Life Cycle Assessment Framework:
Incorporating an extended environmental perspective in the Haldex Project Management Model

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Preface

This master's thesis was conducted during the spring of 2015, representing the final part of my five year long master's degree in Industrial Engineering and Management at Lund Institute of Technology, Lund University. The thesis was initiated by Haldex in order to evaluate the potential of incorporating environmental performance as additional decision support in the Haldex Project Management Model.

Since this has been a simultaneously fun, challenging and educational period for me, I would like to thank everyone who have guided and helped me on this journey, always providing your fullest support.

Initially, I would like to thank Kent Jörgensen and Johan Valett, supervisors at Haldex, for your devotion, patience and commitment. Thank you for teaching me about Haldex' company culture and providing meaningful internal insights, but also for guiding me to the right people and for our productive and enjoyable discussions. I would also like to thank all the rest of the people at Haldex who I have been in contact with through various meetings and who were always very engaged and dedicated to help me.

Finally, I would like to thank Bertil I Nilsson, supervisor at the Faculty of Engineering at Lund University, for motivating me and always being supportive. Thank you for also providing the project with valuable external contacts.

I am truly thankful for being allowed to have worked on this project and for everyone who made it possible.

Lund, 2015-06-30

Ola Knutsson

Abstract

Title: Life Cycle Assessment Framework: Incorporating an extended environmental perspective in the Haldex Project Management Model

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Background: An increased concern of environmental issues have made companies, including Haldex, look for new engineering and design practices to keep up with legislations and stakeholder pressure, often by analyzing products' total environmental impact over their life cycles, in so called life cycle assessment studies. The Haldex Project Management Model is a company specific project model where Haldex projects move through, till their completion, and the concern is that life cycle assessment studies have not been included as a deliverable in the Haldex Project Management Model before.

Purpose: The purpose of this Master's Thesis is to develop and present Haldex with a life cycle analysis tool and a framework for environmental impact assessments of new products or changes to existing products, providing evaluation of projects in the Haldex Project Management Model.

Methodology: In this thesis a mainly qualitative research style was used in order to provide the specific life cycle assessment framework, as the work required an exploratory procedure, studying behavior and practices from the inside. Data gathering was conducted using several methods such as interviews, observations, content analysis and an extensive literature review. The framework was developed gradually by analyzing and screening various tools.

Results & Conclusion: Presenting Haldex with a suitable life cycle assessment framework, including assessment tools that are applicable in the Haldex Project Management Model and a product's R&D stages, has been achieved through a preliminary study and analysis. By conducting a preliminary study and examining environmental processes and areas both internal and external to Haldex, a number of criteria for life cycle assessment tools at the company could be set. A screening and analysis of best-practice tools then helped to identify suitable tools for Haldex to begin working with, which are presented in the *Haldex Life Cycle Assessment Development Framework*, which allows environmental assessment progress over time. This includes a semi-quantitative Design for Environment-matrix and accompanied guide, as well as a quantitative carbon footprint analysis where a prototype, accomplished through the spreadsheet software Excel, may be used to start working with the latter tool.

Key words: Life cycle assessment, tool framework, LCA, corporate social responsibility, design for environment, carbon footprint, simplified LCA, life cycle.

Glossary and acronyms

Carbon Footprint	CF, a type of simplified life cycle assessment where only one impact category, climate change, is assessed.
Impact category	Impact category refers to a class representing environmental issues to which the life cycle inventory analysis results may be assigned, for example climate change, acidification or ecotoxicity.
Inputs	Here referred to as activities with environmental impacts that enter processes along the product's life cycle, such as electricity, fuel and raw materials.
ISO	The International Organization for Standardization is a standard-setting organization that develops standards to facilitate international trade.
LCA	Life cycle assessment, sometimes also life cycle analysis, refers to a technique to assess environmental impacts associated with all stages of a product or service's life cycle. A full-scale LCA indicates that guidelines and rules set by the International Organization for Standardization have been followed.
LCI	Life cycle inventory, the data collection part of an LCA, which is an accountant of everything involved in the studied system, including inputs and outputs that have environmental impacts.
Life cycle	A product's life cycle refer to the main stages of a product's life, from raw

	material extraction to use and distribution, to disposal or recycling, also known as cradle-to-grave.
Output	Here referred to as activities with environmental impacts that leave processes along the product’s life cycle, such as waste, emissions and wastewater.

Table of Content

1 Introduction

This chapter is intended to provide the reader with a context to the thesis and increase their understanding of the purpose to the research. This is achieved by giving an introduction to relevant concepts as well as expanding on the abstract and formalities of the thesis such as objectives and deliverables. The chapter ends with an outline of the report.

1.1 Context

1.1.1 Corporate social responsibility

Corporate social responsibility (CSR) is a management term indicating an inclusion of social and environmental concerns in the corporate's business practices. Balancing economic, social and environmental decisions, and still meet the expectations and obligations from firm owners and stakeholders, is a fundamental challenge as well as the job of CSR. With increased pressure of both ethical and sustainable actions, from customers, societies and governments, firms nowadays face negative consequences if excluding CSR work in their business. On the other hand, a successful CSR policy can lead to many competitive advantages, such as access to new markets and customers, increased sales and stronger brand image, higher customer and employee loyalty, and more.[1]

1.1.2 Life Cycle Assessments

Life cycle assessment (LCA) studies are tools used by many organizations to analyze and assess environmental impacts,

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[1] UNIDO, http://www.unido.org/en/what-we-do/trade/csr/what-is-csr.html, viewed on 20 February 2015.

caused by or associated with their products, services or product systems. In short the technique is achieved by:

- Mapping processes and studied systems and collect an inventory of material- and energy inputs and their environmental releases.
- Analyze and evaluate chosen environmental impacts associated with said inputs and their environmental releases.
- Interpreting the results in order to make informed decisions.

By conducting LCAs, corporations or other organizations may be able to make more experienced product development decisions, may use the result in marketing to strengthen brand and to show a care of CSR. They may also use it for public policy making, or more. [2]

1.1.3 Haldex

With traces back to 1887 and now headquartered in Landskrona, Sweden, Haldex develops, manufactures and distributes products for brake and suspension systems on commercial vehicles. Customers include manufacturers of heavy trucks, buses, trailers and axle manufacturers.[3]

The product portfolio includes all main components that exist in a complete brake- and air suspension system. With a global presence in sales, research, service and production, the products are produced in production sites spread across the world, from North and South America, to Europe and Asia. In 2014 Haldex had a net sale of 4.4 Billion SEK and currently employs approximately 2,235 people.[4]

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[2] M.A. Curran, *Development of life cycle assessment methodology: a focus on co-product allocation*, 2008, viewed 15 February 2015.

[3] Haldex Annual Report 2014.

[4] Ibid.

The firm wants to be a trusted source that earns every partnership with customers by providing superior products and first class service. Their mission reads as follows[5]:

> *"Haldex develops and provides reliable and innovative solutions that improve safety, vehicle dynamics and environmental sustainability in the global commercial vehicle industry."*

By following those guidelines, Haldex desire to be the world leader on their market and to provide value for both customers and shareholders, by providing first class technology. Haldex' vision statement is[6]:

"Haldex will be the global commercial vehicle industry's preferred choice as an innovative solution provider with a focus on brake and air suspension products."

To achieve this the company has three core values that is to be integrated in each part of the corporation and its value chain[7]:

- Customer first
- Respect for the individual
- Passion for excellence

At the research and development level, R&D, Haldex corporate procedures include a project model, the Haldex Project Management Model, where each significant project moves through 6 gates, from project approval to acceptability and go-ahead. The concern with the model is that Haldex have previously not had environmental interests incorporated in it, and a review of suitable LCA tools is

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[5] Haldex Power Point Introduction presentation, viewed on 11 March 2015.

[6] Ibid.

[7] Haldex Power Point Introduction presentation, viewed on 11 March 2015.

needed to investigate the possibility to introduce such tools early in the model and a project's development phase.

1.2 Problem description

The product portfolio of Haldex consists of all main components and their sub-systems in a complete brake or suspension system. To remain competitive, projects regarding changes to existing products or entirely new products are introduced regularly, remodeling the look of the portfolio. Development of new products or changes to existing products can have substantial environmental impacts and Haldex is looking to find a method to evaluate this effect, by including life cycle assessment results as a deliverable in the Haldex Project Management Model.

1.3 Purpose

The overall purpose of this project is to develop a life cycle assessment framework where Haldex is used as a case study and such framework is presented to the company, including tools that can be used for evaluation on new products or when changes to existing products are made. This framework would therefore provide environmental evaluation on any new projects in the Haldex Project Management Model, as well as enable the company to capitalize on opportunities in the early phases of a project, with the then possibility of quick and cost-efficient changes. The framework and its tools will thus function as early decision support in Haldex' research and development phases. The implications concern the company but also its stakeholders such as suppliers, customers, etc. Said framework will be generic and, with slight modifications, can suit any modern company working in today's business climate, where having life cycle assessment tools to use are becoming more and more important.

1.3.1 Objective

The objective can be summarized in two goals, the latter being the main one:

1. **Identify necessary criteria for suitable life cycle assessment tools at the case company, Haldex**

Use the knowledge and recognition of these to:

2. **Design applicable life cycle assessment framework**

The two goals are interrelated in such a way that number one – identifying key criteria – will be needed for the larger goal, to successfully develop a life cycle analysis method, or framework, since the latter's usefulness is of high importance to the case.

1.3.2 Delimitations

The thesis will focus on evaluating the possibility of introducing a life cycle assessment framework at Haldex in Landskrona and the author cannot guarantee that the results will be applicable or the most suitable framework on other Haldex sites or locations. However, it is intended to be applicable for the entire product portfolio.

1.4 Framework of the report

The following chapters are all introduced with a short summary and the report follows a logical order, of which the outline is presented below:

- Chapter 1, *Introduction,* intended to provide readers with content to the thesis, giving background to problem definition, purpose, objectives and the text's framework.

- Chapter 2, *Methodology,* research methodology for the thesis is presented and explained, as well as an account of research and data collection methods.

- Chapter 3, *Frame of reference,* provides literary background and concepts behind the thesis, including corporate social responsibility, the pillars of sustainability and life cycle assessment theories.

- Chapter 4, *Empirical study*, intended to provide conclusions on which environmental- and Haldex areas are important to analyze for the purpose of designing a suitable assessment framework. Environmental impacts from a typical Haldex product are identified in order to understand the scope and data need of said framework. Additionally, criteria for the Haldex assessment framework are presented. The empirical study is conducted with the help of methods explained in the methodology chapter.

- Chapter 5, *Analysis,* based on the empirical study and frame of reference, the analysis provides a screening of assessment tools and introduces theories of models that fit the criteria and requirements for the specific Haldex life cycle assessment framework.

- Chapter 6, *Proposition,* final conclusion, the framework and its tools are described. The framework has been designed through knowledge gathered from the analysis.

- Chapter 7, *Discussion and work down the road,* reflections are stated regarding the working procedures of the thesis and chosen methodology together with recommendations on implementation and future work.

2 Methodology

In the following chapter research methodology chosen for the thesis is introduced and choices are clarified. This is followed by theory regarding different approaches to data gathering and the preferred method used in this research is explained. Further, the chapter ends with a discussion on how to secure the credibility of the data and the study.

2.1 Research methods

Research methods are tools to solve a problem and generally imply the various techniques and procedures used to collect data and information about the research subject. A general saying is ”all forms of research are needed since all research problems cannot be solved with one research approach.“ This implies that there are several different methods to approach research problems. As long as the approach is well reasoned and rationalized it can thus be valid for the research at hand.[8] Some common perspectives that often affect a researcher’s choice of method are whether the research is more positivistic in nature or whether it is deemed to have added value from a more interpretive style. These perspectives will be discussed below.

2.1.1 Positivism vs. Interpretivism

Positivism vs. interpretivism concerns an area dubbed the ”theory of knowledge” and a research field called epistemology. One often asked question is the acceptability and recognition of specific know-how, what can and what cannot be seen as valid knowledge within a subject area. Especially important is the question whether social reality

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[8] Frankel *et al.*, ’The white space of logistics research’, 2005.

can and should be studied with the same principals and methods practiced within natural science. Positivism concerns the viewpoint regarding the importance of following and imitating the perspective of natural science whereas interpretivism is the perspective based on the importance of proper understanding and interpretation.[9]

Though it is hard to pinpoint everything positivism is accredited with, some principles are oftentimes mentioned:

- Only appearances - and thus knowledge - that can be verified through the senses should be recognized as real knowledge.
- The purpose of positivism is to create hypotheses which can be tested and thus make it possible to challenge explanations and their laws.
- Knowledge is achieved through gathering of information, which is what create the foundation of laws and their regularity.
- Science should be free of assessment and judgment.
- There is a clear difference between scientific and normative claims and only the former belong with the natural science field.

From these principles it is possible to deduce another viewpoint of positivism, to separate between theory and research. The main role of research is seen as the work to test theories and to provide material for the development of laws. Based on this thinking, theoretical terms that cannot be properly observed with strict requisites are deemed unscientific.[10]

The perception of fundamental differences between social scientific case studies and those from natural science is the reasoning behind another perspective, the interpretivism.

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[9] A. Bryman, E. Bell, *Företagsekonomiska Forskningsmetoder*, 2011.
[10] Ibid.

This perspective is based on the alleged importance of a strategy that recognizes the difference between humans and case studies of natural science. The researcher must here try to capture the subjective signification and meaning of social actions. This perspective states that social reality is meaningful and therefor also human actions are meaningful. As opposed to positivism, where theory's relation to research is to be tested, interpretivism's greatest value lies in generating theories. This perspective, and a research being more interpretative in nature, usually leads to a higher use of qualitative research approaches, whereas quantitative approaches are commonly utilized when the research is of a more positivistic essence.[11]

2.1.2 Qualitative and quantitative research

Research methods can commonly be found on a spectrum ranging between two extremities, one side being more objective (quantitative research methods are prevalent) whereas the other side has a more subjective style (qualitative research methods have a higher level of acceptance). The objective approach tends to emphasize measurement as well as analyses and relationships between studied variables. To achieve this, oftentimes statistical elements are introduced and designed to quantify how studied objects behave or respond to action in certain ways. Through adding new knowledge and testing hypotheses (putting them up for elimination), new laws are found and explained, usually through searching for regularities. A criticism occasionally used against quantitative research methods is how the complexity of the elements used to analyze these objects can make it difficult to interpret the results, as well as the very large sample sizes needed to achieve reliable results. Likewise, information can be difficult to understand and is often thwarted by the social context and perspective of the researcher.[12]

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[11] A. Bryman, E. Bell, *Företagsekonomiska Forskningsmetoder*, 2011.

[12] Frankel *et al.*, 'The white space of logistics research', 2005.

To be able to study social and cultural phenomena, usually the more subjective and interpretive style of qualitative research methods are applicable. These methods make a point of understanding the inside of the world rather than the outside – because the world is allegedly relativistic and only from a first-person point of view can one truly understand the surroundings. Qualitative research methods regularly face critiques of being non-scientific and biased, being called almost more journalistic in nature than they are scientific. A qualitative researcher would say it is necessary to use such exploratory research though, to get familiar with a setting, its context and human constraints, before more strict research is initiated.[13]

2.1.3 Research approach for the thesis

To develop an LCA framework, suitable for the way Haldex operate, different data collection methods such as interviews, observations and general participation will have to be conducted. To find relevant processes that ought to be incorporated in the model, the perspective of generating theories, interpretivism, rather than strictly testing hypotheses, positivism, is useful. Since this work, and the methods mentioned above, will require studying behavior and practices from the inside – an exploratory procedure - the analysis will use mainly a qualitative approach. Inputs from interviews, observations etc. are mostly subjective which also supports this approach.

2.2 Data collection methods

To do legitimate analyses a researcher must use reliable and valid information. Bryman and Bell mentions some of the most commonly used gathering methods, from both quantitative and qualitative research and name them; interviews, surveys, observations, content analysis,

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[13] Frankel *et al.*, 'The white space of logistics research', 2005.

literature reviews, experiments and focus groups.[14] The different methods have specific advantages in some circumstances and disadvantages in others, which is why, like with research methodology, not all data collection methods suit all research questions. Due to this, it is oftentimes advisable to use a mixture of methods to get the full picture of a complex study.[15]

In this research a combination of interviews, observations, literature reviews and content analysis are to be used and these methods be discussed more comprehensively in the following subchapters.

2.2.1 Primary data

Primary data consist of data that the researcher gathers him/herself, and which is not already gathered data from a second source. Hence, the researcher will be more familiar with the material and can more easily ensure the quality of the data – two often highly valued advantages when conducting complex research. Interviews and observations are two of the more familiar sources of primary data, though the former can also be of a secondary kind.[16]

2.2.1.1 Interviews

Interviews are likely the most frequently used data collection method within qualitative research and the flexibility it offers is surely a possible reason why. The method consist of information being gathered through direct answers to questions, and interviews can be conducted by both posing predetermined questions using a template, or the interview can be more of a conversational nature. Further, the technique can either use questions with fixed response alternatives or open questions, and sometimes

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[14] A. Bryman, E. Bell, *Företagsekonomiska Forskningsmetoder*, 2011.

[15] Frankel *et al.*, 'The white space of logistics research', 2005.

[16] R. Patel, U. Tebelius, *Grundbok i Forskningsmetodik*, 1987.

both.[17]

An advantage to collecting data through interviews is the possibility of modifying the questions and course of the interview according to the respondent's answers, as the interview is being conducted. Thus this method opens up for a possibly deeper level of understanding regarding the target subject. However, it can sometimes be time-consuming.[18]

Within qualitative research, unstructured and semi-structured interviews are considered the two most important types of interviews, though there also exist a completely structured type. The latter takes the form of a verbal survey where the interviewee have fixed respond options, whereas the two former types are more loosely conducted by the researcher and different underlying motivations, beliefs and actions are meant to be uncovered. With less structured interviews, the interest can more easily be targeted against the respondent's viewpoints while a structured interview usually mirror the interest of the researcher instead.[19]

In this thesis the purpose of conducting interviews is to get a greater sense of which processes in Haldex' operations are environmentally relevant and may directly or indirectly cause environmental impact, as well as to get an understanding of the current level of environmental knowledge in the company. To achieve this a structure to conduct the interviews shown in Figure 2.1 will be followed. This structure implies that unstructured interviews will initially be used to get a greater sense of the company and its work, while gradually more semi-structured interviews are to be held, in order to validate ideas and suggestions about the framework being created. It is also possible that the latter phase will include completely structured interviews if specific input is needed for the

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[17] R. Patel, U. Tebelius, *Grundbok i Forskningsmetodik*, 1987.
[18] M. Björklund, U. Paulson, *Academic Papers and Theses,* 2004.
[19] A. Bryman, E. Bell, *Företagsekonomiska Forskningsmetoder*, 2011.

design. Both phases are part of a complete research system with the main goal of being able to create a suitable life cycle assessment framework for Haldex, including recommended analysis tools. The circular arrows in Figure 2.1 indicate the ever-present possibility of new data and ideas a long the way, and thus a possible need of an iterate research. By talking to the people who might eventually use the framework early, they will have the chance to influence the project and possibly the suggested tools, which could reduce risk of aversion to something new. To get as broad information as possible, interviews will also be held with people at different positions across various stages of the supply chain; from development to sourcing to logistics and sales.

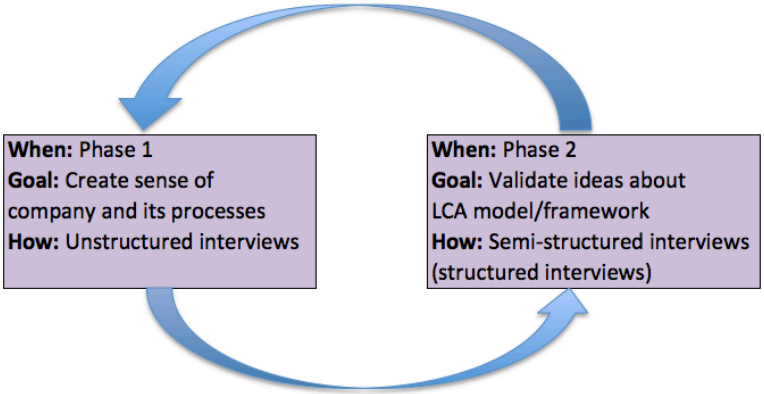

Figure 2.1. Interview flowchart.

2.2.1.2 *Observations*

Observations imply a direct first person perspective of the studied object or activity and the recording of its behavioural patterns. Active observations are common within the field of qualitative research and is conducted by the researcher placing him/herself at the setting and social milieu to try and get a sense of how the setting works, and what the individuals attribute to the setting. Other observation methods include non-active observations (where the researcher watch from a distance), and different levels of structured observations, where strict predetermined rules exist to observe and register the findings.[20]

Observations will be made during the entire research process and these will include daily interaction at the headquarter in Landskrona. The goal of the observations is to observe different areas of the company and achieve further knowledge of all the different work processes, in order to increase the understanding of which processes are causes of environmental impacts.

2.2.2 Content analysis

Though content analysis is similar to several types of observations, it is such a commonly used method that it is possible to rationalize its usage as a stand-alone data collection approach. By systematically analyzing texts, websites, documents etc., through dividing information into predetermined categories, content analysis helps the researcher achieve a broad and extensive coverage of data. By having the same process be standardized and repeatable, it is an often unobtrusive, yet flexible, method.[21] Methods for collecting secondary data are explained in the subchapters below.

2.2.3 Secondary data

There are a few advantages of using secondary data, i.e. already gathered data. Finding the data yourself can be both costly and time-consuming and, if the source is credible, very large, valid information samples can be found. From these it is also possible to conduct analysis of subgroups or subsets and even cross-functional analyses. Likewise, secondary data is often useful to create necessary theoretical foundation for further studies.

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[20] A. Bryman, E. Bell, *Företagsekonomiska Forskningsmetoder*, 2011.

[21] Frankel *et al.*, 'The white space of logistics research', 2005.

2.2.3.1 *Literature review*

A literature review implies a study of written material such as books, journals, reports etc., which is an often resource effective method used to find large amounts of information and to map the already existing knowledge within the targeted field[22]. When exploring existing knowledge and reviewing written sources, trustworthiness of the sources and their content must be considered. An author’s objectiveness to the subject should also be considered, similar to when conducting interviews.[23]

The intent of this thesis’ literature reviews is to gain a solid foundation of theories regarding life cycle analyses and the modern sustainability development, as well as increase the understanding of company processes and culture at Haldex. The reviews will thus include analysis and reflection on previous collected data, both regarding life cycle analyses concepts and today’s environmental context as well internal information about Haldex as a company. A thorough study of LCA models, tools and principles will be conducted.

Several books will be studied during the research, one example being *Life Cycle Assessment (LCA)*, by Walter Klöpffer and Birgit Grahl, which will be one of the main sources of information for the Frame of reference chapter, and used to receive academic guidelines to LCA in practice and its various stages. Further, to receive an academic foundation, the Lund University library catalogue Lovisa, as well as search engines such as LibHub and LUBsearch will also be used in order to find relevant academic journals etc. To increase the understanding of Haldex as a company, Haldex’ intranet will be used for internal data collection.

Key words to find appropriate literature include sustainability, life cycle, life cycle assessment, life cycle

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[22] M. Björklund, U. Paulson, *Academic Papers and Theses,* 2004.

[23] R. Patel, U. Tebelius, *Grundbok i Forskningsmetodik*, 1987.

inventory, carbon footprint, corporate social responsibility, environmental design and more.

2.3 Trustworthiness

To ensure the merit of the research, input data should be of high quality, as should any final recommendations. To create trustworthiness and make sure the research is insightful one would like to know if the result is valid, reliable and also valuable. For qualitative research a few different principles can be studied further to evaluate this and these principles - authenticity, reliability and transferability - will be discussed in the subchapters below.

2.3.1 Authenticity

A type of validity worth mentioning is authenticity, which implies that any data or results should be authentic. Further, it implicates that what is studied, or who, should be able to recognize themselves in the study. That however does not mean that any result highlighting contradictions and inconsistencies is not authentic but rather insinuates the importance of not distorting the research without specific reasons. Authenticity can be increased by going back to interviewees a second time and give them a chance to clarify or confirm what was said the first time (this as long as the respondent does not want to change prior truthful statements which obviously does not make it authentic.).[24]

2.3.1.1 Validity

Validity is a criterion concerned with whether the research is built on the right foundation or not, i.e. if we are researching what we truly want to research, given the study. As shown in subchapter 2.3.1 above, validity has several meanings, especially when conducting qualitative research.

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[24] J. Alvehus, *Skriva uppsats med kvalitativ metod: En handbok,* 2013.

Another aspect to consider is that results and conclusions should preferably be built on systematic work including data gathering and analyses. A systematic work implies using methodological reasoning to challenge and build the research approach and be able to prove the history of the subject, by ways of documented recognition. Another perspective of validity is whether the knowledge claim is credible in the eyes of others, i.e. the importance of having a communicative aspect in the research, by testing the relevance and strength of newfound knowledge and conclusions through dialogue. A final way to describe validity is pragmatically, which means to view its relevance from a larger perspective. A question to ask is whether the newfound knowledge and result is significant and possibly applicable elsewhere, or not.[25]

To ensure the authenticity and validity of this study, interviews will be conducted according to the flow earlier described in Figure 2.1, where ideas and newfound knowledge is tested iteratively. Interviews with several individuals across various divisions of the company will also be held. The major goal of this thesis is to create a life cycle assessment framework that is applicable for the way Haldex works, which is why the author will, through every stage of the process, pragmatically think of its final convenience and possibility of adoption.

2.3.2 Reliability

Reliability is another perspective used to discuss the quality of the research and its findings. This criterion targets whether the result is repeatable or not and examines if the measurement is dependable, i.e. if the same research is conducted again, would the results be the same? However when conducting qualitative research a large part of the work is built on interpretation, which interferes with the classical meaning of reliability mentioned above. Thus

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[25] J. Alvehus, *Skriva uppsats med kvalitativ metod: En handbok,* 2013.

other suggestions on how to discuss reliability in qualitative research have emerged, one such example being credibility.[26]

Credibility is a criterion judging the final results based on how well the theoretical ideas developed seem to follow the researcher's observations. This is interesting because, especially in qualitative research, there is oftentimes a possibility of different social behaviors emerging during the groundwork, which may or may not affect the results.[27]

In order to ensure the credibility of the research, and to dilute possible outlier observations and findings not relevant due to irregular social behavior during the data-gathering phase, multiple sources of data from several data-gathering methods will be used.

2.3.3 Transferability

Transferability refers to the ability of transferring findings and attained knowhow to other situations and similar activities. Though qualitative research oftentimes is dependent on the context of the events studied, it is regularly used as the foundation for more generalized findings.[28]

The result of this thesis should be comprehensively written and contain detailed descriptions to ensure any readers and stakeholders can make proper evaluations about the finding's transferability. The chapters regarding frame of references and empirics will thus contain a foundation of underlying concepts and ideas. The final framework and tools should preferably be generic enough, so that it works on most new products or product changes in the Haldex' product portfolio.

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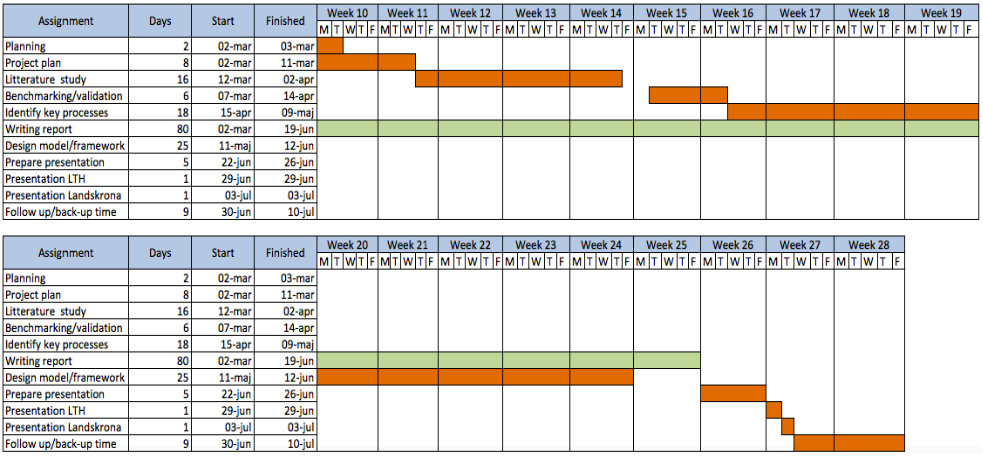
[26] J. Alvehus, *Skriva uppsats med kvalitativ metod: En handbok*, 2013.
[27] A. Bryman, E. Bell, *Företagsekonomiska Forskningsmetoder*, 2011.
[28] Ibid.

2.4 Research development

Figure 2.2 illustrates the logical order of the research. The first stage is a problem definition phase, which implies also setting up realistic and approved objectives. For the next phase building a theoretical foundation and enough know-how to succeed with the aspirations and goals of the thesis is of importance. This will be achieved through an extensive literature review and content analysis ranging through a large part of the research process. Both preconditions internal to the company, as well as external preconditions that the author can identify, must be explored to deem their relevance for later analysis. A benchmarking with other firms, as well as online publications, will also be held to validate ideas and thoughts acquired in the literature review phase. Further into the work, different types of interviews and observations will be conducted, to gather inputs about processes at Haldex. This phase also consist of further studying the concepts about LCA theory and analysis of current environmental work at Haldex. One of the last phases will consist of creating a life cycle assessment framework suitable for Haldex. The analysis and design of the framework will be conducted gradually in a loop structure. This project will end with recommendations on future work and a verbal presentation of the work in Landskrona. Thesis writing will likely be on going through each phase of the research process, to ensure an even distribution of the workload.



Assignment	Days	Start	Finished
Planning	2	02-mar	03-mar
Project plan	8	02-mar	11-mar
Litterature study	16	12-mar	02-apr
Benchmarking/validation	6	07-mar	14-apr
Identify key processes	18	15-apr	09-maj
Writing report	80	02-mar	19-jun
Design model/framework	25	11-maj	12-jun
Prepare presentation	5	22-jun	26-jun
Presentation LTH	1	29-jun	29-jun
Presentation Landskrona	1	03-jul	03-jul
Follow up/back-up time	9	30-jun	10-jul

Figure 2.2. Order of the research.

3 Frame of reference

The following chapter will provide the literary background and reference for the thesis and thus cover key ideas and essential concepts of the work and the purpose behind the study. Literature studies and content analysis of books, journals and publications make up the foundation the chapter is based on. Concepts behind corporate social responsibility, the three pillars of sustainability and the Triple bottom line are presented. The chapter ends with the framework behind a full-scale LCA.

3.1 Corporate Social Responsibility

What does it mean for a company to be socially responsible? The concept corporate social responsibility (CSR) and its believed value have undergone a big journey for the past several decades. Though its agreed-upon definition may vary slightly depending on whom you talk to, one often-used definition today would be variations of “the responsibility a company takes for society and its environment”.

Corporate social responsibility is believed to first have been mentioned in the early 1960s but a pioneering aspect of the term, corporate philanthropy, likely started a change already a decade earlier. AP Smith Manufacturing, a New Jersey US company, was then allowed to donate $1500 to Princeton University without violating shareholder interest. In the lead up to this, shareholders had disapproved of the gift and claimed it was against the directors’ duty to act against shareholder interest. However, the New Jersey Supreme Court cleared the way for the company with its donation and this publicized 1953 ruling is believed to have opened the doors for a new view of what corporates could do for their environment and society.[29]

Following the 1950s, with its early corporate philanthropy, came the 60s and 70s, an era where modern activism exploded in many countries, and as a result continued to change the business environment. During the 1970s attention was given to social responsiveness, not just responsibility, indicating that often pure action was being overlooked and many now claimed that corporates had a duty in working both with corporate action and proactive action on the social scene. Thus came several social legislations during this decade such as the creation of the Environmental Protection Agency (EPA), the Equal Employment Opportunity Commission (EEOC), etc. This meant that, from then on, corporations had stronger incentives to view environment, employees, consumers and more as legitimate stakeholders of their business.[30]

Today this mean that corporations have to balance commitment to their owners while at the same time satisfying larger groups of stakeholders and their needs, both of which may be legal or ethical. NGOs, activist groups and the everyday man, through social media, often closely monitor public practices including those from corporations. Acts that the public consider irresponsible or unethical will in turn often bring unwanted media attention. The thought is that unwanted media attention can seriously damage a brand and its reputation, which likely could mean unhappy customers and a decrease in sales for the firm. Additionally many also believe that it can affect employee satisfaction and thus the firm risk not being able to attract the best work force and possibly also a high turnover rate of employees. With an increasing amount of everyday people and potential customers caring about responsibility for a

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[29] P.L. Cochran, R.A. Wood, ”Corporate Social Responsibility and Financial Performance”, 1984.

[30] Ibid.

sustainable society, there are nowadays also unwanted corporate restrictions and regulations any negative media attention can lead to. In this media rich environment, and everybody being only a few seconds away from connecting with people all over the world, it is now more than ever important for firms and corporations to have and to keep a good reputation. Word of mouth travel faster than ever and with a good repute the firm will already have an edge over many of their competitors and are likely to be more trusted and experience positive media coverage. Over the past 50-60 years, corporate social responsibility has thus become something that, if not dealt with seriously and often also genuinely, a firm will nowadays have to deal with serious consequences, both from governments, media and customers.[31]

Though accepted by most firm owners of today as an important strategic tool, the crux of CSR continues to be that a company with shareholders is first and foremost a business with an economic role and obligation to fulfill the corporation- and shareholder interests. Critics thus say that CSR goes against or may take focus from a company's economic role. On the other side is proponents saying CSR is not just non-profitable window-dressing but something that actually may increase a company's long-term profit.[32] Is there necessarily a conflict of interest between economic growth and social responsibility? Michael Porter and Mark Kramer, through an article in *Harvard Business Reviews*, put it in a concise way:

"[i]n the long run...social and economic goals are not inherently conflicting but integrally connected"[33]

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[31] M. Malik, "Value-enhancing Capabilities of CSR: A Brief Review of Contemporary Literature", 2015.

[32] Ibid.

[33] M.R. Kramer, M.E. Porter, ''The competitive advantage of corporate philanthropy'', 2002.

They argue that many business decisions might be socially viable - meaning that economical investments often have social returns – and vice versa. This is, according to them, natural and implicates that businesses should consider projects that have meaningful returns of both. Porter and Kramer are saying that firms should use the very meaning of corporate strategy to find areas in which their specific business proposition find value for both the firm as well as society, areas where social and philanthropic interests are aligned with the firm's specific know-how. In finding social needs close to ones area of expertise, the company will likely also be more efficient in addressing these needs, and may also expect greater long-term profit, according to Porter and Kramer, who states that one should exploit the synergies between the social and the economic, rather than minimize them.[34]

3.2 Three Pillars of Sustainability

It would seem difficult for anyone to have missed the increase talk of sustainability over the years. However, though the term is old, it is not until the last few decades when we have really begun to view the term sustainability from different perspectives. At the World Commission on Environment and Development in 1987, the United Nations said about sustainability:

> *"The development that meets the needs of the present without compromising the ability of future generations to meet their own needs."*[35]

To do this complex situation justice it requires having to look at sustainability from different perspectives which is why the UN decided on a new framework, the *three pillars*

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[34] M.R. Kramer, M.E. Porter, "The competitive advantage of corporate philanthropy", 2002.

[35] C. Gimenez, J. Rodon, V. Sierra, "Sustainable operations: Their impact on the triple bottom line", 2012.

of sustainability, with three individual perspectives of sustainability recommended to be handled with care going forward:

1. Environmental
2. Social
3. Economical

These perspectives, along with UN's stated definition, indicate sustainability nowadays mean to not only protect the environment long-term, but to also maintain social and economic well-being for both current and future generations. Due to these definitions, working responsibly today means a consideration of – and possible balance of – natural, human and economic capital.[36] A further look reveals how each pillar has its own complex meaning. Social sustainability for example tells that any sustainability work should not only be socially- but also ethically viable. Though a desire to balance the pillars equally, trade-offs and conflicts of interests are regularly occurring (biodiversity vs. costs of preserving it among many other examples). Trade-offs thus have a constant presence when discussing sustainable development questions, also at company levels.[37]

Though trade-offs are likely to always be part of the sustainability agenda, lately people driving change have begun to talk about how looking for synergies during any development question is worth going the extra mile for. The quest is to find room where socioeconomic outputs and state of environment are all increased and to do so requires a new way of thinking - system thinking - which produces positive

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[36] General Assembly, //www.un.org/en/ga/president/65/issues/sustdev.shtml, viewed on 15 March 2015.

[37] Frischknecht *et al.*, "Principal sustainability components: empirical analysis of synergies between the three pillars of sustainability", 2012.

outcomes for all three pillars. One such example is the trade-off regarding biodiversity and cost of defending a beautiful scenery, which long term will increase both desire to live in an area as well as tourism, which would increase profit for local communities. For industry heavy corporations another example would be the work of sustainable or green technology, which could reduce use of nonrenewable energy sources and/or other waste and emissions, and in turn lead to cost reductions and better living conditions.[38]

3.3 The Triple bottom line

An extension of the three pillars of sustainability, and a way to operationalize the pillars, is through the triple bottom line philosophy. The triple bottom line is a management and accounting framework that wants to expand the way corporations interpret the bottom line, which refers to the profit or loss which is reported at the very end of a business activity, i.e. revenues or expenses. Only looking at economic profit reduces the complexity of the formulas and thus the efforts needed as inputs, however following the increased awareness of a need for smart development, many organizations desire a method to evaluate their work in a broader context than that. The Triple bottom line model thus expands the bottom line concept into three P: s, *profit, planet, people,* which together describe the goal of sustainability - to do good by these factors. When corporations apply this goal in their business model, sustainability becomes no longer just an ethical choice for them. Now they not only have economical obligations towards regular shareholders, but also various interests from an increased amount of stakeholders – really anyone who is affected by the actions of the firm.[39]

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[38] C. Gimenez, J. Rodon, V. Sierra, “Sustainable operations: Their impact on the triple bottom line”, 2012.

[39] P. Ahi, C. Searcy, “Assessing Sustainability in the Supply Chain: A Triple Bottom Line Approach”, 2015.

To achieve not only economical profit, but also to increase environmental and social profit, firms likely have to implement new programs, activities or tools in their business models. Developing initiatives to increase sustainable awareness in the entire supply chain and life cycle of product systems is one way of working to achieve this goal. The latter is a possibility by working with environmental analysis models such as LCA or life cycle inventory studies (LCIs). As mentioned in Section 3.2, the main objective is to find synergies and studies show that firms successfully implementing environmental action programs often see improvement in both environmental, social and in economic performance. There may be several explanations of why, one being less waste as well as cost savings derived from resource reduction and increased efficiency.[40]

The following section and its subchapters will provide a closer look at one popular environmental analysis method, the full-scale, life cycle assessment.

3.4 Life Cycle Assessment

3.4.1 Life cycle

The life cycle of a product, service or product system includes every step and phase of the object, from an idea, to extraction of raw materials, to the final end-of-life phase, usually when the product is no longer in use due to the technical or economical lifetime having passed. This is called a *cradle-to-grave* analysis, when the entire life cycle is investigated. Naturally, depending on type of corporation and industry, one product's life cycle and its smaller phases

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[40] C. Gimenez, J. Rodon, V. Sierra, "Sustainable operations: Their impact on the triple bottom line", 2012.

will often look different from many other life cycles.[41] A simplified life cycle of a tangible product is shown below, in Figure 3.1.

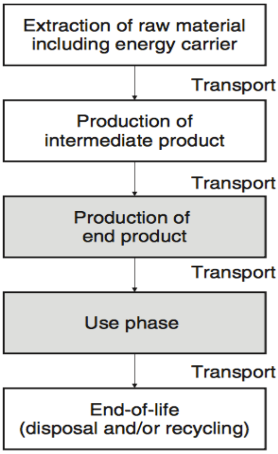

Figure 3.1. Simplified life cycle of a product.[42]

A closer look at most life cycles would reveal several more processes, for example larger ones like manufacturing, assembling of parts, distribution, maintenance, reparations, disassembly and more. In turn, these are also possible to break down even further, into subprocesses.

3.4.2 International Organization for Standardization

The International Organization for Standardization (ISO) has, for nearly 70 years, been providing guidelines and requirements for standards, which they have published and developed for the world to see. With 163 member countries, it is a non-governmental and independent organization whose standards give specifications for products, services and systems, enabling and facilitating trade as well as ensuring quality, safety and efficiency. The ISO 14000

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[41] M.A. Curran, *Life Cycle Assessment Handbook: A Guide for Environmentally Sustainable Products*, 2012.

[42] B. Grahl, W. Klöpffer, *Life Cycle Assessment (LCA): A Guide to Best Practice,* 2014.

series is a family of standards regarding environmental management and it is under this category where the standards 14040 and 14044 are found, which specifically deals with life cycle assessment.[43]

3.4.2.1 ISO 14040/14044

ISO 14040 and 14044 describe the framework for full-scale LCAs, as well as principles and directions. The standards also contain a description of LCA that reads:

> *”LCA studies the environmental aspects and potential impacts throughout a product’s life (i.e. cradle-to-grave) from raw material acquisition through production, use and disposal. The general categories of environmental impacts needing consideration include resource use, human health, and ecological consequences”*

The ISO standards are regularly revised and the latest big update was done in 2006, although these, regarding environmental management, were reviewed in 2010. [44]

Highlighted in these standards are the ISO certificated structure of an LCA and the inclusion of mandatory phases in a legitimate full-scale study, see Figure 3.2. These phases are:

1. Goal and scope definition
2. Inventory analysis
3. Impact assessment
4. Interpretation

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[43] About ISO, http://www.iso.org/iso/home/about.htm, viewed 20 March 2015.

[44] ISO14040:2006,http://www.iso.org/iso/home/store/catalogue_tc/catalogue_detail.htm?csnumber=37456, viewed 20 March 2015.

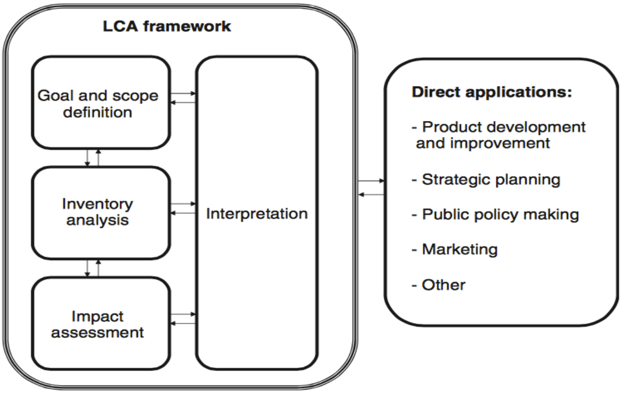

Figure 3.2. LCA phases according to ISO 14040.[45]

As seen in the figure above, ISO 14040 (and 14044 which builds on the aforementioned standard and completes the framework) also contain possible applications for an LCA study. These include product development and improvement, public policy making, marketing and more.[46]

Detailed descriptions of the four required phases are also given by the standards, though no specific methodologies for each phase are presented. A closer look at the phases is presented in the subchapter below, Full-scale LCA structure.

3.4.3 Full-scale LCA structure

Figure 3.2 above shows arrows in both directions between each phase in a full-scale LCA. These indicate that conducting such a study often requires an iterative way of working. The four phases are nowadays internationally mandatory if wanting to do a full-scale LCA and as will be seen in this section, full-scale LCAs in practice are almost always highly resource demanding.

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[45] ISO14040:2006,http://www.iso.org/iso/home/store/catalogue_tc/catalogue_detail.htm?csnumber=37456, viewed 20 March 2015.
[46] Ibid.

3.4.3.1 Goal and scope definition

Defining goal and scope is the first phase of an LCA and according to ISO, it means:

> *”The goal and scope of an LCA shall be clearly defined and shall be consistent with the intended application. Due to the iterative nature of LCA, the scope may have to be refined during the study.”*

This phase requires giving and writing answers to questions ranging from what the objective of the study is, to why it is being conducted and for whom it is done, as well as if it is meant to be made public. After having answered these questions a closer look at the system is required. This step is preferably conducted through creating a system flow chart where all unit processes in the studied system are to be shown as well as their relationship with one another.[47]

The goal and scope definition should additionally include chosen cut-of-criteria (used to potentially exclude processes from the system flow chart), natural-, technical- and system boundaries, as well as geographical boundary and time horizon. The first phase of the study also requires an LCA conductor to state what allocation methods should be used to create fairness, if for example one process also produces outputs due to objects outside of this study. The researcher will have to state what type of data he/she presumably will need for the study, whom collects it and how, as well as what data likely will need to be procured from whom.[48]

Also included in the goal and scope definition should be the chosen impact categories – indicating what harm (or benefits) the outputs and flow have on the environment,

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[47] B. Grahl, W. Klöpffer, *Life Cycle Assessment (LCA): A Guide to Best Practice,* 2014.

[48] Ibid.

information that is required later on in the study. Additionally their indicators and characterization factors should also be included. If the firm operates in a risky environment, risk assessment for special situations should also be mentioned, according to ISO.[49]

Another important step and key element in this phase is to determine the functional Unit (fU). The functional Unit determines equivalence between systems and is a measure of the function of the studied system. A common method to decide on fU is to use annual quantities. If the study includes products of particularly high lifetime, a length of use-time must also be included in the description of functional Unit.[50]

3.4.3.2 Inventory Analysis

The second phase of conducting a full-scale LCA is the inventory analysis. In short, this phase is a material and energy analysis where the system flow chart is developed even more than was conducted during the goal and scope definition. The inventory analysis description according to ISO 14040:

> *"(...) phase of life cycle assessment involving the compilation and quantification of inputs and outputs for a product throughout its entire life cycle".*

In this phase, all unit processes within the system boundaries of the system flow chart should be looked at and the energy and material flows quantified. As seen in Figure 3.3 below, all product systems have inputs and outputs consisting of material and energy flows. By doing a thorough and extensive data collection, it is possible to look

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[49] ISO14040:2006,http://www.iso.org/iso/home/store/catalogue_tc/catalogue_detail.htm?csnumber=37456, viewed 20 March 2015.

[50] B. Grahl, W. Klöpffer, *Life Cycle Assessment (LCA): A Guide to Best Practice,* 2014.

at the inputs and outputs of all the internal unit processes, with environmental impacts.[51]

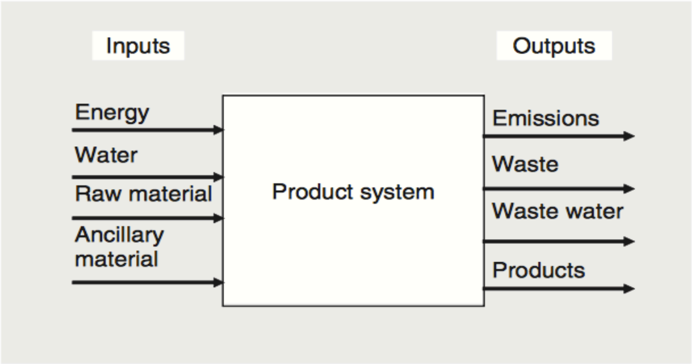

Figure 3.3. Energy and material flow of a product system. This overview of a system should be broken down further, to internal unit processes.[52]

It is very rare that all data needed will be easily available and can be procured as primary data. Contacting suppliers, sub-suppliers, etc. is usually necessary to analyze the full lifecycle and as such, data acquisition is usually one of the most complex and time-consuming parts of a full-scale LCA. For every data acquired it also needs to be documented regarding origin and quality, because, according to ISO 14040/14044, transparency and comprehensibility are central to legitimate LCAs. If data is missing, it will have to be estimated and tagged as such in inventory and later discussed in the interpretation phase.[53]

A final part of the inventory analysis is calculations of the data inventory. This is often done in software programs similar to Microsoft Excel and the allocation rules that were stated in the goal and definition phase should be used here.

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[51] B. Grahl, W. Klöpffer, *Life Cycle Assessment (LCA): A Guide to Best Practice,* 2014.

[52] Ibid.

[53] B. Grahl, W. Klöpffer, *Life Cycle Assessment (LCA): A Guide to Best Practice,* 2014.

3.4.3.3 Impact Assessment [54]

The impact assessment category is what makes a true LCA study and separates it from purely a life cycle inventory study (called an LCI, a study where the impact assessment phase is excluded). The full-scale LCA requires that the study considers and quantifies the potential environmental impacts from all of the system's inputs and outputs that interact with the environment. ISO describe this phase as follows:

> *"Phase of life cycle assessment aimed at understanding and evaluating the magnitude and significance of the potential environmental impacts for a product system throughout the life cycle of the product"*

This phase has a few mandatory steps and a few optional. First a clarification of the impact categories chosen in the goal and definition phase needs to be done. Here one also needs to describe the category indicator and characterization factor. For example the impact category "climate change" would in most cases have an indicator of "radiative forcing (Wm^{-2})" and a characterization factor of "global warming potential for each kg CO_2-equivalents/kg gas". ISO does not provide a list of impact categories so this is up to the researcher and conductor of the LCA to choose. When impact categories have been described, one should assign the inventory analysis' results to each relevant category, for example all greenhouse gases are to be assigned to "climate change" and acid-forming gases to "acidification". Then, with LCA software tools, it is possible to calculate category indicator results and get the full environmental impacts of the studied product system.

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[54] B. Grahl, W. Klöpffer, *Life Cycle Assessment (LCA): A Guide to Best Practice,* 2014.

3.4.3.4 Interpretation

Interpretation is the last step in a full-scale LCA and it is important because it is in this phase where one actually draws conclusions on what have been studied. To do so there are a number of things that need to be looked at. ISO 14040 notes that:

> "*Interpretation is the phase of LCA in which the findings from the inventory analysis and the impact assessment are considered together or, in the case of LCI studies, the findings of the inventory analysis only. The interpretation phase should deliver results that are consistent with the defined goal and scope and which reach conclusions, explain limitations and provide recommendations*".

The steps to achieve this is also given by ISO and contains identification of any significant issues noted in earlier phases as well as evaluations based on completeness, sensitivity and consistency checks. The sensitivity check in particular is mandatory according to ISO 14044 if choices between several allocation rules have been possible in the prior phases of the study. Such an evaluation is done to estimate uncertainties in the full-scale LCA, possibly created by the choice of cut-off criteria, impact categories, and allocation rules as well as due to uncertainty in data quality.[55]

Finally the LCA result should be reported to the intended audience where the different phases, assumptions, methods, limitations, results, conclusions etc., are addressed. If the LCA is intended to be made public, there needs to be a critical review of it as well, beforehand. This is done by an

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[55] *ISO 14044:2006, http://www.iso.org/iso/catalogue_detail?csnumber=38498, viewed 5 April 2015.*

independent panel which controls whether the methods are done according to ISO standards or not, if the methods are scientifically and technically valid, if the data have been used appropriately, if seemingly the right interpretations have been made and if the study is transparent. Such a review is not necessary if the study is only intended to stay inside the organization, possibly to be used as decision support.[56]

3.4.4 Different types of environmental analysis studies

The most thorough and legitimate, ISO-certificated environmental analysis model of today is the full-scale LCA, however it requires a lot of time and effort from the companies conducting them. Many smaller or medium sized companies (sometimes also larger ones) have found difficulties in operationalizing LCA as an analysis tool because of the large demand for resources, including time, money and qualified personnel to conduct them. In order for companies to start conducting full-scale LCAs regularly, they would need to make these resources available as well as gather practical and reliable environmental and process data to keep close (and be updated when needed), so as to not having to do extra work each time a new analysis is to be done.[57] For these reasons, particularly when it comes to decision making in the design phase, when little time is available, and it can be difficult to get quantitative and specific data, simplified LCA tools such as LCIs or carbon footprints are sometimes necessary means instead.

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[56] B. Grahl, W. Klöpffer, *Life Cycle Assessment (LCA): A Guide to Best Practice*, 2014.

[57] EPA, http://www.epa.gov/sustainability/analytics/life-cycle.htm, viewed on 12 April 2015.

3.4.4.1 Life cycle inventory study

As previously mentioned, an LCI is an LCA without the third phase, impact assessment. LCIs are also legitimate environmental studies according to ISO 14044 and, with small differences, also contain the phases goal- and scope definition, inventory analysis and interpretation. Conducting an LCI thus mean to mainly do an analysis of the resource usage and the emissions caused by the product system being studied. Integral parts of such a study are process chain analysis or energy analysis, also known as the cumulative energy demand, CED. [58]

Though LCIs are applicable when not enough resources are available for a full-scale LCA, there are reasons why, if time, money and personnel are available, LCAs are considered the more reliable, thorough study. First and foremost it is due to the complexity of energy and material releases. For example comparing two products or product systems where one is using less energy in its life cycle, but releases more toxic substances even with a small mass flow, it is not reliable to say that the first product performs environmentally better than the second one. If one wants to study potential environmental impacts, an impact assessment phase is necessary.[59]

3.4.4.2 Carbon footprint

Probably the most talked about and recognized environmental problem of today is global warming and a reduction of greenhouse gas emissions ought to be the natural solution, which is why measuring the carbon footprint and global warming potential (GWP) have become an often used study. Carbon footprint (CF) refers to global

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[58] B. Grahl, W. Klöpffer, *Life Cycle Assessment (LCA): A Guide to Best Practice*, 2014.
[59] Ibid.

warming potential and is a type of simplified life cycle analysis where climate change is used as the only impact category in the study. Though here it is advised to be cautious: when only one impact category is analyzed, it cannot be called a full-scale LCA, since it is not thorough enough and will not present the full picture of environmental impacts along the supply chain. For example, if the product system shows a low CF per fU, there may still be other environmental risks or impacts, which discourage this aspect. By focusing exclusively on carbon and only one impact category, it is possible to underrate the complexities of a product system's potential environmental performance.[60]

Still, measuring the carbon or ecological footprint of product systems is a potential life cycle assessment regularly used by many corporations (again, likely when resources are scarce or when global warming is the main driver for the sustainability policy) and thus there are also guidelines to follow here, in order to properly measure, calculate and report the CF. Guidelines developed by the World Business Council for Sustainable Development (WBCSD) and the World Business Resource Institute (WRI) are oftentimes recommended. The guidelines on how to conduct such studies are hoped to ease corporations into conducting them and doing so in a correct way. Today there are several national and international policies, such as the Kyoto-protocol and CO_2-certificate trading, exclusively regarding CO_2-emissions, which implicates that studies such as carbon footprint might be an interesting option for companies, again if necessary resources for a full-scale LCA is not available.[61]

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[60] M.J. Franchetti, D. Apul, *Carbon Footprint Analysis: Concepts, Methods, Implementations and Case Studies*

[61] Ibid.

4 Empirical study

In this chapter a preliminary study conducted to understand Haldex' important processes and supply chain is presented, beginning with an introduction to a typical Haldex product. Observations and conclusions from the pre-study are also included in the chapter, as is identified areas with environmental impacts related to a typical Haldex product. The chapter ends with conclusions from the pre-study and a set of tool criteria that is the basis for the analysis in Chapter 5.

4.1 Haldex' product portfolio

As mentioned earlier, Haldex develops, manufactures and distributes products for brake and suspension systems on commercial vehicles, with manufacturers of heavy trucks, buses, trailers and axle manufacturers as noted customers.[62]

The product portfolio consists of two main product categories:

- Product Range Foundation Brake
- Product Range Air Controls

The former product category includes disc brakes, automatic brake adjusters and actuators, which are wheel-end products for brake actuation and lining wear adjustment. The latter category includes air dryers, air suspension system valves and electronically regulated subsystems, and these are all products used to dehumidify,

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[62] Haldex Annual Report 2014.

clean and control compressed air in the brake system.[63] The brake adjuster, one of Haldex' oldest products, was used as reference when conducting interviews and during the pre-study on Haldex' internal and external processes.

4.1.1 Automatic brake adjuster

An automatic brake adjuster is an essential part of any air brake system, adjusting the brakes while the vehicle is being used and maximizes braking efficiency. The brake adjuster, seen in Figure 4.1, is attached to a brake drum and its various components, such as an S-camshaft, pressure rod and brake shoes. When braking occurs, air is let into the brake chamber, which thrusts the pressure rod out. The brake adjuster then, due to pressure from the rod, rotates the S-camshaft, which presses the brake shoes against the drum attached to the wheel. This completes the brake process.[64]

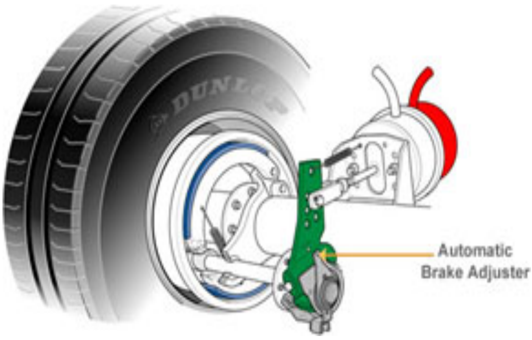

Figure 4.1. Automatic brake adjuster on a drum brake.[65]

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[63] Haldex, http://www.haldex.com/en/GLOBAL/Products/Product-categories/Brake--Suspension-Systems/, viewed on 25 March 2015.

[64] Haldex India, http://www.haldexindia.in/products/automatic-brake-adjuster.aspx, viewed on 18 April 2015.

[65] Ibid.

4.2 Preliminary study

To eventually being able and set appropriate criteria for a life cycle framework at Haldex, a preliminary study was conducted. Here relevant environmental impacts for a typical Haldex brake adjuster was studied as well as Haldex' own material supply chain and knowledge of environmental issues, with the reference being the Swedish Haldex' operations. Additionally, barriers (to understand the challenges with working with environment) but also drivers to work with environmental issues were studied as it was thought that people need motivation to start working with new routines and possible new work tools. With knowledge from the pre-study, the goal was to identify suitable requirements for the potential life cycle assessment tools at Haldex. The study was conducted with methods described in Chapter 2, such as:

- Interviews.

To get the full picture, each part of the supply chain at Haldex in Landskrona was examined, through various interviews with representatives from the different departments.

- Everyday site observations at Landskrona.
- Internal data from Haldex' Intranet.
- External data from relevant literature and interviews with independent parts such as environmental consultants and academia environmental experts.

4.2.1 Observations from pre-study

The most essential observations found during the pre-study were as follows:

Haldex

- Keeping low costs throughout the supply chain is very important for Haldex.[66]
- The brake adjuster's life cycle could be illustrated, as seen in Figure 4.2, and is larger than Haldex' own controlled supply chain, including both early raw material extraction from suppliers to Haldex' subcontractors, as well as end-of-life activities from end-consumers.
- In many Haldex' individual supply chain areas, environmental issues seem to be looked at more operationally than strategically, with for example keeping track of incoming materials and using lists to recognize hazardous chemicals.
- Haldex have data of materials and energy both entering and leaving the company, but up- and downstream supply chain data is harder to achieve and need to be asked of from subcontractors and customers.
- Possibly Haldex' R&D department's largest environmental mission today is working with weight optimization of their brake adjusters.[67]
- Haldex' supply chain includes materials from many different countries and also different modes of transport.[68]
- Design and purchasing departments have a central role and large effect on sustainability. Haldex want their suppliers to be ISO-certified but factors such as

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[66] Interview with SVP Research and Development, R&D.

[67] Interview with VP R&D, R&D.

[68] Interview with Manager Logistics, Operations.

quality and costs are primarily looked at when choosing suppliers to work with.[69]

- Haldex work with environmental performance indicators and the site in Landskrona also have yearly environmental goals, the 2014 goal being, amongst others, to reduce used chemicals.[70]
- Previous environmental work and action plans at Haldex have targeted CO_2-releases as an important problem to deal with.[71]

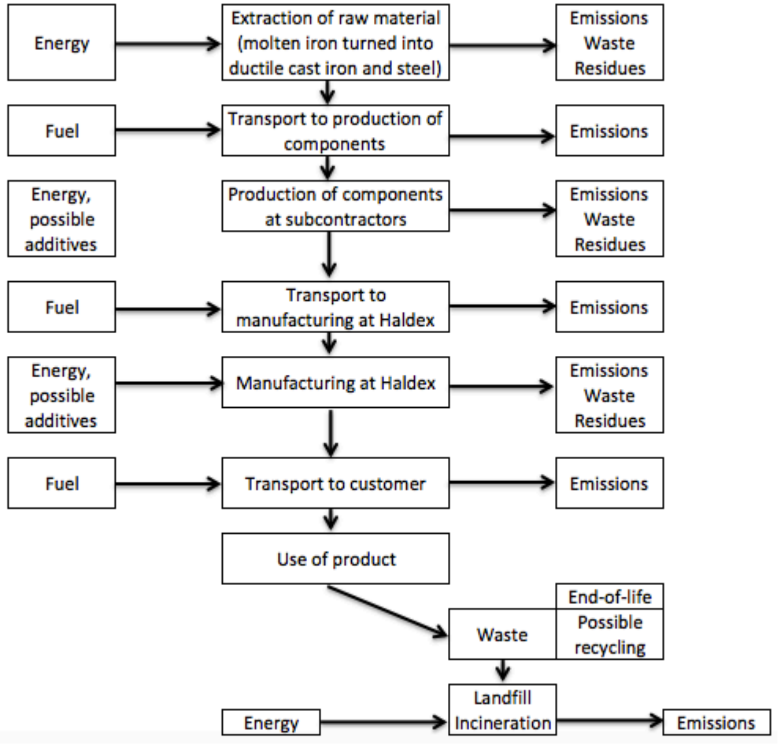

Figure 4.2. Flowchart over a Haldex automatic brake adjuster's life cycle.

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[69] Interview with SVP Global Sourcing & Logistics, Sourcing.
[70] Interview with Haldex' property manager.
[71] Miljöinfo, Haldex Landskrona, 2015.

Externally

- The automobile industry is increasingly caring more about environmental issues, much due to regulations and legislation but also customer requirements, to create a market position, follow competition, cost reasons and company policy.[72]
- Preventing sustainability in industrial supply chains are economy, lack of time, lack of competence, lack of routines, lack of motivation, lack of innovation or, simply, nothing.[73]
- Sustainability issues often seem related to the supply chain position. Companies close to the final customer generally focus on characteristics of the main function of the product, such as being lightweight or its energy efficiency, while a company up-stream focus on specific elements such as not using certain chemicals or materials, energy use in production etc.[74]
- In today's business environment it can be costly to not work with environmental issues, as seen in the subchapter below.

4.2.1.1 Environmentally related costs

From the preliminary study it was clear that Haldex, as any company with stake- and shareholders, care about the economy. To successfully start working with life cycle models, the needs from a business standpoint should be fully understood. One way of discussing these needs are to look at environmentally related costs, i.e. costs that, in one way or another, are attributed to the work done - or not done

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[72] Swerea Power Point, http://www.swerea.se/en/areas-of-expertise/energy-environment/lifecycle-asessment-lca, viewed on 20 April 2015.

[73] Ibid.

[74] Swerea Power Point, http://www.swerea.se/en/areas-of-expertise/energy-environment/lifecycle-asessment-lca, viewed on 20 April 2015.

- when it comes to the environment. It is important for a company to recognize that these costs are relevant for management decisions in all parts of the value chain, including product design, purchasing and for performance evaluations. One way of classifying these costs is a full-cost accounting based on four categories:

- Direct costs (waste management, maintenance, capital expenditure, etc.).
- Indirect costs (monitoring, training, etc.).
- Potential liabilities (potential fees, fines, taxes, etc.).
- Less tangible costs (image, moral, less enthusiastic workers, etc.).

History also shows that companies not only risk paying costs for past or current environmentally damaging activities, but also further on may be held responsible for their current actions. Since sustainable development is now on the political- and business agenda, this indicates a growing risk for extra costs the longer a company delays working responsible with their environmental causes. However, to do so companies will first have to identify areas within the company with the most potential to reduce their environmental damage.[75]

4.2.1.2 Haldex areas with environmental impacts

By conducting the pre-study and trying to set suitable criteria for life cycle tools at Haldex, relevant environmental impacts related to a typical Haldex' product were studied. Relevant impacts were here defined as those large enough to be worthy of recognition based on their possible damage to the environment, and which were also possible to monitor. The latter indicates a possibility to create action plans based on the identified processes with environmental impacts. The

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[75] I. Nilsson, *Integrating Environmental Management to Improve Strategic Decision-Making*, 2001.

impacts were looked at by using a MET-matrix, since this tool is fairly easy to use and also evaluates the three main areas most often associated with environmental problems throughout a product's life cycle, which should make it a useful method. The results are shown in Table 4.2.

4.2.1.2.1 MET-matrix[76]

The MET-matrix is a tool useful at the very start of the design process, in order to identify a product's impacts on the environment throughout its life cycle. The tool was developed at Deft University in the Netherlands in 1997, to be used by designers and product developers. It was created to be at service when redesigning products in order to facilitate environmental comparisons with new and old designs. Being able to provide both qualitative and quantitative evaluation, the MET-matrix assess a product by focusing on three aspects:

- The materials
- The energy
- Toxicity

MET stands for Material, Energy and Toxicity and assessments of these factors are done throughout the five main stages of the product's life cycle, from materials production to end-of-life. This is illustrated in a matrix with rows and columns, as seen in Table 4.1.

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[76] T. Bhamra, V. Lofthouse, *Design for Sustainability: A Practical Approach*, 2008.

Table 4.1. MET-matrix.[77]

Phase of life cycle	Materials	Energy	Toxicity
Materials production	Identification and quantification of the materials of the system	Evaluation of the energy generated by the production of these materials, their transformation or their transport to the site of production and assembly	Identification of potentially toxic materials but also the waste generated during the phase of mining and processing
Manufacturing	Identification of auxiliary materials required for production	Evaluation of energy consumption related to production	Identification of waste produced during the production phase
Distribution	Identification of materials required for packaging	Evaluation of consumption in the use phase	Identification and quantification of waste associated with the use and maintenance
Use	Identification of materials related to the use, such as consumables or maintenance	Evaluation of the consumption in the use phase	Identification and quantification of waste associated with the use and maintenance
End of life	Identification of materials needed to manage the end of life product	Energy needed for the management of the end of life product	Identification and quantification of waste generated during the end of life, including reused or recycled material

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[77] ECO-design tools, http://eco3e.eu/toolbox/indicators/, viewed on 22 April 2015.

The tool works by a conductor adding information in each cell, where potential environmental problems regarding both input and outputs of materials, energy and toxic emissions are recorded. The materials column may, for example, include quantities of non-renewable materials, how much material is mined, materials likely to create emissions during production, materials not suitable for recycling and reuse or materials inefficient in their use, as well as issues associated with auxiliary materials. The second column, energy, may be used to record and quantify energy consumption in the life cycle, including the product itself as well as possible transportation, operating, maintenance and recovery. The toxicity column may include toxic emissions released to land, water and air. By including the main stages of a product's life cycle vertically, and various environmental impacts horizontally, the matrix may function to create an environmental profile of a product. However, depending on how thorough a study the conductor wants to do, and also taking into account data-availability early in the product development phase, it is possible to use the tool qualitatively as well.[78]

In fact, the easiest way of working with a MET-matrix is probably to start adding qualitative information in each cell, to get a fast overview of potential environmental troubles associated with the studied product, and then gradually enter quantitative values wherever possible, for a more detailed and thorough examination of the system. The tool may then be used to understand environmental trade-offs made in the early R&D phase and design phase, e.g. discussing whether or not to use a heavier material if the material is also easier to disassemble and recycle at the end-of-life stage. By looking at the full life cycle a MET-matrix helps facilitate discussion and possibly discover areas where the product might be improved to become more sustainable. The tool can then also be used to compare different product

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[78] T. Bhamra, V. Lofthouse, *Design for Sustainability: A Practical Approach*, 2008.

generations and to more easily communicate a product's environmental profile.

When studying Haldex' processes with environmental impacts, it was best to first define what belonged to the product system being studied (a typical automatic brake adjuster (SABA-80 000) was used as a reference product) in order to know what to include in the investigation. The procedure, typically how you would work with a MET-matrix[79], went as follows:

1. Define system boundaries (this is especially important if one wants to be able to compare different products later on). For any ecofriendly design, it is critical to not only study the physical product, but also consider possible consumables and other products that the product need to function properly over its lifetime. For the automatic brake adjuster, its use phase was looked at as a brake adjuster's weight on a truck being travelled for its entire technical lifetime (200 000 km).

2. A needs analysis is conducted. This is to recognize the complex system boundaries defined earlier, and learn if there are more efficient ways for the product system to satisfy the needs identified. For an automatic brake adjuster it was determined that the current system fulfills its need (keeping the brakes working and the vehicle safe) effectively and in an efficient way.

3. Before filling in the MET-matrix, a functional analysis is to be done. This includes examining the actual lifetime of the product and its possible energy consumption, i.e. the product's functionality. To fully understand the product, it can be,

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[79] T. Bhamra, V. Lofthouse, *Design for Sustainability: A Practical Approach*, 2008.

hypothetically, broken down into its various pieces and subcomponents, to measure its weight, the type and amount of different materials and to identify the different components connections between each other. With the help of an internal Bill of Material (BOM), it was possible to analyze the typical automatic brake adjuster, its components, their weight and different materials[80]. It was already determined that the product functions efficiently to fulfill its needs and here, studying its weak and strong aspects, it was identified that making the product more lightweight, if possible without reducing its quality, would greatly decrease environmental impacts along the entire lifecycle. During this step of the procedure, it was possible to suggest a few improvements. These included:

- Reduce the brake adjuster's total weight.
- Increase the estimated lifetime of the brake adjuster.
- Reduce the amount of smaller components.
- Identify the components that wear out first.
- Increase recyclable material (this was already high but its worth always having on the agenda).

To analyze the strong and weak aspects of the product, the *EcoDesign Checklist* by Brezet and van Hemel was used to make sure the right questions were asked. This list can also be used when the MET-matrix is fully conducted, and weak spots have been identified, to help the product developer design the product to avoid environmental impacts.[81]. An example of an EcoDesign Checklist, by Brezet and van Hemel, is shown in Appendix A.

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[80] Bill of Material, SABA 80 000, 2015.

[81] H. Brezet, C. van Hemel, *EcoDesign: A promising approach to sustainable production and consumption*, Paris, France, 1997.

4. In the final stage of the procedure as many cells as possible in the MET-matrix should be analyzed and have information added to them. Having begun conducting a pre-study at Haldex in Landskrona, the following mostly qualitative MET-matrix in Table 4.2 was possible to develop for a typical Haldex' automatic brake adjuster.

Table 4.2. MET-matrix of identified Haldex areas with environmental impacts.

Haldex automatic brake adjuster			
Phase of life cycle	**Materials**	**Energy**	**Toxicity**
Materials production	Iron casting (2,5 kg)	Energy content of materials. A substantial amount of energy is consumed in preparation e.g. in melting and molding processes	Metal scrap, liquefiers for injection molding, toxic emissions from preparation
	Steel (1,3 kg)		
Manufacturing	Finite resources. Coating, paint, degreasers, lubricants for the machines, oil, chemicals, curing salt for heat treatment	Process energy (wheel/house/screw manufacturing)	Colour dust from powder painting, oil mist, refrigerant from auxiliary materials, cooling, waste oil, sludge/scrap from manufacturing, hazardous waste, grease
Distribution	PE, wood, cardboard-well, paper	Transport energy: long distance freight transports with truck (diesel fuel) and boat	Large CO_2 releases
Use	Negligible	Modelled as weight on truck driving brake adjuster technical lifetime: lots of transport energy needed	Large, indirect CO_2 releases when the truck is driving
End of life	High percentage of recyclable material. Metal scarps are recycled and the small amounts of plastic parts are incinerated	Energy load from reprocessing, transports, incineration	Landfill

The following conclusions were drawn from discussions due to the MET-matrix and identified areas with environmental impacts:

- The amount of cast iron and steel are to some extent possible to affect, by reduced scrap and minimized waste within the organization, or by a redesign of the brake adjuster. A less heavy brake adjuster would reduce environmental impacts in all parts of the life cycle.
- Many chemicals used in machine equipment and metal processing are to some extent possible to affect, as is the painting process, which might be redundant.
- Energy used in manufacturing is possible to affect.
- Transports to and from Haldex are somewhat possible to affect, through choice of suppliers and transport vehicle.

As mentioned, this MET-matrix was mostly done in a qualitative fashion but further work, preferably with someone who knows both the product and have knowledge in environmental impacts, would be able to add more quantitative values to the matrix, which would make product comparisons through the matrix easier. Due to not requiring that much environmental knowledge, it is possibly a useful tool to start working with environmental assessments.

4.2.2 Conclusions from pre-study

The problem areas and conclusions made from the pre-study can roughly be summarized as follows:

- A framework need to be somewhat simple, since environmental life cycle expertise is not spread out within Haldex and a potential model is intended to be used by employees with other work duties, i.e.

fear of this being seen as *"yet another extra thing we need to do"*.

- Full-scale LCAs are resource demanding and, with time, money and competence all being identified as barriers to sustainability, if Haldex wants to conduct full-scale LCAs, the company either needs to work more closely together with subcontractors and customers, or get the help of professional environmental consultants with proper commercial software. A simple LCA might thus be more appropriate for regular decision-making inside the company and should be investigated further.
- For Haldex to start working with lifecycle models, the usefulness needs to be communicated throughout the company, preferably from a business and economic standpoint, to create motivation.
- In the long run it could be costly for Haldex to not work with environmental issues and the risk is only increasing the further the company waits.
- For smoothest implementation, new potential sustainability models should start as test-projects used for experimenting and then eventually be scaled up. Haldex need to create routines and, by time, competence to work more with environmental sustainability in a consistent and strategic way.
- By using a MET-matrix, areas with environmental impacts from a typical Haldex product could be identified in a communicative way. Based on the result, it is possible to create action plans for the product's environmental profile, such as continuously work to reduce weight, while still keeping a high quality.
- The MET-matrix also helped recognize that the use phase and releases of carbon dioxide is one of the biggest impact areas of a typical Haldex product. Likewise, it indicated that eventual assessment models at Haldex need to be able to have a fairly large scope, due to a long life cycle.

4.3 Criteria for life cycle assessment tools at Haldex

Based on the observations and conclusions from the empirical study a few different criteria for the eventual life cycle framework at Haldex could be determined. These are presented in Table 4.3, in no particular order:

Table 4.3. Criteria for life cycle assessment tools at Haldex.

Knowledge

- Knowledge required for a first tool should first and foremost be about the product itself but further environmental information or training may be needed if a larger assessment is to be conducted.

Application

- A tool should be applicable on both new and existing products and it should be possible to conduct the assessment early on in a project, as decision support in the R&D stage.

Life cycle and scalability

- The tool should be able to cover the entire life cycle of a product, though preferably offer the ability to scale the scope up and down, depending on how thorough assessment the conductor wants to do.

Data type

- The required data type should preferably be quantitative for a more decisive conclusion but a qualitative or semi-quantitative model, or a framework that is able to evolve from qualitative to quantitative, should be easier to implement.

Sustainability

- To ease the adaptation, the sustainability coverage is excluded to environmental impacts only and should be able to identify environmental impacts and areas to improve, though for future work, economical aspects would be good to be able to incorporate in the potential tool.

Costs

- The tool should be free of charge since it may be used on a regular basis.

5 Analysis

The following chapter is based on the empirical study and includes life cycle analysis concepts and tools that suit identified criteria. Screenings of different tools were held in order to discover those with the most potential and this includes an introduction to *designing for environment* and *simplified LCAs*, which will be useful for the result presented in Chapter 6.

5.1 Environmental analysis tools

With the growing concern of environmental issues, product developers across a big range of industries have had to adopt new engineering and design practices to keep up with legislations and stakeholder pressure. This is achieved by implementing routines, methods and tools to monitor and minimize environmentally damaging activities.

From the literature review several different types of life cycle assessment tools have been identified, see Table 5.1 for some of the studied methods, and a larger way of classifying them is to group them in either qualitative or quantitative tools. Whereas the qualitative tools are suitable in the concept phase, the quantitative kinds are often useful later on in the product development phase when data is more available and a detailed environmental profile of the product is wanted. Unlike qualitative tools, which are quick and relatively simple to use, quantitative tools often require large amounts of information and possible expertise. However, they also provide less margins of error, due to being more objective in nature and thus, a quantitative tool often enables product comparisons, which may prove difficult with a qualitative tool. [82]

Some tools, which share many of the same advantages as qualitative tools but still include somewhat objective functions, may be called semi-quantitative.

Table 5.1. Different types of life cycle assessment tools.

Software & expert systems	• GaBi • SimaPro • Eco-it
Checklists and guidelines	• MET-matrix • DfE-matrix • Philips Fast Five • Eco-design checklist
Rating tools	• MECO-matrix • Sustainability Balanced Scorecard
Analytical tools	• MIPS • Full-scale LCA • Simplified LCA • LCC

The analysis began by a considerable screening of different life cycle assessment tools, subjectively chosen in the literature review, against the predetermined criteria. For a closer look at this screening see Table 5.2, where different tools were put to test against the necessary criteria. An “X” indicates that the method fulfilled the criterion, whereas a “_“ sign indicates no or low fulfillment. The “X/_“ sign indicates that the tool/method moderately fulfilled the criterion.

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[82] J. Vicente, R. Frazão, F. Moreira da Silva, Ecodesign *tools: One basis to operationalize Sustainable Design*, 2011.

Table 5.2. Screening of various life cycle assessment tools

CRITERIA METHOD	Knowledge	Application	Life cycle and scalability	Data type	Sustainability	Costs
MECO-matrix	_	X	X	X	X	X
MET-matrix	X	X	X	X/_	X	X
DfE-matrix	X	X	X	X	X	X
Simplified LCA	X/_	X	X	X	X	X
Full-scale LCA	_	X/_	_	X	X	X
SimaPro	_	X	X	X	X	_
Sustainability Balanced Scorecard	X	X	X/_	X	_	X
Eco-it	X	X	X	X	X	_
LCC	_	X	X	X	_	X

The many different method categories that were studied, some of which cover both qualitative, semi-quantitative and fully quantitative tools, include:

- *Software systems,* such as SimaPro, GaBi or Eco-it, which, based on the determined criteria, were deemed too resource demanding (knowledge and time) and costly to use on a regular basis as they require commercial licenses.
- *Checklists and guidelines*, such as the MET-matrix described earlier in subchapter 4.2.1.2.1, which met most of the criteria though since it cannot be conducted in a purely quantitative fashion, i.e. create a final score, it was deemed to only moderately fulfill the data type criteria. Philips Fast

Five and Eco-design checklists were eliminated because the former not being able to cover the entire life cycle and both of them being entirely qualitative, i.e. not being able to provide good enough decision support. Also studied was the DfE-matrix, which met all predetermined criteria for potential tools at Haldex.

- *Rating tools*, such as a MECO-matrix or a Sustainability Balanced Scorecard, which, based on the determined criteria, were deemed to require too much knowledge and time to use regularly, as well as including too large sustainability perspective (the latter).
- *Analytical tools,* such as Material Input per Service (MIPS), full-scale LCAs, life cycle costing analyses (LCC), and simplified LCAs (including carbon footprint) were also studied. Based on the determined criteria, MIPS had too little sustainability scope and a full-scale LCA and LCC (which also includes economy in the sustainability definition) are too resource demanding to be used regularly and the latter also have too large a sustainability scope. A simplified LCA met most of the criteria, though only moderately when it comes to *knowledge*, since more expertise than purely about the product and its qualities is required.

Following the extensive screening, a few tools and concepts were able to be selected as the most promising life cycle assessment tools for Haldex, based on the company's conditions and prerequisites. These include the DfE-matrix (a semi-quantitative tool), which met all the criteria, as well as the MET-matrix (a tool with the option of using it entirely qualitative) and a simplified LCA (an entirely quantitative tool). Even though they did not fully meet all criteria, the latter two were still considered interesting since, because of their nature, they may offer different conclusions compared to a semi-quantitative tool. Additionally they may possibly be used supplementary to such a tool or may still be deemed appropriate choices for other situations. The MET-matrix, due to not being able to provide a final score, was however not analyzed further beyond its introduction in Chapter 4. The DfE-matrix and simplified LCA are both studied in the following sections.

5.2 Design for environment

One widespread practice for companies to pro-actively work at being environmentally minded is called Design for Environment, DfE, and, in short, it is a company philosophy that aims to meet customer's requirements in a more sustainable way, through minimizing environmental loads associated to resource consumption and waste from company activities. This is achieved through working with specific tools and principles, often tailored to the needs of the applicants.[83]

As a concept, DfE is used to optimize environmental performance throughout the entire life cycle of a product and, along the way, integrate ways to identify and possibly monitor environmental loads from all areas associated with the product, which requires working proactively with several targets. Some important targets to consider include the ones listed in Table 5.3:[84]

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[83] A.A. Jensen *et al. Life Cycle Assessment (LCA) - A guide to approaches, experiences and information sources*, 1998.

[84] Ibid.

Table 5.3. Design for environment targets.

Materials selection	Reduce materials use
	Use more durable materials
	Increase use of recycled and reyclable materials
	Minimize toxic chemicals content
Production impacts	Reduce waste from processing
	Reduce energy used in production
	Minimize use of toxic chemicals
Production use	Incriease energy efficiency
	Reduce waste and emissions associated with the product
	Minimize packaging unless the environmental benefits outweigh the negative impacts
Design for recycling and reuse	Increase recyclable materials and design for easy disassembly
	Simplifying products by keeping different parts and types of materials low
	Labor the product
Extend the lifetime and design for end of life	Make it easier to upgrade the product
	Make parts accessible for easier maintenance
	Design for a safe and easy disposal

As shown from these areas above, the DfE philosophy does, in many ways, address the same concerns and problem areas as LCAs according to ISO, which is why it should be possible for companies to accommodate and connect LCAs with a design for environment philosophy and other tools. If it is deemed too complex and resource demanding to conduct full-scale LCAs on a regular basis, the loss of not routinely conducting such a study may be covered by working with simpler DfE-tools in the product development phase, and proactively consider potential environmental impacts. One such possible DfE-tool is the Design for Environment-matrix, which will be further looked at in subchapter 5.2.1 below.

5.2.1 DfE-matrix

A Design for Environment-matrix is intended to systematically allow integration of the DfE philosophy into already existing design practices, where quality, costs, safety and other aspects are likely to already be considered, making environmental conditions an extra decision-making component in product development. Originally designed for AT&T, the matrix is a tool for industrial products where a product design is scored and evaluated by aspects related to the object, which would have environmental impacts over the product's life cycle.[85]

Practically the tool is a matrix-questionnaire which asks the conductor to answer between 1-60 already defined questions, found in the accompanied guide *Design for the Environment – A Competitive Edge for the Future*, ranging from topics regarding premanufacture till the end-of-life stage. By answering these questions, each phase of the life cycle gets a total score, as does the overall product, and a product's strengths and weaknesses from an environmental perspective can be identified. As shown in Table 5.4, a DfE-matrix, this tool examines five life cycle stages:

- Premanufacture
- Manufacture
- Packaging and distribution
- Use and maintenance

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[85] J. M. Yarwood, P.D. Eagan, *Design for the Environment: A Competitive Edge for the Future (toolkit)*, 1997.

- End of Life

The questions address design and environmental topics regarding three categories; material use, energy use as well as waste, and ought to make the product design team consider potential environmental impacts throughout the life cycle. By answering each question, either a yes or a no, a predetermined score may be added to its corresponding cell in the matrix, which will present a final score once the conductor have answered all applicable questions. This final score becomes an environmental profile of the product.[86]

Table 5.4. DfE-matrix.[87]

Life Cycle Stage	Environmental Aspect					Total
	1. Materials	**2. Energy Use**	**3. Solid Residue**	**4. Liquid Residue**	**5. Gaseous Residue**	
A. Premanufacture	(A.1)	(A.2)	(A.3)	(A.4)	(A.5)	
B. Product manufacture	(B.1)	(B.2)	(B.3)	(B.4)	(B.5)	
C. Distribution, packaging	(C.1)	(C.2)	(C.3)	(C.4)	(C.5)	
D. Product use, maintenance	(D.1)	(D.2)	(D.3)	(D.4)	(D.5)	
E. End of life	(E.1)	(E.2)	(E.3)	(E.4)	(E.5)	
Total						

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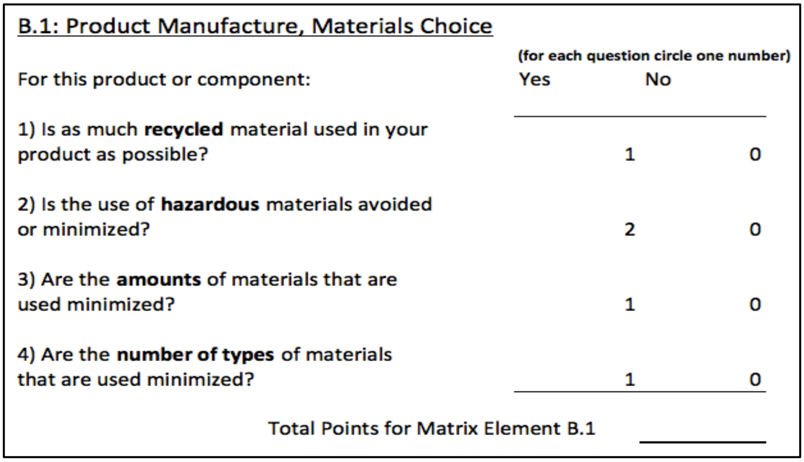
[86] J. M. Yarwood, P.D. Eagan, *Design for the Environment: A Competitive Edge for the Future (toolkit)*, 1997.
[87] Ibid.

For each cell in the matrix a maximum score of 5 can be achieved, making the total achievable score in the bottom right cell 125, after summing all rows and columns. As this tool should be used for internal decision-making, it is possible to make the life cycle assessment easier by excluding stages of the life cycle (or postpone answering these questions), for example the premanufacture row where suppliers have to be surveyed. If so, cell B.1, where questions regarding material use in manufacturing is asked, should be the place to start scoring the matrix. For clarifying purpose, and to get a sense of the type of questions asked in the accompanied guide, the particular B.1 questions appear according to Figure 5.1:



B.1: Product Manufacture, Materials Choice

(for each question circle one number)

For this product or component:	Yes	No
1) Is as much **recycled** material used in your product as possible?	1	0
2) Is the use of **hazardous** materials avoided or minimized?	2	0
3) Are the **amounts** of materials that are used minimized?	1	0
4) Are the **number of types** of materials that are used minimized?	1	0

Total Points for Matrix Element B.1 ________

Figure 5.1. Element B.1-questions according to the DfE-matrix guide.[88]

After answering the questions, a score from 0-5 that is to be entered in the B.1 cell is achieved, by summing the by the guide determined value, s for each question in the right hand column. A "yes" answer (where the point value is between 1-5) reveals high compliance with environmental standards, whereas a "no" answer (where the point value always equals 0) implies improvement possibilities.

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[88] J. M. Yarwood, P.D. Eagan, *Design for the Environment: A Competitive Edge for the Future (toolkit)*, 1997.

For all questions, the tool is designed in such a way that, if the question is not possible to answer for the studied product, or the product have no environmental impact here, the “yes” answer and corresponding score should always be circled.[89] The questions above are random examples used in this thesis for teaching purposes and all questions can be found in Appendix B, or, for a more detailed description, in the guide *Design for the Environment – A Competitive Edge for the Future*.

The DfE philosophy and matrix have been or is being used by companies such as Philips, Sony and AT&T, but also companies in the automobile industry such as Motorola, General Motors, BMW and Volkswagen, the latter with an expressed goal of eventually creating automobiles out of 100% reusable and/or recyclable parts. They are thus using the DfE philosophy and DfE-tools to continuously study the disassembly and materials recycling in their automobiles.[90]

A DfE-matrix is suitable for design engineers and product developers to use early in the R&D phase. This is the phase when decisions of resource use, manufacturing processes etc. are made, and these will determine much of the latter environmental impacts, i.e. after a product is designed, many environmental characteristics will be fixed. Plus, the sooner an eco-design tool is used, the more options for change exists and that change’s cost will only increase with time.

Though the DfE-matrix is suitable for incorporating environmental aspects in the design phase, it can just as well be used for evaluation and comparisons between already existing products, creating environmental profiles with their total scores. There are more advantages to using the DfE-

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[89] J. M. Yarwood, P.D. Eagan, *Design for the Environment: A Competitive Edge for the Future (toolkit)*, 1997.

[90] Ibid.

matrix however. If used early on in the product development phase, it allows the company to take a proactive approach to environmental considerations and may also clarify priorities for improvement, identifying hotspots and areas in the life cycle with not as high scores. Additionally it is a tool which is not necessarily resource demanding to use, a barrier for companies to start working with environmental issues, as identified in the empirical study. Likewise, the tool mainly requires that a conductor knows their product and materials, the production processes etc. and does not personally need to be an environmental expert to use it. Finally, the more someone uses the tool the easier it should be to answer its questions, and the guide is clear that it should be possible for a company to eventually adapt and modify the questions, to better fit their own production and requirements. For maximum effect, this is something that is recommended when an environmental expertise gradually have been built in-house, and should make the tool even more useful.

As the tool offers predetermined questions that allow scoring a product, yet many questions are to be subjectively answered, it is described as a semi-quantitative tool. The next section will instead look at purely quantitative tools.

5.3 Simplified LCA

A full-scale LCA according to ISO, as seen in the frame of reference chapter, is almost always a very time consuming project and often requires a software program to conduct the impact assessments and data collection. The practical use of quantitative life cycle assessments in the industry have made it clear that in order for many companies, including Haldex, to use such life cycle assessments as regular decision support, the tools need to be made easier to understand and less time consuming. This was the main idea when industry professionals and academics started to develop streamlined or simplified, quantitative LCAs, derived from know-how of the full-scale tools and ISO guidelines. Guinée et al. describes the quantitative, simplified LCA as:

> *"A simplified variety of detailed LCA conducted according to guidelines not in full compliance with the ISO 1404X standards and representative of studies typically requiring 1 to 20 person-days of work"* [91]

In other words, a simplified LCA means to not fully comply with every ISO standards' requirements, in order to reduce the complexity of a full-scale LCA. By analyzing the latter tool, the conclusion made was that this could be achieved in three ways:

1. By reducing the scope of the assessment (and not include all stages of the life cycle in the product system).
2. By reducing the data need of the assessment (and allow generic secondary data, instead of more accurate specific data, for one or several stages of the life cycle).
3. Or both, to reduce the scope and data need, which could be made in various different designs, possibly according to Figure 5.2.

Taking these conclusions into account, one example of a quantitative, simplified LCA could thus be to make your own calculations, by exclusively using primary data from personal manufacturing and generic data for subcontractors and customers. Such latter data or indicator values may be found in industry-specific databases, national LCI databases, databases for European or global averages or, in worst case, a conductor will have to use guesstimates. It would also be possible to define the product system and life cycle as only parts of the supply chain the company have

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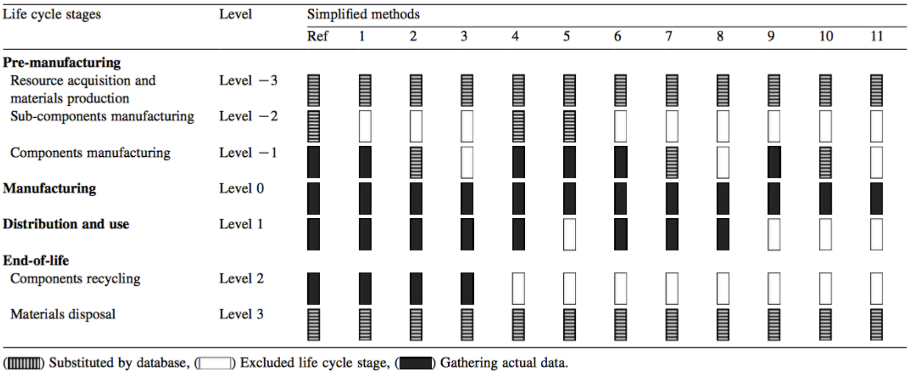
[91] J B. Guinée *et al., Handbook on Life Cycle Assessment: Operational Guide to the ISO standards,* 2002.

direct effects on and exclude other parts from the life cycle assessment, such as the activities from end-customers or raw material manufactures. Another example of a quantitative, yet simplified LCA is a carbon footprint analysis, as described in subchapter 3.4.4.2, when the data need has been reduced significantly, with only one impact category (climate change). For more tips on how to design quantitative LCAs, Figure 5.2 shows several different scenarios where a simplified LCA is designed to reduce the complexity of the study, by using the three identified methods above.



Life cycle stages	Level	Simplified methods											
		Ref	1	2	3	4	5	6	7	8	9	10	11
Pre-manufacturing													
Resource acquisition and materials production	Level −3	▥	▥	▥	▥	▥	▥	▥	▥	▥	▥	▥	▥
Sub-components manufacturing	Level −2	▥	☐	☐	☐	▥	▥	☐	☐	☐	☐	☐	☐
Components manufacturing	Level −1	■	■	▥	☐	■	■	■	▥	☐	■	▥	☐
Manufacturing	Level 0	■	■	■	■	■	■	■	■	■	■	■	■
Distribution and use	Level 1	■	■	■	■	■	☐	■	■	■	☐	☐	☐
End-of-life													
Components recycling	Level 2	■	■	■	■	☐	☐	☐	☐	☐	☐	☐	☐
Materials disposal	Level 3	▥	▥	▥	▥	▥	▥	▥	▥	▥	▥	▥	▥

(▥) Substituted by database, (☐) Excluded life cycle stage, (■) Gathering actual data.

Figure 5.2. Various designs of simplified life cycle assessment models.[92]

The figure above vertically shows 12 different simplified life cycle assessment models, starting with a reference model where all stages of the life cycle are included but where the conductor at few of the levels (resource acquisition and materials production, subcomponents manufacturing and materials disposal) have substituted primary data with generic data. Looking specifically at design 3, 8 and 11, these have all excluded components manufacturing from the model which means that no data have to be gathered from the subcontractors, often one of the most time consuming activities in a full-scale LCA.

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[92] H. Tak, J. Lee, J. Ryu, E. Kwon, "Simplified LCA and matrix methods in identifying the environmental aspects of a product system", 2005.

However it is important to acknowledge that all the described simplified LCA designs in this subchapter makes the word “life cycle” tricky, since not all parts of the real life cycle are included or possibly sufficiently assessed. Thus such simplified LCAs should be strictly used internally and not for marketing or other public disclosure. The methods have still proved useful for many companies when there is a shortage of resources, as training tools, or when the objective is not to make a definitive public statement on a product’s environmental profile, but rather to get a comprehensive picture of a company’s current environmental situation. According to Graedel and Saxton, a simplified LCA’s function is mainly to identify environmental hotspots, or areas in the product’s life cycle where there are opportunities for improvement, which, from a cost and change perspective, would be useful in the R&D phase.[93]

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[93] T. Graedel, E. Saxton, ”Improving the Overall Environmental Performance of Existing Telecommunications Facilities”, 2002.

5.4 New Haldex life cycle assessment framework

The conclusions from this extensive analysis is summarized in a list of tools and suggestions below, that best meet the identified criteria in the empirical study and have thus been pinpointed as the most suitable tools to use in Haldex' current R&D phase, as decision-support in the Haldex Project Management Model. The bolded bullet points will therefore be included in the life cycle framework presented in Chapter 6 and serve as the main topics of said chapter.

- **Introduce a DfE-matrix and guide early on in the R&D phase.**
    - A qualitative MET-matrix may be used to start recognizing environmental problems.

- **When evolved, use a simplified LCA and at first a carbon footprint analysis.**

With time, having a life cycle assessment framework should prove to be beneficial in promoting life cycle thinking and sustainability at Haldex, e.g. help make more informed decisions. This could, among other things, prevent future costs, strengthen company brand, discover product improvements and produce more quality with less resources.

6 Proposition

In this chapter the suggested framework for a life cycle assessment model at Haldex will be covered. The design of the framework is created according to expressed guidelines, which is presented in the first section of the chapter. Finally, a short summary of the thesis' objectives and how they have been worked on are recognized.

6.1 Guidelines for the design

When developing the framework for a life cycle assessment model at Haldex a set of guidelines was used. First, by observing activities and by interviewing employees at the site in Landskrona, existing routines for R&D practices could be identified, as could general knowledge and scope of attention paid to environmental issues at the company. The hypothetical framework for a life cycle assessment was to be built by aligning, as close as possible, the framework against the current knowledge and routines. Secondly, the list of "best-practice" tools in Section 5.4, identified by a preliminary study and extensive analysis of several methods, was studied. Lastly, when designing the framework, there was always in mind to present something with essential "bang for the buck", meaning something useful and easy to start with, without making too big an intrusion in existing routines. This was to create buy-in for the models and framework and to ease implementation of them. Haldex is a company with a several decades-long company culture and have their own way of working with things, so not straying too far off from existing routines was deemed necessary for any new procedures.

6.2 Haldex Life Cycle Assessment Development Framework

For Haldex to start developing life cycle assessments, and incorporate environmental issues as additional decision support in the Haldex Project Management Model and accompanied R&D processes, they need new routines to do so. This is only achieved from experience and using a semi-quantitative DfE-matrix tool to facilitate early discussion would be a great way to start creating such routines. An entirely qualitative MET-matrix that, similar to the DfE-matrix, does not require large amount of data or extensive environmental knowledge, may also be used at this point, as a gateway, to the more complex tools. When the company has evolved in their environmental work, and want to use more quantitative tools which offer objective and more easily communicative scores, it would be a good idea to start conducting simplified LCAs, with the least resource demanding tool being a carbon footprint analysis. These likely require more detailed expertise and possibly own databases, unless a time-consuming data gathering is allowed to be performed. If eventually such expertise and data gathering is a reality, Haldex should be able to start developing bigger life cycle assessments, using simplified LCAs that include more life cycle stages and environmental impacts than a carbon footprint analysis does, see Section 5.3. That is, however, set as an environmental vision for now. The Haldex Life Cycle Assessment Development Framework, for when and what tool to start with, is presented in Figure 6.1.

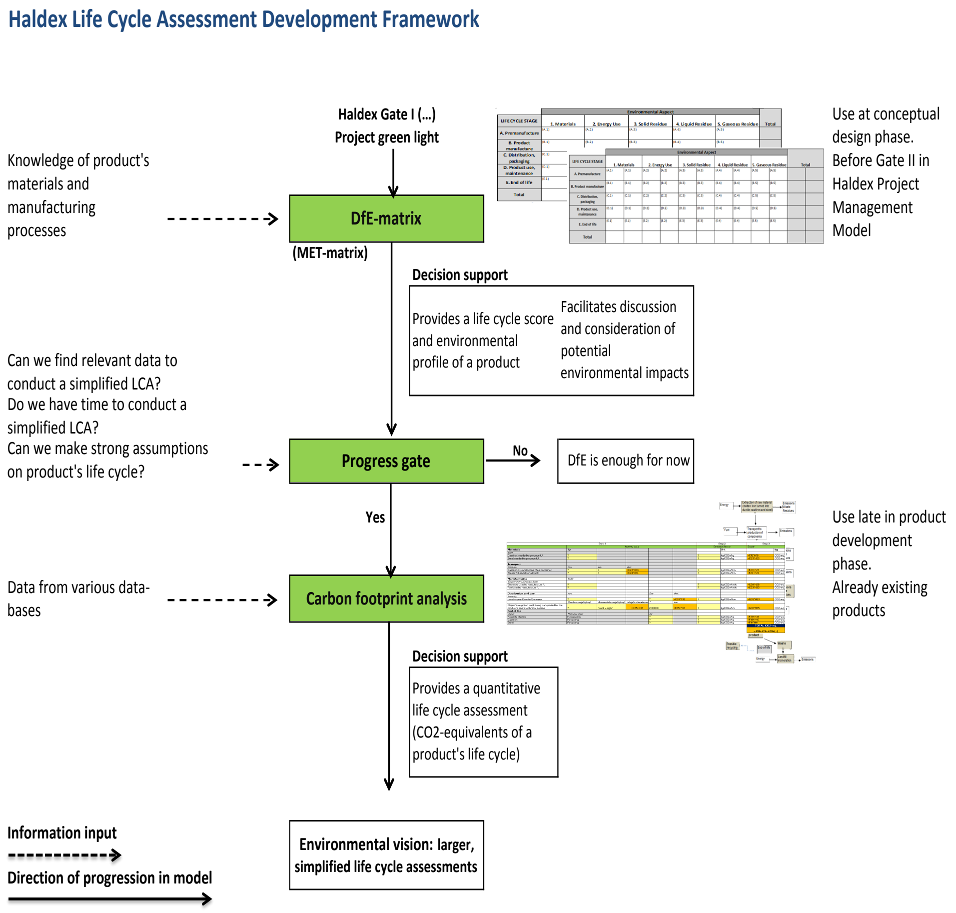

Figure 6.1. Overview of the Haldex Life Cycle Assessment Development Framework.

This framework, which presents a work progress over time, presents the DfE-matrix (and/or the MET-matrix if that is deemed easier to begin with) as the best way to start incorporating environmental impacts as additional decision support when developing new products or evaluating existing products. The Haldex Project Management Model exist of different gates at the R&D level where a project passes through before implementation, and the DfE-matrix is suitable early on, before gate II, when additional product criteria are looked at. When the company have more experience and resources, they can eventually also use a quantitative carbon footprint analysis which offers less margin of errors and more conclusive results, i.e. possibly argued as better decision support. However, since it also requires more input data, environmental knowledge and specific, quantitative information about the life cycle, it is more difficult than a DfE-matrix to start working with. For these reasons, the recommended framework includes a development gate, with a few subjective "suitability" questions that should be answered in a certain way, before taking on carbon footprint analyses as decision support for product development. For use early on in the Haldex Project Management Model, it may be decided that a DfE-matrix is more applicable anyway, since fewer, quantitative assumptions about future life cycle impact factors will have to be made, compared to any quantitative tool where detailed data often is required to get a result. Such detailed data may be hard to find at the first stages of any project and a carbon footprint analysis, being a purely quantitative tool, is thus easier to use late in the product development process, or with already existing products.

Below is a closer look at the two main levels of the Haldex Life Cycle Assessment Development Framework, the DfE-matrix and carbon footprint analysis, and how they might be used at Haldex.

6.2.1 First introduce a DfE-matrix and guide

If one wants to immediately bypass the qualitative MET-matrix, a Design for Environment-matrix would be useful early on in the Haldex R&D phase, when there is a purely conceptual idea for a new product, or ideas for changes to existing products. Being semi-quantitative, the DfE-matrix is relatively easy to implement and, due to its possibility to provide a score (unlike the MET-matrix), allows for environmental issues to be integrated as an extra decision basis in the product development process. For maximum effect, the tool should primarily be used by design and product development teams, with knowledge of materials and manufacturing processes that the different concepts require. The guide *Design for the Environment – A Competitive Edge for the Future* should be inquired to start working with the matrix and as the team increase their environmental knowledge and grow more comfortable with the tool, they can adapt and modify the questions accordingly to better fit Haldex' own products. The guide recommends at least half a working day to go through the evaluation, and if subcontractors were to be evaluated, that would obviously require a longer time (though these could be surveyed ahead of time with a little bit of good planning).

The DfE-matrix, due to its accessibility and convenience, will, even if the team is not able to answer all the questions, be helpful to facilitate discussion and consideration of potential environmental impacts caused by a product's life cycle. As experience and knowledge accumulates, it should be possible to develop a Haldex tailored tool out of the generic guide, with modified questions that better suit their own products' life cycles.

A DfE-matrix was designed in Microsoft Excel, shown in Table 6.1, allowing two product concepts to be evaluated at once, which may be used if product comparison is the desired purpose of the tool.

Table 6.1. DfE-matrix for product comparisons.

Life Cycle Stage	Environmental Aspect										Total
	1. Materials		**2. Energy Use**		**3. Solid Residue**		**4. Liquid Residue**		**5. Gaseous Residue**		
A. Pre-manufacture	A.1	A.1	A.2	A.2	A.3	A.3	A.4	A.4	A.5	A.5	
B. Product manufacture	B.1	B.1	B.2	B.2	B.3	B.3	B.4	B.4	B.5	B.5	
C. Distribution, packaging	C.1	C.1	C.2	C.2	C.3	C.3	C.4	C.4	C.5	C.5	
D. Product use, maintenance	D.1	D.1	D.2	D.2	D.3	D.3	D.4	D.4	D.5	D.5	
E. End of life	E.1	E.1	E.2	E.2	E.3	E.3	E.4	E.4	E.5	E.5	
Total											

Going through the standard questions (or possibly modified and company specific) in the guide, each twin-cell can be filled in almost simultaneously if the question is answered for both product concepts. Of course, if this seems complicated it is easy to use the standard matrix in Table 5.4 instead and concentrate fully on one concept at a time, and then conduct the evaluation for the second concept later on. For the scoring, an idea is to normalize the rating system to the number of questions answered. Another idea is that, when one is comfortable with the tool, it is also possible to set requirements for its decision support, such as:

- Environmental parameters that score less than 5 have to be addressed further.
- Life cycle stages that score less than 25 have to be addressed further.

The scores needed to be achieved may be determined based on how important the green design is to the product concept and as decision support in the Haldex Product Management Model. It may be wise to start with modest expectations and increase them with time and arrival of new product generations. The above example, of scores 5 and 25 respectively, would be the best possible scenario, for a complete green-design.

6.2.2 Progress gate

The framework also includes a few recommendations on when the company is ready to try and conduct carbon footprint analyses. These recommendations come as questions that, if answered affirmative, indicate that it is possible for Haldex to take on this type of quantitative model. The questions include:

- Can we find relevant data to conduct a simplified LCA?
- Do we have time to conduct a simplified LCA?
- Can we make strong assumptions on the life cycle of the product, this early in the project?

It is really up to the project manager or conductor of the study to answer these and to know whether a carbon footprint analysis would be feasible or not, for this project or at this point of time. If Haldex eventually can create an extensive internal database of their own, with indicating factors such as kg CO_2-equivalents/unit process, many of these questions would be able to answer affirmative right away but as of today, that data would have to be found mostly elsewhere if a large part of the life cycle is to be investigated.

6.2.3 Secondly, introduce a simplified LCA

A carbon footprint analysis, an analytical tool described in subchapter 3.4.4.2, measure the global warming potential of a product's life cycle. This tool is useful since, if used internally in the company as a simplified LCA, its scope can be scaled up and down depending on how thorough the assessment is intended to be. Additionally it should, due to its quantitative nature, give an easily understood and communicative score of the product's environmental impacts, described as released CO_2-equivalents. Of different quantitative, yet simpler, life cycle assessments, this is the first type of simplified LCA that is recommended for Haldex to eventually start working with for several reasons:

1. Doing a quantitative life cycle assessment with several impact categories would be more resource consuming. Including more than one impact category is instead kept as an environmental vision for the future.
2. An LCA's data inventory phase has been identified as generally the most difficult phase, both due to the time needed to find all data, but also due to the expertise needed to work with it. With time Haldex should ideally build their own data inventory to regularly be able to conduct quantitative LCAs and the most feasible database to start building up internally would seem to be CO_2 use and CO_2-equivalents. This because it is the most likely indicator already available in-house or in industry specific or national databases.
3. As identified in the preliminary study, Haldex already have targeted CO_2-releases as an important environmental issue and have created some routines to work with this.

To conduct a carbon footprint analysis, it is recommended to follow the procedures of a full-scale LCA, chronicled in Section 3.4 and its subchapters, though since this is a simplified LCA method intended for internal use, the complexity could be significantly reduced. For designing the tool it is therefore advised to look at Section 5.3 and the tips of various simple life cycle assessments to decide upon the right scope for each specific project. For the carbon footprint analysis, the inventory data that will need to be collected are inputs and outputs along the product's life cycle (shown in Figure 4.2 for a typical Haldex product) that have global warming potential, i.e. mass of CO_2 or CO_2-equivalents.

After deciding the scope of the assessment the conductor may use a spreadsheet tool such as Excel to start the calculation procedures. In such a program the defined product system's different stages and procedures with environmental impacts are lined up and activity data (materials, electricity, transport distances, etc.) are entered into cells next to them. Secondly, corresponding quantitative emission factors (such as kg CO_2-equivalents/kg material) should be entered in a cell next to the activity data. These are the factors that may take time or prove difficult to find, though since global warming is such a recognized issue, it should be easier than other environmental data of its kind. For such generic, secondhand data, national databases or industry specific databases should be investigated. Finally, the activity data multiplied with corresponding emission factor will give a CO_2-equivalent score and total global warming potential for that process/stage of the life cycle, and eventually, if all wanted data are found, the entire studied system will receive a total global warming potential-score.

By following The Greenhouse Gas protocol guidelines developed by the World Resources Institute and the World Business Council on Sustainable Development, as described in subchapter 3.4.4.2, and applying Haldex-specific knowledge from the preliminary study on environmentally damaging activities, a prototype of a carbon footprint analysis model as described above in Excel could be designed. This prototype, see Appendix C, may be used for training or teaching purposes, or to start conducting carbon footprint analyses. Though note that this should merely be a point of departure to add/remove life cycle stages, processes and data, depending on the project and what specific product is to be assessed.

In the prototype it was decided to exclude the components manufacturing stage, since that would require specific and often hard to get data from subcontractors (this prototype includes the life cycle stages marked with grey, as shown in Figure 6.2 below). It was also decided that mostly generic data is acceptable for several stages of the life cycle, which is shown by the color-coding in the prototype.

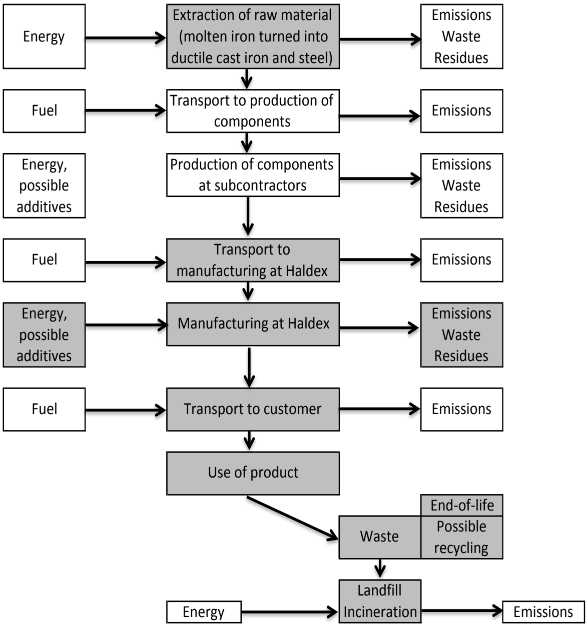

Figure 6.2. Life cycle of a Haldex brake adjuster illustrating specific stages included in the carbon footprint analysis prototype.

As seen in the figure, the stages where data is required from subcontractors have been excluded in the prototype. At the extraction of raw material, distribution and end-of-life stages, it is recommended that generic data (if possible accumulated emission factors) for fuel consumption, emissions, energy etc. are gathered to further ease the use of the model, since Haldex will have little control to monitor these stages themselves.

Also, if this tool is used in the product development phase, assumptions will obviously have to be made on future quantities such as transport distances, energy needed for manufacturing, etc. This tool is thus suitable for already existing products or late in the R&D process, when there are finished concept designs and more quantitative data available, and also where the conductor could determine a functional Unit, such as “one brake-adjuster X over a technical lifetime of Y km”. Figure 6.2, as well as the full carbon footprint prototype that were created can, as previously mentioned, be seen in Appendix C, including excerpts from practical guidelines and formulas on how to use it.

To start using quantitative tools such as the carbon footprint analysis, and eventually more complex simplified LCAs, Haldex need to collect data, and over time, facilitate access and improve that data. This should be an iterative process and initially, data of relative low quality due to limited availability may have to be used. The more environmental expertise accumulated and simplified LCAs conducted, Haldex should improve the data quality by replacing old data with higher quality data as it becomes available. This is particularly important for life cycle activities that have low data quality or high emissions.

6.3 Final conclusion

The main purpose of this thesis was to present Haldex with a suitable life cycle assessment framework including assessment tools that are applicable in the Haldex Project Management Model and their R&D stages. This has been carried out through a preliminary study and analysis, and covered in the later chapters of the thesis.

Remembering the objectives of the thesis, an early target was to define a set of criteria that would aid in screening various life cycle assessment tools and in the analysis find those most applicable for Haldex to start working with. Through the preliminary study the chosen criteria were expressed as:

- A model that, if wanted to, can cover the entire life cycle of a product and allow the option to scale its scope up and down depending on size of the project.
- A first model that does not require large environmental expertise to start working with.
- A model that, for now, exclusively assess the environmental aspects of sustainability.
- A model that can be used in the R&D phase of a project and on both new and existing products.
- A model that could provide at least a semi-quantifiable verdict for possible product comparisons, without requiring a costly software license to use it.

Introducing Haldex to suitable life cycle assessment tools have been achieved by designing a framework with allowed possibility for environmental development over time, taken into consideration the aforementioned criteria. This includes a semi-quantitative Design for Environment-matrix and accompanied guide, as well as a quantitative carbon footprint analysis where a prototype, accomplished through the spreadsheet software Excel, may be used to start working with the latter tool.

7 Discussion and work down the road

The final chapter presents a discussion on the methodology of the study and the overall procedures followed in order to do conduct it, together with recommendations on implementation of the suggested framework. The chapter concludes with suggestions for future work.

7.1 Discussion

Having conducted the study according to the described methodology should result in a reliable and useful result, which may prove valuable as a natural stepping-stone for future work. With the research procedures following a qualitative style, it is true that this makes for a subjective result, but it is not necessarily feasible to produce a life cycle assessment framework, suitable for a specific company, by conducting an objective analysis. I also believe that the suggested work down the road will prove helpful and this thesis could facilitate further reviews.

In hindsight, the interview structure described in Figure 2.1 could not be fully accomplished since there were a restricted time span time and it was not possible to do that many follow-up interviews. It might thus have proved effective to conduct the first interviews earlier, so that after the time-consuming analysis it would have been possible to go back and validate tools, as well as further introduce the suggested framework, to ensure a buy-in was possible to achieve at the company. However, due to the extensive preliminary study conducted and subsequent knowledge gathered, the decided criteria should be right for Haldex at this point of time, from where the company is right now in their environmental work. With the then time-consuming and considerable analysis, it was possible to make educated decisions for which tools to recommend right now and as a result, both goals described in Section 1.3.1 have been achieved.

7.2 Implementation

My message on how to best implement a new environmental assessment framework is *learning through action*, i.e. just start doing it. Trying out and documenting progress will eventually create consistent and systematic routines, that best suit the company. This is the goal and in order to get there, I have identified a few success factors, illustrated in figure 7.1 below:

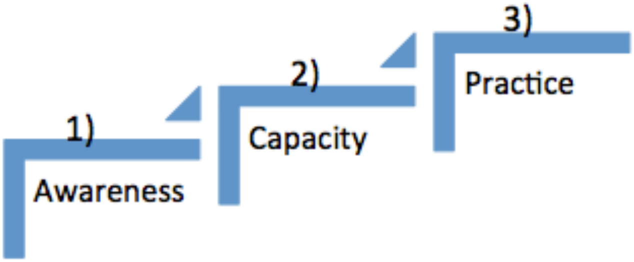

Figure 7.1. Learning through practice.

1. Create awareness

Haldex staff becomes aware of the issues and are motivated to tackle them. This might be achieved through newsletters, web conferences, meetings, etc. e.g. methods to bring large quantity of information to a large audience. Broad information is required.

2. Create capacity and room for new routines

Haldex will need to identify its own specific challenges in incorporating a new framework and tools to work with, such as corporate culture and old routines. The team that potentially should work with the tools, as they might need buy-in to do so, easiest achieves this and they should work together to find ways to solve practical problems that they might identify during step 1. Possibly a screening workshop, to set guidelines and create future consistency, might be helpful. This is also favorable in order to build the right capabilities, which will be necessary, and it is a success factor that likely requires more detailed information than the first one.

3. Practice

With untested solutions to identified practical problems, Haldex should learn through action and continuously improve the usage of the tools by looking for improvements. Possibly larger workshops or creating smaller test projects for experimenting and teaching purposes, and to gradually scale up these projects, should be useful. Such smaller projects should also be documented to allow future evaluation of them. By setting a vision for how to eventually use the framework, the development towards the desired direction will increase in speed, as each practiced situation will be a stepping-stone for eventually reaching the goal. Such vision might be its eventual place in the Haldex Project Management Model. Additionally, implementing life cycle assessments as operational tools should ultimately become part of the company environmental management, which will require commitment to the initiative and support from top management to be achieved.

7.3 Recommendations for further work

When this life cycle assessment framework for Haldex was worked on, some theories which were found to lie outside the scope of this study, but still worth looking into, were encountered, as well as ideas on the direction for what to do next. These could either not be made right now due to time constraints or them naturally being generation II of the suggested tools. These ideas and theories are presented below and it is the hope that this study will urge someone to take them on when the time is right.

Company specific DfE-matrix

Working with the generic questions presented in the first DfE-matrix guide, originally created for AT&T though used by several companies, should be the easiest way to start using a DfE-matrix and getting to know the tool. However, as stated earlier, it should be possible to eventually modify some of the questions to better fit Haldex' specific products and life cycle processes. This would enable the DfE-matrix to create even more thorough environmental profiles for the Haldex products, and still facilitate discussions and proactive considerations of environmental issues along the life cycles. To create the most suitable questionnaire for the matrix, preferably those with the most knowledge of the products, including their materials and components, their use phase etc., and also those with environmental expertise should work together. It is thus recommended that the first questionnaire is used to begin with, to get conformable with the tool and to build accumulated knowledge and expertise, and when Haldex is ready, look into developing modified questions.

Sustainability framework with both environmental and economic considerations

If sustainable products were to be sustainable only from an environmental perspective, without meeting customer needs or adding value, they will likely only appeal to a green niche. An environmental life cycle assessment will add extra decision support in the research and development phase but for added motivation and extra buy-in, it could be practical to have a framework including tools that measure sustainability from both an environmental and an economic perspective. Examples of such tools would be incorporating life cycle costing analyses, LCCs, with traditional LCAs. Another example is EPS; an environmental priority strategy tool developed by the Swedish Life Cycle Center, which is used to put economic values on environmental impacts along the product's life cycle.[94]

All such frameworks that aid in analyzing both environmental and economic impacts will only strengthen lessons learned, although their complexity made it deemed too much to introduce at once, in this thesis. However, such a framework would make it easier to identify sustainability trade-offs, as discussed in the section of the three pillars of sustainability and the triple bottom line. Luckily, tools like life cycle costing could eventually quite smoothly be integrated to the Life Cycle Assessment Development Framework presented in this thesis, without much change of structure, as they have similar procedures and data requirements as simplified LCAs, using similar life cycle thinking and perspectives.

7.4 Academic contributions

It is worth mentioning that this framework, though built for conditions found at Haldex Landskrona 2015, may easily be adapted for other Haldex locations but also other businesses since it is generically built and with different levels of workload and knowledge required for the included tools, as well as different possible outcomes, depending on what one wants from the tool.

From an academic perspective this is important because environmental problems and activities has fast become a truly urgent topic, on several levels. Both on a societal

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[94] Interview with Project Manager at the Swedish Life Cycle Center.

level, as well as an everyday and a business level, people are now having to actively and proactively work with environmental problems just to have a sustainable future. It is becoming increasingly important for companies to work with these questions to, for example, keep a strong brand image, avoid environmental costs and to keep good relationships with their customers and stakeholders. Academia was involved in developing the first simplified life cycle assessment methods and for the best results they should continue to work close with businesses in the present and future development of new tools, in order to best ensure said sustainable future. The academic world has always been a great source of information and since this is becoming such a hot topic it is important that academia stay in the forefront and continue to research the subject. For companies it may have become obvious by now that business as usual will not be entirely possible anymore and so they may need to extend an arm to academia and the possible experts on environmental and sustainable work, and then incorporate the newfound knowledge in their business models. Thus it is important that academia have the trustworthiness and knowledge needed to help, as it looks likely that more and more companies are going to ask for it.

Life cycle assessment frameworks, such as the one in this thesis, may thus prove beneficial for not only Haldex, but also other companies that want to be successful in today’s business climate, and help them to start work with necessary tools. For academia, this thesis and the subsequent result may prove a source of information for where to start looking and which areas are worth studying, since these are the areas companies likely are going to need help with, as this case study at Haldex proved.

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APPENDICES

Appendix A, Example of an Eco-design checklist

Needs analysis	
How does the product system actually fulfill social needs? • What are the product's main and auxiliary functions? • Does the product fulfill these functions effectively and efficiently? • What user needs does the product currently meet? • Can the product functions be expanded or improved to fulfill users' needs better? • Will this need change over a period of time? • Can we anticipate this through (radical) product innovation?	EcoDesign strategy @ new concept development • Dematerialization • Shared use of the product • Integration of functions • Functional optimization of product (components)
Life cycle stage 1: Production and supply of materials and components	
What problems arise in the production and supply of materials and components? • How much, and what types of plastic and rubber are used? • How much, and what types of additives are used? • How much, and what types of metals are	EcoDesign Strategy 1: Selection of low-impact materials • Clean materials • Renewable materials • Low energy content materials • Recycled materials • Recyclable materials • EcoDesign Strategy 2: Reduction of material usage

used? • How much, and what other types of materials (glass, ceramics, etc.) are used? • How much, and which type of surface treatment is used? • What is the environmental profile of the components? • How much energy is required to transport the components and materials?	• Reduction in weight • Reduction in (transport) volume
Life cycle stage 2: In-house production	
What problems can arise in the production process in your own company? • How many, and what types of production processes are used? (Including connections, surface treatments, printing and labeling) • How much, and what types of auxiliary materials are needed? • How high is the energy consumption? • How much waste is generated? • How many products don’t meet the required quality norms?	EcoDesign Strategy 3: Optimization of production techniques • Alternative production techniques • Fewer production steps • Low/ clean energy consumption • Less production waste • Few/ clean production consumables
Life cycle stage 3: Distribution	
What problems can arise in the distribution of the product to the customer? • What kind of transport packaging, bulk packaging, and retail packaging are used (volumes, weights, materials, reusability)? • Which means of transport are used? • Is transport efficiently	EcoDesign Strategy 4: Reduction of material usage • Reduction in weight • Reduction in (transport) volume • EcoDesign Strategy 5: Optimization of the distribution system • Less/ clean/ reusable packaging • Energy-efficient transport mode

organized?	• Energy-efficient logistics
Life cycle stage 4: Utilization	
What problems arise when using, operating, servicing and repairing the product? • How much, and what type of energy is required, direct or indirect? • How much, and what kind of consumables are needed? • What is the technical lifetime? • How much maintenance and repairs are needed? • What and how much auxiliary materials and energy are required for operating, servicing and repair? • Can a layman disassemble the product? • Are those parts often requiring replacement detachable? • What is the aesthetic lifetime of the product?	EcoDesign Strategy 5: Reduction of impact in the used stage • Low energy consumption • Clean energy source • Few consumables needed • Clean consumables • No wastage of energy or consumables • EcoDesign Strategy 6: Optimization of initial lifetime • Reliability and durability • Easy maintenance and repair • Modular product structure • Classic Design • Strong product-user relation
Life cycle stage 5:Recovery and disposal	
What problems arise in the recovery and disposal of the product? • How is the product currently disposed of? • Are components or materials being reused? • What components could be reused? • Can the components be reassembled without damage? • What materials are recyclable? • Are the materials identifiable? • Can they be detached quickly?	EcoDesign Strategy 7: Optimization of the end-of-life system • Reuse of product (components) • Remanufacturing/ refurbishing • Recycling of materials • Safe incineration

Appendix B, Instructions for using the DfE-matrix

1) **Information from a survey of your parts and raw materials suppliers is used to answer the A.1 - A.5 matrix element questions.** If you do not wish to survey your suppliers, or want to do it at a later time, begin with the questions for matrix element B.1.

2) **Answer each matrix question on pages 21-27 "yes" or "no." If the answer is "yes", circle the number of points in the "yes" column for that question. If the answer is "no", circle the zero for that question. If the question does not apply to your product or your product has no impact in this area, answer "yes."** For example, question B.4 asks, "If hazardous solvents or oils are used, have alternatives been thoroughly investigated?" If your process does not use solvents or oils at all, then the product design has no potential impact in this area, and your answer would be "yes." The questions have been written so that "yes" indicates a positive or no environmental impact, whereas "no" indicates a negative environmental impact.

3) **For each matrix element, determine a score from 0 - 5 by adding the number of circled "yes" answers. Enter this number in the corresponding box on the matrix.** For example, if you answered "yes" to the first two questions in Matrix Element B.2 (product manufacture, energy use) "4" is placed in **row** 2, **column** 2. Note that each matrix element or box is mapped to its corresponding questions by a number in the upper left hand corner.

4) **Add the scores in each column and write the total in the corresponding cell in the "Total" row. Add the scores in each row and write the total in the corresponding cell in the "Total" column.**

5) **Add the numbers in the "Total" column and again in the "Total" row. The sums should be the same. Enter this sum into the remaining box on the bottom right-hand corner of the matrix**. The result is a relative score for the product that can be used to compare a product currently being designed with an existing product, or to compare alternative designs for a new product. The totals for each of the life stages (rows) and the environmental impacts (columns) indicate areas of strength and areas for improvement in terms of the environmental attributes of a product over its entire life-cycle. The scores are relative, comparative scores that are strictly for internal company use. The maximum total score without matrix element A (supplier survey question information) is 100 points. With matrix element A the maximum score is 125 points.

Premanufacture

As indicated by the survey of your suppliers:

A.1: Premanufacture, Materials

What percent of your company's suppliers for this product or component have an Environmental Management System (EMS) in place? (circle one)

0% or unknown = 0 points
1 to 5 % = 2 points
6 to 25% = 3 points
26 to 50% = 4 points
>50% = 5 points

A.2: Premanufacture, Energy

What percent of your company's suppliers for this product or component have formal energy conservation practices in place, such as the Environmental Protection Agency's Green Lights Program? (circle one)

0% or unknown = 0 points
1 to 5 % = 2 points
6 to 25% = 3 points
26 to 50% = 4 points
>50% = 5 points

A.3: Premanufacture, Solid Residue

What percent of your company's suppliers for this product or component have ISO 9000 or ISO 14000 in place or regularly publish a company environmental report? (circle one)

0% or unknown = 0 points
1 to 5 % = 2 points
6 to 25% = 3 points
26 to 50% = 4 points
>50% = 5 points

A.3: Premanufacture, Liquid

What percent of your company's suppliers for this product or component have a water conservation program ? (circle one)

0% or unknown = 0 points
1 to 5 % = 2 points
6 to 25% = 3 points
26 to 50% = 4 points
>50% = 5 points

A.5: Premanufacture, Gaseous

What percent of your company's suppliers for this product or component have a formal program in place for minimizing air emissions? (circle one)

0% or unknown = 0 points
1 to 5 % = 2 points
6 to 25% = 3 points
26 to 50% = 4 points
>50% = 5 points

Enter the point value of each of the circled answers into the corresponding " matrix element A boxes" of toolkit matrix sheet for this product or component.

B.1: Product Manufacture, Materials Choice

(for each question circle one number)

For this product or component:	Yes	No
1) Is as much **recycled** material used in your product as possible?	1	0
2) Is the use of **hazardous** materials avoided or minimized? (see *figure 5 page 58, Hazardous Chemical Index, page 32)*	2	0
3) Are the amounts of materials that are used minimized?	1	0
4) Are the number of types of materials that are used minimized?	1	0

Total Points for Matrix Element B.1 ________

B.2: Product Manufacture, Energy Use

For this product or component:	Yes	No
1) Do the manufacturing process minimize the use of **energy- intensive** processes? *(for example, multiple cycles of heating and cooling, inefficient motors, see Motors Challenge Program page 63 etc.)*	2	0
2) Do manufacturing processes use cogeneration, heat exchange or other techniques to utilize wasted energy?	2	0
3) Is there minimal transportation between manufacturing and assembly points?	1	0

Total Points for Matrix Element B.2 ________

B.3: Product Manufacture, Solid Residue

(for each question circle one number)

For this product or component:	Yes	No
1) Are waste materials minimized and reused to the greatest extent possible during manufacturing? *(e.g., mold scrap, cutting scrap etc.)*	1	0
2) Have raw material and parts suppliers been contacted to encourage them to minimize the amounts and types of packaging materials entering your facility?	1	0
3) Has your company maximized the opportunities to reuse and reduce packaging waste when parts are shipped between facilities?	1	0
4) Has intentional introduction of all lead, cadmium, mercury and hexavalent chromium into the product materials been avoided?	2	0

Total Points for Matrix Element B.3 ________

B.4: Product Manufacture, Liquid Residue

For the manufacture of this product or component:	Yes	No
1) If **hazardous** solvents or oils are used have alternatives been thoroughly investigated? *(see vendor lists in the Reference Information section for information on alternative solvents and oils, if no solvents or oils are used in the manufacturing process the answer is "2" or no environmental impact)*	2	0
2) Are opportunities maximized to capture and reuse liquid by-products generated during the manufacturing process? *(if no solvents or oils are used in the project the answer is "2" or no environmental impact)*	1	0
3) Is the generation of **water pollutants** avoided or minimized?	2	0

Total Points for Matrix Element B.4 ________

B.5: Product Manufacture, Gaseous Residue

For the manufacture of this product or component:	Yes	No
1) Is the generation of **global warming or ozone-depleting gases** avoided? (see *Climate-altering Chemical Index, page 60)*	2	0
2) Is the generation of **hazardous** air pollutants avoided during the manufacturing process?	2	0
3) Is the use of solvents, paints, coatings or adhesives with high evaporation rates eliminated or minimized? *(i.e., materials that emit high VOCs or volatile organic compounds)*	1	0
Total Points for Matrix Element B.5		

Distribution, Packaging

C.1: Distribution, Packaging, Materials Choice

(for each question circle one number)

For this product or component:	Yes	No
1) Have **reusable transport packaging options** been explored for distribution between company facilities?	1	0
2) Have **reusable transport packaging options** been explored for distribution between your company and your suppliers?	2	0
3) Are **recycled** materials used in the transport and retail packaging ?	1	0
4) Are **recyclable** materials used in the transport and retail packaging ?		
5) Is the number of different types of materials used in the packaging minimized?	1	0
Total Points for Matrix Element C.1		

C.2: Distribution, Packaging, Energy Use

For this product or component:	Yes	No
1) Is either reusable packaging or material of the lightest weight and volume, yet functional transport and retail packaging material used?	5	0
Total Points for Matrix Element C.2		

C.3: Distribution Packaging, Solid Residues

For this product or component:	Yes	No
1) Is the packaging designed for easy separation of materials for reuse or recycling?	1	0
2) Are the types of packaging used commonly recycled?	2	0
3) Are the packaging materials clearly marked or easily identified by material type? *(e.g., plastics with resin type label etc.)*	2	0

Total Points for Matrix Element C.3 ______

C.4: Distribution, Packaging, Liquid Residues

(for each question circle one number)

For this product or component:	Yes	No
1) Have maximum precautions been take to prevent hazardous liquid spills during transport? *(e.g., extra containment layers or safety valves, if there are no hazardous liquids in the product or component the answer is "5" or yes, for no environmental impact)*	5	0

Total Points for Matrix Element C.4 ______

C.5: Distribution, Packaging, Gaseous Residues

For this product or component:	Yes	No
1) Does the transport or retail packaging not contain chlorinated polymers or plastics which may produce hazardous emissions if incinerated at low temperatures? (see Polymers page 62)	3	0
2) Does the packaging not contain bromated flame retardants that may produce hazardous emissions if incinerated at low temperatures?	2	0

Total Points for Matrix Element C.5 ______

Product Use, Maintenance

D.1: Product Use, Maintenance, Materials Choice

For this product or component:	Yes	No
1) Is the product or component easily disassembled for upgrade, repair or reuse?	1	0
2) Are parts readily available for the repair of this product or component?	1	0
3) Are potential barriers to recycling avoided such as using fillers, additives, or imbedded metal threads in plastics, applying paint to plastics, or using materials of unknown composition?	2	0
4) If plastics are used are they clearly marked by resin type?	1	0

Total Points for Matrix Element D.1 ______

D.2: Product Use, Maintenance, Energy Use

(for each question circle one number)

For this product or component:	Yes	No
1) Does the design facilitate minimal energy use while the product is in service?	2	0
2) Can this product or component adjust energy use based on the level of activity? (e.g. go into "sleep mode" during inactivity)	3	0

Total Points for Matrix Element D.2 ______

D.3: Product Use, Maintenance, Solid Residue

For this product or component:	Yes	No
1) Does the design avoid building in disposable components such as "one-time- use" cartridges, containers or batteries?	1	0
2) Are snaps, darts, screws of the same head type or other removable fasteners used and are adhesive or welds avoided for joining parts to make it easier to disassemble, repair, reuse or recycle?	2	0
3) Is this product designed to be easily repaired and/or upgraded rather than replaced entirely?	2	0

Total Points for Matrix Element D.3 ______

D.4: Product Use, Maintenance, Liquid Residue

For this product or component:	Yes	No
1) Does use of the product avoid the release of substances known to be **water pollutants**? (see Hazardous Chemical Index, page 32)	5	0

Total Points for Matrix Element D.4 ______

D.5: Product Use, Maintenance, Gaseous Residue

(for each question circle one number)

For this product or component:	Yes	No
1) Is the emission of hazardous **air pollutants** avoided during use or maintenance? *(see Hazardous Chemicals List, page 32)*	2	0
2) Is the emission of **global warming** and **ozone- depleting gases** avoided during use or maintenance? *(see Hazardous Chemical Index, page 32)*	3	0

Total Points for Matrix Element D.5 ______

End of Life

E.1: End of Life, Materials Choice

For this product or component:	Yes	No
1) Are the materials are easily reused or commonly recycled?	1	0
2) Are the materials easy to separate and identify by type?	1	0
3) Upon disposal are none of the materials required to be disposed of as hazardous waste?	1	0
4) Has the intentional introduction of lead, cadmium, mercury and hexavalent chromium into the product materials been avoided?	2	0

Total Points for Matrix Element E.1 ______

E.2: End of Life, Energy Use

For this product or component:	Yes	No
1) Can the plastic or fiber parts be safely used for energy generation ? (i.e., incineration, see Polymers on page 62, if there is no plastic or fiber materials used the answer is "2" or yes)	2	0
2) Upon disposal are there no hazardous materials that need to be transported to hazardous waste management facilities? (i.e., additional energy use is required to transport materials for special handling)	3	0

Total Points for Matrix Element E.2 ______

E.3: End of Life, Solid Residues

(for each question circle one number)

For this product or component:	Yes	No
1) Does the infrastructure exist (inside or outside the company) to recover/recycle the solid material(s)?	2	0
2) Does the product design avoid joining dissimilar materials in ways that are difficult to reverse?	3	0

Total Points for Matrix Element E.3 ______

E.4: End of Life, Liquid Residues

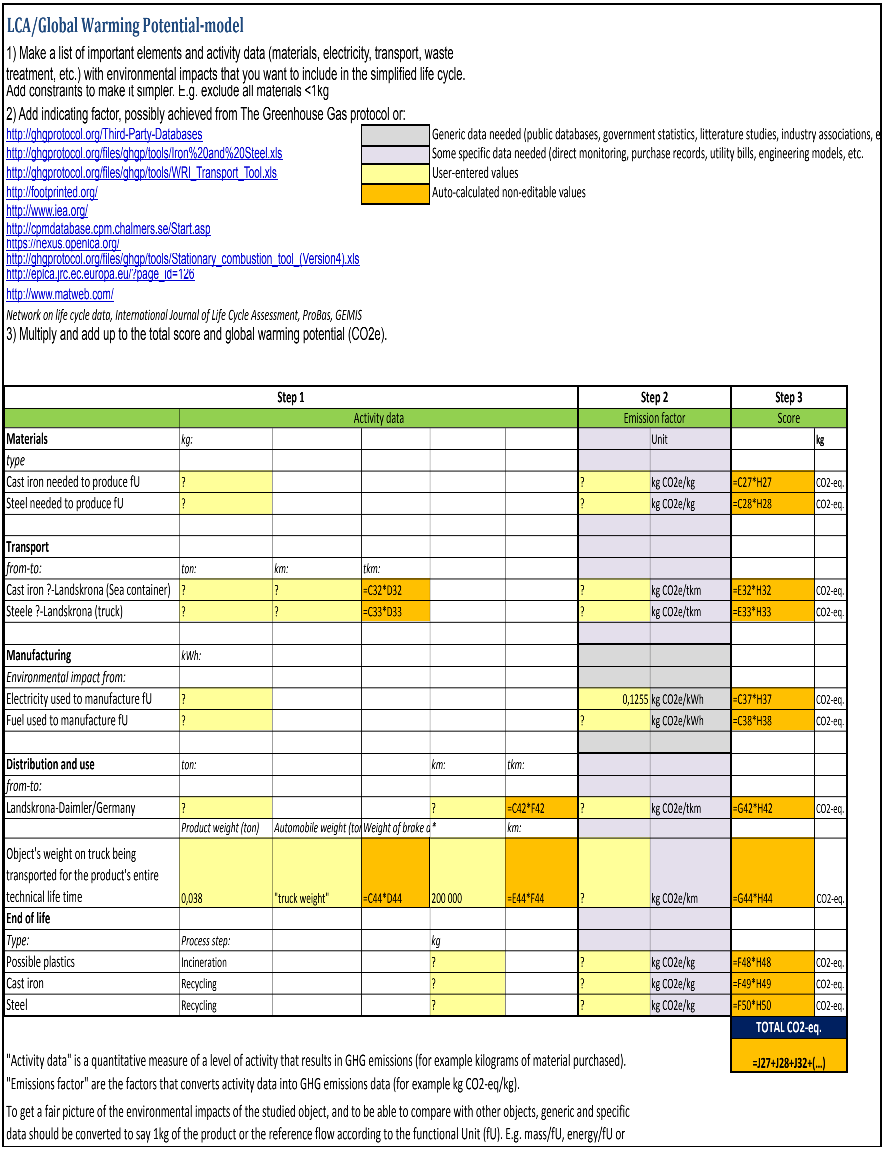
For this product or component:	Yes	No
1) Is the product designed so that problem liquid materials can be recovered during disassembly? *(if there are no liquids in the product or component the answer is "5" or yes, for no environmental impact)*	5	0

Total Points for Matrix Element E.4 ______

E.5: End of Life, Gaseous Residues

For this product or component:	Yes	No
1) Is release of substances known to be **ozone-depleting** and/or **global warming gases** avoided upon disposal of this product or component? *(see Climate-altering Chemical Index, page 32)*	2	0
2) Can gases contained in the product be recovered at the time of disassembly rather than lost? *(if there are no gases contained in the product or component the answer is "2" or yes)*	1	0
3) Is release of substances known to be **air pollutants** avoided upon disposal of this product or component?	2	0
Total Points for Matrix Element E.5		

Appendix C, Simplified LCA prototype and excerpts from guide on how to use it



LCA/Global Warming Potential-model

1) Make a list of important elements and activity data (materials, electricity, transport, waste treatment, etc.) with environmental impacts that you want to include in the simplified life cycle.
Add constraints to make it simpler. E.g. exclude all materials <1kg

2) Add indicating factor, possibly achieved from The Greenhouse Gas protocol or:

http://ghgprotocol.org/Third-Party-Databases
http://ghgprotocol.org/files/ghgp/tools/Iron%20and%20Steel.xls
http://ghgprotocol.org/files/ghgp/tools/WRI_Transport_Tool.xls
http://footprinted.org/
http://www.iea.org/
http://cpmdatabase.cpm.chalmers.se/Start.asp
https://nexus.openlca.org/
http://ghgprotocol.org/files/ghgp/tools/Stationary_combustion_tool_(Version4).xls
http://eplca.jrc.ec.europa.eu/?page_id=126
http://www.matweb.com/

▨ Generic data needed (public databases, government statistics, litterature studies, industry associations, e
▢ Some specific data needed (direct monitoring, purchase records, utility bills, engineering models, etc.
🟨 User-entered values
🟧 Auto-calculated non-editable values

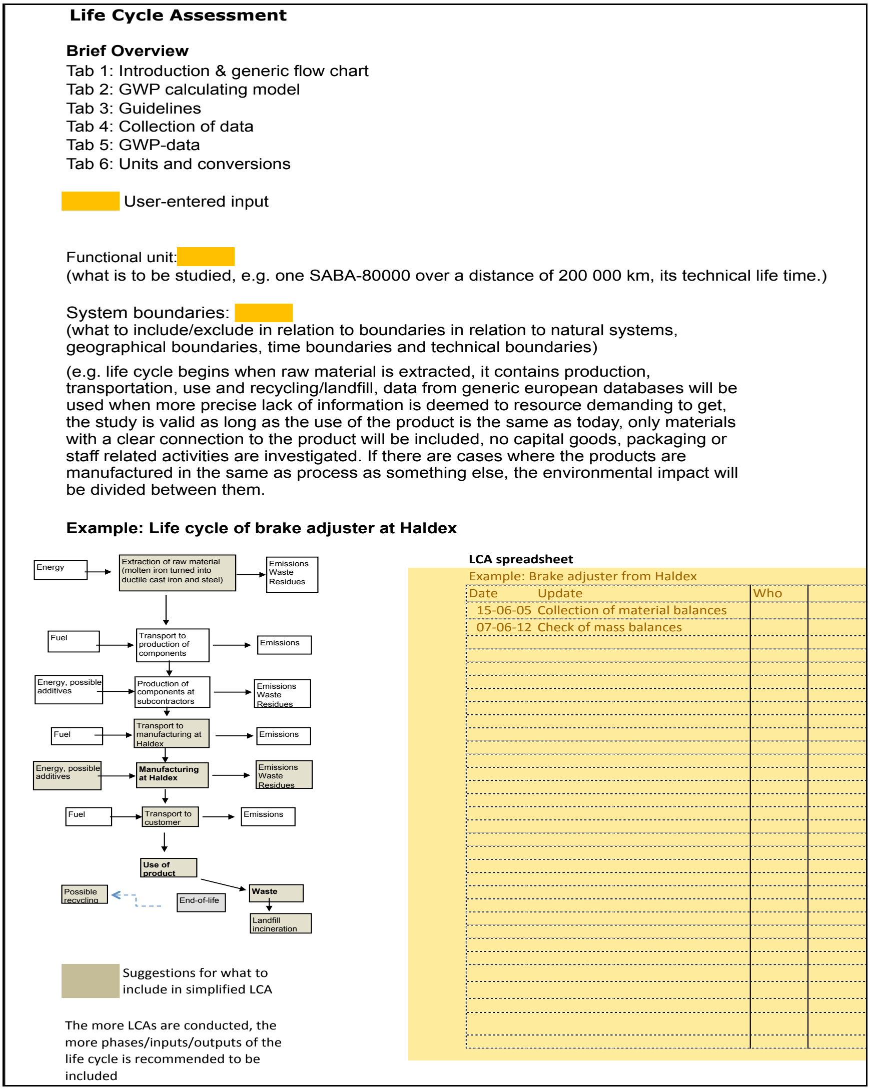
Network on life cycle data, International Journal of Life Cycle Assessment, ProBas, GEMIS

3) Multiply and add up to the total score and global warming potential (CO2e).

Step 1						**Step 2**		**Step 3**	
	Activity data					Emission factor		Score	
Materials	*kg:*						Unit		**kg**
type									
Cast iron needed to produce fU	?					?	kg CO2e/kg	=C27*H27	CO2-eq.
Steel needed to produce fU	?					?	kg CO2e/kg	=C28*H28	CO2-eq.
Transport									
from-to:	*ton:*	*km:*	*tkm:*						
Cast iron ?-Landskrona (Sea container)	?	?	=C32*D32			?	kg CO2e/tkm	=E32*H32	CO2-eq.
Steele ?-Landskrona (truck)	?	?	=C33*D33			?	kg CO2e/tkm	=E33*H33	CO2-eq.
Manufacturing	*kWh:*								
Environmental impact from:									
Electricity used to manufacture fU	?					0,1255	kg CO2e/kWh	=C37*H37	CO2-eq.
Fuel used to manufacture fU	?					?	kg CO2e/kWh	=C38*H38	CO2-eq.
Distribution and use	*ton:*			*km:*	*tkm:*				
from-to:									
Landskrona-Daimler/Germany	?			?	=C42*F42	?	kg CO2e/tkm	=G42*H42	CO2-eq.
	Product weight (ton)	*Automobile weight (to*	*Weight of brake d*	*	*km:*				
Object's weight on truck being transported for the product's entire technical life time	0,038	"truck weight"	=C44*D44	200 000	=E44*F44	?	kg CO2e/km	=G44*H44	CO2-eq.
End of life									
Type:	*Process step:*			*kg*					
Possible plastics	Incineration			?		?	kg CO2e/kg	=F48*H48	CO2-eq.
Cast iron	Recycling			?		?	kg CO2e/kg	=F49*H49	CO2-eq.
Steel	Recycling			?		?	kg CO2e/kg	=F50*H50	CO2-eq.
								TOTAL CO2-eq.	
								=J27+J28+J32+(...)	

"Activity data" is a quantitative measure of a level of activity that results in GHG emissions (for example kilograms of material purchased).
"Emissions factor" are the factors that converts activity data into GHG emissions data (for example kg CO2-eq/kg).

To get a fair picture of the environmental impacts of the studied object, and to be able to compare with other objects, generic and specific data should be converted to say 1kg of the product or the reference flow according to the functional Unit (fU). E.g. mass/fU, energy/fU or



Life Cycle Assessment

Brief Overview

Tab 1: Introduction & generic flow chart
Tab 2: GWP calculating model
Tab 3: Guidelines
Tab 4: Collection of data
Tab 5: GWP-data
Tab 6: Units and conversions

🟨 User-entered input

Functional unit:
(what is to be studied, e.g. one SABA-80000 over a distance of 200 000 km, its technical life time.)

System boundaries:
(what to include/exclude in relation to boundaries in relation to natural systems, geographical boundaries, time boundaries and technical boundaries)

(e.g. life cycle begins when raw material is extracted, it contains production, transportation, use and recycling/landfill, data from generic european databases will be used when more precise lack of information is deemed to resource demanding to get, the study is valid as long as the use of the product is the same as today, only materials with a clear connection to the product will be included, no capital goods, packaging or staff related activities are investigated. If there are cases where the products are manufactured in the same as process as something else, the environmental impact will be divided between them.

Example: Life cycle of brake adjuster at Haldex

▨ Suggestions for what to include in simplified LCA

The more LCAs are conducted, the more phases/inputs/outputs of the life cycle is recommended to be included

LCA spreadsheet

Example: Brake adjuster from Haldex

Date	Update	Who	
15-06-05	Collection of material balances		
07-06-12	Check of mass balances		