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LIFE CYCLE ASSESSMENT ON DIFFERNET TIMBER BRIDGE TYPES: DECK BRIDGE, BLOCK GIRDER BRIDGE, TROUGH BRIDGE, PYLON BRIDGE

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ABSTRACT: Germany's national climate targets set the ambitious goal of achieving net zero emissions by 2045, which is in line with the Paris Agreement. The construction sector is a key player in reducing greenhouse gas emissions. In Germany, the focus has always been on the building sector, while little attention has been paid to civil infrastructures. At the international level, civil infrastructures are increasingly assessed and analysed for their environmental impact using life cycle assessment (LCA), although here, too, the use category of foot and bicycle bridges has hardly been studied. In the context of local mobility, foot and bicycle bridges (FBB) play an important role in the regional and local transportation network. Since in Germany timber bridges are used for FBB this paper presents, a standardized approach for life cycle assessment of bicycle bridges. A total of four different types of timber bridges are distinguished: deck, block girder, trough and pylon. The LCAs were performed following the applicable standards. The results show that the impact is influenced by different bridge components, although provides a basis that allows a first impression of the LCA results.

KEYWORDS: life cycle assessment, timber bridges, environmental footprint, carbon storage

1 INTRODUCTION

In line with the Paris agreement of 2015 [1] and in view of sustainable development goals, Europe has defined ambitious climate protection targets to be achieved by 2050. With 95 percent probability, human action has the greatest impact on climate change. [2] The use of resources is directly related to environmental impacts such as global warming and greenhouse gas emissions. Neverless, demand for natural resources will increase due the growth of the world population and increasing urbanization, as well as the needs of built city infrastructure. [3,4]

In the context of local mobility, foot and bicycle bridges (FBB) play an important role in the regional and local transportation network. The municipal budget situation is often a decisive criterion for awarding contracts. The construction of infrastructure demands nearly 40 % of all raw material consumption.

Bridge structures under municipal responsibility are assumed to be in similar condition to bridge structures under federal or state responsibility, increased replacement can be expected. It is therefore important to create basic data and to develop a uniform application system and to demonstrate the applicability and advantages to decision-makers.

The European Commission promotes the use of organic building materials such as wood from sustainable forestry to minimise the footprint of constructions through resource efficiency and circularity combined with transform parts of the construction sector into a carbon sink [5].

The primary energy non-renewable (PENRT) input in the life cycle represents the use of primary raw materials, the global warming potential (GWP) shows the impact on the global environment.

2 LITERATURE

The literature shows the beginnings and the developments of LCA in the field of bridges.

The beginning of LCA conducting on bridges were made by Horvath and Hendrickson [6], Widman [7] and Lünser [8] in 1998 wherein they compared different bridges on the environmental impact through the choice of material. Further LCA studies were conducted to analyse the impact of the of new materials compared to conventional materials [9]. Comparing of similar bridge components and materials with different maintenance scenarios were carried out by Penadés-Plà et al. [10]. Itoh et al. investigated for example whether the overall environmental impact of a bridge with increased maintenance is lower [11]. There have also been studies that examined the environmental impact of different bridge forms in different material categories by considering the construction and maintenance phases in terms of energy consumption and CO2 emissions [12].

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In a further study, an approach is being developed in which the risk of natural events, such as earthquakes, is to be taken into account in the life cycle assessment of a bridge [13].
Although LCA has been applied in the research context of bridges since 1998 and a wide range of impacts have been studied taking into account varying aspects, it has not yet found its way into practice and is still rarely used in decision making. This is mainly due to the application method, which has not yet been harmonized.
To identify the significant differences in the methodological approach a literature survey were conducted. The main differences were identified, for example, in the:

- functional unit
- system boundaries
- functional equivalence
- period of consideration
- considered product systems

The functional unit (FU) is the basis for comparing LCA results. The survey has shown that the FUs are consistent within the studies but differ between studies, as follows:

- m² superstructure.
- m² roadway
- absolute or percentage comparison
- m superstructure.

The differences in the FUs complicates the comparison of different studies, regardless of functional equivalence and system boundaries.

system boundaries
The determination of the spatial and temporal system boundaries makes it possible to limit the system to be considered, in this case the bridge structure, so that concrete results can be obtained.
The spatial system boundaries include different observation areas in the studies carried out. For example, in some studies, the system boundaries are set such that the entire structure falls within the observation space. In other studies, however, the system boundaries are based only on the superstructure, or/and the effects of potential traffic disruptions due to rehabilitation measures are included.
The temporal system boundary allows the system to be divided into specific phases over the life cycle phases in order to identify specific hotspots. Thus, the historical development of the databases shows that more and more detailed life cycle phases could be included in the investigations.

functional equivalence
The definition of functional equivalence according DIN EN 15643-5 is, in which the function is described by the functional equivalence. The functional equivalence describes the quantified functional requirement and/ or technical requirements of an engineering structure or of a assembled component, and serves as a basis for comparisons. [14]
Most studies compared two alternative variants designed for the same conditions and for the same location.

period of consideration
The period under consideration can vary depending on the category of use, the main material or the objective of the study. Within the survey the period of consideration varies between 50 and 200 years. For the use categories, the time periods considered were defined as follows:

- Foot- and Bicycle bridge 50 years
- Railroad bridge: 100 to 120 years
- Highway bridges: 50 to 200 years

considered product systems
Bridge structures are examined in varying detail in the studies within the areas of consideration. Component groups are defined as the umbrella term for the grouping of components that serve similar purposes. The levels of detail differ from study to study. For example, bridge structures are only considered subdivided into the component groups substructure and superstructure (cf. [15]) or more detailed levels of detail are formed (cf. [8,16–18]).

The literature survey has also shown that most LCA studies were conducted for road bridges. And most of the conductions were not always in line with the standards.
Different studies has approved that the materials use in the construction has a variable of environmental impacts (e. g.: [6–10,19]).

3 METHODOLOGY

3.1 LIFE CYCLE ASSESSMENT

Life cycle assessment (LCA) is a methodical approach to assessing the environmental impacts associated with all phases of a construction's life, i.e., from raw material extraction through material processing and use to the end of use stage. The generally applicable standards are specified by the principles and framework in ISO 14040 [20] and the requirements and guidance in ISO 14044 [21]. Applied LCA for the construction sector is specified by EN 15804 [22], in which the framework is related to the building product level, and by EN 15978 [23], in which the framework conditions for assessing the environmental performance of buildings is defined.
The modular structure of the entire life cycle is in accordance to EN 15643: 2021 [24], which includes the production and construction phase (module A), the use phase (module B) and the end-of-life phase (module C).

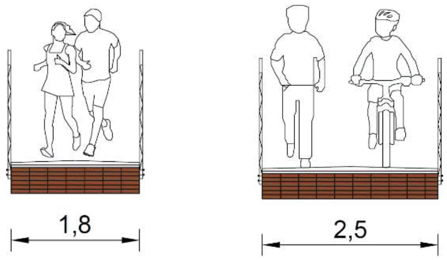
3.2 LCA FOR FOOT AND BICYCLE BRIDGES

The framework for the conduction of LCA is explained step by step for the calculated bridges. The step of categorisation by main materials use will be skipped within this study.

3.2.1 Use category

In the first step the considered use category is defined. Within this study the considered use category is FBB and

FB and is defined analogously to the recommendations of the *Forschungsgesellschaft für Straßen und Verkehrswesen e. V.*, in which the geometric framework is defined. Accordingly, it is determined that a FB should have a minimum walkway width of 1.80m and a FBB a minimum path width of 2.5m. Figure 1 illustrates the distinction.



(a) (b)

Figure 1: *Minimum path widths accordingly EFA und ERA, a) FB, b) FBB*

3.2.2 Bridge types

The different types of timber bridges which were considered as for foot and bicycle bridges (FBB) are as follows.

Deck bridge (DH): The main girder of the timber deck bridge consists of at least two solid girders and spans the entire bridge cross-section. The deck is attached to the longitudinal girders. The deck can be either waterproof or water-bearing. Depending on the decking, the structural timber protection is designed. [25]

Figure 1: *Example of a deck bridge*

Block girder bridge (BH): A further development of the traditional deck bridge is the timber block girder bridge. The timber block girder is composed of a solid block glued with timber and spans the entire cross-section of the bridge. The entire block cross-section can be used as a roadway, with the roadway itself serving as additional weather protection. Structural timber protection is established by the shape of the cross-section, the overhangs, and adequate air circulation. [25]

Figure 2: *Example of a Block girder bridge*

Through bridge (TH): The main structure of a wooden trough bridge is formed by two main girders and is located between the roadway and the railing at the railing level and is secured against tipping by a stiffening steel to prevent overturning. Structural wood protection is provided by the top cover and lateral cladding of the main girders. main girders. [25]

Figure 3: *Example of a Through bridge*

Pylon bridge (PH): The main component of the load-bearing system of cable-stayed or suspension bridges are pylons. The pylons are used to transfer loads from the superstructure to the substructure via stay cables or via hangers. The superstructure is formed by a bracing girder so that the loads from the deck are distributed to the cables or suspension cables. The stiffening of the superstructure eliminates the need for supporting structures. The types of construction described above are suitable as superstructure. [26]

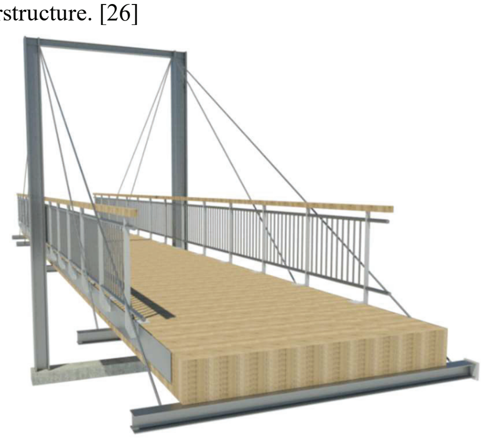


Figure 4: *Example of a Through bridge*

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3.2.3 Period of consideration

Within this study the considered period is 50 years.

3.2.4 Bridge size

The study includes a total of 10 bridges of different size and bridge type. The sizes of the considered bridges are listed in Table 1 and vary between 63 to 288 m².

Table 1: *Bridges and road areas*

Bridge	Road Area [m²]
DH4	69
BH1	288
BH2	68
PH1	114
PH3	146
PH4	125
PH5	141
TH1	85
TH3	63
TH4	169

3.2.5 Considered product systems

Despite the different types of construction, bridges are basically of comparable design and can be divided into main components and subcomponents. In bridge construction, a distinction is made between superstructure, substructure and equipment as main assemblies. Whereby a component group includes components that serve similar purposes.
In the context of this study, the superstructure is considered, which integrates the component group of equipment.

3.2.6 Functional equivalence

As the aim of this study is not to compare but to generate results to create a database the functional equivalence as it is defined is not given. Al considered bridges belong to the use category of foot and bicycle bridge.

3.2.7 Database and calculation program

Since 2013, the dataset Oekobau.dat comply with the standard DIN EN 15804 and includes information on the environmental impact of construction, transportation, energy disposal processes and building materials, enabling life cycle assessment over the entire life cycle.
The results base on Oekobau.dat Version 2020-I.
The calculations were conducted with the R_ENI-LCA Tool. The Tool is explained details in Özdemir [27].

4 RESULTS

The LCA-Results for the indicators GWP and PENRT are shown in Figure 5 and Figure 6.

The Database for the indicator GWP and timber bridges are between 3 and 7 [kg CO2 eq./m²*a]. Whereby the minimum GWP value was calculated for the bridge TH1 and the maximum Value for the bridge PH1.

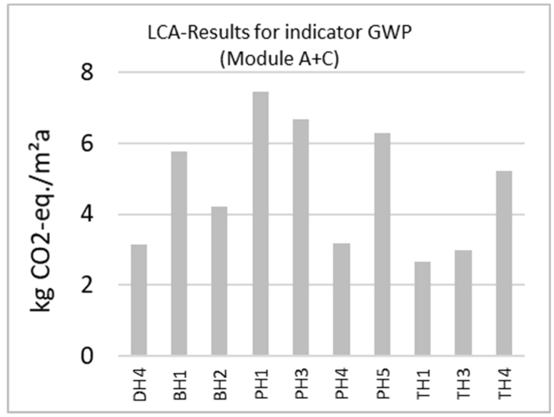

Figure 5: *LCA Results (Module A+C) for Bridges for indicator GWP [27]*

The Database for the indicator PENRT and timber bridges are between 32 and 92 [MJ/m²*a]. Whereby the minimum PENRT value was calculated for the bridge TH1 and the maximum Value for the bridge TH4.

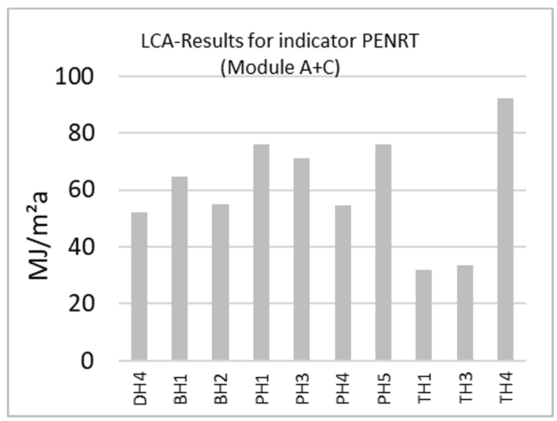

Figure 6: *LCA results (Module A+C) for Bridges for indicator PENRT [27]*

5 CONCLUSIONS

This study considers in detail the environmental impacts of municipal bridge structures, timber FBB, over the entire life cycle. The area of the use category GRB does not play a role in previous research on LCA. The present work forms the basis for further research projects.
An LCA bridge database can assist decision makers in decision making and facilitate the classification of LCA results. In the context of local mobility, foot and bicycle bridges (FBB) play an important role in the regional and local transportation network and focusing on timber bridges here could be an interesting focus for additional climate protection.

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