Managing life cycle assessment of buses

An investigation on how Volvo Buses can meet environmental requirements from green public procurement, now and in the future

Master of Science Thesis in the Industrial Ecology program

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Abstract

The public transport sector in Sweden is moving fast towards a more sustainable future with the environmental criteria used in public procurement processes becoming increasingly ambitious. This increased ambition, in turn, influences companies active in the public transport sector. One of these companies is Volvo Buses; who are among the world's largest bus manufacturer. The thesis aimed at investigating possible future environmental requirements in public procurement that might be relevant for Volvo Buses and similar companies. Volvo Buses are currently conducting life cycle assessments (LCAs) on buses, however, there is an ambition to make the process more efficient. The thesis intended to identify areas of improvement in the LCA process at Volvo Buses. In line with this were a reasonable level of detail of the LCA investigated, as well as what phases in the life cycle that is the most relevant to focus on.

The study found that as long the fuel is non-renewable, the rest of the life cycle has close to negligible CO_2 impact. As follows, to demand an LCA on an entire bus would not add any further value to the public procurement process as the use-phase dominates the emissions. However, LCA becomes increasingly relevant when the fuel used in the public transport sector moves towards more renewable sources. In line with this are both the EU and local public transport agencies in Sweden investigating the possibility to incorporate LCA in public procurement for buses. In order to meet the requirements of tomorrow, Volvo Buses needs to improve the structure surrounding the LCA continuously. In line with this should focus also be on the integration of life cycle management deeper into the organisation by including other operations within and external to the organisation. With a more agile and fast-paced LCA process, combined with the extensive knowledge that already exists, Volvo Buses would be ready to excel in future procurement processes.

Keywords:
Life Cycle Assessment, Green public procurement, Buses, Public Transport, Environmental Product Declaration, Life Cycle Management

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Julia Lindholm, Gothenburg, June 2019
Louise Lorentzon, Gothenburg, June 2019

Contents

Abbrevations

Life Cycle specific

LCA	Life Cycle Assessment
LCI	Life Cycle Inventory
LCIA	Life Cycle Impact Assessment
LCM	Life Cycle Management
TTW	Tank-To-Wheel
WTT	Well-To-Tank
WTW	Well-To-Wheel

Impact categories

AP	Acidification Potential
EP	Eutrophication Potential
GWP	Global Warming Potential
HTP	Human Toxicity Potential
ODP	Ozone Depletion Potential
POCP	Photochemical Ozone Creation Potential

Miscellaneous

B7	Diesel with 7 % renewable mixture
CVD	Clean Vehicle Directive
EPD	Environmental Product Declaration
GPP	Green Public Procurement
HVO	Hydrogenated Vegetable Oil
PCR	Product Category Rules
PTA	Public Transport Authority
RME	Rapeseed Methyl Esters
VGR	Region Västra Götaland

1
Introduction

The world today can be described as a complex one; with social, economic, technical, political and environmental activities all linked in an intangible web. Aspects such as new technology enabling instantaneous communication and revolutionary innovations, combined with increased globalisation, resulting in a volatile market place for many companies (Hunkeler et al., 2003). A market place where stakeholders are increasingly aware, and thus, demanding more from companies in terms of ethical, social and environmental performance. Due to this, an increased number of companies are including various corporate social responsibility (CSR) activities in their internal strategies (Blome et al., 2014). The focus in the CSR-work has traditionally been on social issues, such as ethics and poverty. However, over the last decade, environmental activities have increased in their perceived importance in society and by extension at company-level (Blome et al., 2014). Moreover, companies are increasingly taking into consideration the potential of environmental initiatives rather than seeing them as only expensive and time-consuming. Rusinko (2007) and Nikolaeva and Bicho (2011) addresses how environmental work can be a competitive advantage in the long run. To be in sync with the trends and live up to the stakeholders' perceptions does not only strengthen the brand's reputation but is also likely to help companies gain a competitive advantage of being first with new sustainable solutions.

The rising social awareness is also visible in how regulators and authorities have progressively higher standards on what is acceptable in procurement processes. In the public transport sector the initiative of Green Public Procurement (GPP) is frequently used by various actors to include environmental information as a basis for public procurement (Bouwer et al., 2006), (The Swedish Environmental Protection Agency, 2009). GPP can not only be a great contributor to a city's overall sustainability, but there are also examples where it helps stimulate markets for sustainable services and goods (The Swedish Environmental Protection Agency, 2009). In the case of the public transport sector, the Original Equipment Manufacturers (OEMs) have to perform on environmental issues in order to participate in tenders. For example, Sweden aims at having a fossil-fuel independent vehicle fleet by 2030 (Xylia and Silveira, 2017), (Regeringskansliet, 2013). To be able to achieve this level of fossil-fuel independence, the transport sector has to reduce the share of fossil fuels significantly. It is thus likely, according to Xylia and Silveira (2017), that the sector will be under various environmental regulations in the future.

Companies are increasingly trying to utilise various environmental methods in their operations to meet indirect environmental demands from the public as well as direct ones from customers. One way to integrate environmental work into an organisation is by using the method of life cycle management (LCM). The method utilises various tools and techniques to organise and manage the environmental work. However, it also contains the idea of integrating environmental thinking into every aspect of an organisation (Hunkeler et al., 2003). One commonly used practice, as part of the overall LCM work, is the activity of conducting life cycle assessments (LCA) on products. An LCA consists of several steps where the main goal is to map out the environmental impact a product entails during its entire life (Baumann and Tillman, 2004). The LCA results can be used in environmental reports and in product declarations to promote and support environmental work. The LCA results can also function as a foundation for internal strategic decisions or in the design process as a way of identifying areas of improvement. However, for a company with many different and complex products, the activity of conducting a life cycle assessment might be a time-consuming and challenging task (Baumann and Tillman, 2004), (Manzini et al., 2006). In this study, the bus manufacturer Volvo Buses is investigated with focus on their LCA work.

Volvo Buses is one of the world's largest manufacturer of buses with operations in more than 140 countries, and headquarters in Gothenburg, Sweden (Volvo Buses, 2018). They are a subsidiary of the Swedish vehicle corporation Volvo Group, and the group overall is fully committed to becoming the leading provider of sustainable transport solutions. This commitment is highly relevant for Volvo Buses as they are active in the public sector, and thus, sensitive to various regulations that might affect the public procurement process. Volvo Buses' clients are increasingly demanding more information and transparency about the buses' life cycle and the environmental effects throughout all stages of a bus's life. (Volvo Buses, 2018). Reflecting their commitment towards their clients and the environment is the fact that Volvo Buses was pioneers in the field of conducting LCA on buses, and made their first one in 2005. Note that when the company name "Volvo" is used throughout the report, it refers to Volvo Buses.

2
Literature review

2.1 Green public procurement

Alignment with stakeholders' interests to ensure long-term success and profit is a crucial factor for companies. This might seem trivial, but for a company active in the public sector, this might be easier said than done. Bus manufacturing companies who are engaged in public procurement are, to a large extent, dependent on more than just end-customers; regulations, social pressure, and public procurement processes are all factors to consider. In this chapter, the concept of green public procurement (GPP) is presented, and how it applies to the bus sector specifically.

Public procurement makes up a significant part of many countries total GNP (Gross National Product); for example has Bauer (2009) looked at the Nordic countries and found that public procurement constitutes around 16 % of a country's GNP. This high number implicates that public procurement can result in considerable environmental impact depending on national strategies. Both Cheng et al. (2018) and Bauer (2009) describe how public procurement can function as a driver for market development towards environmentally conscious products by pressuring the private sector to perform. This pressuring can be done through suitable policies or creation of markets where it is favourable to be sustainable (Cheng et al., 2018). Aldenius and Khan (2017) identifies both direct and indirect effects of a sustainable public procurement process. Direct effects are, for example, if a public purchaser accounts for a large share of the market, the emissions have been proved to decrease significantly, and indirect effects entail innovation and niche-market creation (Aldenius and Khan, 2017). As a result of this are procurement processes increasingly perceived as a way to promote sustainability; it is, for example, stated as a way to reach the sustainable development goals by the United Nations 2030 Agenda for Sustainable Development that countries increasingly need to promote sustainable procurement (Ghisetti, 2017).

The European Commission has set a non-binding public procurement target within the EU that favours environmental, social and economic performance improvements of products and services. Thus, the level of sustainable public procurement varies significantly between countries and regions due to different ambition levels and prerequisites (Cheng et al., 2018). Public procurement that focuses on environmental issues is commonly referred to as Green Public Procurement (GPP) (Bouwer et al., 2006). GPP can be used for promoting environmental innovations by selecting perhaps not the most short-term economically feasible products, but instead aiding the commercialisation of products with lower emissions (Bauer, 2009).

2.1.1 Green public procurement for buses

The public transport sector represents 27 % of the total person-km driven over a year in Sweden (Xylia and Silveira, 2017). Public transport in Sweden is, in general, organised based on regions. There are 21 regional public transport authorities (PTAs) in total, and the different PTAs are responsible for one region each and can consist of a county, municipality or a combination of the two (Aldenius and Khan, 2017). Strategic plans and long-term targets for the region are decided by the PTAs who, in turn, is in contact with the politicians. The PTAs are handling procurement processes with either bus manufacturers directly, or operators who buy and drive the buses (Aldenius and Khan, 2017).

The work with green public procurement has been aligned with the overall environmental work in Sweden over the last decade. As a result, a significant increase in the use of fuel that entails lowered amounts of CO_2 in the public transport sector has been be seen (Aldenius and Khan, 2017), (Bauer, 2009). The Swedish bus sector has seen some rapid changes in regards to the amount of renewable fuel being used per vehicle-kilometres. An increase from 8 % in 2007 to 58 % in 2014 has happened all while the number of vehicle-kilometre increased with 17 % in the same time-period.

The alignment of green public procurement and environmental work has lead to a situation where close to all purchases in the public sector in Sweden today consist of some environmental requirements. The requirements are locally decided, and thus, differs between cities within Sweden. The national agency for public procurement in Sweden, Upphandlingsmyndigheten, has set criteria which are publicly available and voluntary to use in GPP for different kinds of goods and services (Svensk Kollektivtrafik, 2018). Even though there are no criteria for public transport per se, there exists a partner co-operation with parties from government and public transport authorities which aims at doubling the volume of public transportation in Sweden by 2020 (Svensk Kollektivtrafik, 2018). It offers a range of environmental standards that are voluntary to use in tendering processes. These standards entail regulations on CO_2 emissions as well as energy-usage and noise levels for a range of different bus sizes. Xylia and Silveira (2017) point out the importance of a political will, strategic planning and policies to achieve a public transport sector running on renewable fuels.

There are, however, some environmental regulations used in public procurement that are not decided locally, and are thus not voluntary. One example is the Euro class standards that regulate how much tailpipe emissions, such as CO, HC, PM and NO_x, that are allowed to be emitted by heavy-duty diesel vehicles per km. The Euro class VI is the latest standard which entails the lowest allowed emissions to this day. In the voluntary Swedish standard, engines with other Euro classes than VI are allowed in specific amounts. There are, however, planned to be phased out over time (National Agency for Public Procurement, 2015).

The practice of green public procurement is a useful tool to influence a sector to be more environmentally friendly, as have been shown in the section above. Companies active in the public sector will accordingly be under an increasing amount of pressure stemming from ambitious green public procurement processes. This will likely imply changes for Volvo Buses in the future. Volvo Buses has identified the method of LCAs as a convenient way to meet clients' requests and has been conducting LCAs in various sizes since 2005. In the chapter below, various ways to incorporate sustainability into organisations, where the method of conducting LCAs is one of them, is presented.

2.2 Environmental practices at companies

A common way to integrate the concept of sustainability into an organisational structure of a company is to use the method of life cycle management (LCM) (Hunkeler et al., 2003). LCM considers a holistic approach to sustainable impacts of a system, such as a product or a company, and utilises various tools and techniques to incorporate sustainability performance (Saur et al., 2003). While it entails not only environmental aspects of sustainability but encompasses social and economic aspects of a product's life cycle as well, it is most commonly used when companies wish to enhance their environmental performance (Hunkeler et al., 2003). LCM brings together all relevant actors associated with the business, such as suppliers, manufacturers, retailers and purchasers. Thus, it enables the opportunity to include a life cycle perspective in the decision-making process as well as the overall strategy of the company. For example, does Hunkeler et al. (2003) describe how LCM has the possibility of improving decision making by providing information of higher accuracy about a company's environmental impact.

The overall environmental impact that a company entails is highly affected by activities from all organisational levels within and external to the company. Thus, to consider the entire organisation when working with sustainability; from marketing, purchasing to research and development, design to strategic planning and management, is crucial to ensure a robust sustainability performance (Hunkeler et al., 2003). Moreover, the method of LCM also extends outside of the company and can, if chosen, also entail the supply-chain. Rebitzer (2015) points out that to have a close relationship with suppliers do ensure not only high quality and enhanced reputation but also the possibility of reduced cost and overall added value for all actors in the value chain. Darnall et al. (2008) give an example from the automotive industry where a company evaluated their plastics and steel suppliers to ensure that their products did not indirectly contain any toxic or environmentally damaging components, and in the process improved the supply chain by reducing waste.

To already have an active supply chain is beneficial when companies are to oversee the total environmental performance of their products (Martin Murray, 2019). There is a growing interest in sustainable-thinking companies, and an increased amount of stakeholders are pressuring companies to be more sustainable, as was described in the Introduction. A commonly used method within LCM, to meet these demands, is to conduct life cycle assessments (LCAs) to investigate products' environmental impacts. In the following sub-section, the method of LCA is described.

2.2.1 Life Cycle Assessment

Life cycle assessment is the method of mapping and modelling the flows of energy, material and emissions that are used and emitted in each stage of a product's life-cycle (Baumann and Tillman, 2004) A simple version of an LCA is to conduct a Screening LCA which entails identifying "hot spots" in the product life cycle and activities that are easy to improve (Pre-sustainability, 2018). It can function as an initial overview of the environmental impacts, and thus, is it suitable for internal communication and decision making within a company. The more complex version of an LCA is the ISO-compliant one which typically takes substantially more time to conduct than a screening LCA. The ISO-compliant LCA generates detailed and comparable results that can be communicated externally to customers. In this case, the LCA should be done according to the ISO 14040/44 standards, and have robust data collection and quality assurance. LCA is an iterative process consisting of four steps, see Figure 2.1.

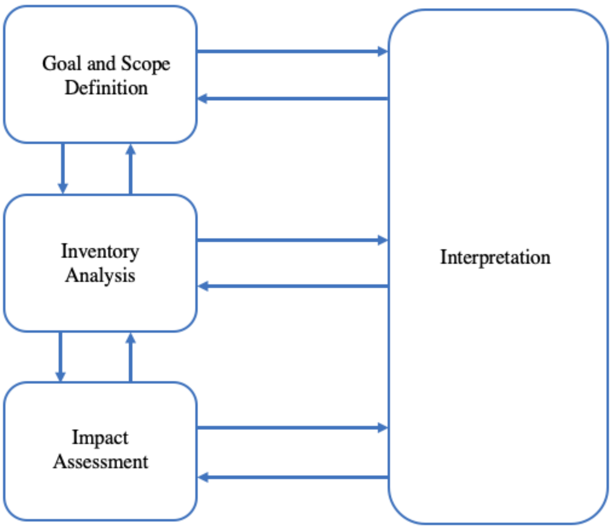

Figure 2.1: The LCA methodology. As can be seen, the LCA is very much an iterative process. The study starts with a goal and scope definition, continues with inventory analysis where the data is collected and modelled, and lastly, an impact assessment is done. In every step the various results are interpreted to ensure quality.

In the goal and scope stage, the intended application of the study is stated, the context is clarified, and the overall modelling of the system is done. The modelling entails stating the relevant system boundaries as well as stating the significant assumptions and limitations. The second step of an LCA is to conduct an extensive inventory analysis in which a model of the system is designed based on the goal and scope from the previous step. Typically a flow model is created to illustrate system boundaries, and the environmentally relevant flows of energy and mass are identified and further quantified through an extensive data collection process. When all data is gathered, the next stage is to describe what environmental consequences this data entails (Baumann and Tillman, 2004). The impact assessment is a step-wise way to convert inventory data to information that is environmentally relevant to a higher degree; for example, might all the emissions flows of NH_3 be recalculated to a eutrophication potential that says something about the environmental consequences of the emissions. The very last stage in conducting an LCA is to interpret the results. This interpretation is done in order to make sense of, and draw conclusions from, the possibly large number of result parameters. The interpretations part of an LCA often uses some analysis of the robustness of the results using a sensitivity and uncertainty analysis (Baumann and Tillman, 2004).

The data collection of the extraction and production of material and components is very much affected by the flows of information throughout an organisation and between several organisations. The company conducting the LCA must get information from various part of their internal organisation, but also their suppliers, and perhaps their supplier' suppliers. Fazeni et al. (2014) offers the idea of how an LCA can provide an active overview of the entire process chain. In the same way as an actor in a supply chain network require constant communication to ensure smooth flow of information, do the people responsible for the LCA have to interact with the rest of the organisation regulary (Fazeni et al., 2014). Additional benefits from conducting an LCA and integrating it into the organisational flow of information is that environmental impact or legal issues are identified in an earlier stage of the product development process. Thus, is the method of conducting an LCA very much included in the LCM practice as it entails opportunities for the entire company and its suppliers to improve their sustainability performance.

Several LCA studies have previously been made on buses (e.g. (Ercan et al., 2015), (Nordelöf et al., 2017)). It is traditionally more common to consider and regulate tailpipe emissions. However, these studies show that depending on what environmental impact that is investigated, other life-cycle phases might become relevant. Ercan et al. (2015) examine what CO_2 emission levels, air pollutants as well as total costs, that an average bus results in throughout its entire life cycle. This examination is done with different fuel types as well as different driving routes. Ercan et al. (2015) find, among other things, that while SO_2 is not a major risk in the tank-to-wheel phase due to restrictions on its content for any of the fuel types, it still has an important impact on the overall LCA results as the production of fuels, well-to-tank, result in high emissions. Even though the focus of the study made by Ercan et al. (2015) is not to identify environmentally damaging hot-spots, but rather to see the "Cost-CO_2" trade-off, it is possible to identify processes in the life cycle that are particularly damaging. For fossil-based fuels, it is possible to see that the well-to-wheel phase has the most CO_2 emissions. For the electric bus the production and the well-to-tank, the electricity production, has the highest CO_2 emissions depending on where it is procued. These results are in line with what Nordelöf et al. (2017) found in their study; the use-phase, well-to-wheel, was overall the most CO_2 intense for the diesel alternatives, while the material production phase dominated the electric bus. However, similar to the study by Ercan et al. (2015), the choice of electricity production is crucial. In the case with "dirty" mixture, the electric bus has an overall worse CO_2 profile than for example a PHEV (Plug-in hybrid electric vehicle) gas bus (Nordelöf et al., 2017). For an electric bus where the electricity comes from local wind energy, the use-phase only accounts for 18 % of CO_2 emissions during the entire lifetime (Nordelöf et al., 2017).

2.2.1.1 Environmental Product Declaration

To be able to communicate how well a product performs environmentally, companies may use the method of conducting an Environmental Product Declaration (ISO, 2006). An EPD entails constructing a complete LCA and communicate it to stakeholders through pre-defined product declaration frameworks. EPDs are independently verified, and their main purpose is to communicate comparable and transparent information about the environmental impacts of a product's whole life cycle (EPD International AB, 2018b). These product declarations could, for example, be used in the green public procurement processes as a verification of compliance with the set requirements for a specific product. The EPD standard follows the ISO 14044 and the ISO 14025 (EPD International AB, 2018b).

To ensure comparability between similar products, there exist several product category rules (PCR) that provide comprehensive frameworks for calculations and allocation scenarios for different products (EPD International AB, 2018a). The product categories are divided based on the product kind, for example is "Vehicles and transportation equipment" one overall category in which aeroplanes, yachts, jets and buses, all have a PCR each. Even though there exists a PCR framework for buses, this has only been used once to produce a certified EPD for a coach (EPD International AB, 2018b). Thus, an EPD is currently not an established method in public procurement to the authors' knowledge.

2.3 Aim

Based on the literature review, it is possible to see that the world around Volvo Buses is quickly changing and important stakeholders are becoming increasingly ambitious. This is both due to social awareness and political pressure. All of which also is visible in the procurement processes of public transport. Hence, the thesis aims at investigating possible future requirements that might be relevant for Volvo Buses and similar companies, and how these can be met successfully.

Volvo Buses has, as was described in the Introduction, identified LCA as one way of meeting requirements from clients. However, to enable Volvo Buses, and similar companies active in the public sector, to meet future requirements, it is desirable to make the LCA process more efficient. Based on this, a case study will be conducted at Volvo Buses, where an LCA is to be done on one bus model. This case study aims to identify areas of improvement in the LCA process as well as a reasonable level of ambition while still meeting future requirements. Moreover, ideas from the theory of LCM will be considered to see if it can aid the LCA procedure at Volvo Buses. Together with IVL, the Swedish Environmental Research Institute, this thesis will be a part of a larger research project that is done at Volvo Buses. The intended audience for the thesis overall will be interested parties, other students or researchers, and employees at Volvo Buses and similar companies.

3
Methodology

3.1 Project procedure

The thesis can, in large, be divided into two integrated parts: the investigation of the future of green public procurement processes, and the case study at Volvo Buses. The case study consisted of the LCA and an investigation of what environmental requests Volvo Buses currently receive from their clients. During the work procedure, the two parts were very much integrated. An overview of the methodology can be seen in Figure 3.1.

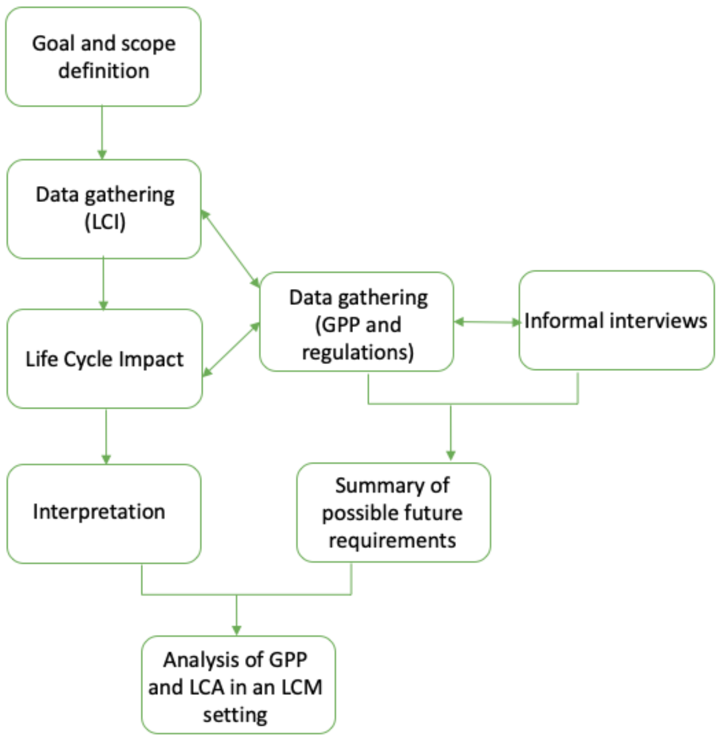

Figure 3.1: Flow chart of the methodological steps taken in the study. Arrows between steps are visible to display interactions between activities.

The project procedure started with an explorative information-gathering to obtain an idea of how the situation of public procurement is today, specifically in the region Västra Götaland. Semi-structured interviews with responsible people at the region Västra Götaland were carried out to gather knowledge of the future of public procurement in this region. Moreover, how the strategies and public procurement criteria, decided by the region, influence Volvo Buses were investigated. This investigation was done through informal conversations with the contact person at Volvo Buses, and entailed what kind of client requests Volvo Buses currently receive, and how these are handled. As part of the case study at Volvo Buses, a life cycle assessment (LCA) was conducted on a Volvo 8900 bus. The results, from both the LCA and the investigation into the future of green public procurement, were combined and analysed in an overarching life cycle management setting. This combination was done to be able to identify how Volvo Buses can meet future environmental demands through an improved LCA process, both internal and external to the company. In the LCA, Volvo's internal guidelines were used and assessed to identify which parts of the data gathering that can be made more efficient. Moreover, based on what was deemed to be environmental hotspots in the LCA results parallels to the future criteria in green public procurement ware drawn.

3.2 Green Public Procurement

The investigation into the future of public procurement for the transport sector was very much influenced by what it looks like today. Both the public transport agencies' point of view, and Volvo Buses', who are increasingly affected by various criteria, were considered. Official reports from the EU, as well as local strategies from the region Västra Götaland, were studied. This knowledge was used as the basis for the informal interviews done at Volvo Buses, Västtrafik and region Västra Götaland (VGR). To describe how the case study at Volvo Buses was conducted, the word 'interview' is used very loosely; it was more of a conversation with the main contact at Volvo Buses, Andreas Carlén. The interview with the Sustainability strategy manager at Västtrafik, Hanna Björk, was a semi-structured interview done via a telephone call. Even though the asked questions were prepared, the conversation was not limited to these. A similar approach was done with the contact at region Västra Götaland, Leif Magnusson. The questions used in the semi-structured interviews can be found in Appendix A.1.

3.3 LCA methodology

A life cycle assessment was conducted on one specific bus; the Volvo bus 8900. The LCA has been done according to the LCA standards ISO 14040:(2006) and ISO 14044:(2006).

3.3.1 Goal and scope

The main goal of the LCA study was to identify environmental hotspots: what stages in a bus' life that contributes the most, and how that changes with different fuel types. The LCA process at Volvo was also investigated to find areas of improvement and draw parallels to green public procurement. This was used to explore how to make the LCA process at Volvo more efficient. The LCA in itself was based on the

LCA standards (ISO 14040 and ISO 14044) as well as Volvo Buses' internal LCA guideline. The studied bus was the Volvo bus 8908RLE_6x4, which is a bus with a rigid body and low entry. The engine was an 8 litre Euro VI diesel engine and the gearbox an iShift.

3.3.1.1 Functional unit

The function of a bus is to transport passengers, and thus, the functional unit can be described as transporting passengers during the lifetime of the bus, which is 1 500 000 km over 12 years.

3.3.1.2 System boundaries

The LCA study considered the entire life cycle of a bus; from the cradle to the grave. Thus, all activities from raw material production to end-of-life were taken into account.

The material production has been modelled using mostly generic data from ecoinvent while processes associated with certain materials that are Volvo specific has been according to specific data from Volvo plants. Moreover, Volvo manufacturing has been modelled using specific data, and component manufacturing has been modelled in the same way to account for external suppliers. To investigate how the environmental impact changes with different fuel types, both a conventional diesel B7 and the biodiesel HVO were chosen to represent two cases of the use-phase.

The components of the bus were produced in several parts of Europe, and the bus itself was assembled in Wrocław, Poland. The bus is assumed to be driven in Europe, and thus, is the geographical boundaries limited to mostly in Europe. The study itself was retrospective as it looked at already existing products and technologies.

Figure 3.2 illustrates the main phases that the LCA entails. The green boxes are the so-called background system and entail processes that are external to Volvo, while the blue boxes are the foreground system, which contains the Volvo-specific processes. The orange boundaries represent the scope of this study. Note that maintenance typically is part of a cradle to grave study, but it was not within the boundaries of this study. To investigate maintenance was found to be very time-consuming, and the outcome typically does not weigh up to the time spent, based on previously made LCAs on buses and similar vehicles by IVL (Nordelöf et al., 2017).

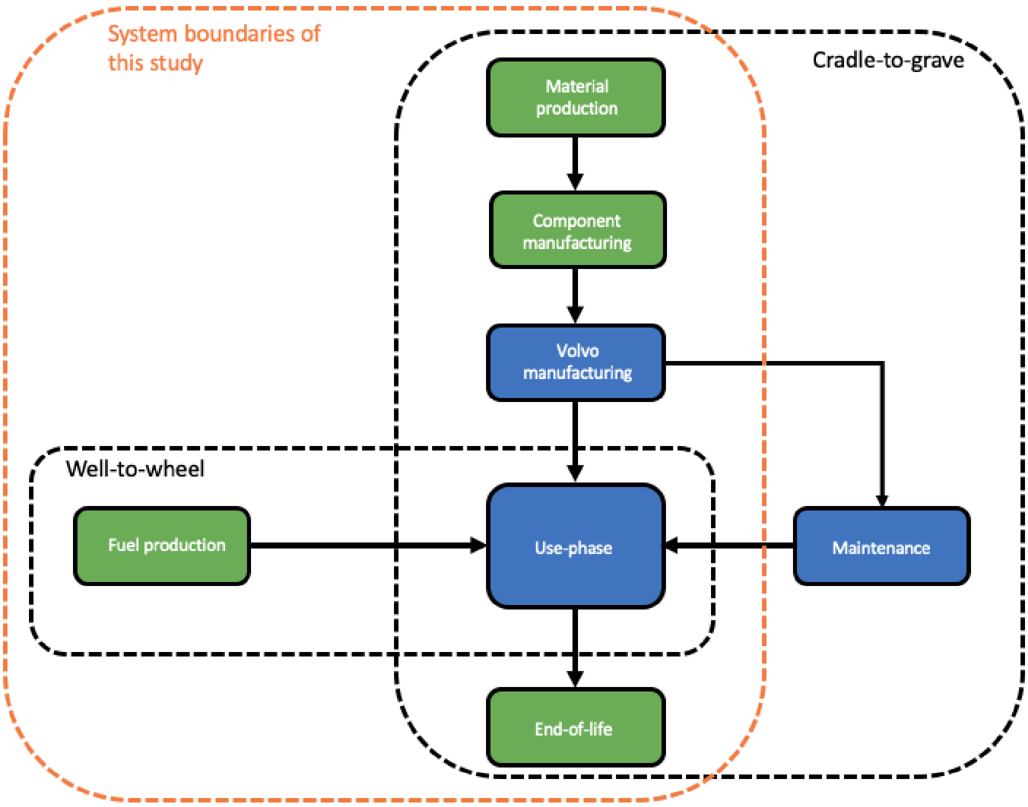

Figure 3.2: Process flow chart of the investigated system where green boxes represent the background system, while blue boxes represent the foreground system where specific data have been used. The orange boundaries represent the scope of this study.

There are, however, some additional processes that were not considered, due to lack in data availability as well as relevance in this study:

- Maintenance of the bus during use-phase.
- Production, use-phase and end-of-life for packaging materials.
- Production of capital goods and infrastructure during different stages in the bus's life cycle.
- Environmental impacts from personnel activities, such as business travels or food.
- Materials that are not assumed to be recycled at the end-of-life stage, for example, plastics.

3.3.1.3 Data quality requirements

The investigated bus was assumed just to have been produced or will soon be produced, and the data that were used were thus assumed to represent an image of the present situation. Old data were only used if no other data were available. Possible estimations and simplifications are explained in more detail in section 3.3.2.1.

3.3.2 Life Cycle Inventory (LCI)

The life cycle inventory step can be divided into material production, component manufacturing, Volvo manufacturing, use-phase and end-of-life. Material production and component manufacturing are external activities, while Volvo manufacturing is internal. Data used in the life cycle assessment study were provided mainly by Volvo Buses through their bill of material databases. When data were lacking in the databases, it was collected manually, and estimates were done. Modelling of the LCA system was done in the GaBi software using Volvo Group specific datasets as well as data of commonly known materials from Ecoinvent databases. It should be mentioned that it was only the bus body that was focused on in the LCA. The rest of the bus was taken from already made LCAs on similar products at Volvo Group. These existing LCAs have been conducted similarly and are, thus, considered to be of high quality. To make these simplifications were considered reasonable as the goal of the study is not to complete an LCA on a full bus, but rather to identify environmental "hot-spots", and explore the LCA procedure at Volvo Buses.

3.3.2.1 Material production

The bus has been modelled using data taken directly from Volvo Buses for the body of a specific 8900 bus with rigid body and low entry. In cases with components of low weight and where no material information was available, it has been compared to similar components and assumed to have the same materials. As a last resort educated guesses were made on remaining components without material data. Data down to 1 kg components has been investigated manually and is deemed to have higher accuracy than the parts with a lower weight. The omitted parts make up approximately 5 % of the total weight of the investigated body. Again, it was only the bus body that was investigated in more detail, while data for the chassis, engine and gearbox were gathered from already made LCAs. The chassis was taken from a similar model; the 7900, which has approximated 70 % of its components in common with the 8900 bus. It should be noted that the 7900 bus is 3 tonnes lighter than the studied 8900 bus while otherwise being very similar in structure to one another. Data has been collected from a recently made LCA at Volvo Trucks where an iShift gearbox and a DTI8 530 hp diesel engine have been used, to account for the powertrain. The chosen engine is close to identical, apart from having more horsepower than the studied bus engine.

3.3.2.2 Component manufacturing

All external component manufacturing is represented in this step of the LCA. There are numerous small parts, which are necessary for the full bus, whose origins are not feasible to investigate in detail. It was decided, to account for the lack of specific data, that the data from Volvo's internal manufacturing sites and all transportation are equal to the estimate of the external manufacturing. This estimation was in line with the internal LCA guidelines at Volvo Group.

3.3.2.3 Volvo manufacturing

Data from Volvo's manufacturing sites were gathered internally from Volvo Buses' own reporting system and represented the internal Volvo sites for 2018. The frames of the bus were welded together in Uddevalla, Sweden, and the entire chassis was assembled in Borås, Sweden. The gearbox was made in Köping, Sweden and the engine was manufactured in Lyon, France. Finally, the entire bus was assembled in Wrocław, Poland. Data have been allocated based on the number of produced units of the bus model, for all production sites. For CO_2 emissions from the production sites, the electricity consumed in each plant has been used to calculate the emissions. Transportation data were included in the Volvo manufacturing data and was divided into two categories: internal and external transport. Internal transportation was defined as transport between Volvo plants, and external transportation as the transports from tier one suppliers to Volvo plants.

3.3.2.4 Use-phase

The use phase was divided into two cases: one with regular diesel B7, and one with a type of biodiesel called HVO (Hydrogenated Vegetable Oil). The two fuel types were chosen to be able to investigate the importance of fuel-type, but also to be more relevant to the case of region of Västra Götaland where a majority of buses drive on fuel that entails lower CO_2 emissions. The driving distance used in both cases was given by Volvo Buses and was assumed to be 1 500 000 km during the bus lifetime of 12 years. The fuel consumption of the entire bus was taken from a SORT (Standardised On-Road Test) simulation report from Volvo, where three different driving cycles were evaluated. The one that was deemed most relevant for this LCA was the SORT 3, which is a suburban cycle with an average speed of 27,57 km/h, and a fuel consumption of 35,52 l/100km (Clean Fleets, 2014).

The fuel used in the first case is a B7 diesel with 7 % mixture of RME (Rapeseed Methyl Esters). A combination of urea and water is used to mitigate the emissions of NO_x from the fuel, and taken into account in the calculations for both cases. The data for the fuel and urea Well-To-Tank (WTT) emissions were taken directly from Ecoinvent. The Tank-To-Wheel (TTW) emissions were gathered from F3 (2013).

The second case, with HVO, was modelled with the same fuel- and urea-consumption as the first case. In the GaBi software, the WTT use-phase was modelled using HVO that originates from beef tallow waste with emissions of 13,93 gCO_2 eq./MJ. The emissions associated with the production of beef were excluded in this number. Depending on what the HVO was produced from, the WTT emissions vary greatly from about 5 gCO_2 eq./MJ for the waste product pine oil, to the worst case of 68 gCO_2 eq./MJ when HVO is produced from palm oil (Börjesson et al., 2013). Hence, the chosen HVO is on the lower end of CO_2 eq. emissions. The TTW emissions were gathered from F3 (2013).

3.3.2.5 End-of-life

Recycling and collection rates were taken from internal documents at Volvo Buses. The documents contain several materials that are assumed to be recycled after the bus reaches the end of its lifetime and are sent for scrapping. The mitigation of virgin material as primary production is handled through a credit modelling that is used at Volvo Group and is in line with the ILCD (The International Reference Life Cycle Data System), which is a general framework for LCAs in the EU.

3.3.3 Life Cycle Impact Assessment (LCIA)

The chosen impact categories are Global Warming Potential (GWP 100), Acidification Potential (AP), Eutrophication Potential (EP) and Photochemical Ozone Creation Potential (POCP), see table 3.1. These particular impact categories were chosen based on the investigation of requirements from both Volvo's clients and relevant LCA standards. This is presented further in section 4.1.1.1. Eutrophication was only mentioned twice, but it was chosen nonetheless as NO_x emissions from combustion of fossil fuels contributes to a fairly large share of eutrophication around the world (World Resources Institute, 2015). Since this LCA considered both B7 diesel, with a high content of fossil carbon, and HVO, with biogenic carbon, it was deemed relevant to include eutrophication as an additional impact category.

Table 3.1: Selected impact categories

Impact category	**Description**	**LCIA method**	**Example of contributing flows**
Climate change	Impact of human emissions on the radiative forcing of the atmosphere	GWP100, IPCC AR5	CO_2, CH_4, N_2O, CFCs
Acidification	Impacts due to acidifying pollutants	Acidification Potential, CML 2001-2016	NH_3, NO_x, SO_2
Eutrophication	Impacts on ecosystems due to high environmental levels of macronutrients	Eutrophication Potential, CML 2001-2016	NH_3, P, NO_x
Photochemical ozone creation	Formation of photochemical smog due to reactive chemical compounds	Photochemical Ozone Creation Potential, CML 2001-2016	CO, VOCs. NO_x

3.4 Delimitations

The study has mainly looked at the region of Västra Götaland in Sweden with a few brief outlooks in Europe. For green public procurement, the procurement process itself was not investigated or valued more than to see how the future of public procurement might look like. Moreover, when considering the public procurement of vehicles, only buses were studied.

The method of LCM was only loosely used as a setting for the discussion and analysis of the green public procurement and LCA and was not in itself analysed or investigated at Volvo to any great length. One important limitation of the LCA was the decision to only gather data for the bus body, and use already existing LCAs for the rest of the bus. This simplification was deemed necessary and sufficient for the purpose of this study. Data for the chassis and powertrain were, thus, taken directly from already made LCAs to make the process more efficient. The chassis was taken from a specific 7900 bus which. However, the chosen 7900 bus was approximately three tonnes lighter than the 8900 bus, which most likely resulted in an under-sized chassis. Despite this, it was deemed to be a good estimation to make under current conditions, and it is within the scope of this study. The final results were meant for discussion on how to meet future client environmental requirements rather than to be used in real procurement processes.
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4
Results

The results chapter is divided into two parts; first current requirements, as well as possible future requirements, are investigated. The focus is both on the EU level, and regionally in Gothenburg, Sweden. Examples of environmental requirements that Volvo Buses gets from clients, and at what frequency, are presented as a way to illustrate current demands. Moreover, future requirements based on the conducted interviews are presented. Next, relevant LCA results are presented as graphs. Both of these seemingly different parts are creating the groundwork for the concluding recommendations towards Volvo Buses and any company active in the public sector.

4.1 Green public procurement of buses

First, a summary of requests that Volvo Buses currently received due to public procurement criteria is presented. Moreover, to get a grasp on what the future of green public procurement might look like, semi-structured interviews have been conducted at the region Västra Götaland and the public transport agency (PTA) Västtrafik. These interviews are presented in this section.

4.1.1 Volvo Buses and environmental requirements

Volvo Buses continuously gets various environmental requirements from their clients about information that can be used in procurement processes. According to Andreas Carlén, Energy Efficiency and Environmental Director at Volvo Buses, (personal communication, April 11, 2019), these environmental requests vary greatly. Questions about the recyclability rate are among the most commonly occurring. There are also questions regarding what materials in the bus that are recycled and what materials that are deemed to be short-lived and thus, have to be switched. Another example is when clients want to know about the material production of the bus; more specifically, various environmental impacts during the cradle to gate phase. Another relatively common request from Volvo Buses' clients is a carbon footprint certification, such as PAS 2050 or ISO 14067. All of the examples mentioned this far can be met by Volvo Buses today. Some clients ask for a fully certified EPD, which is considered to be time-consuming and beyond what any regulation demands, according to Andreas Carlén (personal communication, April 11, 2019). However, Andreas points out that clients do not often want a full EPD, or are fully aware of what an EPD entails. Instead they are usually more interested in something similar to a carbon footprint, or a smaller-scale LCA. Both which Volvo Buses can deliver.

Another common request, according to Andreas Carlén, Volvo Buses (personal communication, April 11, 2019), is information about chemicals and what is referred to "substances of very high concern" (SVHC). These are chemicals that are decided by the European Union to be limited in their use according to the REACH Regulation. Additionally, information on how Volvo Buses work with suppliers to ensure that SVHC chemicals are phased out, or used in as low amounts as possible, is frequently requested. Batteries are another example of something that is under many regulations and will, according to Andreas, likely be even more regulated in the future as electrification becomes more widespread. Volvo Buses can currently meet all of the mentioned requirements from clients. When working with demands from clients, Andreas' team has a close connection with the purchasing unit at Volvo Buses, who in turn is in direct contact with the suppliers.

4.1.1.1 Summary of common requirements today

A table has been made to facilitate comparison between the common environmental requirements that Volvo Buses currently receive from their clients, and what factors that are considered in the green public procurement criteria in Västra Götaland as well as in some common standards, see table 4.1.

Table 4.1: A summary of the current impact categories used in various requests, criteria and standards. The GPP document is the green public procurement document made by the Swedish Public Transport Association (Svensk Kollektivtrafik, 2018). PCR for buses (product category rules) is the framework used in EPD (environmental product declarations). ILCD is a EU-made framework for LCAs in general. EFC (environmental footprint calculator) is an internal footprint calculator at Volvo Group.

	Volvo's clients	GPP document	PCR	ILCD	EFC
GWP100	x	x	x	x	x
AP		x	x	x	x
EP			x	x	
Energy		x	x		x
Water use			x		x
HTP		x		x	x
POCP		x	x	x	x
OLDP		x	x	x	
Resource depletion			x	x	
Use of resources	x		x		x
Waste			x		

The GPP document refers to the green public procurement document made by the Swedish Public Transport Association, Svensk Kollektivtrafik, which is composed by parties from government and public transport authorities such as Västtrafik and region Västra Götaland (Svensk Kollektivtrafik, 2018). The examined standards are the ILCD (The International Reference Life Cycle Data System), and the PCR framework for buses set by the EPD. EFC (Environmental Footprint Calculator) is an internal calculator design by Volvo Group. It is possible to identify that all use GWP100 (Global Warming Potential). Moreover, AP (Acidification Potential) and POCP (Photochemical Ozone Creation Potential) are both commonly used.

4.1.2 Future requirements

Regulators and clients in procurement have increasingly higher standards on what is acceptable in procurement processes, and this is in line with the increased public awareness on environmental impacts. Starting in 2019, newly produced heavy-duty trucks in the EU have to track and report on their CO_2 tailpipe emissions as well as their fuel consumption (European Commission, 2018a), (Transport and Environment, 2019). This tracking and reporting is part of the very first regulation to exist that requires truck manufacturers to report on the CO_2 emissions from the end-pipe. The EU regulation states that trucks produced from the year 2025 are required to have 15 % lower CO_2 emissions levels than 2019 baseline levels, and in 2030 the levels have to be at least 30 % lower than in 2019 (European Commission, 2019a). The legislation was decided by the European Commission in 2018, to increase the transparency of fuel consumption as well as lowering greenhouse gas emissions within the EU as part of the plan to reach the goal set by the Paris Agreement (Rodríguez and Delgado, 2018). The new regulation entails heavy-duty trucks as a first step, but is planned to expand to also include other vehicle types, such as smaller trucks, buses and coaches from the year 2022 (European Commission, 2018b).

Another legislation from the EU is the Clean Vehicle Directive (CVD). CVD is a directive designed to promote clean and energy-efficient road transport in procurement processes. Minimum procurement targets for every vehicle category and each Member State have been set by the directive to achieve an increased amount of clean vehicles (GRZYB, 2019), (European Commission, 2019b).

The targets that CVD entails are handled regionally in each country. Leif Magnusson, public transportation and infrastructure at region Västra Götaland (personal communication, April 17, 2019), express that Sweden is ahead in the CVD targets in general, and describes how the region Västra Götaland works with the targets. He explains how the region Västra Götaland tries to stay ahead of the legislation by putting pressure on companies in green public procurement processes. However, he points out the importance of not pushing too far or setting too daunting targets due to the imminent risk of not getting anything done. Instead, VGR often lean on up-coming legislation from the EU or the Swedish government as these are easier to justify (L. Magnusson, personal communication, April 17, 2019).

In a document from the European Parliament, the possibility to extend the CVD legislation to cover environmental effects from all stages of a product's life and not just tailpipe emissions is being investigated with deadline in 2022 (Erbach, 2018). Leif Magnusson (personal communication, April 17, 2019), describes that as long as the fossil-based fuel is what is the most commonly used in the public transportation sector, there is not much need for life cycle assessments as the use-phase contributes to a substantial share of the total CO_2 emissions. However, there has been a shift from fossil-based fuel to fuel that entails lower levels of CO_2; now 93 % of all bus traffic in the region of Västra Götaland is driven on fuel with low CO_2 emissions. This increase in what Leif described as "sustainable fuels" highlights the growing need to know the environmental impact associated with the rest of the life cycle phases since the impact from the use-phase is reduced.

The public transport agency (PTA) in the region of Västra Götaland, Västtrafik, has a vision of using only fuel with low CO_2 emissions for all the public vehicles in the region (Västtrafik, 2018). Today, 96 % of the public vehicles in the region have this kind of low CO_2 fuel (Västtrafik, 2018). This vision is also visible in the procurement for public transport; Västtrafik has long-term goals on low CO_2 fuel alternatives, energy efficiency and noise reduction, and are actively only dealing with companies who meet their targets. Moreover, Västtrafik sees a long-term need for more electricity driven vehicles as a result of the more stringent fuel regulation in Sweden. This regulation, called Reduktionsplikten, started in 2018 and aims at promoting biofuels by making it mandatory for fuel suppliers to reduce greenhouse gas emissions from diesel and petrol with a certain percentage each year (Energimyndigheten, 2018). Based on this has Västtrafik identified a possible shortage of biofuel in the future, and is thus focusing on electricity instead. Overall is Västtrafik aiming at reducing their CO_2 emissions per person-kilometre by 80 % from 2006 to 2020 (Västtrafik, 2018).

The region of Västra Götaland has, together with Västtrafik, conducted an environmental and climate strategy document for future public transport solutions in Västra Götaland (Magnusson et al., 2018). This strategy document is influenced by the CVD from the EU, as well as UN's and Sweden's environmental targets among other documents. The overall goal is to create a long-term sustainable transport sector in Västra Götaland by setting ambitious goals. For example, the climate goal is to decrease the emissions of fossil CO_2 per person*km with 80 % until 2020 compared to emission-levels 2006. Until 2035 is the targeted decrease 90 % compared to 2006. Differences geographically give different prerequisites to reach the goals, and this is considered. Hanna Björk, sustainability strategy manager at Västtrafik (personal communication, April 26, 2019), states that they already have reached a 70 % decrease in emissions compared to 2006 levels, but that this number will not decrease much more without considerable electrification of the vehicle fleet. Hanna explains that they strive to have approximately half the bus fleet in Gothenburg electrified by 2035, and the rest is running on bio-based fuels with a robust environmental profile. The electrification is mainly meant for the city-areas, while the regional buses outside of Gothenburg are most likely going to be driven on different kinds of biofuels.

In line with an increased number of electric vehicles is there a need to put requirements of the impacts associated with the manufacturing of the batteries, according to Hanna Björk (personal communication, April 26, 2019). She describes that possible first criteria on LCA in public procurement will be on batteries and hazardous chemicals. For the battery case, it is debated whether the use of scarce resources in batteries is sustainable in the long run (Transport & Environment, 2017). Energy use and greenhouse gas emission from battery production are additional environmental factors that a battery entails (Romare and Dahllöf, 2017). All of these impacts boil down to the questions of how often batteries must be changed, and how high their recyclability rates are (Transport & Environment, 2017). Both which are essential to consider and monitor in the future if Sweden is to have a genuinely sustainable vehicle fleet (Transport & Environment, 2017). Leif Magnusson (personal communication, April 17, 2019), also mentions that there are studies currently being made in the regions of Stockholm and Skåne in Sweden where the possibility of introducing LCA on batteries into public procurement is being investigated. The result from these studies is likely going to be used by VGR and Västtrafik in the future.

Leif highlights the need for some standardised way of conducting LCAs on buses as well as third-party verification that can be used in the public procurement process to ensure that demands are met and to increase transparency in the process. There is no such framework currently in use; however, Leif mentions the EPD framework as a possibility to use as a foundation. If this kind of framework is to be implemented, there must exist a reasonable way for the PTAs to verify the quality of an LCA.

4.2 Life cycle assessment results

To meet the possible future requirements, Volvo Buses has the ambition to make the process of conducting an LCA smoother. This entails both the data gathering process, as well as identifying environmental hotspots to focus on. The data gathering, and the entire LCA, was made by following Volvo Buses' internal guidelines. The data gathering procedure was the most time-consuming out of all the steps in the LCA. This was due to the complexity of a bus and the amount of data that had to be collected manually.

To identify environmental hotspots, a life cycle impact assessment of the gathered data was done. The chosen impact categories were based on the investigation of commonly occurring requests from Volvo's clients, a public transport green public procurement document, and commonly used LCA standards. This decision is explained more thoroughly in section 4.1.1.1.

The use-phase of the bus was divided into two cases; one for when the bus was driven with diesel B7 which is a common fuel-type in large parts of Sweden and Europe, and one case with HVO as fuel. HVO is more commonly used in Västra Götaland as a result of their ambitious green public procurement in recent years. Data used to calculate both use-phases can be seen in Appendix A.2. Figure 4.1 shows how the CO_2 eq. emissions (expressed in Global Warming Potential, GWP100) during the use-phase changes for the bus depending on which of the two different fuel types are used. Thus, the two green bars represent two different fuel-type cases. It can be seen that the emissions from B7 diesel are approximately five times larger than the WTW emissions from 100 % HVO fuel. However, note that the use-phase is predominantly larger than the other phases in the life cycle regardless which one of the two fuel types that are used. For B7 diesel, the use-phase contributes to 96 % of the total life cycle emissions, and in the case with HVO fuel, it contributes to 83 %. The reason for this is the well-to-tank emissions of HVO production that causes it to have a fairly high CO_2 emissions since the tank-to-wheel (TTW) phase of HVO is free of fossil carbon.

Since the use-phase in itself is something that bus manufacturing companies cannot affect to any great extent, it is relevant to look in more detail on the material production and manufacturing. Global warming potential in CO_2 eq for the production of materials, manufacturing of components, the internal manufacturing at Volvo and the end-of-life scenario is presented in Figure 4.2. Note here how large raw material production is compared to both manufacturing phases. A more detailed view of material usage and end-of-life, a third graph is illustrated in Figure 4.3. Here the total (material production minus end-of-life) is calculated to account for the credit that is given when a material is recycled, and virgin material is avoided in the material production. An overview of the most common materials, according to weight, is illustrated in the pie chart in Figure 4.4. It shows that aluminium and steel are the two most commonly occurring materials in the bus body. Results for the remaining impact categories can be found in Appendix A.3.

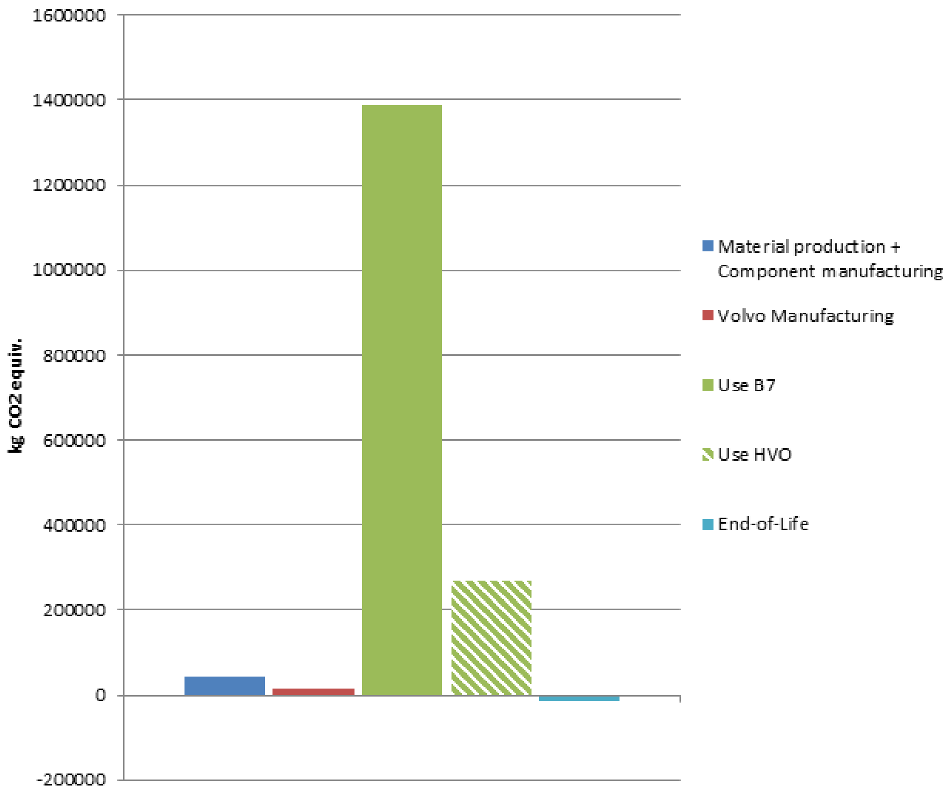

Figure 4.1: Global Warming potential (GWP100) for the whole bus with the two cases for fuel: B7 diesel and HVO. Here it is possible to see that even with HVO as fuel, the use-phase dominates the total CO_2eq emissions of the life cycle.

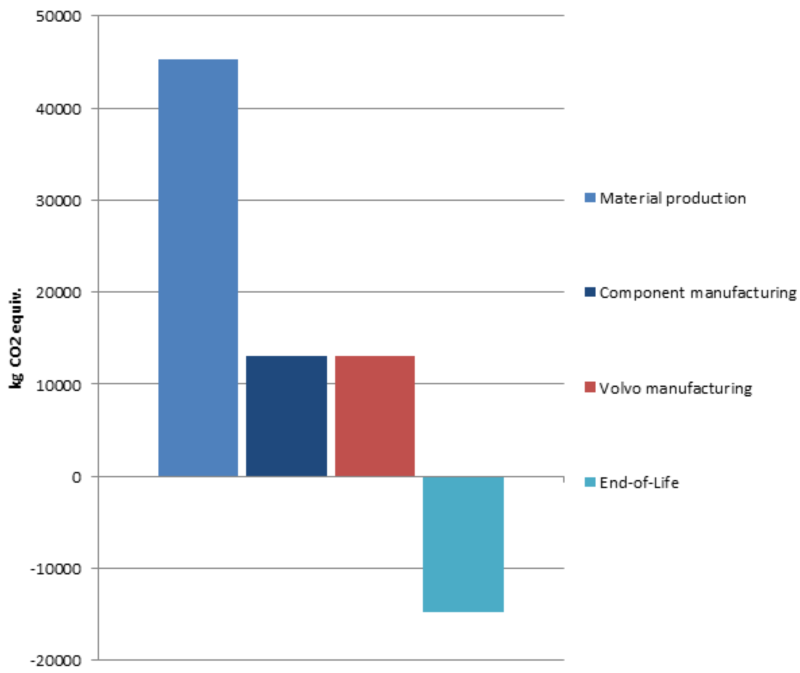

Figure 4.2: Global Warming potential (GWP100) for the life cycle of the bus, excluding use-phase. Noe that both the material production and the component manufacturing are external processes. When use-phase is ignored, the material production step results in the largest amounts of CO_2 eq.

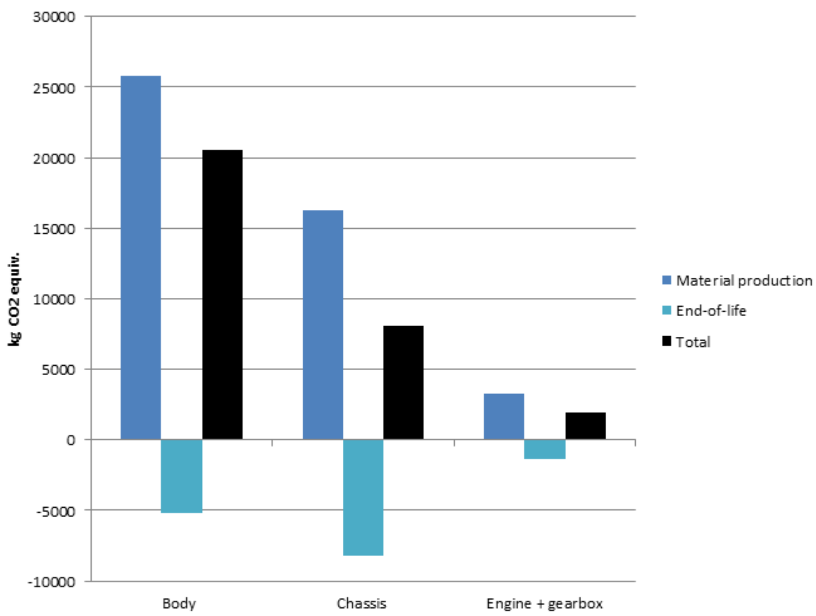

Figure 4.3: Global Warming potential (GWP100) for all materials in body, chassis, engine and gearbox. Here the total emissions (material production minus end-of-life) is calculated to account for the credit that is given when a material is recycled, and virgin material is avoided in the material production.

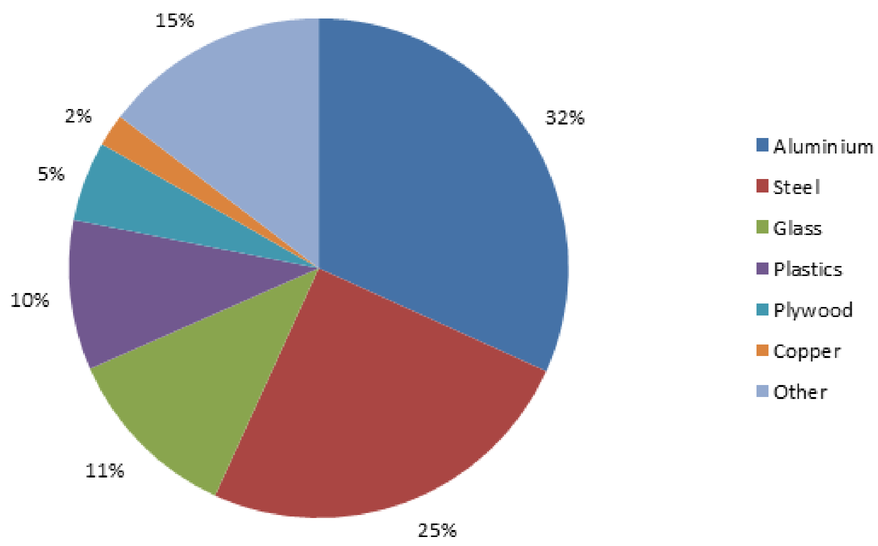

Figure 4.4: Material composition of the bus body according to weight. Steel and aluminium are the two most commonly used materials.

5 Analysis

5.1 Life cycle assessment

The primary purpose of conducting the LCA was to determine areas of improvement in the LCA procedure at Volvo Buses, as well as trying to identify which phases in the bus's life cycle that causes the largest emissions. The LCA was done in accordance with Volvo Buses internal LCA guideline. In this section, the necessary assumptions made during the LCA are discussed to identify which assumptions can be justified depending on the goal of the LCA.

In the data collection step of the LCA, approximately 95 % of the data in weight was mapped to its associated material. Within the scope of the study, the last 5 % is deemed not to affect the results. If, on the other hand, the goal of the LCA was to be used in external communication, then the last remaining percentages could be relevant to focus on. However, in order to successfully collect and map all the data, considerable time would be required, time which could reasonably be spent elsewhere in the study. Furthermore, whether these last percentages were important would also depend on what impact categories were focused on. For example, while scarce resources are often used in small amounts, they typically have significant impacts. Thus, if the focus is on scarce resources, the last percentages might be relevant. On the other hand, if the focus is on climate change, a few kilograms would not make a difference on a five-tonne bus body.

When modelling the external component manufacturing, the internal manufacturing data from Volvo plants and the internal and external transportation are used as an estimation. It is worth questioning whether the assumption is a reasonable one to make in order to compensate for the lack of data from external tier-one suppliers. It is possible, and perhaps even likely, that the plants have improved their production since this became standard procedure. If that is the case, it would not be visible in the LCA results. Moreover, it is increasingly common to buy "clean" electricity, in other words, electricity with little or no carbon emissions associated with the production. Still, to investigate what the reality looks like at all the different external production plants would probably not be feasible at the moment due to the large amounts of suppliers involved in a product. Even if it was done, it is not guaranteed that the results would differ significantly from what is used today. Moreover, the environmental impact caused by the manufacturing phase, both external and internal, corresponds to a relatively small part of all emissions caused during the bus's life cycle, see Figure 4.2 in section 4.2.

5.2 Future requirements in public procurement

As have been described throughout the study, and in more detail in section 4.1.2; Volvo Buses, and similar companies active in the public sector, are increasingly getting more complex environmental requests from clients. Volvo Buses are currently meeting their client's requests for chemicals and substances, as well as carbon footprint and LCAs successfully. To be able to produce LCAs on buses is far ahead of what is currently required by the law and various regulations, and that in itself might show Volvo Buses' ambition-level in these matters. Despite it not being mandatory by the law, Volvo Buses can meet these type of environmental demands. This level of ambition is also reflected in the market that Volvo Buses operates in; the public sector is moving fast towards a sustainable future with agencies such as the Region Västra Götaland (VGR) and Västtrafik wanting to stay ahead of the law. Not only is it in the interest of these agencies to keep up with the law, but they are also directly affected by it. For example, VGR usually refers to upcoming laws when creating their strategy as this makes the strategy more viable (Leif Magnusson, personal communication, April 17, 2019). On the other hand, if VGR is too demanding, there is a certain risk that the targets will not be reached at all, and the companies shy away from responsibility.

The region Västra Götaland and the public transport agency (PTA), Västtrafik, are both open and transparent with their future ideas and strategies to ensure that the criteria are achievable for the various bus manufacturing companies. Volvo Buses, in turn, gets the possibility to keep track of upcoming regulations that might affect public procurement but also gets to influence the direction of the strategies somewhat. This communication creates a synergy that benefits all parties and is identified as a crucial building block in how Volvo Buses should handle future requirements. That is, to stay in "the loop" and be updated on where the world around them is heading.

The regions of Stockholm and Skåne are investigating the possibility of having LCAs on batteries as criteria for public transport vehicles. As the entire bus fleet is moving towards electrification, especially in Gothenburg and Sweden, it becomes increasingly relevant to consider the manufacturing of large batteries. Since the battery pack in electric vehicles is a significant component that is not present in conventional buses, it is relevant to consider the added impact from the manufacturing of these. The battery pack can, thus, be considered an environmental hot-spot that is worth investigating in more detail. The importance of other life cycle phases is further confirmed when looking at the conducted LCA in this study: in Figure 4.1 it is possible to see how the material production becomes increasingly important when the fuel entails less CO_2 emissions.

In the case with B7 diesel as fuel, the use-phase represents 96 % of the total life cycle CO_2 emissions of the bus. However, the fuel B7 diesel is not commonly used in region Västra Götaland for public transportation, and this case might thus be regarded as more representative of a European market. It can also explain why LCA on material production and manufacturing has not been considered to be used in procurement processes before; the other phases of the life cycle is negligible when the use-phase has such a significant impact. It is very likely that it has not been relevant, or even passable, to claim that an entire LCA is necessary to do when a single fuel consumption number would have been sufficient when diesel such as B7 was the standard.

The HVO fuel has a lower climate change impact compared to conventional diesel due to its biogenic carbon content. In this case, the use-phase represents approximately 83 % of the total life cycle emissions of CO_2 for the bus, see Figure 4.2. While this still represents a large percentage of the entire life cycle, the actual emissions from the use-phase are significantly smaller than in the B7 case. However, in both of these cases, the use-phase is dominating the life cycle emissions of CO_2. The used HVO has relatively low CO_2 emissions per MJ since it was produced from residue waste. Börjesson et al. (2013) reported that there are HVO with as low as 5g CO_2 emissions per MJ, which would be an improvement by approximately 64 %. Using this type of HVO would have lowered the impact of the use-phase further, and thus, making other phases of a bus's life more relevant to investigate. Nordelöf et al. (2017) pointed out, it is possible to see that for an electric bus, the use-phase is significantly smaller than for other fuels. This is especially true if the electricity is the average Swedish electricity mix or when it comes solely from wind power, which was used in the study by Nordelöf et al. (2017). In the cases with clean electricity mix, the material production phase is dominating the CO_2 emissions. Thus, when the impact of the use-phase is moving towards a lower value, the other phases in the life cycle becomes more relevant, and it cannot be justified to be negligible in procurement processes any longer.

If results from LCAs on batteries are to become criteria in public procurement processes, there is a need for a common framework to ensure comparability and quality. At present, there exists no such framework that is widely used. Leif Magnusson at VGR expressed a need for such a framework that could be third-party verified. As it is not up to the region Västra Götaland to create such a framework, is it likely that an already existing framework will be used as a foundation if LCA becomes mandatory in GPP. For example, does Leif mention that EPD, or a version of it, could be utilised in the future to fill this need. However, the EPD is nowhere near being the industry standard even though it would, in both theory and practice, be possible to perform one on such a complex product.

5.3 Volvo and the future of public procurement

To conduct an LCA is, as has been seen in this study, a time-consuming activity due to the large amounts of data that had to be collected manually. However, the LCA conducted in this study is a thorough LCA of the bus body. It can, therefore, be argued that meeting criteria in LCA frameworks, such as EPD, would be possible for Volvo Buses. According to the findings of this study, it is not the lack of data or knowledge per se that is the issue, but rather an improved structure behind the LCA process at Volvo Buses that is needed. If an improved structure were established to support a more efficient LCA procedure, the overall time would likely decrease drastically as the most time-consuming parts were to match components with substances as well as finding the correct data.

The briefly introduced LCM theory, section 2.2, can offer ideas on how to successfully deal with the necessary structural improvements for LCAs at Volvo Buses. Primarily does LCM emphasise the value of considering the integration of activities across an organisation; both horizontal across functions, but also vertically, so that top management gives enough resources and support. For example, might the various environmental requests from clients function as a foundation for future LCA work within Volvo Buses. Requirements that are common today, such as a list of dangerous chemicals will entail a certain level of work to identify the chemical-list and contact suppliers. In this activity, there could be great opportunities to harvest knowledge and outline an environmental process. While, for example, a list of substances might not be the end-results of an LCA, it is an essential component in the environmental knowledge collection. Thus, an idea is to create a continuous flow of knowledge by combining the activity of meeting client's demands with an LCA process that spans over several operations.

An important factor in order to have a successful LCM adaptation is to make sure people feel responsible for the success and the outcome of the environmental work. For example, to engage the marketing unit to a higher degree than today is deemed important. The various environmental requests from clients are typically received at this unit, and thus, if this is communicated earlier to the LCA practitioner, the lead time can be reduced significantly. In light of the idea of increased communication between operations, there is an interesting opportunity for Volvo to extend their environmental work further down the supply chain. As can be seen in Figure 4.2, the total external production emissions is significantly higher than the emissions for internal manufacturing. The material production data is the highest. To set increasingly ambitious goals for their suppliers, as a response to the growing social public pressure, would be an appropriate way to ensure increased sustainability externally to the company as well. This would then both make the emissions from the entire life cycle of the bus lower, but also establish frequent contact with suppliers and smoother data-collection.

The risk of not being able to perform fast-paced and efficient LCAs when it is demanded in procurement processes is a possibility, as a failure to deliver could cost Volvo Buses the entire tender. Thus, to make the structure behind the LCA process more agile and efficient is recommended. The LCA process can, for example, be made modular by using pre-existing LCAs on separate components which can easily be assembled into a specific bus model.

6

Concluding discussion

6.1 The road ahead

The public transport sector in Sweden is moving fast towards a sustainable future with agencies such as the Region Västra Götaland and Västtrafik wanting to stay ahead of the law. Both the EU and public transport agencies in Sweden are investigating the possibility to incorporate life cycle assessments in public procurement for heavy-duty vehicles and buses in the future. The agencies in Sweden are looking into batteries specifically, while the EU has a focus on the entire vehicle. That said, based on the conducted LCA in this study, it is clear that as long as the fuel is non-renewable, the rest of the life cycle has close to negligible CO_2 impact. In these cases, it is not adding any value in the public procurement process to demand an LCA on an entire vehicle. However, there is a will for incorporating LCA in public procurement processes with agencies such as Västtrafik and VGR stating that electrification and LCA on batteries are the future. The findings of this study show that LCA becomes increasingly relevant when the fuel used in public transportation move towards renewable sources and lower CO_2 emissions, both on batteries in electric buses as well as on entire vehicles.

This thesis shows that, despite it being time-consuming to create an LCA for a complex product, such as a bus, it is entirely possible. However, in order to meet the requirements of tomorrow, Volvo Buses needs to continue to improve the LCA procedure in an integrating manner. The focus should partly be on how to make the data-collection step more efficient for the LCA practitioner. This includes improvements on coverage of substance information, which reduces the need for assumptions and could make the data more reliable. However, in order to increase efficiency and reduce the needed resources when conducting an LCA, an improved structural framework surrounding the LCA is necessary. This would be a structure that allowed the LCA to be increasingly fast-paced and agile. Today, to create an LCA is a time-consuming process that needs to be started each time a request is made. The LCA process could instead be divided into modules which contained already-made LCAs on individual components. This way, when a request for a particular bus model is made, Volvo Buses can assemble one based on the modules. In line with this, the focus should also be on the integration of life cycle management deeper into the organisation. By including other operations within and externally to the organisation, a more fast-paced and efficient process can be established. With an agile and fast-paced LCA process combined with the extensive knowledge that already exists, Volvo Buses would be ready to excel in future procurement processes.

6.2 Suggestions for further studies

Some factors need to be further investigated to be able to draw more definite conclusions on where the future of green public procurement is headed. One recommendation is to conduct more studies where the focus is on other regions in Sweden, or perhaps entire countries. It is also endorsed to go deeper into the green public procurement process, and how it influences, and in turn are influenced by, the companies active in the public sector.

To be able to say something in general about how prepared companies are for possible future criteria on LCAs, there is a need to broaden the scope and focus on other companies in the sector. This study can be seen as a sample of how it works at one company. In light of this is it also recommended to investigate further internal LCA procedures in combination with the theory of LCM to gain more understanding of how it can enhance the structure behind LCA. In order to meet the demands from an increasingly ambitious world, companies in general, and especially those active in public procurement, need to incorporate environmental thinking deeper into the organisations, and across operations.

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A

Appendix

A.1 Interview questions

The interview with both VGR and Västtrafik was arranged in a similar way and the conversation was based on, but not limited to, these questions:

- How does green public procurement function in the region today?
- How much influence do [company name] have in the decisions on criteria used in GPP?
- What do [company name] think the future of green public procurement is going to look like? Specifically for buses.
- In light of the investigation on LCA for buses in the EU. Does [company name] think it is relevant, and is this something that [company name] have discussed before within the organisation?
- Is the focus currently on tailpipe emission and fuels? Is there ambition to expand and focus on other phases in the life cycle? Such as material production recycling.
- It is mention in the combined strategy between region Västra Götaland and Västtrafik document that you both are concerned with the production and recycling of batteries in electric vehicles. How is this going to be implemented?

A.2 Use-phase calculation

Use-phase data is presented in table A.1. All data for WTT comes from the ecoinvent database. TTW data for B7 diesel comes from JEC and TTW data for HVO comes from (F3, 2013). All impacts are calculated into potentials using the same LCIA methods that is presented in Table 3.1.

Table A.1: Data that formed the basis for calculations of the WTW emissions during use-phase.

		B7		**HVO**	
Impact category	**Unit per litre fuel**	**WTT**	**TTW**	**WTT**	**TTW**
GWP100	kg CO2 equiv.	0,81800	2,08000	0,79244	0
AP	kg SO2 equiv.	0,00278	0,00139	0,00095	0,00014
EP	kg PO4 equiv.	0,00060	0,00026	0,00025	0,00003
POCP	kg NMVOC equiv.	0,00039	0,00340	0,00006	0,00157

A.3 Life cycle impact results

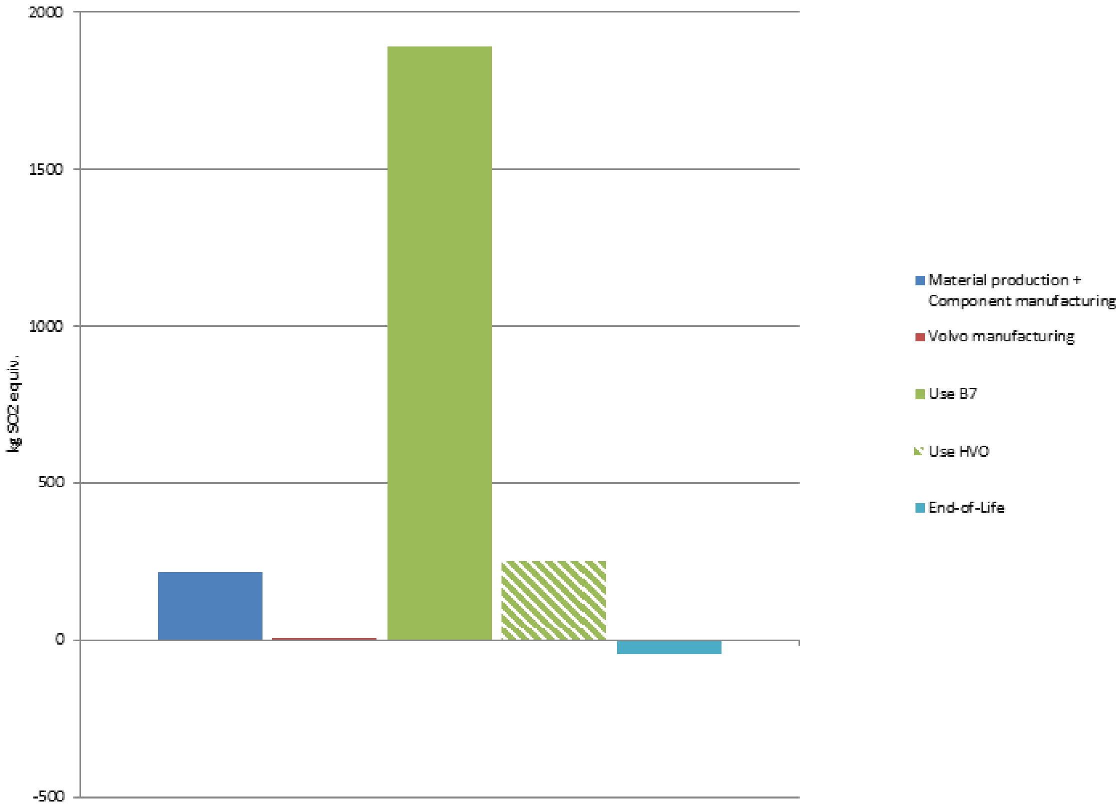

Figure A.1: Acidification potential for the whole bus with the two cases: B7 diesel and HVO. The emissions from HVO during use is nearly equal to the emissions caused in the material production phase.

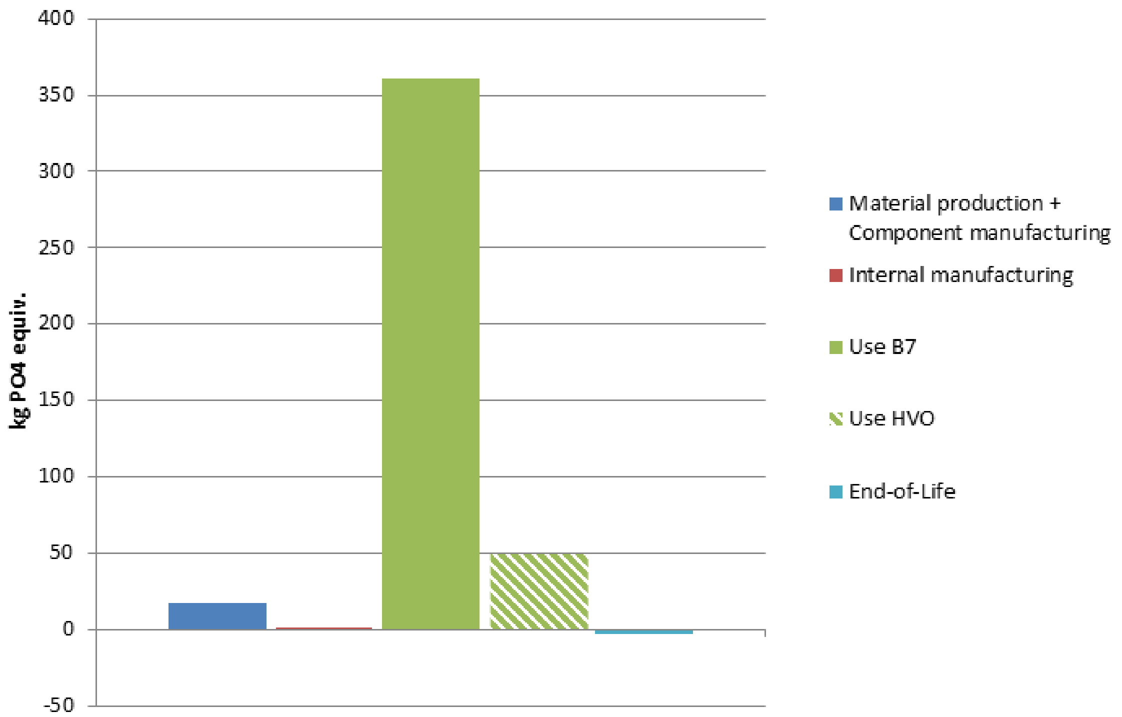

Figure A.2: Eutrophication potential for the whole bus with the two cases: B7 diesel and HVO. Both use-phases stand for a big proportion of the life cycle emissions.

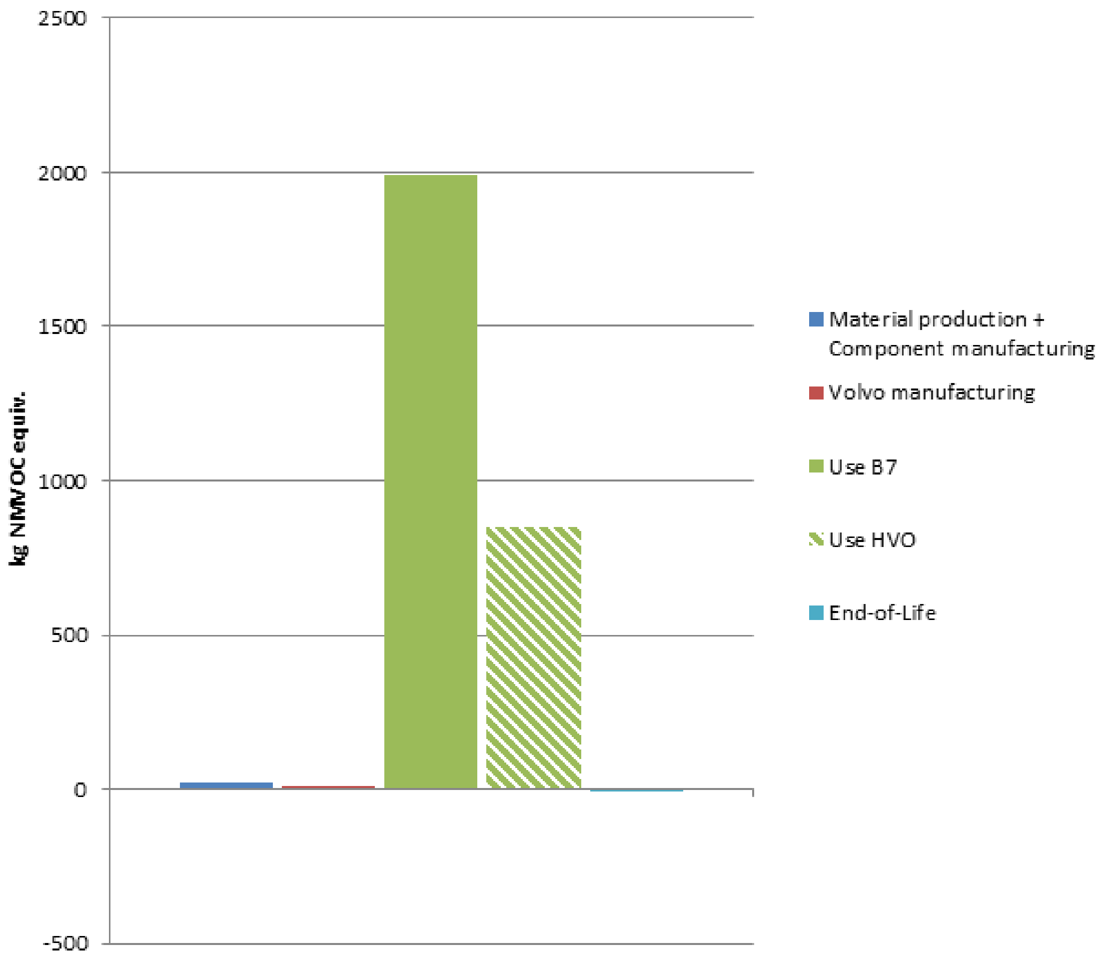

Figure A.3: Photocemical ozone creation potential for the whole bus with the two cases: B7 diesel and HVO. Both use-phases stands for a significant proportion of the life cycle emissions due to the emissions of NMVOC related to combustion.