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PROCEEDR
OPTIMISING RESOURCE USE FOR ROADSIDE INFRASTRUCTURES

Overview and critical assessment of LCA/LCCA road infrastructure tools and roadside Infrastructures

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Version 3
Date: 06.12.2023
Dissemination level: Public

AIT Austrian Institute of Technology
Chalmers University of Technology
ERF European Union Road Federation
TRL

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CEDR TRANSNATIONAL RESEARCH PROGRAMME

Call 2020: Resource Efficiency and the Circular Economy

PROCEEDR

OPTIMISING RESOURCE USE FOR ROADSIDE INFRASTRUCTURES

D1.1 Report on existing LCA/LCCA-tools and roadside infrastructure solutions including a SWOT analysis of existing tools

Work package / task: WP1 / task 1.1

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1 Introduction

During last decades due to increasing the world population and number of consumers, a dramatic growth in consumption of raw materials worldwide has occurred, and this has led to depletion of natural resources and environmental impacts. The main contribution to the energy use and greenhouse gas (GHG) emissions in the transportation sector is typically referred to the vehicle operation. However, these environmental impacts can be generated as well during construction, operation, maintenance, and demolition of road infrastructure (Miliutenko et al, 2014). Accordingly, the environmental impact of noise and safety barriers as two components of road infrastructure can be considered and analyzed.

Life Cycle Assessment (LCA) as a reliable tool is widely used by companies, policy planners, and road management organizations to evaluate the level of environmental impacts produced by different infrastructures. The LCA evaluates the whole life cycle of the product, including the sourcing of raw materials, manufacturing, distribution, transportation, and end-of-life disposal. A lot of producer companies in different fields like road infrastructures, use an LCA tool to improve their operational performance and develop a sustainability strategy. LCA can express ways to these companies in order to improve their product's environmental impact, regardless of whether the company hires a third-party company to perform the LCA, or purchases software to do it itself. (Wilkinson, D. B., 2012) Policy planners, National Road Administrations (NRA) and road management organizations are also some other stakeholders that are interested in using LCA method to assess the overall life cycle environmental impacts of the materials used for the road construction and maintenance. This approach might enable stakeholders to compare different scenarios for different stages of producing and using road infrastructures to suitably modify the environmental performance of them (Guerrieri et al, 2015). There are a lot of companies developing software packages that can be used for Life Cycle Analysis (LCA) or other type of ecological and environmental analysis.

In this report, as a first part of PROCEEDR project, a literature review has been conducted to evaluate different LCA tools used by different stakeholders. The focus is on roadside infrastructures specifically noise and safety barriers. However, some other tools that have been used in road construction sector are also evaluated.

2 Methodology

A systematic literature review combined with tools' websites and participants feedback is conducted to answer the following research questions:

- What are the LCA tools mostly used to assess roadside infrastructures?
- What are the LCA tools specifically used to assess noise and safety barriers?
- What are databases of these tools?
- Who are the owners and users of them?
- What aspects and indicators are they looking through?

In the first part of this study, **literature** which has mostly investigated LCA guide or specific projects using LCA tools are considered to survey the relevant works in this field. To answer these research questions, the literature search has been performed in Google scholar as a bibliographic source by using "LCA, LCCA, Life cycle assessment, tools, software, road infrastructure, transportation, noise barrier, safety barrier" as keywords. Then by using "AND" and "OR" operators, different blocks and a search string which is (LCA OR LCCA OR Life cycle assessment) AND (tools OR software for) AND (road infrastructures OR noise barriers OR safety barriers) have been built. A screening of the first 20 results has been performed by looking through the abstracts and 10 articles among them have been detected as probable useful ones for the defined research question. Finally, to obtain some more valuable sources to answer the research questions, the snowballing strategy has been conducted by going through the references of a chosen article and extracting 3 more new probable helpful articles. Moreover, the collected relevant articles were filtered through the screening of the titles, abstracts and through an examination of their full texts.

In the second part of the literature review, it is attempted to make a short description of some of the most important LCA tools which have mentioned in the first part. This part has been conducted by going through the developers'websites, tools' manuals, thesis projects, and some other papers.

3 Guide for LCA of road and rail infrastructure

Guide for LCA of road and rail infrastructure was a joint effort of the Nordic National Road Administration (consisting of Norway, Sweden and Finland) to further develop their LCA tools and procedures. Therefore, a project, NordLCA project started in 2017 (Hamel et al., 2020). The objective of this project was to create a comprehensive guide on utilizing Life Cycle Assessment (LCA) in the planning, construction, and maintenance of roads and railways. The guide primarily focuses on carbon emissions but can also be applied to other environmental impact categories. The intended audience for this guide includes LCA users such as project leaders, planners, and procurement professionals. Additionally, tool developers and buyers can also find value in this guidance. The guide is divided into two parts: the first part serves as an introduction (Chapters 1-3), while the second part (Chapters 4-6) provides methodology definitions, and implementation guidance, and ensures clear understanding and communication of results. What follows in this section is based on the NordLCA report which is available in English, Norwegian, Danish and Finish (Hamel et al., 2020).

LCA addresses the potential environmental aspects and impacts from the cradle, where raw material is extracted through production and used, to the grave and disposal. Several methodological options will affect the LCA results including defining scope and system boundaries, functional unit, data source and quality, impact assessment methods and so on. To make the comparability of results possible, there are European standards developed for LCA and civil engineering work which are presented Figure 3.1. The green boxes are the building's environmental-related standards while the red and blue ones respectively refer to the social and economic performance of buildings. The light blue boxes reflected three sustainable aspects of civil engineering works.

The NordLCA report uses EN 15643-5:2017 (civil engineering works) and EN 15978 (building level assessment) as basic recommendations. ISO standards 14040 and 14044 give rules for performing LCA for all products and services.

Based on NordLCA's suggestion, defining the LCA study should consist of defining the Goal and Scope, Data quality and life cycle impact assessment. In scope definition functional unit follows the ISO 14044 standards and system boundaries should follow EN 15804:2019 and EN 15978:2011. Through this guide and most of LCA infrastructure software, the focus is on green gas emissions, however, it is recommended that chosen environmental impact categories should cover all that is mentioned in EN 15804:2019.

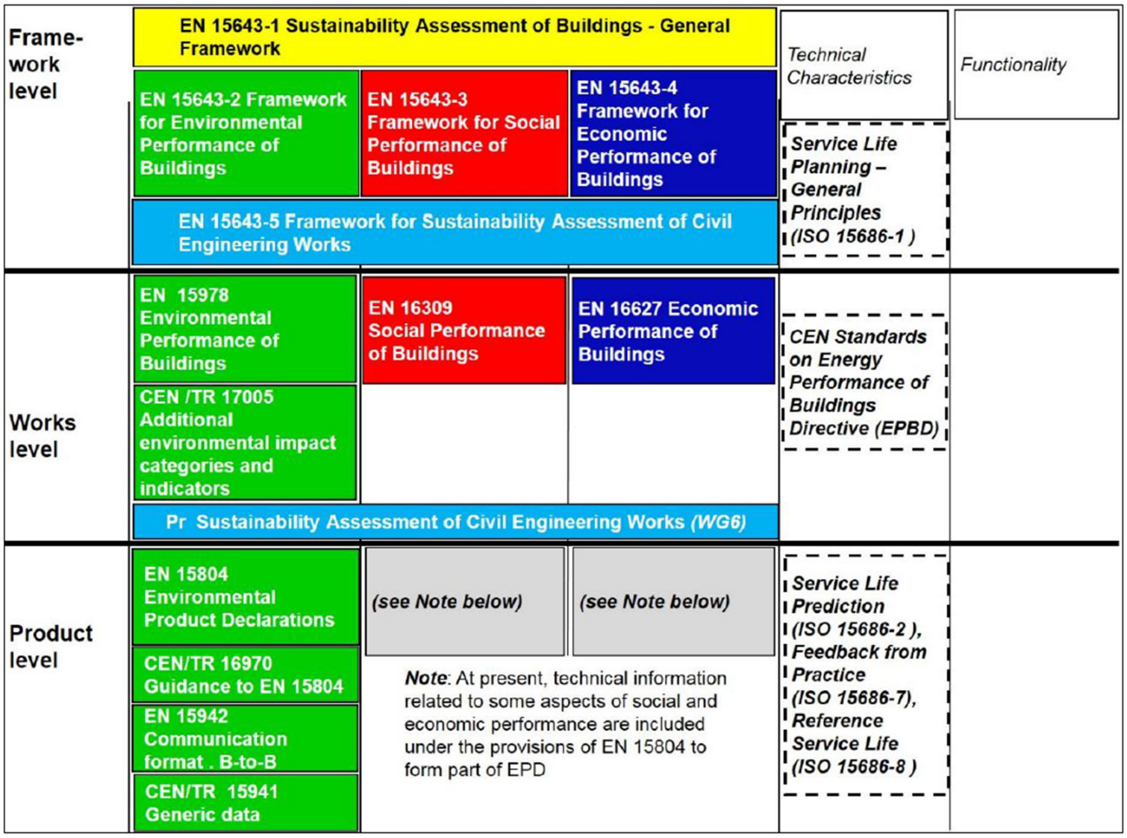


Figure 3.1 Developed European standards for LCA and engineering work (Hamel et al., 2020)

Error! Reference source not found. shows modules included in the social economic and environmental assessment of EN 15643-5 2017.

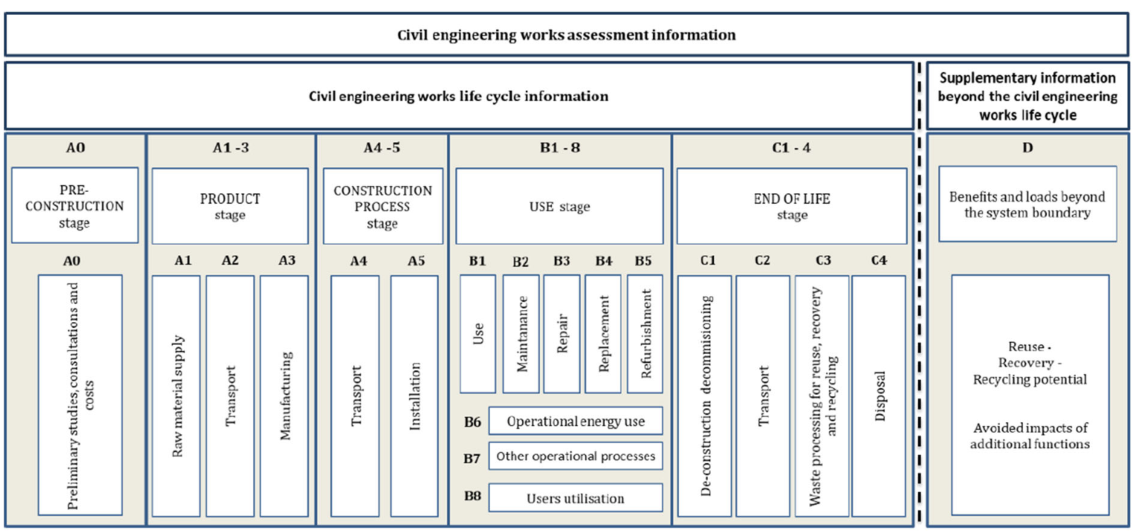


Figure 3.2 Included modules in EN 15643-5:2017 standard for social and environmental assessment

NordLCA report categorizes LCA implementation in road and railway planning into 5 stages based on the road and railways planning in Sweden, Norway and Finland, these processes consist of feasibility studies, preliminary engineering, final engineering planning, construction and operation and maintenance. *Table 3.1* summarizes The LCA implementation in each of these processes.

Table 3.1 LCA implementation in road and railway planning (summarized based on Hamel et al. (2020)*)*

<table>
<tr><th rowspan="3">Road and railway planning processes</th><th colspan="5">LCA study definition</th></tr>
<tr><th rowspan="2">Goal</th><th colspan="3">Scope</th><th rowspan="2">Data quality</th></tr>
<tr><th>Product system definition</th><th>Functional unit</th><th>System boundaries</th></tr>
<tr><td>Feasibility studies</td><td>Providing decision support for transportation selection solutions</td><td>It is one complete rail/road infrastructure system</td><td>One completed project in operation over the study assessment period</td><td rowspan="3">Material production (A1-A3) and construction (A4-A5) Operation, maintenance activities such as winter maintenance, lighting, and tunnel ventilation. Use of infrastructure such as traffic emissions</td><td>It is recommended that sources from previous LCA studies on similar projects be chosen</td></tr>
<tr><td>Preliminary engineering Planning</td><td>Assessing environmental impacts of alternative corridors (it is also possible to assess specific elements)</td><td>Project (e.g., the road from point A to point B) or element (e.g., bridge, tunnel)</td><td>One completed project in operation over the study assessment period</td><td>It is recommended that sources from previous LCA studies on similar projects be chosen</td></tr>
<tr><td>Final engineering Planning</td><td>Assessing environmental impacts of alternative components such as pavement, asphalt type or railway sleepers</td><td>Project (e.g., the road from point A to point B) or Element (e.g., bridge, tunnel) or component (e.g., pavement) or Material (e.g., bitumen)</td><td>Road infrastructure: one km of a road or one m^2 of road; Rail infrastructure: one km of railway</td><td>for material types and quantities (A1-A3) specific data can be used in combination with generic average values for emissions factors.

For A4 and A5 general average values can be used</td></tr>
</table>

Construction	Assessing the environmental impacts of alternative materials and products	Project (e.g., the road from point A to point B) or element (e.g., bridge, tunnel) or component (e.g., pavement) or material (e.g., bitumen)	Road infrastructure: one km of a road or one m^2 of road; Rail infrastructure: one km of railway		for material types and quantities (A1-A3) specific data can be used in combination with generic average values for emissions factors. For A4 and A5 general average values can be used
Operation and maintenance	Assessing environmental impacts of alternative options considered during maintenance activities, such as resurfacing, rebuilding of pavement and replacement of railway sleepers	Project (e.g., the road from point A to point B) or element (e.g., bridge, tunnel) or component (e.g., pavement) or material (e.g., bitumen)	Road infrastructure: one km of road/one m^2 of road; Rail infrastructure: one km of railway		for material types and quantities (A1-A3) specific data can be used in combination with generic average values for emissions factors. For A4 and A5 general average values can be used

4 LCA tools in roadside infrastructures projects

Different software tools have been developed to evaluate the environmental impact of road and transport infrastructure through the LCA method, and to help road authorities and contractors provide decision support which are presented in8 Appendix. This chapter describes the software tools that are currently most relevant and used in the field. These are VegLCA, EFFEKT, Meli, One Click LCA, ECO-it, Dubocalc, InfraLCA, Klimatkalkyl and Geokalkyl. The life cycle stages mentioned in the upcoming sections are following the EN15978: 2011 terminology (see *Figure 4.1*).

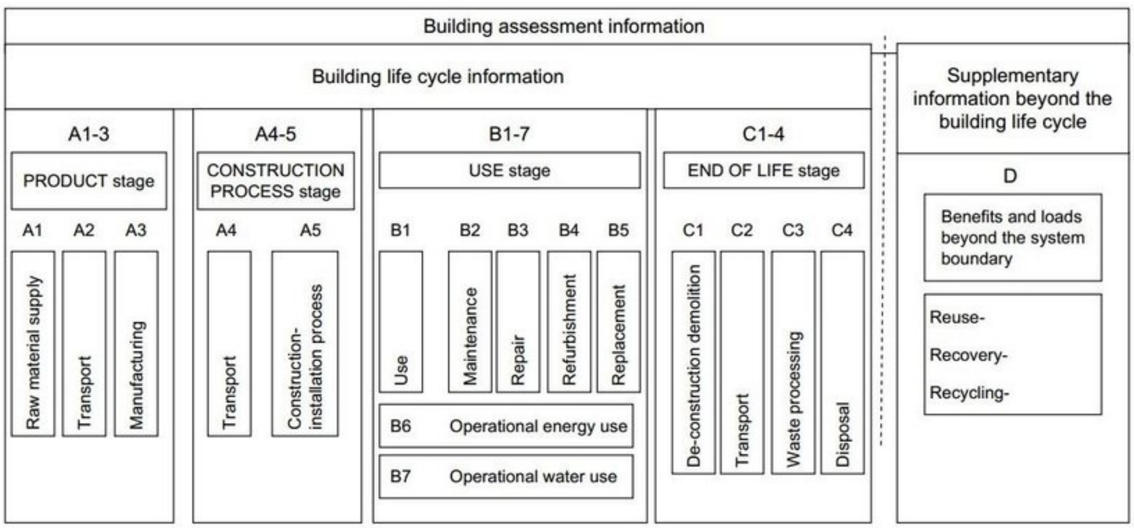


Figure 4.1. LCA stages according to EN 15978:2011.

4.1 VegLCA

VegLCA is an Excel-based LCA tool which is developed for Norwegian National Public Roads Administration (NPRA) in 2015. The latest version of VegLCA, V5.10B, has updated in May 2022. It consists of two tools, an overall and a detailed tool. The overall tool is for early planning when detailed infrastructure planning is not available (Rønnevik et al., 2022). The main focus of this tool is global warming potential. However other indicators such as acidification, eutrophication, photochemical smog and energy usage can be evaluated (Von Der Tann et al., 2022). The included life cycle stages are A1-A3 (product stage), A4-A5 (construction process), B4 (replacement) and B5 (refurbishment). It has a pre-selected process (mostly based on Ecoinvent) for early design and is simple to use to see the comparison between different options (ibid).

VegLCA is developed according to the same hierarchic structure used by road planners and entrepreneurs calculating economic budgets which is called the process code. This makes the software a simple and practical tool for road planners (Nord-LCA, 2017). This tool can be **used at the end of the planning stage** to define the material and design choices, the source of materials and the construction equipment needed. For data input, some default values of emission factors are provided in the tool, but new values can be used for some known cases.

Some project specific emission intensities such as EPD data can be added as well (Reeves et al, 2020).

VegLCA tool is able to **improve environmental optimization at a full level**, by defining material choices to use in components and layers of roads, transportation distances for soil and rock masses, equipment and technologies of construction, designing bridges and tunnels, operation and maintenance plans, etc. In road administrations procurements, VegLCA can be applied to provide environmental impact budgeting as part of the decision process (Nord-LCA, 2017). VegLCA is an addition to an earlier software, EFFEKT, which aimed to calculate GHG and cumulative energy consumption of road infrastructure in the early planning process(O' Born et al., 2018).

It can be observed in the figures below a screen shot of the input sheet for bridges and quays and some of the result summary sheets.

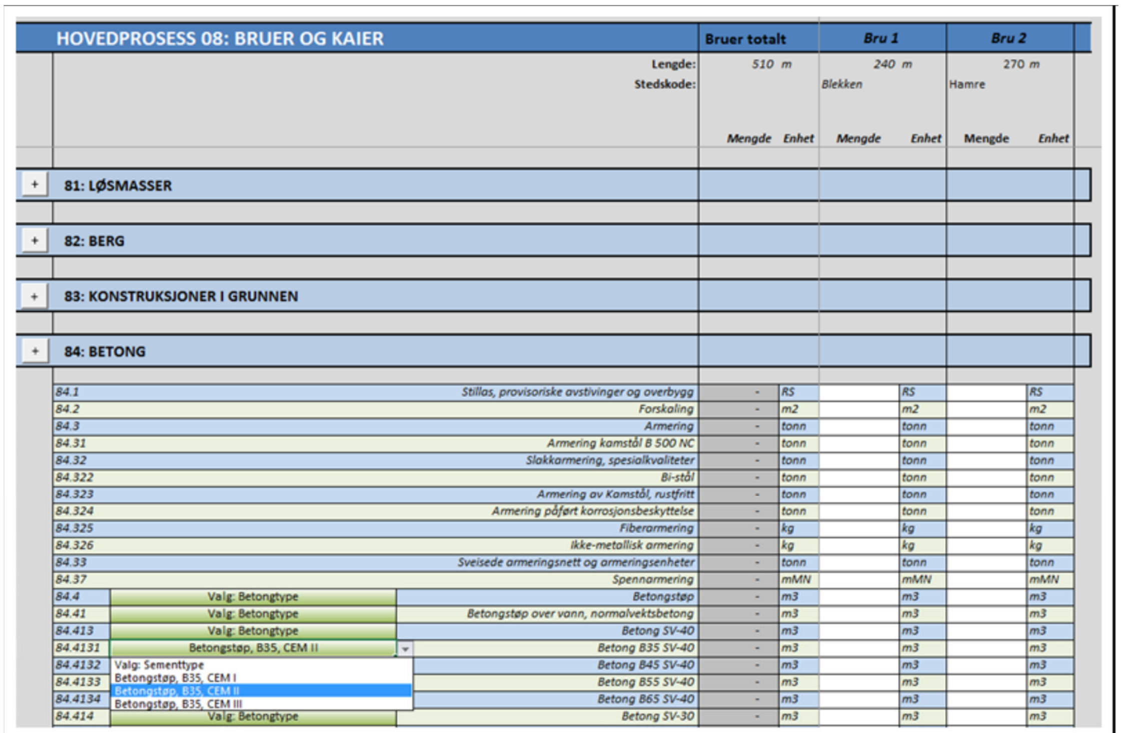


Figure 4.2. An input sheet of VegLCA tool (Nord-LCA, 2017).

Resultater for E6 Egge - Sletta, totalt for 60 års analyseperiode

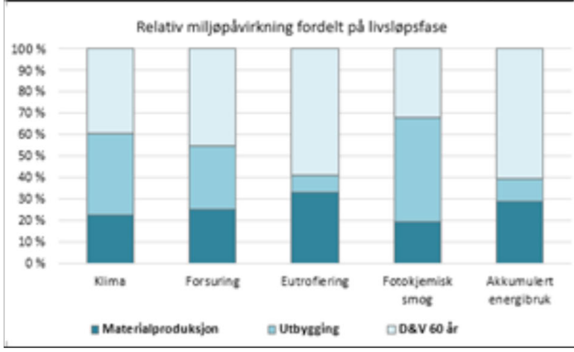
Prosjekt- og analysebeskrivelse

Navn på den som har utført analysen	J. Hammervold		
Dato for analyse	02.11.2016		
Analyseperiode	60	år	
Utslippskoeffisienter brukt i analysen	Norske gjennomsnittsdata		
Utbyggingsprosjekt	E6 Egge - Sletta		
Vegtype	Motorveg klasse A		
ÅDT	10 000		
Fartsgrense	90	km/t	
Antall felt	4		
Vegbredde	23	m	
Vegstrekningens totale lengde	2 470	m	
Veg i dagen	*1 420*	*m*	*57 %*
Tunnel	*540*	*m*	*22 %*
Bru	*510*	*m*	*21 %*

	Fordelt på livsløpsfase				
	Klima	Forsuring	Eutrofiering	Fotokjemisk smog	Akkumulert energibruk
Livsløpsfase	*tonn CO2e*	*kg SO2e*	*kg P-e*	*kg NMVOC*	*GJ*
Materialproduksjon	493	4 089	138	3 400	35 099
Utbygging	840	4 873	35	8 386	12 761
D&V 60 år	866	7 350	245	5 606	73 999
Sum	**2 199**	**16 311**	**417**	**17 391**	**121 858**

	Utbygging				
	Klima	Forsuring	Eutrofiering	Fotokjemisk smog	Akkumulert energibruk
Materialkategori	*tonn CO2e*	*kg SO2e*	*kg P-e*	*kg NMVOC*	*GJ*
Sprengning	-	-	-	-	-
Anleggsmaskineri	613	3 716	14	6 429	8 913
Massetransport	227	1 157	21	1 956	3 848
Elektrisitet	-	-	-	-	-
Sum	**840**	**4 873**	**35**	**8 386**	**12 761**

	D&V 60 år				
	Klima	Forsuring	Eutrofiering	Fotokjemisk smog	Akkumulert energibruk
Materialkategori	*tonn CO2e*	*kg SO2e*	*kg P-e*	*kg NMVOC*	*GJ*
Asfalt	615	6 277	117	4 533	60 818
Betongelementer	-	-	-	-	-
Betonghvelv	-	-	-	-	-
Anleggsmaskineri	36	216	1	373	518
Elektrisitet	66	191	31	148	10 279
Grus/pukk	-	-	-	-	-
Kamstål	-	-	-	-	-
Plasstøpt betong	-	-	-	-	-
Sement	-	-	-	-	-
Sprøytebetong	-	-	-	-	-
Konstruksjonsstål	149	666	96	552	2 384
Trevirke	-	-	-	-	-
Annet	-	-	-	-	-
Sum	**866**	**7 350**	**245**	**5 606**	**73 999**



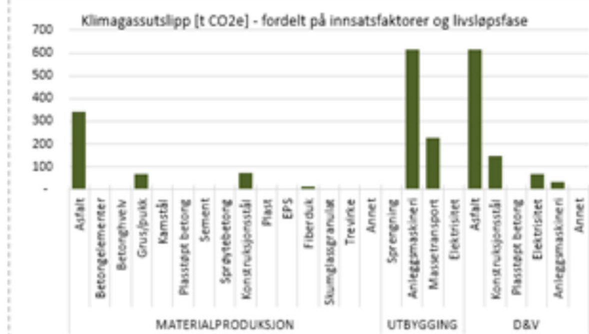


Figure 4.3. A result sheet of VegLCA tool (Nord-LCA, 2017).

4.2 EFFEKT

The Norwegian Public Road Administration has developed and been using another LCA tool called EFFEKT. This tool is originally developed to implement cos-benefit analysis (CBA) of road construction projects. By increasing greenhouse gas emissions in the transport sector, LCA method is also added to this tool in order to measure energy consumption during the life cycle and GHG-emissions such as CO2-equivalents (Liljenström, C, 2013).

In this tool different infrastructures such as roads, bridges and tunnels could be compared. Ferries are also considered in this software since they are an important part of the Norwegian transport network. LCA stages that are included in EFFEKT are material production, construction and operation, and maintenance. Operation of traffic is also considered, but this tool does not calculate the end-of-life stage. However, this stage for bridges does not contribute much to the overall results of the LCA impacts (Sandvik and Hammervold, n.d.).

Regarding **input data**, it is attempted to be not complicated and just data which are already considered for the economic module and information in the early planning stage are included. Materials that are included in EFFEKT for roads are aggregate/gravel, asphalt, hot mix, explosives, and steel. Asphalt, concrete, explosives, PE-foam, rebar, and steel are considered for tunnels, and for bridges, asphalt membrane, asphalt, concrete, rebar, and steel are included.

For the construction operations, excavation of rock and soil including transportation of excavated masses withing the project are considered. Regarding the operation of the road infrastructure, road lighting electricity, tunnel ventilation systems and pumping of water away from tunnels are included. There are no maintenance activities considered for tunnels and bridges, but for roads, producing materials to implement the re-pavement of the road after a certain time is included. Since the standard time period for analyzing the impacts in the economic version of EFFEKT is 25 years, this period is also used for LCA method. The default service life used for all elements is 40 years, but changeable by users. Materials, fuels, and technologies used in operation and maintenance stages are assumed to be as same in construction stage. Background input data for different material consumptions for instance the amount of steel needed to build a bridge with a definite size is calculated based on information of previous Norwegian road construction projects, and regression equation for that material consumption of different types of bridges. The database used to calculate the energy consumptions and emissions is Ecoinvent 2.2, just the electricity mix is adopted from Norwegian and Nordic mix (Liljenström, C, 2013).

4.3 Meli

The initiation of LCA tool development for infrastructure projects in Finland commenced in 1999 with the introduction of Meli, which focuses on earthworks, pavements, and soil improvement and its database contains the significant environmental impacts and burdens associated with roadside infrastructures (NordFoU, 2017), including energy and fuel consumption, leaching heavy metals into soils and atmospheric emissions of NO_x and CO_2 (Mroueh et al., 2000).

Meli is an Excel-based tool for calculating and comparing the environmental impacts of different alternatives of road infrastructure production, transportation, construction and maintenance (Mroueh et al., 2000). Certain sections of the Meli database have undergone updates after its initial development. Specifically, a tool called Meli-HEL was created for the City of Helsinki, focusing on evaluating the life cycle assessment (LCA) of soil reinforcement methods. Additionally, a web-based tool known as Meli2017 has been developed to feed the needs of planners and designers (NordFoU, 2017). Figure 4.4 shows the presented result in the tool.

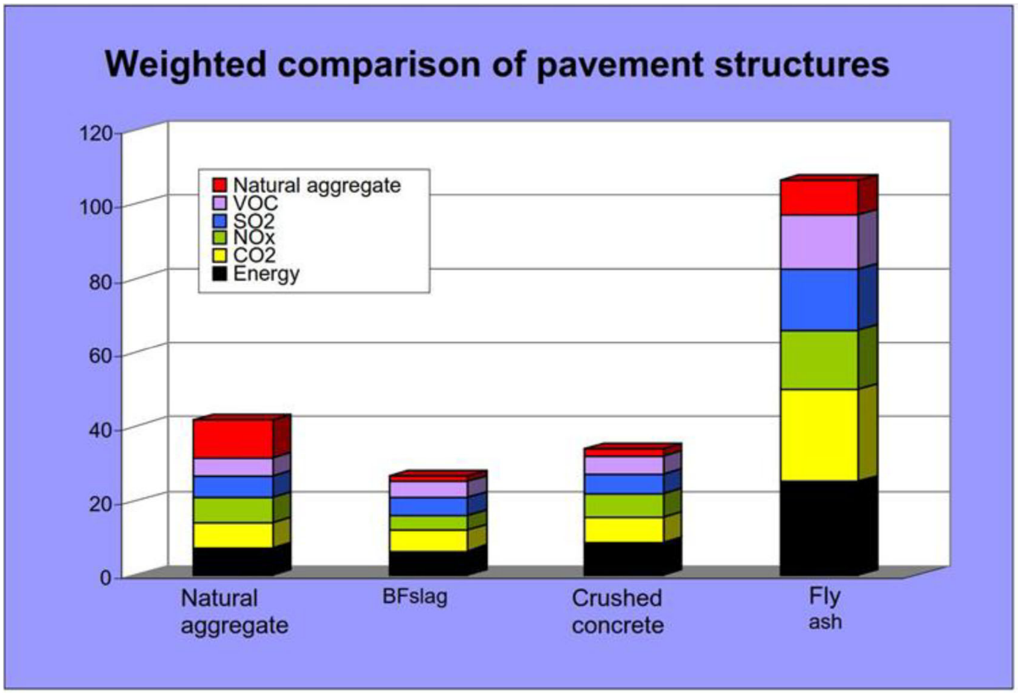


Figure 4.4 Results from Meli calculations

4.4 One Click LCA

One Click LCA is a tool designed by One Click LCA (former Bionova Ltd.) for conducting Life Cycle Assessment (LCA) and Life Cycle Cost (LCC) assessments within the construction industry. It incorporates local data and holds certifications from various rating systems, including BREEAM, LEED, and DGNB (NordFoU, 2017). One Click LCA stands out as a browser-based cloud service dedicated to the environmental and life cycle assessment of both infrastructure and building construction. This comprehensive service incorporates over 4,500 current and validated environmental profiles of construction materials. Notably, it encompasses special materials specifically relevant to infrastructure projects. To ensure credibility, the service has undergone third-party verification to align with EN 15978 standards (Pasanen and Miilumäki, 2017).

Based on Pasanen and Miilumäki (2017) the computation process involves the creation of an infrastructure object within the One Click LCA tool. Subsequently, titles corresponding to the materials, structures, and transport outlined in the list are chosen from the tool's database. Masses and transport distances are inputted for the selected items, and the program then computes results based on the provided data. The outcomes are presented in a concise summary table, or they can be preserved and exported as a detailed Excel report for further analysis and documentation. Figure 4.5 presents the tool's calculation screenshot.

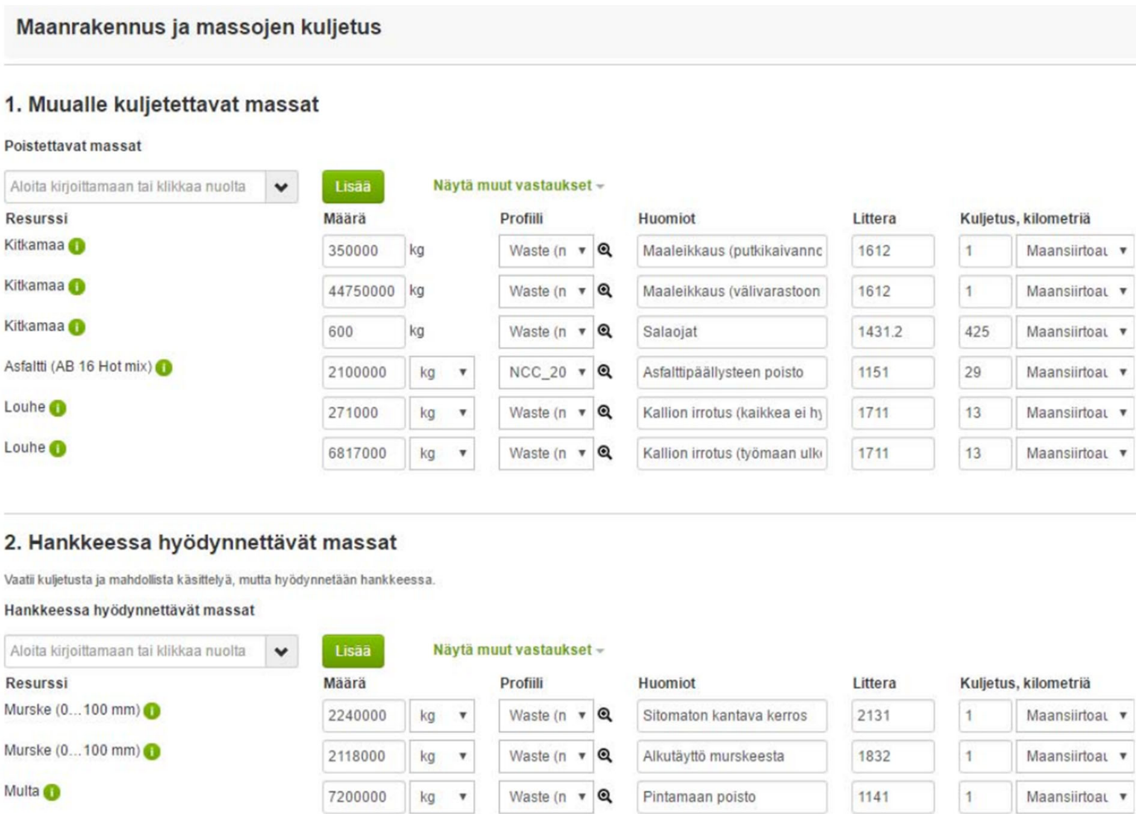


Figure 4.5 Screenshot of the One Click LCA calculation tool (Pasanen and Miilumäki, 2017)

4.5 Dubocalc

Duurzaam Bouwen Calculator (Dubocalc) is a LCA tool developed in 2014 by The Ministry of Infrastructure and Environment of Netherlands, Rijkswaterstaat. The main purpose of Dubocalc is **calculate impact of construction project towards the environment**, hence the results will be used to compare the tender offers. According to van Eldik et al. (2020), Dubocalc utilizes the environmental attributes (e.g., GWP) in the National Environmental Database of Netherlands to calculate the environmental impact scores (EIS), thus convert it into an environmental cost indicator (in MKI = Milieu Kosten Indicator) by performing a shadow price method. Further, to van Eldik et al. (2020) elaborated that the shadow price method is executed through the multiplication between EIS (in MKI) and fictitious costs, thus, resulted in the additional "cost" of a design in terms of the environmental impacts. By this mean, the lower the EIS, the least fictitious the offer is, explained by Diemel and Fennis (2017). Dubocalc provide the translation of environmental attributes from the Dutch National Environmental Database to

Unit EIS	Unit	Lifetime (years)	EIS_{CON} (€)	$EIS_{O\&M}$ (€)	EIS_{EOL} (€)
Asphalt (ZOAB)	ton	12	10,621	84,63	0,92
Asphalt (SMA, 0/11)	ton	16	10,372	59,28	0,92
Concrete mortar C20/25 (CEMIII)	m2	100	29,48	0,00	3,21
Concrete mortar C30/37 (CEMIII)	m3	100	15,14	0,00	6,34
Steel sheet pile	ton	100	96,43	0,00	-13,90
Composite sheet pile	ton	30	881,391	2168,32	47,89
Grout anchor	m3	100	28,345	0,00	1,12

EIS. Some examples of outputs from Dubocalc can be seen on Figure 4.6.

When calculating, DuboCalc have the ability to calculate extensive impacts of materials and energy consumption for the whole life cycle which cover modules A1-D or from raw materials until demolition and reuse stage. There are **11 different environmental indicators** used in Dubocalc, Santos et al. (2017) mentioned it consist of abiotic depletion, climate change, ozone depletion, photochemical ozone creation, acidification, eutrophication, human toxicity, freshwater aquatic ecotoxicity, marine aquatic ecotoxicity, terrestrial ecotoxicity. In detail, as described by Vorobjovas et al. (2017), Dubocalc provide several freedoms for the user to decide the mode of materials transportation, make alterations to asphalt type, as well as change the materials and energy consumption features when producing asphalt. Moreover, Dubocalc is beneficial to examine and compare various designs of road whether they have a great number of environmental impacts or not, although the environmental properties used are limited to the national database. There is no explanation whether Dubocalc can be utilized in another country, but as identified by Liu, van Nederveen, Wu and Hertogh (2018), this indicator is only in Dutch version (MKI) and commonly used for the infrastructure projects in the Netherlands. Confirming the statement of Vorobjovas et al. (2017), the software is merely **applicable for the Dutch market since the user can only choose the standardized materials in the Netherlands and the materials should already exist in the market**. In other words, the software does not allow the user to custom their own materials.

4.6 InfraLCA

The InfraLCA is originally VejLCA which then developed and changed the name to InfraLCA. The development of InfraLCA is handled by the Danish Road Directorate. Now, Banedanmark became the co-owner of InfraLCA and help the development of the tool. The program is developed to **calculate the carbon emission impact of infrastructure projects** covering designing, production, and operational phase. InfraLCA is basically a Ms. Excel-based program which composed of database that further can be calculated for climate impact analysis for all products and activities in the infrastructure project and, described by CO-PI (2022), encompasses cradle to grave or cradle to cradle (no waste or full loop) systems. However, there is a contradiction of which system covered by InfraLCA, Vejdirektoratet (2022) mentioned clearly that InfraLCA covered cradle to gate systems which means only modules A1 to A5 are included, and also the module B4. The input for calculating with InfraLCA are numerous, primarily materials and services volumes in tender list format or the number in a more aggregated format. The detail information for input in InfraLCA can be found on Table 4.1.

Table 4.1 Input of InfraLCA (source: Vejdirektoratet, 2022)

Input	Unit	Description
Overall estimate or turnkey contract entries or gross list entries (later in 2021)	Depending on the device of the specified record	The mailing lists are maintained by the Danish Road Directorate and Banedanmark
Material emission factors	• Global warming	EPD format by EN15804

for A1-A3	• Depletion of the ozone layer • Photochemical ozone formation • Acidification • Eutrophication • Dilution of abiotic non-fossil resources • Dilution of abiotic fossil resources	Default values can be found in InfraLCA
Emission factors for transport A4 and distances associated with materials	• Emission factor for tkm • transport and transport in km	Default values can be found in InfraLCA
Energy consumption for built-in works A5	• kWh electricity • liter of fuel	Default values can be found in InfraLCA
Lifetimes of materials for calculations of potentials for B4	Analysis period and service life in years	Default values can be found in InfraLCA

Further, Vejdirektoratet (2022) also formed a system delimitation for InfraLCA, which the information could be found on Table 4.2.

Table 4.2 Software limitation (source: Vejdirektoratet, 2022)

Included modules	**Data basis in model**	**Description**
A1 – A3 Product stage	Generic average emission factors and EPDs	
A4 Transport	Transport distance and generic average emission factors	
A5 Construction installation process	Prerequisites from e.g. The Danish Road Directorate and literature and average emission factors for energy consumption	Prerequisites do not exist for all records
B4 Refurbishment	Lifetime prerequisites for material from Road Directorate	Prerequisites do not exist for all records

Stated by Vejdirektoratet (2022), the output of the calculation from InfraLCA is the accumulated environmental impact for the whole project which grouped based on different phases. The 7 **indicators involved in InfraLCA** are global warming, ozone depletion, photochemical ozone formation, acidification, eutrophication, depletion of abiotic non-fossil resources and depletion of abiotic fossil resources. The default values in InfraLCA are using the generic data which applies to emission factors, transport distances, and lifetimes of product and materials. The standard factors of emissions, which based upon the general market conditions of Denmark, are developed by COWI A/S and the Danish Road Directorate. InfraLCA gives the room for customization for the user which allows user to change the default values into the project-specific values which the values might be adopted from EPDs. Aspects that can be edited are quantities in the offer list, factors of emission, distances of delivery, service lifetime, and etc. (Vejdirektoratet, 2022). The output of the InfraLCA is generated in CO2 emissions amount.

4.7 Klimatkalkyl

Klimatkalkyl is a Life Cycle Assessment (LCA) tool developed by Trafikverket, the Swedish transport administration. Its purpose is **to measure energy usage and emissions associated with infrastructure projects throughout their construction, operation, and maintenance** stages(Reeves et al., 2020). Initially created by WSP consultancy and funded by Trafikverket (Lemperos & Potting, 2015). Klimatkalkyl serves as a valuable resource for **both planning and procurement processes**. It allows the national road authority to establish a baseline and enables suppliers to select designs with lower carbon emissions for tenders (Reeves et al., 2020).

Klimatkalkyl was first launched in 2013 as an Excel-based tool and has since transitioned to an online **web-based** version. The tool draws its resources primarily from previous construction calculations, environmental product declarations (EPD), and experienced-based data from designers (Toller, 2020). Regular updates have been made to each version. **Specifically designed for road and railroad projects in Sweden**, Klimatkalkyl adheres to Swedish procedures and regulations, limiting its usability outside of Sweden (Lemperos & Potting, 2015)

The development of this tool aligns with Sweden's climate policy framework, TDOK 2015:0007, which aims for carbon neutrality by 2045 (Toller, 2020). Consequently, the Swedish Transport Administration has implemented regulations regarding the use of Klimatkalkyl. Since April 2015, it has been mandatory to utilize Klimatkalkyl for calculating greenhouse gas (GHG) emissions in infrastructure projects that exceed 50 million SEK and have completion dates after 2020. Additionally, starting from February 2016, it has been necessary to meet procurement requirements criteria. From March 2018 onwards, requirements for materials and fuels have extended to maintenance and projects under 50 million SEK (Reeves et al., 2020).

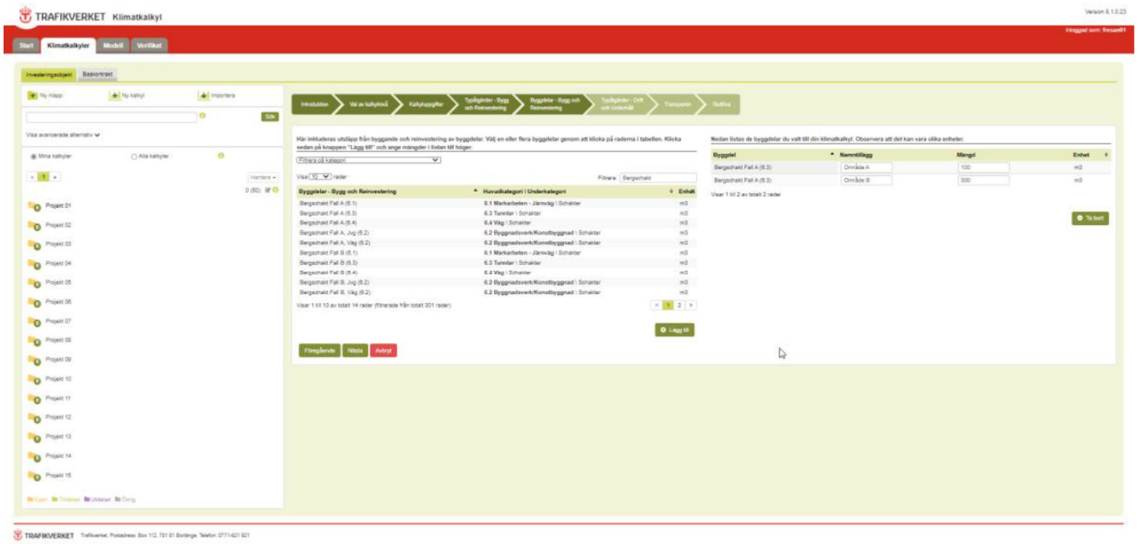


Figure 4.7 Klimatkalkyl user interface (Norberg, 2022)

Based on Reeves et al. (2020) when using Klimatkalkyl, suppliers must obtain approval from a third-party EPD auditor if they are employing materials do not present in the tool's database. Suppliers are required to submit tenders that include calculations of carbon reduction achieved using Klimatkalkyl. Although the calculation itself may not be included, the carbon reduction goal is discussed during contract negotiations. At the end of the project, a climate declaration is submitted based on the actual quantity of materials used.

Klimatkalkyl offers users the ability to compare various route options, such as tunnels and bridges, based on their associated GHG emissions (Reeves et al., 2020). Once a route is chosen, users can measure energy consumption and GHG emissions to identify areas for improvement and emission reduction.

It is not necessary for users to have an environmental engineering background (Lemperos & Potting, 2015) and they have flexibility in selecting input options. GHG emissions can be calculated using Input A (e.g., the specific activity of the project, such as the area of a bridge or the length of a tunnel), Input B (more detailed information about materials, components, or energy usage), or Input C (a combination of the previous two options) (Toller, 2020). Version 5.0 introduced an additional input, Input D, specifically for road maintenance climate calculations. Users can adjust resource templates by altering the number of building components (for Input A) or adjusting the materials and work steps (for Input B). In Klimatkalkyl 7.0, transportation from the factory to the construction site is included, allowing users to modify distances, fuel usage, and, to some extent, transportation modes (Toller, 2020).

4.8 Geokalkyl

Geokalkyl is **an Excel-based tool** which has been developed since 2012 by Vectura and Åf and the Swedish transport administration (Trafikverket) owns and manages it (Granqvist, 2017).

Geokalkalkyl intends to couple LCA with GIS (geographical information system) to be used during the early stage of road infrastructure planning (Karlsson et al., 2017). It aims to compare different alternative corridors based on **energy consumption, green gas emissions and cost for infrastructure projects** where geotechnical measures have great importance (Lindgren, 2018).

The newest version (version 3.0) handles railways (in addition to roads) up to four tracks (Lindgren, 2018). To be able to use the tool, the user should define a long-distance infrastructure connection between two target points (two locations) which can be studied as road or rail connections and the focus of the tool is on geotechnical foundation reinforcement and mass management (ibid).

Geokalkyl is **based on GIS and calculates project-specific data for excavation and fill volume** in the early planning projects based on the map in which the construction project is to be carried out (Liljenström & Björklund, 2022). This tool interprets the soil condition of a project, calculates mass balance for soil and rock handling, obtains facility model and soil layer in 3D that shows the land requirements, proposes few geotechnical foundations reinforcements and where cost and climate impacts take place in facilities estimation (Lindgren, 2018). For using the tool, basic knowledge and familiarity with GIS are needed. In the case of designing line alternatives road or railway designing experience is also required (ibid).

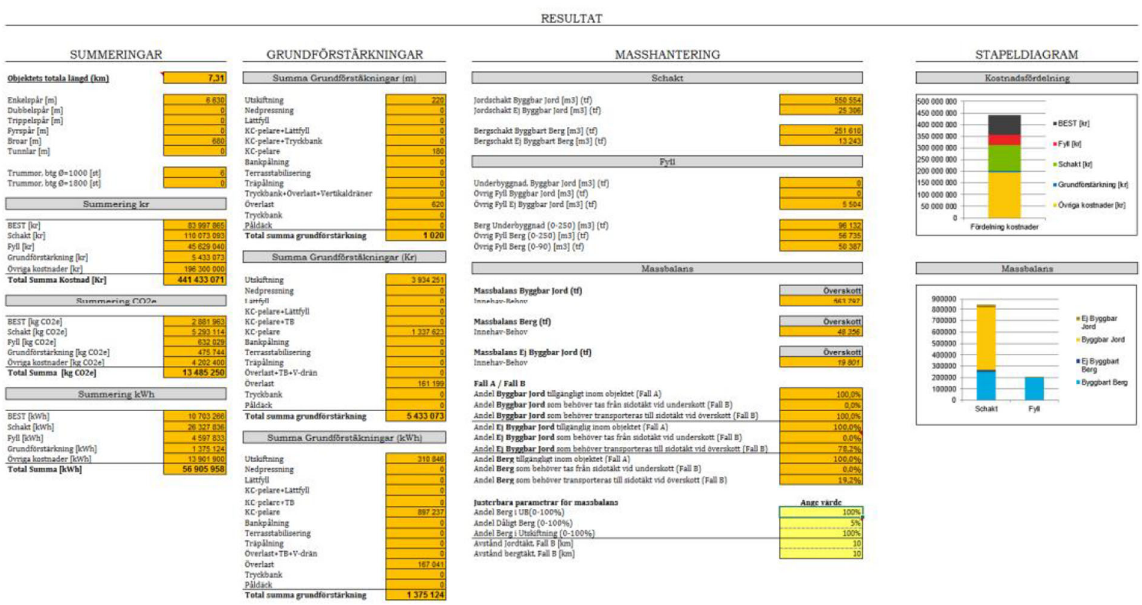


Figure 4.8 Examples of summaries from the Result tab in Geokalkyl (Lindgren, 2018).

Currently, there are a few limitations in the model. It is valid to be used in the early stage and cannot be compared with the completed design and model handles bridges and tunnels through templates (for simplification) (Lindgren, 2018). However, this tool handles both road and rail as well as several different types of sections for each facility (ibid).

5 SWOT-like analysis

5.1 Tool selection for analysis

Following an initial review of Life-Cycle Assessment (LCA) tools and consultation with the NRAs, it was found that different software tools have been developed to evaluate the environmental impact of road and transport infrastructure through the LCA method, and to provide a decision support tool for road authorities and contractors among those tools, Dubocalc, VegLCA, and Klimatkalkyl tools are commonly used by NRAs. All of them have their own advantages and disadvantages, which may mean they are **not suitable to undertake LCA analysis for specific asset types such as roadside equipment** (noise barriers and safety barriers).

The PROCEEDR project aims to develop an LCA tool particularly for roadside equipment. However, drastic changes (either interface or functionality) from the currently used tools might not result in an effective tool implementation. Hence, it is assumed that the best approach would be to understand the pros and cons of currently used tools (Dubocalc, VegLCA, Klimatkalkyl) and use that as a **best practice to develop a new PROCEEDR tool** in the process. In that way, it is expected that LCA specialists from NRAs will be more familiar with the proposed LCA approach and more likely to start using the new tool.

5.2 SWOT-like analysis

Each of the tools (Dubocalc, VegLCA, Klimatkalkyl) have their own advantages and disadvantages. We have applied a SWOT-like analysis to understand and assess these. Our approach has considered the ‘internal’ factors (Strengths and Weaknesses) which are factors directly related to how the tool works, and ‘external’ factors (Opportunities and Threats) which are factors related to the wider environment. However, it should be noted that for this SWOT-like analysis, there was a limitation of available data/feedback from tool users to allow in-depth assessment of both internal and external factors. Bearing that in mind and the purpose of the PROCEEDR project to develop a tool for noise and safety barriers, the content within this analysis was majorly focused on internal factors (strengths and weaknesses). Internal factors are more in control of the tool developers to tailor the tool, so it better meets the needs, requirements, and expectations of tool users. Therefore, this SWOT-like analysis below provides a combined assessment of all relevant positive factors (strengths and opportunities) and negative factors (weaknesses and threats) without separating them.

- ***Strengths*** describe the benefits that tool are good for.
- ***Weaknesses*** describe the disadvantages and risks of using each tool. These are also the areas where tools may be improved if possible.
- ***Opportunities*** refer to favourable external factors that could give additional advantages of using a particular tool.
- ***Threats*** refer to external factors that are beyond control when using a particular tool and which may have the potential for negative implications.

5.3 SWOT-themes

We have also identified a set of 'Imperatives' that provide a context within which the strengths, weaknesses, opportunities, and threats should be considered:

- **Availability -** refers to the general aspects of the tool, such as is it available for everyone, what are the terms for using it, cost of acquiring/licencing and maintaining the tool, is the user interface simple and user-friendly.
- **Applicability –** characterises the users of the tools, is it suitable for the procurement phase, are there any requirements from the government to use this tool, and whether this tool is aligned with the European or national standards for LCA/LCCA.
- **Lifecycle coverage -** refers to the tool's applicability for different project or product/solution lifecycle phases – e.g. can this tool be used for product and construction phases only or does it cover the whole lifecycle? Can this tool be applied for LCA analysis of the "beyond the lifecycle" phase.
- **Data** - covers the input parameters and topics/areas for consideration within the tool. It also refers to the database used in the tool – who owns/updates and is it transferable between regions/countries.
- **Output** - describes what metrics/parameters are used in the tool, what outputs does the tool produce and whether the outputs can be used to seek EPD.
- **Roadside equipment** - investigates whether the tool can be used to undertake LCA/LCCA analysis for roadside equipment, especially for noise and safety barriers.

5.4 SWOT-analysis tables

The tables below show a summary of the strengths, weaknesses, opportunities, and threats for each of the reviewed tools. It should be noted that the SWOT-type analysis was prepared based on the available information that was found online (see references) and did not include any consultation with users of these tools. Hence, there may be limitations to the content and extent of the SWOT-type analysis that has been undertaken.

5.4.1 DuboCalc

Themes	Strengths and opportunities	Weaknesses and threats
Availability	• Easily accessible web-based application • Developed by RWS and made available to all clients and market. Hence meets the needs of the RWS. • Tool is managed, regularly maintained, and further developed. • Regularly organised Dubocalc users group meetings • Projects can be shared with people within the same company by sending an invite. • Security measures such as two-step authentication can be used.	• Available in Dutch language only. • Not free to use. Licence fee is 180-350 euros (depends on the number of licences purchased) per user per year with a maximum of 50 projects per user per licence. • Access to the tool is limited to projects only.
Applicability	• Tool can be used to design an asset and evaluate/optimise sustainability; in procurement procedures; and in monitoring of assets. • Appropriate for construction works in general and roads construction and maintenance. Can be used to assess the impacts of proposed materials, including groundwork, pavement, coatings, inter-layers and under layers. • Tool can be used by road owners/managers and contractors • Dubocalc analysis can be used as a permit criterion in Most Economically Advantageous Tenders (MEAT) for government contracts. • Environmental Cost Indicator (ECI) value can be used as a performance or quality criterion. • Compatible with the EPD methodology (EN 15804) and partly compatible with UNE CWA 17089 (Indicators for the sustainability assessment of roads). Methodology of the LCA	• Tool cannot be used to analyse and/or optimise product/solution sustainability or for verification of sustainability claims. • Tool is not suitable for the project planning phase. • Tool cannot be used by product/solution developers. Model does not allow to model new products/solutions.

Themes	Strengths and opportunities	Weaknesses and threats
	is in accordance with the ISO 14040 standards and Environmental Assessment Method Buildings and Construction • Can be used not only for road infrastructure but also for other sectors (e.g. railways, dams) suitable for calculating different objects in civil infrastructure.	
Lifecycle coverage	• Based on the standardised methodology (ISO 14040) of Lifecycle analysis (LCA). • Is applicable to all lifecycle stages: Construction (A1-A5), Use (B1), Maintenance (B2-B5), End-of-Life (C1-C4, D).	
Data	• Tool comprises of two parts: ○ The Project: input from the user ○ The Library: reference database with basic data. • DuboCalc uses the National Environmental Database for the calculations. This database is managed and periodically updated by Stichting Nationale Milieudatabase. • Database includes product cards with general information about the product such as name, service life and functional unit, the environmental information obtained from a life cycle assessment. The items in the database can have 3 levels: ○ Category 1 data: product-specific (proprietary), tested ○ Category 2 data: industry average (brand-unrelated), tested ○ Category 3 data: industry average (brand-untested), untested This data has a storage of 30% on the MKI value due to the	• Representative of Dutch situation only. • Data older than 5 years has to be updated, otherwise it is withdrawn from the database.

Themes	Strengths and opportunities	Weaknesses and threats
	uncertainty of these values. • Has pre-modelled product/solution environmental profiles (EPD) of building products (from the Dutch National Environmental Database), and therefore does not demand a lot of data input from user. Object Library contains 46 common objects in public civil infrastructure projects which users can import into their projects. The Object Library provides insight into the average structure of objects such as viaducts, junctions, and railways. • The user does not have to fill in the Maintenance and End of Life phases. DuboCalc automatically calculates the replacement of items with a lifespan shorter than the project life.	
Output	• Determines whether the design process or the whole operation results in any sustainability benefits or less environmental impact by demonstrating a lower ECI value for parts of the design. • The methodology of MKI is based on the calculation method of Life Cycle Assessment (LCA) specified in the Assessment Method Environmental Performance Building works. By converting eleven environmental effects into shadow prices, functional units can be compared at a single value (ECI). • RWS assigns a price to specific quality aspects. • Environmental effects used in the tool: ○ Depletion of abiotic resources (excluding fossil energy carriers) - ADP	• Assess environmental impacts only. Cannot be used to assess costs or social impacts. • Determined whether environmental performance requirements are met or not but not on quality. • Impacts of road on well-being, actual need for sustainability assessments, water quantity, relation between urban and suburban development are not considered in this tool.

Themes	Strengths and opportunities	Weaknesses and threats
	○ Depletion of fossil energy carriers - ADP ○ Climate change – GWP 100yrs ○ Ozone layer depletion - ODP ○ Photochemical oxidant formation - POCP ○ Acidification - AP ○ Fertilization - EP ○ Human Toxicity - HTP ○ Freshwater aquatic ecotoxicity - FAETP ○ Marine aquatic ecotoxicity - MAETP ○ Terrestrial ecotoxicity - TETP • Many of the values are based on averages in the construction industry and contains basic LCA data for all conceivable building materials. • Levels of CO emissions are part of the output parameters of the assessment.	
Roadside equipment	• Common objects such as specific bridge of which road furniture (e.g., guardrails, lighting, etc.) are part of that standard object. The benefit of that is when applying main standard object there is no need to apply individual elements of it. • Items are compiled from the building blocks, materials, and processes that are linked to this item and potentially could be used to partly assess roadside equipment (noise barriers, safety barriers).	• However, it is not clear if individual elements (e.g., guardrails) could be considered as standalone objects.

5.4.2 VegLCA

Themes	Strengths and opportunities	Weaknesses and threats
Availability	• Easy to use (excel based calculation tool). • Offline stand-alone tool. • Tool developed in 2015 for the Norwegian Public Roads Administration (NPRA). Funded by NPRA as part of an R&D project. Tool is based on an existing tool ETSI-bru which only covered bridges. • Tool is regularly updated. • The tool is built in accordance with the same hierarchic structure used by road planners for calculating economic budgets (known as the process code in Norway). This makes the tool highly intuitive and easy to use for road planners.	• Available in Norwegian language only – no translation to English

Applicability	• Tool is designed for use at a later stage of the road planning process and in the design and contract phase.
	• VegLCA tool can:
	  ○ Be used for environmental optimisation at a detailed level, regarding material choices in components and road layers, transport distances for earth and rock masses, bridge and tunnel designs, construction equipment and technologies, operation, and maintenance strategies, etc.
	  ○ Can be implemented in tenders, making environmental impact budgeting part of the decision basis in the road administrations procurements.
	  ○ Carry out comprehensive life cycle assessments of all kinds of road infrastructure projects with calculations carried out through several life cycle phases of projects.
	• Tool includes process codes and can be used for both road infrastructure and rail infrastructure.
		• VegLCA is most suitable for as-built road infrastructures. It is less suitable for evaluating alternatives because data at the process code level is often calculated after decisions have been made.
		• Recycling of end-of-life materials (for example, steel in railings that are replaced) is not credited to the life cycle of the infrastructure being analysed. (Using recycled material in construction, on the other hand, provides an environmental benefit in line with emission savings associated with lower consumption of virgin material and possibly less emission-intensive production).

Themes	Strengths and opportunities	Weaknesses and threats
	• All projects exceeding NOK 51 million (approx. EUR 5 million) must use VegLCA to calculate greenhouse gas emissions. • Tool is prepared in accordance with ISO 14040 and EN 15804 standards.	
Lifecycle coverage	• Tool is applicable to A1-A3, A4-A5 and B4-B5 life cycle stages	• VegLCA is not applicable for the whole lifecycle of the asset; the end-of-life stage (C) is missing. It is possible that the next update will include this phase.
Data	• The late-phase calculations require detailed quantity data, while calculations for the earlier stages of the project can be based on more general quantities. • Default values for factors are implemented in the tool (providing generic data for Norwegian and European average data) but can be overwritten by the user where project specific emission factors (such as EPD data) are known. The same is true for inputs like transport distances for earth/rock masses and input materials, energy use in operation, frequency of maintenance operations, energy use in construction equipment, etc. This may mean that VegLCA is transferable to other countries. • It is not necessary to define project-specific factors for all materials and processes, but only those for whom you have your own values.	• Not a great choice of material qualities. There are several types of concrete and construction steel, which are not among the alternatives available in the VegLCA tool. • Emission coefficients have been developed with materials available on the Norwegian market in mind. This affects the production technology and the mix of material qualities. For materials as it is assumed to be produced in Norway, it is assumed that the Nordic electricity mix is used in the production (applies to modelling of factors that are not based on information from EPD).
Outputs	• VegLCA mainly covers greenhouse gas emissions from road infrastructure, but it also includes calculations for the environmental impact categories (Climate impact; Acidification; Eutrophication; Formation of photochemical smog; Energy use). • VegLCA outputs are presented at a high and detailed level such as greenhouse gas emissions per life cycle phase or according to input factors. • The calculation factors are organized into 3 groups: material	• Emission and calculation factors used in VegLCA are not necessarily compatible with other tools such as the Norwegian Public Roads Administration's cost-benefit tool EFFEKT. • Impacts of road on well-being, actual need for sustainability assessments, biodiversity, water quantity, relation between urban and suburban development are not considered in this tool. • There is a number of processes that are indicated with units that are unfavourable in relation to the

Themes	Strengths and opportunities	Weaknesses and threats
	consumption, construction activities, operation and maintenance. • Based on calculated quantities for all input factors the environmental impact is calculated by multiplying the amounts by set emission factors (for example kg CO2 equivalents per m3 of concrete) for each input factor.	environmental impact calculations, and conversions are necessary to obtain figures for consumption materials and/or energy as a basis for the environmental impact calculations. For example, the quantity of road railings is specified per m, while environmental impact is calculated per kg of steel. • Only records in the process code that describe processes that are relevant to total greenhouse gas emissions during the life of the road are included in the analysis. Materials/processes that are of negligible importance for total greenhouse gas emissions are excluded. • Entries in the process code that do not deal with the consumption of materials or energy are omitted.
Roadside equipment	• VegLCA includes some road furniture such as guardrails and road lighting in the model.	• It is not obvious to see how easy it would be to add other road furniture such as noise or safety barriers into the model.

5.4.3 Klimatkalkyl

Themes	Strengths and opportunities	Weaknesses and threats
Availability	• It is an easy-access web-based tool. • There is also a free access version (open version) with the same database and functions as the main version (except the saving option). • The user does not need to have an environmental engineering background.	• The tool and its guidelines are just available in Swedish. • To be able to fully use Klimatkalkyl functions (main version), an authorized account by the Swedish transport administration is needed. • The user cannot save the calculations in the open version tool.
Applicability	• The tool is applicable both in planning and procurement processes by either the national road authority to set a baseline or by suppliers to select a less carbon emission design. • The tool is designed to assist the Swedish Transport Administration and other stakeholders in the: o Including the road and railways infrastructure's energy use and climate impact in the decision basis. o Working with continuous improvement when planning and implementing measures. o Setting climate requirements in procurement according to TDOK 2015:0480 • From April 2015, it has been mandatory to use Klimatkalkyl to calculate GHG emissions for projects over 50 million SEK which are going to be finished after 2020. • Since February 2020 it has been used to meet the procurement requirements criteria • After March 2018, there is also requirement to use the tool in maintenance and projects under 50 million SEK.	• The tool cannot be used by product/solution developers. The model does not allow to model of new products/solutions (the user can just modify the available template resources). • Beside Swedish language of the tool, it consists of specific sections and elements which follow the Swedish procedures based on regulations and makes it difficult to be used out of Sweden.

Themes	Strengths and opportunities	Weaknesses and threats
Lifecycle coverage	• The latest version covers module A (emissions from raw material extraction, processing, transportation, and construction) and Module B (replacement of components whose useful life has ended up as well as continuous operation and maintenance: winter road and pavement maintenance, railway operation, and maintenance and operating energy for lighting, ventilation and pumping water for tunnels).	• Modules C and D have not been considered. • Traffic energy use and emissions during the infrastructure use are not included. • For tunnels and bridges, there is currently no model for operation and maintenance (module B) • Some minor contributions to energy use and climate impact are not included in the model. For example, snow removal on railways, plant control, dust binding, etc.
Data	• The resource template is based on data from previous construction calculations, environmental product declarations, specific product sheets, or experienced-based data from designers. In early versions of Klimatkalkyl, the resource templates for roads are mostly based on background reports from WSP, for railways are based on certified EPD and its underlying LCA model compiled by WSP. • The data is being revised and improved regularly; the last version was updated by Tyrens in 2020.	• Some of the data in an early version of Klimatkalkyl, before version 7.0, are derived from the Ecoinvent database, these may only be used by organizations that have a user license.

Output	• For inputs A, B, and C, outputs are divided into:
	  ○ **Build total, total per project**: energy use and climate impact from all resources use linked to the construction of the project.
	  ○ **Construction and reinvestment, per project and year**: It reflects the annual load from a facility that maintains its function based on components being replaced at a different frequency on their stated lifetime.
		• Assess only environmental impact, cannot be used to assess social and economic impacts.
		• The environmental impact has been only calculated based on CO_2 equivalent emissions not any other environmental indicators.

Themes	Strengths and opportunities	Weaknesses and threats
	○ **Operation and maintenance, per project and year**: energy use and climate impact from the operation of components (e.g., fans, lighting, etc.) as well as pavement and winter maintenance for roads are reported per year.	
Roadside equipment	• Safety barriers (roadside guardrails) have been included	• It is not clear if noise barriers have been included and if user has the flexibility to choose from different types.

6 Recommendations for PROCEEDR tool development

After undertaking in-depth review of advantages and disadvantages of DuboCalc, VegLCA, and Klimatkalkyl calculation tools, the following recommendations for the PROCEEDR tool development can be formulated:

- LCA tool should cover all life cycle phases (from A to D). This is important **to assess the impacts on environment throughout the whole asset lifecycle** as well as to undertake assessment of environmental impacts in individual stages which could result in insights on potential product/solution optimisation areas.
- It is important that the tool is developed **in accordance with EN 15804 and ISO 14040** standards. This would ensure that the comparison of the products/solutions is carried out in a standardised way and results are widely understood and accepted across different NRAs.
- From the noise and safety barrier perspective it would be beneficial to ensure that the tool could be used not only by road managers and contractors to select the right product but also for the product/solution **manufacturers to develop more environmentally friendly products**.
- User interface of the tool should be **simple, well understood and intuitive**. This ensures easier acceptance and usability of the tool amongst potential users. With regards to the tool being user friendly, an understandable guide should be written; it is also important that the tool is prepared in English to minimise language barriers.
- **A web-based application would be preferred** for the tool to make it easily accessible and to facilitate collaboration and cooperation. However, with the use of the online tools, the data security aspects should be properly addressed too.
- A critical feature of the tool will be the **database that supports and informs the calculations**. It is important that this is regularly reviewed and updated and meets data quality criteria in order to minimise differences in results.
- To allow tool transferability across regions/countries, **different weightings** or average regional values should be considered.
- Although the main purpose of the LCA tool would be to **assess the environmental impacts of noise and safety barriers**, it is also important that the tool considers **social, financial** and other technical aspects too.
- Tool integration/linking with BIM environment should be considered for the more extended tool versions and is not part of the PROCEEDR project.

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8 Appendix

Table 8.1 Developed LCA tool in Europe for roadside infrastructure

	Reference	Tool	Indicator	Infrastructure	User/Owner	Developed by
1	(Keijzer et al, 2015)	DuboCalc	GHG (CO2)	Construction industry	The national road authority of Netherland "Rijkswatersta at"	Netherland
2	(Keijzer et al, 2015)	SimaPro	Carbon footprint	Road infrastructures	The national road authority of Netherland "Rijkswatersta at"	Netherland
3	(O'Born et al, 2018)	VegLCA	Energy demand, CO2 emission	Road infrastructures	The Norwegian National Public Roads Administration (NPRA)	Norway
4	(Toller, 2020)	Klimatkalk yl	Energy demand, CO2 emission	Road and railways infrastructures	Swedish Transport Administration (Trafikverket)	Sweden
5	(Lindgren, 2018)	Geokalkyl	Cost, energy consumpti on and Green gas emissions	geotechnical foundation reinforcement and mass management of roads and railways	Swedish Transport Administration (Trafikverket)	Sweden
6	(NordFoU, 2017)	Meli	Energy and fuel consumpti on and emissions into air like NO_x and CO_2	Road infrastructures	Finnish National Road Administration	Finland

7	(NordFoU, 2017)	One Click LCA	Standard impact categories and units (CML/TRACI/PEF)	Construction industry	One Click LCA	Finland
8	(Potting & Lundberg, 2013)	LICCER (Excel based)	Energy demand, CO2 emissions	Road infrastructures	–	CEDR research
9	(Potting & Lundberg, 2013)	EFFEKT	Energy demand, CO2 emissions	Road infrastructures	Norwegian National Road Administration	Norway
10	(Anderson & Shiers, 2009)	BREEAM (Green Guide to Specification)	CO2 emissions, Water extraction, etc	Building construction	UK Government (Department of Environment, Transport, and the Regions)	UK
11	(Ghumra et al, 2009)	BREEAM (Green Guide Online)	–	Building construction	UK Government (Department of Environment, Transport, and the Regions)	UK
12	(Miliutenko et al, 2014)	AMW	GHG, Other	Road infrastructures	–	Netherland
13	(Miliutenko et al, 2014)	Carbon Road Map (CEREAL)	GHG	Road infrastructures	–	CEDR research
14	(Miliutenko et al, 2014)	CO2 Ladder		Road infrastructures	–	Netherland
15	(Miliutenko et al, 2014)	ETSI BridgeLCA	GHG, Other	Road infrastructures	–	Norway, Sweden, Finland as a research tool
16	(Miliutenko et al, 2014)	JOULESAVE 2	Energy	Road infrastructures	–	EU as a research tool
17	(Tudora, 2014)	Eco-Quantum	GHG	Building design	–	Netherland

LICCER

The LICCER is an MS-Excel based tool which is similar to the Norwegian tool, EFFEKT as the main source of inspiration, but extended to be used in Sweden, Denmark and Netherlands. It is designed to be easy is use, and its input data and calculations are transparent. This tool is developed **to be used in early stages** of road planning supporting various relevant infrastructures like road, bridge, tunnel, guardrails as safety barriers, and road lightning. Table 2 below shows different materials which can be used in LICCER tool for infrastructures. All LCA stages from material production to the end-of-life are included in this model to calculate the energy consumption and CO2-equivalents as GHG emissions. Moreover, impacts caused by traffic on the road can be also considered in this tool. Three different road corridors for a given project can be investigated and compared to the current road system. Results can be expressed in three different schemes, including individual results of each alternative, and results of comparison between different alternatives and the reference one by calculating differences of GHG-emissions and energy consumptions. There is another option to generate results in LICCER, in which the user can define input data for three different parts of one road corridor and then compare the aggregated results to the reference case (Liljenström, C, 2013).

Table 8.2 LICCER SWOT analysis

	Strengths and opportunities	**Weaknesses and threats**
Availability	• Available in English language. • Developed under CEDR Transnational Road Research Programme. Hence, focuses on multiple NRA needs. • Free to use. • Easy to use guidelines and user-friendly interface (excel based spreadsheet)	• Not easily accessible on open source or internet.
Applicability	• Tool can be used: ○ to design an asset and evaluate /optimise sustainability; ○ to analyse and/or optimise product/solution sustainability. • Tool is applicable for the planning phase. • Tool can be used by road owners. • Compatible with the ISO 14040 standard which covers the LCA and Life cycle inventory studies.	• Tool cannot be used in procurement procedures, to monitor the environmental performance of assets or to verify the sustainability claims for products or processes. • Tool is applicable for the planning phase only. • Tool is not suitable for road contractors or product/solution developers. • Tool is not compatible with EN 15804 and CWA 17089. • This tool currently is not in use

	Strengths and opportunities	**Weaknesses and threats**
Lifecycle coverage	• Tool is applicable to four lifecycle stages: Production, Construction, Operation, and End-of-life	• Not applicable for after-life (D) life cycle stage.
Data	• Tool covers whole Europe rather than specific country or region • Default data can be inserted for different countries which makes it easily accessible to different countries. • Users can input specific values according to different projects • It can be used at an earlier stage of the application process when there is not much info and in -depth detail about the design of the road infrastructure. • Tool takes into account emissions from traffic on the roads as well as from road infrastructure.	• LICCER guidelines and tool do not provide a database in itself since other existing tools are used. • Data in general is about 5-10 years old.
Outputs	• The model consists of guidelines, based on existing tools and methodologies for LCA for road infrastructure fully integrating modelling of road elements (i.e. road, bridges and tunnels). • Indicators that are used include only GHG emissions (CO2 eq/year) and primary energy (GJ/year) • Results are calculated in terms of cumulative energy consumption and GHG emissions. • The tool is used to compare between two road alternatives such as differentiating between high road assets such as tunnels and bridges.	• Impacts of road on well-being, actual need for sustainability assessments, biodiversity, water quantity, relation between urban and suburban development are not considered in this tool. • Assess environmental impacts only. Cannot be used to assess costs or social impacts. • Results from different studies may not be comparable • The tool is not able to calculate the economic value of total energy use and GHG emissions generated from cradle to grave.
Roadside equipment	• Centre and side guardrails are represented in the model as both concrete and steel guardrails. The material calculations use pre-set values for materials per meter length of road with guardrail, but the	• Focuses more on infrastructure heavy road projects and neglects less infrastructure heavy projects (takes average input values for them).

	Strengths and opportunities	Weaknesses and threats
	user can also provide project-specific values.	• Not applicable to roadside equipment such as safety barriers or noise barriers.

JOULESAVE

This LCA software is developed in 2006 as a collaborative research project called Integration of Energy into Road Design (IERD), between partners from Czech Republic, France, Ireland, Portugal and Sweden, and it can be used in all Europe. This tool is able to investigate **energy use during the construction phase** of the road including production of materials and the operation of vehicles. Similarly, in this model different construction alternatives such as roads, bridges and tunnels can be assessed and compared at the route selection stage and the preliminary design stage (Kennedy, 2006). This tool is capable to be operated with **MXROAD** as an advanced road designing software by Bentley. An updated version of this tool called JOULESAVE2 is developed in 2010 in order consider the maintenance activities. Therefore, JOULESAVE only calculates construction stage of the road including materials production, while JOULESAVE2 is able to perform the analysis of maintenance stage as well in form of repaving. The materials which can be used in this model are aggregates and bitumen, and the volume of these materials can be defined by the user (Kennedy, 2006).

Construction operations which can be considered in this tool are categorized as drainage, services, earthworks, pavement, road markings and traffic signs, and structures. Regarding the earthwork, the tool considers three different types of rock and soil based on the type of excavation procedure, consisting simple excavated soil, ripped soil, and blasted rock. The maintenance phase takes into account producing pavement material step including commonly used pavement materials and low energy materials, and the pavement construction step.

There is another Swedish tool developed by VTI (Swedish National Road and Transport Research Institute) which is called **VETO** in order to analyses the **traffic related energy consumption in conjunction with MXROAD**. Calculations of the energy consumption caused by traffic can be done by incorporation of the VETO model, considering the vehicles, the road geometry, road surface and road surface conditions such as wet or snowy road, meteorological conditions and driving behavior. The economic lifetime of the road is defined to be 20 years, and this time is used as the analysis period regardless of the country. Although this model is capable to be used in all European countries, but it is not feasible to change background data, electricity mix, construction activities, etc. (Liljenström, C, 2013).

ECO-it

ECO-it is known as a simple LCA-based software developed by Pré Consultants BV, which does not need special environmental knowledge to use it. The assessments are based on the Eco-indicator 95 scores in order to calculate the environmental impact of different stages of the life cycle of product. This tool is designed to apply a **quantitative approach for a quick product screening of its environmental performance** and illustrate which steps of the product's life cycle contribute most. The ECO-it investigates more than 500 ReCiPe environmental impact and carbon footprint (CO2) scores for commonly used materials like metals, plastics, paper, board and glass, and covering material production and processing, energy generation, transportation, and waste treatments procedures. It is possible for users to create and edit new databases with different scores by using ECO-edit software (Suppipat, S. et al, 2021) (Pré Consultants BV, n.d). In this tool, calculations are implemented by using linear methods and results can be expressed in a bar or pie graph, in which the environmental hot spots are identified (Jönbrink, A. K. et al, 2000).