TU1406

COST ACTION

QUALITY SPECIFICATIONS FOR ROADWAY BRIDGES,
STANDARDIZATION AT A EUROPEAN LEVEL

Scientific Report on Short Term Scientific Mission

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COST EUROPEAN COOPERATION IN SCIENCE AND TECHNOLOGY

CONTENTS

1. AIMS AND OBJECTIVES

1.1. MAIN GOALS

This Short Term Scientific Mission (STSM) has the goal in the course of the work of WG 4 to analyse a bridge structure with regard to the environmental impacts in a case study. The corresponding bridge structure should be simple and representative. By creating an environmental Life Cycle Assessment (LCA), the framework for a further performance indicator can be established. In a first step, it will be checked the applicability in combination with the performance indicators developed of Work Group 1. In a second step, the environmental impacts of the product and the construction stage of the selected bridge are calculated. The iterative character of an LCA examines these results for information gaps and knowledge gaps. The identified information gaps and any difficulties that may have arisen will later be incorporated into the work of WG 5.

The creation of the LCA should result in environmental hotspots and cut-off criteria. During the STSM, special attention is paid to the applicability and implementation of the environmental KPI in a case study. By creating scenarios for the use stage, it should be shown how different maintenance concepts affect environmental impacts. The successful presentation of maintenance measures within the bridge's life cycle is of particular interest and one of the main goals of the STSM.

As knowledge of the LCA comes from Austria within this STSM and the conservation scenarios have been developed together with the host institution in Portugal, it made sens to calculate an Austrian bridge, but then to translate it into Portuguese framework conditions. This is necessary because the maintenance scenarios are based on Portuguese information.

The framework standards for the creation of LCAs are ISO 14040 (ISO 2006a) and ISO 14044 (ISO 2006b). The standards, which are dealing with the assessment of environmental performance and sustainability of civil engineering works are EN 15643 (CEN 2017) series and EN 15978 (CEN 2011). When performing a LCA these standards has to be followed. The LCA carried out is in accordance with these standards.

1.2. BRIDGE DESCRIPTION

The Austrian motorway operator ASFINAG (Autobahnen- und Schnellstraßen-Finanzierungs-Aktiengesellschaft) and Bonaventura gmbh provided the information on the bridge, which will be dealt with. These companies have provided all relevant data such as specifications, plans etc. The basic information about the bridge is shown in Table 1. The selected bridge is situated in Austria near to Vienna.

Figure 1: Bridge after completion 2008

Table 1: Basic informations obout the calculated bridge

Bridge information	
Static sytem:	Frame bridge
Year of construction:	2008
Bridge class (Austria):	Kl.I
Substructure	
Heavy weight abutment with pile foundation	
Superstructure	
Material:	Reinforced concrete - unreinforced concrete
Transverse section:	Full / massive
Bridge length:	38,3 m
Bridge with:	9 m
Span lenngth:	34,5 m
Bridge surface:	344,7 m²
Pavement	
Road pavement:	Bituminous pavement layer [3cm]
	Leveling layer [6cm]
	Protective layer [6cm]
Sealing:	2 layers bitumen sheets [1cm]
Equipment	
Edge beam:	Reinforced concrete
Railing:	Type B, Steel
Vehicle restrain systems:	Type H2, Steel

2. WORK CARRIED OUT

The work done can be summarised in the following points:

- Development of an LCA case study of an Austrian bridge structure
- Examination of the applicability of the LCA model to case studies of COST TU 1406
- Identification of knowledge gaps with regard to the application of LCA methodology
- Development and analysis of maintenance scenarios and their behaviour with regard to environmental impacts

The aim of this study is to represent the entire life cycle of this structure and to present the environmental impacts caused by this bridge. Part of this life cycle are also the maintenance actions that will become necessary during the period under consideration. By creating various maintenance scenarios, these should then be assessed within the Cost TU 1406 scheme, based on the resulting environmental impacts. As a methodological approach, the standard LCA methodology from the standards mentioned above was applied. In this case, a cradle to grave system boundary has been applied so that all life cycle stages can be considered. Since no iterations were performed within the study, no own cut-offs could be created. So there are the cut-off rules of ISO 14044 to carry. This standard states that only processes that account for less than 1% of the overall result may be neglected. and that can represent a maximum of 5% of the overall result may be neglected. These processes may also represent a maximum of 5% of the overall result. The functional unit is defined as the entire bridge structure because this study is used solely for the analysis of maintenance scenarios and no comparisons are made with other bridges. The period covered by the LCA is 100 years. The framework standard ISO 14040 states that each LCA must go through different steps.

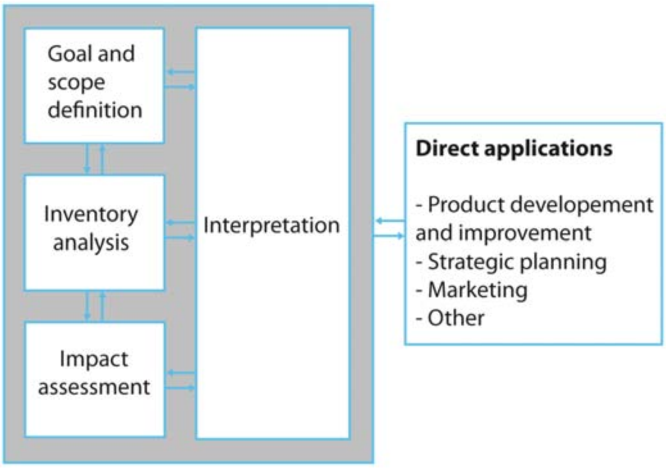

Figure 2: LCA Framework according to ISO 14040

Since the goal and scope definition was already performed in section 1, the inventory analysis should be created next. To create the inventories, several information sources come into play, depending on the life cycle stage. The life cycle of a structure can be divided into different stages (CEN 2011). Below, the inventories are broken down according to the life cycle stage.

2.1. PRODUCT STAGE (A1-A3)

The main focus of this stage is on collecting cradle to gate data of relevant construction materials. The product stage is divided into three sub stages. These represent the supply chain for the production of building materials. This includes the raw material supply (A1), the transport of the raw materials to the place of manufacture (A2) and finally the manufacture of the building materials (A3). The product stage (A1-A3) can be performed by using generic data from existing LCA-databases (e.g. Ecoinvent, GaBi, Gemis, ELCD). In this study the LCA-databases Ecoinvent 3.2 (Wernet et al. 2016) was selected. On one hand, the most relevant datasets were found in the database. On the other hand Ecoinvent is the data collection with the best documentation of data sources and thus the database with the highest quality, representativeness and plausibility (Martínez-Rocamora et al. 2016). Since the environmental impacts of production are related to the masses of building materials used, they also belong to this stage. Table 2 lists the building materials used per component group.

Table 2: Building material inventory

Building material	Quantity	Unit
Foundation		
Ready-mixed concrete	13,68	m³
Gravel, crushed	21,66	t
Reinforcing steel	15,96	t
Dewatering system (drainage)		
Ready-mixed concrete	2,136	m³
Polyethylene pipe, DN 200	18,54	m
Superstructure		
Ready-mixed concrete	1124,02	m³
Reinforcing steel	120,46	t
Polystyrene, extruded	3,21	kg
Sand	13,61	t
Form work	1753,88	m²
Edge beam		
Ready-mixed concrete	64,58	m³
Reinforcing steel	20	t
Form work	148,32	m2
Pavement		
Ready-mixed concrete	15,4	m3
Gravel, crushed	11,55	t
Asphalt	41,3	t
Sealing		
Epoxy resin, liquid	185,4	kg
Bitumen seal	196,7	kg
Sand	463,5	kg
Water	72,13	t
Synthetic rubber	7,36	kg
Polyethylene, extruded	7,2	kg
Bitumen adhesive compound	7,2	kg
Equipment		
Aluminium	1,62	t
Polymethyl methacrylate, sheet	1,641	t
Steel	12,138	t
Polyethylene pipe, DN 75	247,2	m
Polyethylene pipe, DN 200	78	m
Steel	30	kg

2.2. CONSTRUCTION STAGE (A4-A5)

The construction stage covers the various construction processes (A5) from the gate of the building material supplier up to the actual completion of the structure (CEN 2011). Examples of this are earthworks, transportation within the building site, installation of the products and all waste management processes. The environmental impacts attributable to the production of investment goods (e.g. trucks, excavators) are also included. In addition, the transport of materials and products from the factory to the construction site (A4), including transport, storage and distribution is included. The transport of building equipment to the construction site also has to be included.
The data for the construction processes were determined from the specification reports. specification reports are cost calculations and they are based on calculation rules, which are regulated in the Austrian standard ÖNORM B 2061 (ON 1999). The data (consumption and emission) for the construction machinery was taken from the Ecoinvent database, which is based on data from the Swiss non-road database (FOEN).
The transport distances of the various materials from the distributor to the construction site are not shown in the specification reports, as the transport is already included in the material price. Data from the statistical office of the European Union (Eurostat) was used to define realistic distances. The determination of the used transport distances are based on table D1.1 of the statistics on road transport (Eurostat). The following transport distances (Table 3) were derived from the statistical data of Eurostat for Portugal and were applied on the transported goods. More information on the calculation method can be found in Paratscha et al. (2019).

Table 3: Average distances for Portuguese groups of goods (Eurostat)

Group of goods	Average transport distance [km]
Secundary raw material; Municipal waste	57
Metal ores and other mining and quarrying products; peat; uranium and thorium	60
Other non-metallic mineral products	71
Basic metals; fabricated metal products, except machinery and equipment	92
Machinery and equipment	85
Transport equipment	136
Grouped goods: a mixture of types of goods which are transported together	134

2.3. USE STAGE (B1-B5)

The use stage describes the period from the actual completion of the structure to the time when the structure no longer fulfills its function and, therefore, has to be reconstructed. The system boundary of this stage includes the use of construction products and services for the maintenance of the structure (CEN 2011). The period covered by this LCA is 100 years.
Within the specification reports of the analysed bridge, no data could be obtained regarding the maintenance. If there is no physical information available for an LCA, the inputs should be assigned to reflect other relationships between them. For example, data on the input and output side can be assigned in proportion to the economic value of the products (ISO 2006b). As this is allowed by LCA standardization, maintenance scenarios based on life cycle cost calculations have been developed.

Some maintenance scenarios were created for the presentation of the use stage. On the one hand, a basic maintenance scenario based on information from Infrastruturas de Portugal was created. On the other hand, fictive scenarios with different maintenance strategy was assumed.
In the basic maintenance scenario, maintenance actions are carried out every 20 years. The maintenance measures were indicated relative to a complete replacement of the component. So a 100% maintenance action is equivalent to a replacement of the component. The basic maintenance scenario is shown in Table 4.
The remaining maintenance scenarios have been simplified. They do not refer to individual components of the bridge but show the relative proportion to a complete renovation (100%). The maintenance actions for these scenarios are shown in Figure 3.

Table 4: Basic maintenance scenario for Portugal

	1. Maintenace action		2. Maintenace action		3. Maintenace action		4. Maintenace action	
	Time [y]	Maintenance rate [%]	Time [y]	Maintenance rate [%]	Time [y]	Maintenance rate [%]	Time [y]	Maintenance rate [%]
Foundation	**20**	5	**40**	5	**60**	5	**80**	5
piers, abutments, wing wall	**20**	5	**40**	10	**60**	15	**80**	15
Reinforced concrete	**20**	5	**40**	10	**60**	15	**80**	15
Road surface	**20**	20	**40**	100	**60**	20	**80**	100
Sealing	**20**	0	**40**	100	**60**	0	**80**	100
Dewatering (drainage)	**20**	15	**40**	15	**60**	15	**80**	15
Edge beam	**20**	0	**40**	100	**60**	0	**80**	100
Vehicle restrain system	**20**	30	**40**	100	**60**	30	**80**	100
Railing	**20**	20	**40**	100	**60**	20	**80**	100
Noise protection wall	**20**	5	**40**	100	**60**	5	**80**	100

A 100% maintenance action consists in the replacement of every structure part except the superstructure and the foundation. The superstructure (piers, abutments, wing wall, deck slab) and the foundation are indicated with 10% maintenance.

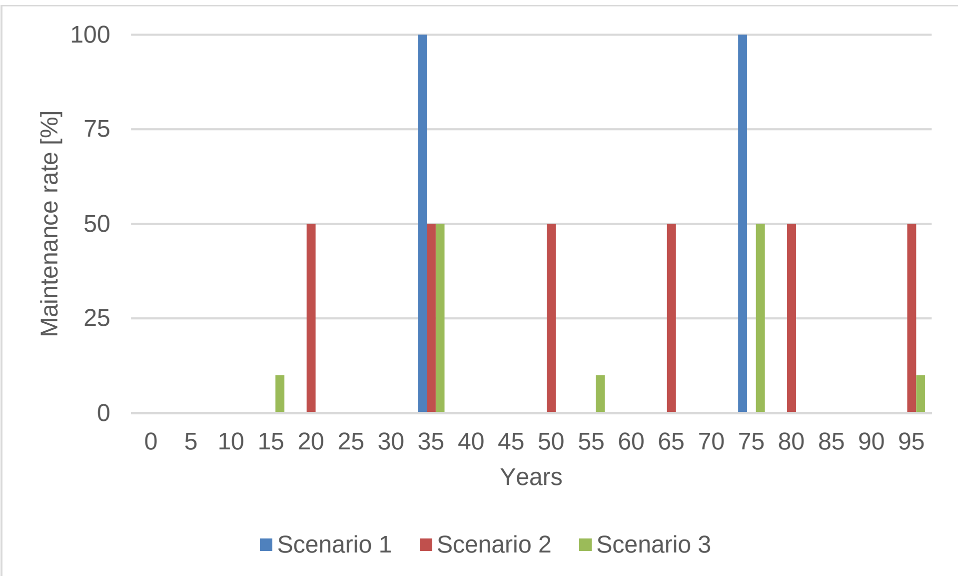

Figure 3: Time-dependent maintenance action of the simplified scenarios

2.4. END OF LIFE STAGE (C1-C4)

Since the building is still in use after the observation period, these stages are calculated as part of the use stage. The resulting processes of demolition and waste treatment incurred by the renewal of components are attributed to the use stage. The complete demolition of the bridge, which would have to be calculated as an end of life scenario, does not take place within the observation period and is therefore not part of the system boundary. However, it is recommended to create this scenario in the course of more extensive studies.

3. MAIN RESULTS

The following part of the evaluation only refers to the global warming potential (GWP_{100}) effect category.

3.1. PRODUCT STAGE AND CONSTRUCTION STAGE (A1-A5)

The results relate to the product stage and the construction stage. So all greenhouse gas emissions are shown, which are caused by the construction of the bridge. The results are presented for the foundation, superstructure, equipment and pavement. The foundation includes the dewatering system. The superstructure includes the construction of all above-ground components with the exception of the pavement and the equipment. The equipment includes the railing, the vehicle restrain system and the dewatering system of the bridge. The pavement contains all the layers that belong to the road pavement, including the waterproofing layer (sealing). The total construction result for the impact category global warming potential is 730.056 kg CO2 eq.

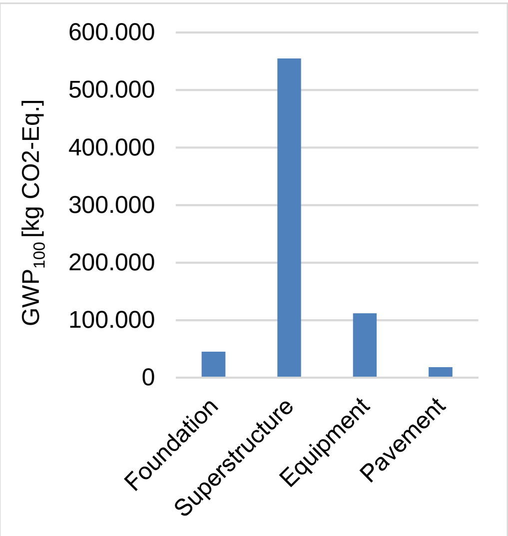

Figure 4: Results for the GWP_{100} (A1-A5) [kg CO2 Eq.]

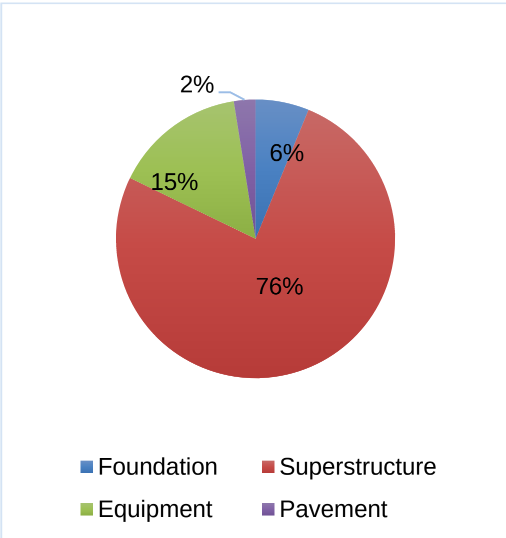

Figure 5: Contribution of the structure parts to GWP_{100} (A1-A5)

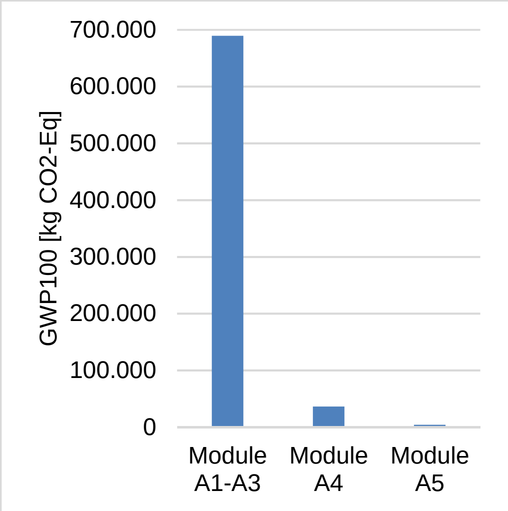

Figure 6: GWP$_{100}$ (A1-A5) results related to the LCA stages

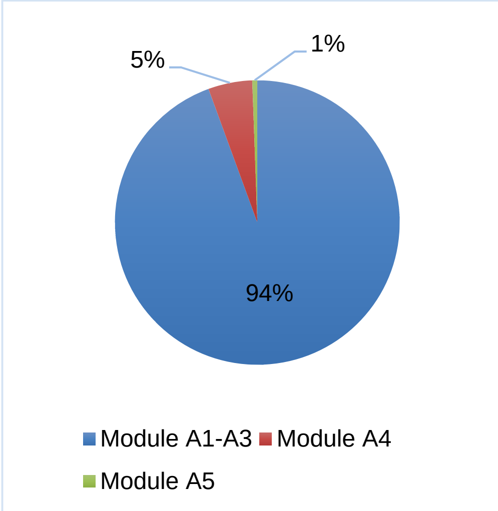

Figure 7: Contribution of the LCA stages to GWP$_{100}$ (A1-A5) Use stage (B1-B5)

3.1.1.BASIC MAINTENANCE SCENARIO

In order to illustrate the use stage, the emissions were calculated by applying the maintenance rates from Table 4. Figure 7 shows the discharges emitted by the maintenance actions every 20 years.

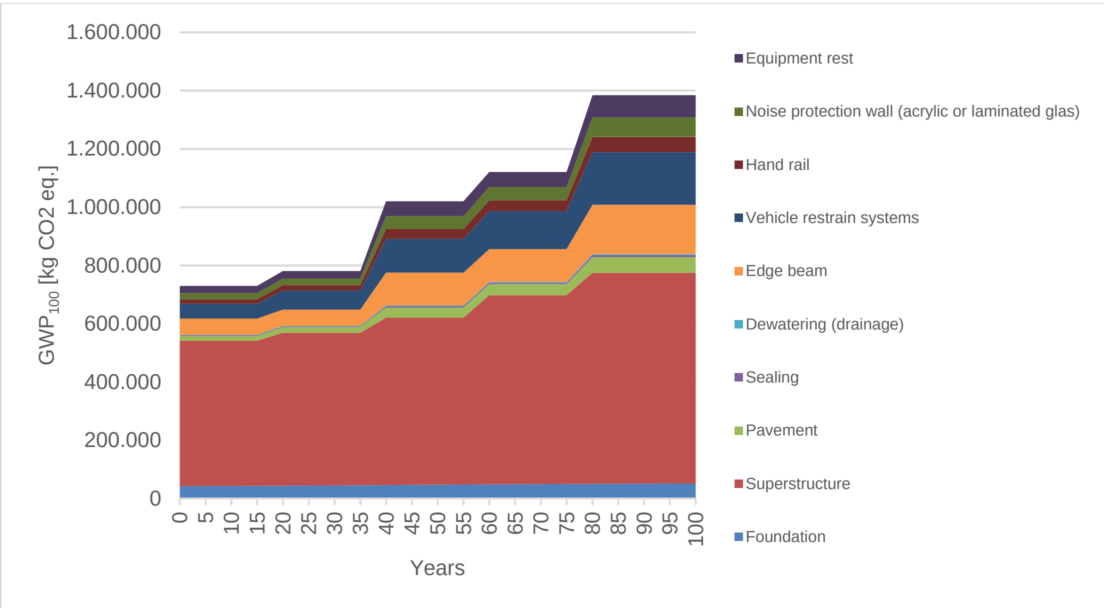

Figure 8: Time-dependent emissions over the life cycle (GWP$_{100}$)

As a result of the maintenance action, another 580 t of CO2 eq. were emitted in addition to the construction of the bridge. This means that the use stage is responsible for 44% of the total emissions (1.310 t CO2 eq.). Although Figure 8 shows that the focus of emissions remains on the superstructure, a significant part of emissions is shifted to the bridge equipment.

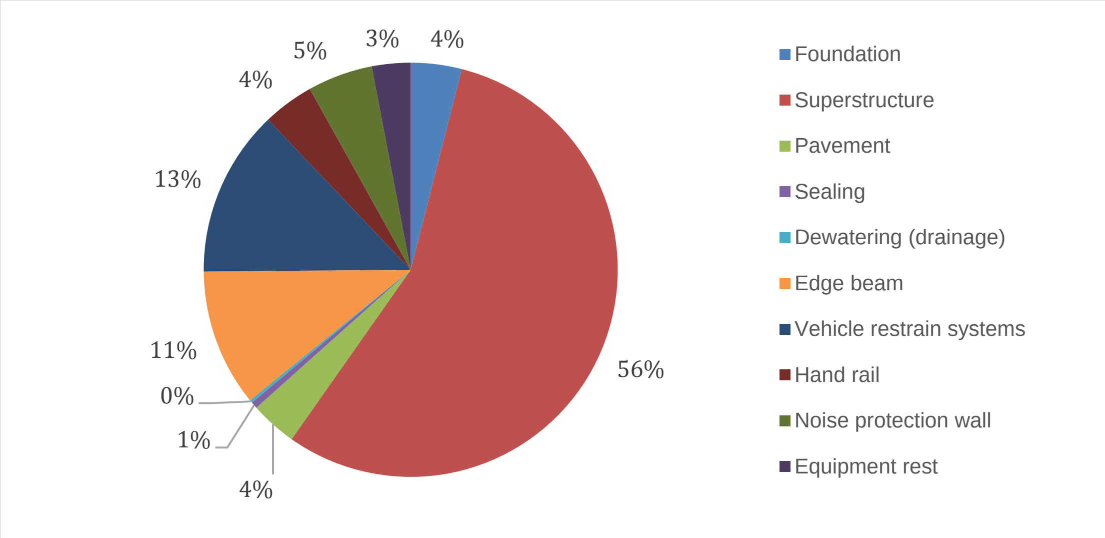

Figure 9: Contribution of the structure parts to emissions over the life cycle (GWP100)

3.1.2.SIMPLIFIED MAINTENANCE SCENARIOS

The scenarios were created in this study for comparative purposes. A sole consideration of these results would be misleading. The different variants lead not only to different results for the GWP100 but also to a different performance of the bridge after 100 years. So when comparing maintenance scenarios, the other KPIs should always be taken into account as well. Figure 9 shows the results of the scenarios and it turns out that scenario 3 shows the best environmental performance, with the bridge being in a worse condition than when using scenario 2.

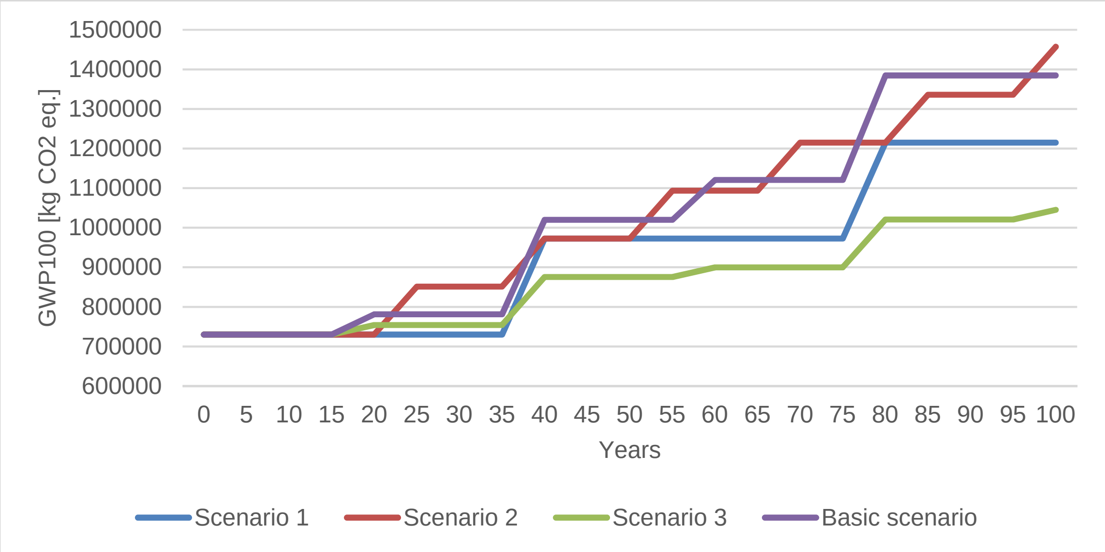

Figure 10: Time-dependent emissions (GWP100) over the life cycle for all maintenance scenarios

3.2. ENVIRONMENTAL ASSESSMENT

The LCA was not calculated only for the GWP_{100} indicator. There are many impact indicators. The most important ones are mentioned in EN 15978. These are given in Table 5.

Table 5: Indicators describing environmental impacts (CEN 2011)

Indicator	Unit
Global warming potential, GWP_{100}	kg CO2 eq.
Depletion potential of the stratospheric ozone layer, ODP	kg CFC 11 eq.
Acidification potential of land and water, AP	kg SO2- eq.
Eutrophication potential, EP	kg (PO4)3- eq.
Formation potential of tropospheric ozone photochemical oxidants, POCP	kg Ethene eq.
Abiotic resource depletion potential, ADP	kg antimony eq.

In order to enable a rating, a reference value must first be defined. In this case, a worst-case scenario was adopted for the worst-case definition (5). This scenario envisages the bridge being built twice within 100 years. This would mean an emission of 1460 t CO2 eq. Whereby the scenarios emit so much for the maintenance:

- Scenario 1: 484,7 t CO2 eq.
- Scenario 2: 727,1 t CO2 eq.
- Scenario 3: 315,1 t CO2 eq.
- Basic scenario: 580,8 t CO2 eq.

In scenario 2, it is assumed that two conservation measures, each with a scope of 50% of the construction emissions, will be carried out. Consequently, the same amount of CO2 eq. is emitted for maintenance as when the bridge is built new, and the scenario is therefore rated with 2.5 for the indicator GWP100. The remaining ratings are shown in the spider diagram in Figure 11.

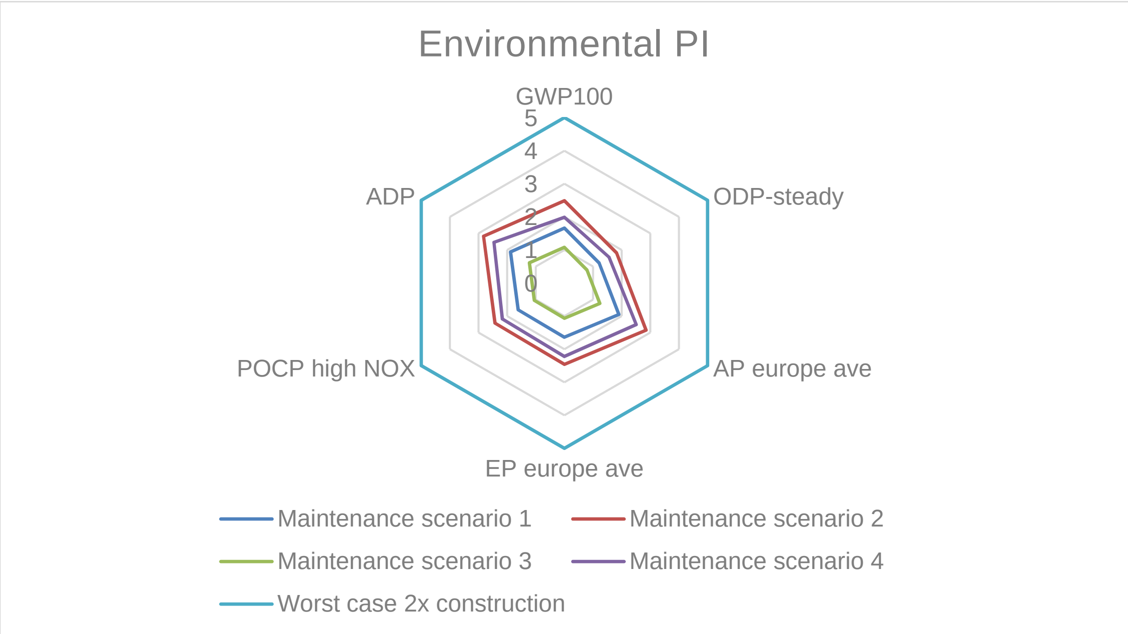

Figure 11: Environmental performance indicators for all scenarios

To convert these performance indicators into a single Environment KPI, there are two options. Firstly, there is the possibility to give different significance to the different PIs and then to transform these results to a single KPI. This is done, for example, within green building rating systems such as DGNB, LEED or BREAM. In this study, all PIs are considered equally significant. So the arithmetic mean of the PIs was used to create the environment KPI (see Figure 12).

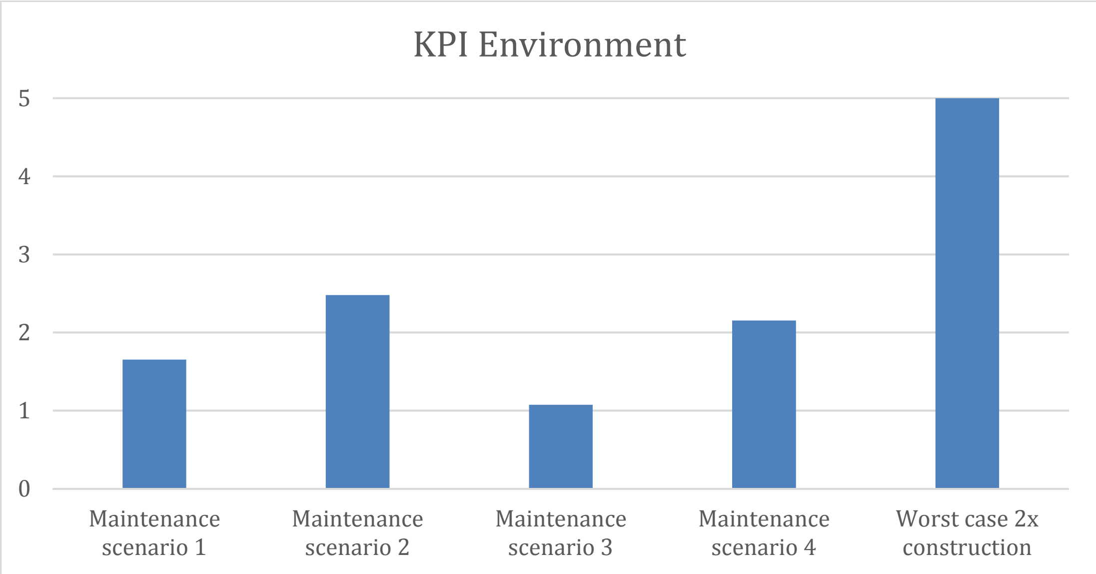

Figure 12: Environmental key performance indicator for all scenarios

4. FUTURE COLLABORATION

Many ideas and knowledge were exchanged during my STSM and I believe that I have developed good relationship with Prof. Matos and the other PhD students. The future collaboration will continue because there is already a lively exchange between our two institutes and both are strongly involved in the COST TU 1406.

5. FORESEEN PUBLICATIONS/ARTICLES

It is planned to fill this study with the remaining KPIs of COST TU 1406 and to make a complete case study. This case study will then be published as a publication.

6. ADDITIONAL COMMENTS

As a PhD student at University of Natural Resources and Life Sciences in Vienna, I am working on a research project supervised by Prof. Strauss, where final objective is to develop a life cycle assessment method for torrent control structures. Therefore, I very much appreciate the fact that I had the opportunity to apply parts of the developed model and to translate it to bridge constructions and that I had the opportunity to gain knowledge about the bridge construction.

I would like to thank to entire COST TU1406 Management Committee for providing me this opportunity. In addition, my thanks go to the host institution and to the exceptional host Prof. Matos. I very much appreciate your detailed supervision and time invested into discussions related to my assignments.

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8. ANNEXES

8.1. CONFIRMATION BY THE HOST INSTITUTION ON THE SUCESSFUL EXECUTION OF THE STSM

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COST ACTION TU1406: QUALITY SPECIFICATIONS FOR ROADWAY BRIDGES, STANDARDIZATION AT A EUROPEAN LEVEL

Confirmation on the successful execution of a Short-Term Scientific Mission

to the Grant Holder of the COST Action TU1406: *Quality specifications for roadway bridges, standardization at a European level*

Guimarães, Portugal, 06 de março de 2019

STSM Applicant: Roman Paratscha
Home Institution: University of Natural Resources and Life Sciences, Vienna, Austria
Host Institution: University of Minho, Portugal

I hereby confirm that we welcome Roman Paratscha in our Institute in Guimaraes, Portugal in February 2019, within the Framework of the TU 1406 Short-Term Scientific Mission (STSM) program for the duration of 10 days.

In consideration of the performed activities, the STSM work was of a benefit for both the STSM applicant and towards the current needs of the COST 1406 Action. During his STSM, he has performed all tasks that were set before and will continue the work on the project goals after the finish of the STSM.

We are looking forward to future cooperation with Mr. Roman Paratscha and his home institution on the COST TU1406 project.

Yours sincerely
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