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Evaluation of an Eco Audit tool - through an LCA of a novel car disc brake

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Abstract

Transport of goods and people is increasing and causing strains on the environment. Road vehicles emit exhaust and non-exhaust emissions. One significant contributor to non-exhaust emissions is particulates generated through wear from braking. The particulates originate from the contact surfaces of the pad and the disc. Particulate emission is a known issue with considerable impacts on plant, animal, and human health.

In the EU Horizon 2020 LOWBRASYS (a LOW environmental impact BRAke SYStem) project (LOWBRASYS, 2017), one of the objectives was to design a novel disc brake that reduces particulate generation during braking. One of the results is a novel disc brake with disc and pad-materials that indicate a significant decrease in particulate formation during use. This is accomplished by changing the materials of the contact pair regarding composition and coatings (Wahlström, Lyu, Matjeka, & Söderberg, 2017). Materials used in the disc brakes cause environmental impacts during their life cycle. Some parts and processes need for example critical raw materials such as tungsten, cobalt, and more (European Commission, 2017).

This paper evaluates a material selection tool with an environmental perspective for product developers called Eco Audit (Ashby et al. 2008). This tool is featured in the CES Edu Pack software provided by Granta Design, Cambridge University (Granta 2018). The purpose of this study is to evaluate if the Eco Audit tool can provide a fast and valid impact assessment from an LCA perspective.

Results of the Eco Audit compared to the SimaPro results indicate that it is possible to make valid conclusions. The validity of the tool is connected to the purpose of the study. If the purpose is to identify critical life cycle phases and environmental impacts, then the tool can accurately aid the user. It could potentially be difficult to make valid conclusions when assessing a product with more complex processes or advanced materials. The tool's strengths are the simplicity and easy accessibility for any user. The trade-off is precision, robustness, and representativeness of the target.

Keywords: Product design, material choice, Life Cycle Assessment, Eco Audit, disc brake

1 Introduction

All materials used in products have environmental impacts throughout the product life cycle. The impacts begin during the extraction of raw materials and continue through the manufacturing phase. The environmental impacts are mainly due to energy needs, resource usage, and waste production. During the use life cycle phase, the product is used, requiring energy, spare parts, maintenance, and other resources depending on the specific product. In the end, the product reaches the end-of-life phase because of different reasons. The product might be worn out, broken, unfashionable, or just dirty. In this life phase, the product is waste managed.

During the product development, it is possible for the designer to assess potential environmental impacts through some software. The purpose could be to monitor how the choice of materials affects the impacts during the life cycle. It is, of course, possible to reduce impacts when designing new products with a conscious choice of materials.

This paper will analyse a material selection tool, with an environmental perspective, for product developers called Eco Audit (Ashby, Coulter, Ball, & Bream, 2008). This tool is featured in the CES Edu Pack software provided by Granta Design, Cambridge University (Granta, 2018). The tool aims to give the product designer possibility to quickly identify the life cycle phase with the primary environmental impact.

In the EU Horizon 2020 LOWBRASYS (a LOW environmental impact BRAke SYStem) project (LOWBRASYS, 2017), a novel disc brake was developed that reduces particulate generation during braking. The reduction is accomplished by changing the materials of the contact pair regarding composition and coatings (Wahlström et al., 2017).

This study intends to evaluate if the Eco Audit tool can provide a fast and valid impact assessment from an LCA perspective. It is of great value to be able to simplify the LCA study to save time and resources, but the validity must also be evaluated (Hochschorner & Finnveden, 2003). The LCA perspective of using the Eco Audit tool is not presented in previous studies. Prior publications about the Eco Audit tool mainly focus on the usability for the designer, e.g. (Agudelo, Nadeau, Pailhes, & Mejia-Gutierrez, 2016; Birch, Hon, & Short, 2010; Marques, 2014) or straightforward application in case studies, e.g. (Mustafa, Abdollah, Ismail, Amiruddin, & Umehara, 2014). The evaluation in this study is made through a comparative case study of two different disc brakes: the novel disc brake developed in the LOWBRASYS project and a reference disc brake. The products are modelled in the tool, and the results are analysed. To be able to evaluate the validity the result is compared to an LCA calculation made in SimaPro which is considered to be a more sophisticated but complex assessment tool (PRé, 2018). A first assessment of the disc brakes was presented at the EuroBrake2018 conference in Hague in May (FISITA, 2018). The first study was conducted in SimaPro (PRé, 2018) demanding more data than for the Eco Audit tool. A new full-scale LCA study of the disc brakes will be published shortly.

2 Method

According to the ISO 14040:2006 standard (ISO, 2006b), there are four steps in the LCA method: goal and scope definition, inventory analysis, impact assessment, and interpretation. The following description of the LCA method is mainly from the ISO 14044:2006 standard (ISO, 2006a). An LCA analyst moves back and forth between the steps during an assessment since the LCA is an iterative procedure. The scope depends on the subject and the intended use of the study. The depth and the breadth of LCA can differ considerably depending on the goal of a specific LCA. The life cycle inventory analysis is an inventory of input/output data about the system being studied. The inventory analysis involves the collection of the data necessary to meet the goals of the defined study. The level of detail can differ between studies. The purpose of life cycle impact assessment is to provide additional information to help assess a product system's inventory results to understand their environmental significance better. In life cycle interpretation the results of an impact assessment are summarised and discussed as a basis for conclusions, recommendations, and decision-making in accordance with the goal and scope definition. Additionally, an evaluation that considers completeness, sensitivity, and consistency checks are included in this step.

2.1 Eco Audit tool

In this study the Eco Audit tool, also called "the tool", is used and analysed, it is included in CES EduPack software provided by Granta Design, Cambridge University (Granta, 2018). The software primarily includes a substantial material database with more than 3 900 materials. The tool evaluates the environmental impact of a product, from the cradle to the grave, presented as six parts of a life cycle: material, manufacture, transport, use, disposal, and end-of-life potential. The impacts are expressed as environmental stressors of energy use [MJ] and CO_2 footprint [kg].

As mentioned in the introduction, previous Eco Audits made with the software mainly focus on direct assessments of products (Mustafa et al., 2014) or analysis of usability for the designer (Agudelo et al., 2016; Birch et al., 2010; Marques, 2014). Most publications are however from a couple of years ago, since then the software has been further developed. The 2017 version, used in this study, include improvement of features in the Eco Audit part, mainly regarding reuse, and warnings to alert the user when using critical raw materials and restricted substances.

2.2 Case study model in Eco Audit

Two different disc brakes are modelled in the tool and compared. The most advanced level, "level 3 Sustainability", is used for the study. The objective is to identify significant environmental impacts in specific life cycle phases. The scope of the study includes the whole life cycle for two different disc brakes, and the geographical scope includes Europe. The disc brakes are used in an average European family gasoline car. The functional unit is defined as decelerating of a car during the lifetime of the car. It is assumed that the lifetime of the car is 240 000 km. The subsections are organised according to the modelling sequence in the tool.

2.2.1 The material, manufacturing, and end of life phases

The parts assessed in the disc brake are two friction material pads and one disk rotor, Figure 1. The materials mixed into the friction pad are a complex mix of resins, metals, and polymers. To protect the immaterial right of the pad manufacturer, it is not possible to specify the material mix further. The disc is cast iron that is cast and machined to the right dimensions.

The difference between the reference and novel disc brake are the material mix of the pads and an additional WC-Co-Cr coating of the novel disc. The efficiency of the flame spray process is about 30 %, i.e. 70 % of the coating powder is discarded. The efficiency is however not possible to model in the tool. The total needed amount of powder materials are added to the model.

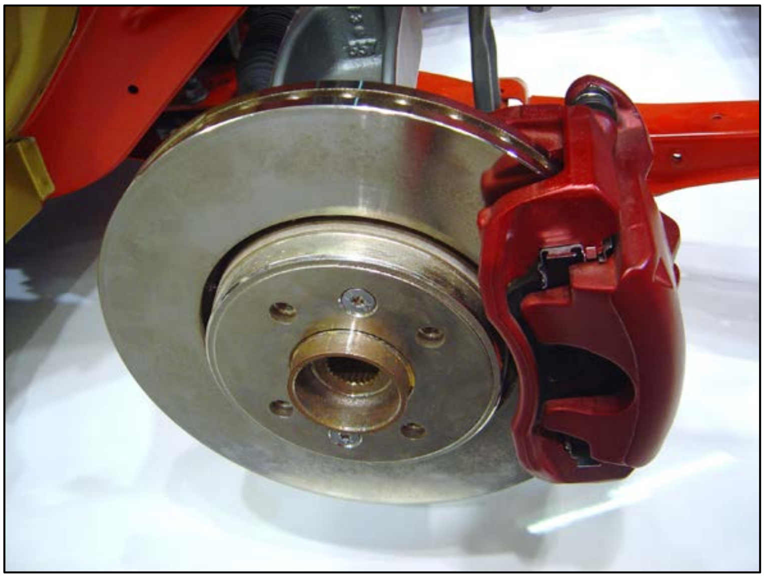

Figure 1. Disk brake, showing the rotor disc and friction pads in the calliper (Wikimedia, 2018)

In the tool, it is possible to set the end of life destiny for each material separately. The reference disc cast iron is material recycled with 45 % material recovery. The pads and novel disc are a mix of many materials, and these are landfilled.

2.2.2 Transport

The parts are manufactured at several sites in EU. Raw materials are assumed to be transported to manufacturing sites. The cast iron disc is made in Poland, the novel disc is coated in Hungary, the friction pads are manufactured in Germany, and all parts are transported to the car manufacturing site to be assembled into the vehicle. All transports are assumed to be made by a 32-tonne truck.

2.2.3 The use phase

The use phase in the tool is modelled either as a static or a mobile mode. In this case, the use is a mobile mode, i.e. is a part of a vehicle, and the fuel and mobility type is a gasoline family car. The mobile use mode is defined by three parameters: the transport type, efficiency, and the distance travelled over the product's life.

During the use phase, a number of spare parts are needed because of wear on the disc and pads. The reference and novel disk brake have different lifetimes, depending on wear rates, in the course of the lifetime of the car. In Table 1. the total amount of disc brake parts needed is presented.

Table 1. Amount of disc brake parts needed during one vehicle lifetime.

Disc Brake part	Novel Disc Brake	Reference Disc Brake
Pads	8	10
Disc	1	2

This means that there is a need for six spare part pads for the novel disc brake, while the reference disc brake requires one disc and eight pads as spare parts. The reference disc must be changed once during the lifetime of the car while the novel disc has the same life-length as the vehicle. In the tool, this is modelled by manipulating the “quantity” of components in the material and manufacturing life cycle phases.

This study will disregard impacts during the operation of the car due to three reasons. First, if the needed disc brake spare parts are added in the material and manufacture phase, the tool calculates the operation impact as if the car carried the spare parts with it throughout the whole lifetime. This extra load influences the efficiency, i.e. additional fuel consumption due to the added mass. Hence, the impact of the reference disc brake due to the additional spare parts would overestimate the impact of the product during operation. Secondly, the primary goal of the EU project was to reduce the particulate emissions during braking. It is not possible to simulate this scenario in this tool. Finally, the impacts due to the operation of the car do not differ between the products, since the same transport type is used, the same efficiency, and the same distance is travelled.

2.2.4 Limitations of the study

There are some limitations of the study due to limits of the tool. The limitations, actions, and implications are described.

- Some of the specific raw materials used by the manufacturers could not be found in the Edu Pack material database. However, the raw material that was closest to the original material was chosen. The difference in environmental impact between original and chosen materials is minor.
- The choice of manufacturing processes in the tool is limited, e.g. metal powder production and thermal spraying are not available as processes. Hence, impacts due to the production of the coating are underestimated.
- The liquid oxygen and kerosene used during the thermal spraying of the novel disc could not be included in the audit. The exclusion is due that these process “raw materials” are not included in the database. Hence, the impact of the novel disc might be underestimated.

3 Results

The critical raw materials and restrictions connected to material choice are identified, and the environmental impacts of energy use and CO_2 footprint are presented for each life cycle phase. Note that the use life cycle phase is zero to highlight the impacts in the other life phases. The impacts of the spare parts used in the use phase are featured in the material and manufacturing phase.

Critical raw materials used for the pads are magnesia, and for the novel disc: tungsten, chromium, and cobalt. Critical raw materials are materials with high economic importance and potential supply risk (European Commission, 2017). Additionally, there is a significant sustainability impact attached to the critical raw material life cycle. Resource restrictions concerned are REACH and RoHS, applying if a sort of UV-stabiliser is used in the friction pads.

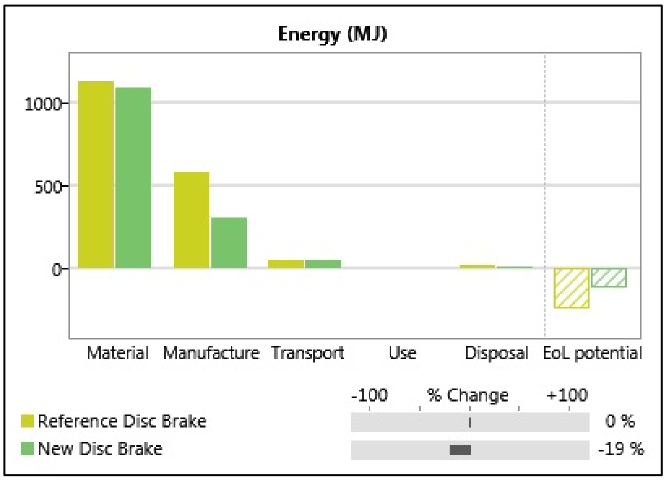

Figure 2. The summary chart of the comparative energy analysis

In Figure 2. a summary chart from the tool, it is evident that the energy use during material and manufacture phases of the reference disc brake is more significant than for the novel disk brake. This is because of the additional need to manufacture spare parts for the reference brake. The percentile change shown in grey, on the lower part of the picture, represents the overall difference in energy usage.

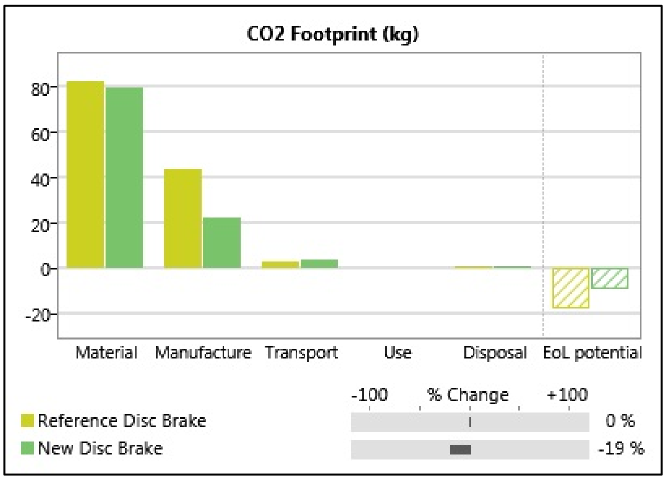

Figure 3 The summary chart of the comparative CO_2 Footprint analysis

The Figure 3, a chart from the tool, shows that the CO_2 Footprint of the reference disc brake is higher during the materials and manufacture life phases than for the novel disc brake. This is yet again because of the additional need to manufacture spare parts for the reference brake. The percentile change shown in grey, on the lower part of the picture, represents the overall difference in CO_2 Footprint between the products.

The most critical life cycle phases are identified, and through the detailed Eco Audit report, it is possible to identify the part with the most significant impact. In this case study, it is the spare parts for the reference disc. Though the materials needed for the coating of the novel disc contributes to a significant impact, the impacts of the production of the two reference discs are more substantial.

However, as stated in the limitations of this study, some processes and materials are missing in the audit, e.g. thermal spraying, liquid oxygen, and kerosene. Therefore, the impact of the novel disc might be underestimated, and conclusions about the comparison of the disk brakes might not be valid.

3.1 Comparing of results

In the EU project, a full-scale LCA study was modelled in SimaPro (PRe Consultants, 2017). Since the study is not yet published and the specific results must be protected, it is not possible to disclose detailed results from the LCA. Although SimaPro can deliver a multitude of impact category results, the trade-off is a higher level of complexity, lower transparency, and possibly it might be more challenging to draw fast conclusions from the result. The Eco Audit result is compared to the SimaPro result and conclusions are drawn about the validity of the conclusions.

The comparing of the results reveals that the conclusions made above based on the results of the Eco Audit are relevant. The audit points out the material and manufacturing life phases as most significant. Further scrutiny in the Audit report pinpoints cast iron disc as the significant impact source of the reference disc brake. The Eco Audit result corresponds to the SimaPro result; hence, the Eco Audit validity claim is strengthened.

The WC-Cr-Co coat on the novel disc is identified, by the Eco Audit, as a significant impact in the novel disc brake material and manufacturing life phases. The raw material impact by the WC-Co is of the same magnitude as the cast iron in both energy use and CO_2 footprint. The impact due to the coating materials is however minimal in the SimaPro calculation. This low impact is due to the difference in data quality. The data in SimaPro concerning tungsten and tungsten carbide is lacking. The Eco Audit calculation, however, uses an updated database concerning the WC environmental impacts. This result indicates that the conclusion about the disc coating impact is critical and of significance for the assessment of the disc brakes.

4 Discussion

The stated goal of this Eco Audit study is to identify critical life cycle phases and environmental impacts. The usefulness of the tool to assess environmental impacts is tied to the purpose of the study. If the purpose is to only get a simple indication of the specific material environmental impact, then the tool can aid in guiding information in the database. The Eco Audit results are compared to SimaPro study results, and the validity of the Audit conclusions are strengthened. However, if the purpose is to assess a complex product with advanced processes, then the results must be interpreted very carefully to avoid ignoring severe impacts or making sub-optimal design decisions. It is as the makers mention in their white paper from 2008 (Ashby et al., 2008), 'the tool lacks some of the features that a full commercial tool requires, but these features come at a penalty of complexity and difficulty of use; simplicity, in teaching, is itself a valuable feature'. Therefore, this tool is suitable for teaching, but care must be taken to explain to the students how the simplicity might alter the outcome. The main strength of the tool is the simplicity and an extensive material database as a foundation. The simplicity indicates that it is easy to learn how to use the tool and results are presented in well understood environmental impacts. Compared to more advanced LCA software the tool saves time and do not require a higher level of expertise in environmental impact assessment, promoting transparency and accessibility for product designers.

The simplicity is however also a weakness since it affects the external validity, which is the ability to draw general conclusions from the result (Kalaian & Kasim, 2011). As with most

LCA results precautionary approach is to be preferred when making conclusions (Finnveden, 2000). One particular weakness is that many other impact categories are left out; hence impacts such as resource depletion, water use, and land use are not considered. This could lead to an underestimation of impacts.

There is a trade-off between the simplicity and transparency of the tool against precision, robustness, and representativeness of the result. Using only two impact categories enables the designer to quickly get an overview of the potential environmental impacts of a product. However, there is a risk that other critical impacts are missed.

There are several limitations in the tool that could potentially lead to mistakes in interpretation of the results. As stated in the section describing the limitations of the study some raw materials and manufacturing processes are missing in the tool. Additionally, the decision to set operation impacts to zero is due to a limitation in the tool. To avoid overestimation of the impacts and wrongful conclusions about the use phase it was necessary to omit the operation of the car. The effect of this omission is limited since the correct energy use, and CO_2 footprint impact for both products are identical and hence not significant since this is a comparison of two disc brake alternatives. In conclusion, it is necessary to do more studies about the environmental impacts of the material selection. However, the tool can give a quick comparative assessment pointing out potential hot-spots.

According to the design paradox, the product knowledge and freedom of action are in contrast to each other (Ullmann, 2010). In this case study, the main aim was to diminish the particulate emissions during use. Hence, the consequences of the material choice might be considered as secondary. However, with an aim to develop sustainable products, the planning and consideration of all aspects of potential issues are critical. It is not wise to only consider one aspect since the decision might aggravate the environmental performance in a life cycle perspective. That is, the aim to reduce particulate emissions through a change of materials will shift impacts to other life cycle parts.

4.1 Conclusions

This study intends to evaluate if an Eco Audit tool, a feature in CES EduPack material database, can provide a fast and valid environmental impact assessment from an LCA perspective. The evaluation is made through a comparative case study of two different disc brakes. The products are modelled in the tool, limitations are identified, and the results are analysed.

The findings indicate that the most extensive impacts are associated with the additional materials and manufacture of the spare parts. The novel disk has significant impacts caused by tungsten carbide (WC) used for the coating. The limitations of available processes and process resources in the tool could cause a severe underestimation of impacts. However, the strength of the vast material database including potential environmental impacts is significant.

Results of the Eco Audit compared to the SimaPro results indicate that it is possible to make valid conclusions. The validity of the tool is connected to the purpose of the study. If the purpose is to identify critical life cycle phases and environmental impacts, then the tool can accurately aid the user. It could potentially be difficult to make valid conclusions when assessing a product with more complex processes or advanced materials. The tool’s strengths are the simplicity and easy accessibility for any user. The trade-off is precision, robustness, and representativeness of the target.

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