The PROCEEDR Tool to Assess Environmental Impacts, Circularity and Life Cycle Costs of Roadside Equipment

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Abstract. Road transport was responsible for 24% of all carbon dioxide emissions in the EU in 2020. The majority of the transport sector's carbon emissions is related to the operation of vehicles, followed by infrastructure construction and rehabilitation. Roadside equipment, such as noise and safety barriers make a small contribution. Nevertheless, road infrastructure requires extensive use of natural resources and is a major generator of waste, as well as comprising assets with a lifespan of up to 100 years. The PROCEEDR project, funded by the CEDR Transnational Road Research Programme Call 2020 Resource Efficiency and Circular Economy created a software tool to enable National Road Administrations as well as roadside equipment manufacturers to find innovative and sustainable solutions to ease the transition from linear to circular economy in the field of roadside infrastructure. This paper presents a unique software tool that closes a research and knowledge gap and has been tested and validated in several case studies. The work is also based on a state-of-the-art inventory and analyses performed during the first part of the project. We describe the tool development process, benchmark the tool against other available tools and conclude with a critical discussion on points for improvement.

Keywords: Circular economy · Life Cycle Assessment · environmental impacts · life cycle costs · software tool · sustainable noise and safety barriers

1 Introduction

The roadside infrastructure of today is equipped with various devices that have a direct impact on the total amount of virgin materials used for road construction. The National Road Authorities (NRAs) decided to take the lead and support the design of roadside solutions, requiring fewer virgin materials with lower environmental impacts and costs over their life cycle. NRAs have already developed procedures and tools to assess the environmental or sustainability performance of construction projects (see Sect. 2) but

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there lacks a specific tool that combines environmental life cycle assessment (LCA) with life cycle cost assessment (LCCA) together with a circular economy (CE) perspective. So far, globally no tool exists for assessing noise and safety barriers specifically; such a tool allows NRAs to assess the environmental performance and the circularity potential of different noise and safety barriers and also enables roadside equipment suppliers to optimize the environmental performance of their products.

The research project PROCEEDR – Optimising Resource Use for Roadside Infrastructure [1, 2] closed this research gap by reviewing technical and design aspects of roadside solutions to enable the development of innovative and comprehensive software to assess the environmental performance of noise and safety barriers and their circularity potential. The PROCEEDR software tool contains a unique and comprehensive product and material library of noise and safety barriers applied in the EU.

This paper presents the PROCEEDR software tool in its current form. This paper is divided into five chapters. This introduction is followed by an overview of existing tools for the environmental assessment of road infrastructure is presented. Sections 3 and 4 present the software tool development process and discussion of the tool, while Sect. 5 concludes with possible next steps.

2 State of the Art of Environmental Assessment Tools in Road Infrastructures

The LCA method enables policy planners, NRAs, and road management organizations to evaluate the overall environmental impact of road construction and maintenance. There are various tools available to assess infrastructures' environmental impacts, which have been investigated in the PROCEEDR project. The four most relevant tools are presented below. It should be noted that all the relevant information is based on online references and manuals of the relevant tools.

VegLCA, an Excel-based LCA tool developed by the Norwegian National Public Road Administration (NPRA) to assess environmental impact of road and rail infrastructure based on several environmental indicators, focusses on global warming potential [3, 4]. It has pre-selected processes (mostly based on Ecoinvent) and covers A1-A3, A4-A5, B4 and B5 life cycle stages.

LICCER (Life Cycle Considerations in EIA of Road Infrastructure) is an Excel-based decision-supporting tool to compare road corridor options in Sweden, Denmark, Norway, and the Netherlands [5]. It focuses on GHG emissions and energy consumption relating to the infrastructure components of roads, bridges, and tunnels covering all life cycle stages (from cradle to grave).

DuboCalc, launched by Rijkswaterstaat, part of the Dutch water and infrastructure ministry, calculates eleven environmental impacts of civil engineering works for the whole life cycle including after the end of life (module D) [6]. Its database consists of nationally developed Environmental Product Declarations (EPDs) and users can compare different material and design alternatives of all construction and civil engineering works (not just road or infrastructure projects).

Klimatkalkyl is an online web-based tool, developed by Trafikverket, the Swedish transport administration, enabling energy and emission calculations to be undertaken for infrastructure projects during their construction, operation, and maintenance [7]. The tool database consists of historic Swedish construction calculations, EPDs, and designers' experience-based data.

3 The PROCEEDR Tool Development Process

The tool development process started with a comprehensive overview of roadside infrastructure solutions currently in use in Europe (see Fig. 1). This informed the definition of the functional requirements for roadside solutions. The functional requirements together with the benchmarking of LCA and LCCA tools (see Sect. 2) provided the basis for prototyping the first version of the PROCEEDR tool. This first version of the tool has been validated through the application of test cases that allowed for refining the tool.

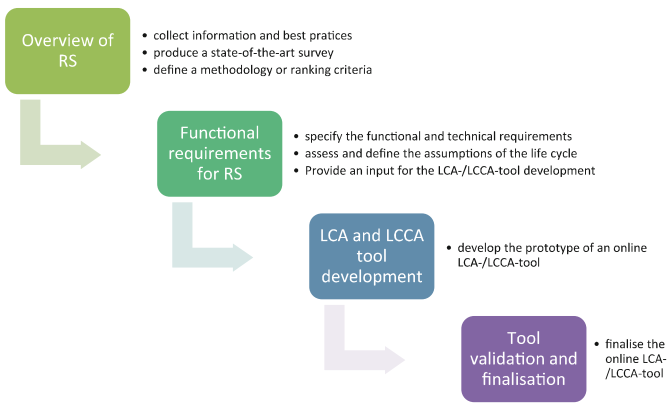

Fig. 1. Work process (RS = Roadside solutions).

The online tool development process to achieve a Minimum Viable Product (MVP) was iterative and followed a combination of software development methodologies including Prototype Methodology and Rapid Application Development (RAD).

After the assessment of existing LCA-/LCCA-software applied by NRA's today (see Sect. 2), a Miro board was created to facilitate the online workshops with the NRA's and manufacturers of roadside equipment to evaluate the flow and functionality of the interface and usability and learnability using the cognitive walkthrough method. The Miro board was used to quickly design and rapidly prototype the frontend with minimal database to support frontend selection list functionality. Initially, wireframe more complex parts of the application with no working functionality. The functionalities have been gradually introduced through subsequent iterations as requirements become more concrete. In parallel, the programming of the software tool began. It was developed using an open-source web application framework supported by a database in the backend. Both Django and Laravel have been chosen for reasons including but not limited to: built-in user authentication system, built-in automated testing environment and writing in Python enables easier integration with backend algorithms.

4 The PROCEEDR Tool

The PROCEEDR tool complies with the relevant international LCA-standards (ISO14040, 14044 and EN 15804.) The main target audience is European NRA's as well as noise and safety barrier manufacturers. Open access LCA software OpenLCA version 2,0 and Ecoinvent version 3.9.1 have been used and the environmental impact assessment method is OpenLCA - EN 15804+A2 Method. The database provides average data for energy, transport distances and material properties for Europe. All default values can be modified by the users to tailor the assessment to their geographical, climatic and economic circumstances for example.

The tool covers the life cycle stages: A1-A3 Production stage, A4-A5 Construction stage, B2 Maintenance, B4 Replacement, C1-C2 Deconstruction and transportation, C3-C4 Waste processing and disposal, and D Benefits and loads beyond the product system boundary. In addition, a CE Indicator has been developed and implemented in the tool.

The following environmental impact indicators are provided by the tool and the users can choose which to include: Fossil Global warming Potential, Biogenic global warming potential, Land use and land use change global warming potential, Total global warming potential, Depletion potential of the stratospheric ozone layer), Acidification potential, Accumulated Exceedance, Eutrophication potential, fraction of nutrients reaching freshwater end compartment, Eutrophication potential, fraction of nutrients reaching marine end compartment, Eutrophication potential, Accumulated Exceedance, Formation potential of tropospheric ozone, Abiotic depletion potential for non-fossil resources, Abiotic depletion for fossil resources potential, and Water (user) deprivation potential, deprivation-weighted water consumption.

To ensure that the tool assesses the environmental impacts of roadside equipment correctly, several case studies of roadside equipment were used and modelled in OpenLCA and calculated the environmental impacts of a few representative noise barriers for the European market. The same system boundaries, inventory data and impact assessment method were selected to enable comparison with the results from the PROCEEDR tool.

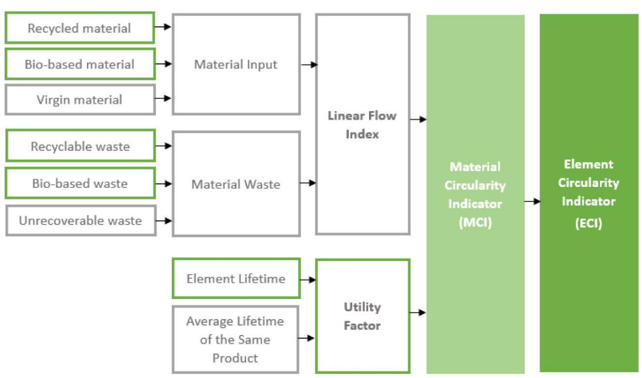

Fig. 2. Tool circularity indicator framework

A comprehensive investigation into the existing circularity methods and tools [8–12] was undertaken as creating an assessment method from scratch would be complex and resource intensive. The concept of a circularity framework (see Fig. 2) is derived from [12] and has been adapted and simplified for the PROCEEDR tool.

Material Circularity Indicators (MCI) are evaluated based on the Linear flow index and the Utility of the product. The linear flow index indicates material that flows linearly and is assessed by the flow of three different categories of materials input and waste. The utility of a product presents how long and intensely a product is used compared to an average product of the same type.

The circularity indicator scores the circularity of each element of barriers on a scale of 0 (fully linear) to 1 (fully circular). Element Circularity Indicator (ECI) is the normalized summation (based on mass) of MCI.

The PROCEEDR tool is composed of six sections:

Log-in: The log-in page allows the user to register or to log in again to continue with an assessment task that has already been entered.

Project Initiation: The project initiation allows the user to select a noise or a safety barrier assessment and the specific type.

Analysis Setting: This step sets the analysis framework. Here the user enters the main information on the roadside equipment to be assessed including the country where construction will take place and dimensions of the roadside equipment study object. The user can also select the environmental impact categories and life cycle stages to be included in the assessment. Finally, the assessment of the circularity potential of the roadside equipment can be enabled.

Input: As a last step before the calculations can be run, the user enters the relevant information for the roadside equipment. To make the solutions more comparable, this step is divided into different parts. This also enables calculations to be performed for existing infrastructure already in situ, for example if only the acoustic panel of a noise barrier needs to be replaced, this can be assessed by the tool. For a noise barrier, these parts are: the foundation, the supporting structure and the acoustic element.

Overview: As you can see in the earlier figures, the user always has an overview of information that has been entered into the software. Before the calculation is initiated, the user has an overview of the chosen parameters so far, enabling them to go back and edit parameters if a mistake is detected at this stage.

Results: After the calculations have been run, the user is provided with a result sheet in the form of a bar chart with the different life cycle stages, the circularity economy potential assessment and costs/ life cycle stage illustrated. Finally, the user can choose to export the data as a csv-file for Excel or as a pdf report.

5 Conclusions

The PROCEEDR project successfully developed a software tool that allows European NRAs to specifically assess the environmental and economic performance of roadside equipment. The development of an indicator of the circularity potential of a noise or safety barrier will highlight synergies and trade-offs between a circular economy and associated environmental impacts, e.g. in some cases, a circular treatment might result in higher environmental impacts than the use of primary materials. NRAs might use the PROCEEDR tool for other reasons, perhaps to assess/compare the offered solutions in a tendering process. Hence, the tool could support roadside equipment manufacturers in reducing the environmental impacts of their products through a more beneficial ecological product design. The PROCEEDR tool offers many benefits to NRAs and manufacturers, but would benefit from further development work. Its modular software architecture allows the addition of other typical roadside equipment solutions, which would require a larger engagement of manufacturers to enter additional product solutions. Different functions in the result analysis and result interpretation including sensitivity analysis would be advantageous but due to time and resource restrictions, this was not possible. A finer granularity of national and local environmental and cost data would make the results more representative. Finally, additional features such as the resulting output in the form of an EPD would likely result in increased interest from manufacturers to provide more input data.

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