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Final Programme Report
CEDR Call 2020 Resource Efficiency and Circular Economy

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Call 2020 Resource Efficiency and Circular Economy Final Programme Report

CEDR Contractor Report 2024-02

by

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Executive Summary

This document provides an overview of the CEDR funded projects CERCOM and PROCEEDR, funded as part of CEDR's Transnational Road Research Programme 2020.

The primary outputs of the CERCOM project are first presented, including:

- Best practice guidance on how NRAs can transition from a linear to a circular economy
- The CERCOM Risk Based Analysis Framework (RBAF) and software Tool
- The CERCOM demonstration case studies.

Subsequently, PROCEEDR is introduced and guidance is provided around sustainability policies and recommendations. The PROCEEDR tool is then presented which evaluates the resource efficiency and circularity potential of roadside noise and safety barriers.

The findings from the final programme conference are presented in order to draw conclusions and next step for programme implementation by CEDR NRAs.

Recommendations are then provided to CEDR in the short, medium and long term.

Initially, NRAs are encouraged to implement the CERCOM Circularity Rubric in order to identify transition pathways, as well as to consider application use cases for the PROCEEDR tool.

Subsequently, it is recommended that the CERCOM Risk Based Analysis Framework (RBAF) be implemented at full scale for a construction and maintenance project. This can be supplemented with refinement of the application of the PROCEEDR tool to a real use case.

The final goal for CERCOM implementation is to consider application of the RBAF to the Tender process. Furthermore, consideration of the extension of the PROCEEDR tool to other street furniture would facilitate scalable application of the outcomes of this work programme.

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1 Introduction

This report was written to provide the final outcomes of the CEDR funded projects CERCOM and PROCEEDR, funded as part of CEDR's Transnational Road Research Programme 2020.

1.1 CEDR Call 2020

In November 2020, CEDR published the Transnational Road Research Programme relating to Resource Efficiency (RE) and the Circular Economy (CE). The Programme was funded by National Road Authorities (NRAs) from Denmark, Ireland, Netherlands, Norway, Sweden, Switzerland and the United Kingdom.

The aim of the research programme was to accelerate the transition of the road infrastructure sector in Europe, from linear economy, into resource efficient circular economy. Circular economy will imply profound changes in matters such as organisational and business models, basis for decisions and manufacturing and construction processes. If national road authorities combine efforts and harmonise standards in demand, the construction sector will be enabled to take the necessary steps.

The research programme has the following sub-themes:

A. Measuring and managing performance
   There is a broad interpretation in different sectors of what circular economy means, and many different approaches are used to realise the principles of circular economy. Hence, the research focussed on the specificities of road maintenance, performance of the assets and their supply chain towards the circular economy goals of:

   - Improved environmental performance
   - Secure supply of materials at a reasonable and stable price

   while maintaining the usual standards of safety, availability of service, and durability/longevity.
   The research looked at common grounds for defining circular economy principles and objectives in road maintenance. It looked at ways for NRAs to harmonise the approaches to measuring and managing environmental performance from a resource perspective (e.g. measuring and improving our carbon footprints, reducing our impact on biodiversity) and to demonstrate the (economic) benefits of
   adopting a circular economy approach.
B. Public procurement to foster circular innovation
   Circular economy principles have been established through previous research and a number of guidance documents have been published in recent years. However, the uptake and the development of circular economy principles is still gaining momentum. Procurement practices shall evolve to foster a strong, stable demand for low carbon, resource efficient solutions. Accelerating these changes calls for the widespread development and promotion of methods in public procurement that stimulate innovation towards circular economy objectives. Circular-oriented procurement utilizing these methods would incentivise innovative companies and help them reach proper economies of scale for a wide diffusion of best practices. Therefore, the research focussed on road maintenance as it generates large fluxes of materials for NRAs, where circular economy principles allow for financially and ecologically advantageous solutions already widely used such as high-grade asphalt recycling.
   This research was expected to provide insight into existing solutions to the implementation of procurement towards circular economy in road maintenance, and

how they helped shape the market structure, along the supply chain. The following topics have been addressed:

- Structural or legislative adaptations that are potentially required to achieve circular goals.
- Specific knowledge and expertise that is required to adequately assess the risk and opportunities that implementing innovative solutions presents for each project on a technical level.
- Functional requirements for the supplier to allow enough flexibility to enable the design and implementation of innovative building technologies. This involves organisational innovation in the procurement process, likely towards more dialogue between the procuring agencies and the industry.
- Measuring and adequately rewarding innovation is a challenge; as outlined in the first sub-theme this procurement strategy must build on a robust method for measuring performance, be it between bidders at the procurement stage, or as performance clause for the building stage.

C. Material research for roadside infrastructure

Achieving a circular economy requires minimising demand for primary resources and reutilising resources in high value applications. NRAs need a wider range of material options to choose from to enhance circularity. At the same time, high functional demand and technical performance requirements still need to be met (e.g. safety, acoustic, maintenance, etc.). New options could be bio-based, renewable resources (such as wood or composites with natural fibres) and the use of recycled/recyclable materials. The scope of this research task is on circular solutions for roadside infrastructure (for instance in noise and safety barriers). In doing so, valuable lessons may be learned relevant to other (more critical) objects.

The assessment of the application of such solutions was based on a multi life cycle approach considering cradle-to-cradle impacts, including resource impacts, long-term environmental performance, and end of life.

Important and relevant aspects that have been balanced in the projects are the technical requirements (e.g. safety, performance), durability, maintenance, costs and different functionalities. Next to that, security of supply, and several other new aspects like adaptability, lifespan extension options, high value recycling/re-use options, carbon capture capacity, etc. have been considered as well.

Furthermore, bio-based solutions for applications like safety and noise barriers, bridges and sign poles have been implemented in European countries. However, the number of these applications is limited and quite new to most of the NRAs.

Hence, the solutions suggested above have been explored and provide a better insight by reaching the following objectives:

- Collating data, best practices and assessments of innovative applications, including bio-based, composite and/or recycled materials, for instance in safety and noise barriers;
- (Multi) LCA and LCC assessment for different applications, taking into account the different environmental conditions;
- The likely systemic supply chain issues associated with (procurement of) bio-based and/or recycled materials solutions;

- Limitations of the application of composites with natural fibres, e.g. assumptions on life time and required maintenance.

1.2 CERCOM Project

The CERCOM project was funded by the Transnational Road Research Programme 2020 under sub-themes a. and b. The project was led by RDS with technical input from the International Transport Experts Network (ITEN - UK), The Danish Technological Institute (DTI – Denmark), Delft University of Technology (TUD - Netherlands) and Hello My PA (HMP – UK). The project commenced in September 2021 and finished in August 2023. Chapter 2 outlines the technical outputs of the project.

1.3 PROCEEDR Project

The PROCEEDR project was funded by the Transnational Road Research Programme 2020 under sub-theme c. The project was led by Chalmers University of Technology (CUT) in collaboration with the AIT Austrian Institute of Technology GmbH (AIT – Austria), the European Union Road Federation (ERF – Brussels) and TRL (UK). The project commenced in November 2021 and finished in December 2023. Chapter 3 outlines the technical outputs of the project.

2 CERCOM

2.1 Introduction

The CERCOM project aimed to accelerate the transition of the road infrastructure sector in Europe, from the linear economy, into a resource efficient circular economy (CE). The objective was to establish current practice and understand the enablers and barriers to achieve transformational change, including the identification of gaps to be addressed. This holistic approach enabled stakeholder needs to be fully understood (NRA and supply chain), develop technical solutions and provide resources that NRAs can use to deliver the necessary change. A key element of the project is the development of an innovative Risk Based Analysis Framework (RBAF) and management tool to facilitate a step change in the adoption of resource efficiency (RE) and circularity principles in procurement and multi-lifecycle management by NRAs across Europe. The approach was validated through three case studies covering different applications, demonstrating the data needed and building stakeholder confidence in the outcomes. The project also delivered tools and supporting resources to assist NRAs in unlocking their CE contributions in an integrated way.

In the first instance, the project aimed to develop an inventory of good practice and make recommendations for approaches that can be adopted by NRAs to accelerate their transition to circularity. The project then developed the RBAF and associated software tool. Finally, these tools were demonstrated through three case studies carried out throughout CEDR NRA regions. It should be note that Life-Cycle Analysis (LCA) was a central focus of each of the CERCOM outputs in terms of circularity, and this concept permeates each of the three primary project outputs as described below.

2.2 Linear to Circular Economy

In order to develop a roadmap for NRA implementation of circularity, CERCOM in the first instance required a definition of RE and CE. Based on previous research, it was found that attempts to address a scope that is too broad are unlikely to be successful since the data to support measurement of performance or assessment of the circularity of different maintenance options is unlikely to be available. Furthermore, National Road Administrations will differ in the extent to which they have already implemented circularity principles and in their rate of development. For these reasons, the following definition was used in CERCOM:

Circular Economy and Resource Efficiency for Road Maintenance means, by design:

- ***Minimising consumption of natural resources***
- ***Designing out waste and keeping resources in use at their highest level of utility***
- ***Optimising the value obtained within each lifecycle***
- ***Improving environmental performance and contributing to societal development***

Whilst the definition of circularity is an important guiding principle, it needs to be translated into practical actions for organisations to embed circular economy principles into their operations. The Framework shown in Figure 1 shows how, at an operational level, material requirements can be assessed, and available resources considered to meet the functional and structural requirements set. The available resources are evaluated against a risk framework with associated metrics. Finally, overall performance is measured, and improvement opportunities identified.

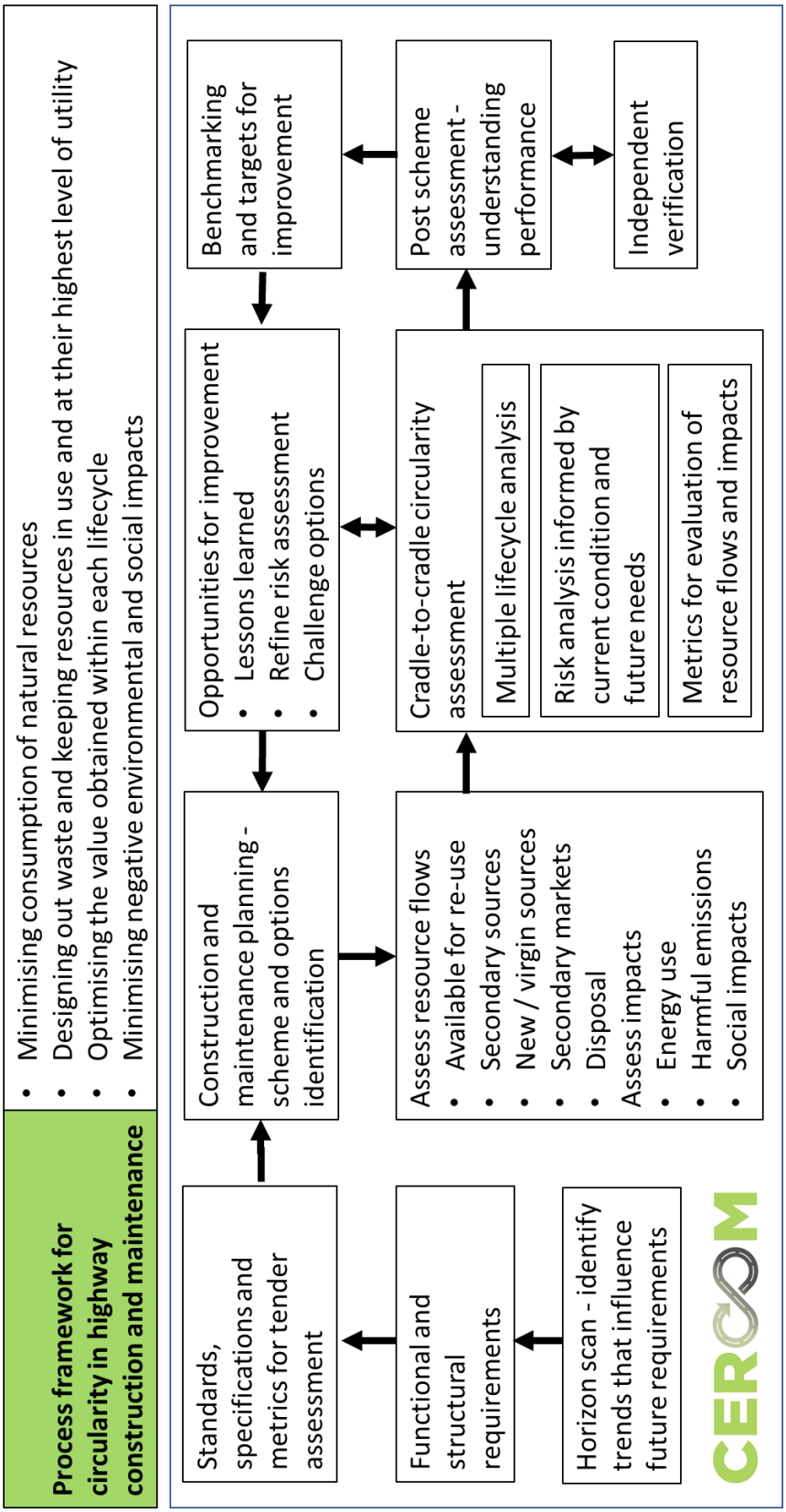

Figure 1 Flow Chart for RECE Framework

CERCOM partners carried out an analysis of current practice internationally as well as a horizon scan, together with extensive NRA engagement through interviews and questionnaires in relation to circularity in order to develop an inventory of good practice when transitioning from a linear to a circular economy. Below is a summary of the identified good practice and recommendations for NRAs to consider during the transition towards becoming more resource efficient and to embed circular economy principles within their organisations.

Good Practice

Define CE
Defining CE to meet National requirements & resonates with the organisation's Goals & objectives, e.g. NH (UK) experience.

- Minimising demand for primary resources and maximising the reuse of resources already in use on the network in as high a value application as is possible;
- Working with suppliers to find new ways to deliver a more resilient and adaptable network
- Achieving security of supply through collaborative working with stakeholders, enabling investment in innovative approaches, securing long-term partnerships; and
- Considering the potential for a natural capital approach to capture the value of land holding

Trial approaches
Enabling transition to CE in maintenance schemes, through trials, feasibility studies, lessons learnt & knowledge transfer, e.g.: National Highways (UK) **'Pathfinder'** projects:

- To support project level CE thinking
- A14 Cambridge to Huntingdon was NH's 1st Pathfinder project
- CE opportunities for A14, but more importantly, for future projects were identified and collated
- Lessons learnt from A14 provided significant input and support success factors to integrate CE thinking into A303 scheme

Start with the end in mind
Embed 'end of life' options at bidding stage of schemes, e.g., RWS A12 scheme:

- Tenders had to include proposals for use/reuse of materials at end of first life and tender evaluation was designed to value the options
- 17-year contract with the supplier to ensure delivery of high-value reuse of resources

Set strict environmental targets
There are examples of environmental targets being set in schemes at the outset. For example, Statens Vegvesen in Norway has stringent emissions targets:

- They mandate that emissions from construction, operations and maintenance and own activities should be cut by 50% by 2030, there should be a 50% cut in emissions on construction sites by 2030 and zero emissions by 2050.
- There are emissions budgets and greenhouse gas accounting for all projects above NOK 51 million and all projects over NOK 200 million must have CEEQUAL

certification. A CO_2 budget is agreed for all new projects, covering multiple phases (pre stages, during planning and prebuild etc). There is a bonus / penalty system around reaching targets for CO_2e emissions.
- There are waste reduction targets on a scheme basis and targets for 100% reuse from maintenance activities.

In Switzerland, there is a requirement to justify any material that is not reused, providing project managers with tools as to how strategies can be incorporated. Whilst most Cantons specify the maximum amount of recycled content, one canton gives a minimum percentage and assesses the amount of recycling and transport distance.

Change standards to allow innovative and circular approaches

A compendium of regulations is published by the Danish Road Directorate, covering most materials, and dictates, what requirements the individual materials must meet during construction. This results in the compendium's requirements for circularity being what is mostly followed.

In 2012, the general work specification for hot-mix asphalt was updated regarding recycled asphalt. Previously the work specification allowed 30% recycled asphalt in wearing course, which was limited to 15% for open-graded and kept at 30% for closed-graded. This was a setback for circular usage of materials. Besides the option of being used in limited amount in wearing courses, asphalt could be used as an unbound material in a lower part of the road structure. Using asphalt in a lower part of the structure would generally result in a downcycling of the material.

In 2020, the Construction Product Regulation changed the regulations from prescriptive based to performance based, completely removing the limitations on the extent of recycling in hot-mixed asphalt. This was confirmed in the most recent publication, in December 2021.

Performance based specifications in general are likely to be a requirement to enabling greater CE and RE, especially considering the requirement for materials to be used over multiple lifecycles. Moreover, performance-based standards give freedom to innovation in material production and use.

Recommendations

Based on the above, the following key recommendations are made:

1. Define CE and RE for your organisation in the context of national targets and organisational priorities.
2. Communicate CE and RE ambition throughout organisations with CERE champions
3. Set CE & RE targets and communicate them throughout the organisation.
4. Define where you are on maturity matrix to enable strategies to be developed to make progress in each of the areas, and to monitor progress being made against targets.
5. Enter into long term agreements with contractors, considering end of first life at outset (e.g., A12 NL)
6. Develop pathfinder projects on various schemes to see how embedding CE and RE works in practice and to bring lessons learned to future projects.

7. Share data with contractors to improve resource use and to develop innovative solutions.
8. Develop performance-based standards and specifications to remove barriers to greater resource efficiency.
9. Consider business models that account for overall value rather than solely, initial cost.

2.3 Risk Based Analysis Framework

One of the key outputs of the CERCOM project was the delivery of the CERCOM Risk Based Analysis Framework (RBAF), and associated software tool, which will be discussed here.

The aim of the CERCOM framework is to build on risk-based methodologies and previous projects to facilitate procurement of circular solutions for road construction and maintenance. The steps involved in the generation of the RBAF are outlined in Figure 2.

Figure 2 CERCOM Risk-Based Analysis Framework

There are 5 steps within the risk assessment framework, as follows:

- **Establish context** - Includes the primary goals of the assessment, the hazards involved, the potential actions to reduce risk, the consequences to be considered and how the hazards and consequences will be calculated, identifying the specific spatial and temporal boundaries of the assessment in question.
- **Evaluate likelihoods** - Includes details on likelihood of a "failure" event (Pf) or the probability of exceedance of a given damage state for given scenarios of hazard and action.
- **Evaluate consequences** – Includes direct and/or indirect consequences/costs associated a with failure event (Adey et al., 2003).
- **Establish additional KPIs** – Involves quantification of RE&CE, Cost, Environment and Social KPIs.
- **Optimize** – Involves optimization of various assessment criteria and KPIs.

For each potential construction or maintenance option, the risk associated with this strategy is calculated (Risk = Pf x Consequences of failure event). Within the RBAF, consequences are taken as the costs associated with a failure event (e.g., the direct and/or indirect costs associated with emergency resurfacing due to premature loss of skid resistance). Any number / type of consequence may be considered in this regard and the process should ideally consider the full range of potential outcomes. For each potential action, the risk associated with each strategy is calculated and used to generate the Risk Reduction Index (RRI), outlined in Eq. (1):

$$RRI_i = \frac{R - R_i}{R} \quad (1)$$

where R = Risk associated with the "Do Nothing" option and R_i = Risk associated with maintenance / construction option i. The *RRI* is then used within the optimization step. "Do Nothing" is considered for the evaluation of risk to establish a baseline scenario. It is a hypothetical case rather than a viable maintenance option. The purpose is to evaluate the risk of carrying out minimal or no maintenance over the reference period, providing a means to quantify the reduction in risk associated with carrying out various maintenance options.

The CERCOM RBAF also integrates circularity factors into procurement practices. However, when considering procurement, it is necessary to also consider more traditional criteria. As such, the RBAF was developed to take account of all these factors. The CERCOM framework considers technical, economic, environmental and social criteria, as well as RE / CE, to assess the change in risks in moving from a linear to a circular economy, as outlined in Figure 3. The framework is applicable to all road infrastructure elements under the maintenance remit (e.g., road pavements, bridges, retaining walls, cuttings and embankments and roadside infrastructure).

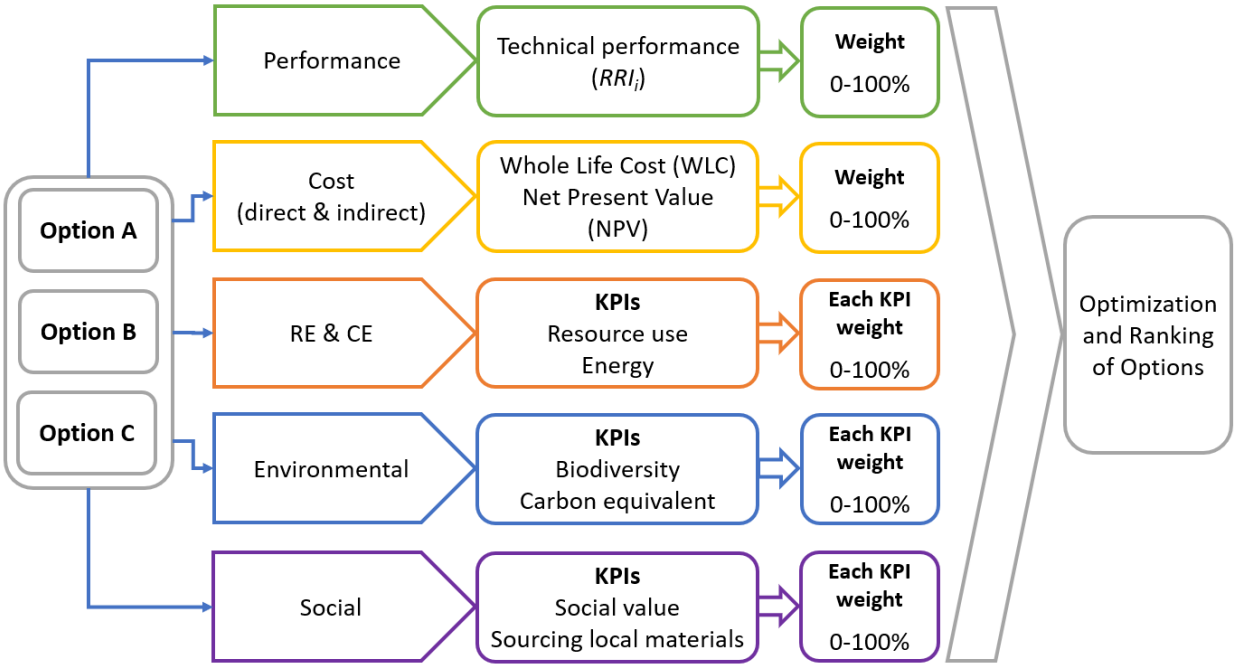

Figure 3 CERCOM Categories for assessment criteria and KPIs

A weighted sum, the Net Risk Reduction Gain ($NRRG$) is incorporated into the CERCOM framework to allow scoring of various criteria to be considered and integrated into a single index for optimization purposes to rank various construction or maintenance solutions.

As with any tender evaluation, weight factors provided by the user are used to quantify priorities of each NRA for a specific project/scheme. The $NRRG$ is used to score the various potential maintenance strategies, amalgamating performance, cost, RE&CE, environmental and social factors using a weighted sum.

2.3.1 Software tool

The objective of the RBAF Software Tool is to provide a user-friendly excel based tool to facilitate the procurement of RE&CE construction and maintenance options, while also considering costs, as well as the performance risk associated with more innovative methods/materials. The tool caters for the level of maturity of the NRA by allowing single or multiple entries of KPI under each category, and user defined numerical inputs or pre-set values to be selected for each criteria/KPI and each construction/maintenance option considered. This section contains a short overview of how the software tool is used in practice. Links to the various resources are provided at the end of the section.

Firstly, for the Performance Category and the calculation of risk, the value of failure probability (Pf) must be a value between 0 and 1.0. Depending on the level of maturity, availability of sufficient data or expertise for the calculation of failure probability, the user has the option to input values directly (calculated using methods such as statistical analysis and/or probabilistic modelling) or use a pre-set scale. For options where the user selects to use the pre-set scale, two inputs are required and are selected by the user from a drop-down menu. One parameter relates to the performance characteristics of the construction/ maintenance option and the other is related to the level of uncertainty the user has in relation to the performance characteristics. This allows the user to account for uncertainty around the use of new or less proven materials or construction and production technologies. The selection is based on expert judgment or empirical data. For performance the available options for selection are:

- Below average
- Average
- Above Average

For uncertainty the available options for selection are:

- Low
- Medium
- High

The two user inputs from the pre-set scale reference a matrix of values for the determination of the Pf value. Pre-set Pf values are approximate to give an indication of relative performance for a comparative analysis and should not be taken as absolute values for safety. It is important to note that all options must meet minimum safety standards outlined in the relevant design codes.

The developed additional KPIs ensure that contractors can be rewarded for producing a scheme that will be long lasting, cost effective to maintain, use limited amounts of raw materials, designed for multiple lifecycles and/or can be readily repaired for (multi) life extension.

A system of ranked interpolation is used to quantify KPIs. The first rank for each KPI is assigned a value of 0.0, and the final rank is assigned a value of 1.0. In the simplest case, a linear relationship is assumed between the first and final rank. Where a more subtle response is required, a multi-linear relationship may be determined between different KPI ranks. Ideally, KPIs should relate to existing targets and practices already defined by the overseeing NRA. For example, an NRA with a target to use more recycled content in maintenance schemes may already define different “levels” or ranks of achievement of this goal. These “levels” can be related to KPI values and ranks for quantifying KPIs for potential schemes.

KPIs are utilized within the calculation of NRRG to integrate critical RE&CE, environmental and social factors. To calculate the additional KPIs, the user can input data directly to calculate KPIs or select pre-set KPI values from a drop-down menu. Within the tool, the KPI pre-set options are a range of values between 0 and 1 and are not KPI specific. The goal is to provide a broad range of values with generic descriptions to enable the user to provide an indication of the value of one scheme option over the other based on user experience, where more specific data to quantify these values is not available. Table 1 outlines the pre-set options available with an example of what these values could represent for an RE/CE KPI (Recycled Content of Solution).

Table 1. Pre-set KPI values with CE example

KPI Value	Description	Recycled Content Example
0	*No commitment to KPI ambition*	*No recycled content*
0.1	*Below minimum industry practice*	*5% recycled content*
0.25	*Minimum industry practice*	*10% recycled content*
0.5	*Exceed industry practice*	*40% recycled content*
0.75	*Far-exceeds industry practice*	*70% recycled content*
1	*KPI ambition achieved*	*100% recycled content*

If Numerical Input is selected for any of the scheme options, then input is required to carry out ranked interpolation to calculate the KPI value. The number of ranks, the unit of measurement for the data considered, the least favourable and most favourable threshold values must be entered, as well as a data value for each proposed construction/maintenance scheme option. When 2 ranks are chosen, a KPI value of 0.0 is assigned to the least favourable rank and a KPI value of 1.0 is assigned to the most favourable rank. A value for each scheme option is entered between these thresholds and linear interpolation is carried out to determine the KPI value. It is possible to select up to 4 ranks and use multi-linear interpolation, with a different slope between each rank. In this case, numerical values must be entered to quantify each rank using a data input value and a corresponding KPI value between 0 and 1, as illustrated in Figure 4. This figure also highlights how the analysis may change depending on the availability of data to quantify the relationship between measurements and KPI values.

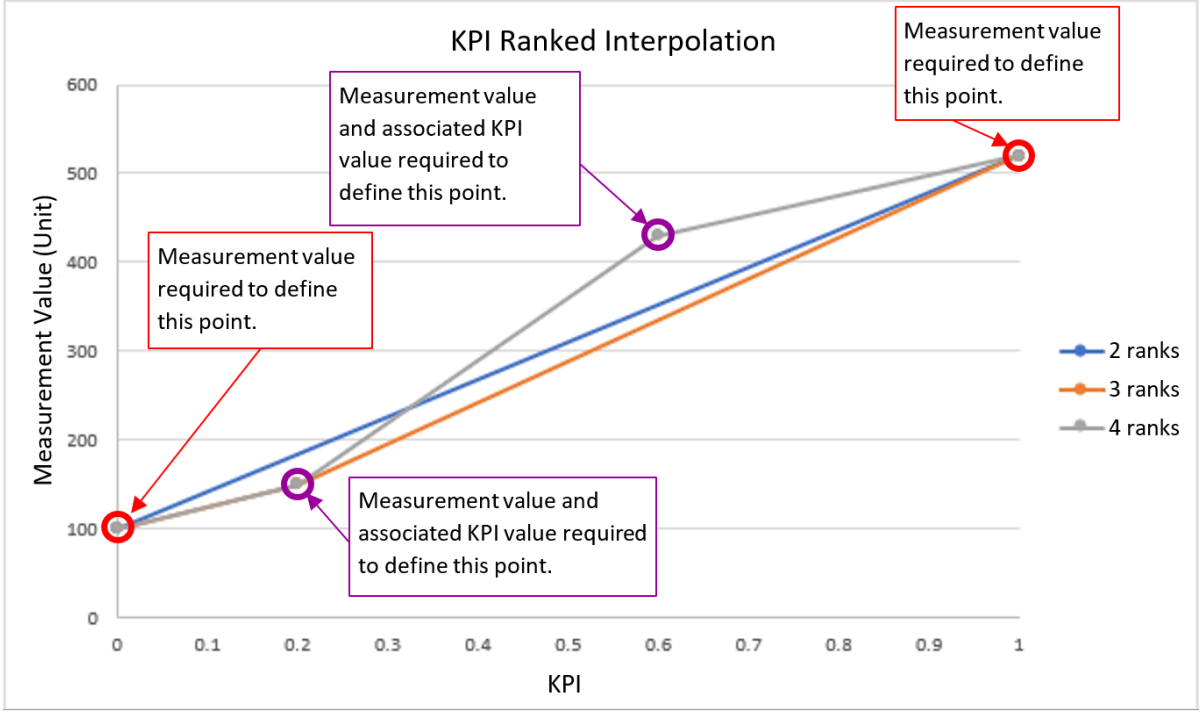

Figure 4 CERCOM Ranked interpolation method

Unlike in Figure 4, in some cases, the graph will have a negative slope depending on the characteristics of the KPI considered. For example, for carbon cost, a higher value of carbon will be least favourable (KPI of 0), and a lower value will be assigned to the most favourable rank (KPI of 1.0), leading to a graph with a negative slope. A KPI relating to recycled content, however, will have a positive slope.

Given the maturity level of most NRAs and limited data currently available for various criteria, it is likely that two ranks will be sufficient in the short term to represent KPI relationships. However, over time as more data is collected, the more advanced options using 3 or 4 ranks may be utilized to more accurately reflect required response of KPIs to measured criteria.

A weight must be applied to each Criteria or KPI defined within the software tool. Different weights can be assigned for each maintenance option, but it is recommended that the same weights are used for each option for a meaningful, comparable output result. The sum of the weights for each option must equal to 1.0, otherwise an error will be displayed and results will not be presented.

The software tool calculates the weighted sum of the Criteria/KPI for each option and generates the NRRG. The construction/ maintenance options with the highest $NRRG$ value is considered the most advantageous option. The results are presented in the form of a graph and a table illustrating the contribution of each weighted criteria/KPI to the overall value of $NRRG$.

The software tool and user manual can be downloaded in the resources section of the CERCOM website below:

https://cercom.project.cedr.eu/resources/

2.3.2 Integration into Procurement Practices

For CERCOM, the objective is to incorporate the RBAF into existing public procurement processes, introducing the quantification of RE & CE KPIs in the consideration of construction and maintenance strategies and life cycle analysis. Typical procurement processes outlined in the Office of Government Procurement Public Procurement Guidelines for Goods and Services[1] and European Commission's Public Procurement Guidance for Practitioners[2] were reviewed. On this basis, it is envisaged that the RBAF tool be used primarily by NRAs as part of the preparation phase and the pre-tendering phase as an iterative process, whilst also informing the development of tender documents as part of the tendering procedure phase, as illustrated in Figure 5.

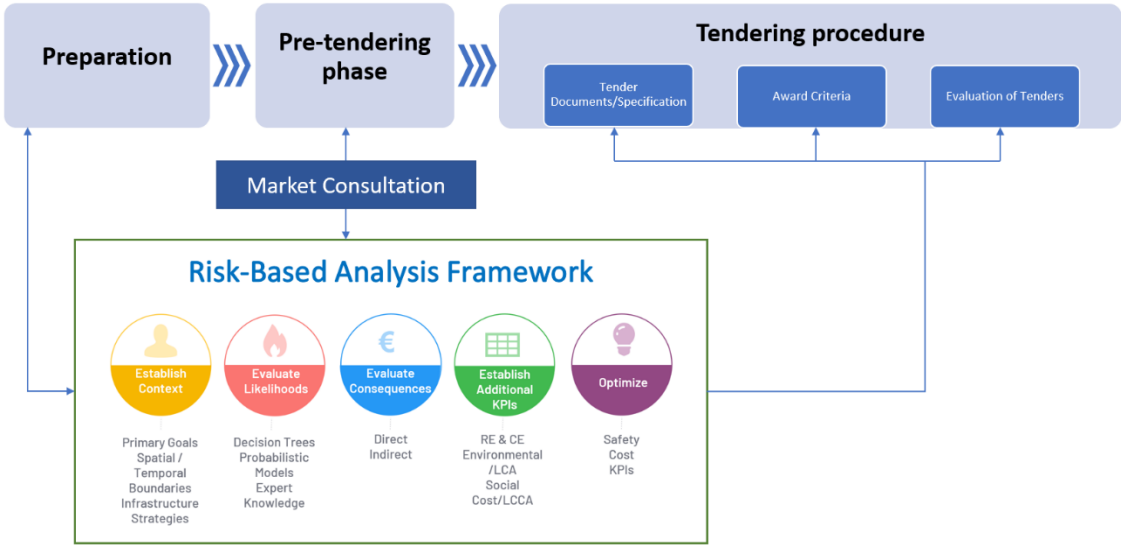

Figure 5 Integration of CERCOM RBAF into Existing Procurement Practices

2.3.3 Integration of Existing Tools and Policies

The Netherlands was the first European country to formalise the process for sustainable procurement, with the Dutch Government establishing clear goals as early as 2005 and embedding this further into their procurement processes. Rijkswaterstaat (the Department of Public Works of the Ministry of Infrastructure and the Environment) developed a methodology for infrastructure projects where the functional specification of the tender together with the quality input from the client ensure an innovative and high-quality solution. The criteria that formed the basis of assessing the sustainability attributes of tenders were CO2 emissions and environmental impact. To facilitate this, the following two tools were developed to measure CO2 emissions and environmental impacts, and are now mandated to be used by all tenderers:

[1] OGP, (2019), Public Procurement Guidelines for Goods and Services, Office of Government Procurement, Ireland.

[2] EC, (2018), 2018. Public Procurement Guidance for Practitioners, European Commission.

- The CO2 performance ladder – a certification system with which a tenderer can show the measures to be taken to limit CO2 emissions within the company and in projects, as well as elsewhere in the supply chain.
- DuboCalc – a life-cycle analysis (LCA) based tool which calculates the sustainability value of a specific design based on the materials to be used. Bidders use DuboCalc to compare different design options for their submissions. The DuboCalc score of the preferred design is submitted with the tender price.

In 2022, Transport Infrastructure Ireland (TII) published a guidance document on the use of the TII Carbon tool which was developed to assess the main sources of carbon emissions throughout the lifecycle of a project, from design, construction, maintenance, operation and end of life[3]. The goal is to align with best practice and enable industry to identify and quantify where potential carbon savings can be made. The tool can be utilised by industry partners to quantify both embodied and operational carbon related to transport and infrastructure schemes in Ireland[4].

In 2015 the Swedish Transport Administration made their climate calculation tool mandatory for all investment projects larger than €5 million, together with climate requirements on carbon reductions in line with national goals.

One advantage of the CERCOM RBAF is the ability to integrate the results of these tools into the developed framework and build on advances already made in the move towards more circular sustainable options.

2.4 Case Studies

CERCOM carried out three case studies to demonstrate the approach of the project outputs. Case studies I and II demonstrate the approach to quantification of circularity for different road construction / maintenance options, while case study III illustrates a strategic approach to CE development, demonstrating how the findings presented in section 2.2 can be implemented in practice.

2.4.1 Case Study I: Asphalt technologies

In this case study, two pavement alternatives were initially assessed, namely, in-situ rejuvenation and resurfacing were investigated under various assessment categories. Rejuvenation is a preventive maintenance technique that involves spraying a compound over the existing pavement surface wearing course layer to extend its service life. Extending the lifetime increases the overall sustainability of the road network by keeping the materials in use for longer periods, minimizing the energy consumed and decreasing traffic disruption due to maintenance operations. In this case study, resurfacing involved milling the existing surface layer and inlaying the layer with virgin raw materials.

The case study highlighted all steps involved integration of the performance metrics computed for various assessment categories into the RBAF software toolkit. The foremost requirement

[3] Transport Infrastructure Ireland Carbon Tool for Road and Light Rail Projects: User Guidance Document, GE-ENV-01106, December 2022. Available at GE-ENV-01106 (tiipublications.ie)

[4] TII Climate Action Roadmap, December 2022. Available at: TII Climate Action Roadmap

of the software was to input the generic information such as analysis period, road length, and proposed maintenance schemes. Next, the input format was defined along with the considered assessment categories. Since the key performance indicators (KPIs) under all assessment categories were numerically computed, 'numerical input' format was chosen. Third, the risk associated with different maintenance options and technical KPIs was entered in the tool in terms of cost of consequences. Note that the probability of occurrence of one or more collisions for the maintenance schemes and do-minimum scenario was 1.0. As such, the differentiation in terms of risk for the alternative maintenance options was dictated by costs associated with failure consequences over the lifetime considered.

The NRRG for rejuvenation was higher than the resurfacing maintenance option. As can be seen in Figure 6, the technical risks associated with the two maintenance options was similar indicative of both technologies being equally efficient in augmenting the skid resistance and alleviating ravelling. Further, the economic and circularity benefits were more pronounced in rejuvenation. The contribution of Net Present Value (NPV) to NRRG in rejuvenation maintenance was significant as it assisted in minimizing the high expenditure associated with typical maintenance option of resurfacing. Though the contribution of CEI to NRRG was high in both the maintenance methods, it was substantial for rejuvenation highlighting the benefit of keeping the asset in place for prolonged periods. Other assessment categories had a relatively lower impact on the two maintenance schemes. Overall, based on the data available, results indicate that preventative maintenance is optimal over the corrective maintenance option of resurfacing.

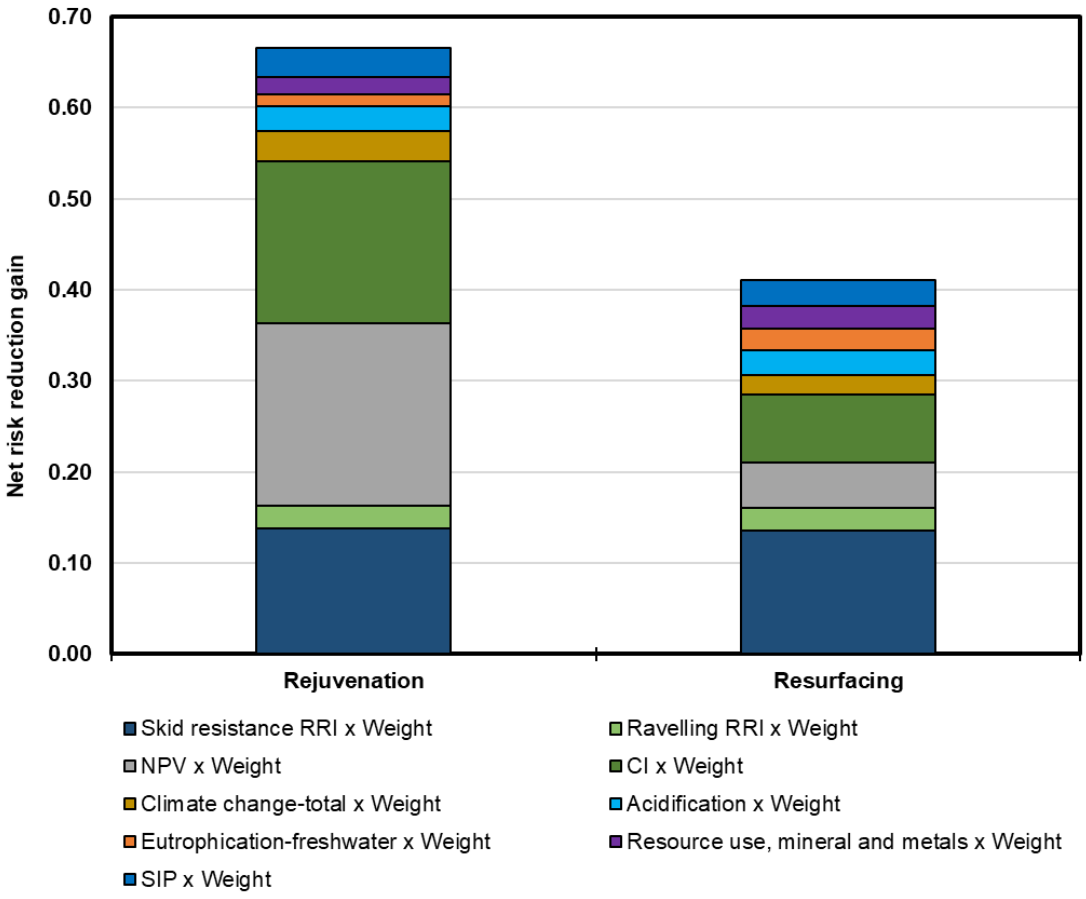

Figure 6 Net Risk Reduction Gain for Porous Asphalt Maintenance Options

A second investigation into asphalt technology considered two pavement maintenance alternatives based on common practice in Denmark. The first scenario is based on the concept of using bituminous stabilized materials (BSM) involving reconstruction of base layer with 100% reclaimed materials extracted from the old pavement and small quantity of foamed bitumen (2.2%). The concept of BSM is being used in Denmark for construction of rural roads by municipalities and private actors. The second maintenance alternative involves patch repair of binder layer followed by resurfacing.

The NRRG for BSM option was 2.5 times higher than the patch repair and resurfacing maintenance option. As can be seen in Figure 7, the contribution of NPV to NRRG was more pronounced in BSM option as it assisted in minimizing the high expenditure associated with typical maintenance option of patch repair and resurfacing. Another major contributor to the NRRG in BSM option was MCI. However, the contribution of MCI to patch repair and resurfacing was nil attributed to its zero MCI. Though the contribution of environmental KPIs to NRRG was high in both the maintenance methods, it was substantial for BSM option highlighting the benefit of minimizing the frequency of maintenance methods. Overall, it may be suggested that the risks associated with BSM maintenance was much lower than the typical patch repair and resurfacing.

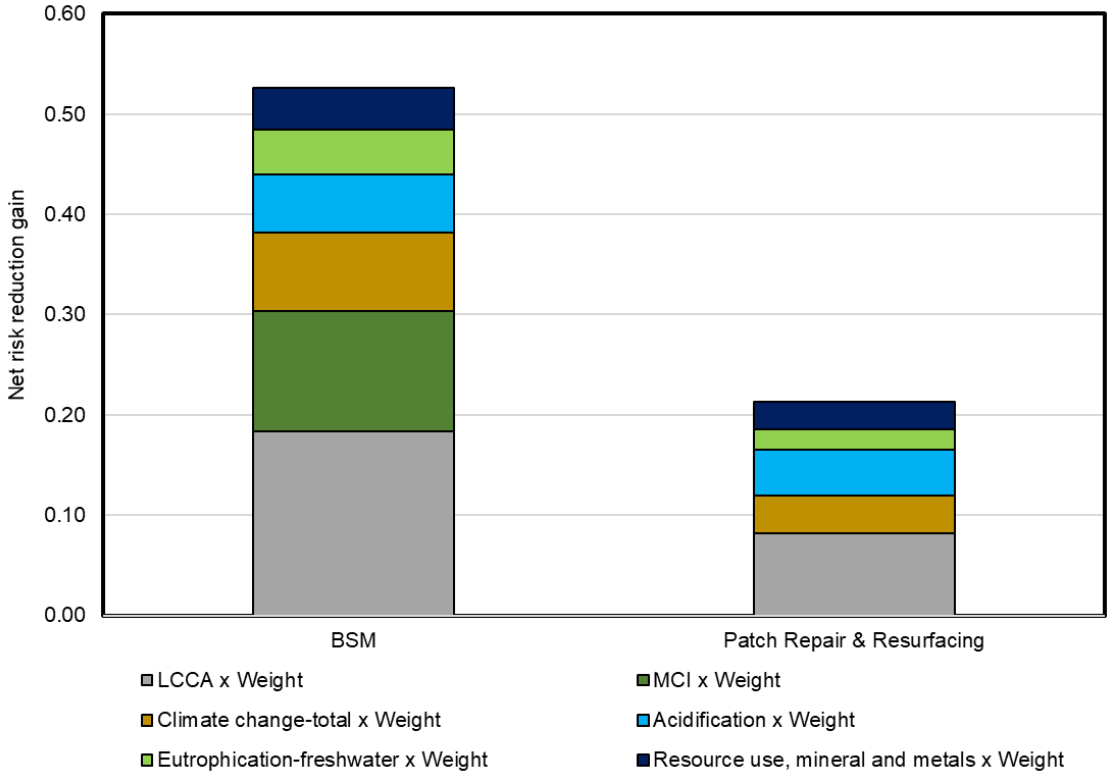

Figure 7 Net Risk Reduction Gain for Bitumen Stabilized Materials and Patch Repair and Resurfacing Pavement Maintenance Options

2.4.2 Case Study II: Concrete Processing technologies

Construction and Demolition Waste (C&DW) is a source of recycled aggregate and in the Netherlands, recycled aggregate production constitutes about 25% of the total aggregate production. However, a majority of the material is downcycled in the base layers of pavements, attributed to the presence of hydrated mortar over their surface, which restricts its application in pavement surface layers and building works. Recent advancements in the processing technologies have allowed production of high grade Recycled Concrete Aggregates (RCA) and the technical risk associated with such technologies by integrating the circularity with economic, environmental, and social performance.

Therefore, the aim of this case study was to analyse and compare two EOL concrete recycling technologies, namely, concrete to cement and aggregates (C2CA) and Stationary Wet Processing (SWP). The NRRG for each maintenance option was identified, which is the weighted sum of KPIs. As can be seen in Figure 8, C2CA recycling technology showed a higher NRRG compared to SWP. Based on the performance models extracted from the literature, the technical performance of the pavements designed with recycled materials from C2CA and SWP technologies had a major contribution to the NRRG. The pavement designed with recycled aggregates derived from C2CA resulted in a lower number of crashes over the design life than SWP attributed to the higher PSV of aggregates, resulting in better SR of the pavement. Additional discussion on the efficacy of models is presented in Appendix D under the section ‘influence of variation in polished stone value on net risk reduction gain’. Further, the value addition from C2CA was higher than SWP ascribed to the greater revenue generation due to the production of high-quality secondary materials. Overall, taking account of available data, it can be suggested that the performance associated with designing a pavement with new generation concrete processing technology (C2CA) was lower than the more conventional method (SWP).

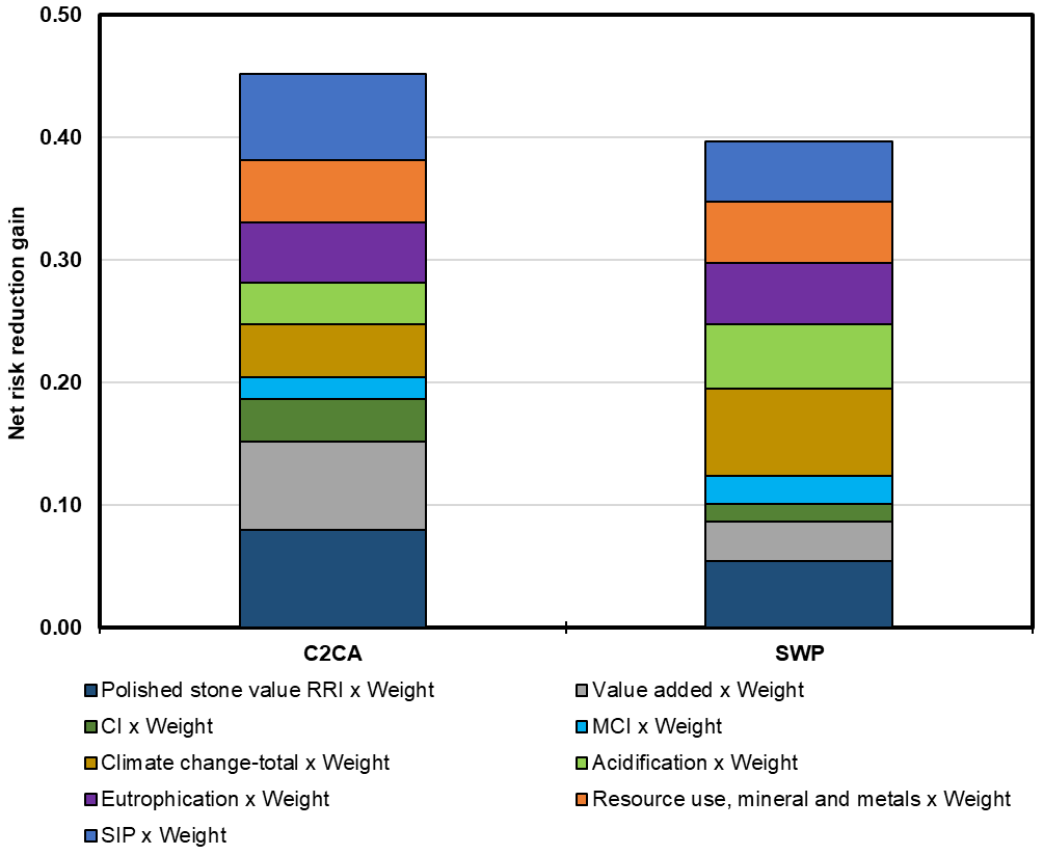

Figure 8 Net Risk Reduction Gain for Concrete Processing Technologies

2.4.3 Case Study III: Strategic Approach to CE

This case study explores the practical implementation of RE and CE principles in the delivery of road infrastructure projects. The objective was to identify strategies adopted by NRAs to embed RE and CE thinking in their organisation and supply chain. The results are presented in two parts: Initially an in-depth investigation of the approach adopted by the UK National Highways (NH) to make CE an integral part of road infrastructure management, followed by a brief description of five initiatives that are in early stages of development from 4 countries (UK, Netherlands, Ireland and Sweden) representing constituent aspects with potential to contribute to CE:

- Initiative 1: Resource exchange mechanism (UK) – (In1)
- Initiative 2: Circular road partner programme (NL) – (In2)
- Initiative 3: Sweating the pavement asset (IE) – (In3)
- Initiative 4: Living document / route map to energy reduction in tunnels (NL) – (In4)
- Initiative 5: Interactive decision support tool for climate action (SE) – (In5)

The case studies confirm the high level of interest and commitment, reported in the earlier review (CERCOM deliverable D2.1) that NRAs have in adopting a CE approach to road construction and maintenance. There is synergy between CE and carbon net zero, and with

national governments committed to binding net zero targets, CE is recognised as fundamental to achieving these targets. There are increasing numbers of examples of the practical steps being taken to embed CE. Different approaches are being taken in the countries investigated, spanning all aspects of organisational maturity:

- CE ambition – defining CE and producing route maps and implementation plans aligned with organisational policy and strategy
- Embedding CE – involving internal and external stakeholders to achieve buy-in to CE aims, raising the profile of on-going trials, and, in general, ensuring greater awareness of the need for and benefits of CE and RE
- Monitoring performance / circularity (KPIs) – NRAs are still in the early stages of understanding and developing appropriate indicators to measure progress to circularity. However, the need for indicators for measuring and monitoring outcomes is recognised and there are examples including measures for constituent elements contributing to CE and RE (amounts of primary and secondary materials used, percentage of waste reduction, etc.).
- Standards – rethinking standards and working to better understand and mitigate barriers resulting from current standards for scheme design, construction and maintenance
- Supply chain – engaging a wider group of stakeholders, including the supply chain, from early in the design process and taking a collaborative approach to developing and delivering innovative solutions
- Business models – exploring mechanisms to move from a linear to CE by recognising the value of designing assets and materials for longer lives, emphasising reuse/recovery/recycling, potentially achieving this through transfer of ownership
- Circular procurement – embedding CE thinking into procurement through better communication between procurement and design/delivery teams, aligning supply chain and client incentives, whole life evaluations etc.

2.5 Conclusions and Further Resources

The CERCOM project provided various outputs to assist in facilitating circular economy uptake by NRAs. These are based primarily around governance / management practices as well as application of a new software tool which quantifies the impact of circular approaches in road construction and maintenance. These outputs were presented in this chapter as well as case studies demonstrating their implementation. As demonstrated in the tables below, all of the expected outputs from the DoRN were achieved.

Sub-theme A of the DoRN for this research theme had the following expected outputs:

Table 2. Sub-theme A of the DoRN and CERCOM achievements

Expected Output	CERCOM Project Output
Framework including principles and definitions, scoping the complex field of resource efficiency and circular economy for specific NRA application, and translating it to performance (indicators)	CERCOM D2.1 deliverable this output as described in section 2.2 of this report
Options for indicator sets, best practices and ways to harmonise the use of these across NRAs and sectors - in the context of barriers and opportunities to driving circular economy	These are delivered within the maturity model rubric in D2.1 of CERCOM and highlighted in this report. Barriers and Opportunities are also dealt with.

development in Europe (e.g. legal framework like EPD)	
Harmonised methods to calculate the proposed indicators - in line with European developing methodology for environmental assessments	Various aspects of KPI quantification are dealt with in CERCOM D2.1, D2.2 and D3.1 (RBAF)
Exploration for developing harmonised data sharing strategies for the (resource) supply chain – between different databases and software tools	This was the main output of CERCOM D2.2 Review of Data Needs, Data Quality and Data Management Systems.
Best practices inventory (top 5) of current systems and their suitability for managing performance towards circular economy.	Best practice from NL, IE, DK, UK and others were identified in D2.1 and developed in Task2.3, considering NRA needs, and informed the RBAF development in D3.1.
Principles translated into scenarios, strategies and (technical) guidelines respectively, with recommendations on the necessary expertise and training (e.g. LCA, WLC16, etc.).	Deliverable D3.1 provided guidelines for performing risk-based analysis. D4.1, 4.2 & 4.3 tested these and WP5 will developed training materials to enable implementation.

Sub-theme B of the DoRN for this research theme had the following expected outputs:

Table 3. Sub-theme B of the DoRN and CERCOM achievements

Expected Output	CERCOM Project Output
Appropriate design standards and specifications;	The literature review and gap analysis of D2.1 considered how well existing standards allow for CE principles and what needs to be done. This was the fleshed out with solutions in WP4 – Case studies.
Innovative public procurement processes	The RBAF was supplemented with a roadmap to implementation which indicated how the KIPs can be used as part of innovative Green Public Procurement processes across the EU
Necessary HR training and personnel expertise	This was identified within D2.1 and further enhanced through the CERCOM training pack.
Assessment criteria and evaluation models of circular performance	This is the main output of the RBAF (D3.1).
Cost-benefit analysis of the circular economy approach – to make better sustainable business decisions	CBA is considered within both the RBAF and the LCA methodology developed (D3.1 & 3.2)
pilot projects targeting one of the points above.	These are presented in section 2.4 above.

Further information on the CERCOM project outputs, including deliverables and video presentations are available in the CERCOM resource pack below:

https://www.cedr.eu/peb-call-2020-resource-efficiency-and-circular-economy

3 PROCEEDR

3.1 Introduction to PROCEEDR

The PROCEEDR project aimed to create a software tool to enable NRAs to identify innovative and sustainable solutions to facilitate the transition **from linear to a circular economy** in the field of roadside infrastructure. Achieving a circular economy requires minimising the demand for primary resources and reutilizing resources in high-value applications. NRAs need a wider range of material options to support the transition from a linear to circular economy. At the same time, critical functional demands and technical performance requirements such as safety, acoustic, structural and maintenance still need to be met. New innovative and sustainable options could be bio-based, use renewable resources (such as wood, reed, loam or composites with natural fibres) or use recycled/recyclable materials. Therefore, the scope of the project is to present an overview of innovative and sustainable solutions in the roadside infrastructure sector, focusing on noise and safety barriers and provide relevant tools to enable the selection of the most suitable and cost-effective solutions.

Noise barriers are a key asset in road infrastructure for this research project because they are made from a large variety of materials and solutions which varies from the most classical options (wood, concrete, wood-fibre concrete or metallic cassettes) to the most innovative ones (cassettes in recycled PVC, sound-absorbing natural fibres, reed, loam, etc.). The assessment of technical performance is based on tests and calculations according to the product standard EN 14388 where acoustic, structural, safety, fire and durability characteristics are considered. Noise barriers also offer the chance to explore innovative solutions for foundation works which are always required for their installation alongside roads. Roughly one-third of the total economic value of the noise barrier is represented by traditional foundation works and alternative solutions, such as ground screws or metallic poles hammered into the ground, can be used instead of concrete kerbs and ground cementation.

Nowadays, the **performance of safety barriers** is assessed according to crash tests of different vehicle types according to the product standard EN 1317-5. Given the high technical constraints to achieve minimum levels of performance required, the use of materials other than steel or concrete has rarely been considered. Timber can be used for safety barriers installed alongside rural roads where lower containment levels are required. Furthermore, for the scope of the present research, considering safety barriers enables us to evaluate the impact of additional materials that could be used for improving the impact of steel or concrete on sustainability. Even a limited improvement achieved by using new materials and/or improving the corresponding industrial processes may lead to a significant impact on the overall sustainability of road infrastructure given the extensive use of safety barriers alongside roads, providing the functional properties are satisfied. Assessing the sustainability of safety barriers must be extended to include the life cycle stages after the production stage.

With reference to noise and safety barriers, special attention should be given to innovative products where **both functions are integrated** and placed on the market as a unique system. These products have more functional constraints as they need to fulfil requirements set for the two individual systems but may perform better overall in terms of sustainability and may provide opportunities to reduce the number of structures on bridges or land use required for installation at ground level. Nowadays, the size and complexity of noise and safety barrier

projects confirms the need to apply the concept of sustainability to these construction activities, as well as to the resources required to produce, install, maintain, monitor and finally, if required, to remove barriers once they have reached the end of their life cycle. This highlights that noise and safety barrier projects require many resources and tend to have a very high impact on the sustainability of the built environment like any other large built structure.

In general, the assessment of the sustainability of noise and safety barrier should be based on an environmental life cycle approach taking into consideration cradle-to-cradle impacts, including resource impacts, transportation, the installation stage, as well as the long-term environmental performance, maintenance, and end of life (also called decommissioning stage). Social aspects should also be considered, for example transparent noise barriers are generally preferred by residents as it helps to minimize the impact of the barrier on the landscape; or some noise barrier materials are preferred over others as they help minimize the heat island effect in the screened zone.

To ensure a holistic life cycle engineering approach, the following issues should be considered: security of supply, adaptability, lifespan extension options, high value recycling/reuse options, carbon capture capacity, and finally overall barrier cost and other economic indicators should be considered. This framework of **technical and functional aspects represents the basis for the further sustainability assessment of a noise or safety barrier** and is based on the calculation and/or measurements of the following parameters: (1) environmental impact, (2) social impact and (3) economic impact.

3.2 Possible Implementation of Sustainability Policies for the main Stakeholders

3.2.1 Identification of the key stakeholders

This section provides a short description and breakdown of the different life cycle stages of noise and safety barriers. When contracting for the supply and installation of noise and safety barriers, as with any road equipment, the following subjects are involved and therefore need to be considered:

1) The **Road Authority** (e.g., NRAs) or the road Manager has the role of setting requirements, procuring installations and maintenance work from contractors as well as preparing the tender specifications, governing the tender procedure, controlling the installation, and maintaining the road equipment during its working life until final dismantling. The Road Authority normally outsources the design activities and the direction of the works.
2) The **Manufacturer** of the road equipment (noise or safety barriers) transforms the raw material into the final product placed on the market: it should be noted that some activities may be subcontracted or in some cases, raw materials may be pre-processed by the **raw material supplier**. Manufacturer and raw material suppliers are in most cases different subjects, therefore separate recommendations are made for manufacturers and raw material suppliers.
3) **Installer or Contractor** is the company in charge of the installation works on or beside the road. This company may have the role of Contractor or may be a subcontractor of the manufacturer depending on the size of the contract, the type of product and the procurement regulations in different countries. The Contractor is the company responsible for undertaking the foundation works, procuring the products, and executing the installation works until the completion of the contract. In some cases, installation activities may be delegated to a specialized company, also known as the Installer.

The following section is intended to provide guidance addressing sustainability topics for the relevant industrial sectors involved in the manufacturing, installation and maintenance of noise and safety barriers. Therefore, **recommendations are given for the following stakeholders: (1) raw material suppliers, (2) manufacturers and (3) installers**. Nevertheless, as the first relevant overarching stakeholder, the role of Road Authorities and/or Road Managers is considered to highlight how they could implement sustainability when dealing with noise and safety barriers.

3.2.2 Role of Road Authorities (NRAs)

When preparing projects for safety and noise barriers, the Road Authority refers to the national legislation that regulates the level of safety required at the roadside for safety barriers or for noise barriers, the maximum acoustic emission limit permitted to impact local residential properties. The projects refer to technical specifications that in some countries are reported in voluntary technical standards[5] which are documents having mandatory or compulsory requirements (ZTV-Lsw[6]). These documents generally concern the specific technical characteristics of the products to ensure durability as well as aspects related to installation and maintenance. Within the European Union, the **European Regulation on Construction Products** (CPR) is a mandatory reference for the evaluation of performance.

In the case of **safety barriers**, an essential aspect is the adherence to the technical and functional requirements that the product must meet to ensure the nationally mandated safety levels for roads. Economic sustainability for safety barriers pertains to selecting interventions that optimize both installation and operational maintenance costs. Through the mechanism of a score-based tender, the Road Authority can reward the use of products that minimize environmental impact. However, it's important to emphasize that this action is effective only through cooperation with the bodies involved in formulating the technical specifications for approved materials for these products (such as steel and its alloys or concrete mix designs). The incentive for improving the production system or construction site logistics has a lesser impact.

The strategy for implementing policies for **noise barriers** is more diverse. Here too, it's important to uphold the functional or technical requirements aimed at achieving noise reduction goals. Nevertheless, it's worth noting that in some cases, these goals are negotiable. Some national legislations allow for noise limits not to be met at all receptors if achieving these goals would necessitate the construction of disproportionate barriers or interventions relative to the intended outcome. From an economic sustainability perspective, in addition to identifying interventions that primarily reduce maintenance costs, economic sustainability is considered at the design level when assessing the cost-effectiveness or cost-benefit ratio of noise barriers. It's increasingly common to seek secondary functions for noise barriers, such as energy generation through photovoltaics or spaces designated for advertising. For noise barriers, the analysis to be conducted at the design stages also involves evaluating the social effects of the

[5] UNI 11160:2005 Linee guida per la progettazione, l'esecuzione e il collaudo di sistemi antirumore per infrastrutture di trasporto via terra

[6] ZTV Lsw 22 - Zusätzliche Technische Vertragsbedingungen und Richtlinien für die Ausführung von Lärmschutzwänden an Straßen (*Additional Technical Conditions Contract conditions and guidelines for the construction of noise barriers on roads*).

implemented interventions. Barriers or even more complex interventions (such as noise-reducing tunnels) must undergo assessment in consultation with the local population, possibly via formalized public debate procedures. Lastly, environmental sustainability is achieved through material specifications. In this case, except for materials for structural use, manufacturers have more leeway to propose innovative solutions while still meeting the required product performance standards.

For both noise and safety barriers, the role of Road Authorities may be dependent on the contract scenarios that are foreseen as follow:

1) **The road equipment may be part of a main contract** where new road infrastructure or the refurbishment or enlargement of an existing one must be undertaken: In this case, a main contractor is generally appointed, and the choice of the manufacturer and the installer of noise and safety barrier is based on negotiations carried on by the main contractor regarding the technical specification to be fulfilled. In this case, construction sustainability can be measured and assessed by a third party. In this situation the contribution of noise and safety barriers to sustainability is generally based on the declaration provided by the manufacturer and required by the NRA (or other client) about the product delivered to the construction site.
2) **Noise and safety barriers are to be installed on existing infrastructure** to mitigate the noise environment at specific receptors: In this second situation, noise and/or safety barriers are the main scope of the work of the contract. They may be purchased by the Road Authority (mainly due to a contract with an entrepreneur) and the sustainability of the chosen product may play a role in the tendering process.

3.2.3 Role and possible Recommendation for Raw Material Producers

Considering life cycle phases as defined in standard EN 15804, raw material producers can directly contribute to: Module A1 and Modules C3, C4. It is important to consider the choice of raw material producers as they will have different sustainability policies and implement them in different ways. When local producers of raw materials are used, this will have a positive effect on the sustainability score in module C4. An example of this is when noise barriers are made with locally produced materials. Producers of raw materials are often industrial companies that are much larger in size compared to manufacturers of road equipment such as noise or safety barriers. Many of these companies implement sustainability policies for all possible applications of their materials in the construction market. In some cases, raw material producers develop dedicated policies for this sector, creating specific products used by the road equipment industry.

A distinction must be made between (1) structural material for which real alternatives are not yet available or will only exist in the long term, and (2) other alternative raw materials than can be used for the construction of noise barrier modules.

Noise and safety barriers are structures that require the use of suitable materials to ensure their performance. Noise barriers need to have strong supporting elements to withstand the environmental loads, while safety barriers need to resist the impacts of errant vehicles. The main **structural materials** used for these structures are steel, concrete and timber (for limited applications), which are covered by the Eurocodes. The Eurocodes are a set of European standards for structural design, developed by CEN, that include the following materials: Concrete (EN 1992); Steel (EN 1993); Composite steel and concrete (EN 1994); Timber (EN 1995); Masonry (EN 1996); Aluminium (EN 1999). The Eurocodes also provide the basis of

structural design and the technical characteristics for structures for buildings and other civil engineering works. The Eurocodes are expected to evolve in the future, but not significantly in the short term. The second generation of the Eurocodes will introduce some improvements and extensions, such as new design methods, new materials, new actions, and new structural types[7],[8]. Some of the new materials that could be relevant for noise and safety barriers are structural glass and fibre-polymer composites (FRP). Structural glass could be used for noise barriers to provide transparency and lightness, while FRP could be used for both noise and safety barriers to offer durability and flexibility[9]. Outside the European context, some materials are gaining attention as a sustainable and renewable alternative for construction. For example, there is a new international standard for engineered bamboo products, but it is not yet part of the Eurocodes [10]. With reference to sustainability for structural materials, reference needs to be made to the existing core Product Category Rules, which are the rules for developing Environmental Product Declarations (EPD) for construction products and services, according to EN 15804. This is the standard that provides the framework for assessing the environmental sustainability of construction products and services, based on life-cycle analysis. Some examples are:

- cPCR-001 Cement and building lime (EN 16908)[11]
- cPCR-003 Concrete and concrete elements (EN 16757)
- Part B: Designated Steel Construction Product EPD Requirements[12]

For structural materials, road equipment manufacturers have limited options:

- For safety barriers, most of the product consists of these materials (steel and concrete) and no viable alternatives are foreseen. Changes that can affect sustainability can be foreseen only for coatings used to ensure product durability. An example explored in current research is that of pre-galvanized steel for safety barriers external surface treatment.[13],[14].
- For noise barriers, structural materials are used for the posts and supports. Some alternatives may be possible among the solutions permitted by the national laws and codes.

For both products, a general recommendation is to choose suppliers with a sustainability policy, i.e. an EPD according to the above specifications.

Non-structural materials are used sparingly for safety barriers. However, they are more common for noise barriers, where many components are of the self-supporting type and can be made of various materials. Acoustic panels or transparent sheets usually do not bear the load of the whole structure. They only need to support their own weight and possibly the weight of additional elements.

[7] Evolution of the EN Eurocodes | Eurocodes: Building the future (europa.eu)
[8] Eurocodes Homepage | Eurocodes (europa.eu)
[9] Second generation of the Eurocodes: what is new? | Eurocodes: Building the future (europa.eu)
[10] A Review of Codes and Standards for Bamboo Structural Design (hindawi.com)
[11] PCR Library | EPD International (environdec.com)
[12] 10010-34_Steel Products Public Comment.pdf (ul.com)
[13] https://constructalia.arcelormittal.com/files/Magnelis_book_EN-7ce049147e586796109b24ba2343fd9d.pdf
[14] https://www.wuppermann.com/en/sectors/vehicle-restraint-systems/

For noise barriers, raw material manufacturers can have a significant impact on achieving sustainability goals. This is the case for plastic materials used for transparent sheets. Polymethylmethacrylate (PMMA) or polycarbonate sheets are widely used in European markets. For both cases some raw material suppliers have already implemented sustainability policies by developing semi-finished products able to fulfil specific requirements for the noise barrier sector. This is the case of sound absorbing solutions or reinforced sheets that can resist vehicle impacts that may happen on the roads [15]. Some manufacturers have also implemented sustainability policies and an associated EPD declaration have been developed and published[16]. Improving long term durability of these products (i.e., resistance to UV) is part of the sustainability policy. There are many cases of raw material producers who propose the use of their products for the construction of noise barriers. An example is the rubber that can be recycled from vehicle tires[17] and used to produce lightweight concrete products with a sound-absorbing function. Another example for metal-type noise panels is the use of recycled material from PET waste to produce polyester fibre panels. In general, the use of innovative raw materials in noise barrier construction can occur both as result of research carried out by the noise barrier manufacturer itself, or due to the attempts of producers belonging to other sectors who are looking for possible uses for waste or by-products of their production cycles, or for the recycling of their products at the end of their life cycle.

3.2.4 Role and possible Recommendation for Manufacturers

The choice of the raw materials is crucial for the sustainability assessment of the product on the market. However, some manufacturers are linked to a specific production chain that limits the change of the base material. In these cases, the base material should be more efficient, better quality or recyclable, or combined with other sustainable materials. This applies mainly to safety barriers, which are often steel commodities or precast elements from concrete companies. This may also apply to noise barriers, although the manufacturers of these products are more inclined to use a variety of different materials. There are cases of noise barrier manufacturers being part of a material chain who are winning in terms of environmental sustainability. This is the case for recycled PVC, which has seen the emergence of companies engaged in the noise barrier sector using PVC obtained by recycling from other production chains (for example, the window industry). The choice of the base material is not an option in most cases for manufacturers and therefore it is necessary to rely on the sustainability policies implemented by the producers of raw materials.

The contribution of the manufacturers is therefore important for the subsequent phases of the life cycle. For phase C3, many manufacturers direct their efforts to improving the energy efficiency of the production plant. In this regard, it is important to note how the production processes of noise or safety barriers do not involve very energy-intensive operations. These are mostly processing and assembly operations where energy consumption is focussed, and the use of renewable energy sources is to be expected. However, it is not considered that this choice is decisive in the improvement of the final sustainability score of the product.

For the manufacturer, the focus should be on improving the production process as this is likely to have the greatest impact on sustainability.

Here are some recommendations that will have a measurable effect on the sustainability of different phases of the product life cycle:

[15] PLEXIGLAS® - The Original Acrylic - PLEXIGLAS®

[16] S-P-05711 - Hammerglass Clear single sheet 12 mm (environdec.com)

[17] E.g. the company Ruconbar: http://www.ruconbar.com/

- Minimize the movement of materials or semi-finished products in the supply chain (A3).
- Identify solutions that minimize the impact of product transport from the factory to the construction site (phase A4). An example can be found in the prefabrication system of concrete noise barriers. The sound-absorbing surface can be obtained separately with the pre-casting of lightweight material tiles of different shape and composition. This solution allows to produce acoustic panels in a normal prefabrication plant of concrete components because it avoids the more complex procedure of fresh casting on fresh concrete.
- Identify solutions that facilitate assembly operations on site (phase A5), especially considering the impact on traffic that these operations have for road equipment in general. An example of this is noise barriers with vertical metal posts with composite profile to avoid the insertion of the panels from above having to be done on site, which helps to minimize traffic delays.

The choices made by the manufacturer also influence the use phase of the product, especially when aimed at minimizing ordinary maintenance interventions (phase B2) made to ensure the durability of the product. For extraordinary interventions, related to accidents or choices of the road manager, the manufacturer must design the product to optimize the repair (B3), replacement (B4) or refurbishment (B5) phases. Finally, for the end-of-life management of the product, the manufacturers can make technical choices to facilitate the dismantling (C1) and removal of materials from the construction site (C2). Again, indications from the supplier of raw materials becomes relevant again for the waste management (C3) and disposal to landfill (C4) phases.

3.2.5 Role and possible Recommendation for Installers

The on-site functionality of noise barriers and road safety barriers largely depends on correct assembly and installation. When placing the product on the market, manufacturers are required to prepare the installation manual containing all the instructions needed for the product assembly and its adaptation to the site conditions. Therefore, training for installation companies is a crucial aspect to ensure their familiarity with the products and to guarantee the functionality through their activities. To complement this training activity, installer certification is provided in many countries[18]. In other countries the national legislation asks manufacturers to supervise and provide the final assessment of the correct assembly and installation[19].
This results in an ongoing **relationship between manufacturers and installation companies** that can also contribute to the improvements of the sustainability score of the installed products by:

- Recommending specific solutions to simplify assembly procedures.
- Optimizing transportation and unloading procedures on-site.
- Developing machinery and procedures for the timely installation and inspection of installed products.

[18] https://www.lantra.co.uk/national-highway-sector-schemes-nhss/austroads/operatives-installers
[19] http://www.unicmi.it/strumenti/prodotti_editoriali/ux79-procedura-emissione-certificato-di-corretto-montaggio-ed-installazione-dei-dispositivi-stradali.html UX79

- Providing innovative solutions for foundation works.

These latter solutions can have significant environmental impacts, especially for noise barriers that require anchoring to the ground to withstand static and dynamic loads including wind and vehicle actions[20] [21].

3.3 Tools for Environmental Declarations

Different types of EPD, depending on the scope and level of detail of the information provided, can be used by manufacturers to declare the environmental performance of noise and safety barriers. The reference standard is EN 15804:2012+A2:2019, which provides the core rules and requirements for developing an EPD for any construction product or services. This standard has been revised and aligned as much as possible with the "Product Environmental Footprint (PEF)", which is a common method for measuring and communicating the environmental performance of products and organizations in the EU. In addition, the product category rules (c-PCR-010 Guardrails and Bridge Parapets) has been published to define the scope and the methodology for sustainability assessment of safety barriers.

The tool developed by the PROCEEDR project can be used by different stakeholders to get acquainted with environmental sustainability evaluation before creating an EPD (Environmental Product Declaration). The tool also contains a database on Lifecycle Impacts (LCI) for products currently used for noise and safety barriers. **Manufacturers can use the PROCEEDR tool to inform an LCA analysis**, the verification of which ensures that the EPD complies with the PCR and is based on reliable data and the subsequent publication, which makes the EPD available to the public. Note that the **role of the manufacturers is to assess the A1 to A3 stages** and they can provide information about the further life cycle stages. In a tender process this is the only robust and relevant data they can provide to the NRAs, which is important in terms of the fairness and correctness of the tender procedure. Nowadays, EPDs are mainly intended for use in business-to-business (B2B) communication, as there is no obligation for manufacturers to provide the environmental declaration when placing the product on the market unless the request for such a declaration is written in tender specifications to implement the Green Public Procurement Directive. Nevertheless, NRAs can, and do require EPDs to verify climate footprints.

A new scenario is envisaged due to the revision of the Construction Product Regulation (CPR 305:2011) that the EU Commission is undertaking with the clear intention of strengthening the importance of sustainability for the characteristics the manufacturer is requested to declare when preparing the Declaration of Performance (DoP) and affixing the CE marking to the product. The CE marking indicates that a construction product conforms with its declared performance and that it has been assessed according to a harmonized European standard. It is a legal requirement for placing construction products on the EU market.

When this characteristic is acknowledged as one of the essential characteristics in the harmonized product standard, then the Environmental Product Declaration (EPD) will confirm that the tool that quantifiably demonstrates the environmental impacts of a product.
The tool developed in the PROCEEDR project can be used both for the voluntary EPD and for the future mandatory CE-marking where sustainability is expected to be included in the harmonized product standards.

[20] https://www.krinner.io/fileadmin/userdaten/Downloads/Englisch/Brochures-Flyer/Segm_Noise_Barrier.pdf
[21] https://www.fonsider.it/

3.4 Critical Issues for Industry Stakeholders

Changes to the CPR are expected to provide a systematic inclusion of the environmental requirements among the performance metrics that the manufacturer must certify with CE marking. Additionally, safety and noise barriers manufacturers are often asked for a declaration of environmental sustainability through an LCA study. The first issue that arises here is represented by the **variability and the number of environmental sustainability evaluation protocols** and databases available on the market. Most of these are based on the EPD declaration scheme according to EN 15804. However, many differences can be encountered due to choices made at national legislation level. Additionally, the presence of different operators who independently develop different schemes leads to complications in this space. The costs related to an environmental sustainability assessment are variable, depending on the chosen evaluation scheme, the third-party certification and on the number of products to be evaluated. Considering that many road equipment manufacturers are small and medium-sized enterprises, the most common issues include:

- **Lack of uniformity of protocols**: companies are forced to make a choice and therefore many are waiting to see which protocol will have greatest influence on the market. All this creates a vicious circle that represents an obstacle to the acceptance of the sustainability approach.
- **Common rule for a common market**: the differences in protocols adopted in individual countries can create a barrier to the market. This partly nullifies attempts at harmonization that have been going on for decades for the European market. The EU Commission is drafting an addendum to the CPR by setting out the applicable systems to assess and verify constancy of performance of construction products, specifically in the space of environmental sustainability.
- **Overarching approach required for sustainability evaluations** within the same product family: This is the case for road safety barriers belonging to the same family that vary only in weight and shape and that require individual declarations, at very high cost to the manufacturers.
- **High costs of some existing databases** that coexist while alternative databases are available for free.
- Need to achieve **familiarity with quantitative data resulting from LCA calculations**. The environmental impacts are measured for different impact categories and may vary significantly. Difficulty may arise when comparing different products on the basis of LCA results. A helpful solution would be to have a calculation of a unique index of environmental sustainability of the product. An example of this is a tool already in use in The Netherlands [22]: This is single-score indicator expressed in Euros that unites all relevant environmental impacts into a single score of environmental costs, representing the environmental shadow price of a product or project.
- Only **LCA modules A1, A2, A3** based on primary data to be considered in tendering process. When defining a scoring system, only robust data should be considered. If other Life Cycle Phases are considered relating to a unique scenario for transport to

[22] Environmental cost indicator (ECI) https://ecochain.com/knowledge/environmental-cost-indicator-eci/

site or the installation phase for example, then these would need to be clearly defined to avoid unfair competition.

3.5 Scenario for Sustainability Implementation

The idea behind the standards developed over the last few years was to **reach a firm quantitative declaration across the different LCA phases** - according to EN 15804 - to highlight those that are most relevant **for improving the overall sustainability** of road noise and safety barriers. In an ideal scenario the following relevant points should be addressed:

- Producers of raw materials should bring new solutions. There is a wide variety of new and innovative materials available to the noise barrier sector (phase A1-A3). In the safety barrier sector is more constrained now and limited to concrete and steel.
- Manufacturers should bring questions to the producers (phase A1-A3) and manufacturers should be flexible enough to implement new materials (e.g., to go beyond CE marking) phase A1-A3).
- Installers should communicate and interact with Manufacturers and bring questions and solutions to them (phase A3-A5).
- Manufacturers should respond to new questions from the Installers (phase A3-A5).
- Phase B is mainly limited to the Authorities, where strong links between all stakeholders are needed: manufacturers, installers, and producer of raw materials.
- Phase C is managed by the Authorities supported by producers of raw materials, installers, and manufacturers.

Improving the sustainability of road equipment is a complex and multifaceted challenge that requires a holistic and integrated approach. Both materials and processes are important aspects to consider for enhancing the environmental, social, and economic sustainability of road equipment. The following suggestions are made to improve the sustainability of noise and safety barriers:

- Choosing materials that have lower environmental impacts, such as recycled, renewable, or biodegradable materials, or materials that have lower embodied energy or carbon footprint.
- Optimizing the design and function of road equipment, such as using modular, adaptable, detachable or multifunctional components, or incorporating smart features or renewable energy sources.
- Improving the construction and maintenance processes of road equipment, such as using efficient methods, technologies, and equipment, or minimizing waste, emissions, and resource consumption.
- Minimizing transport distances by making greater use of local materials.
- Adopting new technologies for foundations works.

It is vital that greenwashing is avoided in the development of sustainability indicators and metrics to evaluate and monitor the performance of road equipment (including noise and safety barriers) and transparency and openness is key to maintain the trust of consumers and industry. “Greenwashing” is the practice of making misleading or unsubstantiated claims about the environmental benefits of a product, service, or activity. It is a form of deceptive marketing that can mislead consumers and harm the credibility of genuine sustainability efforts. In the

context of improving and understanding the sustainability of noise and safety barriers the following points are made:

- It is possible that some road equipment manufacturers try to advertise the aspects of their products that have a major impact on sustainability, but they should do so in an honest and transparent way. They should provide clear and accurate information about the environmental performance of their products, based on reliable methods and data. They should also avoid exaggerating or omitting relevant facts that could affect the consumers' decisions.
- Road equipment manufacturers have a responsibility to communicate the aspects of their products that have a major impact on sustainability, but they should also be accountable for their claims. They should follow the principles and guidelines of ethical and sustainable marketing, such as honesty, fairness, social responsibility and environmental stewardship. They should also be open to feedback and scrutiny from consumers, regulators and other stakeholders.
- Road equipment manufacturers should not be engaged in greenwashing, as it would be harmful for both the environment and the society. Greenwashing can undermine the trust and confidence of consumers and investors in sustainable products and practices. It can also create unfair competition and discourage innovation and improvement among genuine sustainability leaders. It can also reduce the awareness and motivation of consumers and businesses to adopt more sustainable behaviours and choices.

3.6 The PROCEEDR Tool

The PROCEEDR tool is a user-friendly online tool to evaluate the resource efficiency and circularity potential of roadside noise and safety barriers. It encompasses Life Cycle Assessment (LCA), Life Cycle Cost Assessment (LCCA), and a newly developed Circularity Indicator (CI).
This tool enables the user to assess all relevant life cycle stages (cradle to cradle) for the common European noise and safety barriers and their potential environmental impacts and costs. These stages include: production (A1-A3) involving virgin and secondary material extraction, processing, manufacturing, and transportation within and up to manufacturing; construction (A4-A5) encompassing transportation and installation; maintenance (B2) involving regular cleaning; replacement (B4) after the element's lifespan; deconstruction and transportation (C1-C2) for disassembly and transport to recycling or disposal centres; and potential benefits (D) derived from material or energy recovery beyond the product system boundaries. The PROCEEDR tool is valuable for:

- National Road Authority project leads and consultants to compare various barrier solutions, evaluating their environmental impact and circularity potential for both current and future projects (which will be discussed in detail in the following sub-section).
- Manufacturers and designers of roadside equipment to thoroughly assess environmental impact, explore circularity potential, identify optimization opportunities, and compare different design options.

The user can choose to assess from 13 environmental impact categories mandatory for EPDs (including GWP-total, GWP-fossil, GWP-biogenic, GWP-Luluc, ODP, POCP, AP, EP-

freshwater, EP-marine, EP-terrestrial, WDP, ADP-fossil, and ADP-Minerals & Metals). The evaluation of environmental impacts and costs is mostly based on average European data, which is presented in the deliverable D2.2[23].

The Circularity Indicator (CI) quantifies an element's circularity on a scale from 0 to 1, where 0 signifies a completely linear process and 1 represents full circularity. This evaluation is based on criteria such as the linear flow index of materials, including virgin, secondary, and bio-based inputs, and outputs, as well as the product's utility, which considers the duration and intensity of its use relative to average comparable products.

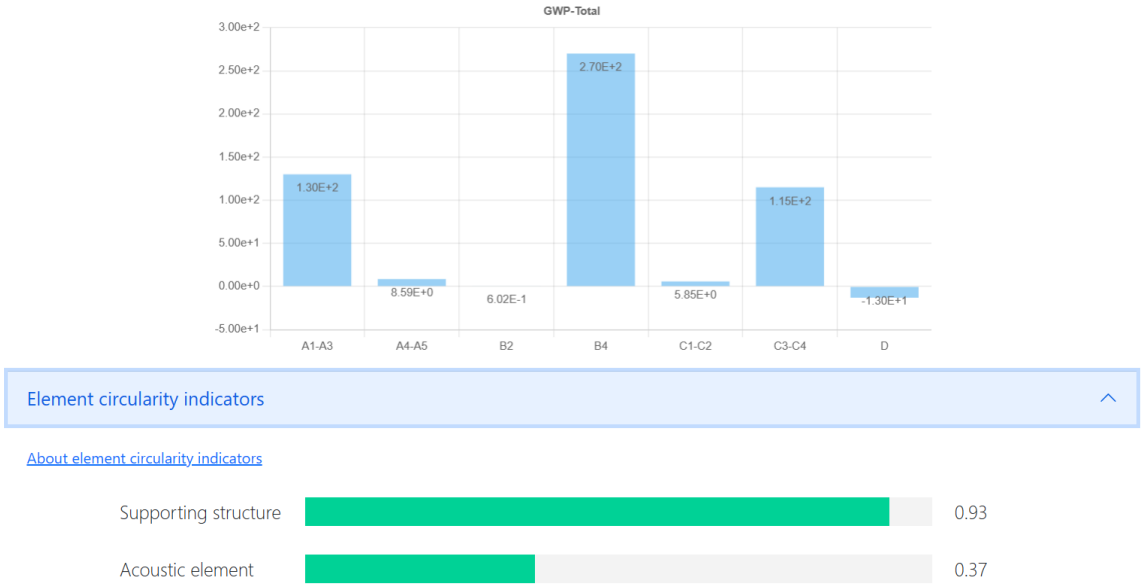

Figure 9 The PROCEEDR outcome visualization for one of the noise barriers

Figure 9 is a screenshot of the tool result for one of the noise barriers, presenting total global warming potential per functional unit within different life cycle stages and CI for barriers' elements. The tool's detailed manual and description is available in deliverable D4.1[24].

3.6.1 How the PROCEEDR tool could benefit NRAs

The PROCEEDR tool enables NRAs and manufacturers to assess the environmental impacts, costs and circularity potential of noise and safety barriers over the entire lifecycle of the product. Three areas have been identified where the PROCEEDR tool could support the sustainability work of NRAs:

- **Tendering process** – There is great potential for using the tool in the tendering process. It could be mandatory, and most useful during the Bid opening and Evaluation stage. Potential contractors would submit their bids in line with required assessment scheme; explicit lifecycle stages could be defined along with Impact Assessment categories to be considered. Default data from the tool database would enable better comparison of the different bids. Once carbon reduction becomes a contractual obligation, the tool would result in a fair and transparent evaluation of competing bids.

[23] https://proceedr.project.cedr.eu/wp-content/uploads/2024/01/PROCEEDR_WP2_deliverable_D2.2_V2-1.pdf
[24] https://proceedr.project.cedr.eu/wp-content/uploads/2024/02/PROCEEDR_WP4_Deliverable_D4.1_V1.pdf

The use of the tool in the tendering process would also encourage noise and safety manufactures to develop and implement sustainability policies and use LCA techniques to assess their results and progress.

- **Benchmarking** – Primarily, the tool could be used for evaluating noise and safety barriers as part of the tendering process. It could also be used within the NRA prior to the tendering process, to assess and refine the selection of barrier solutions for a proposed project. This could be particularly valuable in relation to noise barriers as new materials are often proposed by manufacturers that are claimed to have high sustainability credentials. Benchmarking distinct types of barrier solutions, understanding the importance of the different lifecycle stages and impact categories as well as the circularity potential (via the PROCEEDR tool's unique Circularity Index feature) of distinct types of construction methods and barriers could significantly support the sustainability activities of NRAs.
- **Communication** – the tool provides a comprehensive summary of the results of the environmental and economic assessment of noise and safety barriers; it follows all the relevant standards for environment lifecycle assessment and the calculation steps are understandable, reliable and transparent. These features mean that the tool outputs would support the communication required to improve the sustainability of the products being considered for use in infrastructure projects.

3.7 Conclusion and Further Steps

While the existing tool can already be used by NRAs, there is huge potential for it to be developed further and be tailored to meet specific in-country requirements and specifications for noise and safety barriers. In the long run it could also be expanded to include additional street furniture such as lighting or overhead gantries, or even the many pavement construction options. All of these tasks would require considerable time, effort and financial support to be successful but should result in the most sustainable products being used in the future which can only be a benefit overall.

Sub-theme C of the DoRN for this research theme had the following expected outputs:

- Overview of relevant use cases (could come from any CEDR member country);
- Report on recommendations based on the evaluation of the use cases including the
- design recommendations, and possibly wider applications;
- State-of-the-art review to identify research gaps on durability of these products;
- Online tool for comparative study on costs and benefits and total life cycle – and
- where possible on other harmonised indictors (e.g. economic and societal impacts);
- Software tool to model and assess resource efficiency, or advise changes or
- additions to existing tools (for example on climate change), when using the suggested
- materials for the specific applications.

These expected outputs have been addressed by the following deliverables, although in order to make the most efficient use of resources, the last two expected outputs were combined and one tool was produced - the user-friendly online PROCEEDR tool:

- D1.1 Overview and critical assessment of LCA road infrastructure tools

- D1.2 Sustainability of roadside infrastructure equipment
- D1.3/D2.3 Practical guidelines to assess the use of different materials
- D2.1 A table/list of the specifications of the roadside infrastructures developed in D1.2
- D2.2 A list of assumptions of production, construction, maintenance of roadside infrastructure solutions
- D3.1 Prototype version of the LCA-/LCCA-online tool
- D4.1 Final report on the LCA online tool including user manual
- D4.3 Practical recommendations for NRAs on how to implement sustainability policies by using the PROCEEDR software tool
- Further information on the PROCEEDR project outputs, including the PROCEEDR tool, can be found in the PROCEEDR resource pack at https://www.cedr.eu/peb-call-2020-resource-efficiency-and-circular-economy

4 Programme Final Conference

4.1 Introduction

The final conference for the programme of the CEDR call 2020 was held on the 12th-13th March 2024 in Rijkswaterstaat Westraven office, Utrecht, The Netherlands. The final conference was used as a platform to present the findings and recommendations of the two projects and disseminate project results. The event was also important in facilitating understanding of this work across the funding member states. This chapter highlights the outcomes of the final conference, including highlights, remarks, and recommendations for implementation steps.

4.2 Conference Agenda

4.2.1 Programme Day 1

(In-person and virtual session)

Time	Details	Leader
13:00 – 14:00	Registration & Lunch	PEB
14:00 – 14:15	Welcome and Introduction - Recap on objectives of the DoRN	PEB
14:15 – 14:30	**CERCOM** - Circular Economy in Road COnstruction and Maintenance – Aims and results	RDS
14:30 – 15:30	**Collaborative Session 1: Developing Best Practice: Linear to Circular Economy – CERCOM Project** • Maturity Matrix • Best practice and strategic approach to CE	ITEN
15:30 – 15:45	Coffee Break	
15:45 – 16:00	**PROCEEDR** - Optimising Resource Use for Roadside Infrastructures – Aims and Results	CUT
16:00 – 17:00	**Collaborative Session 2 – PROCEEDR** • PROCEEDR tool presentation • Discussion on the PROCEEDR tool • Recommendations presentation and discussion • Q&A PROCEER project	CUT
17:00 – 17:30	PEB Feedback	PEB
17:30	Meeting close	PEB

19:00	Dinner	PEB

4.2.2 Programme Day 2
(*In-person only*)

Time	Details	Leader
09:00 – 10:15	**Collaborative Session 3: Risk Based Analysis Framework for Circular Procurement – CERCOM Project** • RBAF / Software tool • Case study	RDS / TUD
10:15 – 11:30	**Collaborative Session 4 – PROCEEDR** • Workshop on development and hosting of the PROCEEDR tool • PROCEEDR lessons learnt for standardisation and regulation work	CUT
11:30 – 11:45	Coffee Break	
11:45 – 12:45	Summary of group discussions (implementation issues, open questions, next steps)	RDS / CUT
12:45 – 13:00	Closing Remarks	PEB
13:00	End of Conference and lunch	PEB

4.3 Attendance

The conference was well attended by project partners, PEB members and other representatives. Below is a list of the represented organisations, showing the number of attendees from each organisation.

Organisation	Organisation type	No. in person attendees	No. online attendees
Rijkswaterstaat	NRA - PEB member	3	
Transport Infrastructure Ireland	NRA - PEB member	3	1
CEDR	Programme manager	1	
The Norwegian Public Roads Administration	NRA - PEB member	1	1
Swedish Transport Administration	NRA - PEB member	1	
Dura Vermeer	Construction company	1	
Research Driven Solutions Ltd.	Consultancy - CERCOM	2	1
Delft University of Technology	Research Institute - CERCOM	2	

Organisation	Organisation type	No. in person attendees	No. online attendees
Chalmers University of Technology	Research Institute - PROCEEDR	2	
AIT - Austrian Institute of Technology	Research Institute - PROCEEDR	1	
The Danish Road Directorate	NRA - PEB member	2	
National Highways UK	NRA - PEB member	1	
International Transport Experts Network	Consultancy - CERCOM	2	2
Polish General Directorate for National Roads and Motorways	NRA		1
Transport Community Secretariat (Western Balkans)	Transport administrator		1
ANAS	NRA		1
Zavod za gradbeništvo Slovenije	Construction Research company		1
Directorate of Mobility and Transport - Portugal	NRA		1
Finnish Transport Infrastructure Agency	NRA		1
Turner and Townsend	Construction company		1
European Road Federation	Transport administrator		2
Federal Roads Office Switzerland	NRA - PEB member		2

4.4 Meeting outcomes

An interactive session was conducted at the Final Programme Conference to promote discussion around one specific area of maturity – CE Ambition. Participants were asked to discuss current the topic of CE Ambition within their companies and give an indication of maturity using the stages outlined. Participants from Rijkswaterstaat and National Highways indicated that their organisations were in the Active Deployment Stage (stages 7-9). All other participants indicated that their organisations (TII, DRD, NPRA, Swedish Transport Administration) were in the Early Stages of Practicing (stages 4-6). A participant from the Finnish Transport Infrastructure Agency indicated that their organisation was in the Active Deployment Stage (stages 7-9). Other participants from Rijkswaterstaat and ERF indicated that their organisations were in the Early Stages of Practicing (stages 4-6). This indicates some discrepancy in knowledge across their organisation.

Participants were given time to confer with attendees from other organisations to investigate what had worked well for them, challenges, advice, barriers etc.. The challenges highlighted in the discussion included the following:

- Collaboration with municipalities and other public sector organisations.
- Need for private sector engagement also: the need to involve the entire supply chain and not only end users or NRAs.

- Getting other staff involved: policies and strategies have been developed, it is a challenge to get all relevant personnel engaged. There is a lot of focus on sustainability and carbon, but more tangible CE examples would be useful to encourage engagement. The Maturity Framework was outlined by TII as an effective way to communicate the various factors involved in CE maturity within the organisation.
- Indicators and measures: It is difficult to have just one KPI for CE and difficult to quantify it. It is difficult to set targets for CE when it is difficult to measure it. More than one indicator or a combined indicator is needed to give a good representation.
- Economic value: in Sweden virgin materials are cheaper so there is less advantageous economically to reuse materials. The motivation behind a move to CE is related to waste management and carbon reduction.
- Quality checking, storage and transportation of materials were also outlined as barriers. Environmental laws regarding storage of materials can be also very challenging.

The CERCOM and PROCEEDR project coordinators sought advice from organisations at a high maturity level for CE ambition about how lower maturity organisations can progress. The following advice was indicated:

- Produce a roadmap but ensure to involve principalities and provinces from the start of development, rather than presenting roadmap when it has been finalised.
- Develop a plan for the public sector (or better for NRAs) and then move towards encouraging the private sector.
- It is important to look at multi-life cycle when considering the re-use of materials.
- Focus on the list of Rs as a way to measure ambition (rather than relying on carbon targets).
- People think linearly (quick, cheap) and getting people to think about circularity is a challenge. It is therefore better to start with sectors rather than a whole organisation.
- A successful project in Rijkswaterstaat demonstrated reuse of concrete girders on bridges.
- Finnish Transport Infrastructure Agency has had success with recycling, overcoming the challenges of technical feasibility for road construction and the guidance on use of waste-based materials for construction.
- The key is to start thinking about CE from the early stages, during the planning phase.
- In any cases all participants agreed that "greenwashing" should be avoided, all stakeholders should be aware of this issue. NRAs should try to set clear KPI and transparent processes, especially in the tendering phase.
- It was stated that the supplier chain is very different in the European Countries therefore all stakeholders (also the industry) should be involved as soon as possible.
- It is fundamental to be clear, who is deciding which KPI are more relevant, and how these KPI can be weighted, especially if the goal is to end with one single KPI.
- It is necessary to harmonize the setup for standardisation in this field, but e very high demand of coordination work and resources is needed: a first step should be a cross-border comparison to get an overview on the processes in the different NRAs around Europe.
- More case studies are necessary for testing the developed tools, the case studies should come from different NRAs involved in CERCOM and PROCEEDR projects.

In collaborative Session 3, an overview was provided of the development of the Risk Based Analysis Framework (RBAF) and software tool. Conference participants indicated the following during discussions:

- When queried about strengths and weaknesses, it was suggested that strength of the tool is the move to objective assessment over opinion. The availability of data is seen as a possible weakness, specifically cost of materials, since the cost is dependent on the local situation and values obtained in one location may not be valid when transferred to a different one.
- The social aspect can be difficult to quantify. For noise, a KPI could be aligned to legislative requirements (number exposed and noise relative to threshold). It was outlined that a specific framework was developed as part of the project to assess various social aspects. Questionnaires are needed to gain feedback from stakeholders to provide a means to quantify these indicators.
- For parameters where there is a higher level of uncertainty, a sensitivity analysis should be used to test whether the conclusions are affected by, e.g., variations of +/- 10%.
- For a large renovation and replacement programme, where there is a need to scale and standardise a 'production line', the tool could be used to determine where to set a benchmark for a "green sticker" to reward solutions that are more circular. There is a possibility to use preset values incorporated within the tools as a starting point.
- There was a query about whether there is potential for a contractor to use the tool for greenwashing their product, by inputting misleading data? This is a possibility, but contractors are already making environmental claims and, even with EPDs, as different methods are used for calculation, the results cannot be compared directly. Having a consistent calculation in the tool is a step forward. However, the client also needs to be able to provide scrutiny.
- The CERCOM consortium recommends that NRAs begin to use the tool with familiar indicators, and build up a database and confidence over time, and include more complex indicators once the data and experience is mature enough.
- There are advantages and disadvantages of weighting. With no weighting, the predicted outcomes are presented transparently for decision makers.

Collaborative Session 4 was divided into two parts: first a short Workshop was held on development and hosting of the PROCEEDR tool, secondly the lessons learnt from the PROCEEDR project for the topic of standardisation and regulation work was drawn. The following topics were discussed:

- The potential improvement of the PROCEEDR tool:
  - a ranked interpolation between the different KPI of the PROCEEDR tool can be addressed in further development step.
- Hosting alternatives for the tool:
  - (cloud solutions) 4 possible alternatives + open source (no hosting) and possibility to develop it further for everybody.
- The responsibility of the tool was discussed.
- The topic of traffic disruption is probably more relevant than the cost topic (e.g., in the Netherlands).

The following questions to NRAs have been discussed:

- Training and recommendations to NRAs on "how to implement GPP for noise and safety barriers in Europe."
- Development for specific needs for NRAs.

- Development of case studies.
- Application of the PROCEEDR tool implementing new case studies provided by ERF or generated by NRAs.
- Possible use of the tool to prevent/avoid greenwashing.
- Traffic disruption is currently not considered in the tool; therefore, it should be discussed how this parameter can be considered in further steps.
- The PROCEEDR tool is mainly built to be used to compare solutions or projects.
- Which KPI should be considered (more) relevant and which weighting factors should be assigned to the different KPI?

5 Application of Project Outputs

In this section an effort is made to provide a clear and concise roadmap for NRAs to implement the results of the research programme. The recommended actions are provided in the short, medium and long term.

5.1 Short term actions (6-18 months)

PEB members and other CEDR NRAs are strongly urged to begin the process of CE transition by applying the CERCOM rubric in Appendix A. This should be performed across various levels of the organisation to get as complete an understanding as possible. The rubric provides clear goals to implement and move to the next level. This should be written into the organisations dedicated circularity policy.

In this phase, PEB members and CEDR NRAs are encouraged to identify two to three full scale applications of noise and/or safety barrier projects that can be used to test the PROCEEDR tool. This would also provide the opportunity to explore how best to tailor the tool to support NRA country specific requirements.

5.2 Medium term actions (18 months – 36 months)

Once the organisation has a clear idea of their position on the journey toward circularity, it is recommended that the CERCOM RBAF be implemented at full scale for a construction and maintenance project. The effort required to undertake this analysis and source all relevant data should not be underestimated, as this was identified as a key barrier to implementation. It is recommended that the focus here initially be on “quick wins” – small scale projects which are expected to have sufficient data to quantify circularity impacts across the supply chain. This process has already begun with the CERCOM coordinators currently engaging with PEB members to identify potential full-scale applications.

As soon as NRAs have tested the PROCEEDR tool, the PROCEEDR team (Chalmers, AIT, TRL and ERF) can help in adjusting the tool to suit the specific requirements of each NRA and give detailed support on the use of the tool.

5.3 Long term actions (> 3 years beyond programme completion)

The application of the risk-based approach developed within the CERCOM project to tender evaluation has been set out as the “holy grail” for effective implementation of circularity. The CERCOM roadmap to implementation suggested that this can initially be used as part of the preparation phase and the pre-tendering phases of procurement, for example as part of market consultation to establish a baseline and set appropriate targets or goals before engaging in the pre-tendering phase. Allowing for a collaborative approach from the beginning, as part of the pre-tendering phase, conversations with market stakeholders may be insightful to gain knowledge of materials/methods/processes available on the market to aid the development of specifications to produce better outcomes and reduce time scales. As part of this process, the NRA can continually update and vary the input variables to the RBAF to assess different viable options. Following this analysis, the next stage in the procurement process is to translate information and experience gained into specific requirements and competition parameters. As part of this process, the RBAF will provide vital information for the generation of the

specifications, selection/award criteria and the evaluation of tenders. Regardless of whether National or European rules are appropriate, the criteria for the assessment of tenders must be outlined within published tender documents. In this regard, any weights, KPIs, scoring matrix or evaluation metrics must be assessed and agreed on before publication of the tender. As such, the RBAF is most effective when utilised early on in the procurement process to allow for CE & RE factors to be considered and incorporated into the preparation of tender documents, specification of award criteria and in the evaluation of tenders.

The PROCEEDR tool would have been tailored to the demands and priorities of the interested NRAs. A possible expansion to include other street furniture has been assessed and integrated, The tool has been shared with and is embedded in the supply chain to stimulate innovation and ensure informed decision making. Manufacturers are aware of the legislation and regulatory requirements and have been trained to apply life cycle thinking in their design and production stages for roadside equipment. The tool is mandated for use by the NRA as part of the procurement process and becomes “Business as usual” supporting the transition to the Circular Economy.

6 Conclusions

This report provided a synopsis of some of the main outputs of the CERCOM and PROCEEDR projects, which were funded as part of CEDR's Transnational Road Research Programme 2020. The CEDR call 2020 was first presented and the specific research needs were addressed. The achievement of these aims were then presented in section 2 and 3 for CERCOM and PROCEEDR respectively. The individual conclusions within these chapters map the expected outputs of the DoRN to the project outputs, showing how the CERCOM and PROCEEDR consortium have delivered the required outputs to CEDR NRAs.

The final conference of this CEDR programme was also presented in this report, with an analysis of some of the findings. These were considered by the authors in order to draft the planned roadmap to applying the project outputs in section 5. This will serve as a programme / checklist for the PEB in order to ensure the project outputs are applied across CEDR NRAs going forward.

Overall, the CERCOM and PROCEER projects have been extremely successful in delivering the requirements of the DoRN, to the satisfaction of the PEB.

Appendix A – CERCOM Maturity Model Rubric

CERCOM Maturity level	Engaging in transition to RECE (Stage 1)	Engaging in transition to RECE (Stage 2)	Engaging in transition to RECE (Stage 3)
CE ambition	NRA has not committed to a transition to CE.	NRA has committed to a transition to CE but is yet to define CE within the context of its operations	NRA has committed to a transition to CE and a definition for what CE means in practice is in place
Embedding CE	No staff awareness of CE.	Low staff awareness of CE and how it affects their roles. No innovation in RE and CE	Moderate staff awareness of CE and how it affects their roles. Ad-hoc initiatives to support innovation to deliver CE.
Performance monitoring (KPIs)	Inventory of the resources in use is incomplete, not up to date. No tracking occurs of selected and isolated aspects, e.g., RAP (Recycled Asphalt Pavement) or CO_2.	Work on creating an up-to-date inventory is underway Partial tracking occurs of selected and isolated aspects, e.g., RAP or CO_2.	A partial inventory is available of the resources in use. Tracking occurs of selected and isolated aspects, e.g., RAP or CO_2.
Standards	Standards and methods for treatment of risk are at status-quo, allowing only traditional methods for use of materials, e.g., recycled asphalt.	Standards and methods for treatment of risk allow limited reuse of materials, e.g., recycled asphalt, within traditional methods.	Standards and methods for treatment of risk allow greater reuse of materials, e.g., recycled asphalt, within traditional methods.
Supply chain	No engagement between internal & external	Recognition of need for engagement between internal & external	Engagement is occurring between internal & external stakeholder

	stakeholder communities regarding CE & RE. Suppliers deliver projects as mandated by existing standards.	stakeholder communities to progress to CE Suppliers deliver projects as mandated by existing standards.	communities (e.g., developing guidelines, good practice). Suppliers deliver projects as mandated by existing standards.
Business models	Linear business models (with environmental aspects such as recycling in line with legislative requirements). No whole life costing applied.	Linear business models, (with environmental aspects such as recycling in line with legislative requirements), whole life costing considered but not mandatory	Linear business models (with environmental aspects such as recycling in line with legislative requirements), whole life costing part of decision-making process
Circular procurement	Procurement is on a transactional basis, not on value maximisation Tendering is based on specified technical requirements and suppliers deliver as mandated by existing standards only. No circularity considered within procurement.	Procurement is still on a transactional basis, not value maximisation but some value elements included (e.g., recycling) Tendering is based on specified technical requirements and suppliers deliver on some value elements as mandated by standards	Procurement is on a transactional basis Elements of CE are accommodated although are not specifically designed to influence internal and supply chain behaviours on circularity. Tendering is based on specified technical requirements and suppliers deliver on value elements as mandated by standards

CERCOM Maturity level	Early stages of practicing RECE (Stage 4)	Early stages of practicing RECE (Stage 5)	Early stages of practicing RECE (Stage 6)
CE ambition	Policy to transition to CE and improve RE are under development.	Policy to transition to CE has been published. Targets for transition yet to be identified and developed.	Policy to transition to CE has been published. Targets for RE and CE elements, some developed & others under development

Embedding CE	Growing staff awareness of CE and how it affects their roles. Initiatives are starting to occur that support innovation to deliver CE. Ad-hoc champions in some project teams, but not widely spread across projects	Corporate communication for internal & external audience, beginning to be shared Initiatives to support innovation to deliver CE increasing. Champions in some project teams to enable CE thinking. Supporting instruments, tools and staff training are being developed	Clear communication, internally & externally, on commitment to CE. Corporate commitment to innovation initiatives to deliver CE. Champions in project teams are beginning to drive through change. Supporting instruments, tools and staff training are being developed and implemented.
Performance monitoring (KPIs)	Systems to monitor improvements in RE & CE are being developed. Recognition of need and plan to work with supply chain. On-going work on improving inventories that track resource inputs and outputs. Tracking occurs across multiple aspects and there is awareness of areas for development.	RE & CE are monitored internally, Supply chain involvement increasing. Increasing detailed inventories that track resource inputs and outputs. Greater visibility of performance and awareness of areas for development. KPIs (internal & external) are under development.	RE & CE are routinely monitored internally, the supply chain is required to provide data to support. Increasing detailed inventories that track resource inputs and outputs. Increasing visibility of performance and awareness of areas for development. KPIs (internal & external) are in place, and additional ones being developed.
Standards	Recognition of need for new/revised Standards to accommodate opportunities for high-value use of existing materials (accommodating Repair, Reuse, Repurpose, etc., in addition to Recycle)	New/revised Standards to accommodate opportunities for high-value use of existing materials (accommodating Repair, Reuse, Repurpose, etc., in addition to Recycle) under development.	Standards accommodate opportunities for high-value use of existing materials (accommodating Repair, Reuse, Repurpose, etc., in addition to Recycle). Novel approaches are actively sought through a streamlined process for derogation.

	Novel approaches are not yet accommodated through a streamlined process for derogation.	Progress on accommodating novel approaches through a streamlined process for derogation.	
Supply chain	Collaborative mechanisms, e.g. Early Contractor Involvement at design stage, are being explored. Supply chain contributing to ideas to improve performance and move beyond existing standards	Collaborative mechanisms being tried out in some projects, e.g. Early Contractor Involvement at design stage, and positive attitude to innovation are allowing options for enabling circularity to be explored. Supply chain demonstrating actions to monitor and improve performance.	Collaborative mechanisms, e.g. Early Contractor Involvement at design stage, and positive attitude to innovation are used more widely, enabling progress to circularity. Supply chain demonstrating continued commitment to monitor and improve performance.
Business models	Exploratory work on changes to NRA business models to align with the new CE Policy, e.g., closing the loop and involvement in product life cycles for longer than linear model	New framework for business model, defining NRA value proposition and processes for capturing value being developed.	NRA business model thinking is influenced by RE and circularity principles e.g.: reducing resource consumption, keeping materials in use, minimising ecological and social costs, designing out waste, and consideration of the residual value of resources, products as services.
Circular procurement	Exploratory work on systems and tools to include CE & RE principles within the procurement process. Tendering is based on specified technical requirements and suppliers are encouraged to propose options supporting circularity (e.g., plans for reuse of materials, development of	Designs for systems and tools to recognise CE & RE within the procurement process; this includes collaborative relationships with supply chains. Tendering starting to include functional requirements and circularity (e.g., plans for reuse of materials, development of secondary value chain is encouraged and partly rewarded in procurement process).	Systems and tools to include CE & RE principles within the procurement process are being developed. Circularity (e.g., plans for reuse of materials, development of secondary value chain) is rewarded in tender assessment.

	secondary value chain is encouraged within tendering).		

CERCOM Maturity level	Active deployment of RECE (Stage 7)	Active deployment of RECE (Stage 8)	Active deployment of RECE (Stage 9)
CE ambition	Strategy for transition and route map under development. Targets for RE and CE elements are in place	Corporate strategic plan and route map for the transition are published.	Strategic plan for transition & route map with timeline in place and embedded in the NRA. Targets for RE and CE, monitoring systems to track progress are developed.
Embedding CE	Staff are fully engaged with CE. Commitment and investment in innovation in RE & CE. Champions in project teams are beginning to drive through change, are recognised, and supported by senior management. Supporting instruments, tools and staff training are fully developed and implemented.	Staff are fully engaged with CE. Investment in innovation in RE & CE. Visible leadership at senior level, with accountability assigned to key leadership roles, supported by champions. Supporting instruments, tools and staff training are fully developed and implemented. Progress in development of business and personal objectives for delivery of RE and CE. CE principles are embedded in process as 'business as usual'	Staff are fully engaged with CE. Significant investment in innovation in RE and CE with forward plan to continue commitment. Visible leadership at senior level, with accountability assigned to key leadership roles, supported by champions. Supporting instruments, tools and staff training are fully developed, implemented, and embedded. Business and personal objectives are set for delivery of RE and CE.

	Business and personal objectives beginning to be developed CE principles are defined and understood.		CE principles are embedded in process as 'business as usual', and subject to continuous improvement.
Performance monitoring (KPIs)	A common data standard has been developed. Understanding of materials, input, and output (waste) streams throughout the supply chain is being gathered. Metrics, not yet verified, have been developed for quantification of resources and impacts. Progress is being made on internal & external transparency in performance achieved	A common data standard exists, and databases are being populated with robust data. A detailed understanding of materials, input, and output (waste) streams throughout the supply chain has been achieved. Metrics are in place for quantification of resources and impacts, with third party verification. Internal & external transparency in performance and progress being made to achieve targets.	A common data standard exists and robust, up to date data are available (for NRA and supply chain). A detailed understanding of materials, input, and output (waste) streams throughout the supply chain has been achieved and is routinely monitored and updated as necessary. Metrics in place for quantification of resources and impacts, with third party verification reported upon. Internal & external transparency in performance achieved with reports on progress being made towards targets.
Standards	Standards encourage innovation in high-value use of resources; more work needed to manage risk. Methods for verifying the provenance and quality of materials in a secondary market being developed.	Standards support innovation in high-value use of resources, progress on management of risk. Some methods in place for verifying the provenance and quality of materials in a secondary market.	Standards support and help to embed innovation in high-value use of resources whilst providing effective management of risk. Effective (audited) methods in place for verifying the provenance and quality of materials in a secondary market.
Supply chain	Jointly exploring approaches to move beyond ECI and establish collaborative partnerships and alignment	A Systems approach to partnerships and alignment of incentives throughout the supply chain starting to be used.	A Systems approach is established, with collaborative partnerships and alignment of incentives throughout the supply chain. NRA & Supply chain on track to deliver NRA targets.

	of incentives throughout the supply chain. Supply chain buy-in to move to Circular Economy	Supply chain working with the NRA to deliver targets.	
Business models	Transition to Circular Economy Business Model based on maintaining value of resources underway Systems approach, external factors, supply chain role is being taken into consideration.	Business plans and procurement decisions increasingly driven by Circularity principles, minimising new resource use, improving longevity, repairability and efficiency of current resources.	Circular Economy Business Model based on delivering maximum value of resources and maintaining continuous relationship with supply chain in active use in the NRA. Circularity is inherent in the business models, drives decision making and procurement towards improving longevity, repairability and resource efficiency.
Circular procurement	Systems and tools that include CE & RE are developed and available in procurement. Training on new procurement processes underway. Tendering process includes functional specifications with circularity metrics to assess options.	Systems and tools that recognise and reward CE & RE are embedded in the procurement process. Training is on-going. Procurement process is based on collaborative relationship with supply chain. Tendering process includes functional specifications with circularity metrics embedded into the decision process. Monitoring system to report on progress being developed.	Systems and tools that recognise and reward CE & RE are embedded in the procurement process. Procurement based on collaborative relationship with supply chain is embedded in the NRA. Tendering process includes functional specifications with circularity metrics embedded into the decision process. Monitoring system in place to report on progress, track and demonstrate improvements.

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