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Life Cycle Assessment on two design alternatives of the Driva Bridge

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Summary

Environmental performance of timber bridges during their lifespan has become important in recent years. In this study, two timber design alternatives of the Driva Bridge located in Norway were investigated and compared. The study applied Life Cycle Assessment (LCA) for addressing (1) the distribution of total environmental impact and energy consumption, and (2) the environmental impact and energy consumption variations due to different End-of-Life (EoL) scenarios for timber material. The results relied on five selected midpoint environmental impact indicators. It indicates that different EoL scenarios of timber can largely affect the total environmental impact, and the quantity of steel used significantly influence the total environmental impact as well as total energy consumption.

Keywords: timber bridges, environmental impact, LCA, End-of-Life scenarios.

1. Introduction

With the arising demand on sustainability and environmental-friendliness, Life Cycle Assessment (LCA) has become widely used for assessing and investigating the environmental effects of products. A full LCA examines the effects of a product within defined goal and scope, from the raw material extraction to the final demolition, often referred as “from cradle to grave”. In this context, a product can be for example a timber bridge.

The outcomes of the LCA are expressed as indicators such as global warming, eutrophication, and ozone depletion, mostly in global scale. The main difficulty of interpreting the LCA output is the variety of indicators. Each indicator has its own emphasis, and the user needs to choose the most important indicators and generate conclusions accordingly.

At present, the construction sector contributes largely in the global environmental burden, for example, it covers about 40% of the total energy consumption in Europe [1]. Therefore, construction sector is a big target for improvement. Bridge, as an important part of construction sector, consumes huge amount of construction materials and energy for construction and use. LCA can be used as an important tool in a Bridge Management System (BMS), although it is not yet a common practice, it gains more and more interest. In order to reduce the environmental impact, wood as a natural material is suggested to be used widely in bridges.

When conducting LCA for a bridge, four life cycle stages may be considered:

1) *Material production stage*: raw material extraction and product manufacturing of the bridge
2) *Construction stage*: transportation of materials and equipment to the construction site, installation of the bridge
3) *Operation and Maintenance (OR&M) stage*: use of the bridge during its service life
4) *End-of-Life (EoL) stage*: starts when the bridge is replaced, dismantled or deconstructed, including demolition, transport, and waste processing.

To estimate the operation and maintenance actions during the use of bridges, many methods and sources can be used. One method is to use historical data about maintenance and repair of bridges from existing databases. Another method is to collect data from LCA calculations made by experienced experts on bridge element degradation and repair. Once maintenance and repair actions and corresponding intervals are obtained or determined, they can be applied to the LCA analysis.

2. Case study

The case study compared two design alternatives for the Driva Bridge along the whole life cycle, by using LCA tool.

2.1 General information

Along with the increasing interest in green materials, the Norwegian Public Road Administration decided to build more timber structures in recent years. Meanwhile, the Norwegian University of Science and Technology (NTNU) has a research project about glulam network arch bridges. The network arch idea of bridges was developed by the Norwegian engineer Per Tveit in the 1950s. They have tied arches with inclined hangers, which have multiple intersections.

Driva Bridge is an existing network arch bridge made of steel and concrete, locates in Norway. It has a single span of 111 m, and the rise of the arch is 18 m. The research project from NTNU includes one Master’s Thesis, which dealt with two design alternatives for the Driva Bridge, by having timber network arch system [2]. It is a pilot endeavour, since so far, the longest span of timber bridges in Norway is less than 90 m [3].

The two design alternatives in [2] considered only the superstructure of the bridge, excluded foundation, end supports, possible settlements, as well as detailed joint on the arches and wind bracing. In addition, connections between the deck and transverse beam were not included. The deck and arches of both design alternatives are fabricated out of glulam, strength class GL 32h [4]. Designed life for the two alternative bridges is 100 years.

Chemical protection such as creosote or Cu-salts is not applied.

The deck is made of stress-laminated timber, with effective width of 11,95 m. The glulam beams are 115 mm wide, with 5,5 m distance. For weather protection, zinc cladding is applied on top of the arches, with louvered timber cladding on the sides. The wearing pavement choice is asphalt, which includes base and wearing layer.

For clarification, two alternatives are named as Network arch Bridge Alternative1 (NBA1) and Network arch Bridge Alternative2 (NBA2). Profile of both alternatives are shown in Fig. 1. NBA1 has no steel wind bracing between the arches, and four sets of hangers are spread out of the arch's plane. The arch has constant glulam cross-section, and is split into four parts with an equal length of 30 m. NBA2 has a similar layout to the existing Driva Bridge, with having K-shaped wind bracings. The arch is also split into four parts of equal length, with varied cross-section of each part.

The steel used in the bridge is assumed to be imported from the same provider as the Driva Bridge, the steel provider locates in Europe. The timber is assumed to be provided from a local supplier in Norway.

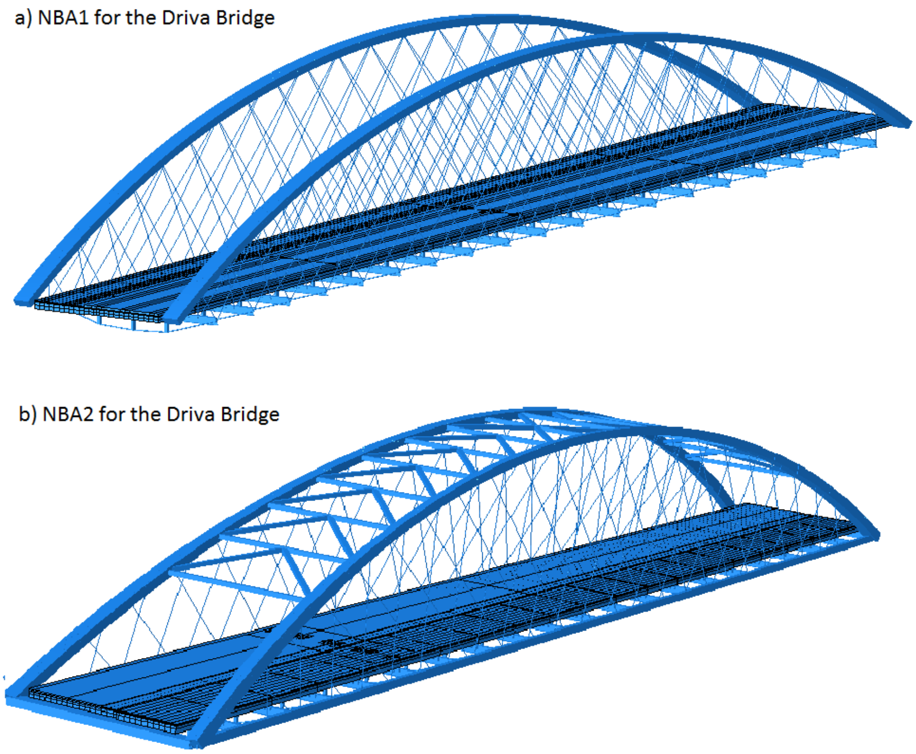

Fig. 1 Two design alternatives for the Driva Bridge [2]

2.2 Specifications of LCA

In this paper, only the superstructure of the bridge during its designed whole life cycle is considered. The goal is to identify how different EoL scenarios of timber contribute to the total environmental impact, and how the EoL of timber influences the energy consumption. The function unit is defined as "bridge effective area within the 100-year service life".

The study utilised *BridgeLCA* tool, in which embedded Ecoinvent database and ReCiPe v1.06 method [5] - [7]. The five selected impact categories were expressed as midpoint indicators: Global Warming Potential (GWP), Ozone Depletion Potential (ODP), Terrestrial Acidification Potential (AP), Freshwater Eutrophication Potential (FEP) and Fossil Depletion Potential (FDP) [8].

2.3 Assumption and simplification of LCA

The study assumed the same erection method, maintenance plan and demolition method for both design alternatives; thus for simplifying the comparison, the diesel and electricity consumption of equipment during the use stage were not included. Minor materials and activities such as formwork, spikes, weathering of concrete were not considered.

For planning the repair and maintenance actions during the use of the bridge, historical records of existing timber bridges that were extracted from Finnish Bridge Register (Siltarekisteri) [9] and [10] were applied. Quantitative data of the major materials were calculated based on [2].

All materials considered to be replaced during the life cycle of the bridge were assumed to be 100% of the original amount. In the aspect of intervals for replacement actions: asphalt would be replaced every 15 years, and the epoxy would be replaced every 30 years. The guardrails and railings would be replaced every 40 years after the opening of the bridge, and the parapets would be replaced after 60 years of opening the bridge.

For the EoL stage, transportation mode and distance from the bridge site to the EoL site were assumed to be the same as from the material factory to the bridge site. In general, the material recycling in the EoL stage is expected to reduce the environmental impact, thus the assumption for the recycling rate is high. Steel was assumed to be 100% recycled [11]. For timber construction waste, the EoL has not been standardised yet. In order to analyse the influence of different EoL scenarios of timber, two scenarios were investigated in this study: EoL1 as of 100% energy recovered and EoL2 as of 100% put into demolition. Moreover, timber material was assumed as carbon neutral, without considering CO_2 uptakes.

3. Results

Comparison lies between the two design alternatives, for both EoL scenarios of timber. Total results of emissions in each of the five selected impact categories were weighted into one single score in accordance with ISO 14044 [12], in order to consider the impact of the individual indicators correspondingly. The weighting factors were applied according to U.S. Environmental Protection Agency, as shown in Table 1.

Table 1. Weighting factors applied in the study according to [13]

Impact category	GWP	ODP	AP	FEP	FDP
Weighting factors	16	5	5	5	5

In order to find the influence of weighting factors, the study compares the normalised LCIA (Life Cycle Impact Assessment) midpoint results and the weighted LCIA midpoint results. The results reveal that with normalised midpoint, the weighted single score of NBA1 under EoL1 scenario is about 75% of EoL2 scenario, for NBA2 under EoL1 scenario is about 83% of EoL2 scenario.

Fig. 2 shows the comparison for EoL1. It indicates that weighting factors can influence both the proportion and the importance level of each impact category. GWP is the most affected category, in which the proportion is increased into three times from the normalised values to the weighted values. While the proportion changes of ODP, AP, and FDP categories are rather small. For both alternatives, the most dominant category is FEP, which takes over half of the total environmental impact; and the least significant category is ODP, which takes less than 0,5% of the total environmental impact. Moreover, the proportion of each impact category for both NBA1 and NBA2 is nearly the same, except the slight differences of FDP and FEP categories. Similar results of Fig. 2 are found for the EoL2 scenario.

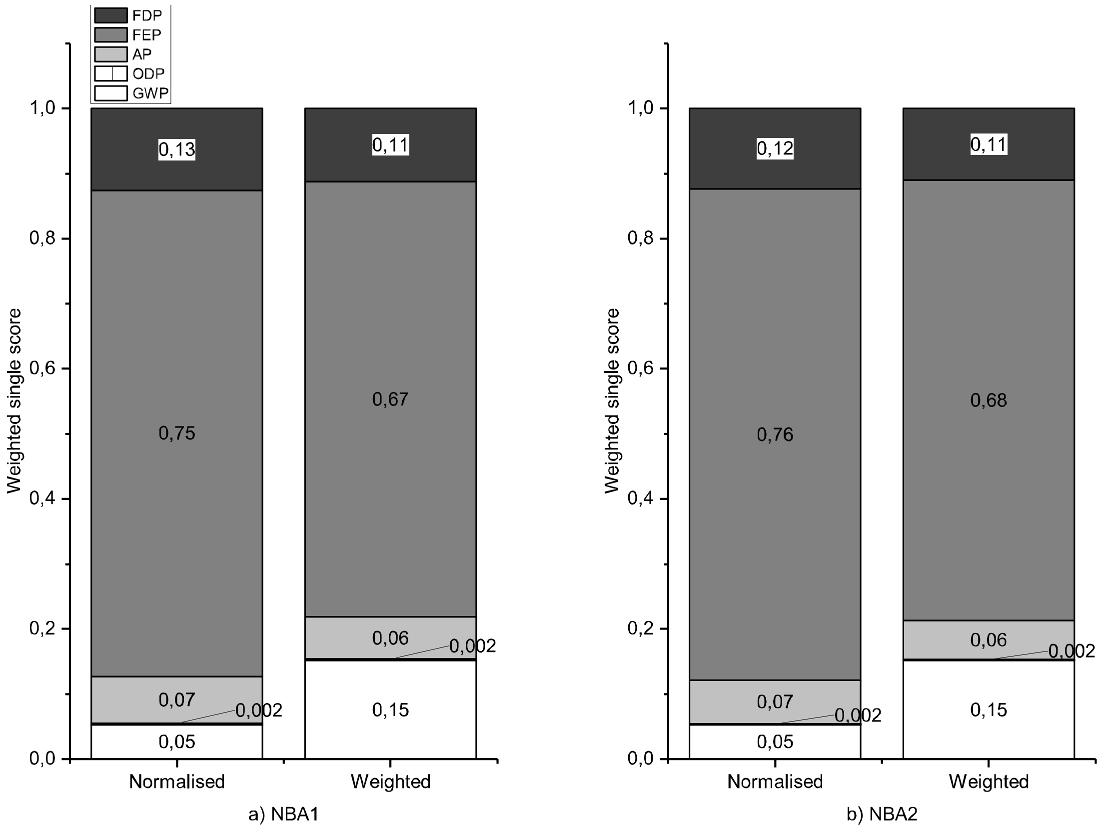

Fig. 2 Normalised and weighted midpoint LCIA results when timber is with EoL1

In the following comparison, for reducing the subjectivity, weighting factors were set equal for the selected five impact categories.

The four life cycle stages introduced in Section 1 were investigated, for addressing the contribution of each stage to the five impact categories. Distribution of all impact categories during each life cycle stage is shown in Fig. 3.

Fig. 3 clearly indicates that, the biggest contributor of all five impact categories is the material production stage, while the least is the construction stage; such result can also be found in [10]. The selection of EoL scenario of timber can largely affects the contribution of life cycle stages to the total environmental impact. The two biggest environmental impact categories induced in the EoL stage are ODP and AP under both EoL1 and EoL2. The contribution of EoL stage for each environmental impact category is much smaller under EoL1 scenario than under EoL2.

As expected, the comparison of different EoL scenarios shows that the bridge with EoL2 has better environmental performance. For example, the environmental impact induced in the EoL stage under EoL2 scenario is nearly one third of each impact category for NBA1, and one fourth of each impact category for NBA2. The midpoint LCIA results change significantly for GWP and FDP categories, where the difference ranges from 8 to 13 times. Under the same EoL scenario, the comparison between NBA1 and NBA2 reveal that, for each impact category, the proportion of EoL stage for NBA1 is bigger than NBA2.

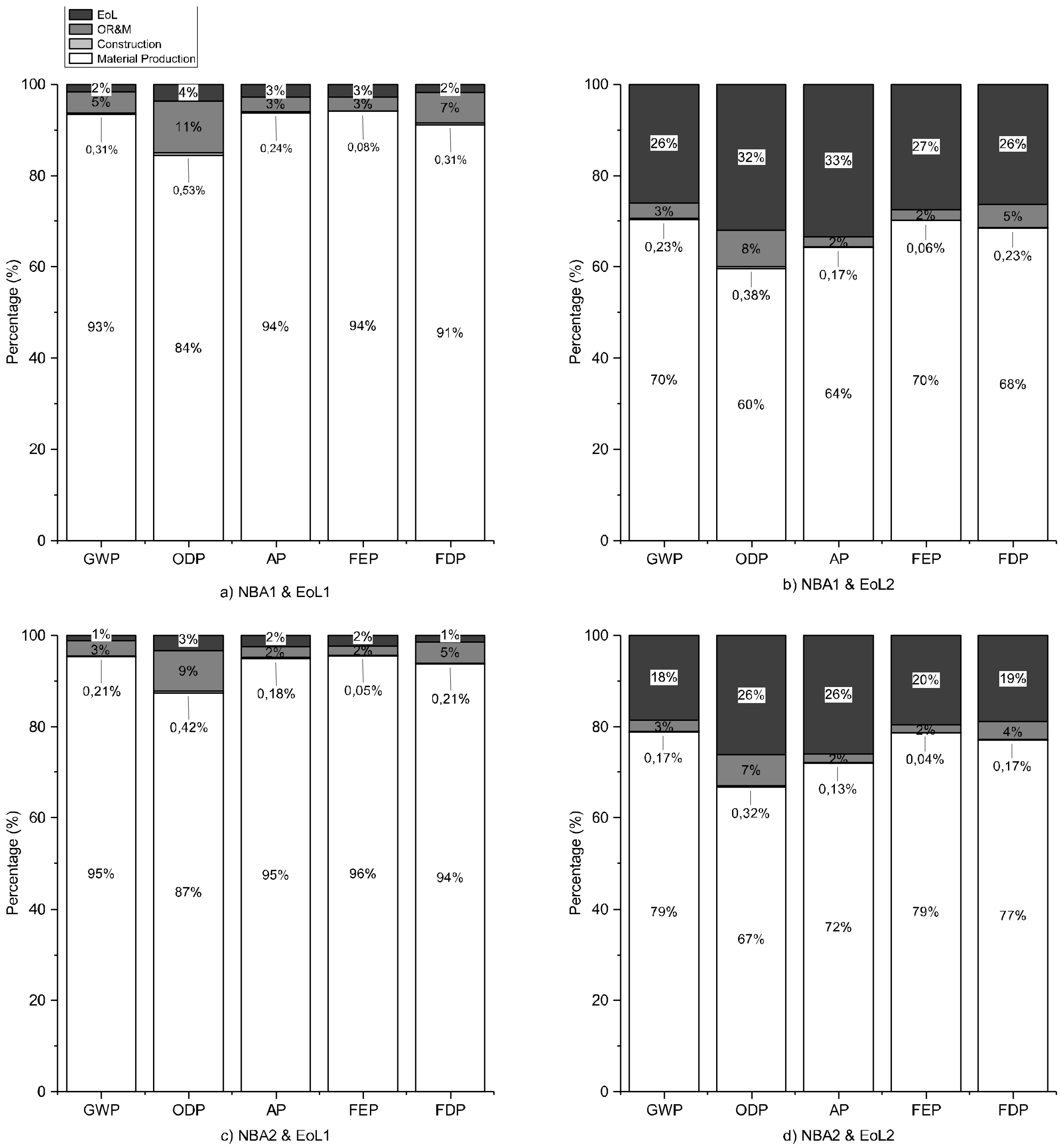

Fig. 3 Distribution of midpoint LCIA results for NBA1 and NBA2

For finding the total energy consumption and its distribution of the two design alternatives, the study compared the results under the two EoL scenarios. When comparing the total energy consumption for both NBA1 and NBA2, no matter the EoL scenario of timber, NBA2 consumed 16% - 18% more energy than NBA1, due to the larger amount of steel used in NBA2. When comparing the energy consumption of each design alternative between EoL1 and EoL2 scenarios, the difference is very small, less than 2%.

Fig. 4 shows the distribution of energy consumption for both NBA1 and NBA2 under the two EoL scenarios. The composition of material quantities and energy consumptions is split into three items: timber, steel, and others. The former two items include the energy consumption caused from material production and corresponding transportation (e.g. transportation due to the import of the material). The major construction materials (here means timber and steel) consumed the most energy, timber as the major material consumed over 50% of the total amount of energy, while steel as the second major material is the second largest of the total energy consumption. Moreover, it shows that increasing the quantity of steel will proportionally increase the addition of energy consumption.

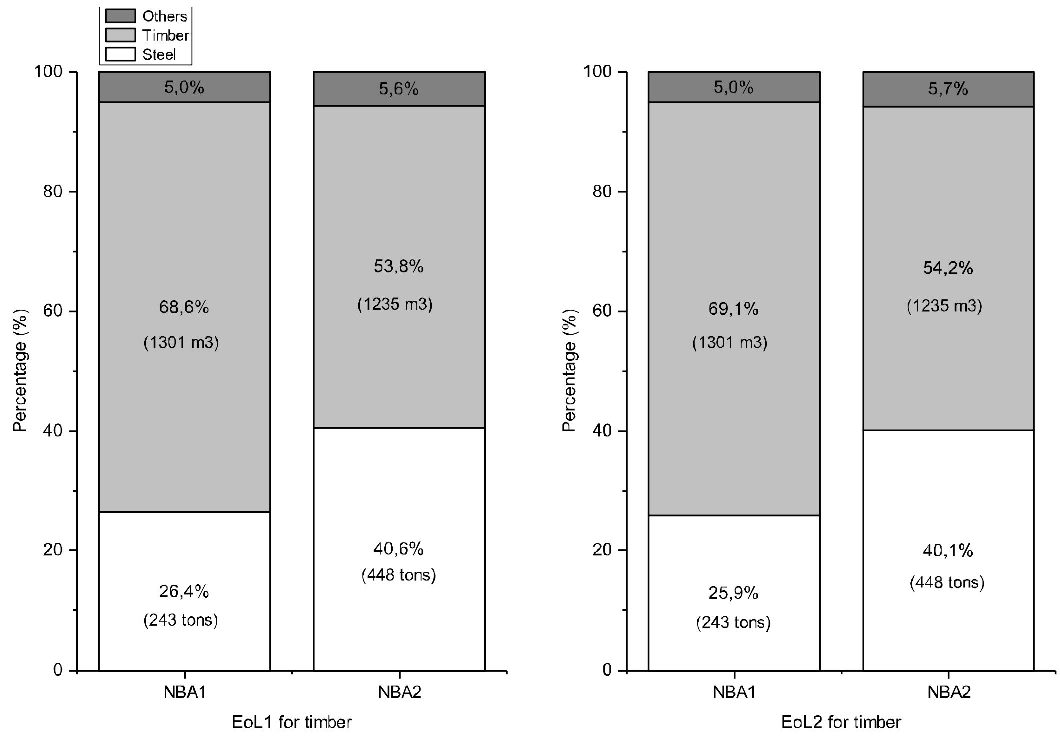

Fig. 4 Energy consumption of construction materials and others

Conclusions

In this study, Freshwater Eutrophication Potential (FEP) and Fossil Depletion Potential (FDP) are the most dominant impact categories, while Ozone Depletion Potential (ODP) is the most insignificant category. However, it may be changed when applying different weighting factors. Different End-of-Life (EoL) scenarios of timber materials largely influence the impact proportion of EoL stage among the life cycle, but insignificantly affect the energy consumption. The preferred EoL of timber is to be 100% energy recovery, which can obviously reduce the total environmental impact; in this study, reducing of the weighted single score of the total environmental impact can be 17% and 25%. The quantity of steel used in timber bridges can significantly change the total environmental impact and proportionally affect the energy consumption. The key factor influencing total environmental impact and energy consumption is the amount of major construction materials used, especially steel.

This study cannot draw general conclusions for all timber bridges. However, the study revealed some key aspects that should be considered carefully, such as EoL scenario of timber and the quantities of other major construction materials than timber.

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