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CARBON FOOTPRINT OF THE RAW MATERIALS OF AN URBAN TRANSIT BUS

Case Study: Diesel, Hybrid, Electric and Converted Electric Bus

LAHTI UNIVERSITY OF APPLIED SCIENCES
Degree Programme in Environmental Technology
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KÄRNÄ, PÄIVI:

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51 pages, 10 pages of appendices

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ABSTRACT

The environmental impacts of a bus have been studied by concentrating notably on the carbon footprint caused during the operation of a bus. It is understandable, since the majority of the emissions are produced during the use. The results of this study, however, provide some in-depth information about the emissions of the first phase of a bus' life cycle, raw material extraction and pre-processing.

In this study, the raw materials of four bus types were investigated with the help of five case studies. Based on this data, the amounts of the most common greenhouse gases per the materials of one bus were calculated. The bus types in this study are two diesels, a hybrid, an electric and a converted electric bus. The examples examined in the study are 12-meter-long buses meant for urban traffic. The study was conducted by utilizing the Product Life Cycle Accounting and Reporting Standard by GHG Protocol, and EcoInvent database.

According to the results of this study, the factors which affect the material carbon footprint of a bus most are the choice of the main raw material and the amount of different electric components. Also the amount of double glass, which is used in windows for safety, causes notable greenhouse gases to all of the case buses. The results of this study are meant to be combined with other studies describing the life cycle of a bus in order to draw a clear picture of the environmental impact of a bus.

The data for this study has been produced as a part of the EcoMill project.

Key words: material carbon footprint, bus, greenhouse gas emissions, kg CO_2e

Lahden ammattikorkeakoulu
Ympäristöteknologian koulutusohjelma

KÄRNÄ, PÄIVI:	Kaupunkilinja-auton raaka-aineiden hiilijalanjälki Tapaustutkimus: diesel-, hybridi-, sähkö- ja konversiosähkölinja-auto
Ympäristötekniikan opinnäytetyö	51 sivua, 10 liitesivua

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TIIVISTELMÄ

Linja-auton ympäristövaikutuksia on tutkittu keskittymällä pääasiassa käytönaikaiseen hiilijalanjälkeen. Tämä on ymmärrettävää, sillä suurin osa päästöistä syntyy käytössä. Tämän tutkimuksen tulokset antavat syventävää tietoa linja-auton elinkaaren ensimmäisestä vaiheesta: raaka-aineiden erotuksesta ja esikäsittelystä.

Tässä tutkimuksessa on selvitetty neljän linja-autotyypin raaka-aineiden määrät hyödyntäen viittä tapaustutkimusta. Yleisimpien kasvihuonekaasupäästöjen määrät linja-auton materiaaleja kohti on laskettu näiden tulosten pohjalta. Tutkitut linja-autotyypit ovat kaksi diesellinja-autoa sekä hybridi-, sähkö- ja konversiosähkölinja-auto. Tutkimuksessa tarkastellut esimerkit ovat kaupunkiliikenteessä käytettäviä 12-metrisiä linja-autoja. Tutkimuksen toteutuksessa on käytetty Product Life Cycle Accounting and Reporting -standardin GHG Protocol -ohjeistusta sekä EcoInvent-tietokantaa.

Tutkimuksen tulosten mukaan pääraaka-ainevalinta ja elektroniikan määrä vaikuttavat eniten linja-auton materiaalihiilijalanjälkeen. Myös ikkunoissa turvallisuuden takia käytettävä tuplalasi aiheuttaa huomattavasti kasvihuonekaasupäästöjä kaikissa tapaustutkimuksen linja-autoissa. Tämän tutkimuksen tulokset on tarkoitettu yhdistettäväksi muiden linja-auton elinkaarta tarkastelevien tutkimusten kanssa, jotta voitaisiin muodostaa selkeä kuva linja-auton ympäristövaikutuksista.

Tutkimuksessa käytetty aineisto on tuotettu EcoMill-projektissa.

Asiasanat: materiaalihiilijalanjälki, linja-auto, kasvihuonekaasupäästöt, kg CO_2e

PERSONAL COMMENT AND ACKNOWLEDGEMENTS

My personal goal while conducting this work was to sum up the whole four years of studies and the main insight I learned during this time: everything we people do has an environmental impact. When we eat, live or travel, we spend natural resources and cause pollution.

It is the same with a bus. A bus is an example of a product which consists of thousands of parts, which someone has produced in order to combine them together. The raw materials of each part have been acquired and pre-processed in order to manufacture the part. I hope the readers of this work will understand at least some of the environmental impacts caused by the manufacture of products. Maybe understanding will change behavior.

I would like to thank all the friendly people, who took part in making this study. There were company representatives, researchers, teachers and friends to give me the needed support to conduct this work. I thank you,

- Reetta Jänis, Project leader in EcoMill project, for being a role model for me

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- Anastasia Sipari from Bionova

- Fellow students and friends: Arttu Vanninen, Jukka Tapio from LUAS

- My inspiring trumpet mentor, Rikupetteri Aaltonen, for cheering me up when the work was not progressing

- Other project workers of EcoMill: Maarit Virtanen and Susanna Vanhamäki

- Teachers of LUAS: thesis supervisor Sakari Autio, Maija Varala language supervisor

CONTENTS

ABBREVIATIONS

CH_4 – Methane

CNG – Compressed natural gas

CO_2 – Carbon dioxide

CO_2e – Carbon dioxide equivalent

EIO-LCA – Economic input-output life cycle assessment

GWP – Global warming potential

GHG – Greenhouse gas

HFC – hydrofluorocarbon

HSL – Helsinki Region Transport (Helsingin seudun liikenne)

ICE – Internal combustion engine

ISO – International Standardization Organization

LCA – Life cycle assessment

LCI – Life cycle inventory

Li-Ion – Lithium ion

MIPS – Material input per service unit

N_2O – Nitrous oxide

NO_x – Nitrogen oxides

PFC – Perfluorocarbon

PKT – Passenger kilometres traveled

SF_6 – Sulfur hexafluoride

SO_2 – Sulfur dioxide

SO_x – Sulfur oxides

VTT – Technical Research Center of Finland (Valtion teknillinen tutkimuslaitos)

GLOSSARY

Acidification potential	Potential of SO_2, NO_x, HCl, NH_3 and HF to contribute to the potential acid deposition, i.e. to form H+ ions.
Activity data	Information which can be measured, modeled or calculated. It is the quantitative data of the activity leading into GHG emissions. In this study, activity data refers to the mass of the material (kg).
Carbon dioxide equivalent (CO_2e)	Unit for comparing the radiative forcing of a GHG to carbon dioxide. The carbon dioxide equivalent is calculated using the mass of a given GHG multiplied by its global warming potential.
Eutrophical potential	The potential to cause over-fertilization of water and soil, which can result in increased growth of biomass.
Function	The service provided by the studied product.
Functional unit	The quantified performance of the studied product.
Global warming potential (GWP)	Value calculated as a sum of emissions of greenhouse gases multiplied by their respective GWP factors.
GWP factor	Factor describing the radiative forcing impact of one mass-based unit of a given GHG relative to an equivalent unit of carbon dioxide over a given period of time.
Iterative process	A process for arriving at a decision or a desired result by repeating rounds of analysis or a cycle of operations. The objective is to bring the desired decision or result closer to discovery with each repetition.

Life cycle assessment	A technique to assess environmental impacts associated with all the stages of a product's life cycle.
Life cycle inventory	Quantification of inputs and outputs of a system.
Material acquisition and pre-processing	Life cycle stage that begins when resources are extracted from nature and ends when the product components enter the gate of the studied product's production facility
Material input per service unit (MIPS)	A concept used to estimate environmental impacts caused by material input from products. Can be calculated for abiotic and biotic impact, or as impact on the water, earth movement and air.
Passenger kilometres traveled	A distance travelled by all passengers.
Powertrain	Group of components which generate the power and cause the motion of the vehicle.
Product life cycle	Phases of a product's life. Consists of the following phases: raw material acquisition, pre-processing, manufacture, distribution and storage, use and end-of-life.
Scope	A chosen range, within which the study is conducted.
Secondary data	Process data that are not from specific processes in the studied product's life cycle.
System boundary	System boundary defines the scope in a more specific level. It indicates which processes are included and excluded in the study.

1 INTRODUCTION

The growth of the number of vehicles has resulted in an increase in the passenger mileage. The average of the kilometers travelled in Finland was 51 800 km for buses in the year 2006. (Tilastokeskus a 2007.) In the year 2011 the number of registered buses in Finland was about 14 200 (Tilastokeskus c 2012). The amount of greenhouse gas (GHG) emissions caused by traffic was about one fifth of the total emissions in Finland in the year 2009 (Tilastokeskus b 2011,15). The European Union has set goals to decrease the GHG emissions and energy consumption by 20 % by the year 2020 (TransEco 2012). All this data show that there is a lot of potential in decreasing the GHG emission of buses.

The majority of emissions caused during the life cycle of a bus come from the use phase, which is a popular topic for studies. The emissions caused during the first phase of a bus' life cycle have, however, rarely been looked into.

The goal of this study is to find out the approximate magnitude of the material carbon footprint of an urban transit bus, which means the greenhouse gas emissions caused by the production of the raw materials used in a bus. The goal is also to investigate how the material choices influence the material carbon footprint of a bus and what the difference is between the material carbon footprints of buses with different means of energy conversions.

This study is based on life-cycle thinking, where the phases of a product's life cycle are raw material extraction and pre-processing, production, distribution and storage, use, and end-of-life. In this study, the first phase, raw material extraction and pre-processing, is being looked into.

The material carbon footprint has been inspected with the help of case buses. The case buses are urban transit buses with the length of 12 meters. The studied bus types are a diesel, a hybrid, an electric and a converted electric bus. The standard for conducting the study was the Product Life Cycle Accounting and Reporting Standard, a part of the Greenhouse gas (GHG) Protocol.

The results of this study do not tell the emissions of the whole life cycle of a bus and they should always be combined with an understanding of the impacts during other stages of a bus’ life cycle. When done so, the results can help bus manufacturers understand which materials cause most emissions and help them develop their products into a more environmentally-friendly direction. The results can also be used when planning calls for bids for bus operators in cities. Other interest groups such as consumers might find this study interesting as well, since it gives information on the product life cycle process.

This thesis has been written based on calculations of the material carbon footprint of different bus types. The calculations have been done as a part of the EcoMill project. The project is coordinated by Lahti University of Applied Sciences and conducted in cooperation with Aalto University. The EcoMill project is funded by the European Social Fund. One of the goals in the EcoMill project is to develop working life qualifications of the students by organizing business cases. The work has been conducted in cooperation with several bus manufacturers such as Caetanobus, Kabus Ltd, MovekoTech Ltd and Volvo Bus Finland Ltd.

2 BACKGROUND OF THE STUDIED BUSES

2.1 Short description of a bus

A bus is a vehicle meant for transporting people. It has seats for the driver and more than eight people. (Ajoneuvolaki 11.12.2002/1090, 10 §.) Buses can vary by size, passenger capacity, energy conversion, number of axles, design, and many other factors. The properties of a bus vary depending on the intended usage of the bus. For example, an urban transit bus has a low floor, several doors, seats with a low backrest and a thin padding, and also space for standing passengers and baby carriages (Kuukankorpi 2012). A coach (a long-distance bus), again, has a trunk for luggage and more seats in relation to the length. Other examples of buses with different structures include mini buses, double deckers and articulated buses.

A bus usually consists of two main parts, a chassis and a body. All the significant technological devices, such as engine, brakes and suspension are located in the chassis. (Kuukankorpi 2012.) Also the axles and tires belong to the chassis. An example of a chassis of a bus is presented in Figure 1.

FIGURE 1. The Chassis of a bus (Volvo 7900 2012).

Powertrain is an important part of the chassis. It consists of a group of components which generate the power and cause the motion of the vehicle

(Wallace 2012). The components classified to belong in the powertrain in this study are presented in Chapter 5.

The body of a bus means the occupant space, that is, the rest of the bus excluding the chassis. Examples of the body parts are walls, roof, nose, rear, doors, windows, interior and seats. It is not very common for the bus manufacturers to produce a bus as a whole (Kuukankorpi 2012). This means that the body is typically built over an already-manufactured chassis.

The main raw material of the bus is usually steel, an alloy of iron and some carbon (How Products Are Made – School Bus 2012). The structure can also be made of aluminium as the main raw material (Kabus kaupunkiliikenneauto 2012). A bus consists mainly of metals, but there are also other materials, such as wood, glass, plastics and technical devices in the structure.

The required properties set to the bus types are defined by the use. Since the urban city buses are used in city traffic and for picking up passengers, they have to be designed for frequent stops and accelerating. Coaches, however, are used on longer routes with fewer stops. (European Stainless Steel Development Association 2007, 111).

2.2 Bus types

In this study, the concept of a bus type means a bus with a certain energy conversion system. The bus types investigated in this study are diesel, hybrid, electric and converted electric bus. There are also other types of buses, such as compressed natural gas (CNG) buses or hydrogen fuel cell buses.

There can be several variants when examining a certain bus type. For example, a hybrid can be a parallel hybrid, a series hybrid or a mixed hybrid, or it can be fitted with a capacitor instead of a battery (Salaterä 2012, Zolfagharifard 2010). The bus types in the case study are presented in Chapter 2.2.2.

2.2.1 Buses used in Finland

A diesel bus is the most common bus type used in Finland (Kuukankorpi 2012). The other bus types used are natural gas (CNG) buses and hybrid buses (Karvonen 2012).

Helsinki Region Transport (HSL) has 86 CNG buses in the metropolitan area (Karvonen 2012; Kuukankorpi 2012). Additionally, there are also two hybrid buses tested by HSL (Karvonen 2012). The other cities testing hybrid buses are Turku and Tampere with a couple of buses in use (Karvonen 2012; Laurikko 2012).

When it comes to electric buses, the city of Espoo is going to test one bus in the near future (Laurikko 2012). Converted electric buses will be tested in two cities in the near future: in Lahti in the beginning of the year 2013 and in Hyvinkää in the spring 2013 (MovekoTech Ltd 2012).

2.2.2 Description of bus types studied in the case

A diesel bus is the most common bus type around the world. The propulsion system of a diesel bus consists of an internal combustion engine (ICE), which uses diesel as the fuel. (ACT Government 2012.) A diesel bus can also run with biodiesel.

A hybrid vehicle is a vehicle with a driveline, which uses at least two different means of energy conversion and two different techniques for storing energy (Braess & Seiffert 2005, 114). The definition of a hybrid vehicle applies to hybrid buses as well. The powertrain of a hybrid bus consists of an internal combustion engine, an electric motor, a battery and an inverter (Dietsche 2011, 646). The hybrid bus studied in the case is a parallel hybrid, which means that it is driven by the battery or directly by the engine.

The energy source of an electric bus is electricity. The powertrain of an electric bus consists of a battery and an electric motor with an inverter (Braess & Seiffert 2005, 102). The battery technology is constantly improving, even though it struggles with high production costs (Hybrid Electric and Battery Electric Vehicles – Buyers Guide 2007, 7; 23).

A converted electric bus is a bus which used to have a powertrain of a diesel bus but has been converted to run with electricity. This means that the diesel powertrain has been replaced with an electric motor and a battery. The aim of the conversion is to lengthen the life cycle of a bus by converting diesel buses which have been used for about 10 years. That is why there might also be other changes in the bus, regarding the interior for example. (Kulju 2012.)

3 PREVIOUS STUDIES

3.1 Introduction to previous studies

There was no other study found about the material carbon footprint of a bus. Usually the GHG emissions caused by the raw material extraction is studied as a part of the production phase of a bus and not separately, as in this study. The reference studies with wider scopes are, however, presented here in order to make some preliminary estimate of the magnitude of the results in this study.

The differences in the scopes are presented in Figure 2 below. The phases of the life cycle are defined by different life cycle methods, such as Product Life Cycle Accounting and Reporting Standard. The green line outlines the scope commonly used in the previous studies, such as Chester and Horvarth's (2009, 7). The red dash line outlines the scope used in this study.

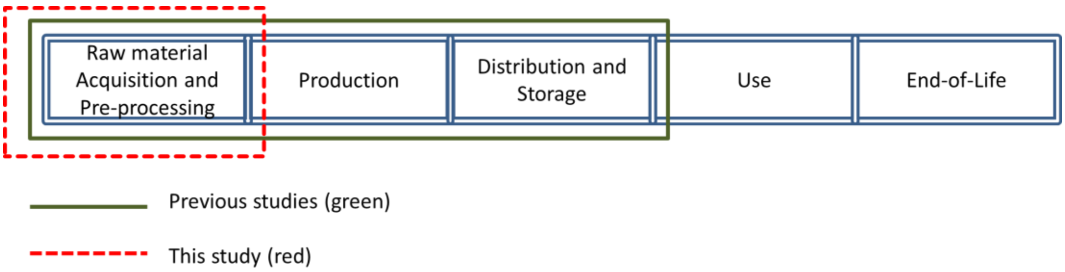


FIGURE 2. The comparison of the scopes in different studies (Source of LCA stages: Bhatia et al. 2012, 34).

3.2 Studies in Finland

VTT, the Technical Research Center of Finland, has conducted a study of the environmental impacts of the materials of a bus in the middle of the 2000s. The environmental issues of transport vehicles have been summarized in a handbook by the INSAPTRANS project (Tonteri 2012). A small part of the handbook deals with environmental effects of the raw materials of a bus structure (European

Stainless Steel Development Association 2007,1). There is no data about the environmental impact of the different means of energy conversion of a bus in the handbook.

The handbook emphasizes the effect of the vehicle weight on the environmental impacts. The reduction in the weight of a bus decreases the amount of produced and recycled raw materials. Furthermore, it lowers the fuel consumption. (European Stainless Steel Development Association 2007, 111.)

Pusenius, Lettenmeier & Saari (2005, 7) studied MIPS (Material input per service unit) values for public roads in Finland. The direct use of road area and the use of natural resources during the life cycle of different forms of traffic were studied. The MIPS values were calculated for the consumption of abiotic and biotic materials, water and air (Pusenius et al. 2005, 8). The MIPS values for production describe the use of natural resources and potential of environmental impacts caused by production of the materials of a bus, but are not comparable with the GHG emission indicators. That is why the results cannot be directly compared with this study.

Nevertheless, some of the data in the study can be exploited. In the study of Pusenius et al. (2005, Appendix 3), the raw material and material weight information of an urban transit bus is described. This information has been used as a point of comparison when analyzing the raw material and weight information of the case buses used in this study. The comparison is presented in Chapter 6, Material carbon footprint calculations.

3.3 Foreign studies

Cooney (2011, 3) conducted a life cycle assessment of diesel and electric public transportation buses in the USA. In the study, a conventional internal combustion engine bus was compared with a battery electric bus using process-based and EIO-LCA (Economic input-output life cycle assessment) methods. The goal of the study was to do research on the environmental impacts of the manufacture and operation of the two bus types.

The conclusion of the study was that the use-phase of a bus causes the majority of the emissions. When it comes to the production phase of the life-cycle, according to Cooney the batteries in the electric system cause significant emissions and other environmental impacts. (Cooney 2011, iv). There was no numerical data presented about the emissions caused during the manufacture or raw material extraction of a bus.

A life cycle energy and emissions inventory has been made for motorcycles, diesel automobiles, school buses, electric buses, Chicago rail and New York City rail in the USA. Vehicle manufacturing in the inventory was studied using EIO-LCA. (Chester and Horvath 2009, 7.) The manufacturing covers the whole manufacturing process starting from the energy use and emissions of the raw material extraction and ending with the assembling of the vehicle (Chester & Horvath 2009, 2).

Chester & Horvath's inventory showed that the GHG emissions of the manufacture of an electric bus was 150 tonnes CO_2e/bus. The corresponding value for an urban diesel bus was 140 tonnes CO_2e/bus. (Chester & Horvath 2009, 5, 43, 70.)

Chester also made a life-cycle environmental inventory of passenger transportation in the USA. The life-cycle inventory included for example vehicle manufacturing, use-phase, maintenance, infrastructure, and fuel production. (Chester 2008, 14.) The calculations for the greenhouse gas emissions of bus manufacturing were performed using inventory data of heavy-duty truck manufacturing. (Chester 2008, 22). The LCA was performed using the EIO-LCA method and the National Transit Database of FTA (Federal Transit Authority). Greenhouse gas emissions of the manufacture of a bus were 129 tonnes CO_2e /bus. (Chester 2008, 56.) Another value was presented for an average bus: the manufacture emissions were 160 tonnes CO_2e / bus. (Chester 2008, 32.)

Assessing the material carbon footprint of a bus by using the data regarding the heavy-duty vehicles is reasonable, as done in the study presented above. The construction of the heavy-duty vehicles and buses is quite similar (Juhala 2012). For example, the chassis in both vehicles is of the same type.

In the presented studies the result was often given as tonnes CO_2e (Carbon dioxide equivalent) per vehicle life. In this study the used unit is tonnes CO_2e/bus, which means the same as per vehicle life. For clarity's sake, all the comparable results are turned into the unit used in this study.

3.4 Evaluation of previous studies

The comparison of the previous carbon footprint studies with numerical results is presented in Table 1. Only two of the studies resulted in actual values of carbon footprint during the manufacture phase.

TABLE 1. Comparison of the CO_2-footprint of the previous studies.

Study	**Scope**	**Result**
TieMIPS 2005	Materials of the bus	kg, see Calculations
Chester & Horvath 2009	Manufacture, electric bus	150 t CO_2e/bus
	Manufacture, urban diesel bus	140 t CO_2e/bus
Chester 2008	Manufacture	129 t CO_2e/bus
	Manufacture, average bus	160 t CO_2e/bus
This case study 2012	Raw material extraction and pre-processing, urban transit bus, different energy conversions	t CO_2e/bus (see result in Calculations)

The numerical values found in the literature are not directly comparable with the results of this study, since none of them investigate only the raw material extraction and pre-processing. However, it is an advantage that there are at least some values to start off with.

Based on the results of previous studies, the material carbon footprint is predicted to be about half or less of the reference studies', 60-80 t CO_2e/bus. In any case, the material carbon footprint should be smaller than the results of the reference studies.

The material carbon footprint results of this study between the buses with different means of energy conversion are assumed to differ to some extent. The most significant difference between the results is assumed to be in the powertrain. Also, the main raw material of the bus is assumed to affect the final results.

4 METHOD

4.1 Life cycle assessment and environmental impact indicators

The basis of this study originates from the product life cycle assessment, LCA, where environmental aspects and potential environmental impacts during the product's life cycle are looked into (SFS-EN ISO 14044 2006, 9). The phases of a product's life-cycle are presented in Figure 3 below. In this study, the scope includes the first phase of a product life cycle, material acquisition and pre-processing.

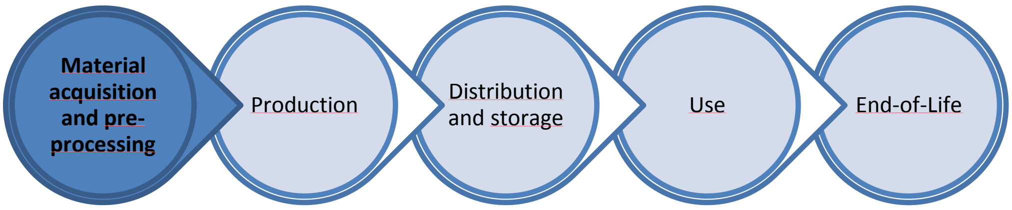


FIGURE 3. Stages of a product life cycle (Bhatia et al. 2012, 34).

The indicator examined in this study is carbon footprint. The other possible indicators to be studied using LCA would have been water, air, abiotic and biotic MIPS values, acidification potential or eutrophic potential (see explanations in the glossary), for example.

Carbon footprint tells the amount of the greenhouse gas emissions in carbon dioxide equivalent and is calculated with the help of global warming potentials (GWPs). According to ISO 14064-2 (2006, 3), global warming potential is a "factor describing the radiative forcing impact of one mass-based unit of a given GHG relative to an equivalent unit of carbon dioxide over a given period of time". The emissions accounted for in this study are the ones required to be looked into in the used method: carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), sulfur hexafluoride (SF_6), perfluorocarbons (PFCs) and hydrofluorocarbons (HFCs). The emissions are calculated using the EcoInvent database for global warming potential of 100 years (GWP 100 a) factors, choosing the values complying with the CML 2001 impact assessment method (EcoInvent 2012).

4.2 Tools for perfoming LCA

There are several tools to help one perform LCA. The ISO 14040 standards offer guidance on the principles for conducting an LCA study. ISO 14064 standard deals with greenhouse gas accounting and verification. (Environmental management – The ISO 14000 family of International Standards 2009,6.) Other and more practice-oriented examples include Product Life Cycle Accounting and Reporting Standard by GHG Protocol, and PAS 2050 (Greenhouse gas protocol 2012; PAS 2050 2012). The method used in this study was chosen to be Product Life Cycle Accounting and Reporting Standard, because it concentrates particularly on the greenhouse gases. ISO 14064 will probably be the most popular method in the future, but was not chosen to be used in this study for two reasons. Firstly, it was released only when the study was already well on the way and secondly it concentrates on measuring the emissions. This study focused on calculating the emissions.

Other tools helping to perform the study are different kinds of databases and calculation programs. EcoInvent is a database offering transparent and up-to-date information for performing a life-cycle inventory (LCI), a quantification of inputs and outputs of a system (EcoInvent 2012; Procter & Gamble 2012). Ecoinvent is by far the most used database and it has been connected with several calculation programs (Antikainen, R. 2010, 22). It is also the database used in this study.

Additionally, examples of different calculation programs on the LCA known in Finland are GaBi, SimaPro, Umberto and Finnish KCL-Eco (Antikainen, R. 2010, 23). This study was planned to be performed utilizing GaBi, but the program concentrates on modeling the processes. There was only a little to model when studying the material and weight information of the bus, and therefore using GaBi was left out of the study.

4.3 Basic definitions of a material carbon footprint study

In order to understand the method used in this study, one should be aware of the most important concepts appearing in it. It is important to understand what raw material acquisition and pre-processing as the first stage of a product life cycle include. Other important concepts in the study are functional unit, reference flow, unit of analysis, activity data, scope and system boundary.

The exact concept of raw material acquisition and pre-processing is defined in Product Life Cycle Accounting and Reporting Standard (Bhatia et al. 2012, 38):

> *The material acquisition and preprocessing stage starts when resources are extracted from nature and ends when the product components enter the gate of the studied product's production facility. Other processes that may occur in this stage include recycled material acquisition, processing of materials into intermediate material inputs (preprocessing), and transportation of material inputs to the production facility.*

Functional unit is "the quantified performance of the studied product" (Bhatia et al. 2012, 134). In this study, the functional unit is a 12-meter-long urban transit bus. Functional unit could also have been different, such as passenger kilometers travelled (PKT).

Reference flow means the amount of studied product, which fulfills the function defined in the unit of analysis. Unit of analysis is the unit based on which the inventory results are calculated. Activity data means the measures of a process which result in GHG emissions. (Bhatia et al. 2012, 136-137). In this study, reference flow is the same as unit of analysis, a 12-meter-long urban transit bus. Activity data in this case is the amount of raw material of a bus stated in kilograms.

4.3.1 Scope and system boundary of the study

The scope in the study is the first stage of the product life cycle, material acquisition and pre-processing. The functional unit in this study is the carbon footprint caused during the extraction and pre-processing of the raw materials of a bus. The functional unit has been chosen so that the results can easily be turned into passenger kilometers travelled. This enables a better comparison with other studies.

System boundary describes the scope in more detail. It outlines the processes which are included in the study. In this study, the system boundary includes raw material acquisition and pre-processing. However, the production of some parts such as electric motors is included in the system boundary. The system boundary outline was conducted knowing that there is no easy access to more detailed information about the raw materials of some parts, but it is possible to access the GWP factors of the parts. Otherwise, the further processing of the materials, such as cutting or welding metals and assembling of the parts is mainly not included in the system boundary. The process map for the bus' life cycle with complete system boundary marked with red dash line is presented in Figure 4 below.

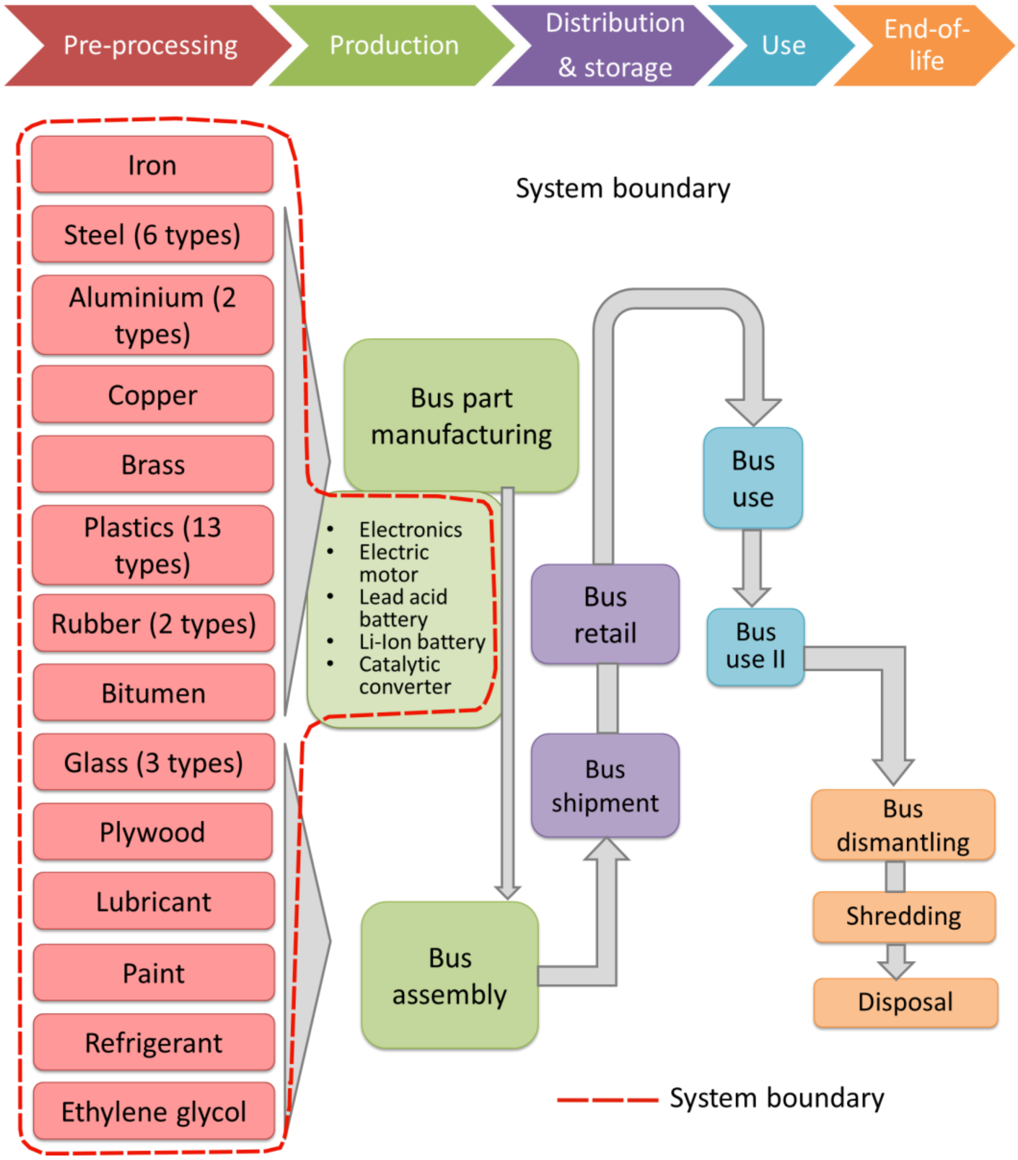


FIGURE 4. Process map with system boundary.

4.3.2 Explanation of the scope outline

In order to find out the most significant factors causing the GHG emissions during a bus' life cycle, the use phase should be looked into. An other important factor would be the manufacture phase, where the electricity consumption causes the majority of the emissions. Also the end-of life of a bus would be interesting to study, since the good recycling opportunities for Li-Ion (Lithium ion) batteries most probably reduce the actual emissions of the electric buses.

The system boundary concentrating only on the raw material acquision and pre-prosessing was chosen, however, for three reasons. Firstly, the use phase is planned to be studied further on in the EcoMill project. Secondly, a study concentrating specifically on the first phase of a bus life cycle has a fresh view point. Thirdly, a boundary with the scope of the whole life cycle of a bus would be too wide for a thesis. Based on this information, the system boundary is set to include the raw material acquisition and pre-processing.

4.4 Steps of conducting the study in accordance to method

There was a data management plan made about the data sources and data management in the beginning of conducting this study, as recommended in the used method. The data management plan is presented in Appendix 1. The execution of the plan succeeded well, considering the iterative nature of this kind of study. Iterative process means resulting in a decision by repeating the stages of the analysis over and over again (BusinessDictionary.com 2012). Conducting an LCA is an iterative process, because the understanding of the matter grows during the progress of the work.

The steps of conducting a carbon footprint study are stated in the Product Life Cycle Accounting and Reporting Standard (Bhatia et al. 2012, 13). The steps of the study, the requirements in each step and the execution are presented in Appendix 5. The study was performed as well as it could be performed within the given time and work frame. All the requirements of the standard were not fulfilled, though. Performance tracking was not conducted and the report of the study was made complying other instructions than of those of the method’s. The assurance was done without reporting. These phases should have been gone through in order to conduct a complete study in accordance with the Product Life Cycle Accounting and Reporting Standard.

5 CASE STUDY DATA AND CLASSIFICATION

5.1 Case buses

The characteristics of the case buses of this study are the following: a low-floor or a half-low-floor urban transit bus with 2 axles and the length of about 12 meters. The weight of the bus varies between about 8 200 kg and 12 000 kg depending on the main raw material. There is space for 68 to 79 passengers depending on the case bus.

There are five case buses and four bus types studied in this work. Two of the case buses use diesel as their source of energy. The other cases are a parallel hybrid bus, an electric bus and a converted electric bus. There is also an already-existing material list of a third diesel bus. The data about a third diesel bus is used as reference information in the calculations. The features of the case buses are presented in Table 2 below.

TABLE 2. General information on the case buses (Puseniut et al. 2005 Appendix 3, Source A 2012, MovekoTech Ltd 2012, Kabus Ltd 2012, Source B 2012).

Feature	Case 1 Diesel (*1)	Case 2 Diesel	Case 3 Hybrid	Case 4 Electric	Case 5 Converted electric (2*)	Reference Diesel (*3)
Bus type	diesel	diesel	hybrid	electric	electric	diesel
Weight [kg] (*4)	8 200	11 340	10 830	12 500	E.g. 12 000	10 926
Doors (5*)	1+2+0	2+2+0	2+2+0	0+2+2	E.g. 2+2+0	E.g. 1+1+0
(ICE) (6*)	x	x	x	-	-	x
Electric motor	-	-	x	x	x	-
Fuel tank [l]	273	250	215	-	-	no data
Passenger capacity	40 seats 29 standing	34 seats 45 standing	34 seats 45 standing	23 seats 45 standing	E.g. 34 seats. 45 standing	no data
Speciality	Aluminium structure light weight		Parallel hybrid	Range 160 km recharging possible any time	Opportunity charging (7*)	Reference

(1*) Kabus 4 City Bus
(2*) Converted electric bus by MovekoTech Ltd
(3*) Volvo 8500 Low Entry
(4*) Excl. driver, fuel and lubrication
(5*) Front door(s) + middle door(s) + back door(s)
(6*) Internal combustion engine
(7*) Charging takes place through a charging rod

The buses are comparable with each other because of the same functionality in each: the case buses are used for urban transportation. Also the length and the passenger capacity are all approximately the same. There are single or double doors either in the front and in the middle of the bus (cases 1-3, 5) or in the middle and in the back (case 4). All the buses excluding Case 1 are approximately of the same weight.

5.2 Trisection of the bus composition

In this study, the body and chassis are studied as separate sections of a bus. Furthermore, the chassis is divided into powertrain and the rest of the chassis. The material carbon footprint is calculated utilizing this trisection of a bus.

The powertrain in this study includes ICE for the diesel buses, electric motor for electric buses, or both in the hybrid bus. Other parts of the powertrain are transmission, cardan shaft and in electric buses, batteries and control system of the powertrain.

The rest of the chassis parts include chassis frame, front and rear axles, wheels, brakes, power steering, pneumatics, electrical wires, cooling system and in diesel buses, an exhaust system, and a battery for starting. The body includes the frame of the bus, walls, roof, doors, windows, heating and seats, for example.

5.3 Material classification

5.3.1 Classical material classification

Dietsche (2011, 135) classifies the materials used in vehicles into four groups. These material groups are metals, nonmetallic inorganic materials, nonmetallic organic materials and composite materials.

Metals are crystalline-by-structure materials, which can be wrought, rolled or cast, for example. Also alloys belong to this group. Alloys are metals consisting of two or more components, at least one of which is metal. (Dietsche 2011, 135.)

Nonmetallic inorganic materials have low thermal and electric conductivity, luminous reflectance and brittleness due to their capacity to be held together by different types of bonds. They are not suited for cold forming. For example, ceramics and glass belong to this material group. (Dietsche 2011, 135.)

Nonmetallic organic materials are comprised of carbon and hydrogen and often have nitrogen, oxygen and other elements in their structure. Natural materials and plastics belong to this group. (Dietsche 2011, 135.) Plastic is a polymeric material with the capability of being molded or shaped, usually by the application of heat and pressure (Encyclopædia Britannica 2012-d). Plastics can be divided into thermosets and thermoplastics (Järvinen 2000, 15).

Composite materials comprise of at least two physically or chemically different components. Fiber glass and cotton-fiber-reinforced plastics belong to this group. (Dietsche 2011, 135.)

5.3.2 Material classification in the case study

In this case study, the material groups are formed based on a different classification from Dietsche, because some of the collected data is in the form of bus parts and some in the form of pre-processed materials. Table 3 presents the material groups and the materials under each group according to the classification in this study.

TABLE 3. The grouping of the materials in the case study

Metals	Devices and batteries	Plastics	Lubricants and chemicals	Other materials
• Iron	• Electrics	• ABS	• Lubricant	• Plywood
• Steel	• Electric motor	• PA	• Paint	• Glass
• Aluminium	• Lead acid battery	• PE	• Refrigerant	• Double glass
• Copper	• Li-Ion battery	• Textile, polyester	• Ethylene glycol	• Rubber, undefined
• Brass	• Catalytic converter	• Reinforced plastic		• Rubber, natural
		• PP		• Bitumen
		• PVC		• Other
		• PUR		
		• PS foam		
		• Silicone		
		• Plastic, undefined		

Grouping metals and plastics to their own groups is an obvious solution. The only exception is reinforced plastic, which is included in the plastics group regardless of the fact that there is also fiber glass resin in the plastic.

The group of lubricants and chemicals includes lubricants used in the transmission, axles and power steering. The adhesive is used in a bus for example to attach the components together. Paint is used for the surface of the bus. Ethylene glycol is used in the cooling system.

In this study, the devices and batteries are gathered into one group. The materials in this group are actually already-assembled parts, which have been studied as parts due to the lack of data about their further construction.

The material group pf other materials includes some organic materials such as plywood, rubber and bitumen, and inorganic materials such as glass. Glass is an inorganic solid material, which is hard, brittle and impervious to the natural elements. Most of the glasses are soda-lime-silica glasses, which compose of sand, limestone and sodium carbonate. (Encyclopædia Britannica 2012-b.) The double glass appearing in the material list of this study refers to a glass product with two sheets of glass, which have an aluminium molding between them. In a bus, glass is used in the windows: the windscreen, the side windows and the windows on the doors.There is both natural and synthetic rubber used in the structure of a bus.

5.3.3 Extraction and pre-processing examples

In this subchapter, there is an example of the extraction and pre-processing of a material from each group. Examples have been chosen based on the importance of the material in the group.

Metallic raw materials are usually processed in two phases: ore beneficiation and additional processes. Beneficiation is the process of dressing crude ore to increase the concentration of the desired metal. The usual beneficiation processes include crushing, roasting, magnetic separation, flotation and leaching. The additional processes such as smelting and alloying result in producing the metal for parts and products. (Encyclopædia Britannica 2012-c.)

Approximately half of the produced lithium in the world comes from brine, which is refined into lithium carbonate. The other half is mined from different minerals, such as lithium aluminium silicate. (Duleep, van Essen, Kampman & Grünig

2011, 27.) Lithium is used in the batteries of electric and hybrid buses. According to Daniel, lithium ion batteries consist of battery cells. The production of a cell starts by forming the electrolytes. A coating machine feeds paste of active materials on collector foils, such as aluminium for the cathode side and copper for the anode side. The foils are cut to correct width and stacked, winded and inserted in cylindrical cases. Finally, the conducting tab is welded. The produced cells are filled with electrolyte. In the end, other needed insulators, seals and safety devices are attached and connected. (Daniel 2008.)

Plastics are made of plastic resins. Plastic resins are produced with chemical techniques into powder, pellet, putty or liquid. (Encyclopædia Britannica 2012-c). Usually the further processing of plastic resins begins with compounding, which means mixing together various raw materials according to the used recipe. Mixing can be done in conventional stirred tanks or with the help of special machinery. Sometimes mixing can take place with the extrusion or molding of the plastic. (Encyclopædia Britannica 2012-d.) Compounding is followed by forming, which refers to the process of melting, shaping and solidifying plastics into different shapes. (Encyclopædia Britannica 2012-d.)

Fiber glass is a fibrous form of glass and it is used in most cases as insulation and as a reinforcing agent in plastics. The process of production starts with obtaining liquid glass either directly from a glass-melting furnace or by melting preformed glass marbles. The liquid is directed into a bushing, which generates fine streams. The solidifying strands can be twisted, or woven into fabrics, for instance. (Encyclopædia Britannica 2012-a.) Fiber glass is used as the resin in reinforced plastic, which is used in the body parts of a bus, such as the roof.

Ethylene glycol is utilized in the cooling system of a bus as an antifreeze agent. It is manufactured from ethylene oxide, which is produced in a direct oxidation process with air or oxygen and a silver-based catalyst. Ethylene oxide is then fed with water at higher temperature to generate mono-ethylene glycol. (Siemens AG 2009, 1.)

The rubber used in the tires is natural rubber (Michelin 2012). Natural rubber comes from rubber trees, from which the raw material, latex, is extracted. Rubber is recovered from latex with the help of an acid. The liquid is driven out and the rubber is rolled into sheets and dried. Synthetic rubber, instead, is in most cases produced from petroleum utilizing the same polymerization techniques as used to synthesize other polymers. (Groover 2011, 192-193)

6 MATERIAL CARBON FOOTPRINT CALCULATIONS

6.1 Conducting of the calculations

The case buses used in the study are presented below. In case 1 the main raw material is aluminium. The main raw material in the rest of the cases is steel.

- Case 1 diesel bus (aluminium chassis)
- Case 2 diesel bus
- Case 3 hybrid bus
- Case 4 electric bus
- Case 5 converted electric bus

The calculations were performed by using the raw material data of each case bus. The materials and the weights of the raw materials were defined for the three sections of a bus: powertrain, chassis and body. The data was divided into material groups. The materials and weights in the case buses according to the used material classification are presented in Appendix 2.

The sources of the data for each bus type are the following:

- Case 1 diesel bus, Case 2 diesel bus and Case 3 hybrid bus – data mainly from the manufacturer of each
- Case 4 electric bus – chassis data from the manufacturer, body data is the same as Case 2
- Case 5 converted electric bus – powertrain data from the manufacturer, body and rest of chassis data the same as Case 2
- Reference Diesel bus – study by Pusenius, Lettenmeier and Saari (2005, appendix 3)

In Case 4, the body data of Case 2 was used in the calculations due to the lack of data regarding the actual body. The results of the calculations regarding Case 4 are considered to be less reliable than of other cases' because of the made assumption. In Case 5, it is justified to make the calculations with the data from Case 2. That is because the business idea in Case 5 bus is to replace the powertrain of a basic diesel bus with an electric system.

6.1.1 Equation for material carbon footprint

The material carbon footprint of a bus was determined by multiplying the weight information of the materials by the GWP 100a factors for each material and by summing up the carbon footprints of the materials. The influence of the emissions has been conveyed as one unit, carbon dioxide equivalent (CO_2e). The unit of GWP factors is kg CO_2e/kg material and the unit of the result of the calculations is turned into tonnes CO_2e/bus. The equation to calculate the carbon footprint for each material is shown in Figure 5.

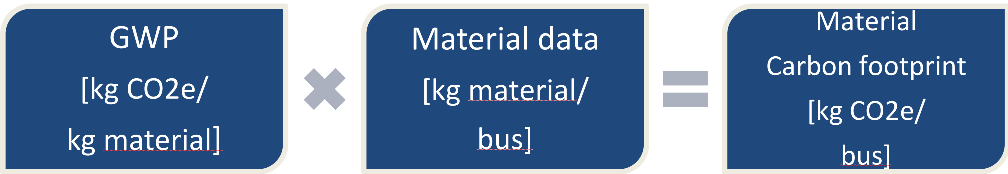


FIGURE 5. Equation to calculate the CO_2e emissions with units (Retold from GHG Protocol 2011, 88).

The used GWP factors include in most cases the GHG emissions caused by the manufacture of the raw material. For some parts, there were ready factors for their manufacture in the EcoInvent. For the parts which did not have an existing GWP factor, the GWP factor was calculated for the rest of the parts' materials utilizing the EcoInvent database and literature sources on percentage divisions of different materials used in the parts.

For the factors taken from EcoInvent, the GHG emissions included in the GWP factor are defined in the CML 2001 impact assessment method. There were some GWP factors taken from other sources. SF_6, PFC and HFC emissions were not included in these other sources. The influence of the missing data is estimated to be small and not to change the results of the study. The sources of the factors for each material and other additional data are to be found in Appendix 3.

The recycling rate of the metals is included in the GWP factors for cast iron, hot-rolled steel, electro galvanized steel, aluminium and cast aluminium. For the other metals, the recycling rate is left out. The recycling rate for steel had to be left out due to the lack of reliable data.

6.1.2 Excluded from the calculations

In some cases, the material data for the case buses was given very specifically. For example, there were several different types of lubricants in the material list given by the source. In such cases, the amount of the most common material was included and the others (less than 1 % of the total weight of the bus) were excluded.

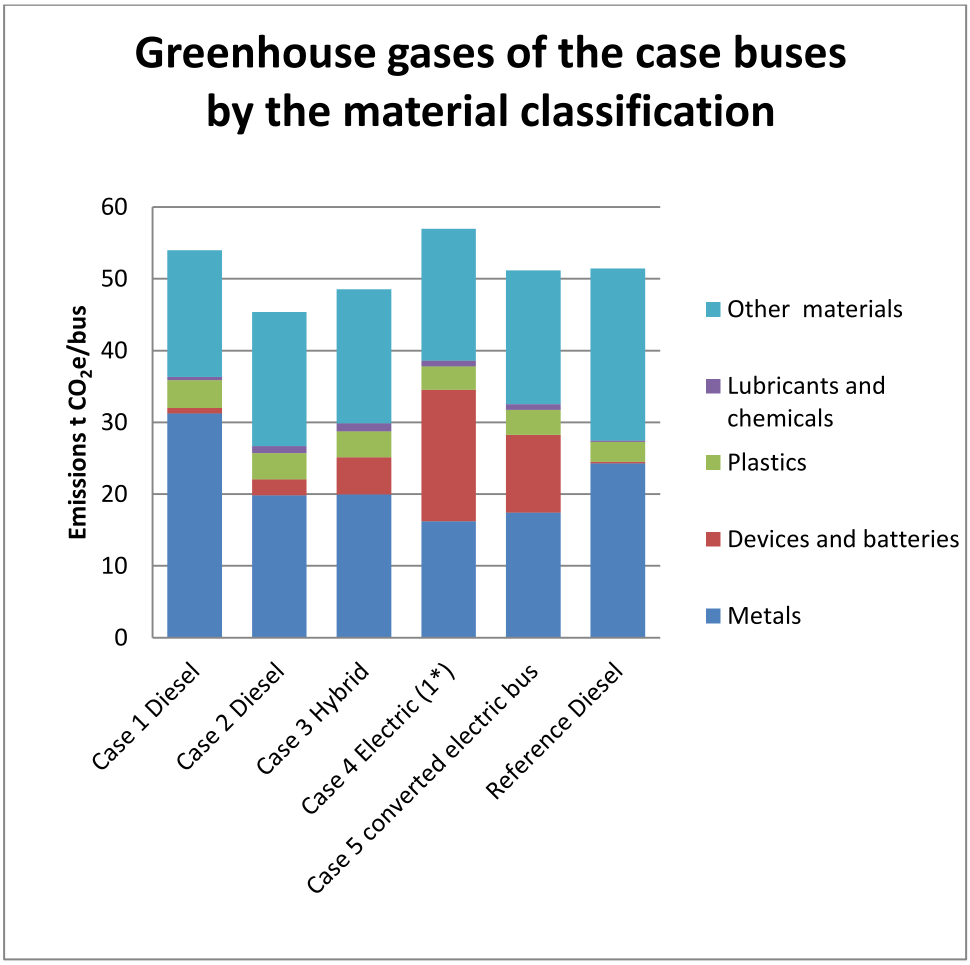
Some of the paints were not included in the calculations, because the weight of the paint was less than 1 % of the total weight of the bus. The paints could not be combined to be one group, paints, because they differ from each other by structure.

The anti-rust agent was left out of the studies because not every manufacturer reported to be using it. The amount of this substance is small and therefore should not affect the result.

The diesel and the equipment used for fuelling up the tank which are used in the diesel and hybrid buses was excluded from the calculations. Also the recharging equipment of the hybrid and electric buses was excluded from the calculations.

7 MATERIAL CARBON FOOTPRINT RESULTS

The material carbon footprints according to the raw material classification are presented in Figure 6. The difference between the smallest and the biggest value is 11.5 t CO_2e/bus. This amount is about twice the carbon footprint of manufacturing a small city car, Citroen C1 (Berners-Lee & Clark 2010). The smallest material carbon footprint is caused by the Case 2 diesel bus and the biggest by the preliminary results of Case 4 electric bus.



(1*) Preliminary results

FIGURE 6. The material carbon footprints of the case buses by the material classification.

According to the results, about one third of all emissions for all the buses is caused by the material group of other materials. Raw material extraction and pre-processing of metals also causes significant emissions. Devices and batteries cause least emissions for the diesel buses, to a larger extent for the hybrid bus and notable emissions for the electric and converted electric buses.

When comparing the steel-structured buses with each other, the raw material extraction and pre-processing of the raw materials of a diesel bus causes least emissions with 45.4 t CO_2e/bus. After that comes the hybrid bus causing 48.6 t CO_2e/bus and converted electric bus with 51.2 t CO_2e/bus. The most emissions are caused by the preliminary results of the electric bus with 56.9 t CO_2e/bus. The material carbon footprint calculated for the reference diesel is about the same as the result of the converted electric bus: 51.4 t CO_2e/bus. The result for the aluminium-structured diesel bus is 54.0 t CO_2e/bus, which is between the results of the reference diesel and the electric bus.

The material carbon footprint for the case 2 diesel bus can be seen as a reference value, with the help of which one can evaluate the other results. The material carbon footprint of the reference diesel bus most probably contains a large error, since the raw material classification in the reference study was done differently.

The material group devices and batteries is best presented in weight in the electric buses. The weight of this material group is less in the hybrid bus and the least in the diesel buses. The material group devices and batteries causes considerably emissions. Therefore it is logical that the material carbon footprints for the hybrid bus and further on, for the electric buses is bigger than of the steel-structured diesel's

One could have expected the result of the hybrid bus to be bigger than that of the electric bus, because a hybrid contains both a diesel engine and an electric motor. The results show, however, that the material carbon footprint of the hybrid bus is smaller than that of the electric bus. This is explained with the smaller energy conversion systems, both diesel and electric, which cause less emissions together than one electric system.

The difference between the results of the two case diesel buses is explained with the different main raw material. As expected, aluminium causes higher emissions than steel as the main raw material. This result calls for further inspection of the other life cycle phases of the buses to show the actual carbon footprint of the bus types.

The highest material carbon footprint is caused by the electric bus. However, the results for the electric bus are preliminary. The large numerical value is partly due to the material classification, which was done less accurately in comparison to other case buses. More importantly, having more electrics in comparison to other bus types increases the material carbon footprint.

The material carbon footprint of the converted electric bus is small in relation to the electric bus. The reason for this is amongst other things the more careful material classification by the source.

When calculating the material carbon footprint of the converted electric bus, the time aspect should have been taken into consideration; conversion of a bus adds extra years for the bus to be operated, which decreases the relative material carbon footprint of the converted electric bus.

The results for each case bus seem to be accurate. Producing the raw materials causes most pollution for the buses containing a lot of electrics or with aluminium as the main raw material. Emissions caused by the material groups other materials, lubricants and chemicals and plastics are fairly similar for the studied buses.

7.1 Deeper look into the results

The weights of materials in each raw material group both in kilograms and percentage of the total weight of each bus are presented in Table 4. Also the material carbon footprints for each material group in t CO_2e/bus and % are shown.

TABLE 4. Weight and material carbon footprint data according to the material groups.

	Case 1 Diesel	Case 2 Diesel	Case 3 Hybrid	Case 4 Electric (1*)	Case 5 Converted electric	Reference Diesel
Metals						
kg	5 916	8 149	7 865	6 869	7 583	8 565
%	72 %	73 %	70 %	59 %	64 %	79 %
t CO_2e/bus	31.2	19.8	19.9	16.2	17.4	24.3
%	58 %	44 %	41 %	28 %	34 %	47 %
Devices and batteries						
kg	140	254	632	2 393	1756	124
%	2 %	2 %	6 %	20 %	15 %	1 %
t CO_2e/bus	0.8	2.2	5.2	18.3	10.8	0.2
%	1 %	5 %	11 %	32 %	21 %	0,4 %
Plastics						
kg	933	896	874	811	833	576
%	11 %	8 %	8 %	7 %	7 %	5 %
t CO_2e/bus	3.9	3.7	3.6	3.3	3.4	2.8
%	7 %	8 %	7 %	6 %	7 %	5 %
Lubricants and chemicals						
kg	139	219	212	99	112	108
%	2 %	2 %	2 %	1 %	1 %	1 %
t CO_2e/bus	0.5	1.0	1.1	0.8	0.8	0.2
%	1 %	2 %	2 %	1 %	2 %	0,3 %
Other materials						
kg	1 134	1 639	1 643	1 553	1 629	1 527
%	14 %	15 %	15 %	13 %	14 %	14 %
t CO_2e/bus	17.7	18.7	18.7	18.3	18.7	24.0
%	33 %	41 %	39 %	32 %	36 %	47 %
Total						
kg	**8 262**	**11 156**	**11 227**	**11 725**	**11 913**	**10 900**
%	**100 %**	**100 %**	**100 %**	**100 %**	**100 %**	**100 %**
t CO_2e/bus	**54.0**	**45.4**	**48.6**	**56.9**	**51.2**	**51.4**
%	**100 %**	**100 %**	**100 %**	**100 %**	**100 %**	**100 %**

(1*) Preliminary results

A bus consists mainly of metals. 59-79 % of the weights of the case buses are metals. They are the main material carbon footprint causers for the diesel case buses 1 and 2. In the reference diesel, the fraction of emissions caused by metals is the same as by other materials, 47 %.

The second largest material group is other materials with about 13-15 % of the weights of the buses. This shows that the proportional amounts of plywood, rubber and glass are about the same in each case. This material group causes about one third of the material carbon footprint for cases 1, 4 and 5 and increases until it is almost one half of the emissions in the rest of the examined buses.

Other materials, including mostly plywood, glass, and rubbers, cause a surprisingly notable share of the material carbon footprint emissions. This is explained by the high GWP factor of double glass. The factor is evaluated to have an equal effect on each of the results, except for the reference diesel, where it might have increased the final result.

The weight of devices and batteries varies significantly depending on the bus type. In diesel cases, 1 and 2, the weight of devices and batteries is about 2 %, and in the reference diesel, 1% of the total weight. In comparison, there is already a significant growth of the actual weight of devices and batteries in the hybrid bus: around 400 kg, which makes 6 % of the weight of the hybrid bus. The proportional share of devices and batteries in electric buses is 15 % for case 5 converted electric bus and 20 % for the case 4 electric bus. This is caused by the weight of the lithium ion battery.

The emissions caused by devices and batteries are small in relation to total emissions in the case 1 diesel bus and the reference diesel. The percentage still remains low with 5 % for the case 2 diesel bus. The share of the material carbon footprint for this material group grows for case 3 Hybrid bus and reaches its peak with the electric buses. The emissions caused by the devices and batteries in the case 4 electric bus, 32%, should be smaller in order to be comparable with the other buses; in this case, there is a lot of weight reported to belong to electrics, which causes significant emission growth.

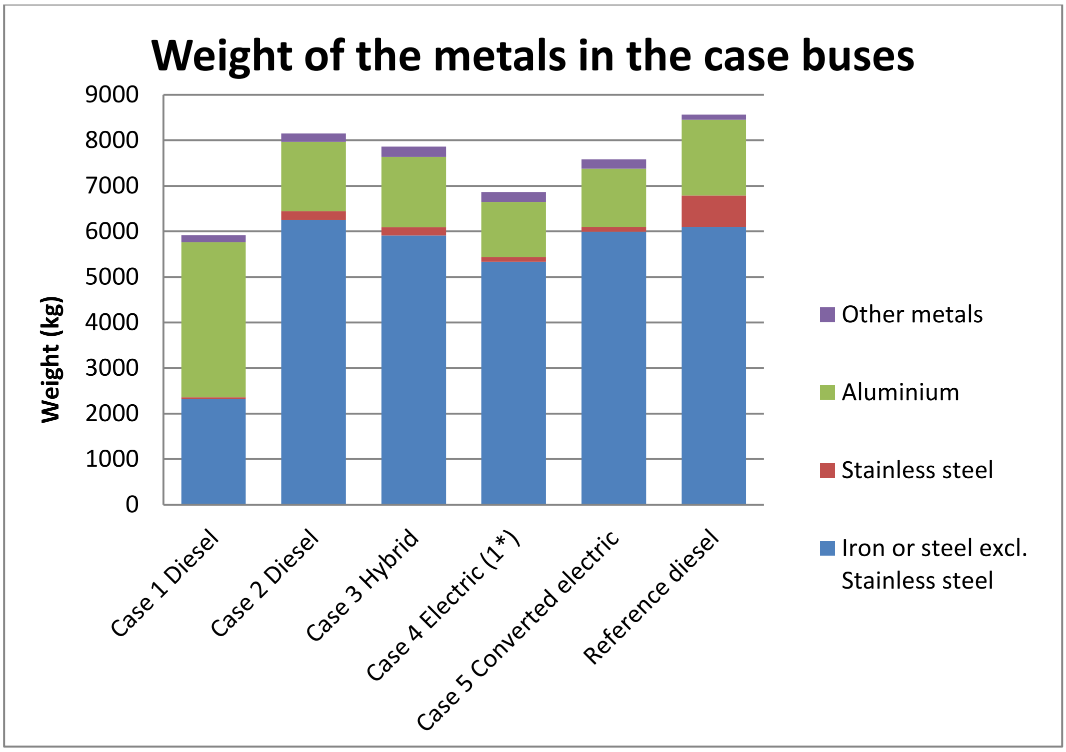
In case 1 the relative amount of plastic, 11 % of the total weight, is big in relation to other case buses. This is probably one of the reasons to explain the light weight of this bus type. In other cases the percentage of the weight of used plastic is 5-8 %. Emissions caused by the production of plastics vary between 5-8 %.

As expected, the amount of lubricants and chemicals is small, 1-2 % in each bus. Also the emissions caused by the production of these materials are insignificant for considering the final results: 0,3-2 % of the material carbon footprint.

The weight of the case 1 bus is smaller than of the other buses, but the percentages of the materials of the total weight is about the same as with the other buses. This means that the materials in case 1 have approximately the same percentages as in other cases.

7.1.1 Effect of metal choice on the material carbon footprint

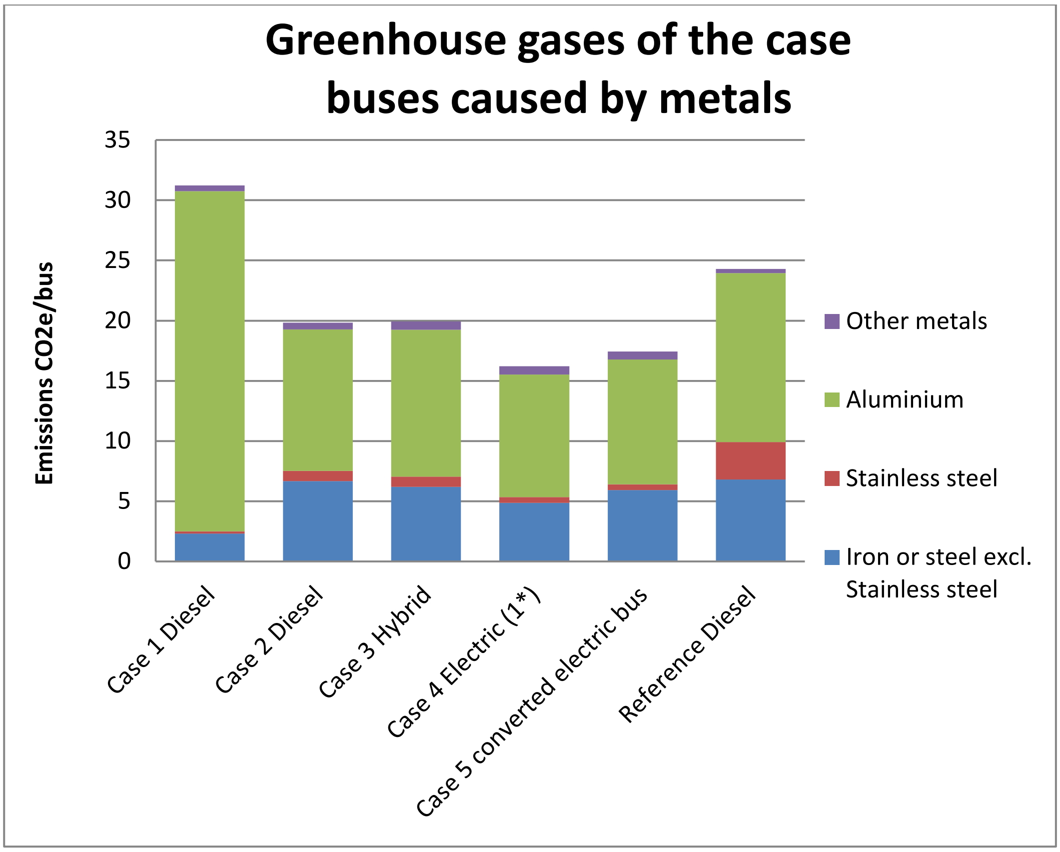
The effect of the metal choice is to be seen in Figures 7 and 8, where the first shows the weight of the metals in the case buses and the latter presents the material carbon footprint of metals used in the studied buses. The numerical data behind the metals' material carbon footprint calculations is presented in Appendix 4.



(1*) Preliminary results

FIGURE 7. Weight of the metals in kilograms for each bus.

The total amount of metals is considerably small in case 1 in comparison to other buses. Also in case 4 there are fewer metals than in the other buses. Some of the metals used in the electric bus are included in the material group devices and batteries due to the form of data given by the manufacturer. This is one of the reasons why the results of case 4 are considered preliminary.



(1*) Preliminary results

FIGURE 8. Material carbon footprint data for the metals of the case buses.

It can be seen in Figures 8 and 9 that even though the main raw material in cases 2-5 and the reference diesel is steel, aluminium is the metal which causes most of the raw material extraction and pre-processing emissions for each of the buses. The material carbon footprint for steel is smaller than for aluminium. Producing of other metals causes little emissions due to their small amount in the bus.

7.1.2 Material carbon footprint by part division

Figure 9 presents how the part division composes the material carbon footprints. The fraction of caused emission by the body structure is shown in green. The amount of emissions caused by the chassis is marked with red and the powertrain in blue. The sum of the material carbon footprints of the powertrain and chassis tell the share of the material carbon footprint of the whole chassis.

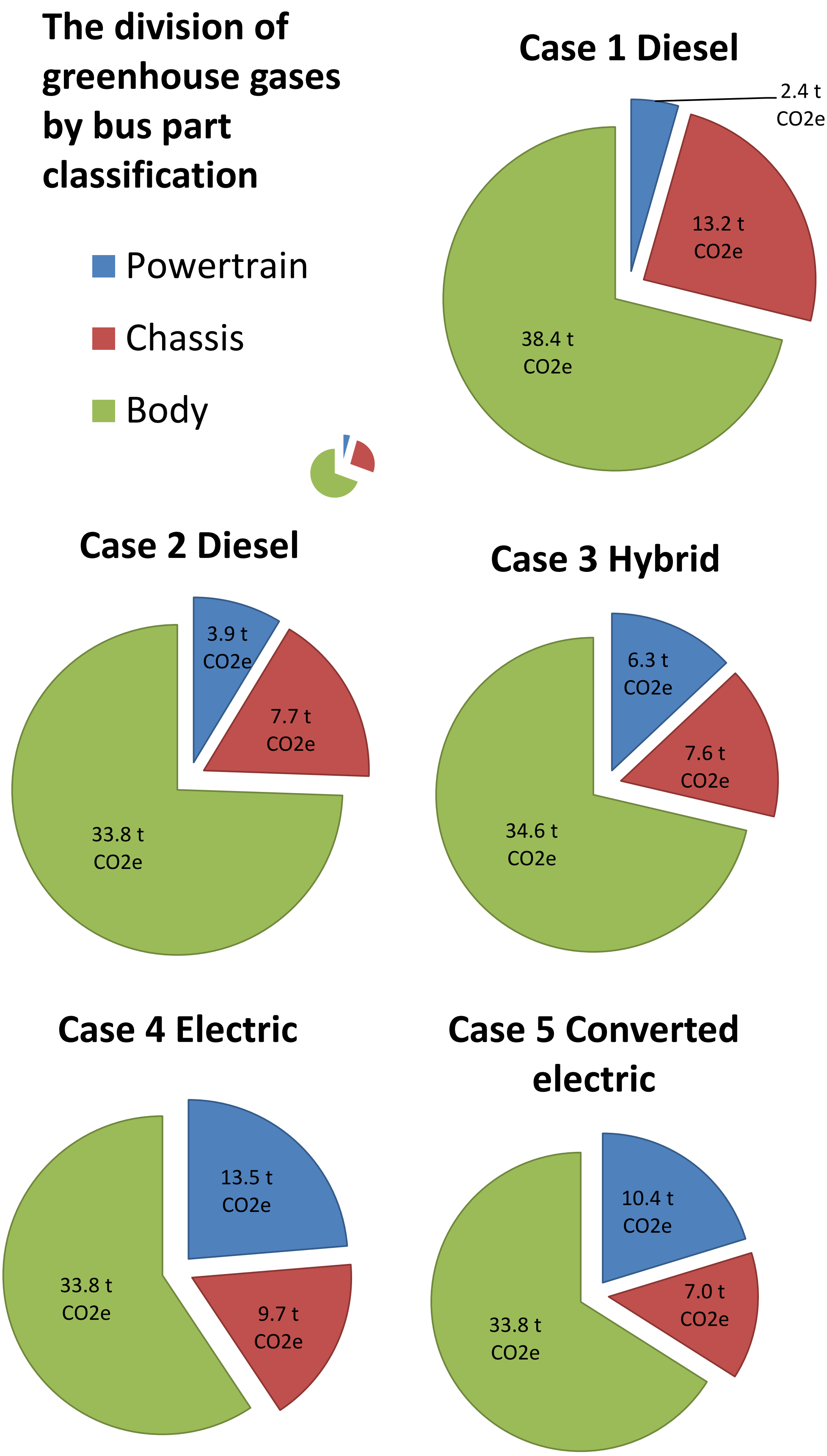


FIGURE 10. The division of material carbon footprint by the bus part classification.

One can see in Figure 10 that the relative proportion of emissions caused by body decreases, when the amount of electric components in the chassis increases. The powertrain of the electric buses and the hybrid bus cause more emissions than ofthe powertrain of the diesel.

The material carbon footprint caused by the body is quite the same for the steel-structured buses: between 33.8 and 34.6 t CO_2e/bus. The material carbon footprint of the body of the case 1 diesel is a little bigger because of the aluminium structure, as expected.

There are some differences in the material carbon footprint of the chassis between the bus types: the least emissions are caused by the chassis of the converted electric bus and the greatest by the aluminium-structured diesel bus. The material carbon footprint caused by the powertrain complies with the other results of the study: the more electrics in the bus, the bigger the material carbon footprint.

7.2 Data quality and sensitivity analysis

The data quality for the materials of this study has been documented but there was no report made on the results. Briefly, the data quality of the materials of cases 1-3 and 5 is between good and very good and the data quality in case 4 is fair. The data used in the case study was either from the manufacturing companies, companies' suppliers, other possible suppliers, or previous studies. The data for the calculations was mostly calculated or estimated by the representatives of the companies. In some cases, the data was measured. According to the used method, calculated data has very good quality and estimated values give a good result. That is why the data quality is between good and very good. The data for the body of case 4 comes from case 2 and is therefore graded to be lower than of the other cases.

The sensitivity analysis should have been conducted as a part of the work. However, due to the time and work frame of a thesis, the sensitivity analysis has been left out of the work. The following variants would have been important to investigate:

- How much does the value of the carbon footprint change when steel/aluminium is used as the main raw material?

- How much would more specific material information regarding the material group electronic and batteries change the results of the whole study?

- What would the result be with more specific data about the material group lubricants and chemicals?

- How much would it change the results, if the recycling rate for all the metals were taken into consideration?

8 COMBINING THE CASE STUDY WITH PREVIOUS STUDIES

In the previous studies, one of the factors affecting behind the environmental impact of a bus was stated to be the weight of the whole bus because of the reduced fuel consumption (Research Fund for Coal and Steel 2007, 1). The weight has also an impact on the material carbon footprint, unless the main raw material is different in the compared buses. A lighter, aluminium-structured bus causes more emissions than a heavier steel-structured bus. That is because the emissions caused by the production of aluminium are very high.

The previous studies also stated that the batteries in an electric bus cause a significant impact on the emissions caused in the production of a bus (Cooney 2011, iv). In this study it was found that batteries, but also other electrics affect the material footprint of a bus.

The size of the carbon footprint of the manufacture of a bus in the case studies was150 tonnes CO_2e/bus for an electric bus, 140 tonnes CO_2e/ bus for an urban diesel bus (Chester & Horvath. 2009, 5, 43) and 160 tonnes CO_2e /bus for an average bus (Chester 2008, 56). The carbon footprint of the manufacture of a non-specified bus is 129 tonnes CO_2e /bus (Chester 2008, 56).

In this study it was found out that the approximate size of the material carbon footprint of a bus varies between 45-54 (57 by the preliminary results of an electric bus) tonnes CO_2e /bus. This makes about one third of the emissions of the manufacture of a bus stated in the previous studies. All in all, one can conclude that the results of this case study comply quite well with the assumptions and previous studies.

9 EVALUATION

9.1 Evaluation of the topic and the method

The topic chosen for study should be critically reviewed. Thinking generally, the increase in the understanding of effectiveness of material production is something to be striven for. On the other hand, looking into something very specific will provide results based on which one cannot make conclusions and, further on, decisions. What can be regarded as a good thing is that the view point in this study is fresh.

The used method was chosen from three possibilities: ISO, PAS 2050 and GHG Protocol. All the methods had their advantages but GHG Protocol was chosen, because it concentrated so clearly on the GHG emissions and also the conducting of the study was well instructed. ISO was left out because the new standard was not ready until in the middle of conducting this study. PAS 2050 might have been a good possibility as well, but it would have been more difficult to carry out due to the complicated instructions.

Another point to criticize was the meeting the requirements of the method. All the phases required in the method were not gone through. It was also noticed during the work, that it was easier to make your own decisions regarding the conduction of the work than to look up from the guidebook what was required to be done.

There are several factors which have an influence on the reliability of the results of this study. When it comes to system boundary, it is important to understand that with the system boundary concentrating only on the raw material acquisition and pre-processing, the results cannot be used for evaluating the carbon footprint of the whole bus. Also combining just this study and the use phase, as planned, will only give the approximate evaluation of all the emissions during the life cycle of a bus, not the actual value. When studying the life cycle of a bus, the whole manufacture phase is estimated to be the second largest causer of emissions after the use phase.

9.2 Evaluation of the calculations

The calculations were made as studiously as possible within the time limit and size of the study. There are, however, several factors which might change the actual emissions of the raw material extraction and pre-processing of the raw materials of a bus.

First of all, there was no information about the geographical location of the different points of manufacture. It was not possible to gain this kind of information from the manufacturers and their subcontractors, because manufacturers still have little data of the origins of their products. On the other hand, taking the location into more specific consideration would also have been impossible due to the level of accuracy of the used GWP factors. They were almost without exception given on the global or European level. The location of raw-material acquisition and pre-processing affects the transportation of different raw materials, which affects the caused emissions. Also the means of transportation and local manufacturing circumstances affect the emissions.

The material carbon footprint of the reference diesel is probably a little bit too big. The explanation to this comes from the original material classification, which was performed in a way different from this study. The fact that glass was not classified separately as double glass and glass causes great changes in the results. Also the amount of other materials increases the material carbon footprint into a greater size. The contents of other materials differ greatly between the case buses as well, which makes it difficult to choose a reliable GWP factor. The variation of the material content in other materials most probably causes error in the final results.

There are three different types of lubricants used in the buses: engine, transmission and axle oil. The lubricants do not have the same structure, but they were still calculated with the same factor. The amount of lubricants is under 1 % of the total weight of the bus, so according to the used method, it could have been left out of the study. Including them into calculations is estimated to have a small impact on the final results.

There were some substances which were left out because they did not fulfill the requirement of being more than 1 % of the total weight. The amount of this kind of materials is evaluated to be 2 % of the total weight at most.

Calculating the theoretical construction of the catalytic converter was based on the material % -data of a 5-kilogram-heavy catalytic converter of a car. The catalytic converters of buses are several times bigger than those of cars, which can lead to unreliability due to a bigger surface area when studying a bigger product.

The calculated total weights of the buses are comparable with the theoretical weights given by the bus manufacturers. The biggest variation in weights takes place with case 2 with 3.4 %, and case 4 with 4.7 % missing from the theoretical weight.

10 CONCLUSION

In this study, the emissions of the extraction and pre-processing of the raw materials of an urban transit bus were inspected. The study was conducted by calculating the material carbon footprint for five case buses and four different bus types. The guideline used in the study was Product Life Cycle Accounting and Reporting Standard by GHG Protocol. The studied bus types were diesel, hybrid, electric and converted electric bus.

The material carbon footprint is about 45-51 tonnes CO_2e for a basic diesel bus, 54 tonnes CO_2e for a diesel bus with an aluminium structure, 49 tonnes CO_2e for a hybrid bus and 51 tonnes CO_2e for a converted electric bus. According to the preliminary results of the electric bus, the material carbon footprint is about 57 tonnes CO_2e/bus.

Metals cause about one third of the material carbon footprint, which is surprisingly little, because about 60-80 % of the weight of a bus comes from metals. When looking at the two main metals used in a bus, producing aluminium causes more emissions than producing steel. Single material groups with significant impacts on the material carbon footprint are electrics and double glass, for example.

When it comes to the materials used in a bus from the emissions point of view, it is impossible to say which combination of the materials would be the best. If you look at the results of this study, the answer would be that one should choose steel as the main raw material and avoid electrics and double glass.

If also the use-phase were studied, the results might be the opposite: the light weight of an aluminium structured bus causes smaller fuel consumption and electric buses enable the use of a cleaner energy source (such as wind energy) or at least the producing of emissions further away from the cities to avoid fine particles and air pollution in the city. In any case, the amount of electrics used in every bus increases as the development goes further. Double glass increases the safety of a bus. Therefore it is hard to start minimizing the materials from this end.

The material carbon footprint of a bus makes one third of the emissions of the whole manufacture of a bus, and probably even less of the totality of the carbon footprint of a bus. The greatest emissions during the life cycle of a bus are caused by the use phase. In order to minimize the emissions of the life cycle of a bus, one of the factors is to choose durable and practical materials, which cause the least emissions during the use phase.

11 PROPOSALS FOR FUTURE WORK

The environmental impacts caused during the life cycle of a bus is a very interesting topic. One could look at the theme from several view points and with different system boundaries. In the future, the following viewpoints are suggested to be studied.

A very obvious topic to take under consideration is the use phase of the case buses of this study. The use phase is an important topic to be studied and there already are several studies conducted of it. One would make an extensive study even by studying the already-conducted studies.

The manufacture phase of a bus is also a good topic to be studied. Using this study as a reference, the study including transportation and the emissions caused in the factories when producing the parts and assembling the buses would complement the overall picture.

Studying the end-of-life of a bus would add extra value especially to the carbon footprint caused by the converted electric bus. The goal in the bus conversion is to add active years of use for the bus. Having more data about the fate of out-of-operation buses at the moment would be important.

For a more reliable picture of the emissions of the converted electric bus, the time aspect should be looked at. In this study, for example, it would have meant dividing the results with active years of use. This aspect was left out of the study because of the time and work frame, but should definitely be looked into.

This leads to a very interesting possibility to be studied: it would be the most important to master the cause and effect of different aspects in the whole life cycle of a bus. It would include not only the caused GHG emissions, but also cover all the other environmental impacts, such as acidification and the use of water and land during the life cycle phases. This kind of understanding turned into knowledge would be very beneficial for cities inviting the bus operators to tender.

Also the first phases of the life cycle of a bus should be studied by finding out the footprints of different components, such as motors, batteries and catalytic converters.

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APPENDICES

APPENDIX 1. Data management plan

APPENDIX 2. Materials and weights of the case buses according to the classification

APPENDIX 3. Additional information on the GWP-factors used in the calculations.

APPENDIX 4. Weight and material carbon footprint data for the metals

APPENDIX 5. Steps in a product standard inventory

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13 April 2012

APPENDIX 1/1. Data management plan

Data Management Plan

Responsibilities

Management of product inventory, data collection for material aqcuisition and pre-processing: Päivi Kärnä, project worker, EcoMill-project.

Product description

An urban transit bus (rigid bus) with two axles. Length 12 meters. Model from the 21th century or later. 5 different models:

1) Diesel bus (combustion engine)
2) Hybrid bus
3) Natural gas bus
4) Electric bus
5) Converted electric bus

Change on 19 July 2012: Natural gas bus excluded due to the lack of data. There will be two case diesel buses and one reference study of a diesel in the calculations.

Functional unit

kg CO_2e /bus or *tons CO_2e/bus* (further could be CO_2e/bus/year of use)

Inventory boundary

Inventory boundary description: This assessment will concentrate on the production phase and furthermore, on the material acquisition and pre-processing of the raw material used in the buses in case.

How the boundary was derived: it is supposed that after the using phase, the extraction of raw materials contribute to the largest environmental impact when talking about the life-cycle of a bus. That is why the material acquisition has been taken into further consideration.

Attributable processes included in the inventory: the mining and concentration of the raw materials.

Attributable processes excluded from the inventory: the processing of the raw material into parts is being excluded because in comparison to the extraction of raw materials, the impacts of the processing are evaluated to be rather small. This lack of information will be critically evaluated in the assurance evaluation. It is also possible to try to make an evaluation of the volume of the impact.

APPENDIX 1/2.

Data summary

Data collection procedures: the data for each bus type will be collected from a suitable bus manufacturer and/or from literature overview.

Data quality assessment and uncertainty assessment

Data quality assessment will be performed by tracking the technology, time of data, geography, completeness and reliability to an excel file. A qualitative data quality assessment will be performed.

There will be no measures for improving the quality of data during this work: the data quality is as good as possible during the study. The study and improvement of the data quality can be further worked on by the person carrying on the study.

Uncertainty assessment will be performed by calculating the studied subject with the variation of 5 %.

Change on 16 August 2012: Performing uncertainty assessment was left out due to the lack of time.

Inventory results calculations

Calculation methodologies: The calculation methodology has not yet been completely defined. So far the ISO standard, PAS 2050 and now the GHG Protocol are being looked into. Most probably one of these methodologies will be used. The narrowing-down of the theme will, however, limit the use of a methodology. This will also be criticized in the assurance evaluation.

Changes in methodologies:
24 April 2012 - It was decided that the GHG Protocol will be used as the methodology in this study.

Used GWP values: the GWP values used in this work will be the up-to-date values which can be found on the internet-site of Greenhouse Gas Protocol: www.ghgprotocol.org.

Changes in GWP values:
24.8.2012 - The GWP values will be for the most part from the EcoInvent database.

Performance tracking

When tracking performance, details of the base inventory adjustment policy = how much can we bend in getting the base information?

Answer: it would be beneficial to decide at this point, where the limits go. It is, however, a little challenging since the precision of the data received is not known. This point will be clarified in the course of the work.

APPENDIX 1/3.

Comments:
24 August 2012 – the limits have been found out during the course of work and will be presented in the final report.

Data storage procedures

How and where the data will be stored?

The answer to this question will most probably become more clear once we have some more information. So far, there has been a general picture of the work pictured in a Prezi-file. The numeric information on the work will be collected onto an excel-file.

File content	**File form**
Contact information	Excel
Overall picture	Prezi
Scope on the structure	Prezi
Information for calculations	Excel
Written information	Word
List of literature references	Word
References	Books, Word, PDF, etc
Report	Word

Backup procedures: the backup procedures of the EcoMill project in Innovation Centre will be enough. No other arrangements will be done.

Quality Assurance/ Quality Control (QA/QC) procedures

The QA/QC procedures will be done by the Table C.2. in the GHG Protocol Document (p. 130).

APPENDIX 2/1. Materials and weights of the case buses according to the classification

Materials and weights of the case buses according to classification

	Material	Case 1 Diesel	Case 2 Diesel	Case 3 Hybrid	Case 4 Electric (1*)	Case 5 Converted electric (2*)	Comparison: Diesel (3*)
		Weight [kg]					
Metals	Iron, cast	358	1062	762	43	385	1531
	Steel	1628	932	932	3 602	1561	-
	Steel, rod	-	468	468	468	468	2408
	Steel, hot-rolled	-	1 528	1 528	298	1 528	1590
	Steel, cold-rolled	238	1 430	1 388	716	1 385	568
	Stainless steel	40	188	188	105	108	690
	Steel, hardened	96	643	638	16	473	-
	Electro galv.	-	192	192	192	192	-
	Other metals	-	-	-	-	-	-
	Al	3 327	1316	1 396	1 209	1 207	1666
	Al, cast	77	209	145	-	68	-
	Copper	126	163	212	219	208	109
	Brass	26	17	16	2	-	3
Devices and batteries	Electrics	20	70	131	282	80	-
	Electric motor	-	-	155	111	70	-
	Lead acid battery	93	118	118	-	-	124
	Li-Ion battery	-	-	183	2000	1 606	-
	Catalytic converter	27	66	45	-	-	-
Plastics	ABS	272	67	67	67	67	-
	PA	9	1	1	1	1	-
	PE	8	32	32	32	32	-
	Textile, polyester	32	22	22	22	22	23
	Reinforced plastic	218	392	392	392	392	553
	PP	2	1	1	1	1	-
	PVC	89	123	123	130	105	-
	PUR foam	96	82	82	82	82	-
	PUR adhesive	100	84	84	84	84	-
	PS foam	55	-	-	-	-	-
	Silicone	13	-	-	-	-	-
	Plastic, undefined	39	92	71	-	48	-

APPENDIX 2/2.

	Material	Case 1 Diesel	Case 2 Diesel	Case 3 Hybrid	Case 4 Electric	Case 5 Converted electric	Comparison: Diesel (1*)
		Weight [kg]					
Lubricants and chemicals	Lubricant	50	95	80	25	35	78
	Paint	48	58	58	38	38	30
	Refrigerant	2	6	8	6	6	-
	Ethylene glycol	39	59	66	30	32	-
Other materials	Plywood	448	726	726	736	726	396
	Glass	58	84	84	84	84	-
	Double glass	374	381	381	381	381	490
	Rubber, undefined	58	120	124	117	110	-
	Rubber, natural	131	182	182	127	182	405
	Bitumen	-	54	54	54	54	54
	Other	65	91	91	64	91	182
	Total	**8 262**	**11 156**	**11 227**	**11 725**	**11 913**	**10 900**

(1*) The data regarding the raw materials of the body has been referenced from case 2.

(2*) All the data except for the powertrain has been referenced from case 2 due to the character of a converted electric bus.

(3*) The material classification of the Comparison diesel bus has been performed according to the best knowledge. For example, the amount of glass was informed as one value. Because the most of the glass in a bus is double glass, the glass amount was classified as double glass as a whole.

APPENDIX 3/1. Additional information on the GWP-factor used in the calculations

Additional data regarding GWP factors used in calculations

	Material	Description of the used GWP factor	Location	Referenced	Source
Metals	Iron, cast	cast iron, at plant	RER	23.7.2012	EcoInvent
	Steel	steel, cold rolled	FIN	9.5.2012	Ruukki
	Steel, rod	steel, hot-rolled, cold-molded	FIN	9.5.2012	Ruukki
	Steel, hot-rolled	hot-rolled steel sheets and profiles	FIN	9.5.2012	Ruukki
	Steel, cold-rolled	cold-rolled steel	FIN	9.5.2012	Ruukki
	Stainless steel	chronium steel 18/8, at plant	RER	9.8.2012	EcoInvent
	Steel, hardened	reinforcing steel	RER	9.8.2012	EcoInvent
	Electro galv.	electro galvanised steel, cradle to gate	GLO	21.8.2012	World Steel Association
	Other metals				
	Al	aluminium, production mix, at plant	RER	23.7.2012	EcoInvent
	Al, cast	aluminium, production mix, cast alloy, at plant	RER	23.7.2012	EcoInvent
	Copper	copper, primary, at refinery	GLO	23.7.2012	EcoInvent
	Brass	brass, at plant	CH	23.7.2012	EcoInvent
Devices and batteries	Electrics	electrics for control units	RER	23.7.2012	EcoInvent
	Electric motor	electric motor, vehicle, at plant	RER	23.7.2012	EcoInvent
	Lead acid battery	calculated: materials of lead acid battery	EU		calculated /EcoInvent*
	Li-Ion battery	single cell, lithium-ion battery, lithium manganiese oxide/graphite, at plant	CN	23.7.2012	EcoInvent
	Catalytic converter	calculated: materials of catalytic converter	EU/GLO	9.8.2012	calculated /EcoInvent*
Plastics	ABS	acrylonitrile-butadiene-styrene copolymer, ABS, at plant	RER	23.7.2012	EcoInvent
	PA	nylon 6, at plant	RER	23.7.2012	EcoInvent
	PE	polyethylene, LDPE, granulate, at plant	RER	23.7.2012	EcoInvent
	Textile, polyester	fleece, polyethylene, at plant	RER	27.8.2012	EcoInvent
	Reinforced plastic	glass fibre reinforced plastic, polyester resin, hand lay-up, at plant	RER	23.7.2012	EcoInvent
	PP	polypropylene, granulate, at plant	RER	23.7.2012	EcoInvent
	PVC	PVC, suspension polymerized, at plant	RER	23.7.2012	EcoInvent
	PUR foam	polyurethane, flexible foam, at plant	RER	23.7.2012	EcoInvent
	PUR adhesive	polyurethane adhesive for automobiles	EU	7.9.2012	Sika
	PS foam	polystyrene foam slab, at plant	RER	23.7.2012	EcoInvent
	Silicone	silicone product, at plant	RER	27.8.2012	EcoInvent
	Plastic, undefined	acrylonitrile-butadiene-styrene copolymer, ABS, at plant	RER	23.7.2012	EcoInvent

APPENDIX 3/2.

	Material	Description of the used GWP factor	Location	Referenced	Source
Lubricants and chemicals	Lubricant	lubricant oil, at plant	RER	28.8.2012	EcoInvent
	Paint	alkyd paint, white, 60 % in H2O, at plant	RER	23.7.2012	EcoInvent
	Refrigerant	refrigerant R134a, at plant	RER	23.7.2012	EcoInvent
	Ethylene glycol	ethylene glycol, at plant	RER	9.8.2012	EcoInvent
Other materials	Plywood	plywood, birch	FIN	26.6.2012	Puuinfo
	Glass	flat glass, uncoated at plant	RER	23.7.2012	EcoInvent
	Double glass	double glazing, laminated safety glass, at plant	RER	23.7.2012	EcoInvent
	Rubber, undefined	synthetic rubber, at plant	RER	23.7.2012	EcoInvent
	Rubber, natural	natural rubber based sealing, at plant	DE	23.7.2012	EcoInvent
	Bitumen	bitumen, at refinery	RER	23.7.2012	EcoInvent
	Other	electronics for control units	RER	23.7.2012	EcoInvent

* calculated based on theoretical data about the part and GWP factors for materials of a part.

GWP = Global Warming Potential

Abbreviations for location
CH = Switzerland
DE = Germany
EU = European Union
FIN = Finland
GLO = Global
RER = Europe

Additional information on the source:
Ecoinvent: GWP calculated in accordance to CML 2001 guidance
Ruukki: Environmental declarations for steel products by Ruukki Corporation
World Steel Association: Data through a questionnaire of World Steel Association
Sika: GWP for Sika adhesive by Sika Group
Puuinfo: GWP for plywood by Puuinfo Ltd.

GWP factors from the Finnish companies Puuinfo and Ruukki: including carbon dioxide, methane and nitrous oxide. Factors exclude sulfur hexafluoride, perfluorocarbons and hydrofluorocarbons.

APPENDIX 4. Weight and material carbon footprint data for the metals

This table shows the weights of metals by subgrouping both in kilograms and percentage of the total weight of each bus. The material carbon footprint for each material group in t CO2e/bus and % are shown under the metal weight data for each subgroup.

	Case 1 Diesel	Case 2 Diesel	Case 3 Hybrid	Case 4 Electric (1*)	Case 5 Converted electric	Reference Diesel
Metals						
Iron or steel excl. stainless steel						
kg	2 320	6 255	5 907	5 335	5 993	6 097
%	39 %	77 %	75 %	78 %	79 %	71 %
t CO_2e/bus	2.3	6.7	6.2	4.9	5.9	6.8
%	7 %	34 %	31 %	30 %	34 %	28 %
Stainless steel						
kg	40	188	188	105	108	690
%	1 %	2 %	2 %	2 %	1 %	8 %
t CO_2e/bus	0.2	0.9	0.9	0.5	0.5	3.1
%	1 %	4 %	4 %	3 %	3 %	13 %
Aluminium						
kg	3 404	1 526	1 541	1 209	1 275	1 666
%	58 %	19 %	20 %	18 %	17 %	19 %
t CO_2e/bus	28.3	11.7	12.2	10.2	10.4	14.0
%	91 %	59 %	61 %	63 %	60 %	58 %
Other metals						
kg	152	180	228	220	208	112
%	3 %	2 %	3 %	3 %	3 %	1 %
t CO_2e/bus	0.5	0.6	0.7	0.7	0.7	0.4
%	1 %	3 %	4 %	4 %	4 %	1 %
Total						
kg	**5 916**	**8 149**	**7 865**	**6 869**	**7 583**	**8 565**
%	**100 %**	**100 %**	**100 %**	**100 %**	**100 %**	**100 %**
t CO_2e/bus	**31**	**20**	**20**	**16**	**17**	**24**
%	**100 %**	**100 %**	**100 %**	**100 %**	**100 %**	**100 %**

(1*) Preliminary results

APPENDIX 5/1. Steps in a product standard inventory (steps retold from Bhatia et al 2012, 23).

Steps in product standard GHG Inventory

The steps in product standard GHG inventory as stated in Product Life Cycle Accounting and Reporting Standard and realization of the steps are presented in this document. Note: Product Standard names "carbon footprint" with the gloss "GHG product inventory".

Steps in a product standard GHG inventory (Phatia et al. 2012)	**Realization**
(Business goals) What is the purpose of the study?	Goal is to find out - the approximate size of CO_2-footprint - factors affecting on the CO_2-footprint
Principles How are the following principles taken into consideration? • Relevance • Accuracy • Completeness • Consistency	Relevance: the study is relevant and serves the benefit of several operators. Accuracy: the GHG emissions are calculated with the best knowledge in hand making sure that the calculated emissions are not systematically greater or less than actual emissions. Uncertainties are reduced as far as practicable. Completeness: the boundaries are defined so that the information can be gathered within the time limit. Consistency: chosen methodologies, data and assumptions allow meaningful comparison of GHG inventory over time. Transparency: the method and time of gathering information is recorded and presented in the report.
Fundamentals of product life cycle accounting	Taken into consideration.
Defining the scope Requirements - CO_2, CH_4, N_2O, SF_6, PFSs and HFCs must be accounted - Define studied product - Define unit of analysis = functional unit - Define reference flow	Scope: Raw material extraction and pre-processing of the raw materials of the bus. - All the 6 emissions are accounted according to the CML2001 impact assessment method. Almost all the used GWPs are from this source. - Studied product: a 12 m long urban transit bus with seat amount of about 40. - GHG emission caused by the extraction and pre-processing of the raw materials of a bus (t CO_2e/bus) - reference flow = functional unit[1]

APPENDIX 5/2.

- Boundary setting - Process map - Boundary details - The time period of a product life-cycle - Land-use change impacts	The boundary is ruled to the raw material acquisition and pre-processing in this study. There might be another study exploring the use-phase of a bus. Process map is included in the report. See Figure 4. Process map with system boundary. Cradle-to-gate for each raw material[2] No relevance Not applicable
Data collection and quality assessment Data quality	Data management plan 14 May 2012 with changes if needed Scoring of data quality indicators 1-4
Allocation	Co-products are not taken into consideration.
Calculating inventory results	- 100 year GWP factor is used - Results in unit of CO_2 equivalent (CO_2e) - Weighting factors for delayed emissions, offsets or avoided emissions are not used, as required.
Uncertainty	Source of information is tracked Source of GWP factors is tracked. Calculation method is explained. All the stages of the study are critically reviewed
Performance tracking	Not conducted in this study.
Assurance The Carbon footprint must be assured by a first of a third party	Assurance is left out due to the time and work frame of the study.
Reporting	Guideline for reporting not adhered to.

[1] The studied materials can be seen as intermediate products where the eventual function is not to be seen. In such cases, the functional unit can be defined as the reference flow.

[2] Gradle-to-gate inventory is relevant and enables further study of the life cycle of a bus.