Life cycle assessment: assessing the environmental impact in the railway maintenance

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Abstract. The railway sector plays an important role in the European transport sector and its environmental sustainability is a highly important issue today recognized by all the main stakeholders, including the European Commission. EU-28 railway transport network consisted of 220,000 km of railway lines in 2013. Such a big railway transport network requires maintenance. Maintenance of a railway infrastructure is a resource- and cost-demanding activity that has as well a considerable impact on the environment. This paper presents the results of the environmental assessment of an innovative new product which aims to decrease the environmental impact of the railway maintenance processes. Life cycle assessment methodology was used and results show that the biggest environmental impact, in all impact categories, is achieved in the use and maintenance phase. In the end, the normalized data of the environmental impact were presented using the standard functional unit for the freight trains: tonne for kilometre (tkm). Additionally, authors have compared two different functional units that could be used in Life cycle assessment of the self-propelled freight railway vehicles, proposing the use of the new functional unit: tonne for working hour (twh). Use of such customized functional unit is more appropriate because of the specific nature of work that self-propelled bulk carriages have.

1 Introduction

The environmental sustainability of the transport sector in Europe is an important subject today and the railway sector plays an important role, although the majority of the greenhouse gas emission still comes from the road transport [1]. In 2013, EU-28 railway transport network consisted of 220,000 km of railway lines. If the railway lines of China, Russia, Japan, and the USA are added, this number could reach 634,200 km [2] that have to be maintained.

In general, railway infrastructure can be divided into [3]: the track, the power supply system, and the signalling system. Maintenance of the railway infrastructure is resource- and cost-demanding activity with a substantial impact on the environment. This is especially true for the maintenance of the track when diesel locomotives are used for shunting the bulk carriages at the site. More precisely, three locomotives have to be used of which one has to work constantly either shuffling the carriage or in the standby. Although its service may be needed only for a short period of time, the locomotive is taken up all day. The Croatian company, RŽV Čakovec has developed an innovative product called Self-propelled bulk carriage (SPBC) that could make railway maintenance more environmentally friendly. SPBC has the capability to move on rails using its own propulsion system managed via remote control. It uses less energy, compared to the three locomotives, but it still has some environmental impact. To assess the environmental impact of the SPBC, an attributional life cycle assessment methodology was used. LCA is a science-based, comparative analysis and assessment of the environmental impacts of product systems, and it is distinguished from other methods by two basic features: cradle-to-grave analysis (Fig.1) and functional unit [4].

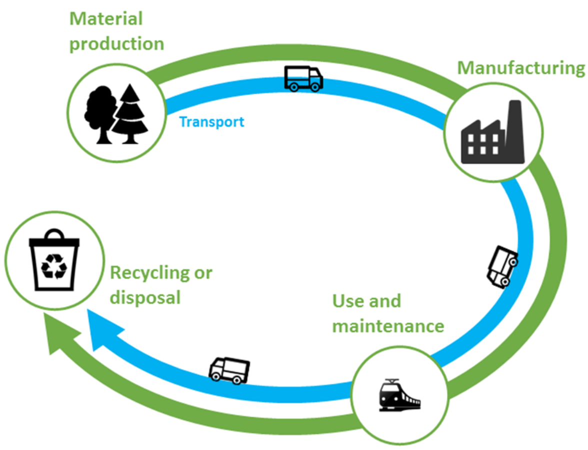

Fig. 1. Cradle-to-grave approach.

LCA methodology has its roots in the late 1960s and early 1970s when the first studies that were focusing on

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environmental impacts from different types of beverage containers took place in the USA [5]. There were studies analysing the environmental impact of the railway industries in different countries [6], [7], [8], [9], [10], [11], but none of the studies was done for the rail bulk carriage.

LCA study is mostly based on assumptions made by the commissioner, and therefore, it is hard to compare the results of the two different LCAs. For companies to be able to compare the results, it is important that the creation of the LCAs for specific product group follow the same rules. This is why product category rules (PCRs) are created.

PCRs give guidance for the development of Type III environmental declarations and are defined by ISO 14025:2006 [12]. Thus, PCRs serve as guidelines for the creation of the LCA studies for the specific group of products. LCAs built according to specific PCRs can be compared.

General LCA approach used in this study is based on ISO 14040 [13] and ICDL Handbook [14]. In order to analyse environmental impact, CML2001 (baseline) method is used.

According to the PCR, the functional unit for the freight trains is tonne-kilometre (tkm). Although SPBC is a freight carriage, it has different regimes than the normal freight train. Therefore, a different functional unit, such as tonne-working hours (twh) might be more appropriate. The aim of this paper is to briefly present the results of the LCA study and give a comparison between the normalized results given in tkm and twh.

2 Methodology

Life Cycle Assessment methodology (LCA) was used to assess the environmental impact of the SPBC. LCA is a science-based, comparative analysis and assessment of the environmental impacts of product systems [4]. The framework for the LCA method is given by ISO 14040:2006 [13], and includes four main phases (Fig. 2): (1) goal and scope definition, (2) inventory analysis, (3) impact assessment, (4) interpretation.

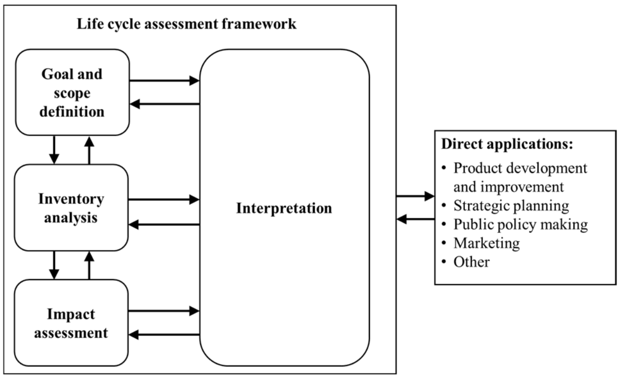

Fig. 2. ISO Life cycle assessment framework.

The first phase of the ISO LCA framework is goal and scope definition. The company wished to gain insights into the environmental impacts of the Self-propelled Bulk Carriage (SPBC). Therefore, the main goal of the conducted study was to calculate environmental impacts using LCA methodology. The studied product system (SPBC) is shown in Fig.3.

Fig.3. Studied product system.

The function of the studied system is to deliver construction materials to the site and discharge the needed amount of materials precisely where they are going to be used. The PCR for rolling stock [15] distinguishes passenger rolling stock and freight rolling stock. The SPBC fits into the category freight rolling stock. Therefore, the basis for the environmental comparison (functional unit) for freight rolling stock used in this study is the transport of one ton of transported and discharged material for one kilometre (1 ton for 1 km).

Product life cycle is divided into three main modules: (1) upstream, (2) core and (3) downstream, and the downstream module is further divided into two phases: (a) use and maintenance (UaM) (b) end of life (EoL) phase. Processes included into the scope of the LCA are shown in Table 1.

Table 1. System boundaries of the studied product system.

Module	Description
Upstream	Raw material extraction. Manufacturing of materials, electricity, and subcomponents.
Core	Rail vehicle manufacturing, energy and auxiliary material use, transportation to final destination.
Downstream	Use and maintenance.
	End of life.

LCA methodology offers to model the environmental impacts in numerous categories. For this study, only five main impact categories were chosen. Categories were chosen based on the recommendation of the PCR for rolling stock [15].

In order to analyse environmental impact, CML2001 (baseline) method is used. According to the PCR [15], five relevant impact categories (IC) were chosen: (1) Global Warming Potential (GWP), (2) Ozone Depletion Potential (ODP), (3) Acidifying Potential (AP), (4) Eutrophication Potential (EP), (5) Photochemical Ozone Creation Potential (POCP).

The most important and most time-consuming phase in performing the LCA is the inventory analysis. Through the life cycle inventory analysis (LCI) phase, the actual data collection and modelling of the system was done following the directions, i.e. goal and scope defined in the previous phase. A brief summary of the information collected through the LCI phase is given further in the paper.

Summarized results of the materials used to produce SPBC are given in Fig.4, from which it can be concluded that more than 97% of the materials are metals.

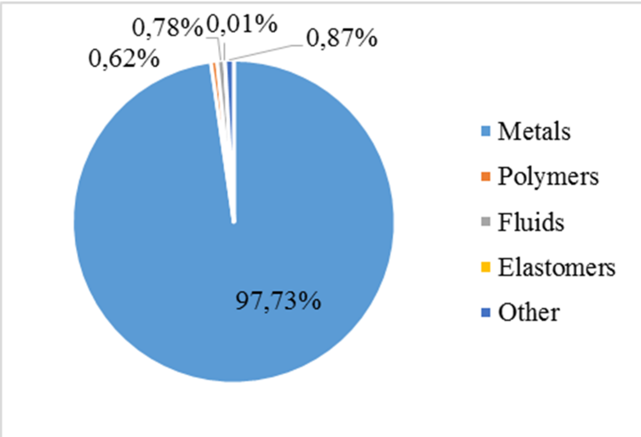

Fig. 4. Materials by type.

Allocation method had to be used to calculate the use of resources, including electricity, gas, and water since the company didn't have information on the amount of resources used per specific product. To allocate the resources, total working hours needed to finish the product were used. First, the total amount of specific resource in a particular time interval was divided by the total working hours in the same period. In this way, a unit amount of specific resource per working hour was obtained. Secondly, this unit amount of specific resource was multiplied by the total amount of working hours invested in the manufacturing of the SPBC. The total amount of working hours for SPBC was 2400 h. Table 2 shows the results of electricity, gas, and water use.

Table 2. Resources included in environmental assessment in core module.

Resource	Amount	Unit
Electricity	5937,30	kWh
Gas	1346,60	m^3
Water	165,60	m^3

Accordingly, the diesel motor technical data obtained shows that it uses 8 litres of fuel per working hour. Taking into account the 35 years long life cycle and approximately 1250 working hours per year of the SPBC, it is estimated that the SPBC will use 350,000 litres of fuel in its whole life cycle.

Based on the data collected and structured during the life cycle inventory analysis phase, life cycle impact assessment (LCIA) was performed using the OpenLCA software version 1.41.

3 Results

Fig.5 shows the results of the LCIA. Environmental impact is shown through five different impact categories and four main phases of the product lifecycle. A detailed description of every impact category can be found in [16].

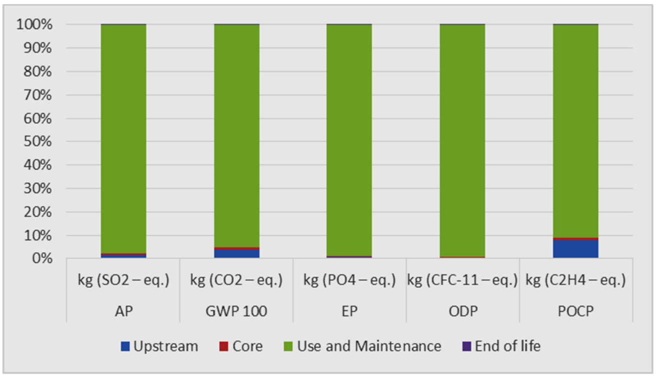

Fig. 5. Environmental impact of the SPBC

As can be seen in Fig.5, the biggest impact on the environment is in the use and maintenance phase in all four categories. The biggest contributing process to the environmental impact in the UaM phase is the "Diesel process". For e.g., for the impact category Climate change – GWP100 through all phases - "Diesel process" contributes 91.84%.

To compare different product systems based on their environmental impact, the values of their environmental impact have to be normalized. Normalization of data was done by calculating the total tkm per SPBC life cycle. The data given in Table 3 were estimated, and based on these data, the functional unit was calculated.

Table 3. Data for calculation of functional unit.

Category	Amount	Unit
Working hours per year	1,250	hours/year
Life span	35	Years
Total working hours	43,750	working hours
Tara weight	37.34	t
Cargo weight (max)	52.66	t
Average weight (80% load)	79.47	t
Average speed (80%)	4.80	km/h
Total kilometres	210,000	km

The functional unit was calculated by multiplying the total kilometres and average weight (80% load) which resulted in 16,688,700 ton per km (tkm). After the functional unit was calculated, the environmental impact results were normalized to the functional unit. Results of normalization are given in Table 3.

Table 4. Normalized environmental impact.

IC	Unit	Upst-ream	Core	Downstream	
				UaM	EoL
AP	kg (SO_2–eq.) / tkm	8,285E-06	3,065E-06	5,264E-04	1,096E-07
GWP-100	kg (CO^2–eq.) / tkm	2,810E-03	7,614E-04	7,021E-02	7,133E-05
EP	kg (PO_4–eq.) / tkm	7,947E-07	3,866E-07	1,198E-04	1,086E-08
ODP	kg (CFC-11 – eq.)/tkm	2,760E-11	6,753E-11	1,262E-08	3,632E-12
POCP	kg (C_2H_4 – eq.) / tkm	1,215E-06	1,688E-07	1,429E-05	6,903E-09

Normalized data obtained from Table 4 represents the environmental impact of the SPBC, measured through different impact categories and achieved by performing the function of transporting one tonne of load over one kilometre.

4 Discussion

Analysing the environmental impact through the given categories, it is obvious that the biggest impact is in the use and maintenance phase of the product lifecycle. As was mentioned earlier, this impact resulted basically because of the use of diesel fuel, i.e., the diesel production and consumption process.

Considering the fact that the very big impact on the amount of the functional unit has an average speed of the SPBC, it will be hard to compare the normalized data of the SPBC with other bulk carriages that are intended for long-distance travel. Therefore, in future calculations, we propose the adoption of the functional unit for the short distance bulk carriage, or more specifically, for the self-propelled bulk carriage such as the SPBC to tonnes for working hour (twh). The functional unit, twh, is more appropriate because the main function of the self-propelled bulk carriage is mainly to discharge the material at the point of use and most of the time it is in a stand-still position. To travel longer distances, it uses a locomotive, but the long-distance travel is not its main function.

If the newly proposed functional unit is used for the normalization, it will result in 3,476,725 twh. The value of the twh functional unit is 4.8 times smaller than the value of the tkm functional unit. Thus, the normalized values of the environmental impact will be increased for the same number.

5 Conclusions

Nowadays, three diesel locomotives are used to manoeuvre bulk carriages during railway track maintenance. Although its service may be needed only for a short period of time, one locomotive is occupied all day. RŽV Čakovec has developed an innovative product called SPBC to tackle this problem and thus decrease the overall impact the railway track maintenance process has on the environment.

SPBC uses 8 litres of diesel fuel per working hour to perform the same activity as would three locomotives. Having in mind that one locomotive uses approximately 300 litres of diesel fuel per hour, it is obvious how big the savings on fuel are. Taking into account the environmental impact of the SPBC, it can be concluded that the biggest percentage of the impact is due to the use diesel fuel. Being able to reduce the amount of fuel used per working hour can directly decrease the impact of railway track maintenance process on the environment. Therefore, the use of the SPBC for certain railway track maintenance activities will reduced the impact on the environment.

SPBC is the prototype of the self-propelled bulk carriage, and it is the only product of this type on the market. But to be able to compare similar products from this product category in the future, experts should consider using functional unit twh (tonnes of transported and discharged material for one working hour) instead of tkm. If self-propelled carriages use twh as the functional unit, a more accurate normalized environmental impact would be obtained. Also it would be possible to compare the environmental impact of the products in the same product category.

The results of the discussed LCA study are used to obtain necessary certificates needed for the commercialization of the SPBC and they are intended for the internal audience. Therefore, there was no comparative analysis done in the study. Also, there are certain data limitations; hence, the study concerns environmental data from Croatia. This means that the availability of this data is limited. Where no relevant sources of data regarding Croatia were available, an EU average data were used.

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