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EDGAR
Evaluation and Decision Process for Greener Asphalt Roads

Final report

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

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EDGAR

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Table of contents

List of abbreviations

ADP: Abiotic resource Depletion Potential
AP: Acidification Potential
CIR: Cold In-place Recycling
EoL: End-of-Life
EPD: Environmental Product Declaration
GPP: Green Public Procurement
HMA: Hot Mix Asphalt
ITT: Initial Type Testing
LCA: Life Cycle Analysis
MADM: Multiple Attribute Decision Making
NRA: National Road Administration
PCR: Product Category Rules
POCP: Photochemical Ozone Creation Potential
RA: Reclaimed Asphalt
RSL: Reference Service Life
WMA: Warm Mix Asphalt

Project summary (English)

The project EDGAR ("Evaluation and Decision process for Greener Asphalt Roads") is a two-year project dealing with sustainability assessment of novel "green bituminous mixtures". The term "green bituminous mixture" is used as a general denomination for any type of bituminous mixture produced by using specific materials or technologies with the aim of reducing the environmental impact.

A wide variety of new types of bituminous mixtures, additives, new production or paving techniques, etc. are nowadays promoted as "green" within the asphalt sector. However, it is very difficult for NRAs to evaluate such technologies and make decisions whether to adopt their use on the road network or not. NRAs and other decision makers are confronted with a lot of missing information and data, as well as the need for a simple but sound methodology to assess in a balanced way the different facets of sustainability (environmental, social and economic).

EDGAR aims to provide such a methodology, which can be readily used by NRAs to evaluate different alternatives and make informed decisions on the selection of the most sustainable solution from a complete life cycle perspective. The methodology is devised as a transparent and flexible methodology, which can be further tailored to the specific needs of NRAs and to new insights and developments.

The project approach was to make optimum use of data, information and calculation tools already available in the context of sustainability and all its aspects and to translate this into practical outcomes.

The following project objectives were attained:

- For the main categories of green asphalt technologies, existing data on all sustainability aspects was collected from literature and other projects. This revealed many knowledge gaps and the need for more accurate and complete data, as described in the first deliverable D1.1. This large amount of data was condensed in a "concerns matrix". This is a matrix showing for each of the considered technologies which sustainability indicators might be affected (positively or negatively) and attracts the attention to particular concerns that need further investigation.
- A quick and qualitative tool for the assessment of the recyclability of "green asphalt", when it will have reached the end-of-life (EoL), was devised. Knowing that asphalt is 100 % recyclable, the use of any new type of material, additive or technology that may obstruct its future recyclability shall be avoided.
- The significance of various sustainability indicators was evaluated for the specific case of bituminous mixtures, in order to end up with a limited set of the most relevant and significant sustainability indicators (the EDGAR "basket of indicators"). This is a manageable set, requiring a reasonable time and effort to assess, and thus of practical use to NRAs.
- Existing tools for the quantitative or qualitative assessment of the basket of sustainability indicators were reviewed and evaluated in order to recommend the most appropriate tools for each indicator for the case of "green" bituminous materials.
- A flexible tool was developed to evaluate any emerging material or technology and to assess its overall sustainability, using Multiple Attribute Decision Making (MADM) methods. The basket of sustainability indicators, as determined by the appropriate assessment tools, is used as input data to the MADM tool. The tool also accounts for the weight or importance a NRA may attribute to each of the indicators, depending on the

application (type of asphalt course, traffic, climate, …) and local practices. The model penalizes missing or uncertain data and thus implicitly urges the asphalt producers and other stakeholders to fill in the gaps and provide more accurate data or evidence.

- Finally, the methodology was demonstrated for a number of selected test cases.

The work was organized in five work packages:

1. *WP1 "Review of energy efficient materials and technologies and classification system for recyclability"* selected the new materials/technologies and the assessment criteria, summarized the information and data for the sustainability assessment of "green bituminous mixtures" in a report (Deliverable D1.1) and proposed a system for a quick, qualitative assessment of their recyclability at the end-of-life.
2. *WP2 "Methodology for the assessment of sustainability"* established rules, selected tools and proposed methodologies that can be used to provide an evidence base with which to make an informed in-depth sustainability assessment of new materials/technologies (Deliverables D2.1 and D2.2).
3. *WP3 "Demonstration of the methodology to assess sustainability"* consisted in the demonstration of the methodology with the calculation for some representative test cases. This demonstration also serves as a practical guideline and puts an emphasis on the key elements to be considered when applying the methodology to new materials/technologies (Deliverable D3.1).
4. WP4 "Dissemination activities", the objectives of which were to disseminate the results to road administrations and other stakeholders. The communication with an Advisory Group ensured that the work done responded to the expectations of national road administrations.
5. WP5 "Management activities" managed the project, making sure that the work plan was respected and that deliverables were in time and of good quality.

Résumé du projet (French)

Le projet EDGAR (*Evaluation and Decision process for Greener Asphalt Roads*) est un projet de deux ans portant sur l'évaluation de la durabilité des nouveaux «mélanges bitumineux verts». Le terme « mélanges bitumineux verts » est utilisé pour désigner de manière générale tout type de mélange bitumineux produit en utilisant des matériaux ou des technologies ayant spécifiquement pour but de réduire l'impact environnemental.

De nos jours, de nombreux nouveaux types de mélanges bitumineux, additifs, techniques de production ou de mise en œuvre, etc. sont dits «verts» dans le secteur des enrobés. Néanmoins, il est très difficile pour les administrations routières d'évaluer ces technologies et de décider si elles doivent les utiliser sur leur réseau routier ou non. Les administrations routières et les autres décisionnaires sont confrontés à un important manque d'informations et de données, et ont besoin d'une méthodologie simple mais efficace pour évaluer et sous-peser les différentes facettes de la durabilité (environnementale, sociale et économique).

EDGAR a pour objectif de fournir une méthodologie de ce type, qui pourra être utilisée par les administrations routières afin d'évaluer les différentes alternatives et de choisir en toute connaissance de cause la solution la plus durable, dans une optique de cycle de vie complet. La méthodologie a été conçue pour être transparente et flexible, et pour pouvoir être adaptée aux besoins spécifiques des administrations routières et aux nouveaux concepts et développements.

L'approche du projet était d'utiliser de manière optimale les données, les informations et les outils de calcul déjà disponibles dans le contexte de la durabilité sociétale et de tous ses aspects, pour les transposer ensuite en résultats pratiques.

Les objectifs suivants ont été atteints au sein du projet:

- Pour les principales catégories de technologies bitumineuses vertes, les données existantes sur tous les aspects de la durabilité sociétale ont été collectées dans la littérature et d'autres projets. D'importantes lacunes ont été mises en évidence, ainsi que la nécessité de disposer de données précises et complètes, comme le décrit le premier deliverable D1.1. Cette importante quantité de données a été condensée dans une "concerns matrix" (matrice de préoccupations). Il s'agit d'une matrice qui présente pour chacune des technologies considérées les indicateurs de durabilité qui peuvent être affectés (positivement ou négativement) par l'utilisation de cette technologie et attire l'attention sur des préoccupations particulières qui nécessitent d'être approfondies.
- Un outil rapide et qualitatif d'évaluation de la recyclabilité d'un «enrobé vert», lorsqu'il a atteint la fin de son cycle de vie, a été développé. Sachant que l'enrobé est recyclable à 100 %, l'utilisation de tout nouveau type de matériaux, additifs ou technologies qui pourrait nuire à cette recyclabilité doit être proscrite.
- Le caractère significatif des différents indicateurs de durabilité a été évalué pour le cas spécifique des mélanges bitumineux, afin d'aboutir à un ensemble limité reprenant les indicateurs les plus pertinents et les plus significatifs (le «panier d'indicateurs» EDGAR). Il s'agit d'un ensemble gérable, nécessitant un temps et des efforts raisonnables, et donc d'utilisation pratique pour les administrations routières.
- Les outils existants pour l'évaluation quantitative ou qualitative du panier d'indicateurs de durabilité ont été passés en revue et évalués afin de recommander ceux qui sont les plus appropriés pour chaque indicateur, dans le cas des matériaux bitumineux «verts».
- Un outil flexible a été développé pour évaluer toute nouvelle technologie ou tout nouveau matériau et pour en estimer la durabilité générale, à l'aide de méthodes

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Conference of European Directors of Roads

Multiple Attribute Decision Making (MADM). Le panier d'indicateurs de durabilité, déterminé par les outils d'évaluation adéquats, est utilisé comme données pour alimenter l'outil MADM. Celui-ci tient compte de la pondération ou de l'importance que peut attribuer une administration routière à chaque indicateur, en fonction de l'application (type de couche bitumineuse, trafic, climat, etc.) et des pratiques locales. Le modèle épingle les données manquantes ou imprécises, et pousse donc implicitement les producteurs d'enrobés et autres personnes impliquées à combler les vides et à fournir des données ou informations plus précises.

- Enfin, la méthodologie a été démontrée pour un certain nombre de cas d'étude sélectionnés.

Le travail était réparti sur cinq *work packages (WP)*:

1. Le *WP1 "Review of energy efficient materials and technologies and classification system for recyclability"* a sélectionné les nouveaux matériaux /technologies et les critères d'évaluation, a résumé les informations et les données pour l'évaluation de la durabilité des «mélanges bitumineux verts» dans un rapport (Deliverable D1.1) et a proposé un système permettant d'évaluer rapidement et de manière qualitative leur recyclabilité en fin de vie.
2. Le *WP2 "Methodology for the assessment of sustainability"* a établi des règles, sélectionné des outils et propose des méthodologies qui peuvent être utilisées pour fournir une base bien documentée afin de réaliser en toute connaissance de cause une évaluation approfondie de la durabilité des nouveaux matériaux/technologies (Deliverables D2.1 et D2.2).
3. Le *WP3 "Demonstration of the methodology to assess sustainability"* consistait à démontrer la méthodologie en l'appliquant sur quelques cas d'étude représentatifs. Cette démonstration sert aussi de guide pratique et met l'accent sur les éléments-clés à prendre en compte lorsque la méthodologie est appliquée à de nouveaux matériaux/technologies (Deliverable D3.1).
4. Le *WP4 "Dissemination activities",* avait pour objectif de diffuser les résultats auprès des administrations routières et autres personnes impliquées. La communication avec un *Advisory Group* a permis de garantir que le travail effectué répondait aux attentes des différentes administrations routières nationales.
5. Le *WP5 "Management activities"* était en charge de la gestion du projet, en s'assurant que le planning de travail était respecté et que les deliverables étaient de bonne qualité et fournis à temps.

Projektkurzfassung (German)

Das Projekt EDGAR (Beurteilungs- und Entscheidungsprozess für grünere Asphaltstraßen) ist ein zweijähriges Projekt, welches sich mit der Bewertung der Nachhaltigkeit von „grüneren Asphaltstraßen" beschäftigt. Der Begriff „grüne Asphaltstraße" wird in der Regel als Beschreibung für alle Asphaltarten verwendet, die mit speziellen Materialen oder Methoden hergestellt werden, die die Zielsetzung haben, die Umweltbelastungen zu reduzieren.
Viele verschiedene, neue Varianten von Asphaltmaterialien, Zusatzstoffen, Produktions- oder Auslegemethoden werden als „grüner" dargestellt. Es ist jedoch für Straßenverwaltungen schwierig, die unterschiedlichen Methoden zu beurteilen, um die Entscheidung zu treffen ob diese für das gegebene Straßennetzwerk angewendet werden soll. Oft fehlen wichtige Informationen und Daten, wenn die Entscheidung über eine eventuelle Anwendung getroffen werden soll. Zusätzlich fehlen einfache aber zuverlässige Methoden, um die unterschiedlichen Seiten der Nachhaltigkeit ausgewogen/ausgeglichen beurteilen zu können (ökologisch, sozial und ökonomisch).
Die Zielsetzung von EDGAR ist es eine Methodik zu entwickeln, die von Straßenverwaltungen benutzt werden kann, unterschiedliche Alternativen beurteilen und kenntnisbasierte Entscheidungen treffen zu können, wenn die meist nachhaltige Lösung in einer Lebenszeitperspektive gefunden werden soll. Die entwickelte Methode gilt als transparent und flexibel und kann dem speziellen Bedarf einzelner Straßenverwaltungen, neuen Erkenntnissen und Entwicklungen angepasst werden.
Der Lösungsansatz des Projektes war Daten, Informationen und Berechnungsmethoden optimal zu nutzen, die bezüglich der Nachhaltigkeit bereits zugänglich waren und diese in praktische Ergebnisse umzusetzen.

Die folgenden Projektziele wurden erreicht:

- Für die Hauptkategorien grüner Asphalttechnologien wurden alle Nachhaltigkeitsaspekte aus der Literatur und anderen Projekten gesammelt. Dadurch wurden viele Kenntnislücken aufgedeckt und der Bedarf für genauere und umfassendere Informationen geschaffen. Dies ist in der ersten Ergebnissen D1.1. beschrieben. Diese umfangreiche Datenmenge wurde in einer „Einflussmatrize" zusammengefasst. Die Matrize zeigt, welche Nachhaltigkeitsindikatoren von den einzelnen untersuchten Methoden beeinflusst werden können (positiv oder negativ) und beleuchtet Bereiche, die weitere Untersuchen bedürfen.
- Ein schnelles, qualitatives Werkzeug wurde erstellt, das für die Bewertung der Wiederanwendbarkeit von „grünem Asphalt" verwendet werden kann, wenn dieser das Ende seiner Lebenszeit erreicht hat. Da Asphalt im Grunde 100 % recycelt werden kann, sollten Methoden, die diese Möglichkeit einschränken, vermieden werden.
- Der Stellenwert der verschiedenen Nachhaltigkeitsindikatoren wurde für Asphaltmaterialen so untersucht, dass ein ausgewählter Katalog an Parametern (EDGAR Parameter) erstellt wurde. Dieser Katalog ist handhabbar, so dass Entscheidungen zeitgemäß und mit angemessenem Aufwand getroffen werden können und damit für den praktischen Gebrauch der Straßenverwaltungen geeignet.
- Existierende Hilfsmittel für die qualitative und quantitative Beurteilung von Nachhaltigkeitsindikatoren wurden überprüft und evaluiert, um die am besten passenden Hilfsmittel für jeden Indikator bezüglich grüner Asphaltmaterialien empfehlen zu können.
- Ein flexibles Werkzeug wurde entwickelt, um neue Materialien und Technologien mit Hinblick auf Nachhaltigkeit basiert auf Multiple Attribute Decision Making (MDAM) Methoden zu beurteilen. Der Katalog mit Nachhaltigkeitsindikatoren wurde als

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Conference of European Directors of Roads

Eingangsparamter für das MDAM-Werkzeug benutzt. Das Werkzeug berücksichtigt auch die Wichtung einer Straßenverwaltung auf verschiedene Indikatoren, abhängig vom Einsatzbereich (Asphalttyp, Verkehr, Klima, etc.) und lokaler oder nationaler Richtlinien. Das Modell benachteiligt fehlende oder unsichere Daten und fordert Asphaltproduzenten und andere damit auf, die Lücken zu füllen und genauere Daten oder Nachweise zu liefern.

- Abschließend wurde die Methode an verschiedenen ausgewählten Beispielen getestet.

Die Arbeit wurde in fünf Arbeitspaketen organisiert:

1. WP1 „Überprüfung der energieeffektiven Materialen, Technologien und Klassifizierungssysteme für Recyclingmöglichkeit“ wählte die neuen Materialien/Technologien und Einschätzungskriterien aus, fasste Informationen und Daten für die Nachhaltigkeitsbeurteilung grüner Asphaltmaterialien in einem Bericht (D1.1) zusammen und schlug ein System für die schnelle qualitative Beurteilung von Möglichleiten für Recycling von Materialien am Ende der Lebenszeit vor.
2. WP2 „Methodik für die Beurteilung von Nachhaltigkeit“ etablierte Regeln, wählte Hilfsmittel und schlug eine Methodik vor, die für das Aufbauen einer Erfahrungsdatenbank benutzt werden kann, um tiefgehende Nachhaltigkeits-beurteilungen von neuen Materialien/Technologien durchführen zu können (Bericht D2.1 und D2.2).
3. WP3 „Demonstration der Methodik für die Beurteilung der Nachhaltigkeit“ bestand aus der Demonstration der Methodik durch die Berechnung einiger repräsentativer Testbeispiele. Die Demonstration kann auch als eine praktische Richtlinie genutzt werden und beleuchtet die wichtigsten Elemente, die bei der Anwendung der Methodik auf neue Materialien und Technologien berücksichtigt werden müssen (Bericht D3.1).
4. WP4 „Vermittlungsaktivitäten“ hatte als Zielsetzung Ergebnisse des Projektes an die Verwaltungen und andere Interessierte weiter zu vermitteln. Die Kommunikations- und Beratungsgruppe stellte sicher, dass die ausgeführte Arbeit den Erwartungen der nationalen Straßenverwaltungen entsprach.
5. WP5 „Projektleitung“ steuerte das Projekt, sicherte dass der Arbeitsplan eingehalten wurde und, dass die Ergebnisse fristgerecht und mit hoher Qualität geliefert wurden.

Prosjektsammendrag (Norwegian)

Prosjektet EDGAR (Vurdering og beslutningsstøtte for grønnere asfaltveger) er et to-årig prosjekt som handler om bærekraftighetsvurderinger av nye “grønne asfalttyper”. Begrepet «grønne asfalttyper» blir bruk som en generell beskrivelse av alle typer asfalt som blir produsert med spesifikke materialer eller metoder med målsetning om å redusere miljøbelastningen.

Mange forskjellige nye varianter av asfaltmaterialer, tilsetningsstoffer, produksjon eller utleggingsmetoder blir framstilt som «grønne». Det er imidlertid vanskelig for vegadministrasjoner å evaluere de ulike metodene for å bestemme hva som skal tas i bruk for sine veger. Det vil ofte mangle viktig informasjon og data når en skal ta beslutning om eventuell bruk. Det mangler også enkle men pålitelige metoder for å vurdere på en balansert måte de ulike sidene av bærekraft (miljømessige, sosiale og økonomiske).

Målsetningen for EDGAR er å framskaffe en metodikk som kan bli bruk av vegmyndigheter for å vurdere forskjellige alternativer og foreta kunnskapsbaserte valg når det gjelder å finne den mest bærekraftige løsningen i et levetidsperspektiv. Metodikken er utviklet for å være transparent og fleksibel som kan skreddersys til spesifikke behov for de enkelte vegmyndigheter og ny kunnskap og utvikling.

Prosjektets framgangsmåte var å bruke data, informasjon og beregningsmetoder som var tilgjengelige innenfor bærekraftsvurderinger på en optimal måte og overføre disse til praktiske resultater.

Følgende prosjektmål ble nådd:

- For hovedkategoriene av grønne asfaltteknologier ble alle bærekraftsaspekter samlet fra litteratur og andre prosjekter. Dette avslørte mange kunnskapshull og behov for mer nøyaktig og komplett informasjon. Dette er beskrevet i første leveranse D1.1. Den store informasjonsmengden ble samlet i en “påvirkningsmatrise”. Matrisen viser hvilke bærekraftsindikatorer som kan bli påvirket (positivt eller negativt) for hver av metodene som ble vurdert og belyser områder som trenger flere undersøkelser.
- Et raskt, kvalitativt verktøy for vurdering av gjenanvendelighet for «grønn asfalt» når den har nådd slutten av levetiden ble laget. Siden asfalt i utgangspunktet kan gjenbrukes 100 % må en unngå metoder som reduserer muligheten for gjenbruk.
- Viktigheten av de ulike bærekraftsindikatorene ble vurdert for asfaltmaterialer slik at vi kunne komme fram til et begrenset sett av parametere (EDGAR parameterne). Dette settet er mer håndterlig slik at vurderingen kan gjennomføres med fornuftig tidsbruk og innsats, og dermed blir egnet for praktisk bruk.
- Eksisterende verktøy for kvalitativ og kvantitativ vurdering av bærekraftsindikatorene ble gjennomgått for å kunne anbefale det mest passende verktøy for hver indikator når det gjelder grønne asfaltmaterialer.
- Et fleksibelt verktøy ble utviklet for å vurdere nye materialer og teknologier med hensyn på bærekraft basert på Multiple Attribute Decision Making (MADM) metoden. Settet med bærekraftsindikatorer ble brukt som inngangsparametere for MADM-verktøyet. Verktøyet tar også hensyn til vekting som vegmyndigheter kan tillegge de ulike indikatorene avhengig av bruksområde (asfalttype, trafikk, klima, etc) og lokale eller nasjonale retningslinjer. Modellen straffer manglende eller usikre data og på den måten vil asfaltprodusenter og andre oppmuntres til å skaffe ny kunnskap for å tette hullene.
- Metodikken ble anvendt på et utvalg av forskjellige case.

Arbeidet ble organisert i fem arbeidspakker:

1. WP1 “Vurdering av energieffektive materialer, teknologier og klassifiseringssystemer for gjenbruk” valgte vurderingskriterier for nye materialer/teknologier, oppsummerte informasjon og data for bærekraftsvurderinger av grønne asfaltmaterialer i en rapport (D1.1) og foreslo et system for rask kvalitativ vurdering av muligheten for gjenbruk av materialer ved slutten av levetiden.
2. WP 2 “Metodikk for vurdering av bærekraft” etablerte regler, valgte verktøy og foreslo metodikk som kan bli brukt til å lage en erfaringsdatabase som kan brukes til å lage dyptgående bærekraftsvurderinger av nye materialer/teknologier (Leveranse D2.1 og D2.2)
3. WP3 “Demonstrasjon av metodikken for vurdering av bærekraft” bestod av demonstrasjon av metodikken gjennom en beregning av noen representative test case. Demonstrasjonen kan også brukes som en praktisk retningslinje og belyser de viktigste elementene som må tas med hensyn til når metodikken skal anvendes på nye materialer eller teknologier (Leveranse D3.1)
4. WP4 “Formidlingsaktiviteter”, hadde som målsetning og spre resultatene fra prosjektet til vegmyndigheter og andre interesserte. Kommunikasjon med rådgivningsgruppen sikret at arbeidet som ble gjort var i tråd med forventningene fra de nasjonale vegmyndighetene.
5. WP5 “Prosjektledelse” styrte prosjektet og sikret at arbeidsplanen ble fulgt og at leveransene ble ferdig til frister og hold god kvalitet

1 Introduction

1.1 Background

Reduction of energy consumption is a major challenge and responsibility for the 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 Transnational Road Research Programme "Energy Efficiency" was therefore to develop concepts and methodologies for road construction and operation with reduced use of energy.

The potential to reduce energy consumption is particularly large for asphalt roads. Considering the volume of bituminous mixtures produced in Europe every year (80 % of the European road network is paved in asphalt), any improvement of the energy efficiency of bituminous mixtures will deliver a considerable contribution to a more sustainable road infrastructure.

Today, there is a wide range of new materials and technologies being developed with a focus on energy efficiency. Energy efficiency can be aspired in different ways, e.g. by reducing the energy consumption during construction, by replacing materials from primary unrenewable resources by secondary or renewable materials or by increasing the durability (longer lifetime, less maintenance). The road construction industry and especially road administrations can play an important role in reducing energy consumption by stimulating and implementing those technological innovations that prove to be the most energy efficient.

Alongside recycling, which is already recognized as the utmost sustainable practice in asphalt industry, many other technologies are being promoted with the aim to improve the energetic performance of bituminous mixtures:

- Use of additives for reducing production temperatures and/or improving performance
- Binder foaming for reducing production temperatures
- Use of rejuvenators for restoring the properties of reclaimed asphalt (RA)
- Use of materials from secondary resources (e.g. steel slag aggregate)
- Use of alternative new materials, preferably from renewable resources (e.g. bio binders)
- …

As these and other novel technologies emerge, their viability needs to be assessed in relation to other solutions on offer and to the conventional technologies already utilised within the industry.

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 are the most promising. As these questions and challenges for road authorities exist in the different European countries, it is the most efficient to handle them in transnational projects. Also, as large asphalt companies operate on a European level, it is crucial that different road authorities develop common viewpoints and use common data, tools and methodologies in their decision processes.

1.2 Project aim

The final aim of the EDGAR project is to bridge the gap between innovation in the bituminous materials sector and adoption of the new technologies by national road administrations (NRAs) and to facilitate quick adoption of the technologies that offer the greatest sustainability benefits for the highways sector and society as a whole.

EDGAR seeks to accomplish this by developing an assessment methodology which makes sustainability information on new technologies readily accessible to the decision-making process.

The methodology proposed is intended to be practical and applicable on short term by NRAs. This means that it should focus 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 should also remain 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.

1.3 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 new materials and technologies:

1. There are other environmental impacts to be considered, in addition to those already described in the European norm EN 15804, which defines 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. Latter include potential risks for health and safety, economic costs, technical feasibility during production and on during paving, impact on performance and maintenance, etc…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).

One of the main assets of bituminous mixtures in terms of sustainability is that they are highly recyclable (up to 100 %), with the valuable properties of both the aggregates and the bitumen transferring from the first to the second cycle (and beyond). This results in high material efficiency and a huge reduction in energy consumption and greenhouse gas 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 quick tool was devised to qualify the potential for future recyclability. The basic idea is that, when it is known in advance that the recyclability potential will be zero or very low, further detailed assessment of sustainability 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 many factors, like performance characteristics of the material, construction quality, evolution of traffic, climate and maintenance schemes. This implies many uncertainties, which will have a huge impact on the final outcome of any sustainability assessment. Therefore, 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 have the advantage that 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.

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

- To obtain a better overview of existing knowledge on the sustainability aspects of asphalt technologies, the project team started with a review of literature and output from other projects. The specific aims and outcome of this review are further discussed in chapter 2 of this report.
- Starting from an extensive list of sustainability indicators used in the construction industry, the list was narrowed down to a limited but essential set of indicators. The process leading to this basket of indicators is described in chapter 3. Given the importance of recyclability and performance, as explained above, it was decided from the start that these two characteristics should be contained within the basket. For recyclability, a flowchart was designed which allows to assess the recyclability potential and attribute a score for recyclability.
- Having determined the basket of essential sustainability indicators, Multiple Attribute Decision Making (MADM) methods were used to aid the decision maker in the assessment of the overall sustainability of a specific technology, in comparison to other alternative solutions or to a known reference. Chapter 4 describes these methods and rounds up the methodology.
- A demonstration on some interesting test cases is described in chapter 5 and finally, chapters 6 and 7 are dedicated to the conclusions and perspectives of the project.

This approach allows to make optimum use of data and information and calculation tools already available in the context of sustainability. It leaves a high degree of flexibility, because each NRA can decide which tools they prefer to characterise the indicators and they can attribute weights, depending on the relevance of each indicator in the context of the project or application. Also, the MADM approach allows to add new indicators or to omit others if new insights or new priorities should arise in the future years.

2 Review of materials and technologies for bituminous mixtures

The first task within the EDGAR project was to conduct a wide-ranging review of existing literature and completed or ongoing research projects related to the technologies and their impact on sustainability. This resulted in a review report (Deliverable D1.1).

2.1 Aims of the review

The aims of this review were:

- To provide an overview of available information on 'green' technologies used in the bituminous materials sector, specifically the information related to the most important sustainability criteria.
- To make a critical evaluation of the information and identify gaps in the existing knowledge.
- To identify 'alerts' for a given material or technology. These are issues that have been identified that could possibly jeopardize the overall sustainability and therefore are concerns to be considered by NRAs.

Table 1 shows the categories of technologies considered. This list is not exhaustive, but includes the main technologies that are already available to road administrations and other clients. For some of these categories, it may be debatable whether they can actually be labeled as 'green', but this is exactly why a thorough sustainability assessment methodology such as the methodology developed in the EDGAR project is needed.

Table 1: Technologies selected for review

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

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For each of these technologies, the review discussed the information and data found regarding the impact on the following sustainability indicators: global warming potential, use of energy and material resources, air pollution, recyclability at the end-of-life, health and safety and financial/economical costs. The impact on performance was also discussed, because of the importance for the expected maintenance and lifetime in a life cycle perspective. This set of sustainability indicators, which was selected at the start of the project, is rather coarse and probably not complete. An in-depth study of the relevance of various sustainability indicators in the field of bituminous materials has led to the recommendation of a more adequate "basket of indicators" in a later stage of the project (see next chapter).

Report Deliverable D1.1 was not intended as a complete and finished literature review. There is probably more information to be found and more information will certainly appear in the coming years, since sustainability issues are gaining more attention day by day. However, production of this deliverable has proved very useful in terms of framing the future work planned in the EDGAR project.

2.2 Conclusions and output

Deliverable D1.1 provided a good overview of current knowledge and knowledge gaps, but it was recognized that the information remains very general and the reliability is often debatable. One of the biggest problems is that the boundaries of the system to which the data apply are not always well defined. In that case, it is difficult to interprete or to compare data. 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 (e.g. the production of raw materials or transport).

The review has confirmed that there are still many knowledge gaps, despite of the fact that some of these technologies have already been in use for many years. Regarding the main categories of sustainability criteria considered, the following general conclusions were drawn:

- *Global warming potential* is one of the most commonly evaluated impact categories. For bituminous mixtures, GWP is mainly attributed to the processes of extraction/production of the 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 the constituent materials (including special additives), information is often missing.
- The *use of resources for energy* is also well covered, but the findings are similar to what is found for GWP. This is logical, since the emission of CO_2 is largely due to the combustion of fossil resources for drying, heating and transport. Therefore, there has to be a strong correlation between GWP and the use of resources for energy for bituminous materials.
- In the 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, for various special additives, the use of material resources for the production of the additives is rarely documented or considered, which often portrays an incomplete picture with regards to the overall sustainability of the product.

- *Air pollution* is often 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 RA and secondary materials.
- *Health and safety issues* are rarely discussed, probably because it is very difficult to demonstrate if there are any impacts. Some researchers did measure the exposure of workers to air pollutants, dust and various chemical substances. Results were always below the detection limits.
- The impact on *financial cost* is reasonably well documented, but the impact 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 the maintenance needs, the estimated lifetime and a discount rate, used to determine the present value of future cash expenditure. This requires additional information which is not always 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 cause future health risks when recycling takes place at EoL. But even if there are no health risks, 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 discussed in such depth.
- *Performance* is well covered for many techniques, 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 accepted, but one should remain alert 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, the following lessons were learned:

- It became clear that, for the following work packages of EDGAR, the project team would have to dig deeper to find more detailed and reliable data, or methodologies that can be utilized to provide reliable data.
- The 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.
- The report formed a good basis for the selection of the test cases to demonstrate the methodology in WP3. It was already clear that the use of RA should be among the most important test cases, since the benefits of this technique are apparent for each criterion that was considered, especially for GWP, use of energy and material resources and financial costs.

Next to the review report, a further output of this review was the so-called ‘matrix of considerations’ (www.ntnu.edu/web/edgar/edgar). 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.

3 Sustainability indicators relevant to the bituminous materials life cycle

Following the project approach and the conclusions of the review described in the previous chapter, it was decided to seek for a manageable set of indicators, which are:

- relevant to bituminous mixtures;
- measurable or quantifiable by NRAs;
- covering all stages of the life cycle from cradle-to-grave (or cradle-to-cradle in case of 100 % recycling);
- including all essential aspects of sustainability and thus allowing to make a fair overall assessment.

Selection of these indicators and specification of the units and methods to measure them could be regarded as a recommendation of "core rules" for sustainability assessment of the product category of bituminous materials.

3.1 EDGAR in relation to Environmental Product Declarations

Core rules for the sustainability assessment of construction products in general are described in the European standard EN 15804, which sets the rules for producing Environmental Product Declarations (EPDs).

Deliverable D1.2 made a review of existing standards and other documents relevant for sustainability in construction works, comprising the EN 15804 and existing EPDs for asphalt and related products. The aim of this review was to explore the relevance and applicability of EPDs and the process to develop EPDs, within the scope of the EDGAR project. Only a few examples of EPDs were identified in the domain of asphalt, and these are all fairly nondescript, simply listing the functional unit and the quantified impacts without any interpretation and not reaching beyond 'cradle-to-gate'.

The conclusion of the review was that the process for developing EPDs, according to the rules set out in EN 15804, does not fully respond to the purpose of EDGAR for the following reasons:

- The EPD process is too time- and data-intensive, with a total set of 24 indicators that have to be declared, requiring commercial software and a very specific expertise in the field of sustainability assessment.
- EPDs do not consider social and economic indicators, which are also envisaged in the scope of EDGAR.
- Existing EPDs do not go beyond 'cradle-to-gate', since this would require an estimation of a Reference Service Life (RSL), which is very difficult for the case of a road paving material.

Given the conclusions above, it was decided that the EDGAR methodology should complement rather than adhere completely to the EN 15804 approach. The EDGAR methodology will filter sustainable novel asphalt solutions from less sustainable solutions and therefore provide a useful intermediate step that could later lead to full assessment of the product through creation of an EPD. This process would accelerate the implementation of novel technologies, giving a stronger drive to innovations. Figure 1 indicates how this might work.

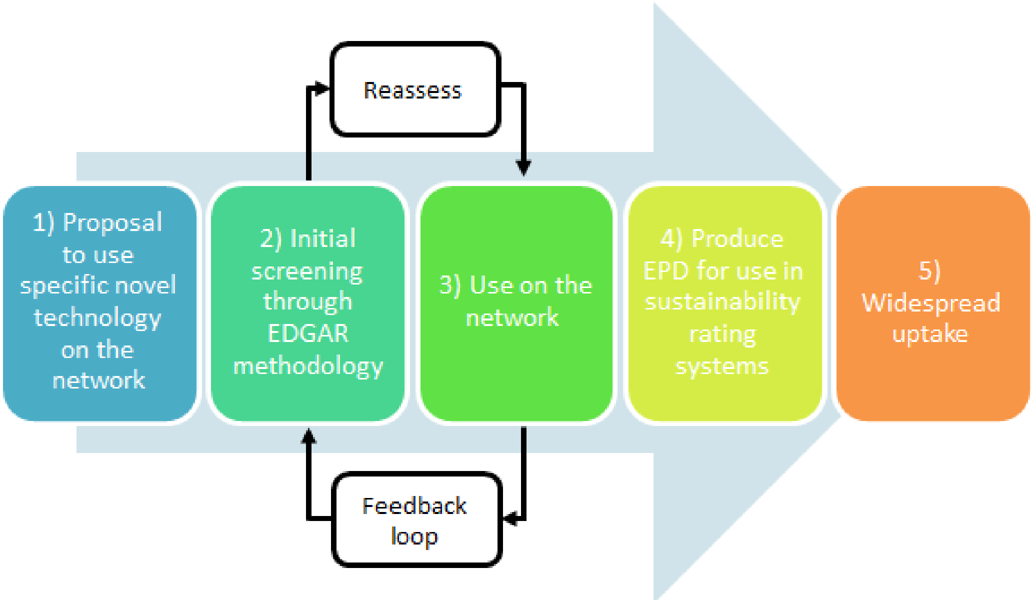

Figure 1: The EDGAR methodology in relation to EPDs

3.2 Environmental indicators within the scope of EN 15804

The European standard EN 15804 sets the rules for producing 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’. 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 of normalization is described in (ILCD, 2010). It 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 can then be discarded.

In Deliverable D2.2, this process was applied to bituminous mixtures. Therefore, impact indicator results were retrieved from 5 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 normalization 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)

3.3 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. In Deliverable D2.1, a review is given of various norms and standards related to social and economic performance indicators used within the construction industry. This resulted in an extensive list, as given in Annex B of D2.1. The indicators with a potential relevance to bituminous technologies were discussed in more detail in Deliverable D2.1. However, 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 was 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. The availability of assessment tools was further explored in Deliverable D2.2 and summarized in chapter 4 of this final report.

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)

These indicators were considered by the project team as the most relevant ones, since they are the most likely to be affected by the selection of the bituminous material or technology used.

3.4 The EDGAR basket of indicators

In the previous sections, the most relevant environmental and socio-economic indicators in relation to bituminous materials and technologies have been 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', that were drafted by the EC (EC Staff Working Document, 2016). This document describes the most significant environmental impacts to be assessed in the 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. This is however an approach that could be reconsidered. By defining rolling resistance as a separate indicator, its importance could be more highlighted.

Health and safety of road users and workers was translated into skid resistance, since this is the only quantifiable safety characteristic which is directly dictated by the selection of the bituminous material (for the surface course). This leaves out air pollution and smog creation, but these criteria are already considered separately in Acidification Potential (AP) and Photochemical Ozone Creation Potential (POCP).

Finally, two more indicators were added to the basket:

Recyclability:
As recognized by all stakeholders, *recyclability* is the most important sustainability indicator of an asphalt road, as it leads to huge environmental and economic benefits. High recycling rates are already rewarded at the start of a life cycle, since there is less need for primary materials. Recyclability however is an indicator that evaluates benefits beyond the present life cycle. By assessing this indicator, it is verified if the material will still be recyclable at the end of the life cycle. Knowing that asphalt can be recycled multiple times, this is of major importance. To assess future recyclability, a flowchart was designed which allows to assess the recyclability potential and attribute a score for recyclability (Deliverable 2.2, Annex C).

Performance:
As explained in the introduction, the approach followed in EDGAR 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 indirect measures of the expected lifetime and they have the advantage that they are more easily acquired by NRAs.

The final 'basket' of indicators (Table 2) thus comprises eleven indicators covering environmental, socio-economic and performance aspects. This basket of indicators is not an absolute selection that shall suit any NRA for any type of application. Other indicators may be added, while some indicators may prove to be of little impact on the final decision. The application to some test cases or real cases is expected to demonstrate this more clearly.

Table 3: Basket of indicators

Indicator	Description
Global warming potential	Evaluating the contribution to climate change of the technology in material terms
Depletion of resources	Assessing primary resource depletion
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
Recyclability	Assessing the potential for the valuable properties of asphalt's constituents to be retained into the next lifetime
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 installation of the material 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

4 The EDGAR methodology

4.1 Framework

Figure 2 presents the structure of the methodology. 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.

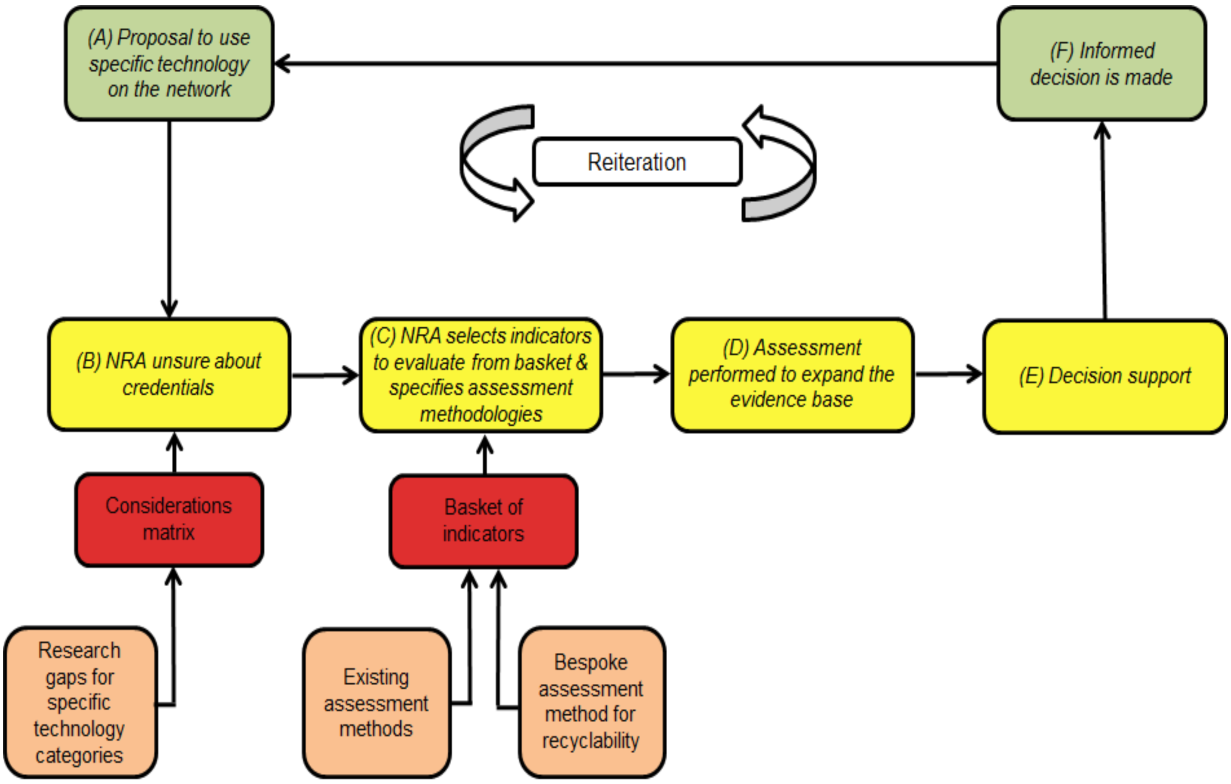

Figure 2: Decision making context and decision support from EDGAR

The different steps in the evaluation and decision process are as follows:

Step A – Proposal to use the novel technology on the network
An application is made by a contractor to use a new technology on the network. At this stage the product has already been CE marked by the manufacturer.

Step B – NRA is 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 'considerations matrix', produced from a synthesis of research supporting the adoption of different types of technology on highways, will assist NRAs to identify areas where the evidence base might be lacking for specific families of technology. More information on how this matrix was formulated is presented in EDGAR Deliverable 2.2.

Step C – NRA selects indicators to evaluate from the basket of indicators and specifies the assessment methodologies
A basket of eleven indicators (table 2) has been arrived at through evaluation of a wide range of environmental and socio-economic indicators in the context of bituminous mixtures and through the process of normalisation, as described in chapter 3 of this final report and in EDGAR Deliverable 2.2. 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 concerns identified in Step B, NRAs will select the indicators that they would like to be measured or assessed. 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 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 an 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 production if the technology is targeted at a process improvement. This will give a point of reference on which to base relative comparisons or rankings.

Step E – Decision making support
Having been provided with the results, the NRA can insert the results into the MADM based decision support framework that is described in more detail in chapter 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.

This process can be iteratively repeated whenever new or better data become available (e.g. through trial sections), to increase evidence and consequently gain confidence in the decisions made.

4.2 Assessment of the basket of indicators

Methodologies were reviewed in relation to each indicator and a recommendation of which to use was made. 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). Some recommended methodologies are presented in Table 3. For more information on these methods and tools and for further references, the reader is referred to deliverable D2.2.

It is worthwhile to note the wide variety of possible tools and the fact that the selection will finally depend on the common practice of each NRA and on their possibilities. For instance, if there have already been some trial sections, a Close-proximity measurement on site is preferential to a laboratory test to evaluate the noise reduction potential.

Table 3: Some recommended methodologies/tools for assessment

Indicator	Recommended methodology or tool	Output format
Global warming potential	AsPECT v4.0 (cradle-to - gate)	$kgCO_{2e}$ per tonne of asphalt
	MIRAVEC (in use phase impacts)	CO_2 in tonnes
Depletion of resources	(Guinée & Van Oers, 2002)	Abiotic depletion per tonne of asphalt
Air pollution (including photochemical oxidant formation and acidification)	ECORCE v2.0 or PaLATE	Emissions per tonne of asphalt
Leaching	CEN/TS 16637 leaching tests and USEtox 2.0 potentials (Rosenbaum et al, 2011)	Human toxicity potential (cases/tonne asphalt)
Noise	Laboratory drum methods or Close-proximity (CPX) or Statistical pass-by (SPB)	dB
Recyclability	EDGAR bespoke methodology	Score between 0-100 %
Skid resistance	Pendulum test (lab) or SCRIM (on site)	Tool dependent
Responsible sourcing	BES 6001	Points system
Financial cost	Cost model developed in EARN project	€/tonne asphalt
Traffic congestion	QUADRO	€/tonne asphalt
Performance (durability)	Resistance to fatigue	ε_6 microstrain
	Resistance to rutting	mm or µm/cycle or %
	Water sensitivity (ITSR)	%
	Stiffness	GPa

4.3 Decision making support

A decision support methodology is required in order to evaluate and compare various alternatives and assist the NRAs in the decision making process. For the purpose of EDGAR, a multi-attribute decision making (MADM) method has been developed, based on the work carried out by Bueche (Bueche, 2011).

The input to the MADM process consists of the data generated for each selected criterion, this for the different alternatives (*i.e.* assessment of the basket of indicators previously discussed). These various data form the so-called “input matrix”. Note that the completion of the input matrix can be time consuming and quite difficult and this should not be neglected. However, it is not compulsory to provide data for each alternative and criterion, this because some MADM methods can consider missing data in the evaluation by increasing the “unknown component” in the final alternatives ranking. In this phase, it is especially important to make a distinction between qualitative and quantitative criteria, but also to clearly identify the boundaries for the evaluation of each specific criterion.

The input matrix is then fed into the decision making process, leading to an evaluation and a ranking of the various alternatives. The decision making process has been developed as a four-level process, in which each level provides its own contribution in the decision process with also an increase in the complexity in function of the level considered. Multi-attribute Decision Making (MADM) methodologies are introduced only in the third and fourth levels, with the introduction of user preferences and qualitative criteria. Existing MADM methods applied in other domains were selected for implementation in the specific context of asphalt mixture evaluation. The application of MADM also permits to perform a sensitivity analysis of the ranking and include some probabilistic aspects characterizing the confidence in the alternative ranking.   A global overview of the evaluation methodology is proposed in Figure 3, each specific level being detailed below.

1. In the first level, a Pareto representation is used to identify the dominant processes for each criterion over the lifespan of each 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.
2. A first comparison of the alternatives is conducted at the second evaluation level. 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.
3. In the third evaluation 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.
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 also the most complex, but it allows to take into account the uncertainty of a given performance, and data unknown.

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

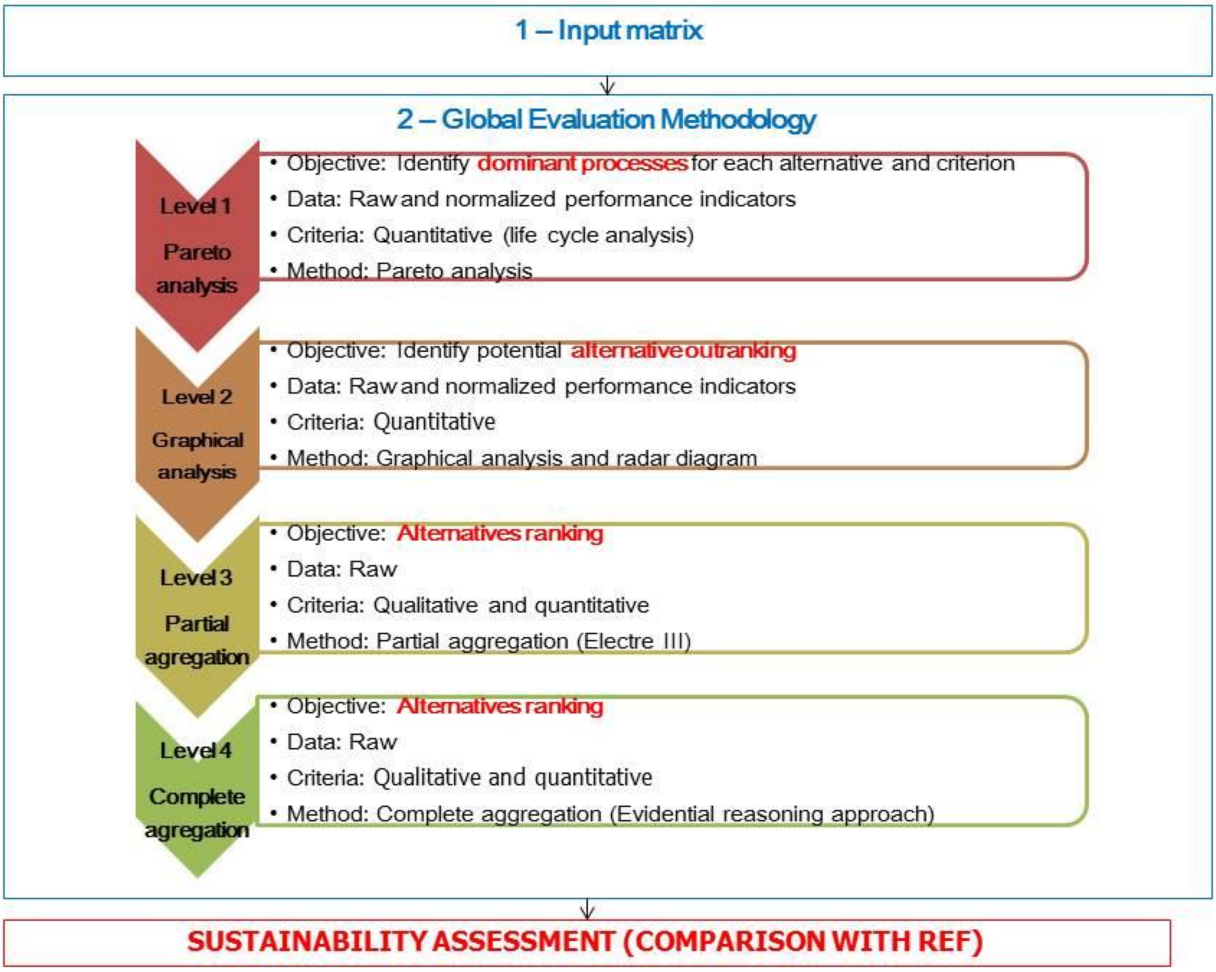

Figure 3: Decision making process followed in EDGAR

5 Demonstration of the methodology

In the final phase of the project, the methodology was demonstrated by a practical case study (deliverable D3.1). Besides demonstrating how the methodology works, deliverable report D3.1 also describes the difficulties encountered to obtain 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. The different solutions evaluated are given in table 4.

Table 4: Overview of the selected test cases

Case	Description
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. The aim of these test sections was to compare WMA sections with a reference HMA section. The sections with HMA and the WMA (using a synthetic wax) were used to provide some of the data and conditions for test cases 1 and 2. The other three cases were not applied on the test sections and therefore, much of the data related to these test cases were collected from literature and other sources. Especially the cold in-place recycling alternative was 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 especially the lack of accurate data on performance characteristics. For more details on the conditions and assumptions regarding the different cases, one is referred to deliverable D3.1.

The solutions were evaluated based on the basket of indicators proposed in chapter 4, section 4.2. The assessment tools used for some of the indicators have been modified or are different from the tools recommended in table 3, in order to facilitate the assessment process. The flexibility of the EDGAR methodology allows to do this, giving each NRA the freedom to use the most appropriate assessment tools in the context of the practical application.

An important step in the evaluation process is the choice of the weighting factors, expressing the importance attributed to each indicator. This choice depends on type of course, traffic intensity, climate,... However, this choice is also partly user dependent. To evaluate this user dependency, every project partner independently defined the set of weighting factors. Fortunately, it was found that there were no large inconsistencies between the partners, and the weighting factors proposed by the four partners were averaged to continue the exercise.

Based on the assessment of the indicators and weighting factors, the different alternatives were evaluated and a ranking was obtained. Subsequent sensitivity analysis evaluated the stability of the ranking obtained.

The most important conclusions drawn from this exercise are the following:

- The Excel-based software tool allows the user to perform the evaluation and thereby gain appraisal of the impact of the various indicators. There are four different levels in the analysis. The first two levels can give some interesting information before progressing to a more in-depth analysis in levels 3 and 4. Only levels 3 and 4 can make a ranking of alternative solutions.
- It is not a simple task to find accurate data for all indicators. This is a finding in common with any type of sustainability assessment tool. Without correct and accurate input data, you can't expect to obtain accurate output. Even though the EDGAR methodology strived to a small number of indicators, it was still time consuming to collect the input data. Within the short time scope of this project, there was not enough time to go sufficiently far in search of literature and other data sources. However, for the purpose of this report, the quality of the input data is of less importance, since the purpose was mainly to demonstrate and evaluate the methodology.
- Some of the indicators, such as responsible sourcing or skid resistance, did not play a role in the ranking of the alternatives. That is because the case study considered here is such that there is no or little variation in these indicators from one alternative to the other. However, this doesn't mean that these indicators are not important for sustainability analyses. For example, if two solutions would be provided by two different companies, one of which is very much concerned with responsible sourcing while the other is not, the indicator 'responsible sourcing' should be able to make a difference.
- A tool like this MADM tool shall be considered as a decision aid, not as an absolute solution. The user 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 cold in-place recycling solution ranked as the best solution. However, it is known that CIR as such is rarely used, due to its high sensitivity to surface ravelling. In practice, a CIR course is always protected by a slurry seal or a thin surface course to prevent this type of damage, even on a road with relatively low traffic volume. Hence, it was not correct to consider CIR as a viable alternative, without also counting the impact of the protective overlay. If the user is aware of this, he will be able to understand that CIR without a protective overlay gets a high ranking, because ravelling resistance is not considered as a performance indicator.
- The test cases have shown that for some indicators, such as GWP and air pollution, the use stage has an overwhelming contribution. In this study, the contribution from traffic in the use stage was not considered, simply because it would mask the differences between the alternatives in the other stages. However, this emphasizes that an NRA should also 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. In other words, the solution is expected to be sufficiently stable. Therefore, sensitivity analyses are needed to check the stability or robustness of the ranking solution.

Application of the methodology to this test case also highlighted potential ways of improvement:

- The performance indicator shall be refined, in order to better characterize the overall performance. For example, this indicator should also cover the resistance to ravelling, a very important performance characteristic for surface courses. The work done in the ongoing CEDR project DRaT (Development of the Ravelling Test), may contribute to this improvement.
- Using lifetime prediction could be a viable alternative to the evaluation of the performance indicator, provided the lifetime prediction is sufficiently accurate. Such a lifetime prediction will of course be based on the performance characteristics of the asphalt. A further improvement could then be provided by using the outcome of the CEDR project CONSISTEND, which also allows to assess the effects of construction quality on the lifetime.
- Effort should be made to refine the assessment methodologies for indicators that are outweighed by 'in use' impacts, to isolate the specific material-related contributions to the overall impact score. The justification for this would be that material choice can only influence a small fraction of overall in-use exhaust emissions. The other major contributors to overall exhaust emissions, such as the vehicle and tyre characteristics, road profile and roughness, are defined by external factors and therefore should not be included in a material-based assessment.
- The sensitivity analysis may become a very extensive and time consuming work. It is impossible to change all the parameters in all possible degrees. Guidelines on how to perform such an analysis in the most efficient way may be of help to the user.
- The user friendliness, quality of graphs and interactivity of the tool can be improved, but this goes beyond the scope of the present project which only aimed to develop and demonstrate the methodology.

It is important to emphasize that the principal aim of this case study was to demonstrate and evaluate the methodology and not to make an exact or general assessment of the different alternative solutions. Much of the input data used was based on very little evidence, because time constraints did not allow the project team to go further and find more accurate data. Consequently, the final ranking obtained shall not be generalized, as it depends on the input data which are in some cases not very accurate. Secondly, the ranking depends on the practical application (distance plant-work site, type of plant, traffic, …).

As a final remark it has to be mentioned that 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.

6 Perspectives and implementation

The EDGAR project set out a methodology and developed a tool to demonstrate the methodology. It is recognized that this tool is not a finished product, but provides a good base for improvements and further developments

The most important ideas of the project team for further developments of the methodology are:

- Performance shall be described more accurately. In this project, performance was characterized by rutting resistance, water sensitivity and fatigue (the last one being less relevant for 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 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 in turn depends on performance characteristics, construction quality, evolution of traffic, climate change, …). A lot of work is being done in this area to improve and refine such models. For example, the tool developed in the CONSISTEND project uses data related to construction quality in order to improve the life time prediction of an asphalt course.
- 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 methods (only on site tests are meaningful for rolling resistance).
- Using the ‘Considerations matrix’ and baseline data for a standard reference material, would streamline the process. The user can then focus on the assessment of the indicators of concern and default to the reference data for the remaining indicators.
- 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.
- Future work on this methodology should be driven by experience and feedback from the end-users, which are in first instance the NRAs.

7 General conclusions

The EDGAR project focused on the development of a general 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 both transparent and flexible. Transparency is important, since the user shall be able to track the origin of the data used and understand the assumptions used to make a correct interpretation of the outcome. Flexibility means that the user can choose the preferred assessment tools, add other indicators to the basket of indicators or delete indicators with less relevance, and attribute weighting coefficients to each of the indicators.

The 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 sustainability aspects. 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 appropriate tools to quantify or measure these indicators and finally, making a decision with the support of MADM methods.

Use of the methodology and the MADM tool was demonstrated in the final stage of the project with a number of test case.

Such a methodology will allow to enhance 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 towards contractors and the public. Indeed, it can be used to compare different proposals in a tender and helps justifying some decisions and choices made. 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.

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