course), the loading conditions (traffic) and climate. In this context, it is worthwhile mentioning that the ongoing CEDR project DRaT (Development of the Raveling Test) is working on a standard test method to measure ravelling resistance.
- Lifetime prediction models could be considered, in order to replace performance characteristics by expected lifetime (which depends on performance characteristics, construction quality, traffic, climate change, …).
- Since the case study clearly showed the dominance of the use stage for criteria like GWP and air pollution, rolling resistance could be considered as a separate indicator, to put this important key parameter more into the spotlight. However, this calls for a better understanding of the different parameters of the asphalt which determine rolling resistance and for accurate assessment.
- The Excel-based tool could be improved for user friendliness. For example, default values for the weighting factors could be provided for the ease of users who are not sufficiently familiar with the methodology to make an appropriate choice.

Acknowledgements

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, the Netherlands, Norway, Slovenia and the UK.

References

Bueche, N., 2011. Evaluation des performances et des impacts des enrobés bitumineux tièdes", Thèse EPFL No 5169, Lausanne, Switzerland

Bueche, N., Anastasio, S., De Visscher, J., Hoff, I., Maeck, J., Peeling, J., Schobinger, B., Wayman, M., 2016. Demonstration of the methodology to assess sustainability, EDGAR Deliverable D3.1 (www.ntnu.edu/edgar)

EN 15804, 2012. Sustainability of construction works – Environmental Product Declarations – Core rules for the product category of construction products", CEN

De Visscher, J., Vervaecke, F., Vanelstraete, A., Soenen, H., Tanghe, T., Redelius, P.,2010. Asphalt production at reduced temperatures and the impact on asphalt performance, Proceedings of the 11th International Conference on Asphalt Pavements, August 1-6, 2010, Nagoya, Japan

De Visscher, J., Anastasio, S., Bueche, N., Hoff, I., Maeck, J., Peeling, J., Schobinger, B., Vanelstraete, A., Vansteenkiste, S., Wayman, M., 2015. Energy efficient materials and technologies and their impact on sustainability, EDGAR Deliverable D1.1 (www.ntnu.edu/edgar),

EC - Joint Research Centre - Institute for Environment and Sustainability, 2010. International Reference Life Cycle Data System (ILCD) Handbook – General guide for Life Cycle Assessment - Detailed guidance. First edition, March 2010; EUR 24708 EN; doi:10.2788/38479

EC Staff Working Document, 2016. EU Green Public Procurement Criteria for Road Design, Construction and Maintenance, SWD(2016) 203 final

Wayman, M., De Visscher, J., Maeck, J., Peeling, J., 2015a. Recommended product category rules (PCRs) for bituminous materials and technologies, EDGAR Deliverable D2.1 (www.ntnu.edu/edgar)

Wayman, M., Anastasio, S., Bueche, N., De Visscher, J., Hoff, I., Maeck, J., Peeling, J., Schobinger, B., 2015b. Guidance document on the sustainability assessment for bituminous materials and technologies, EDGAR Deliverable D2.2 (www.ntnu.edu/edgar)