CHALMERS

Life cycle assessment of chainsaws

A case study of two Husqvarna products with different power systems

Master of Science Thesis in Environmental Measurements and Assessments and Industrial Ecology, for a Sustainable Society

ANNA RÚNA KRISTINSDÓTTIR
DIEGO FERNANDO PEÑALOZA CORREDOR

Division of Environmental Systems Analysis
Department of Energy and Environment
CHALMERS UNIVERSITY OF TECHNOLOGY
Göteborg, Sweden 2011
ESA Report No. 2011:9

Thesis in Environmental Measurements and Assessments and Industrial Ecology
REPORT NO. 2011:9

Life cycle assessment of chainsaws

A case study of two Husqvarna products with different power systems

ANNA RÚNA KRISTINSDÓTTIR
DIEGO FERNANDO PEÑALOZA CORREDOR

Division of Environmental Systems Analysis
Department of Energy and Environment
CHALMERS UNIVERSITY OF TECHNOLOGY
Göteborg, Sweden 2011

Life Cycle Assessment of Chainsaws
A case study of two Husqvarna products with different power systems

ANNA RÚNA KRISTINSDÓTTIR*
DIEGO FERNANDO PEÑALOZA CORREDOR†

With support from Husqvarna AB

ESA Report No. 2011:9
ISSN: 1404-8167

Division of Environmental Systems Analysis
Department of Energy and Environment
CHALMERS UNIVERSITY OF TECHNOLOGY
SE-412 96 Göteborg
Sweden

Telephone: +46 (0) 31-772 1000

*Contact author 1: annankrist@gmail.com
†Contact author 2: godiepeco@hotmail.com

Chalmers Reproservice, Göteborg, 2011

ABSTRACT

The environmental benefits of using batteries as an alternative power system in combustion driven consumer goods is a subject of interest in the quest for a more sustainable society. Producers are also on increasing scale looking for possibilities to reduce the environmental impacts of their products and studying their life cycle and assess the impacts is a very helpful tool for more sustanable innovation. This study was conducted for Husqvarna AB who is interested in learning about the life cycle and environmental impacts of two professional top handle chainsaw models. They have very similar function but different power systems; a gasoline driven two-stroke internal combustion engine and an electric motor with a Lithium-ion battery. A Life Cycle Assessment was used to model the two product's systems, and ready-made LCIA methods were used to compare the products in terms of the chosen functional unit, square meters of cut Swedish wood. The results showed dominance by the use phase for both products, with lubricating oil production and electricity or fuel production as the processes that contribute the most to the total environmental impacts. The results proved to be sensitive to reductions in the amount of energy and lubricating oil inputs for the use phase, as well as changes in the use phase energy systems. After applying the EDIP, EI99 and EPS 2000 weighting methods, the battery powered model had lower environmental impact single score for all cases. These results, the assessment method, focus points of improvement and suggestions for implementing life cycle thinking in the company are discussed in this report.

REPORT OUTLINE

As the results of the inventory analysis and the impact assessment are rather extensive, they will be presented as an appendix, where the reader can look for further details about the specific calculations and assumptions, the data obtained and the specific results of the study. The report itself will provide an introduction to the project, description of the execution as well as discussions on the analysis and interpretation of results. The introduction chapter covers the relevant background information regarding the products, the company and the objectives of this study, as well as a short introduction to the LCA methodology and its applications in product development. In the method and execution chapter the goal and scope of the study will be established, defining the system boundaries. Also the selection of impact assessment methods and the strategy for data collection will be explained. In the result chapter the main outcomes of the study will be analysed and interpreted, additional scenarios are modelled for sensitivity analysis and the products compared. Finally, in the conclusions chapter, the findings of the study will be discussed with regard to the project objectives, the lessons learned and further work will be discussed as well.

ABBREVATIONS AND CLARIFICATIONS

Husqvarna	The company, commissioner of the study
Huskvarna	Location of on-site facilities for Husqvarna
LCA	Life Cycle Assessment
T540XP	Petrol powered chainsaw model name
LCI	Life Cycle Inventory
LCIA	Life Cycle Impact Assessment
EDIP	Environmental Design of Industrial Products (weighting method)
EI99	Eco Indicator 99 (weighting method)
EPS 2000	Environmental Priority Strategies in product design (weighting method)
REACH	Registration, Evaluation, Authorisation and Restriction of Chemicals (Directive)
US	United States
EU	European Union
ISO	International Standard Organisation
R&D	Research and Development
POM	Polyoxymethylene
PBT	Polybutylene Terephthalate
PET	Polyethlyene Terephthalate
PE	Polyethylene
PP	Polypropylene
PVC	Polyvinylchloride
PCB	Printed Circuit Boards, same as printed wiring boards
PWB	Printed Wiring Board, same as printed circuit boards
USLCI	United States Life Cycle Inventory (database)
EcoInvent	Inventory database
GWP	Global Warming Potential
EP	Eutrophication Potential
AP	Acidification Potential
BOM	Bill Of Materials

TABLE OF CONTENT

1. INTRODUCTION

In this introductory chapter, relevant information that the project is based on and influenced by will be presented. In order to give relevance and base for the main drivers behind the project a brief background about the commissioner will be described, the products involved will be introduced as well as previous similar studies performed for the company. Also, the LCA methodology in relevance for its application in this study will be presented.

1.1. Husqvarna

Husqvarna is the world´s largest manufacturer of outdoor and garden tools such as chainsaws, trimmers, lawnmowers and garden tractors, and is leading in Europe in irrigation products under the brand Gardena. It has facilities all around the world, but originally comes from Huskvarna, a small town outside the city of Jönköping in Sweden where it still has a manufacturing site. Husqvarna is also one of the leaders on the global market for equipment and diamond tools for the construction and stonework industries. Husqvarna actively strives at developing innovative products in, among other things, motor technology. To obtain a deeper knowledge of the environmental loads and impacts that various motor technologies have on the environment, Husqvarna started an initiative to use Life Cycle Analysis (LCA) for products containing these technologies.

The company commissioned this project as a master thesis, written by two students at Chalmers University of Technology in collaboration with the company engineers. The company required a LCA for a certain product, a top handle chainsaw. This product has two relatively new models with different power systems, and the environmental profile of these two models is the object of this study. Their interest is to compare the models, but also learn about environmental impacts of their products.

1.2. Objectives and desired outcomes

According to the company's first requirements on the project, the studies main objectives are:

- A life cycle analyses for products with different motors and energy supply.
- An analysis of which processes or phases in the products life cycle contribute to the largest environmental impacts.
- Suggestions for measures to reduce the products' environmental impacts.
- Suggestions for how Husqvarna can better integrate life cycle analyses in its development work.

After initial meetings with the head of environmental affairs, some additional expectations from the company were manifested, as they expressed their request that the results were presented in a way that they were accessible for non-experts in LCA field and could easily be communicated within the company. They also expressed their special interest for impact categories such as global warming potential and toxicity as those have been their main target categories of improvement for their products and are dealt with on a corporate level. '

1.3. The Products

The products included in this study are both top-handle chainsaws made for trimming of trees by professional gardeners. These kinds of saws are designed to combine good performances with exceptional ergonomic conditions (Husqvarna AB, 2011f). The main difference between the two products is the power system, one of them being petrol-powered with an internal combustion engine and the other with a lithium-ion battery and an electric motor.

The T540XP is a new improved model of a petrol-powered chainsaw. XP stands for a newly designed motor system that has the potential of reducing fuel consumption by up to 20% and harmful exhaust emissions up to 60% compared with previous models (Husqvarna AB, 2011f). It will be manufactured in Sweden, and marketed mainly in Europe and the United States. Currently south of Europe is the largest market for this kind of product and is expected to be for the foreseeable future (Husqvarna AB, 2011f).

The battery-powered chainsaw is a new product in the Husqvarna collection. The market will probably be the same as for the T540 XP chainsaw. The main intended benefits of this product are reduced health risk for the user by greatly limiting exposure to emissions as well as reduced noise and overall better environmental performance (Husqvarna AB, 2011d).

The products are both obliged to compliance with the existing environmental regulations, with regard to chemical content and emissions, REACH directive (EC 1907/2006) and general exhaust regulations (Husqvarna AB, 2011e).

1.4. Previous LCA Studies for Husqvarna

Husqvarna has recently performed a life cycle assessment on another product in their collection. It was a master thesis conducted in 2010, where two different lawnmower models were studied and compared. One of the products was a conventional petrol-driven walk behind lawnmower that is controlled manually while the other one was battery driven and automotive, meaning it could be programmed to work without manual control. The study was carried out mainly for learning purposes and secondarily for comparison purposes (Lan, X., & Liu, Y. 2010).

The results of the study indicated that the use phase was the dominant stage of the life cycle for both products, and that the electricity production composition has relatively large influence on the results of the study. The results identified the potential of increased share of recycled metals in the production phase as an alternative to reduce the environmental impact of the products (Lan, X., & Liu, Y. 2010). Furthermore the experience of this study showed that the main results were somewhat predictable but the LCA work and results need to be adapted better for communication within the company to increase opportunities for learning and use. That would help to increase the value of the LCA work for Husqvarna.

1.5. About Life Cycle Assessment

The main objective of LCA studies is to assess environmental aspects and potential impacts of a service or product and support decision-making with regard to environmental issues. This is often a very complex task and in order to enhance the credibility of the results it needs to be done in manner that is transparent and enables fair comparison of results. The LCA methodology provides a set of tools for the assessment and a framework for the studies procedure. The methodology in general, especially the ready-made impact methods and theory for application of LCA in various contexts is in constant development and will be discussed shortly in the next section. The LCA framework though is well established and is supported with international standards, ISO 14040 (1997) and subsequent, guidelines and extensive literature within the field. For an overview of the LCA methodology, the book "The Hitch Hikers guide to LCA" can be used (Baumann & Tillman, 2004), and Finnveden et al. (2009) provides a brief on recent developments in the field. The LCA framework is extensive in the way that it includes all stages of the product's life cycle but is still flexible enough to make methodological choices suiting the intended purpose and communication of results, so long as transparency is maintained. In the following subsections the theoretical background for each step in the framework will be briefly introduced. The main procedures and steps of the LCA framework can be illustrated as in Figure 1.

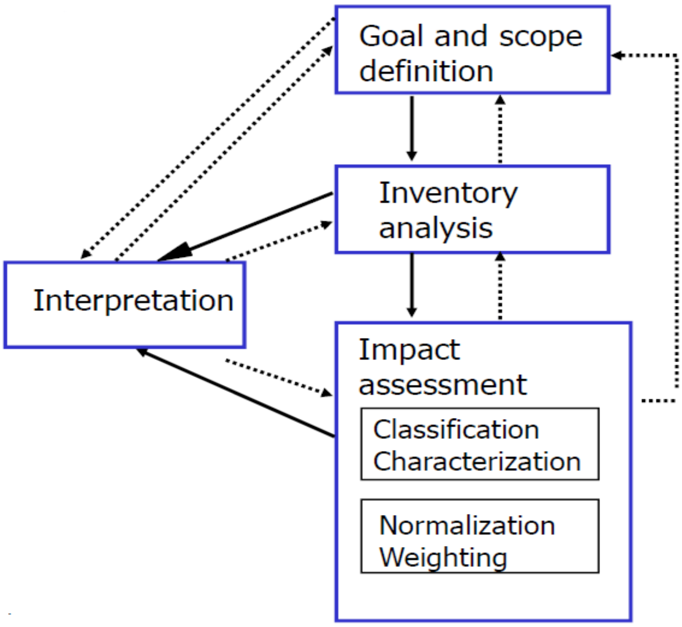

Figure 1 The LCA framework (Baumann & Tillman 2004:20) and also consistent with ISO 14040.

The first stage is the goal and scope definition, where fundamental methodological choices are made according to the purpose of the study. The next step is the inventory analysis, where the data from processes and activities in the product's life cycle is gathered and analysed. This step can be rather time consuming, so the impact assessment is often performed in parallel. Finally, the results are interpreted so major contributors and improvement alternatives can be identified. Also, sensitivity analysis is to be performed to assess the reliability of the study. The whole process is then iterative as findings on the way can give reason to adjust choices made in previous steps to improve the assessment (ISO 14040, 1997).

1.5.1. Goal and scope definition

In this step the stage is set for the project. That includes describing the projects' context and defining its aim and boundaries. It should be made clear what is to be studied, for what reason, application and for whom. The challenge is to formulate the goal definitions specifically enough to be able to be consistent in methodological choices made during the project. This step also includes definition of the system boundaries of the study and the choice of a functional unit, definition of what terms the results will be communicated. System boundaries include definition of the technical system studied, its time and geographical relevance and the environmental impact considered. The intended level of data detail should also be specified, if the study is performed for a specific site or represents an average for a certain type of system. All these decisions and the set system boundaries influence the project procedure and its results and it is very important for the quality of the project that they are clearly communicated (Baumann & Tillman 2004: 24-29, 73-95).

1.5.2. Inventory analysis - data collection

The inventory analysis is often the most time consuming of the LCA process, as it is the where the product life cycle is modelled and all relevant data for the construction of the model is gathered according to the boundaries and conditions established in the goal and scope definition. The data includes all the environmentally relevant inputs and outputs from each process in the life cycle and flows referenced to the functional unit. In this stage, challenges such as data quality, allocation of flows between products and recycling loops need to be addressed (Baumann & Tillman 2004: 25-29, 97-128).

1.5.3. Impact assessment - methods

Impact assessment consists of the mandatory elements: classification and characterization to defined categories, as well the optional elements: normalization and weighting (ISO 14042, 2000). Classification sorts the inventory data for resources use and output from all included processes according to their contribution to environmental impact categories. Characterization includes the quantification of the contribution to each environmental impact and translation to an equivalent unit. While the impact assessment for emissions is mainly based on the same scientific background and environmental principles the way of expressing the results differs between life cycle impact assessment methods (LCIA), meaning that the choice of impact categories and equivalent units differs between LCIA methods based on their intended use and purpose. The ISO standard recommends certain impact categories to be included at minimum for a holistic overview of environmental impacts (ISO 14040, 1997), as listed in Table 2. The ISO standard suggests three headlines for environmental impact assessment: resource use, ecological consequences and human health (ISO 14042, 2000). These headlines are not very specific, so a ready-made LCIA method can be used in order to use more specific impact categories that can be interpreted into units and numbers. According to the commissioners' needs and the studies purpose, they can also be limited or a focus given to certain impact categories more than others. Most of the LCIA methods also include the following optional steps, normalization and weighting of results. Those steps involve aggregation of the results, first normalising towards a common measure for each category and them weighing of the categories with a score to a single scale which enables the calculation of a single score for the total environmental impacts. Weighting of impact categories needs to be done with caution as they assign a value for the importance of each impact toward the other and one needs to be aware of what perspective and relevance that value is based. Results from different weighting methods cannot be compared and can give very different results though applied to the same system. One of the main differences between the ready-made LCIA methods regards the presentation of the results. In some methods all the assessment steps are executed in one step and only so called endpoint results are presented, including the weighting of expected effects for each category. Whereas other methods have the opportunity of viewing the midpoint results, earlier in the cause-effect chain, representing the objective impact potential for each category (Baumann & Tillman 2004: 29-31, 129-173).

A couple of common impact assessment methods have been designed especially for product development in companies. They are shortly described as follows:

EDIP

The EDIP method (Environmental Design of Industrial Products) was developed by the Institute for Product Development (IPU) at the Technical University of Denmark in 1996 but factors were updated in 2004. The method offers a holistic overview of impact categories and the opportunity to analyse midpoint results, characterization results, before weighting factors are applied. The weighting method is based on the distance-to-target principle and the factors are set the Danish political target emissions per person in the year 2004. It includes a more detailed set of impact categories than recommended by the ISO 14040 standard as illustrated in Table 2. Two categories, ecotoxicity and resource use, are though excluded from the aggregated single score results in the method because politically set targets are not available due to their different characteristics. Instead the resource use is dealt with in a separate section, EDIP resources only, where each resource is expressed in terms of use of pure resource and weighting results based on proven reserves per person in 1994 (PRé consultants 2008).

Eco-indicator 99

Eco-indicator 99 (EI99) is a LCIA method initially designed to be a weighting procedure. It presents endpoint results for a restricted number of categories, based on a damage oriented approach. The weighting factors are derived from a panel that assessed the seriousness of three damage categories: Human health (DALY), Ecosystem quality (loss of species/area, time) and Resources (surplus of energy needed for future extractions). There are three versions of the method based on the main recognised perspectives towards environmental issues and influences the way the damage may be assessed. Eco-indicator 99 (E) is a recommended and commonly used version of the method (PRé consultants, 2008).

EPS 2000

EPS 2000 method (Environmental Priority Strategies in product design) was developed as a tool for a company's internal product development process. It is based on a damage assessment oriented approach using willingness-to-pay "to restore changes in the safe guard subjects" as a monetary measurement for weighting. Five safe guard subjects serve for choice of impact categories: human health, ecosystem production capacity, abiotic stock resource, biodiversity and cultural and recreational value. The method delivers endpoint results, expressed in ELU (environmental load unit), representing the expected damage from the environmental impact, weighted with the willingness-to-pay to restore it (PRé consultants 2008).

1.5.4. Interpretation

Result interpretation and presentation is greatly influenced by the project goals and the study commissioner. The intended audience influences the choice of information of interest, as well as the study goals also determine what results call for being analysed especially. For studies where the main goal is to learn about the product system and find improvement alternatives, dominance analysis is very relevant. If the goal of the study is to compare two or more products or systems, weighted results can be very useful. The level of expertise of the intended audience is another aspect to be taken into account, as for people who are not so familiar with the LCA methodology more aggregated and simple result presentation are preferable (Baumann & Tillman 2004: 175-195).

1.6. LCA application in product development

One of the requests for the project was to include considerations on how the LCA can be better integrated in the commissioners' work and the results easily communicated. In the following section the key aspects and recommendations for LCA application in product development are introduced.

Product development is one of the main applications of LCA. But as Baumann and Tillman (2004: 235-254) argue that it is also a very challenging application of LCA because of how it can be time consuming and requires its practitioners to have a certain competence in interdisciplinary communication. The modern market puts a pressure in companies to come up with new products faster than their competitors, so the product development process should not take much time. This is why a regular LCA can be too extensive for this purpose, and a variation of shorter and limited LCA methodology could instead be applied.

For a successful integration of LCA in the process of product development a key step is that the commissioner begins by defining the environmental requirements and considerations for its own products and operation. Further on, simple environmental goals are developed for the way the products or the company operate with regard to environmental considerations and a simplified methodology for the main principles that are specific for their products and services. For multinational corporations such as Husqvarna this step can be especially challenging as the importance of different environmental impacts can vary for different locations and their suppliers and stakeholders can have very different values and views on what are the most important impacts. Also some environmental considerations might be difficult for the company to influence, for example supporting systems like raw material production processes, electricity production and waste management. There does not exist a global standard for weighting that can be applied within all fields and reported on and therefore it can be difficult for organizations to decide what is important for them and what not. Last but not least these environmental considerations need to be addressed along with other kinds of requirements and criteria set in the current product development process regarding performance, cost and the customers' requests for example. At some points trade-offs will be necessary between environmental improvement and other requirements, but that is a key aspect dealt with in product development even without environmental considerations. To be able to take informed decisions about trade-off that best serve the interest of the company it is recommended that the company develops this simplified methodology based on its own ambition, culture and values (Rebitzer et al, 2004).

It is also important to introduce the relevant knowledge about LCA within the company. There are different possible ways to do this; new members with the necessary skills can be added to the product development team or the current personnel can be trained so they can develop and use the simplified methodology previously mentioned. Anyway, it is important that all the people involved in the product development process familiarises with the life cycle thinking and identifies the simplified methodology adapted to the companies needs and intentions to be able to pass that knowledge and integrate throughout the organization (Rebitzer et al, 2004).

Another key point is that LCA application should be included as early as possible in the product development process. From the conception and marketing analysis of the product the environmental impacts should be considered, as the initial stages of the process allow a wider range of changes with lower economic implications. Modifications in later stages more often involve higher cost, so it is highly recommended that the environmental requirements be taken into account from the very beginning of the product development process (Baumann & Tillman 2004: 236-240).

When applying the LCA methodology, the availability of relevant data is one of the key challenges in the process. As argued by Katsuyuki and Hirao (2011), and as experienced in this study, obtaining this data from suppliers and business partners is often a difficult task, since there are no regulations that require reporting for ecodesign and the lack of economic benefits from data submission. This is why they recommend the additional use of other tools such as Material Flow Cost Analysis, so there are economic incentives for improvements. Rebitzer (2004) also highlights the importance of linking the LCA methodology to economic- and other non-environmental departments.

There are many tools available that can assist in the application of LCA in product development. Ecodesign, matrices and simple software tools that require only some training are some examples. LCA is a very relevant tool, but some additional tools are required to develop this simplified methodology such as reliable databases, manuals, procedures and certain rules of thumb for the product development process regarding the environmental impacts. Some good examples of tools are the MET matrix, LCA software such as Eco-IT or EcoScan, or even a combination of tools (Baumann and Tillman 2004: 242-249).

Husqvarna has not carried out many LCA studies, and has not developed its own methodology to include LCA in the product development process or introduced the knowledge. This is why this study will be carried away with an “ordinary” quantitative LCA methodology, as it is intended to provide the company with a starting basis for further development of this simplified methodology, and give an idea of where to start constructing the environmental requirements for these products mentioned before.

2. METHOD AND EXECUTION

In this section, the methodological choices that we made during the execution of the study will be discussed.

2.1. Goal and scope definition

The goal of the project was to analyse the life cycle of two products with regard to their environmental impact. The LCA also serves as a base for comparison between two product types with inherently different power supply and background energy systems; a traditional gasoline two stroke motors and Lithium-ion battery driven motors. Furthermore, the aim was to contribute to higher level of understanding of environmental impacts from motor equipment and how they can be reduced.

The product under assessment is a top handle chainsaw intended for professional or semi-professional market (Husqvarna AB, 2011a). The two product models considered were:

- T540 XP: model with petrol driven internal combustion engine.
- The battery saw: model with an electrically powered Lithium-ion battery motor.

Figure 2 Image of an internal combustion engine motor like the Top-Handle T540 XP model (Husqvarna, 2011f).

2.1.1. Functional unit

The functional unit is used to link all material flows and environmental impacts to a common denominator. This enables a fair comparison between the products based on the service they provide instead of one product unit. In this study the area of cut wood serves for functional unit, measured to 1000 m^2 of cutting through Swedish soft wood. Standardized tests are used to evaluate the product performance towards the cutting through Swedish soft wood (Husqvarna AB, 2011f). This is a measure suggested by Husqvarna as it is a relevant measure for them. The values used to derive the functional unit are displayed in Table 1. For clarity and communication purposes the impact results are though first presented and analysed for the total lifecycle of one chainsaw (unit) of each product before normalizing towards the functional unit.

Table 1 Values used to derive the functional unit (Husqvarna AB, 2011f). The normalizing factor is used to divide the impact results with regard to the functional unit.

Product	Functional lifetime	Performance (cut soft Swedish wood over the whole lifetime)	Normalizing factor
T540 XP Motorsaw	800h	10 213 m^2	10,2
Battery saw	800h	8000 m^2	8

2.1.2. System boundaries

The study includes the whole life cycle of the chainsaws, from raw material extraction to waste treatment (cradle to grave). A general distinction was made between three life cycle stages for the products: Production, Use phase and End-of- life, as illustrated in Figure 3.

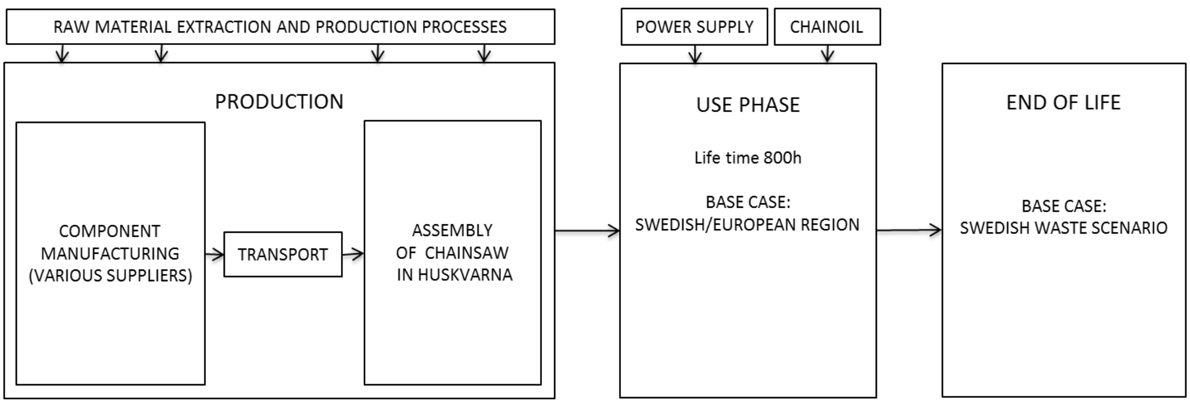

Figure 3 Overview for the general life cycle for the products.

An effort was made to consider impacts from all processes through the life cycle of the chainsaws. However, a special focus was given to processes that are different between the product type production and those who are within the range of influence of Husqvarna. Regarding the recycling processes in the end-use phase, the recycling scenarios modelled do not account for avoided products or credits for primary materials. Therefore, there are no recycling loops.

As one of the intended outcomes of the study was to identify potentials to improve the environmental performance of the products, the following distinction was made among the processes regarding the level of influence that the company has over their environmental impacts. This distinction was taken into account for the improvement suggestions, as the measures taken in processes where the company have higher influence have a better chance of being successful. The categories in this distinction come as follows:

- *Direct Influence*: These are processes that can be directly influenced by company decision-making, and every improvement alternative can be easily implemented. An obvious process is for example the assembly of the product itself. This includes the design, especially when it directly affects the use phase, though the company does not have any absolute control over that. In the use phase, the impact is also influenced by the user's proper and efficient use, whereas in the assembly process background systems like the electricity production can influence the impact as well.

- *Secondary Influence*: The process in this category can't be directly influenced by the company decision-making, but the company may still influence significantly the environmental aspects of these processes. The component manufacturing processes are categorized here, as Husqvarna has the possibility to influence its direct component and transport suppliers with and choose which actors it co-operates with.
- *Low Influence*: Finally, the processes where the companies have the lowest possibility of making an influence. Even if the company can make an active effort to influence certain aspects in these stages, most of the environmental impact is influenced by other stakeholder's decision-making. The end-use phase fits in this category, since the user's disposing and the actors in charge of the waste management mostly affect it. Even though the company can increase the product recyclability cooperation with other stakeholders are needed for the full realization of the improvement. Other processes in this category are the upstream processes of the product assembly, specially the impacts of the extraction and refining of materials.

2.1.3. Technical scope

This study includes all processes and raw material needed for the production, use and end-of-life for the products studied. A focus was set on key processes, such as the electricity or fuel production required for production processes and use phase. A special attention was given to the processes under the direct control of the company and the waste management processes regarding the different end of life scenarios.

The capital goods such as buildings, machinery and processes that require personnel and labour needs were not included in this study. The building processes for infrastructure are excluded as well. The impact of transportation is limited to the required for raw material production and transportation of components to product assembly as described better in the following chapter. This excludes the transportation required to distribute the product to market, during use and collection to the waste management facilities.

2.1.4. Geographical boundaries

Both product types will be manufactured in the Husqvarna facilities in Huskvarna, Jönköping, and will be assembled there. Most of the components come from different suppliers around the world and an effort was made to take the geographical influence into account and consider the geographical relevance of environmental impacts.

The base scenario used for the analysis of the two products is modelled with a use phase and end-of-life in Sweden. The base scenario is used for the comparison between the two product models and for identification of their environmental hot spots. Although, to study the influence of the geographical location of the use phase, other representative scenarios were constructed and assumed to be the same for both products. The impact of use location is presumed to have significant influence on the comparison as the electricity production varies between market regions. Also the fuel standards and waste scenarios are different between regions. The following additional use scenarios were modelled and are described in detail in the inventory analysis, appendix A.1 & B.1 and the sensitivity analysis, chapter 3.2.1:

- Sweden: The Nordic electricity system and Swedish fuel standard and waste scenario
- Average European electricity, fuel standard and waste scenario
- Average North- American electricity, fuel standard and waste scenario

2.1.5. Time Horizon

The data used for this study was collected in 2011. The site-specific data from Husqvarna's environmental reporting corresponds to the year 2010, while the bill of material for both models were last updated in January 2011. The datasets obtained from SimaPro refer to various years based on which database they belong to. In the input-output tables in respective inventory analysis, appendix A.1 and B.1, the information about the used datasets can be found. The majority of the data used is from EcoInvent and has the time scope of the year 2000 for processes and 2004-2005 for energy generation (PRé consultants, 2008).

This study was performed with a retrospective approach, which means the environmental impacts of a modelled system are accounted for and there is no analysis of consequences of strategic changes to the system. Nevertheless, in the results interpretation possible alternatives of modified systems are discussed, such as increased motor efficiency or use of recycled materials.

2.1.6. Allocation

The only allocation problem faced in this study regards the allocation of the site-specific data from the Husqvarna facilities towards one chainsaw. To solve this problem for the assembling site a strategy already used by the company was followed, which is used to allocate costs and other aspects of the processes to one single product. For this, a unit called "equivalent unit" is used to account for the total product output of the site. Every manufactured product is allocated with a specific amount of equivalent units, according to size and complexity of each product. Hand-held product such as a chainsaw corresponds to one equivalent unit, and other bigger products such as riders correspond to a higher number of equivalent units. Regarding the allocation of the data from the light metal factory the problem dealt with using weight relation, using the manufactured output in weight and the relative weight used in the T540 XP product.

2.1.7. Choice of impact assessment methods and analysing strategy

The impact assessment methods were chosen based on their abilities to fulfil the two main goals of the study, analyse each product system for improvement possibilities and provide a fair basis for comparison. In order to avoid value loaded impact assessment results the possibility to analyse mid-point characterization results was preferred for analysis of the system and then multiple weighting methods used for the comparison purposes.

The EDIP method was chosen for its practical and transparent characterization procedures, making it possible to analyse the system more objectively. The characterization to impact categories is thorough and in line with the ISO standard as illustrated in Table 2. The impact for each category is presented in equivalent units that are simple and transparent. This is important given that the company had shown interest in certain categories and they want the results to be easily communicated.

Each product system was analysed based on the EDIP characterization values, using a dominance analysis and constructing an impact profile. The weighted results were used to help identify impact categories of importance for each product. According to the shown interest of Husqvarna a special focus was also given to global warming potential, toxicity and resource use, including water use.

Later when the products are compared weighting methods are applied to make the overall impact easier to understand and to be communicated. For the comparison of the products, single scores were calculated with regard to the functional unit using all three methods introduced in chapter 1.5.3, the EDIP, EcoIndicator 99 (E) and EPS methods.

Table 2 Impact categories included in EDIP and their relevance to the ISO Standard.

ISO 14042 Categories (ISO 14042, 2000)		Related EDIP Categories
Resources	– Energy and material	Resources (all)
	- Water	Resources (all)
Ecological consequences	- Global warming potential	Global Warming 100a
	- Stratospheric ozone depletion potential	Ozone Depletion
	- Photochemical ozone creation potential	Ozone Formation (Human) Ozone Formation (vegetation)
	- Acidification potential	Acidification
	- Eutrophication potential	Aquatic Eutrophication EP (N) Aquatic Eutrophication EP (P) Terrestrial Eutrophication
	- Ecotoxicity impacts	Ecotoxicity Water Chronic Ecotoxicity Water Acute Ecotoxicity Soil chronic
Human health	- Human toxicity potential	Human Toxicity Air Human Toxicity Soil Human Toxicity Water
Other non-related to ISO 14042		Hazardous Waste Slag/Ashes Bulk Waste Radioactive Waste

2.2. Producing the inventory

The material composition and product performance data for the inventory analysis of the products was provided by the product engineers at Husqvarna and then matched with data obtained from the SimaPro software. The software includes databases with inventory data that accounts for extraction of ores and production processes up to delivery of raw materials, a so called cradle-to-gate inventory. Site-specific process data was provided by Husqvarna regarding energy use and waste flows at their facilities. For components from other suppliers, general data on manufacturing processes were used to account for impacts to the extent that available datasets allowed, but transportation from raw material production to article suppliers was excluded. An emphasis was put on matching the data applied with region-specific data where possible, but otherwise world average data was used. The majority of the data comes from

EcoInvent and US LCI. In this section data handling for inventory calculations and impact assessments for each product will be detailed, including the explanation of methodological choices and necessary assumptions that have been made.

2.2.1. Data Collection

The data collection was performed in different levels of product specific detail and varying approaches fitting each life cycle stage. For upstream processes, raw material extraction and production and most components manufacturing, data was obtained from the SimaPro database.

The datasets are general, though with some opportunities for regional specification but the level of product specific detail are lower than with direct collection of data. For the in-house processes like the assembly of the product and the light metal components factory, site-specific data with high level of detail was used, with direct measures of material requirements, waste generation and energy use performed and provided by the company.

For the use phase scenario modelling, the data was obtained from the company's R&D department as a result of the performance tests for both of the products. This data includes emissions from the T540XP, fuel and energy requirements and maintenance or spare parts needs for the product's lifetime. For the end use stage scenarios average data was used for each analyzed region, and existing datasets were used as well. For energy related processes such as electricity mixes or fuel production in the use phase, existing datasets with average data were used for each modelled scenario. For the battery saw, the environmental impacts of the battery pack were modelled using data from previous studies on Lithium-ion batteries. The different levels of detail in the data collected are shown in Figure 4.

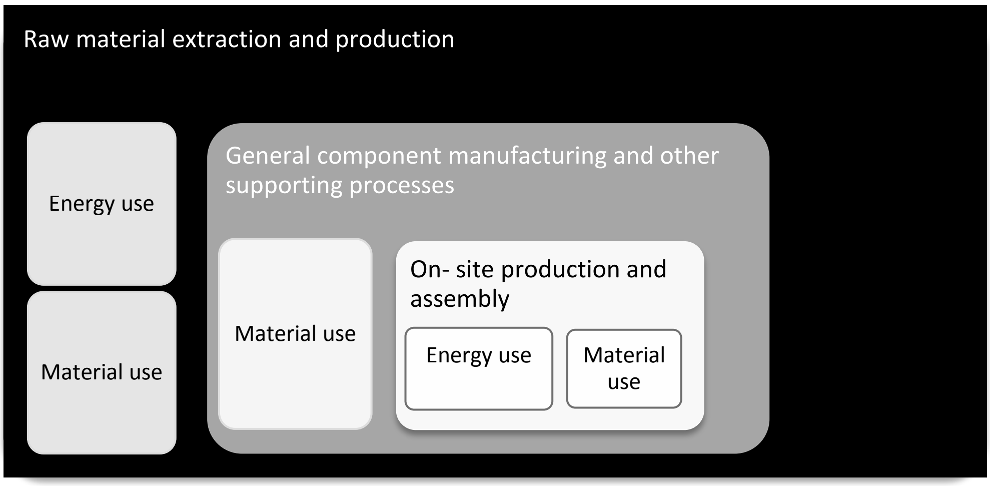

Figure 4 Different levels of detail for the data collection process.

The SimaPro software was used to model the life cycle of the products. Other programs such as Microsoft Excel can be used as well to perform calculations, with the main advantage of a better control over methodological choices in processes whose datasets are already established with given boundaries and limitations that cannot be modified in the case of SimaPro. On the other hand, using an LCA software tool such as SimaPro makes calculations less time consuming and has lower risk of human mistakes in data entry, even as with SimaPro there is still the risk of using data in an inappropriate way. Also, as will be discussed in the next section most of the data used in the study was taken from existing datasets that were obtained from SimaPro and therefore easier to use them directly in the software.

When using the SimaPro software tool the most relevant material and process data was chosen from the databases featured in the software. The data includes inventory for upstream processes like raw materials extraction and refining, as well as all the required transport, energy production and waste scenarios modelling. The software refers to the impact generated by one product, and for comparisons it was normalized to the functional unit.

2.2.2. Data quality and reliability

As discussed in the previous section the data used in this study was obtained from different sources for each phase of the product's life cycle. The data for upstream processes from raw materials extraction to component manufacturing and transport were obtained from the SimaPro datasets, while the data for the product assembly and use phase was obtained from the company's direct measurements. As for the end-use phase, a combination of statistical data for the waste stream splitting and datasets for treatment processes.

SimaPro datasets come mainly from two very transparent and consistent databases existing, Ecoinvent and the USLCI databases. They have very high standards for their datasets and their documentation, making them a very reliable choice for this study. The company's knowledge of the environmental aspects of its suppliers is very limited, so the datasets are an excellent second choice to replace site-specific data.

As for the site-specific data from Husqvarna used for the production and use phase, there are some aspects that need to be taken into account. Regarding the production phase and the use phase emissions, the data quality comes with no questioning, since all of it is obtained from direct measurements performed by the company. Perhaps the only limitation for the production phase is the allocation for one chainsaw, as many of the company's products are manufactured in the same site and it is difficult to allocate how much of the impacts belong to one product, especially for the Battery saw, since it has not been manufactured yet.

As for the data used to model the user phase, it was provided from the design engineers in the R&D department for each product. They provided data such as the oil required for chain lubrication, energy and fuel consumption, the cutting capacity, spare parts and lifespan for one product; and there is the possibility that it differs from the actual amounts decided by the user. Also, there is the uncertainty of safety factors used by designers, which tend to overestimate these numbers for the sake of the product's performance. Anyhow, this is the data that will be used to model the product's systems, since it is the most reliable source available.

2.2.3. Inventory analysis limitations

Many assumptions were made for this study, and all of them will be explained in detail in the inventory analysis appendix. Nevertheless, this section presents the main sources of uncertainty in the study and limitations in its results.

- There is no data available to account for the chain oil emissions to soil during the use phase. This is why the environmental impacts of this spilling are not taken into account in this study, which is one of its main limitations. There is a big influence of the use phase in the total environmental impact of the products as will be discussed in the next section, and this emission to soil could influence some of the outcomes. Based in previous similar studies on lubricating oils, their ecotoxicity impacts are not as important as other categories, but should not be neglected (Igartua et al, 2010).

- The data for processes required to manufacture components from raw materials is not very specific. This study did not include specific information from suppliers and the process in each of their sites. Only average manufacture data for steel, plastic and metal products was used to account for these processes, which gives a level of uncertainty for the component manufacturing stage.
- The transportation required for the distribution of the finished product from the company site to the final consumer is not taken into account due to the unavailability of data. For comparison purposes this would not make a difference since both products would require the same transportation as their targeted market is different, but for product learning (the main goal of this study) this could be a source of uncertainty that needs to be further assessed.
- The certainty of the estimation of functional lifetime might be heavily influential for the comparison of the products. Whereas the cutting capacity is easy to measure in standardized tests, the functional lifetime is highly influenced by the user scenario and has a higher uncertainty. The battery product is new on the market and therefore experience and information about the actual durability of the product might be more uncertain than that of the conventional motor one. The same applies to the durability of the batteries and the number of batteries, which affects their end-of-life treatment or recyclability and might be very important for the comparison of the two systems. Also, extended functional time will influence the share of the user phase (and increase the impacts share of the power supply) in the whole life cycle analysis.
- Regarding the material composition of the products, it was not possible to find specific datasets for some materials and components such as Polyoxymethylene (POM), Polybutylene Terephthalate (PBT) and Neodymium magnets (see Appendix). Some proxies were used to account for these using materials with similar properties, raw materials and production processes; but these data gaps present a source of uncertainty.
- The data obtained from the company regarding use phase emissions from the T540 XP covers only certain substances, which are regulated by environmental law. Because of this, additional data from general fuel burning processes in equipments had to be included to account for other pollutants. Also, the provided data comes from the testing of the product in Sweden, and using a specific fuel. The geographical variance in the type of the fuel used and the limitations in the burning data are a source of uncertainty for the use phase, which is increased by the high contribution of this process to the life cycle impact of the product.
- For the Battery saw, some of the materials included in the Bill of Materials have no specifications. All the steel was accounted as cold rolled, the entire POM was accounted as homopolymer, all of the Aluminium was obtained from suppliers and none from the Light Metal Components process, and all the thermoplastics were accounted as Polypropylene. Later on, when the design of the product becomes more specific, the environmental impacts could differ from what was modelled with this study.
- The end use phase of the battery pack was modelled assuming a 100% collection rate and using a mix of data from the available technologies for treatment. This scenario is still to be met by the company and its take back schemes, and also could vary along the different geographical scenarios where the product will be used. Therefore, there is an uncertainty also in the possible end use fate of the batteries.

RESULTS AND INTERPRETATION

This section will focus on the discussion of the results, highlighting the most relevant findings regarding the project goals and clearing the way towards the conclusions and recommendations. The whole results are displayed in Appendix A & B, including the Inventory Analysis, Impact Assessment and more detailed definitions of the different scenarios and datasets used in the study. Additional scenarios will be discussed in order to illustrate the sensitivity of the model to important parameters, assumptions and methodological choices.

2.3. Environmental "Hot Spots" in the base scenarios

One of the main goals of this study was to find the stages, processes or materials in the product life cycle with the highest contribution to the total environmental impacts, as these also have the highest potential for improvement. In this section, these so called "hot spots" will be discussed for each of the products in the study with analysis based around both the specific process as well as the material composition of the components and their raw material precursors. This analysis is based on the Swedish scenarios, as defined in A.1.2-3 and B.1.2-3, with use of fuel according to Swedish fuel standards for the petrol driven T540 XP, Swedish electricity for the battery saw and end-use waste treatment according to Swedish statistics. Other possible use location scenarios will be discussed in section 3.2.

2.3.1. Hot Spots for the T540XP

From the characterisation (mid-point) results in A.2.1, a clear dominance by the use phase can be observed. The fuel use for the chainsaw operation is by far the largest contributor, with the production of the fuel and the production of the lubricating oil for the chain upstream but belonging to the use phase. As displayed clearly in the impact profile, **Fel! Hittar inte referenskälla.**, the chainsaw production processes and the end use scenarios have very small shares for all the impact categories except one and never a dominant impact.[1]

For further detail on impacts assessed see A.2.3. The importance of the use phase efficiency, location and waste treatment scenarios will be explored in the subsequent chapter 3.2.

2.3.2. Hot Spots for the Battery saw

For the case of the battery saw, the use phase also has a clear dominance in the total environmental impacts of the product, see characterisation (mid-point) results in the appendix B.2.1. The impacts for this phase come mostly from the production of the lubricating chain oil and the production of the electricity used to charge the battery for the chainsaw operation. The production of the chain oil is the main hot spot process, dominating most of the categories including global warming and acidification. The production of the battery saw has though a substantial contribution to the overall impact which can be related to lower impacts during the use phase as will be discussed in section 3.4, giving the production processes a bigger share in the total impact. The production phase dominates for a number of categories; resource use,

---

[1] [Detailed hot spot analysis in Abstract C]

hazardous waste and some toxicity subcategories for example, see Figure B- 4. This means that the production phase also includes some valuable hot spots for improvement and a special attention will be given to the components and materials in the product later in this chapter.[2]

For further detail on impacts assessed see B.2.3. The importance of the use phase efficiency, location and waste treatment scenarios will be explored in the subsequent chapter 3.2.

2.4.Sensitivity to alternate energy systems for the use phase

The final results of every LCA depend on its system boundaries, among others the geographical boundaries. For this case, the geographical location of the use phase can make an important difference, as each country is subjected to different conditions regarding electricity mix or petrol quality as well as end-of-life treatments. As explained before two other representative scenarios were constructed and assumed to be the same for both products. The scenarios are then:

- Sweden: The Nordic electricity system and Swedish fuel standard and waste scenario
- Average European electricity, fuel standard and waste scenario
- Average North- American electricity, fuel standard and waste scenario

In this section the effect of different use locations on the results will be analysed for each product and the main differences highlighted. The comparison of the total score results for the T540XP and the Battery saw with different use scenarios are showed in Figure 5 and Figure 6. Only some of the categories are shown, those of importance and interest for Husqvarna.

2.4.1. Use scenarios for the T540XP

For the case of the T540XP, the main changes with the different use scenarios were in the waste scenario, as each location had a different way of splitting the waste flows. The datasets used for the petrol production only changed for the US scenario, since no regional data was available for Swedish petrol and therefore the same dataset was used for the Swedish and the US scenarios.

It can be observed in Figure 5 that all the categories have different levels of response to the change of the background energy system. Some of the categories such as global warming had little variance, while categories as ozone depletion and water eutrophication had dramatic changes. These changes are observed mostly in the US scenario, as a different datasets for petrol production was used. This mean that the model is highly sensitive to background energy system changes, as different data in petrol production leads to different results.

2 [Detailed hot spot analysis in Abstract C]

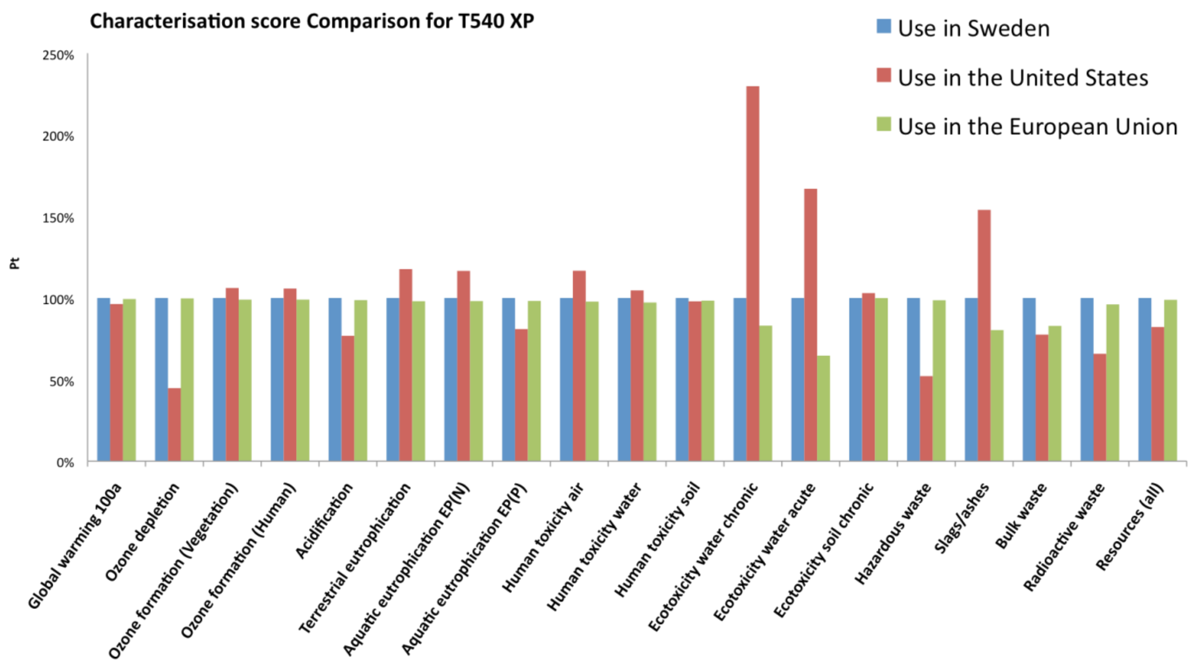

Figure 5 Comparison of different energy systems (facilities, raw materials) for the use phase of the T540XP.

2.4.2. Use scenarios for the Battery saw

From Figure 6 it can be noted that using the product in Sweden has less environmental impacts than using it somewhere else, at least for most of the categories. However, using the product in Sweden has a very high score on the radioactive waste category. This result comes from the high share of electricity from nuclear power plants used in Sweden, which have an overall lower environmental impact but still have to deal with the problem of radioactive waste. Using average electricity data from the European Union in the model had higher results than the other scenarios for most of the categories, especially in global warming potential and ozone depletion where the difference is more notorious.

For further discussion more country specific data should be used, and more local studies should be performed. But the most important thing to observe from these results is that the environmental impacts of the products are very sensitive to the location of the use phase, as the production of electricity and waste management are processes that change with location. This can be observed from the dramatic changes within the different scenarios and for the different categories, changes that were expected given the dominance of the energy input of the use phase in the overall environmental impacts.

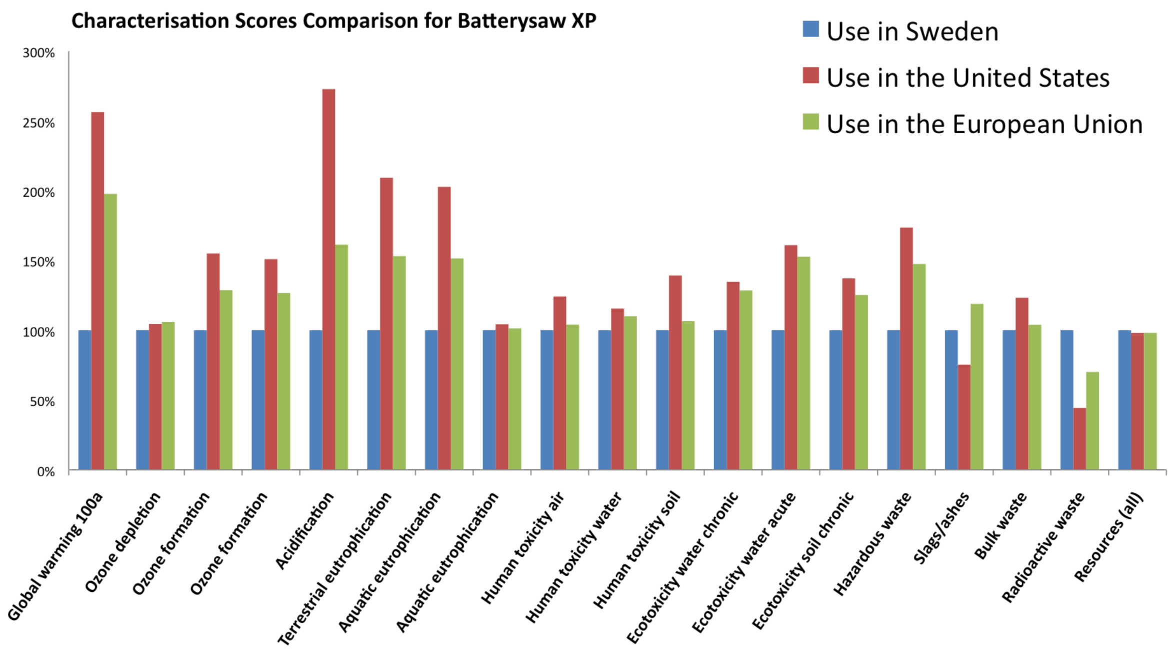

Figure 6 Comparison of different energy systems for the use phase of the battery saw.

2.5.Sensitivity to material substitution

One of the first alternatives that come to mind when improving the environmental performance of a product is the use of more environmentally friendly materials. In this scenario this alternative is explored, as the system is modelled assuming that almost all material is made from primary raw materials.

The goal of this model is not to find an optimal share of recycled materials; it is rather to illustrate the potential environmental savings of using them. Therefore, the system was modelled using a share of secondary materials for metals (when datasets were available) and a share of biopolymers for plastics (Granulate Polylactide). It is known that for most of the materials, recycling processes imply some quality losses, which could affect their properties and therefore their performance. This is why two different scenarios were modelled, one with a reasonable 20% share of the raw materials accounted as secondary metals or biopolymers and another one with an increased 40% share of those materials. The results for this scenario are shown in Figure 7 and Figure 8, where the relative change in impact for the production phase only are displayed for all categories.

As can be seen from the results, the potential for improvement by material substitution is rather limited, as the environmental impacts of the production phase did not change much with the choice of environmentally preferable materials in the products for almost all the categories. Note the scale on the graphs though, the ecotoxicity soil chronic category sticks out because of possible impacts from the recycling process. But in general the model is not very sensitive to the changes in the kind of material used in the product as the production phase contributes to a relatively small impact for the whole lifecycle.

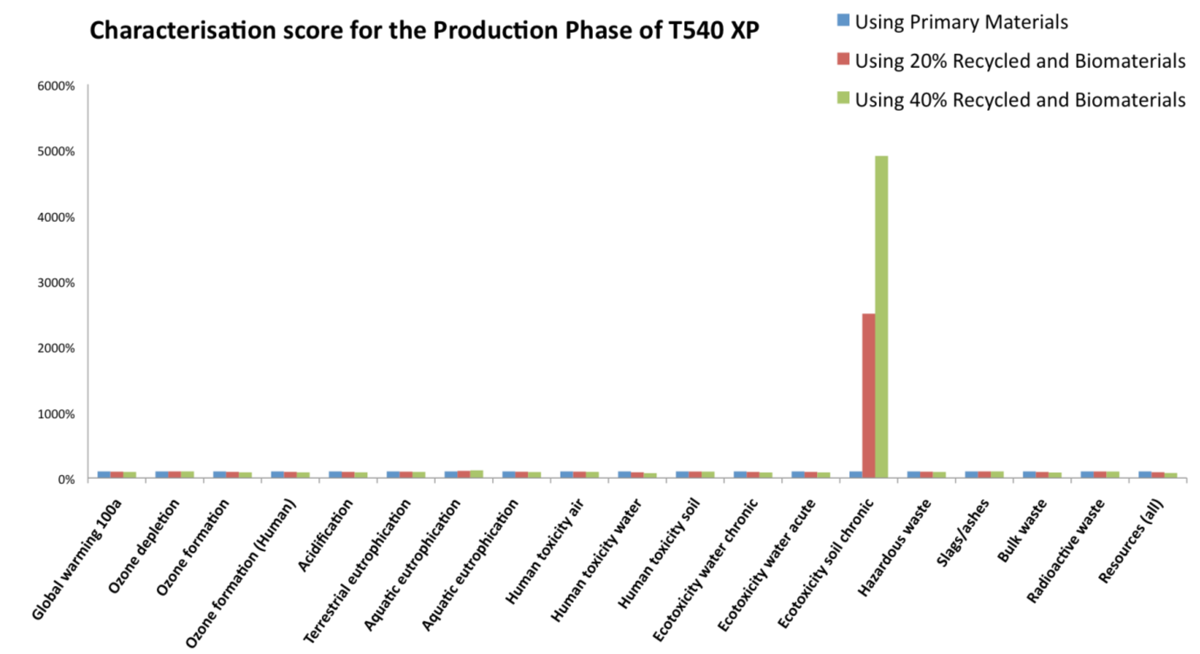

Figure 7 Comparison of the production phase characterisation scores for the T540 XP, between using primary materials or other environmentally preferable materials.

The results indicate that for the T540 XP the potential environmental improvement of the production phase can be to 12% for some categories for the scenario with 20% recycled material and biomaterial substitution. With a further implementation of 40% recycled material the potential is obviously multiplied with 2.

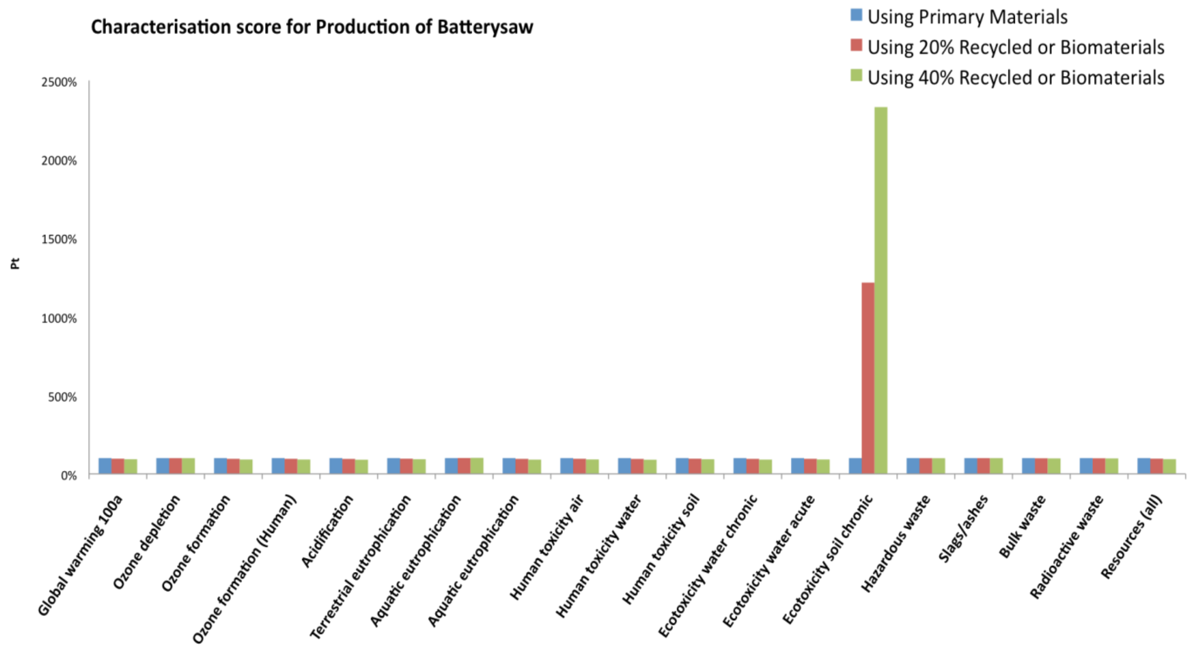

Figure 8 Comparison of the production phase characterisation scores for the battery saw, between using primary materials or other environmentally preferable materials.

The results indicate that for the batterysaw the potential environmental improvement of the production phase can be to 5% for some categories with 20% recycled material and biomaterial substitution and then a factor of 2 for further implementation of 40% recycled material.

2.6. Sensitivity to changes in the end use scenario

As will be further explained in the Inventory Analysis appendix, waste streams statistics were used to model recycling rates for each use location. The products are assumed to be collected and treated with a mix of available technologies. In this section, the importance of the recyclability of the product and take back schemes will be highlighted by including a scenario with no end use recycling. The results are shown in Figure 9 and Figure 10, where the scores for the waste scenarios with and without end-use recycling are compared.

The environmental impacts from the T540XP system without end-use recycling are higher for most of the impact categories. For most of these categories the difference in the score is low, which is caused by the little influence that the end use phase has over the total environmental impact. Still, this is an indicator that the end use phase should not be neglected, and the recyclability of the product should always be taken into account.

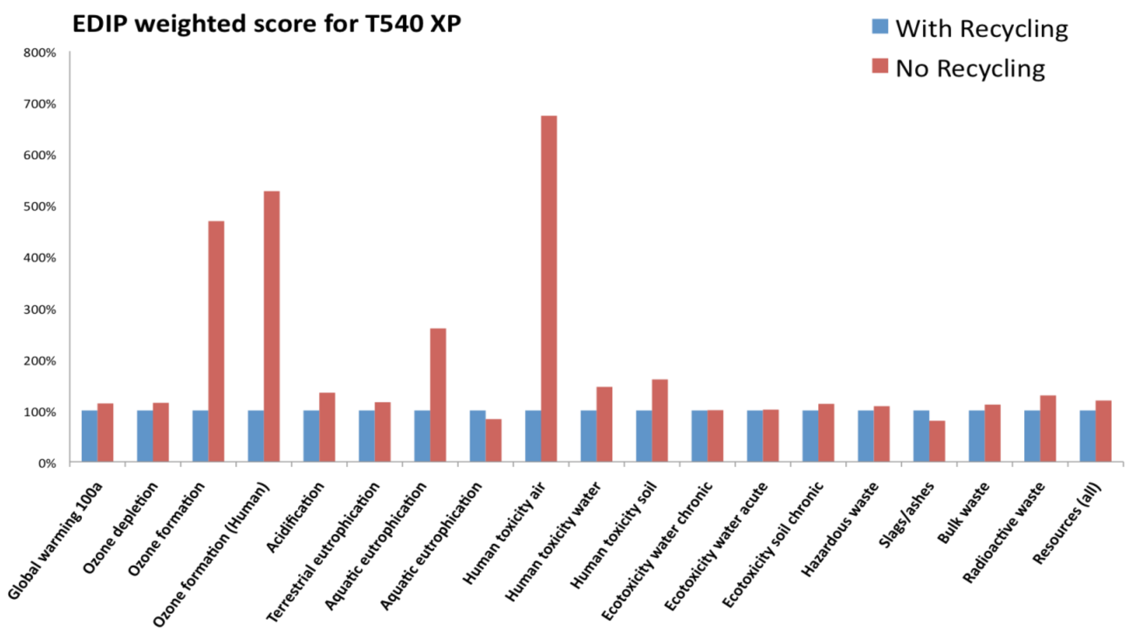

Figure 9 Comparison of the T540XP end use scores with no recycling scenario.

In the case of the battery saw, it was assumed that the product was collected and treated with a mix of available technologies. For the no-recycling scenario all of the materials will be split between waste incinerations and land filling, including the battery pack. The case of the battery pack has a certain level of uncertainty, as there are no datasets available to account for its treatment in landfills.[3]

[3] Further analysis of results in appendix C.

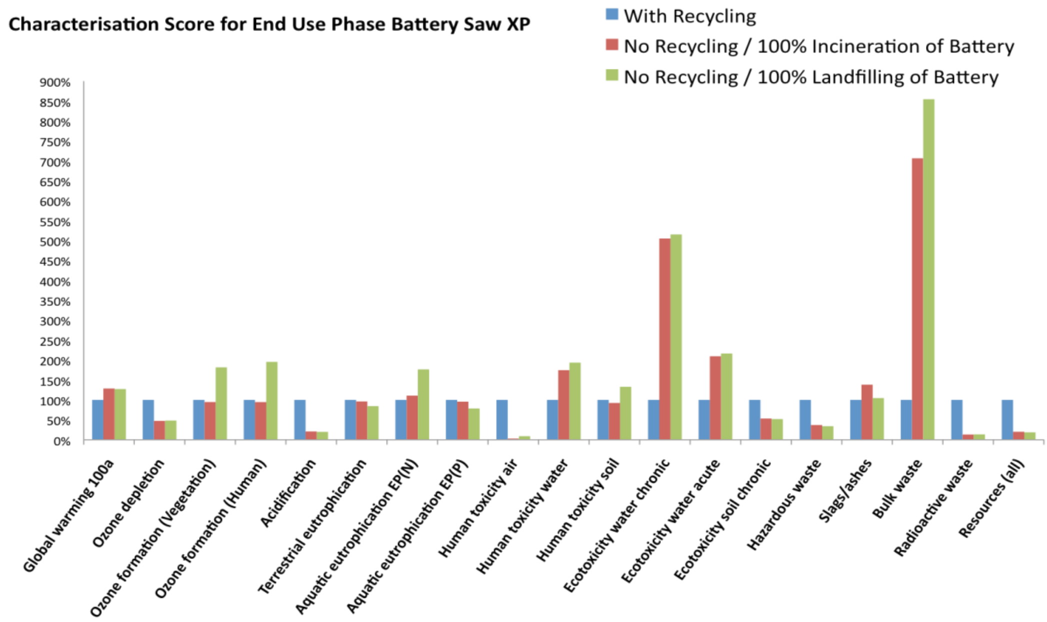

Figure 10 Comparison of the Battery saw end use scores with varying waste scenarios for the battery saw.

2.7. Sensitivity to changes in the use phase energy efficiency

As discussed in section 3.1, the dominant processes in the products systems are the energy use (fuel and electricity), and the lubricant oil and fuel production. In this section, the sensitivity of the model to changes in consumption of these energy and lubricants are tested. Two additional scenarios with fuel and lubricant savings of 5% and 20% were modelled, results displayed in Figure 11. Only the total weighted single score results are shown, as the change affected all the categories linearly and the overall result is clearer for the single scores.

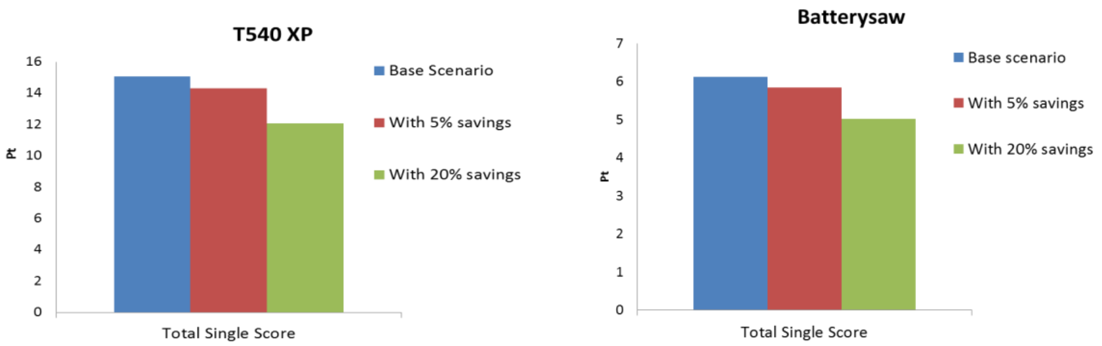

Figure 11 Comparison for the T540 XP (left) and battery saw (right) EDIP total single scores with different degree of energy and lubricant oil savings.

As can be observed in figure 11, the relation between energy and lubricant savings and environmental impacts reduction is linear for both the products. Any achievement in energy efficiency and lubricant inputs (without changing the composition of the fuels or energy) has direct influence on the environmental impacts of the product systems. Changes in this parameter have by far the largest influence on the overall result. This is a strong indicator that use phase efficiency has the most preferable improvement potentials.

[Chapter 3.6 Comparison between the products moved to appendix C]

3. CONCLUSIONS

3.1. Study goals

In this first section, the questions the company wanted to answer by performing this study will be solved according to the results obtained. The suggestions for the company to integrate life cycle thinking in its product development work will be covered in section 4.2.

3.1.1. Processes and phases with higher environmental impact

The results show a very similar trend with the use phase dominating the environmental impacts for both of the models. For the T540XP, the fuel burning process in the use phase has the highest contribution with the fuel production and lubricating oil production processes coming behind. The total environmental impact is affected by the energy systems in the use phase, but these processes are still dominant with alternative energy systems.

Regarding the material composition, steel components and light metal components (Aluminium and Magnesium) are dominant in the production phase. However, the total environmental impact of the product is not very sensitive to material substitution. The end-use phase has a low contribution to the environmental impact of the product, and changes in the end use scenario have little influence in the final results.

As for the battery saw, the production of lubricating oil is the main contributor, while the production of electricity for the battery charging and the production phase have an important contribution for the environmental impact of the product as well. The energy system in the use phase has a high influence in the environmental impact, although it does not affect the use phase dominance.

Even as material substitution makes relatively small difference in the environmental impact of the product, the production of components has relatively larger influence than for a combustion motor product, with electronic components such as PCBs, wires and charger as the dominant materials. The end-use phase also has a low contribution, but even as changes in the waste scenarios seem to make little difference, there are still some uncertainties regarding the environmental impacts of the waste treatment for the battery pack.

[Chapters 4.1.2 Measures to reduce the product´s environmental impacts and 4.1.3 Product comparison moved to appendix C]

3.2. Life cycle thinking in product development

According to the findings discussed in section 1.6, the company is advised to take the following recommendations into account in order to implement life cycle thinking into its product development process:

- Develop a short and simpler LCA methodology, using its own company values and the previous LCA studies as a base.
- Define the environmental requirements and considerations for its products.
- Introduce relevant knowledge to the company.
- Introduce life cycle thinking as early as possible in the product development process.
- Link life cycle thinking to economic tools in order to engage suppliers more effectively showing the economic benefits.
- Introduce relevant tools such as matrices or software, choosing the ones that can be adapted more easily to the company's values and working methods.
- Taken into account the level of influence the company has over each process when establishing priorities and adopting measures for improvement.

The company possesses strengths as well, which will be advantageous towards implementing life cycle thinking. For starters, performing this kind of study shows a particular motivation and ambition towards sustainability, and giving resources for this shows top-management commitment. Including life cycle impacts on the product development process is the next step, and the change of the power system from motors to batteries may be a step towards more sustainable solutions for consumer goods. This means Husqvarna is on the right track to improve the environmental performance of their products.

Finally, many things have been written and many examples and case studies can be found in the literature. But the most important step is always the first. It will take time for the company to develop its own methodology, since all the tools and methods available must be adapted to the way the company works. Therefore, the best way to reach an ideal methodology is by experience. This is why it is recommended to start as soon as possible, with studies such as this or the lawnmowers study as a base reference.

3.3. The practice of LCA

Life Cycle assessment is a very practical tool that allows its practitioners to make a wide range of assumptions. When working with complex consumer goods such as the T540XP and the battery saw made with many different components and materials and sold and used in a global scale, these assumptions prove fundamental to model the product's systems. Making such assumptions, as well as making some methodological choices solved many data gaps found in the way. Under this perspective, the choice of LCA as a tool was right for this particular study.

This complexity of the products was a setback during the data collection stage. From the start it was decided that site-specific would not be used data for the upstream processes in the production phase. Then, the data collection was limited to existing databases, and some of the components of the products are made of innovative materials with very limited data availability. Even as the impacts from the production phase proved not to be significant compared with other phases, for further research it is recommended that an effort be made in collecting site-specific data from suppliers. Surveys and data inquiries via the purchase department can be performed.

The communication with all the company personnel involved in the project was very efficient, since everyone showed special interest in the outcomes of the study or a special interest in being helpful. Although, the data obtained form the suppliers was limited. The fact that the component suppliers are scattered around the world could reduce the chances of efficient communication, especially if surveys and data inquiries are to be made. The importance of supplier communications is often overlooked, and in this kind of studies it could be an important factor towards good results.

Using the SimaPro software tool was in general a positive choice for the study. The first stages of data collection were slow, since the software was not a familiar tool. Along the way some technical setbacks with the hardware and the software took some time to solve, and this had an impact on the productivity. On the other hand, a lot of time was saved in the calculations, as no special model had to be typed in other programs. Also, the datasets included in the software libraries proved to be enough for the study and no additional data libraries had to be used. For future works with LCA software, it is recommended to be aware of which processes and emissions are being accounted for in the environmental impacts and which are not, since some time they can be included and they will appear, but the software can't account for them as it has no data to do it.

Regarding the weighting methods, a choice is always difficult as they can easily influence the result. Each method is developed according to the specific values of its developers, and these values affect directly the importance of each category and therefore the weighting factors applied. In this study, characterisation results were used as much as possible so this possibility was avoided. The choice of the EDIP method matched the requirements regarding the impact categories, but had some impact in some results such as the high score of the radioactive waste category. This high score was caused by the importance of this issue in Denmark, where the method was developed. As for the comparison, the use of EI99 and the results obtained proved that the choice of the weighting method was not critical for the final conclusion.

3.4. Further work

If the company intends to deepen its knowledge regarding the environmental impacts of these specific products, there are some data limitations that should be further investigated. As discussed in section 2.2.2 there are some limitations regarding the inventory analysis.

The environmental impacts of the emissions of lubricating oil to soil during the use phase should be further investigated. Since the use phase is dominant for both of the products and there are important amounts of lubricating oil consumed during the use phase, the environmental impacts from these emissions could have an influence in the final results. Also, there could be a link with the toxicity categories, which are of interest for the company as previously stated. All the impacts caused by the lubricating oil in this study come from its production, and they have an importance significance, but none of it comes from its emissions to soil.

There is a need to increase the knowledge of the environmental aspects of the component suppliers for the upstream processes in the production phase. Building knowledge about the processes involved in the manufacturing of the components purchased is a slow process that requires a very good communication with suppliers. This knowledge would fill many data gaps in this study regarding environmental impacts from upstream processes for certain materials for which proxies were used and the transformation processes required to manufacture components, which were accounted for with general datasets or previous studies as in the case of the battery pack, the battery charger, POM components and PBT components.

Another aspect that is worth further research is the transportation of the final products from the production phase to the user. The information regarding this transport can be documented in a more detailed way, so the proper average amount of transport can be allocated for each unit. The transportation distances are grouped using the transport suppliers, while the distribution for each type of product and the transport modes would be very valuable information for this type of studies in general.

Finally, the battery saw production model can be further improved by updating the data with more specific materials, when those are better defined. When the product development phase reaches its final stages, more specific materials can be included and the environmental impacts of the production phase will be better modelled, and the identification of hot spots in the production phase can be better modelled.

4. REFERENCES

Baumann, H., & Tillman, A.-M. (2004). *The Hitch Hiker's Guide to LCA*.
Lund: Studentlitteratur AB.

Brydson, John A. (1999). *Plastics Materials*.
Oxford: Butterworth-Heinemann.

Eurostat. (2011). *Annual road freight transport, by age of vehicle* [online] available from <http://epp.eurostat.ec.europa.eu/portal/page/portal/product_details/dataset?p_product_code=ROAD_GO_TA_AGEV> [04-20-2011]

Eurostat Waste Statistics (2011) *Treatment of waste (Tonnes)* [online] available from <http://appsso.eurostat.ec.europa.eu/nui/show.do> [29-04-2011]

Finnveden, Göran et al (2009). "Recent Developments in Life Cycle Assessment".
Journal of Environmental Management 91, 1-21.

Furlani, Edward P. (2001). *Permanent magnet and electromechanical devices : materials, analysis, and applications.*
London: Academic. Sections 1.14 and 1.16

Goodman, Sidney H. (1998). *Handbook of Thermoset Plastics*.
Westwood, New Jersey: Noyes Publications. Table 6-21.

Jönköping Energy. (2011). *Fjärrvärme och miljö*. [online] available from <http://www.jonkopingenergi.se/web/Fjarrvarme_miljo.aspx > [02-04-2011]

Husqvarna AB. (2011a). Article Analysis Report, Material Analysis Report and personal communications with Mats Andersson.
Huskvarna: Not Published.

Husqvarna AB. (2011b). Environmental report (Environmental data collection Manufacturing Office and Ramp D. (2011-01-26) Huskvarna site) and personal communication with Jonas Willaredt.
Huskvarna: Not published.

Husqvarna AB. (2011c). Personal communication with logistic department, Felipe Colas.
Huskvarna: Not published.

Husqvarna AB. (2011d). Bill of Materials and personal communications with Jan Gustavsson.
Huskvarna: Not published.

Husqvarna AB (2011e). Definition of functional lifetime and product performance from Jan Gustavsson and Mats Andersson.
Huskvarna: Not Published.

Husqvarna AB (2011f). *Pro forestry products* [online] available from <http://www.husqvarna.com/us/forest/products/xp-saws/husqvarna-chainsaws-xp-saws/> [01-05-2011]

A. Igartua (2010). "Alternative eco-friendly lubes for clean two-stroke engines". *Tribology International*, 44, 727-736.

ISO14040 (1997) *Environmental management - Life cycle assessment - Principles and framework.* Geneva, Switzerland: International Organisation for Standardisation (ISO).

ISO 14042 (2000) *Environmental Management-Life Cycle Assessment-Life Cycle Impact Assessment* .
Geneva, Switzerland: International Organisation for Standardisation (ISO).

Katsuyuki, N. & Masahiko H. (2011). "Collaborative activity with business partners for improvement of product environmental performance using LCA". *Journal of Cleaner Production*, 19, 1189-1197.

Lan, X., & Liu, Y. (2010). *Life Cycle Assessment of Lawnmovers - Two Case Studies.* Göteborg, Sweden: Chalmers University of technology.

Notter, Dominc A. et al (2010). "Contribution of Li-Ion Batteries to the Environmental Impact of Electric Vehicles". *Environmental Science Technology*, 44, 6550–6556

Plastics Europe (2010). *Plastics: The Facts 2010. An Analysis of European plastics production, demand and recovery for 2009*. *(Figure 6)*. [online] available from <http://www.plasticseurope.org/document/plastics---the-facts-2010.aspx?Page=DOCUMENT&FolID=2> [21-04-2011]

PRé consultants (2008). *SimaPro Database Manual, methods library.* [online] available from <http://www.pre.nl/download/manuals/DatabaseManualMethods.pdf > [01-03-2011]

Rebitzer, Gerald et al (2004). "Life Cycle Assessment, Part 1: Framework, goal and scope definition, inventory analysis and applications". *Environmental International,* 30 (5), 701-720.

Sandler, S., & Wolf, K. (1992). *Polymer Syntheses, Volume I.* San Diego, California, USA: Academic Press Inc.

US Environmental Protection Agency (2010). *Municipal Solid Waste Generation, Recycling and Disposal in the United States: Facts and Figures for 2009 (Table 1)* [online] available from <http://www.epa.gov/osw/nonhaz/municipal/pubs/msw2009-fs.pdf> [30-03-2011]

World Steel Association (2010). *Steel Statistical Yearbook 2009 Table 6* [online] available from <http://www.worldsteel.org/?action=publicationdetail&id=97> [18-03-2011]

APPENDIX

The material composition and product performance data for the inventory analysis of the products was provided by the product engineers at Husqvarna and then matched with data obtained from the SimaPro software. The software includes databases with inventory data that accounts for extraction of ores and production processes up to delivery of raw materials, a so called cradle-to-gate inventory. Site-specific process data was provided by Husqvarna regarding energy use and waste flows at their facilities in Huskvarna. Note the difference between the company Husqvarna and their facilities in Huskvarna. For components from other suppliers, general data on manufacturing processes was used to account for impacts to the extent that available datasets allowed, but transportation from raw material production to article suppliers was excluded. An emphasis was put on matching the data applied with region-specific data where possible, but otherwise world average data was used. The majority of the data comes from the EcoInvent and US LCI databases. In this section data handling for inventory calculations and impact assessments for each product will be detailed, including the explanation of methodological choices and necessary assumptions that have been made.

CONTENT

- Inventory analysis and results in appendixes were omitted for confidential reasons -

A. T540 XP chainsaw petrol powered

A.1. INVENTORY ANALYSIS

The inventory analysis for the T540 XP was carried out for the main product life stages as shown in Figure A- 1. Inventory data for impact of raw material extraction and production processes used in all stages were obtained mostly from the EcoInvent and USLCI datasets in SimaPro.

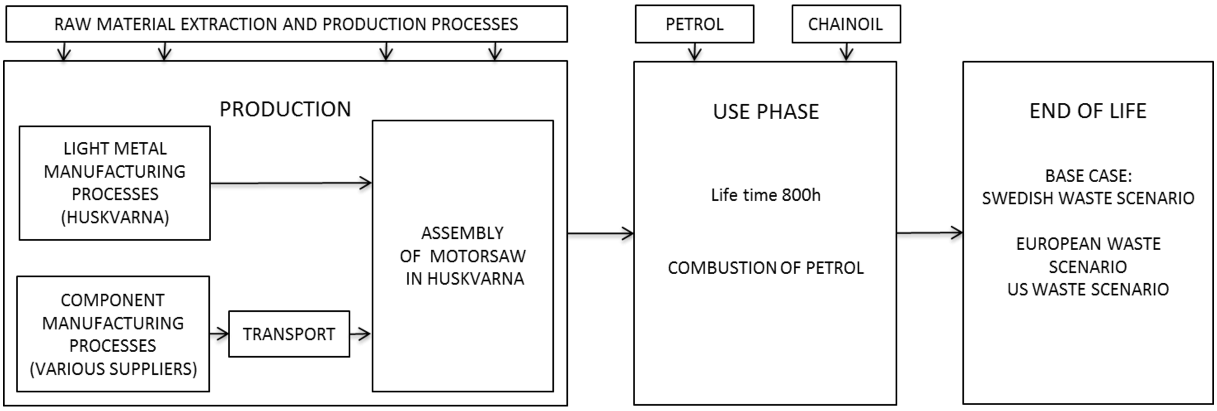

Figure A- 1 The main product life stages of the T540 XP motorsaw as they were represented in the inventory.

The hypothesis was that material production and the use phase would have the highest impact and therefore an effort was made to collect complete data and reach a good degree of confidence for those product stages. Following are descriptions of what each stage includes in terms of material use and specific processes.

- **The following chapters were omitted for confidential reasons –**

B.Batterysaw – Electricity powered

B.1. INVENTORY ANALYSIS

The inventory analysis carried out for the battery chainsaw is shown in Figure B- 1. Inventory data for impact of raw material extraction and production processes used in all stages were obtained from the EcoInvent and USLCI datasets in SimaPro.

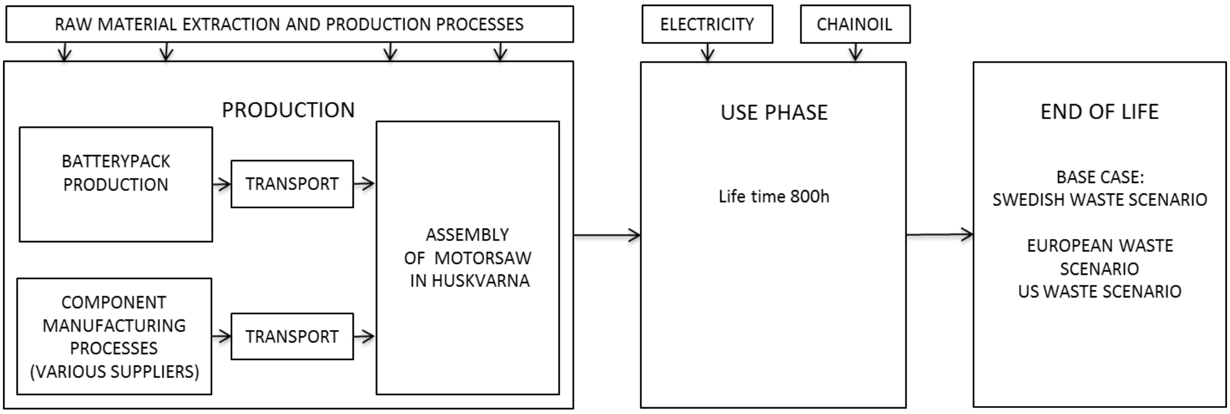

Figure B- 1 The main product life stages of the Battery saw as they were represented in the inventory.

For the battery saw, the highest impact was suspected to come from the battery production, use and disposal. Therefore the battery life cycle was of special focus in the inventory analysis, and a higher level of detail was intended for the processes involved. In the following sections the different stages and processes for the battery saw life cycle will be described, including the main assumptions in the inventory analysis.

B.1.1. Production phase for battery chainsaw

The material composition of the product was obtained from Husqvarna product engineers (2011d), with an exception for the battery pack. For the battery pack composition, a previous study by Notter et al. (2010) was used in order to account for manufacturing processes of the battery, from the raw materials extraction to the production of the battery pack. In **Fel! Hittar inte referenskälla.** the raw material and respective weights required to produce one chainsaw and the datasets used for calculations are listed.

Battery Pack

For the battery pack manufacturing and material composition, data from a recent study for lithium-ion batteries used in vehicles was used (Notter et al., 2010). The product system was modelled according to the information provided by that study, including all the processes and materials required to produce 1kg of battery pack from cradle to gate as illustrated in Figure B-2. All background process estimations for the manufacturing of chemicals and components in the battery are listed in good detail in supplementary data from Notter et al. (2010). The only modification to the model for these background processes was for the anode production process, where instead of assuming the loss of Copper for recycling, it was accounted as a Non-Ferrous metal recycling process.

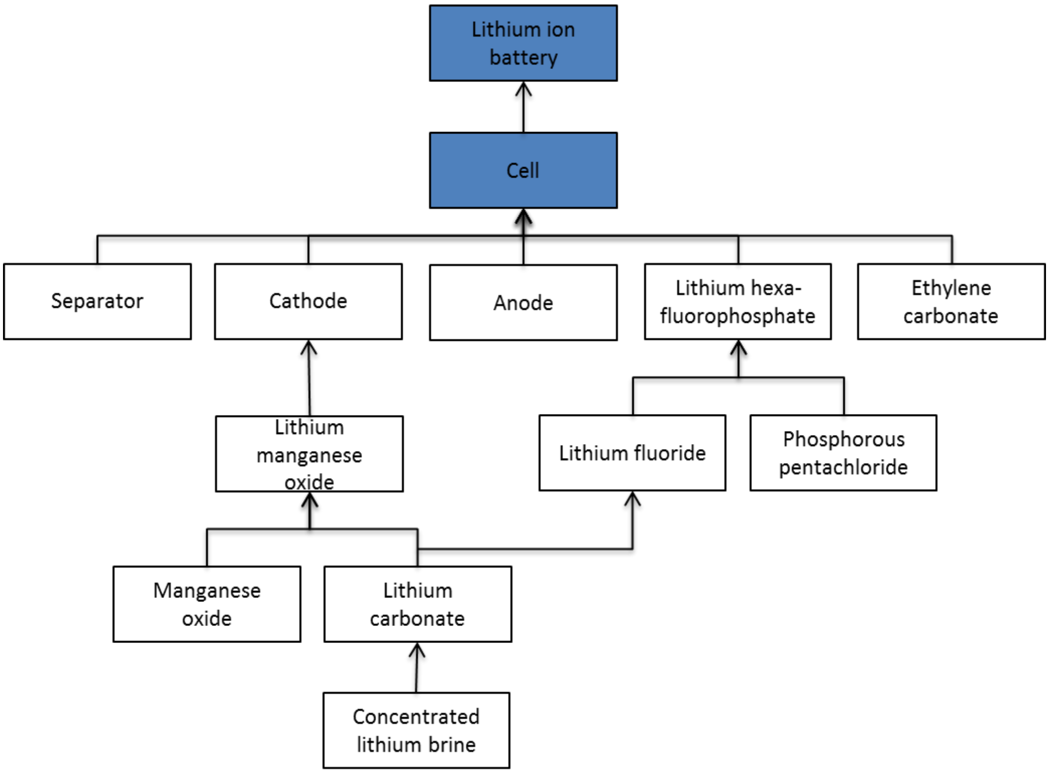

Figure B- 2 Battery pack composition and involved processes adapted from Notter et al. (2010). Data for blue boxes are listed in this section but for full input lists see support material from Notter et al. (2010).

The product system for the battery pack as whole was adapted to the appropriate weights used in Husqvarna battery chainsaw.

- **The following chapters were omitted for confidential reasons –**