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Investigation of greenhouse gas emissions from the production of tin cans

- An evaluation of the EcoProIT method

Master of Science Thesis in Production Engineering

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Göteborg, Sweden, 2013

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Front cover:
Superstudio
Caption:
EcoProIT Method
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Preface

This master thesis was carried out during spring term 2012 at the institution for Product and Production Development at Chalmers University of Technology. The Master programme was Production Engineering and the Thesis covers 30 credits.

We would like to thank Emballator Ulricehamns Bleck and EcoProIT for the opportunity to participate in this project.

The supervisor was Jon Andersson and the examiner was Björn Johansson as a member of the EcoProIT project Anders Skoogh was also available for support during the master thesis. We would like to thank them for their support during this project. We would also like to thank everybody at Emballator Ulricehamns Bleck for answering our many questions with a smile.

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Joakim Larsson & Marinetta Törnberg

Abstract

The interest for the environment among industries has increased in recent years. One reason is the demands from legislations and restrictions getting harsher as well as higher demands from customers. Emballator Ulricehamn's Bleck is a packaging company with an environmental conscious. They wish to know how much environmental impact their products have, expressed by a Global-warming Potential (GWP) value. EcoProIT (2010-2013) is a project working on combining the increasing use of Discrete-event Simulation (DES) models with Activity-based costing (ABC) to investigate this. Instead of measuring monetary values the ABC and the DES will measure time and consumption of energy to calculate a more dynamic GPW value.

This master thesis has evaluated the EcoProIT model by investigating the GWP value of 2.5l – 6l (production line 180-1) cans at Emballator. The conclusions show that the GWP value varies from ~2.37 GWPs for a 2.5l can to ~4,35 for a 6l can. The model shows that the variation for one can vary, for example a 2,5 litres varies between ~2,19 and ~2,88 GWPs. The most significant in house contribution to the GWP value is waste materials and processes and it is recommended to further analyse the waste in the production flow.

The conclusions drawn after working with the EcoProIT method is that a pre-study should be performed before embarking on a similar product. The pre-study should focus on which parts of the production system that have the highest impact in terms on GWP value. The study will help when identifying important parameters and accuracy requirements that are needed to move forward in the project as well as deciding how and what parts of an existing DES-model built with production objectives in mind. DES-model need to be modified. This master thesis recommends that the EcoProIT method is evaluated on an existing DES model.

Table of Content

Definitions and abbreviations

ABC – Activity-based Costing
AGV - Automated Guided Vehicle
DES – Discrete-event Simulation
EcoProIT method – Method developed by the EcoProIT project (2010-2013)
EcoProIT model – The model created using the EcoProIT method
GWP - Global-warming Potential
ISO – International Standard Organisation
LCA - Life Cycle Assessment
LCI - Life Cycle Inventory
LPG - Liquefied Petroleum Gas
MTTF - Mean time to failure
MTTR - Mean time to repair
SOU - Statens Offentliga Utredningar
SMHI - Sveriges Metrologiska och Hydrologiska Institut

1. Introduction

In recent years there has been an increased focus on environmental research and sustainable production. Government restrictions as well as EU regulations are issued regularly for a variety of industries, most prominent among the car industry controlling the CO2 emissions etc (Cuenot 2009).

EcoProIT is an on-going project at Chalmers and the main objective is to enable labelling of products and a tool for evaluating the environmental footprints during the lifecycle of a product. To then be able to connect several steps in the product lifecycle and get a final dynamic environmental impact. Different EcoProIT models should create a cluster or a chain as work together to support each other's GWP calculations. A part of EcoProIT's project aims to develop a new tool and methodology (the EcoProIT method) for environmental evaluations using DES. The thought behind the EcoProIT method is that is should be possible to implement on an existing DES model (Andersson et al 2011).

1.1 Background

Emballator is a market leading packaging manufacturer with strong environmental and quality focus. They provide metal and plastic packages to food, paint and technical chemistry industries. The packages range from bottles, bottle caps to cans and containers. Emballator Ulricehamn's Bleck, here after referred to as Emballator, produce cans ranging from 0,33l to 25l where the majority of the customers are in the paint industry.

As a mean toward becoming an even more sustainable company, Emballator wish to label their products with environmental metrics. This would enhance their environmental profile among their customers as well as create and advantage against their competitors (Gallego-Álvarez et al. 2010). Emballator anticipates similar restrictions and regulations, as those in the car industry, within their own field, as well as their customers' field. They view this master thesis as a proactive measure.

Traditionally Discrete-event Simulation (DES) has been used to evaluate the relationship between monetary units, materials, time and other resources (Banks 2004, Banks 1999). With an Activity-based Costing calculation (ABC), activities in an organization are identified and indirect and direct costs are allocated to the product or services in accordance to their respective consumption of these activities (Skärvad & Olsson). Both are traditionally used separately, von Beck and Nowak (2000) showed that an ABC calculation can be implemented in a DES model.

Emblemsvåg (2001) showed that ABC calculations suit well when performing an environmental impact analysis (Life Cycle Assessment, LCA). This is supported by a recent study by Andersson et al (2011) that conclude that ABC calculations in a DES model is a suitable combination to perform a LCA for a manufacturing system. This master thesis aims to implement this in a real world scenario by using the EcoProIT method that is under development.

1.2 Purpose and objective

The purpose of this master thesis is to analyse green house gas emissions, expressed as Global-warming Potential (GWP) to provide Emballator with relevant environmental data that can be used as a basis for an ecolabel on their product or in a product catalogue.

This master thesis will also provide researchers from the EcoProIT project with a test implementation of environmental metrics in DES for enabling the development of a new methodology and tool for environmental evaluations using DES here after referred to as the EcoProIT method.

The objectives of this master thesis are:

- To find the amount of greenhouse gases produced in the current state, measured per product.
- To find all sources of greenhouse gases for the product and identify the most significant sources, contributing with at least 80% of the total GWP value.
- To use and evaluate the EcoProIT method.

1.3 Problem formulation

This master thesis will answer the three main-questions below. To help Emballator improve their GWP value this master thesis will also answer sub question 1a. For Emballator's environmental commitment to reach out to their customers it is important that they (Emballator) know how they can and are allowed to use the GWP values.

MQ1 How much greenhouse gases (expressed in GWP) are omitted to produce one product (can + lid)?

SQ1 What can Emballator do to reduce their greenhouse gas emissions?

There is no current method to follow when working with environmental factors and DES. This is one of the questions EcoProIT is trying to solve. The insecurities regarding the EcoProIT model is investigated by answering the sub-questions.

MQ2 Is EcoProIT’s method suitable when investigating GWP impact?

SQ2a What are the differences between the input data management for the EcoProIT method and the data for a LCA or a traditional DES?

SQ2b What are the difficulties when verifying and validating a model created with the EcoProIT method in terms of environmental aspects?

These questions will be investigated with the focus on the following areas:

- Time consumption
- Result accuracy
- Possibility to maintain and update the model.

1.4 Delimitations

The following points define the general delimitations for this master thesis.

- This thesis will consider all activities inside the factory until the products leave Emballator (gate to gate). Environmental metrics from preproduction, scrap in production, usage and recycling and the end of the product life cycle will be taken into consideration but will not be investigated further.
- Measurements for energy consumption on the machines/processes were done during the spring 2012 and are assumed to be valid for the whole year.
- DES model will only analyze products produced at the 180-1 production line at Emballator.
- The DES-model will be based on process and production data but will not be used to make production analysis or consider economic factors.
- The EcoProIT method is still under development and the description available so far will be followed. Changes to the method during the time of this thesis will be taken into consideration if they are possible or applicable.
- The EcoProIT method will be evaluated by execution, focusing on the questions in the problem formulation (SQ2a and SQ2b).
- Comparisons between the EcoProIT method and similar or related methods will only regard SQ2a and SQ2b.

Delimitations concerning the model will be further described in chapter *4.5.7 Delimitations of the model.*

1.6 Factory description

Emballator's factory in Ulricehamn produces a wide range of metal cans in different sizes. The cans are slightly conical to improved decrease storage volume and stack ability. There are many ways to design the cans to fit customer's needs. For example; handles or no handles, a range of different lids and the printing on the cans can be specific for each batch.

Figure 1 The different components of a can that will be discussed in the report

Emballator manufacture several different can sizes. The size focused on in this master thesis has the top diameter 180mm and is a conical can. The line where the cans are produced is one of two manufacturing this size, 180-1 and 180-2. Depending on the height of the can different volumes are achieved. The 180-1 production line manufacture 2.5l, 3l, 4l, 5l and 6l cans. The cans are produced from metal sheets stored in a raw material buffer. The sheets are processed through an enamel paint machine and a printing press before stored in the printed sheet buffer. The sheets are stored in this buffer until Emballator receives an order for those cans. The sheets are moved to the 180-1 production line where they are cut and formed into cans. A bottom and an optional gripping wire are attached. The system will be described in further detail in chapter *4. System description.*

1.7 Disposition

This master thesis will continue with a theoretical framework describing important aspects for the purpose of this project. Thereafter the EcoProIT method will be described. This will be followed by a system description, which includes the information flow, the production flow, the energy flow, and a model description. After that the results from the EcoProIT model will be presented followed by an analysis of the result and evaluation of the EcoProIT method. The discussion will handle the above-mentioned chapters and which results in the conclusions and recommendations.

2. Theory

To be able to answer the questions asked in the introduction a theoretical framework will be presented in this chapter. The theoretical framework consists of theory about global warming, life cycle assessment, steel industry, Activity-based Costing, Discrete-event Simulation and input data management

2.1 Global warming

The greenhouse effect is a process where the thermal radiation from the earth's surface is absorbed by the atmospheric greenhouse gases and bounced back to the surface of the earth. Increases in concentration of greenhouse gases in the atmosphere have lead to what is referred to as global warming. Global greenhouse gases due to human activities have grown with 70 % between 1970 and 2004. Since the early 20^{th} century the Earths average temperature has increased by 0.8°C and about two thirds of the increase has occurred after 1980 (Climate change synthesis report 2007).

2.1.1 Greenhouse gases

There are several gases that contribute to the greenhouse effect. The most significant are:

- Carbon dioxide (CO_2)
- Methane (CH_4)
- Nitrous oxide (N_2O)

Each of these have different ability to reflect thermal radiation back to earth and also different residence times. Because of the different residence times it is impossible to find a measurement to compare greenhouse effect potential of the gases without defining the time horizon. (Lashof, Ahuja 1990) The GWPs are therefore calculated with different time interval, commonly 20, 100 and 500 years. The residence time is not always known and therefore the values should not be considered exact. GWP is expressed as a factor of carbon dioxide, which has a GWP of one as per definition. See Table 1 below with GWP calculations with different time interval for some common greenhouse gases. (Climate change synthesis report 2007)

Greenhouse gas		GWP value		
Common name	Chemical formula	20 years	100 years	500 years
Carbon dioxide	CO_2	1	1	1
Methane	CH_4	72	25	7,6
Dinitrogen oxide	N_2O	289	298	153
CFC-11	CCl_3F	6730	4750	1620
Carbon Tetrachloride	CCl_4	2700	1400	435
Methyl Chloroform	CH_3CCl_3	506	146	45

Table 1 GWP values for some greenhouse gases (Forster et al, 2007).

2.2 Life Cycle Assessment

Life Cycle Assessment (LCA) is a systematic tool to evaluate the impact on the environment of a product, process or activity. LCA takes the whole life cycle in to consideration, from cradle to grave (Curran 2004). It includes material extraction, manufacture, usage and end of life. An LCA does not only consider CO_2 but all kinds of environmental emissions such as atmospheric emissions, waterbourne wastes, solid wastes etc. See Figure 2 below.

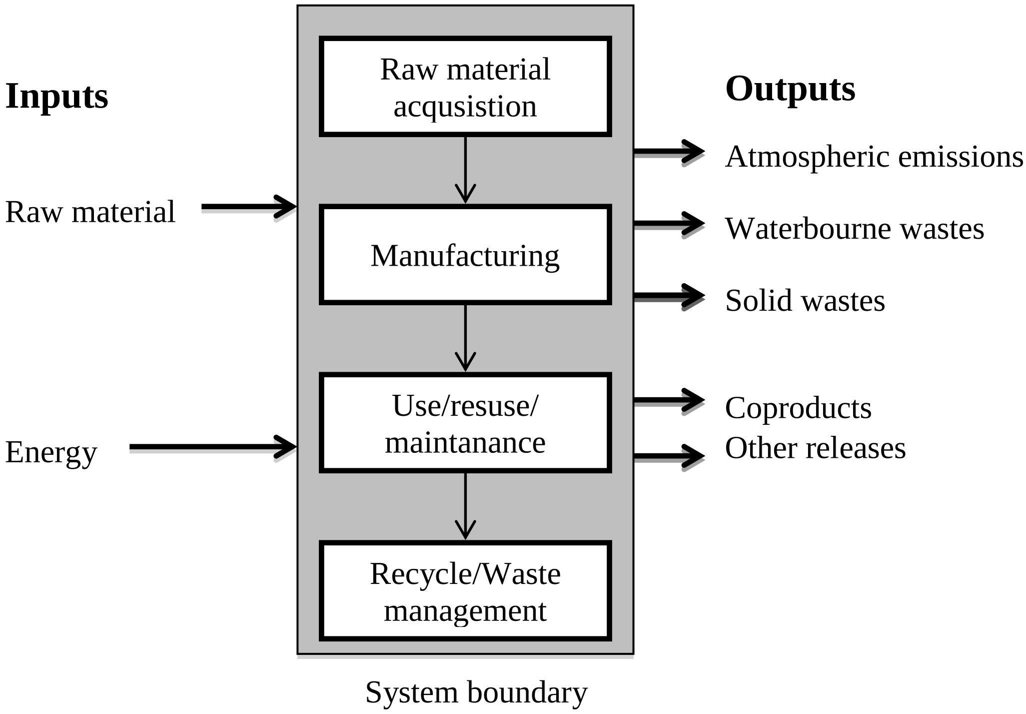

Figure 2 Input, output and system boundary in an LCA

The principles and framework for conducting an LCA is described by the International Standard Organisation (ISO), in ISO 14040. In the ISO framework there are four steps to conduct an LCA described in ISO 14041-14044.

ISO 14041 *Goal and scope definitions* – Define and describe the product, process or activity. Establish the boundaries and the context in which the assessment is to be made. Find which environmental effects will be reviewed. This is an important phase and will have a strong influence on the result.

ISO 14042 *Inventory analysis* – Identify and quantify air emissions, solid waste disposal and waste water discharges. This stage is described in ISO 14042.

ISO 14043 *Impact assessment* – Assess the potential effects of the releases identified in ISO 14042.

ISO 14044 *Interpretation* – Evaluate the results from the inventory analysis and the impact assessment. Consider the uncertainties and assumptions used to generate the results. (Rebitzer et al 2004).

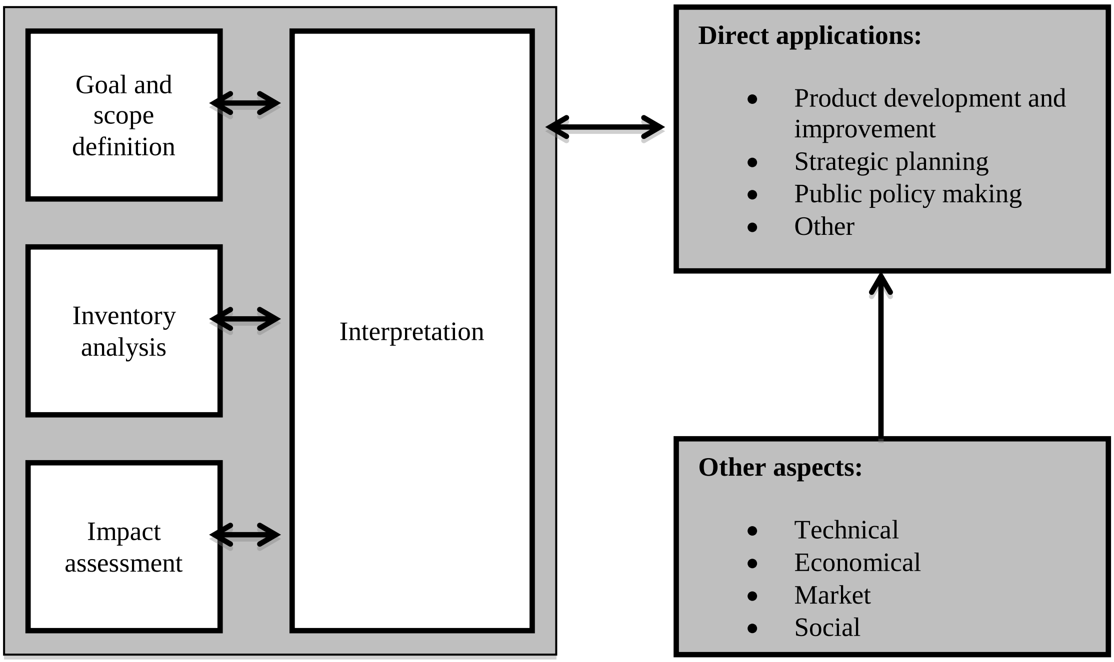

Figure 3 Life Cycle Assessment Framework - phases of LCA (Rebitzer et al 2004).

According to Curran (2004) LCA faces three key barriers.

1. Lack of awareness of the need to look holistically at the overall impacts of actions.
2. Difficulties finding reliable and publicly available data.
3. Lack of an agreed upon life-cycle impact assessment model.

2.3 Steel industry

Iron is a common element in our environment and essential for many living things. Most of the iron is compound in the crust of the earth as magnetite (Fe_3O_4) and hematite (Fe_2O_3). Iron takes part of a natural cycle where it transforms through different compounds. When iron is removed from natural steel cycle and processed to steel it enters into the technical steel cycle. The steel is then manufactured into a product and when that product is used up or in another way consumed it can be recycled and made into new products. There are two ways for the steel to exit the technical steel cycle. It could be too polluted with other materials to be used in existing industry processes or it can go back to the natural steel cycle through corrosion (Widman 2001).

Today about 35-40 % of all steel is produced from recycled steel. To produce steel from recycled material is a an easier and less energy consuming process than using iron ore. To produce one ton of steel from iron ore consumes 23 GJ while only 7 GJ is consumed to make the same amount out of recycled steel (Widman 2001).

It is difficult to find figures for the national recyclability for steel cans and even if it were possible to find these it would be impossible to separate Emballator's product from the rest. However World Steel Association (2011) has calculated that about 68 % of steel cans where recycled in 2007 worldwide. According to SOU, 62 % of all steel was recycled in 1999 (SOU 2001 – 102). The figures from SOU are calculated as recycled steel divided by the amount of steel products produced that year.

According to Jernkontoret's research on the steel cycle, a lot of the application and products using steel, such as bridges and cars, are used for a much longer time, than for instance a can, before they are recycled. If the median time until recycling, for steel products, is twenty years the amount of steel recycled that year should be compared to the production of steel products twenty years ago. Since the total production of steel today is higher than it was twenty years ago it is impossible to reach 100 % by using the same calculations as SOU (Ekerot 2003).

2.4 Ecolabeling

Ecolabeling is attracting more and more companies who see this as an essential factor to consider in their industrial and commercial strategies. In 1998 and 1999, ISO standardized ecolabeling practises and adopted the ISO 14020 series in which three different types of ecolabels are proposed (Lavalle & Plouff 2004).

2.4.1 Type I - Environmental labeling

Type I environmental label is standardized by ISO 14024 and the goal is to identify overall environmental performance of a product or service within a particular product or service category. This performance should be based on life cycle considerations. Many countries, including Sweden has adopted this environmental labelling type. Al type I labels include two steps. First a committee of the ecolabel program establishes a set of minimum requirements needed to obtain the label. The second step is that companies are given a certification to use the label on products that fulfil the requirements (Lavalle & Plouff 2004).

2.4.2 Type II - Self declared environmental claims

Type II environmental label is standardized by ISO 14021 and describes the environmental claim as an “environmental declaration made without certification from an independent third party, on the part of manufacturers, importers, distributers, retailers or any other entity able to gain benefit from this declaration”. The goals for type II of environmental labels are to promote environmental performance, to reduce inaccurate claims, to decrease confusion, to facilitate international trades and to allow customers to make informed decisions (Lavalle & Plouff 2004).

In the ISO standard a set of requirements are established which must be followed. These requirements say that the information must be accurate and not misleading. It also says that the information must be true for the finished product as well as it must also take the life cycle into account. This is to identify a potential increase in an environmental impact pursuant to the decrease in another (Lavalle & Plouff 2004).

Frequently used terms in this kind of declaration are:

- Compostable
- Degradable
- Designed for disassembly

2.4.3 Type III – Environmental declaration

Type III product declaration is described in ISO 14025. The declaration consist of environmental information such as percentage of recycled material, information on toxic substances and other information about a product´s environmental impact on a simplified performance report card. This declaration does not usually contain comparative claims but the information in the declaration may be used for such a comparison. If the information should be used for comparative claims the ISO standard 14040 must be followed (Lavalle & Plouff 2004).

The information on a type III environmental declaration must be based on procedures and results from a quantified life cycle assessment compliant with ISO 14040 standards. For many small and medium size businesses a complete life cycle assessment is too expensive and requires too much time investment (Lavalle & Plouff 2004).

2.5 Activity-based Costing

ABC is a financial method to assign costs of activities or resources in an organization to all products or services based on the actual consumption by each. In ABC two types of costs are identified. These are:

- *Direct costs* – Costs that can be traced directly to a product or service. Examples of these costs are material costs and machines that are only used for one product.
- *Indirect costs* – Costs that cannot be traced directly to a product. These costs are also called overhead costs. Examples of these costs are resources used for more than one product or services such as forklifts and heating of facility.

To get the true cost for each product or service the indirect costs has to be divided among the products or services manufactured. Cost drivers are identified to distribute the indirect costs. It is important to identify the correct cost driver and this is sometimes difficult since there may be several causes for one indirect cost. (Skärvad and Olsson 2008)

2.6 Discrete-event Simulation

Discrete-event Simulation (DES) is used to model the real world or a conceptual idea that is to be built or created in the real world. The models are often built in the image of production systems where the need for testing before implementing is needed or where system/process improvement is needed. DES can also be used to improve other areas such as healthcare, military or service sectors (for example hospitals and restaurants). The difficulties of predicting how a system of processes will behave and how they dynamically affect one another is one of the benefits of using DES (Banks 1999).

Traditionally Banks method is used when working with a simulation project, there are several steps included. Two of the steps are especially relevant for this project and are discussed in more detail in the two following subchapters. For further reading and information about the other steps and on Banks method please see Banks (1999).

2.6.1 Demands on input data for a traditional DES project

There is variety of issues concerning input data for DES projects. One in particular is the time aspect. According to Skoogh and Johansson on average 31% of project time is spent on input data management and according to and Trybula (1994) between 10 and 40%. The variations in time depend on the share of each category of data that needs to be collected. Following Robinson and Bhatia (1995) example one can divide the data into three different categories (Table 2).

Category	Type of Data
A	Available data
B	Not available but collectable data
C	Not available and not collectable data

Table 1 (Robinson & Bhatia 1995)

Category A represents already available data such as previous time studies or from automated logging systems. Category B represents data that needs to be collected for example through time studies. Category C is neither available nor collectable and needs to be estimated. The estimations have to be carefully done for the sake of the model quality. Depending on the data composition in terms of the three categories time spent working with the data differs. Only 7 % of companies have all data available for DES projects (Skoogh and Johansson 2007). Perera and Liyanage (2000) identified the major causes of inefficient data collection, these are:

- Incorrect problem definition
- Lack of clear objectives
- High system complexity
- Higher level of model details
- Poor data availability
- Difficulty in identifying available data sources
- Limited data handling capacity

For further reading on major causes of inefficient data collection see Perera and Liyanage (2000).

According to Skoogh and Johansson (2007) the most time consuming activities are:

- Data collection
- Mapping of available data
- Data analysis and preparation.

In addition their study showed that only 20 % of DES projects finished their input data management according to set plans. The reason for this is that the company where the DES project is performed often overestimate the usability of the data or is unfamiliar with what type of or amount of data that is generally needed in DES projects. This leads to unforeseen work because of re-evaluations, calculations and additional measurements (Skoogh and Johansson 2007).

The quality of the model is dependent on the quality of the data, which increases the need for efficient input data management. As the amount and complexity of the data grows so does the need for structure and order in the input data management (Skoogh and Johansson 2008).

2.6.2 Input data management method

Skoogh and Johansson (2008) developed a structured methodology for the input data management process. The methodology consists of 13 steps, see figure 4, and is a tool to decrease the time and secure the quality of the data management. The method is especially important for those with limited experience of DES projects (Skoogh and Johansson 2008).

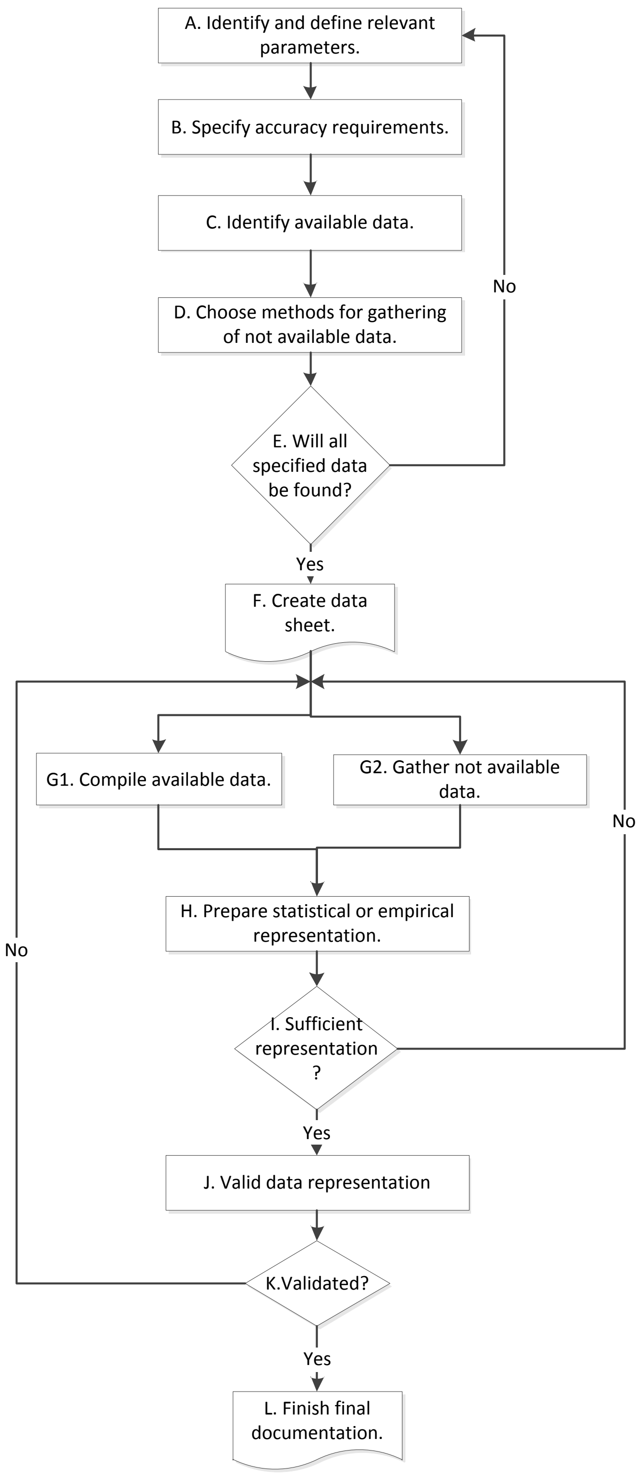

Figure 4 Input data management (Skoogh & Johansson 2008)

A. Identify and define relevant parameters

As the headline implies one should identify and define relevant parameters with regard to project objective. It is important to take level of detail into consideration as well as the system complexity to find a appropriate compromise. This should be accomplished by getting to know the system through experienced personnel with system knowledge or company production technicians, or both. With more system knowledge it is possible to define how each parameter should be measured to best be represented in the model. When measuring it is important to define, when or where, to start and stop to the measuring (Skoogh and Johansson 2008).

B. Specify accuracy requirements

The purpose and objective of the projects together with the knowledge of the system to be modeled will have to be guiding when deciding which accuracy level is needed on the different parameters. A parameter with less influence on the result can be less detailed than one important for the result. This can at a later stage be approved or disapproved by a sensitivity analysis. Skoogh and Johansson (2008) recommend this for all borderline cases. To get a good representation of a process a lot of data needs to be collected. The more variability a process has the more data is needed, in case of processes that are fairly constant, such as robot cycle time etc, only enough data to rule out any unexpected variability is needed (Skoogh and Johansson 2008).

C. Identify available data

Identify which category (A, B or C in *2.6.1 Demands on input data for a traditional DES project*) the desired data belong to, to make the most of all available data. In industry a lot of processes are measured and data collected, but not intended for a DES project. Therefore many companies believe they have enough and sufficient data for a DES projects when this is not the case. It is important to make sure that it is possible to collect the data and that it is on the right form or possible to get the correct form through calculations (Skoogh and Johansson 2008).

D. Choose methods for gathering not available data

Some of the data in DES projects are almost always not available, either category B or C. In the case of category B data case time studies, video recordings and other types of data collection is necessary. When time studies are made with stopwatches and similar it is important to define where the process measured starts and ends as described in step *A. Identify and define relevant parameters*, this is especially important if several people are measuring. Category C data is most common in not yet existing processes or systems and needs to be estimated with care. Time studies and video recordings of existing similar processes can be used for these estimation (Skoogh and Johansson 2008).

E. Will all specified data be found?

“Found” in this step refers not only to finding data but to make sure the data satisfies the demands made in the previous steps *B*, *C* and *D*. If the demands, such as number of data points, data accuracy or data quality are not satisfied problems may occur further down the line. According to Skoogh and Johansson (2008) step *I* and *K* are especially vulnerable to this and would result in less quality model. If the demands cannot be fulfilled, the need for future iterations is likely

F. Create data sheet

Skoogh and Johansson (2008) recommend that a data sheet is created where all raw data as well as all analyzed data is kept. It is discouraged to keep the analyzed data in the interface spreadsheet and the raw data in a temporary document. This less structured method is more time consuming since there is a possible risk of data loss (Skoogh and Johansson 2008).

G1. Compile available data

The category A data is collected as specified in step *C* and the amount of data specified in step *B*. Usually the data needs to be processed and additional efforts made to sort, filter, calculate and convert the data to a desirable form. This to prepare the data for the coming statistical or empirical representation in step *H*. If the data is previously analyzed it need only be validated as described below in step *K*. (Skoogh and Johansson 2008).

G2. Gather not available data

In this step the focus is to make category B or C data category A (Robinson and Bhatia 1995).

Category B data that is to be collected is a time consuming task (Skoogh and Johansson 2008), especially if they are gathered from a low frequency system or the product variability is high (high cycle time variability or long cycle time). Time studies on operators are controversial and this is usually solved with video cameras. However this means a doubling in real time measurements to collect data.

To gather category C data is less time consuming. Category C data should to the furthest extent be based on assumptions and estimations made by a process expert or highly knowledge of the system. Gathering category C data can be time consuming if it is based on similar systems or processes or historical data (Skoogh and Johansson 2008).

When both step *G1* and *G2* are done it is possible to move onto step *H.*

H. Prepare statistical or empirical representation

For the data to be implemented in the simulation model the raw data prepared in *G1* and *G2* need to be represented by statistical or empirical distribution, traces or bootstrapping (Robinson 2004).

I. Sufficient representation?

In this step the distributions from step *H.* are evaluated. There are several ways to do this, for example with a goodness-of-fit test. Goodness-of-fit test can be difficult to pass for large number of samples. Skoogh and Johansson (2008) suggest graphical comparison of the representational and original data. This given that the accuracy requirements regarding level of significance are fulfilled (step B.). This can be ensured at a later stage with a sensitivity analysis for the parts where less satisfying results are present for the graphical comparison (Skoogh and Johansson 2008).

If the accuracy requirements are not fulfilled, iteration from the steps *G1* and *G2* might be necessary. In the worst case scenario the iteration has to start at step *B*, which could have significant repercussions for the simulation model (Skoogh and Johansson 2008).

J. Validate data representation

According to Sargent (2010) lack of data validation is most commonly the reason model validation fail. It is also a costly and time consuming process. A validation of the data can save time and further iterations during the model validation (Skoogh and Johansson 2009). It is a difficult process to attain adequate validation quality data. The difficulties lies with the fact that the data for the conceptual model and project is based on is the same data it will be validated against (Sargent 2010). Both Sargent (2010) and Skoogh and Johansson (2008) recommend structure in the data collection process as the best guideline to avoid validation problems.

Skoogh and Johansson (2008) recommend that to reach a good enough validity the data collection process should be performed alongside discussions with process experts. A final check is also advised towards the end where the data is reviewed in a structured way.

K. Validated?

When the data is validated it is ready to be incorporated in the model. The validated data can still cause problems in the model validation. If this problem occurs it is important to reevaluate the data to find the reason for the problem. Skoogh and Johansson (2008) conclude that a lot of the problems occur due to miscalculations in step H but that the problem might stem as far as choice of gathering method, step *C* and *D.* (Skoogh and Johansson 2008).

L. Finish final documentation

This entire method for data input management is focused on documentation, therefore most of the data should at this stage already be documented. To facilitate further studies and future projects as well as maintaining the validation some additional documentation is needed, such as (Skoogh and Johansson 2008):

- Gathering methods
- Sources of data
- Validation results
- Assumptions made

This should be compiled in a data report and complete data sheet (Skoogh and Johansson 2008)

3. Method

3.1 Description of the EcoProIT method

EcoProIT 2010-2013 is an ongoing project in the Product and Production Development department at Chalmers University of Technology (Chalmers PPD).

As a step towards this master thesis goal, the method used is the EcoProIT method. Parallels can be drawn between this method and Banks method traditionally used for DES projects but there are some important differences. For more information about Banks methodology, see Banks (2004). Among other things Banks model does not facilitate the verification and validation of environmental aspects (Banks 2004). The description below of the EcoProIT model is a summation from unpublished documents by the EcoProIT project.

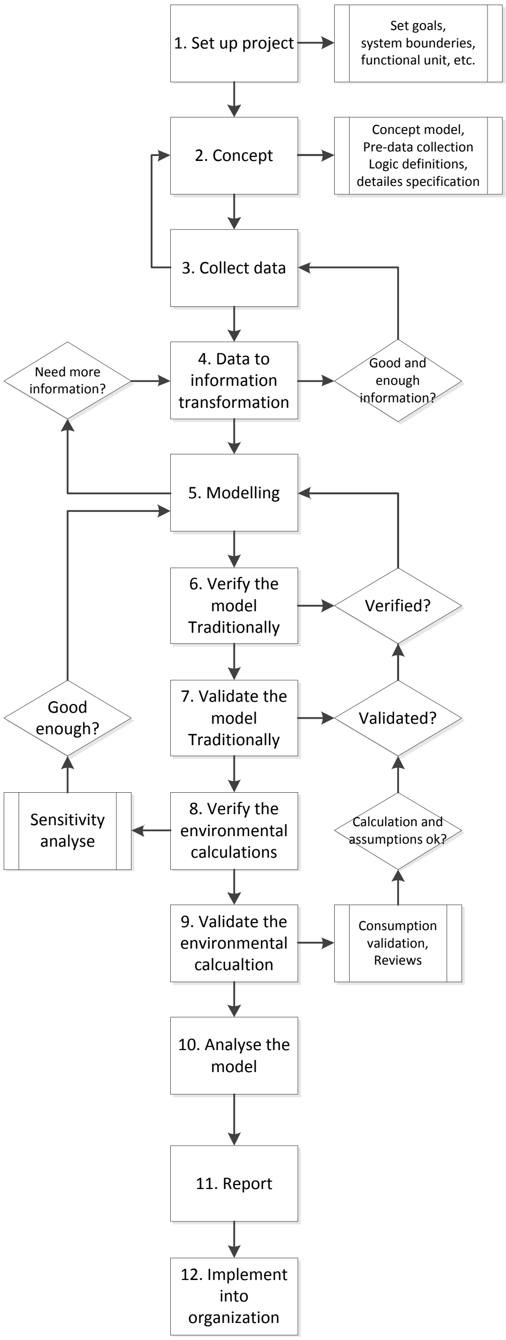

Figure 5 The EcoProIT method

1. Set up project

The goal definitions are a crucial part of a project, when these are set satisfactory the goals will help decide the level of detail for the project. They will be useful when defining the system boundaries for the environmental analysis. As a result of the system boundaries and the goals it is possible to define the limitations of a project.

2. Concept

A conceptual model is a schematic showing the system logic and flow. To develop and verify this, close collaboration with the people in day to day contact with the real system is needed, discuss all assumptions made. The conceptual model develops throughout the project to coincide with the level of detail needed to fulfil the previous set goals. The system boundaries are clarified. A part of creating a conceptual model and moving forward in the project is to define where and what type of data that has to be collected. The concept phase and data gathering is closely linked.

3. Data gathering

With the conceptual model as a base it is possible to identify the data needed for the model. The data can be categorized as process data, material data, energy consumption data and energy content data.

> *Process data:* Logged data, interviews and measured data, much like in a traditional DES project.
>
> *Material data:* What materials are used, material histories, solvents paints etc.
>
> *Energy consumption data:* How much electricity, Liquefied petroleum gas (LPG), oil, compressed air is consumed etc.?
>
> *Life Cycle Inventory (LCI)-data:* Emissions for the electricity used, LPG content etc.

It is possible to gather data and start building the structure of the model simultaneously although, it is necessary to gather some amount of production data before it is possible to start with the model. This is a step towards a complete conceptual model and important not to make unnecessary mistakes (or waste time).

4. Transformation of data to information

Usually data straight from a log or measured cycle time need to be filtered, sorted, calculated converted etc. before it can be used in the simulation model. It is useful to represent information, energy and production flows etc. schematic as a complement to the conceptual model. This step includes calculating the different distributions necessary to create a dynamic model.

Is the Information enough to implement the model? This question should be possible to answer with the help of the goals and the conceptual model. If the answer is no, more data need to be collected.

5. Modelling

The model can be built with software specially developed for DES models or with ordinary languages such as C++. It is important that the code is structured and built in layers with a traditional DES as a foundation and the environmental aspects built as the outer layer. This will facilitate both verification and validation at a later stage as well as make the simulation model more flexible (Banks 1999).

6. Verify the model traditionally

The verification ensures that the model is working as the conceptual model, following its logic laws etc. It is also done to ensure that the code is running correctly, no infinity loops etc. The verification of the code is closely connected to the modelling since the verification needs to be done continuously through the modelling.

7. Validate the model traditionally

To validate a model is essentially to make sure that it corresponds to reality. It is also essential to be able to trust the models final result enough to use it for an analysis.

There are a number of steps that can be taken to ensure this. Through historical data validation, does the model perform according to realty with historical input data compared to historical output data? Does the model perform according to reality during extreme conditions such as breakdowns, overload or under load of the system? A Turing test can be performed, output data from reality and output data from the model is compared by someone familiar to the system.

8. Verify the Calculations for Environmental Impact

It is important to make sure the model level of detail corresponds to the goals set. This is done by a sensitivity analysis. A sensitivity analysis makes sure that the data, from the sources that have the most impact on the products, is detailed enough and modelled in corresponding level of detail. An analysis should be performed on the sources that together stand for 80% of the GWP impact.

9. Validate the Calculation for Environmental Impact

To validate the environmental part of the DES let a certified reviewer review/validate the analysis. It is possible to compare the result to similar products with similar analysis, keep in mind the different methods (dynamic static and so on) and differences. Another possible way to validate is to compare a cell's or process' used consumables to the same in the model. It is important to define the limitations for the analysis and document these together with the analysis. Otherwise the environmental impact analysis becomes invalid (changes etc.).

10. Analyse and use the Model

The model is analysed so that the current state is known. This is important when evaluating the different improvement suggestions modelled.

11. Communicate the Results

When all experiments and analysis are done and documented the information regarding and answering the projects goal should be compiled. The correct information should be communicated to correct stakeholders.

12. Implementation in organisation

The EcoProIT method is still under development and has not yet defined guidelines for how to implement in organisation. The thought is to be able to use both the production analysis and production changes to also see how the GWPs are affected. The case study in this master thesis is a part of the development of the EcoProIT method.

3.2 Method for evaluating the EcoProIT method

Evaluation of the EcoProIT method has been done continuously throughout the master thesis work. To have an organized workflow of the evaluation an affinity diagram has been made. This is also called the KJ-method after its originator Jiro Kawakita. Below is the method described as by Bergman and Klevsjö (2003).

- The first step is that all kinds of ideas and thoughts are written down on small cards or "post it" notes. Preferably this is done in brainstorming sessions. It is important that everyone is allowed to have his or her say.

- All notes are gone through to make sure that everybody agrees on what the text says. If necessary new notes are written that better represent the essence.

- The notes are then placed in different groups. There may be notes that do not fit together with any other notes and these are then called “lone wolves” or “vagrants”.

- A headline is decided for each group. The headline should in some sense sum up the group.

- Arrows are drawn between the groups to illustrate the relationship between the groups. The arrows are moved around until the group members agree that they describe the connections correct.

Some adjustments had to be made to the method to fit the purpose of this master thesis. Since the ideas and thoughts have come up during the whole project time the affinity diagram has been improved and reworked continuously throughout the project. Discussions have also been held with members of the team working with the EcoProIT project.

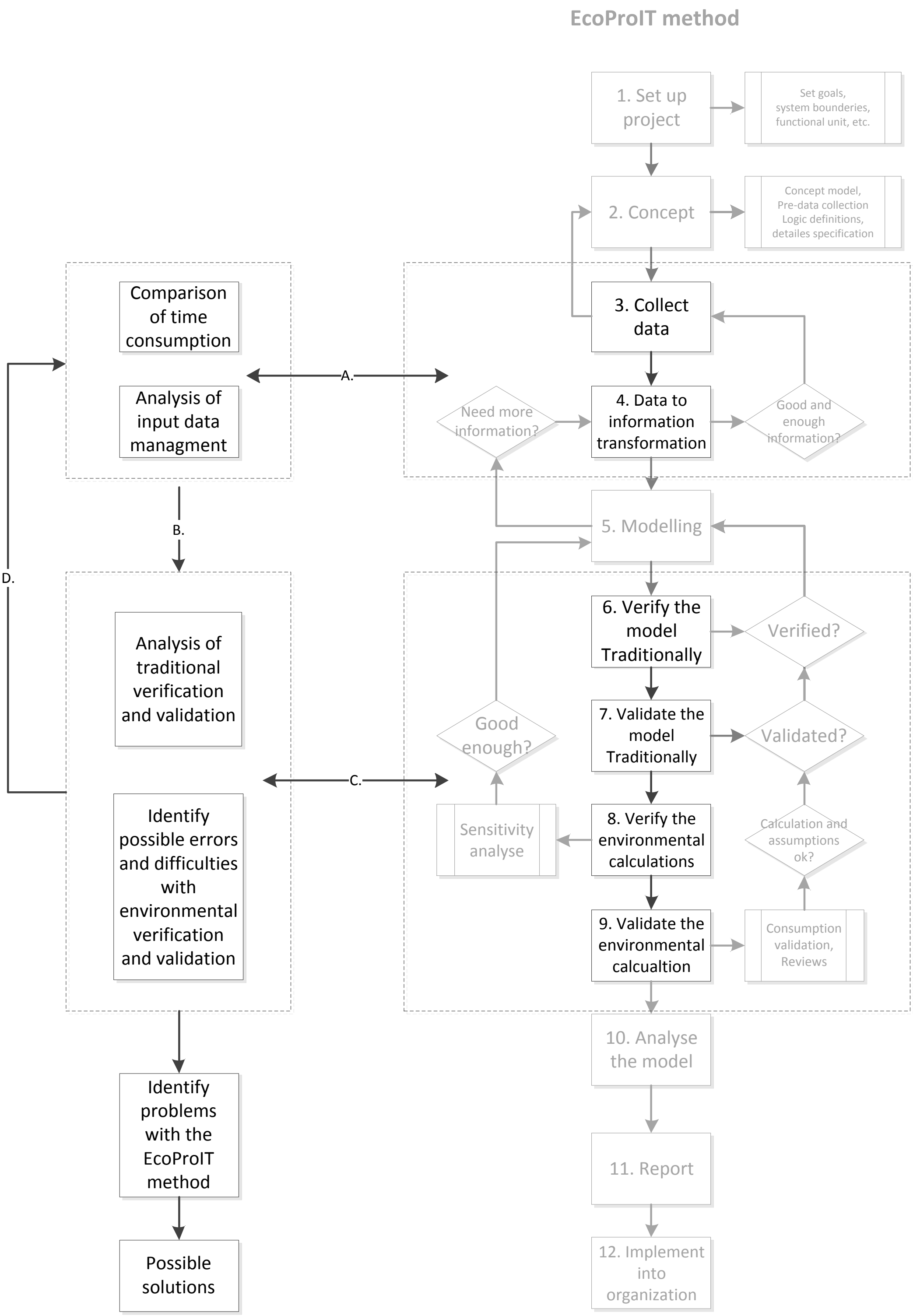

Figure 6 Method for evaluating the EcoProIT method

The focuses of the evaluation were, in accordance with the objective, input data management and verification and validation. These two areas are closely linked and one affects the result of the other which is represented in Figure 6. The evaluation have at times spilled into other areas as well, these have been presented if they are relevant for the EcoProIT method or connected to the focus areas mentioned in the problem formulation.

When step three was reached in the execution of the EcoProIT method the time consumption of the environmental part of the input data management were documented for future reference. This step is represented by arrow A in Figure 6. There are several projects performed evaluating for example time consumption (Skoogh and Johansson 2009) and input data management (Skoogh and Johansson 2008) on DES projects. In combination with the theory gathered and previous experience of DES projects a comparison was made. It was possible to compare the time spent collecting and processing data in this project with the evaluations previously done.

The analysis of the input data management depends in part on the data validation and the general input data management method used in the EcoProIT method, represented by arrow A in Figure 6. It also depends on the result from the verification and validation analysis (and error identification and difficulties). Therefore the analysis cannot be completed without feedback from this part. This is represented by arrow D in Figure 6.

In turn the analysis of the verification and validation depend on the result from the Input data management analysis, represented by arrow B in Figure 6.

When the analyses were done, their combined result highlights problems within or relating to the focus areas. Solutions where sought for these problems.

The result of this evaluation will be a time chart and identification of possible errors. The analyses will be presented in chapter *6. Analysis* together with suggested improvements to the EcoProIT method.

3.3 Conduction of the EcoProIT method

In this chapter a description of how the EcoProIT method has been implemented is presented. The result, the EcoProIT model, refers to both a DES model and an excel interface for GWP calculations.

3.3.1 Concept

It is important to have a full understanding of the system before embarking on the simulation part of a project. In this master thesis the production flow is important, in addition the energy flow and the material flow is as relevant. Since the GWP is derived from all parts of the system each flow and their logic is necessary to get an understanding of the system. To visualize a conceptual model several softwares are available, in this master thesis Microsoft Office Vision 2007 (Visio) was used. In Visio it is possible to create several different types of schematics both for business and administrative flows and maps, as well as engineering flows.

To get a good overview of the system the production leaders explain how and where the products and its components were transported and processed throughout the factory. Blueprints of the factory were also used to get a better understanding of the flow. For the understanding of all the energy sources and resources used, the facility manager gave a thorough description of the energy flow in the factory. The description also included information about some of the processes such as the enamel and printing press ovens and the effect of solvents on the temperature in these.

When the conceptual model of the production and material flows was created the production leaders could verify it. The energy flow created was verified by the facility manager. As a step towards a complete conceptual model the system boundaries are set in accordance with the master thesis goals and clarified together with the schematic flows of the factory.

In the real system large stock are kept as buffers between the departments. Because of this the ordering system had to be studied carefully to be able to interpret this into the model. The enamel and printing press processes where the ones thought to cause the most impact and was focused on for collecting data. The reason for this is the use of liquefied petroleum gas (LPG) and the burning of the enamel in the ovens. Therefore all the above aspects (material, energy consumption, production process) were taken into consideration.

3.3.2 Data gathering

Expert fit was used to find the statistical distribution for a collection of data points, at times empirical data was used.

Data gathering should be as objective as possible and should observe the process without affecting it. Methods often used are filming, interviews, observing, time studies etc., see chapter *2.6.2 Input data management method*. In this master thesis the existing production data was used as far as possible. At Emballator the production process can be uneven i.e. planned stops on the chosen line, hardly any setup on day to several setups and failures the next, depending on the customer demand and material. This made time studies diverse and data points difficult to collect. The production data was therefore complemented and validated with interviews and observations, see chapter *2.6.2 Input data management method.*

Several types of data that was gathered, therefore the approach differed. Some data was easily accessible in the production lines process systems, some had to be filtered, sorted, calculated converted etc, and others were measured. To make sure all parts of the facility where included data was gathered mainly for the year 2011, some of the earlier data does not include new additions to the factory and building (latest added 2009).

3.3.3 Modelling

The model was built with a software license that was available to the master thesis, AutoMod 12.3.1, which is based on a general purpose simulation language. A special purpose simulation language will generally have fewer errors than that of a general purpose simulation language. On the other hand the opposite is valid for flexibility (Sargent 2010). The EcoProIT method is new and unfamiliar and therefore the choice of software was decided so that not to cause unnecessary work or disruptions to the schedule. Because of its flexibility AutoMod is well suited for modelling a factory as well as the phantom parts of the model keeping track and calculating the environmental aspects.

The production part of the model was built first and divided into sub processes according to the conceptual model. Each part was modelled separately and thereafter added to the final model. This minimizes the time spent correcting errors in the entire code as well as simplifies the verification and validation process (Sargent 2010). By using load specific attributes in the model the loads created could be specified according to gathered data described in chapter *3.3.2 Data gathering*. These specifications could be number of cans in one order, size of can, number of enamel layers, type of bottom etc. With the help of the attributes the loads move through the system as the real steel sheets, these are divided into cans at the same part in the system that the real cans are created.

For the environmental part, attributes where also used to calculate the time each load spent in the different processes, keep track of number of plastic layers etc. This together with the more process specific attributes would then act as a basis for further calculations on GWP.

The GWP calculations were done using excel where sheets with relevant process data, material data, LCI data and distributing calculated the GWP values for materials and processes using different excel algorithms.

3.3.4 Verify the model traditionally

Verification is necessary to make sure the model is behaving according to the logic of the conceptual model and that no logic choices are missing in the model. Verification of the model is also to make sure that the simulation language is used in the correct way. This is possible to accomplish is several ways for example by structured walkthroughs, trace, input output relation and using the software debugging option (Sargent 2010)

One should keep in mind that errors that occur can be caused by the data, conceptual model or other factors regarding the program or software (Sargent 2010). Verification of the model was continuously done while modelling. This to make sure not to build on something that is already faulty and minimize time spent searching for errors. By tracking entities throughout the system errors where made visible and possible to correct. Tracking was in this case done by printing messages in different parts of the process. The AutoMod debugger is also helpful when tracking or in general verifying the program. By sending single loads or very high number of loads through the system errors could also be detected and corrected.

When printing the attributes (cycle time etc) to excel, errors or unreasonable times were a good indication of errors in the code.

3.3.5 Validate the model traditionally

Validation is important to make sure that the model behaves according to reality or reflects that part of reality that is modelled to a satisfactory extent. In context of the conceptual model it is making sure the conceptual model corresponds to reality (Sargent 2010).

When the data collection were made some of the data were saved, others were not applicable. Several of these could be of use for the system validation. For example number of cans produced per shift and utilization of the processes. The time spent in the different processes are important from a GWP stand point, therefore these were viewed as especially important to validate. The excel sheet were the process times etc were printed were useful when validating. The cycle times that were printed served as a good validation point and data for several orders could be compared to the real system. The loads could be traced through the system and distributions and empirical representation could be validated (Sargent 2010).

Where insecurities in the data or the model where discovered a sensitivity analysis where performed. This could help validate which factors are important from a GWP perspective.

3.3.6 Verify the calculations for environmental impact

The EcoProIt method is still under development and there is limited literature or instructions for verification of the environmental aspects. The LCI data were therefore collected and chosen together with master thesis supervisor, Jon Andersson, and its examiner, Björn Johansson. The material requirements were filled to as large extent as possible and where LCI data were missing substitutes were found that satisfied the requirements as far as possible.

When collecting environmental data from the production system it is handled with the same procedure as the ordinary production data. Therefore also going through the same validation process. The data collected and measured by the electrician is assumed to be correct.

To verify that the calculations are correct the GWP excel sheet where thoroughly inspected. This was done continuously as it grew and simultaneously as the excel sheet with the AutoMod result was tested and verified, to make sure the units corresponded. The data was also compared to see if the values were reasonable in relation to each other.

As described in *3.1 Description of the EcoProIT method* a sensitivity analysis should be performed on the sources that together stand for 80% of the GWP impact

3.3.7 Validate the calculations for environmental impact

The results from the model should be compared to similar products keeping different methods in mind. No LCA data has been found, therefore this is not possible. The result has been internally reviewed by three people.

4. System description

In this chapter a description of the production system is presented. The description is complemented with an account of the information and energy flow. These three parts together represent the conceptual model that has been the base during this master thesis.

4.1 Information flow

The sales office establishes a contract between Emballator and a customer. These contracts handle questions about size, appearance and number of cans. The contracts can also regulate other commitments such as an obligation for Emballator to keep a safety stock of finished cans. After a contract is established one or several orders for cans will arrive to Emballator in accordance with that contract. There are two kinds of contracts.

- Short term contract. Usually the customer is obligated to buy the specified quantity within a year. When the quantity has been shipped the contract have to be renewed.
- Long term contract. The contract specifies a yearly quantity.

The first order of a contract is delivered within 15 days, but the following parts have a five days delivery guarantee. This means that large quantities of printed sheets are stored in the printed sheet buffer awaiting customer orders. Emballator have recently started contacting customers if their printed sheets have been in the buffer for more than a year. The customers are then obliged to either order cans or hire the storage area.

The contracts are sent to the production planning office. A rough planning for the enamel and printing process is done by the planning office for the needed quantity. Depending on the size of the contract the production planning office may divide the contract into two or more printing operations. This is done in order to keep the stock of printed sheets down. This planning is made in SAP and will trigger an in house order to the printing and enamel office. Adjustments of the rough planning from the planning office are made in the printing and enamel office to keep the set up times to a minimum. For example, batches with the same size, colour or enamel is done after each other to reduce the set up times.

Orders for cans arrive to the production planning office. When planning the sequence of the order set up times as well as priority is taken into consideration. This means that the operators are not allowed to change the sequence of the orders without first asking the production leader. This is because the operators do not know if the can order is make to stock order or if the customer is already waiting.

4.2 Production flow

The cans produced at Emballator are produced in eight different lines. Each production line produces cans with a certain upper and lower diameter. The height of each batch of cans can be varied meaning that the volume of the cans can be changed at each line. The production line focused on in this master thesis is called 180-1 which produce cans with an upper diameter of 180mm and a bottom diameter of 168 mm. In this line five different volumes is produced; 2,5l, 3 l, 4l, 5l, and 6l. The production flow can be seen in figure seven below. Descriptions of the different processes will follow, as well as a description of the important buffer areas used within the facilities.

Flow 180-1

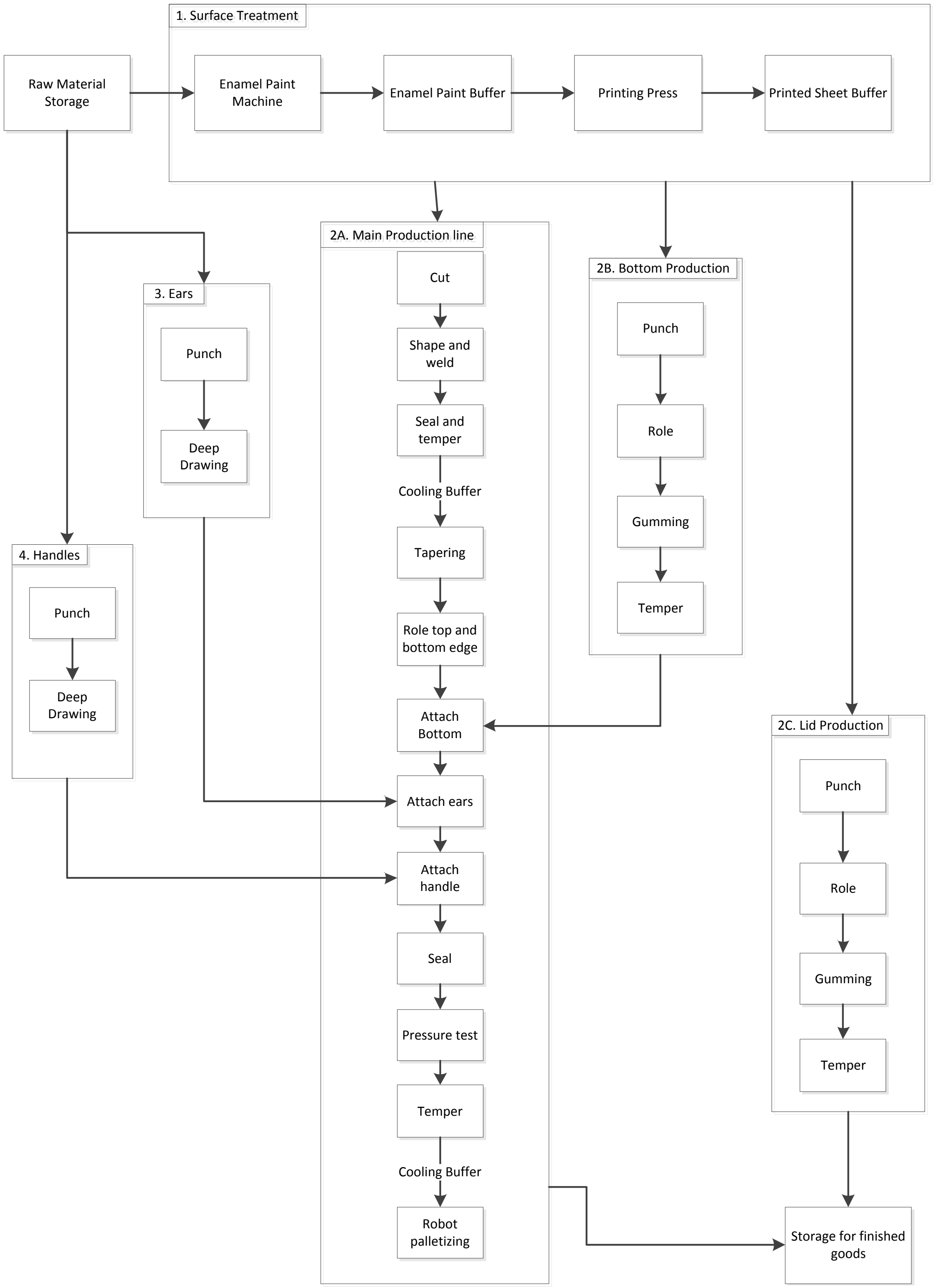

Figure 7 Flow for the 180-1 cans.

4.2.1 Surface treatment

The surface treatment is illustrated in step 1 in figure 7.

1. Metal sheets in different sizes, depending on which size of can will be produced, are transported to Emballator and stored until needed.
2. The metal sheets are transported by forklift to the enamel paint machine. There are approximately 22 different types of enamels that can be used in the enamel process. The sheets go through the enamel paint machine at least one time. Depending on whether the sheets should have enamel paint on one or two sides and which enamel paint that should be applied, it may be necessary to run the sheets through the enamel paint machine two or three times. Every cycle includes:
    - One coating operation
    - Heating in oven to harden the enamel
    - Cooling transport
3. After the enamel paint machine the sheets are stored in a buffer next to the enamel paint machine.
4. Depending on the customers' needs the sheets can be printed in a printing press. The printing operation consist three stages.
    - Two color printing operation
    - Heating in oven to harden the color
    - Cooling transport

   It is possible to apply two colors each run through the printing process. For some prints it is necessary to run through the printing process up to eight different times. On average there are 4.2 colors in each print. After the printing process the sheets are transported by forklift and stored in a buffer until needed.

4.2.2 Main production line

The fully automated main production line is illustrated in step 2A in figure 7.

5. The sheets are transported with forklift from the buffer to the can machine. The steps in the can machine are:
    - The sheets are cut to desired size depending on the height of the can. Each sheet is now corresponding to one can.
    - The sheets are welded to a cylindrical shape. To make sure the weld damage does not compromise the seal of the can, enamel paint is applied at the seam. The cans are thereafter tempered and transported on a conveyor that works as a cooling buffer.
    - The cylinders are made conical by applying pressure to the upper part of the cylinder.
    - The cans are tapered and the top rim is gradually folded to get the desired height and profile of the rim. The can is then turned upside down, to achieve the desired profile on the bottom rim, also by gradually folding the edge.
    - The bottom is attached by folding the rim.

- The ears are attached the cans by spot-welding them to the sides of the cans.
- The handles are thereafter attached to the ears. The handles are unrolled and shaped at a sub flow to the main line, here the plastic grips are attached to the handle of some orders of cans.
- Enamel paint is applied to the welding points of the ears.
- A pressure test is performed to make sure the cans performance is satisfactory.
- The cans go through an oven to harden the enamel paint at the welding points.
- After the oven the cans are cooled on a conveyor belt and then packed by a robot to a pallet.

4.2.3 Post production

6. The pallets are picked up by an automated guided vehicle (AGV) and transported to a station where the pallets are covered with plastics.
7. After step 7. the pallets are transported with a second AGV to third AGV that transport them to the storage area for finished goods. Here they are picked up by a forklift and transported to the right place.
8. Soon before the truck comes to pick up the pallets they are moved from their place in the storage of finished goods to an area at the pick up place.

4.2.4 Lid production

The lid production line is illustrated in step 2C in figure 7.

9. The raw material for lids is metal sheets and these are surface treated with enamel in the same manner as step one, two and three above. On rare occasions they also go through the printing operation in step four. There are several kinds of lids to meet all kinds of customer needs. Emballator uses several different fully automatic lid machines and three of these are used for production line 180-1.
    - The metal sheets are transported with a forklift to the lid production machine.
    - Round pieces are punched out of the metal sheet in specific pattern to reduce waste.
    - Depending on what kind of lid that is produced the lids are rolled in different steps to the finished shape.
    - A rubber is placed on the side that will be in contact with the can to make sure that the lid will be able to retain he substance in the can. The rubber is liquefied when applied to the lid but will soon harder to a rubber.
    - When the lids are finished they are they are packaged and transported to the storage area for finished goods.

4.2.5 Bottom production

The bottom production line is illustrated in step 2B in figure 7.

10. The bottoms are produced in the same manner as lids. As for the lids there are different types of bottoms to meet the customers' needs. The only differences in the production flow between the bottom production and he lid production is that when the bottoms are finished they are stored until needed at the main production line.

4.2.6 Ear production

The ear production line is illustrated in step 3 in figure 7.

11. There are two sizes of ears used at Emballator depending on the size of the cans. Both kinds are produced in the same way in similar machines. The cans produced in the 180-1 production line uses the smaller size of ears.
    - The steel for the ears arrives to Emballator on rolls and stored in the Raw material warehouse.
    - When the rolls of steel are needed a forklift transfer the ear production line transports them.
    - A fully automatic machine produces ears in the following steps:
    - Round pieces are punched out
    - Every piece get a hole in the middle that the gripping wires later can be attached to.
    - The pieces are deep-drawn to a small cup.
    - The machine spits out the finished ear to a container.
    - The container is picked up by a forklift and stored until needed at the line.

4.2.7 Buffer and storage areas

According to Emballator's purchaser the raw material storage that contains about 9000 tons of steel (as of February 2012) and the maximum capacity (to not take up space intended for other purposes) is between 6000-6500 ton. Emballator's desire is to lower the inventory level in this area. The high raw material inventory is partly due to long lead times and insecurities in deliveries, since the raw material is purchased from Asia.

In comparison to the raw material buffer there is a small buffer area for the sheets processed in the enamel machine. These are processed regardless of order and works similar to a safety stock so that the printing machine always have available sheets.

In the printed sheet buffer every contract has its own space, and every customer can have several contracts. There are also buffers for ears, bottoms, lids etc. Because of the buffers one process does not have to wait for products from another process earlier in the production flow.

4.3 Energy flow

Emballator uses electrical energy, LPG and solvent in the enamel as energy sources.

Emballator uses LPG for heating the facility. Since the ovens at the printing process, enamel process and after the welding operations at the can production line generates heat to the facility Emballator only need to heat the facility during the winter. When the average outside temperature for day and night is above four degrees the production at Emballator is enough to keep room temperature inside the facility. Because of the Swedish climate no cooling of the facility is needed.

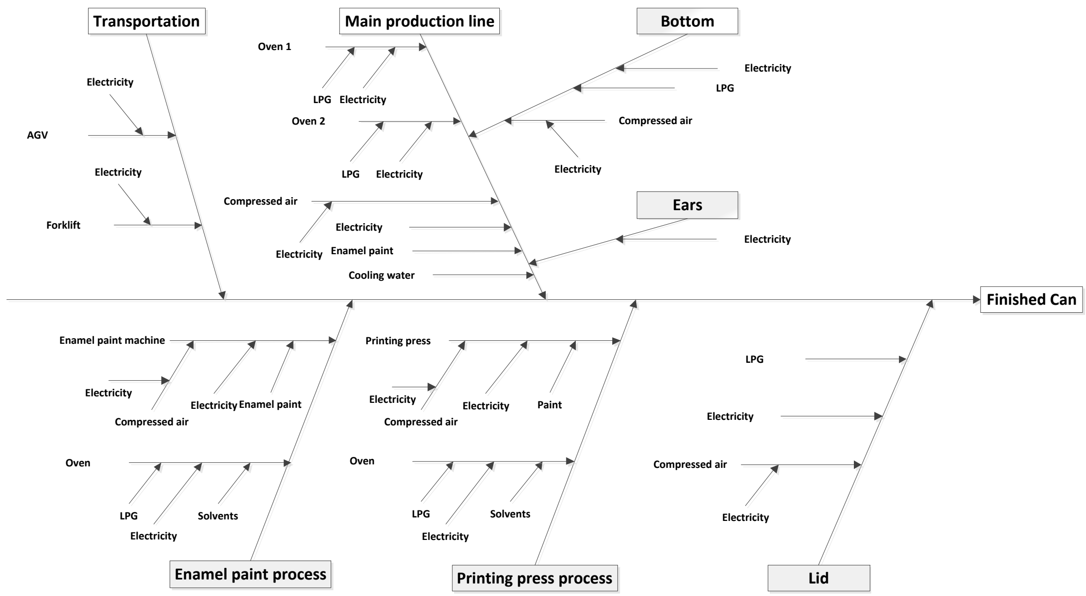

Figure 8 Energy flow at Emballator

4.4 Data gathering and data to information transformation

Much of the process data were available through the process computer systems used by the production leaders and operators. It was necessary to evaluate the data from a quality perspective. Discrepancies where dealt with by discussing with production leaders and assumptions were documented for the future model. There were also unstructured interviews with operators responsible for the processes.

4.4.1 Process data

The enamel machine and the printing press are to a large extent used by products bound for other production lines than that of 180-1. The data not regarding 180-1 was used to find distributions for order sizes, number of incoming raw material, number of printing rounds and number of enamel layers etc for non 180-1 lines. The different lines where not differentiated but treated as one type of sheet and can.

Data for the enamel paint machine was retrieved from the machines stop log data for 2011. This included stops, failures and set up times. In the collected data all stops were marked with a cause, i.e. set up time, kind of failure or service action. During the interviews the operators explained that they did not always label the stops with the correct description (i.e. setup marked as failure and vice versa), due to inadequate information. Therefore to a large uncertainty was present to separate the setup time from the failures. Because of this the distribution for mean time to repair (MTTR) includes set up times and the distribution for the mean time to failure (MTTF) represent the time to failure or set up.

The stop times in the enamel process and the printing process are considered as indirect costs since the stops are assumed to be related to the machine and not because of the nature of the order. To distribute the GWP contributions due to stops, the total time of all stops for each process was summed up and divided with the total number of sheets that had gone through the process during the same time frame. Each sheet is then given a GWP contribution that is divided among number of cans, bottom or lids that sheet will later becomes. Since the set up times in the enamel process is not possible to separate from the stop times these GWP contributions were also distributed as overhead costs.

The stop log for the printing press for 2011 was collected. This include order number for each order, number of times that order had gone through the printing operation, start and end time for each order, start and end time for set up and start and end time of stops because of failure or service. Stops for adjustments or failures in the middle of an order are not recorded. From the collected data the distributions for MTTR and MTTF for the longer stops between orders and set up times could be calculated. To find all short stops, such as minor adjustments, not recorded in the collected data, the speed in sheets per minutes where calculated for each order and then distribution was found.

The system to record set up times and stop times, in the 180-1 production line, is considered too complicated by Emballator's employees and is not in use. Therefore it was not possible to find data points for MTTR or MTTF. Instead the time recorded for quality checks for every thousand can were studied. From this data it was possible to find the time between the first quality check on one order, to the first quality check for the next order. From the times between these time points a rate of cans per minute was calculated. In this way the set up and failure times are included in the cans per minute data. Distributions for batch sizes up to 1000 cans, 1001-2000, 2001-3000, 3001-4000 and above 4000 cans were calculated. This separation of batch sizes was done in order to make the set up times more proportional to the number of cans.

The data for the lid, bottom, ear and plastic wrapping machine were not considered as important as for the enamel paint machine, printing press and production line. This assumption would have to be validated in the sensitivity analysis. Data for the lid and bottom machines were collected by estimations by operators.

The ear machine and plastic wrapping machine were observed for a couple of minutes for estimations of the cycle times.

4.4.2 Material data

Both the mass and specification of content for each material used in production were needed. Some materials, such as plastic handles, are optional and for these materials the share of orders with and without these options were also needed.

The amount of each material was collected from SAP. Plastic handles and wrapping plastic are not specified in weight but only pieces per can and length. For these materials a physical example was collected and weighed.

It is difficult to find out the exact content for each material. Most of the chemicals are only labelled with the suppliers name and the material safety data sheet only mentions components that are toxic or flammable. Since it would not be possible to find LCI data for supplier specific products, estimations based on the material safety data sheet were considered good enough.

Blueprints of the metal sheets were studied to find the exact amount of steel used for all cans. Also the wastes due to the cutting of metal sheets were retrieved from these blueprints.

The raw material sheets used for the 6l can are used for other products as well. There are no data available regarding how the 6l sheet is used among other can sizes. The blueprints show a large amount of scrap for the 6l cans. In reality the production use the scrap for other cans as well as using the sheet for other cans when there is a lack of the correct raw sheet.

4.4.3 Order, contracts, transportation and buffer data

To find a distribution for batch sizes, data from can production line with reported cans per shift were studied.

The contracts divisions into suborders depend on the size of the contract and the customer. The larger the contract the more sub-deliveries, this is usually the case there are of course exceptions. Some contracts stay in the system for a long time sometimes up to a year or more. Because of the contract system it was not possible to find sufficient historical data to support this representation. The data could not be validated and a simplification for the order system had to be made. This simplification is based on the call offs of produced cans statistic. A sensitivity analysis will have to ensure if this is a good enough representation. The sensitivity analysis will also have to rule if the differences in time in buffer because of this simplification have a significant impact on the final model. The theory behind this problem is acknowledged in the theory chapter *2.6.2 Input data management method.*

To find the distances for transportation of materials to Emballator the purchaser at Emballator named the cities from where the materials are shipped. Google maps and Eniro were used to find the distances from each supplier. Materials shipped from Asia are assumed to be shipped by boat to Göteborg and then shipped by truck to Emballator in Ulricehamn. Shipments from Europe (not including Sweden) are assumed to be shipped by train to Göteborg and then shipped by truck to Ulricehamn. All shipments from Swedish suppliers are assumed to be shipped by truck.

Efforts were done trying to find the dynamic of the storage areas. Data from 2011 for the raw sheet buffer, buffer for sheets with enamel, buffer for printed sheets, buffer for finished cans and buffer for bottoms were collected and analysed.

The raw sheet buffer data contained information about incoming and outgoing parts for each sheet size. Since the batch sizes are quite large only a few points of data for each sheet size were available.

The buffer for sheets with enamel contained information about incoming and outgoing amounts for each kind of sheet with each kind of enamel layers. At most, twelve data points were available for each kind of sheet.

Data for the buffer for printed sheets were collected using SAP. Since the sheets in the buffer for printed sheets are custom made for each kind of can the data contained information for incoming and outgoing sheets for each kind of can. Due to the high variety of products it was not possible to draw any useful conclusions.

The data collected for the buffer of finished goods contained information of incoming and outgoing amount of cans for every month. Due to the high variety of products it was not possible to draw any useful conclusions.

The data collected for the buffer of bottoms contained information about the incoming and outgoing amount of each bottom type for each month. At most, twelve data points were available for each kind bottom.

4.4.4 Energy consumption

The energy sources at Emballator are electrical energy, Liquefied Petroleum Gas (LPG) and compressed air. The compressed air is produced by compressors using electrical energy.

The electricity consumption for the entire factory is available at the owner of Ulricehamn's power distribution grid. It is measured by the hour. To complement this data Emballator's electrician was able to help with consumption measurements throughout the flow, as well as the forklift batteries/chargers and the compressors producing he compressed air.

It was not possible to measure the consumption of compressed air at each place where it is consumed. Instead the facility manager looked at the efficiency of the compressor at a given time when he knew which machines that where active. From this data he could estimate the share of the consumption.

The consumption of LPG for heating the ovens at the enamel paint machine and the printing press machine could be collected by observing sensors near the ovens. Attempts were done trying to find the stoichiometry for the combustion of solvents in the enamel and LPG in the enamel process and the LPG in the printing press process.

During the autumn of 2011 Emballator exchanged their utility unit, and therefore also their energy source for heating the facilities, from oil to LPG. The consumption of LPG is very much associated to the outside temperature. About twenty data points of LPG consumption could be found and together with temperature data from Sveriges Metrologiska och Hydrologiska Institut (SMHI) an equation could be calculated for the LPG consumption depending on the outside temperature. The equation shows that when the average outside temperature for one day and night rises above 4°C no LPG is consumed for heating the facility. This is because the ovens at the paint machine and enamel paint machine produces so much heat to the rest of the facility.

4.4.5 Distribution factors

Distribution factors for distributing overhead GWP contributions was calculated by analysing blueprints of the sheets together with number of cans produced for each can size during 2011 and number of cans per pallet for each can size. The distribution factors were calculated both for each can size and for each can production line.

- Share of pallets produced
- Share of cans produced
- Share of metal sheets consumed
- Share of weight consumed
- Share of cutting waste

Also, the blueprint of the facility was studied to find the share of the total area for storage of finished goods, can production line, raw material buffer and so on.

The working hours during 2011 for enamel paint machine, printing press and can production line were calculated by analysing data for reported cans or metal sheets. By looking at times the number of shifts at each resource was counted. If there had been any activity during one shift it was assumed that the resource was running during the entire shift. After counting all shifts it was multiplied with the number of minutes for each shift. From the total number of minutes the share of an entire year was calculated for each resource.

LCI data for steel, steel wire, enamel paint, alkyd, boat transport, truck transport, train transport, polyethane, polystyrene, production of LPG, combustion of LPG, water, electricity, where collected with support from Björn Johansson and Jon Andersson using SimaPro 7.3.

GWP data were collected from Intergovernmental Panel on Climate Change (IPCC) Report of the Intergovernmental Panel on Climate Change 2007. For additional reading about the LCI and GWP data collected please see *Appendix*.

4.5 Model description

The functional unit is the can and its lid, since the system starts with the raw material sheets so does the model. The large inventories on hand throughout the real system acts as buffers between the production processes. The effects the processes have on each other are decreased and in turn the dynamic between them. This is mirrored in the model and supported by the production technicians. The buffers reduces the dynamic in the real world as well as in the model. Each process is only dependent on itself and its breakdowns and setups.

The order data is based on the call offs, made when delivering cans, as mentioned in *4.1 Information flow*. The order numbers for the cans correspond to the bottoms and lids. The order gets a specification in the beginning of the code which decides what type of bottom and lid. The specification also give number of enamel layers, printing press rounds, speed in 180-1, plastic handle or not, number of plastic packaging layers etc. These factors decide how and how fast the loads move through the processes.

4.5.1 Enamel process

There are four steel sheets processed for 180-1 production line, these in turn have between one and three enamel layers. All 22 type of enamels or their thicknesses have not been modeled, instead an approximation of one, two or three layers in combination with the four different sheet types have given 12 different types of enameled steel sheets.

Nr of Enamel Layer	Type of steel sheet			
	1	**2**	**3**	**4**
1	1	2	3	4
2	5	6	7	8
3	9	10	11	12

Table 3 The different combinations of sheets and enamel.

The enamel machine and the printing press are to a large extent used by products bound for other production lines than that of 180-1. The data compiled about non 180-1 was used to model loads to simulate not available time in the enamel machine and printing press. By this the printing press and enamel machine would be dynamically occupied by non 180-1 sheets. These loads where discarded after the printing press since there is no processes where the 180-1 and other lines share processes after the printing press. The printed sheet buffer accommodates sheets to all lines, but to simulate Emballator's entire product variation in the model is not within the scope of the project.

4.5.2 Printing press

Each printing round gets a cycle time and a setup time, a distribution decides whether a failure or maintenance time is appointed to that printing round. Since the print on the can is customer specific a similar simplification as in the enamel process has been done for the sheets processed in the two color printing press. The sheets processed in the printing press intended for the 180-1 line are printed between one and seven rounds. This results in 84 different combinations of sheets. Since the printing press can handle two colors the one and seven rounds correspond to between 1 and 14 colors, there is no historical or other data supporting any assumptions on the number of colors.

Nr of printing rounds	The different enamelled sheets											
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
1	1	2	3	4	5	6	7	8	9	10	11	12
2	13	14	15	16	17	18	19	20	21	22	23	24
3	25	26	27	28	29	30	31	32	33	34	35	36
4	37	38	39	40	41	42	43	44	45	46	47	48
5	49	50	51	52	53	54	55	56	57	58	59	60
6	61	62	63	64	65	66	67	68	69	70	71	72
7	73	74	75	76	77	78	79	80	81	82	83	84

Table 4 Different combinations of enamelled sheet and printing press rounds

4.5.3 Can production line

In the 180-1 line the setup and failure time is included in the cycle time, by that logic a larger order has a higher speed per can than a small order. This is specified in the beginning according to order size.

The raw material sheets are cut into the metal sheet creating the body of the can. This is represented in the model by cloning the load into the same number of pieces. For new loads some of the attributes are recalculated to create the attributes per can instead of per sheet.

4.5.4 Bottom and lid

The bottoms also begin as loads representing steel sheets that are divided into bottoms. The lid is manufactured in a similar way as the bottom therefore they are represented in a similar manner in the model. The type of bottom decides the number of enamel layers. For the lid the different types can have different combinations of enamel layers and this is therefore decided by an empirical distribution.

4.5.5 Validation

Because the processes do not affect one another a validation on the entire system is not necessary. Therefore the decision was to validate the separate processes. This is supported by the sensitivity analysis. In accordance with the objective to find the GWP impact for a can and its lid it is shown that time in buffer is less important to the total GWP value.

To validate the processes separately the utilization process time, and output where evaluated on the processes thought to be of most significance, these where:

- Enamel paint machine
- Printing press
- 180-1 production

In the model the enamel process' utilization is significantly lower than in reality and therefore also the output. The data used in the validation is not detailed enough to make a good comparison and the sensitivity analysis show that this process is very significant to the total GWP value. The process times in the model correspond well to reality and since the enamel process have a high impact on the GWP value (LPG and solvents) this is of importance for a valid model. The assumption of twelve enamel and sheet combinations exist is a too rough simplification since the material aspect has a high impact on the GWP value. This is also a fact for the LPG consumption and combustion when the enamel is burned. Therefore the enamel process in its entirety cannot be fully validated.

The validation situation for the printing press is similar to that of the enamel machine. The utilization and output is to low in comparison to the real world. It has not been possible to find the specific cause but it is probably due to insufficient quality of the input data. The process time corresponds well to the real situation including setup times. The printing round simplification with 1 to 7 printing rounds instead of 1 to 14 colors might be sufficient since the number of printing rounds decide number of times in the oven, which in turn has a high GWP impact because of its LPG consumption.

The material data is also significant but since there is no historical data for previous orders regarding number of colors there is no possibility to model or validate this.

In the 180-1 production line the utilization from the model is lower compared to the data taken from the 180-1. It should be mentioned that the utilization data is very rough and is extracted from the shift times of a year. The setup times are included in the cycle time and therefore also in the utilization for both numbers. The output from the 180-1 production line is also lower compared to a similar period. The difference in output and utilization correspond. According to this it is not possible to validate the 180-1. If this is put in relation to the GWP impact for 180-1 process the sensitivity analysis show that the 180-1 process have a less than 2 % contribution to the total GWP.

Over all the process times correspond well to reality in the three above mentioned processes. From GWP impact point of view this is more important to the final result than the output or utilization. This stems from the lack of dynamic between the processes. It is therefore possible to say that the model output regarding process times is valid. It is also possible to conclude that the model output from a product variation point of view is insufficient in comparison to the GWP impact the material has, and is not possible to fully validate.

4.5.6 Excel interface

The important measures such as time in enamel machine are printed from the AutoMod model to an excel sheet. This sheet serves as a raw data document to an excel interface. Some modifications have to be done to the raw data document to connect data from lids and bottom to the correct can. Thereafter the excel interface retrieves data from the modified raw data file. The excel interface contains information about GWP values for materials and energy sources, distributing factors, material data (such as metal sheets sizes) and energy consumptions per hour for all resources. The interface calculates the GWP value for the materials and processes using excel algorithms and presents the results for one can in each order. The results for each can are then grouped together to show some key results. These groups are:

4.5.7 Delimitations of the model

The following points define the assumptions and simplifications of the EcoProIT model.

- The different sheets not belonging to 180-1 where not differentiated but treated as one type of sheet when used in the enamel machine and printing press.
- The product variations for 180-1 were simplified by not differentiating between enamel layers and instead only count the number of layers (between one and three). Which results in 12 different combinations of sheets and enamel
- A similar simplification was done when handling the printing rounds. Since the number of prints are not available the number of printing rounds are used instead.
- Since the print is customer specific and numerous variations are possible a simplification was made where the sheet can have between one and seven printing rounds. This result in 84 different combinations of sheet, enamel and print.

- The bottom production is not a constraint and bottoms are therefore always available to the 180-1 line.
- If steel sheets from processes are used because there is a lack of the correct steel sheets this is not modeled, this includes cans, bottom and lid.
- Because there are large inventories of raw material it is assumed as always available in the model
- There are some lids that are sent outside the Ulricehamn facilities, these are not included in the model.

5. Result

The results will be presented in this chapter. First of is the results from a time comparison between an EcoProIT project and a traditional DES project. Thereafter the other focus areas, result accuracy and possibility to maintain and update the model, will be presented. These are based on the field notes. The three focus areas affect each other and it is not always possible to separate their influence. The third part of this chapter consists of GWP results from the model.

5.1 Generic Result from Field Notes

In this chapter the information gather regarding the EcoProIT method is presented. The information here is not necessarily connected to Emballator’s production system, but nonetheless discovered during and relevant to this master thesis.

5.1.1 Time Comparison

When working with an EcoProIT project the amount of data that needs to be collected and processed is significantly larger than that of a traditional DES project. This is based on the fact that there is not an already existing DES model. These are the data needed to perform the environmental part of a EcoProIT project:

- Material data (type of material and weight/amount, frequency distributions)
- LCI data gathering
- GWP interface, overhead calculations and calculations from model
- Energy consumption and calculation

Below is a table with the amount of time spent. The calculations are based on 20 weeks (5 working days) and two people (total 200h). They exclude time spent on input data management for production data (and colliding or intertwined data).

	Time spent (days)	Percentage of project	Comment
Material Data	7.5	3.75%	Material data is not always possible to divide into environmental and production data.
LCI data	1.5	0.75%	Does not include calculations
GWP interface	15	7.5%	Includes output data from DES-model and calculations in the GWP interface, including the LCI data and overhead calculations.
Energy consumption data and calculations	10	5%	Time for data collection made by the electrician is approximated
Total time spent on environmental input data management.	34	17%	
Approximated by Skoogh and Johansson 2007		31%	Average time spent on input data management in traditional DES-project.
Total:		**48%**	

Table 5 The data is approximated by the project group, the emballator electrician and the master thesis supervisor.

The time spent on input data management in a traditional DES project is according to Skoogh and Johansson (2007) approximately 31%. It is possible to say that an EcoProIT project will take more time in comparison to a traditional DES project. If the numbers are summed up the total time spent on input data management in this EcoProIT project is 48%.

This time comparison is focused on the entire project and the input data management method used in this master thesis. It does not investigate further the time spent validating the LCI data since these are already revised.

5.1.2 Result Accuracy

A LCA can be perceived as more accurate than it actually is since gives a static GWP value as a result. The EcoProIT result in a span between two values and therefore correspond better to reality, since the real value is based on the dynamics of the production system. The difficult part of the EcoProIT model is to validate it. As mentioned in chapter *3.3.7 Validate the calculations for environmental impact* the GWP value needs to be compare with a similar product (such as steel cans or containers of similar size/weight) and also reviewed. If there is no similar value to compare to, the validation is uncertain. There is also the question of who should review the result as a final validation. In traditional Validation one seldom hires an outside person to review due to high cost and time aspects.

If the model is built in a systematic manner it should be relatively easy to validate (and verify) new parts or new data and add them to the model. This would keep a high accuracy and also keep the model validated. This will in the long run help when updating and maintain the model, which brings the next topic.

Because of the lack of information regarding verification and validation this Master Thesis has identified some focus areas for verifying the EcoProIT model. There are a couple of errors that can occur in regard to the environmental data:

- Errors in collected LCI data, wrong LCI data collected or not accurate enough LCI data.
- Errors when collecting environmental data from production system.
- Errors in calculations in model/interface
- Misinterpret parts of, or the production system.

5.1.3 Possibility to update and maintain model

The key to a flexible system is always organisation, documentation and building the model and calculations in a structured manner. As mentioned in input data management chapter. Since many iterations where made with the input data, most of these scenarios where tested on the EcoProIT model as well. Given these guidelines the following conclusion could be drawn regarding updating the model.

The first thing to clarify is what the update or maintenance regard. Does it regard the LCI data? Environmental data from the production system? Changes in the production system? If the changes concern the documentation and data (LCI – update, different material, product composition, product specification, cycle times etc) the existing excel-sheets needs to be handled with care and changes made will have to be carefully executed since errors in these sheets can create problems when verifying. The excel-sheets contain large amounts of data and errors here can cause time consuming corrections. The changes in themselves does not have to be time consuming but if data need to be collected and processed this could be a time consuming task.

Some changes such as product composition and cycle time need to be edited in the code. They must in some cases be processed with Expertfit to get a statistical distribution. In this case it is also important to make sure changes in the code is executed in a correct manner. Errors here could cause time consuming validation and verification. To avoid errors and to make changes easier, a good structure in both the code and the interface is necessary.

Changes to the existing production system, which affect the accuracy of the conceptual model that the simulation model is built after, will mean changes in the simulation code. If these changes are possible and in consistency with the objectives the model is built after, they could be realized. Otherwise a new model would be the answer.

Changes to the production system, such as adding a machine could be incorporated in an existing system without it being overly time consuming (given that the data already exists). The dynamic affects of a new machine would be reflected in the GWP result.

Any changes made on the model or the data would require verification and validation.

5.2 The Emballator production system and EcoProIT method

This chapter will go through some of the information gathered with field notes that regard Emballator and production systems similar to theirs. The Emballator production system was a good trial for the EcoProIT method since many of its drawbacks surfaced.

The large inventories on hand throughout Emballator's system acts as buffers between the production processes. The effects the processes have on each other are decreased and in turn the dynamic between them, this is mirrored in the model. The GWP result also shows that the time in buffers in this case are of less importance to the GWP impact.

The question is which processes in the production system do really affect the products GWP dynamically? The answer is that most of the variation of the GWP impact is due to the material combinations and wastes, not the dynamic between the actual processes. This will be further described in chapter *6.2 Analysis of GWP result*.

The DES imbedded in EcoProIT is a good tool when investigating how the different parts of a system affect each other. If the production system is more static the DES is not used to its full potential. As showed earlier the DES is a time consuming process and in cases where it is not suitable other methods that do not take the dynamic of the model into consideration could be used instead.

This master thesis was early focused on the enamel machine and printing press as these where thought to be the processes with the largest GWP impact. The result from the model showed that the accuracy requirements set where not at a good enough level of detail. This reduces the confidence in the result. The increased level of detail would increase complexity of the model. To model Emballator's production to a satisfying extent and get a more dynamic model the level of detail would have to be increased. This is today limited by AutoMod and the great complexity of Emballator's possible product variations'.

As a lot of the dynamic in the case of Emballator is caused by the variation in material specification. As mentioned in chapter *4.5.1 Enamel process* there are 22 different types of enamel in several different combinations of between one and three layers. The assumption with 12 combinations described might be sufficient from a production validation point of view but not sufficient from a GWP impact point of view. This implies that the Input data method used is insufficient to the needs of the EcoProIT method and the accuracy of the result suffers as a consequence.

When building a DES-model and validating it traditionally assumptions are made that can compromise the GWP impact, to make the validation possible. This gives a model that compromises or jeopardizes both the result from the GWP impact and the possibility to use the model for production analysis. The focus on processes working as in reality is less important in a GWP context. It is therefore important that the focus lies on GWP impact for identification and definition of parameters as well as specification of accuracy requirements (step *A* and *B* in *2.6.2 Input Data Management Method*).

If the LCI data used have been reviewed and the calculations have been reviewed. And given that the DES model (with its gathered data) is validated and verified. The model should be validated. It is of course of value to compare the result to similar products made with similar analysis. This is as mentioned in *5.1.2 Accuracy* a difficulty. The problems with finding LCI data for similar products are due to the cumbersome task of performing an LCA. Many smaller companies avoid it because of the time and cost aspect, see *2.2 Life Cycle Assessment.*

5.3 GWP result from the model

One of the objectives of this Master Thesis was to find the major sources that contributed to 80 % of the total GWP result. However, this is dependent of how the different sources are divided. For example, the total GWP can be divided in material contribution and in house contribution but the material contribution can be further divided in steel and plastic and the steel can be divided in the different parts of the can to where it is used. Therefore this chapter will cover the most interesting results from the model. For further analysis please see appendix II for a complete list of all contributions.

The results below are based on output from 117 batches consisting of 370 000 cans. The values are calculated with 100-year GWPs. Table 6 shows the mean GWP value together with smallest and the largest GWP value for the different can sizes.

Can size	Means GWP value	Smallest GWP value	Largest GWP value
2,5 l	2,37	2,19	2,88
3 l	2,71	2,34	3,33
4 l	2,93	2,67	3,46
5 l	3,24	2,93	4,18
6 l	4,35	3,82	4,69

Table 6 GWP value for the different can sizes produced in 180-1

The GWP value can be divided into in house contributions and contribution due to materials consumed. The in house contributions consist of all processes, in house transportations, heating of facility, consumed water and material wastes. The material wastes include production of material and transportation to Emballator. See figure 9.

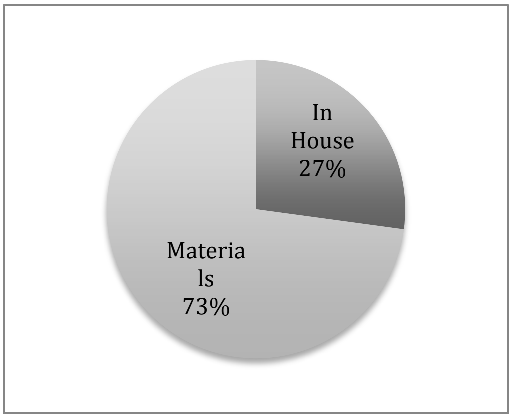

Figure 9 In House processes and materials contribution to the GWP value.

5.3.1 In house contributions

Figure 10 shows the in house contributions divided into processes, waste and other in house contributions. The other in house contribution consists of heating of facility, overhead consumption of electricity, water consumption and in house transportation. As can be seen the waste contribution is 49%, the share of the processes are 49% and the share of other in house contributions are 2%. Figure 11 shows the share of the wastes from different parts of the can and overhead waste.

Figure 12 shows the shares of each process of the processes contribution. As can be seen in this figure the printing and the enamel process represent almost all of the processes contribution to the GWP value.

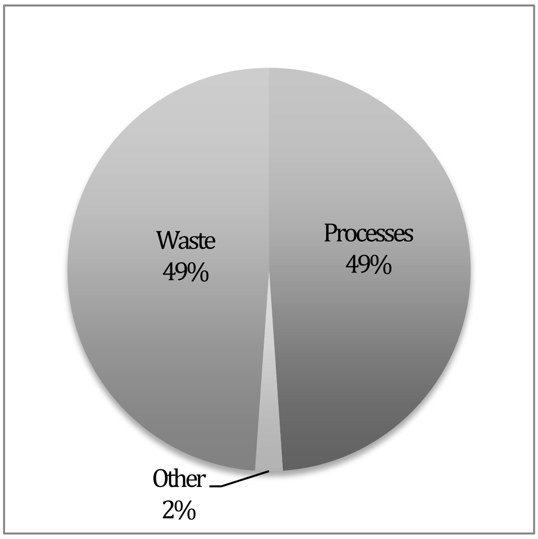

Figure 10 The In House contributions to the GWP value divided in waste, processes and other contributions.

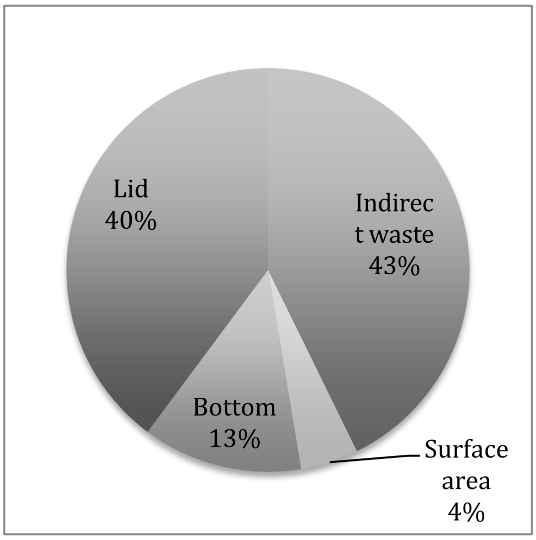

Figure 11 The waste contribution divided bottom, steel, surface area and overhead waste.

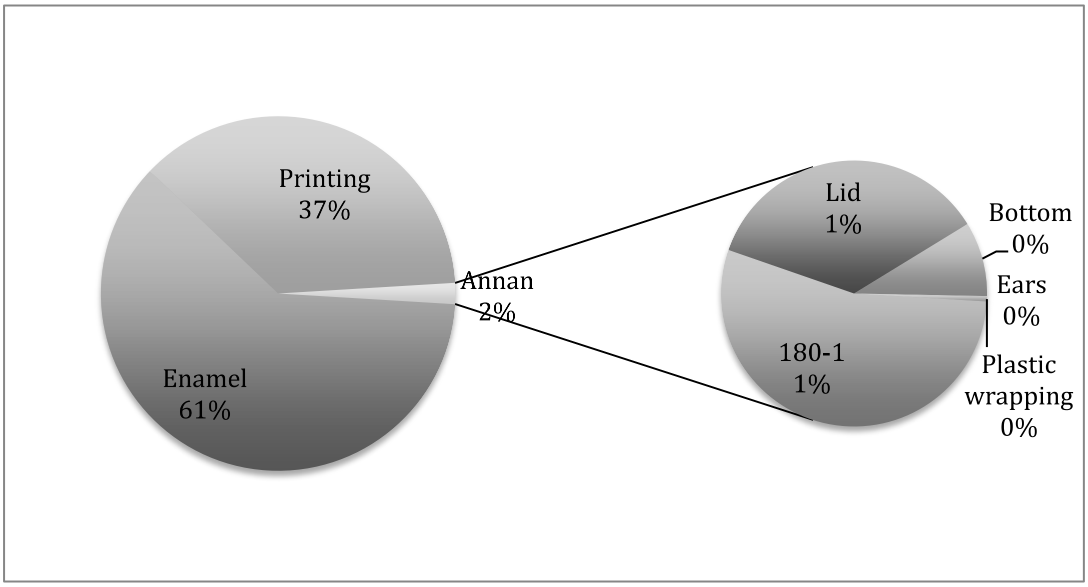

Figure 12 The process share divided in the different processes.

Figure 13 shows the shares of the different sources to the contribution of other in house contributions in figure 12.

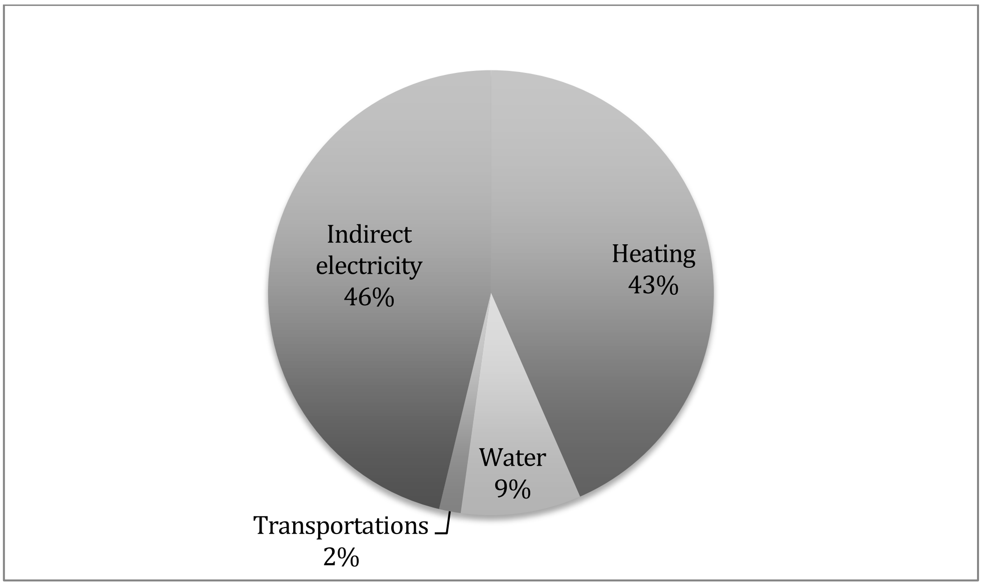

Figure 13 Shares of the different sources to the other contribution in figure 12.

Figure 14 and 15 shows the set up times and stop time compared to actual process time. As described in chapter *4.4.1 Process data* it is not possible to separate the set up time from the stop time in the enamel process. The process time in the printing process also includes stops in the middle of batch.

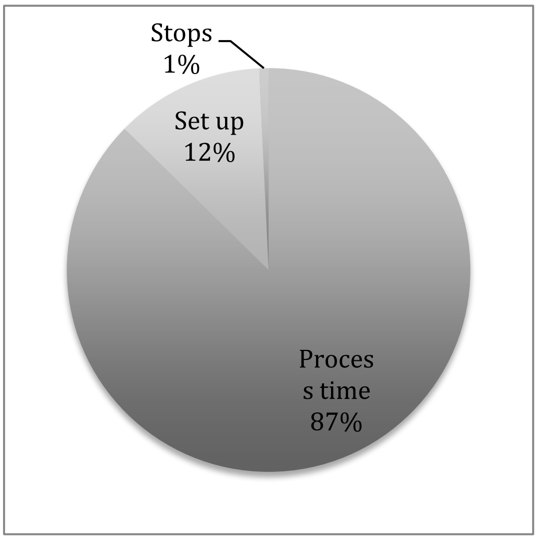

Figure 14 Set up times and stop times compared to the process time in the printing process.

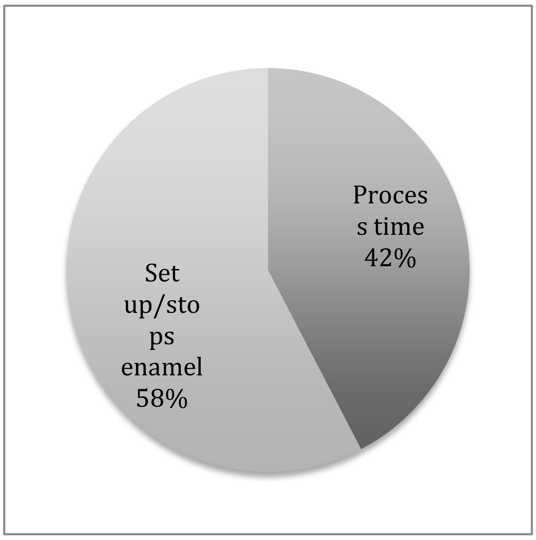

Figure 15 Set up time and stop time compared to the process time in the enamel process.

5.3.2 Material GWP contribution

For all materials the transportation from supplier to Emballator contributes with 13% of the GWP for materials, see figure 16. The most significant contribution of the transport GWP is the transport of steel to Emballator. Of this transportation 91,2 % is because of the transportation with boat from China to Göteborg.

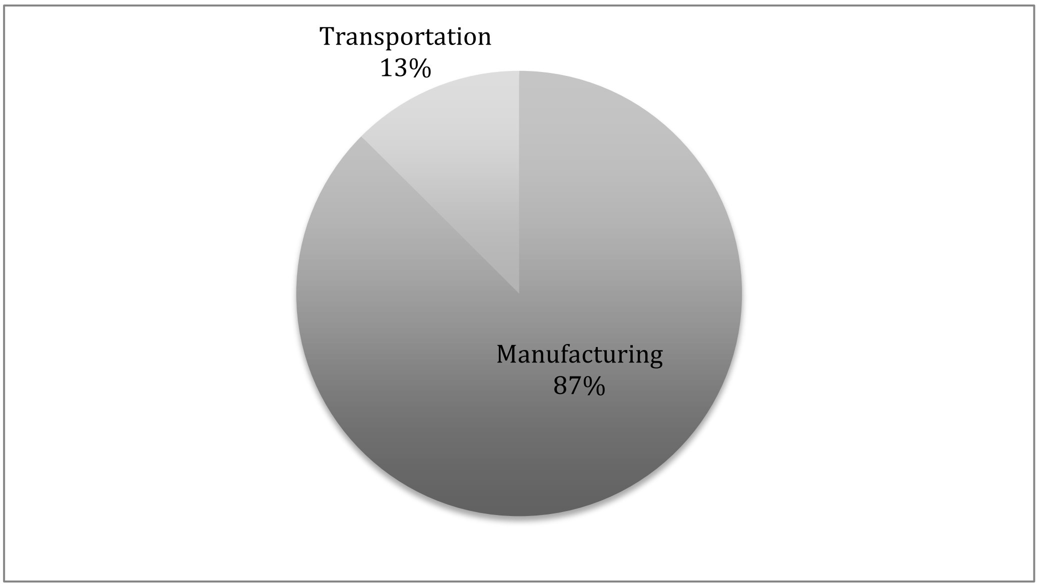

Figure 16 The transportation share compared to the manufacturing GWP contribution.

The share of each material to the material contribution can be seen figure 14. The steel for the mantel, lid and bottom represent 99 % of the materials GWP contribution. Whether there is a plastic handle and one or two plastic layers in the plastic operation, differ between the orders and the chart represent a mean value for the orders from the model. If we would have looked at only one order with plastic handles or two plastic layers these would have a greater impact on the GWP contribution.

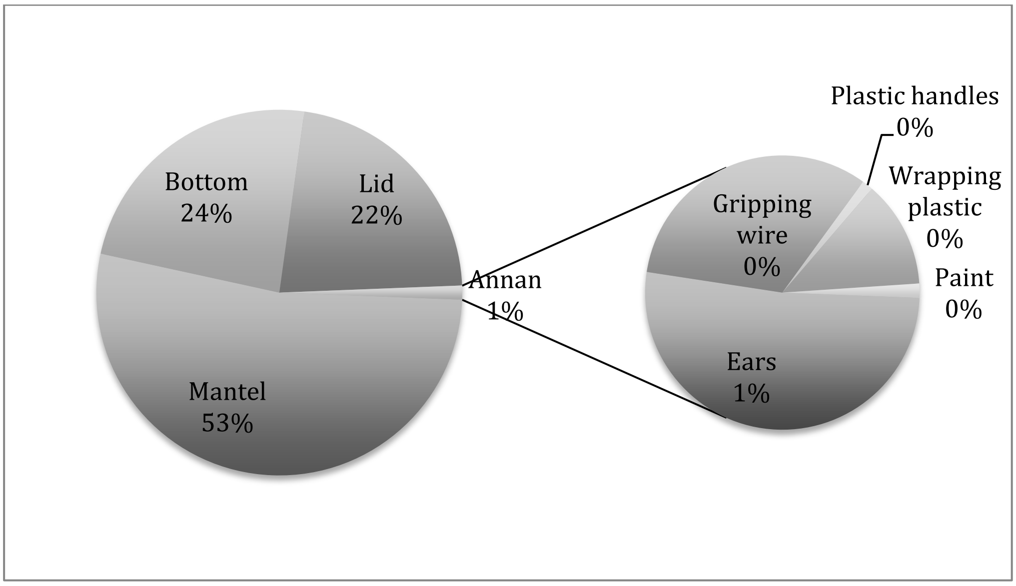

Figure 17 Share of GWP contribution for materials for a can.

5.3.3 Waste Contribution

Figure 10 in chapter *5.3.1 In house GWP contributions* shows that waste of material represent 49 % of the in house contribution to the GWP value. Another interesting point of view is to compare the wastes to the direct materials used. Figure 18 shows that waste of materials contributes with 18 % of the GWP value of all materials. Figure 17 in chapter *5.3.2 Material GWP contribution* shows the shares of the GWP impact for the different direct material and figure 11 in chapter *6.1 In house GWP* *contributions* shows the different shares of GWP impact due to cutting lids, bottoms, surface areas and indirect waste.

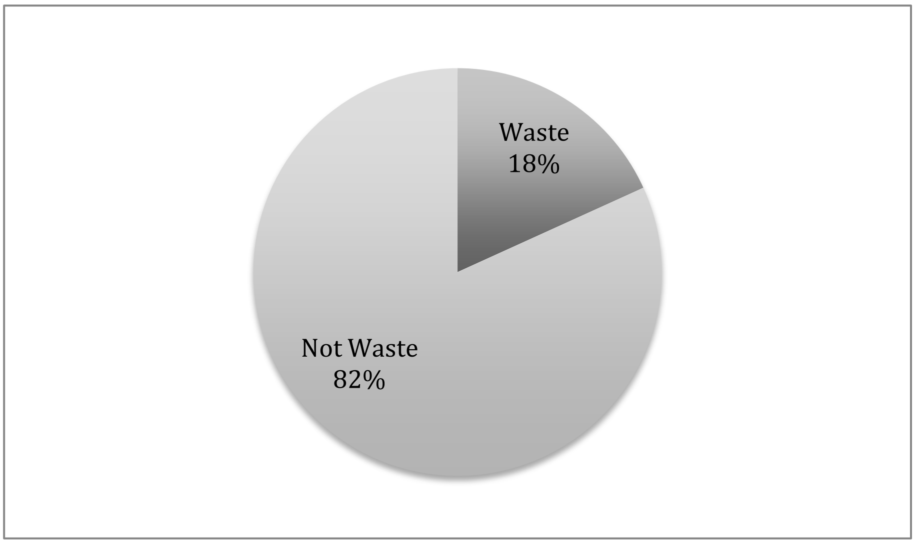

Figure 18 All material contribution divided in waste and direct material.

6. Analysis

This chapter contains analysis of the GWP results from the model and problem identification of the EcoProIT method as well as improvements suggestions.

6.1 Problem identification of the EcoProIT method

The input data management and validation of an EcoProIT project go hand in hand. If the identification of important parameters and accuracy requirements are misjudged early on the quality of the project will suffer.

Before one decides to implement the EcoProIT method one should keep in mind that it has the same restrictions as a traditional DES method. The system to be evaluated should be investigated to see if a DES model is suitable, as in any simulation case. This is a difficult task since the model is often built by outside personnel not previously knowledgeable about the system or company. Enough knowledge and experience is achieved to late in terms of choice of evaluation method. It is hard in the beginning of a project to know which parts of the system that have a high impact on the GWP and which are less important. Compared to the sometimes intuitive production data it is not always clear where the GWP impact is most significant. There is a risk of missing relevant information if the identification of important parameters is erroneous and the accuracy requirements might be set to low.

Since Emballator were not interested in any production analysis, the DES model in this case was built from a production perspective but to fulfill environmental objectives. Generally a DES-model is built with clear production objectives and parameters are set accordingly. In this case the production data was of low quality and it took much iteration to get satisfying data. Assumptions and simplifications where made that might have compromised the DES model as well as the environmental result.

After this analysis the problems are identified as validation and quality issues and a decreased GWP impact sensitivity. These problems are caused by a series of issues.

The identified problems with the EcoProIT model are:

- Lack of accuracy in required areas, too much accuracy in not required areas.
- Assumption and simplifications compromise the result.
- Contradiction between production and environmental objectives.

As discussed above the validation and quality issues was a result of lack of accuracy in areas where it was necessary, as well as two much accuracy in not necessary areas (unnecessary work, time factor, not needed to validate). This was due to assumptions made early in the project that compromised both production and environmental result by compromising each other’s dynamic affect on the result. This is due to the fact that the accuracy requirements where based on solely environmental objectives. A part of the issue is the fact that there are no clear instructions for how to approach an EcoProIT project where there is no existing DES model. Or instruction of how to approach the problem if there is an existing DES model.

6.1.1 Suggested improvements

The suggested improvements will try to resolve the issues presented in the chapter above.

The first stage in an EcoProIT project should be a thorough evaluation of the real system. This would serve as an initial evaluation of the GWP impact and prevent mistakes when making assumptions and prevent compromises between production and environmental objectives. This would decrease time spent on unnecessary work as well as focus on what is important.

The Pre-Study would include the following steps:

1. Collect data
2. Identify which materials and energy consumptions have high GWP impact.
3. Identify in which processes are created/consumed
4. Evaluate and base the identification important parameters and accuracy requirements on it.

To identify which materials are used and the amount of these a possible source is the purchases made during the last year. It is also important to identify the energy consumption and type of energy source. This would include electricity, LPG etc. For these materials and energies initial rough LCI data should be found, with these it is possible to identify which materials and energy consumptions have the highest GWP impact.

An initial sensitivity analysis should be performed the study should include:

- Materials used in the process (type and amount)
- Energy consumption (LPG, electricity etc)
- Initial rough LCI data for these materials

If there isn't an existing DES model it would be more effective to build a DES-model from a set of objectives focused on production analysis but not contradicting or compromising the environmental objectives or accuracy requirements set in the previously recommended Pre-Study. If using an existing DES-model it is important to study the model and the assumptions made when building it to make sure it has an accurate level of detail or is possible (within a reasonable time) to modify. Without the Pre-Study it would not be possible to know where or how to modifying the DES-model or which data is significant for the result.

The GWP contributions should early in the project be categorized in direct costs or indirect GWP contributions. In some cases it may be difficult to distinguish between direct and indirect GWP contributions. If a machine stops, the GWP contribution due to that stop can be considered as a direct GWP contribution if the stop is because of nature of the batch processed at the time of failure. However, if the machine stops independent of the batch it should be considered as an indirect GWP contribution and be distributed among all products with a distribution factor.

Figure 20 is a schematic of the different routes possible in the beginning of an EcoProIT method depending on the requirements and desired result of an EcoProIT model.

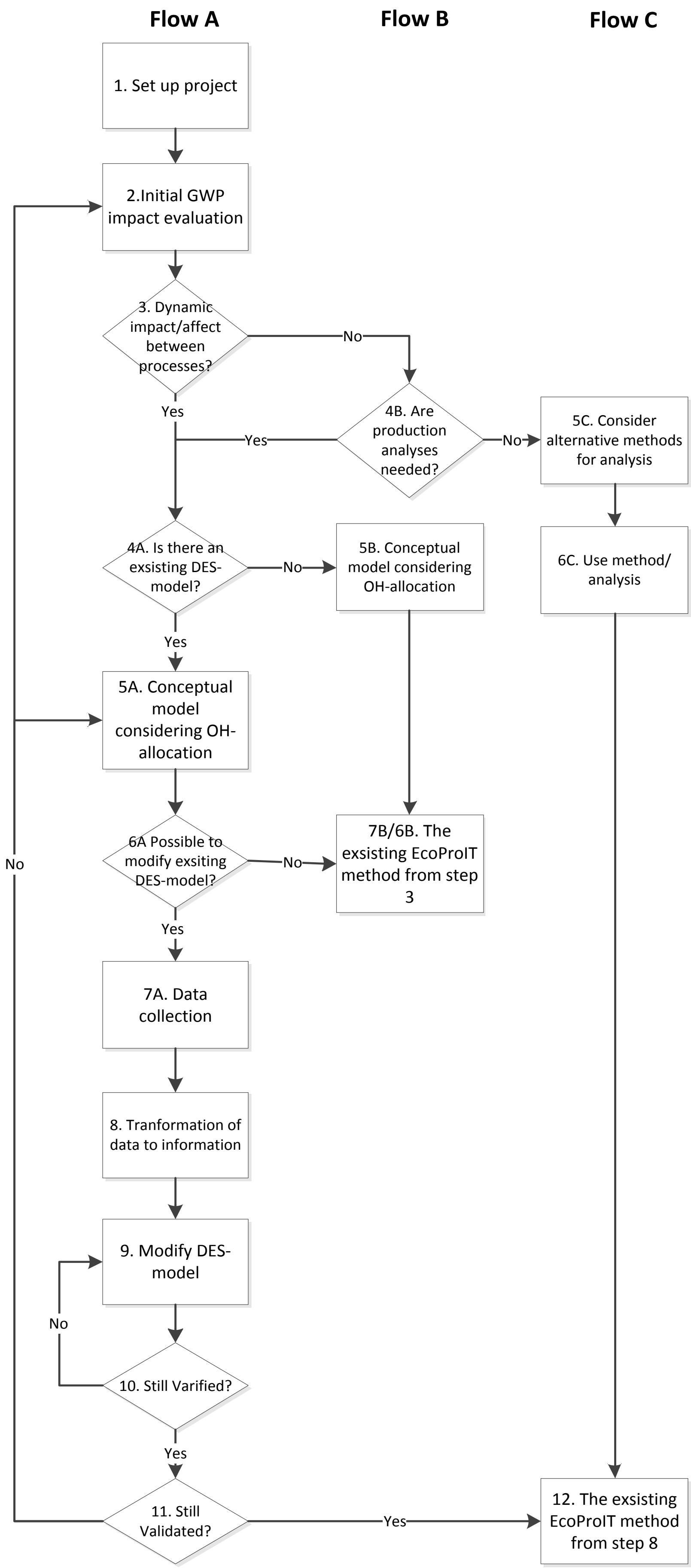

Figure 20 Addition to/modification of the EcoProIT method

6.2 Analysis of GWP result

Table 6 in chapter *5.3 GWP results from model* shows that the GWP value increases as the volume of the can increases. This is because the mantel area increases and therefore the amount of steel used which means that the number of mantels per sheet decreases. Therefore more sheets have to be used to make the same number of cans. This affect GWP values from both the enamel process and printing process. The number of sheets is also a distributing factor for overhead costs when allocating the heating of the raw material buffer, buffer for sheets that have gone through the enamel process and buffer or sheets that have gone through the printing process.

Table 7 shows GWP values from table 5 expressed in GWP per litre. It shows that the GWP per litre decreases as the volume increases. The 6 litres can is not according to the pattern. This is because of the large, in comparison to other can sizes, waste when cutting the surface area from the metal sheets for this can size.

Can size	GWP value per litre
2,5 l	1,03
3 l	0,92
4 l	0,75
5 l	0,62
6 l	0,72

Table 7 GWP values per litre

The differences in GWP within each can size is because of a lot of different factors. The different factors and how they affect the total GWP value can be seen in table 8.

Factor	Decreases GWP	Increases GWP
Number of enamel layers on surface area	Few enamel layers	Many enamel layers
Number of enamel layers on lid	Few enamel layers	Many enamel layers
Number of enamel layers on bottom	Few enamel layers	Many enamel layers
Number of printing rounds	Few printing rounds	Many printing rounds
Time per sheet in each printing round	Few seconds per sheet	Many seconds per sheet
Time per sheet to set up printing process	Few seconds per sheet	Many seconds per sheet
Plastic handles	No	Yes
Number of plastic wrapping	One plastic wrapping operation	Two plastic wrapping operations
Time per can in can production line	Few seconds per can	Many seconds per can

Table 8 Factors affecting the GWP value

Figure 21 shows the impact on the variation of processes and material for a three-litre can. Since the set up time or the enamel process is distributed as an indirect cost it has a lesser impact on the variation than in reality. Since this master thesis has not focused on the variation of material wastes that figure cannot be considered exact.

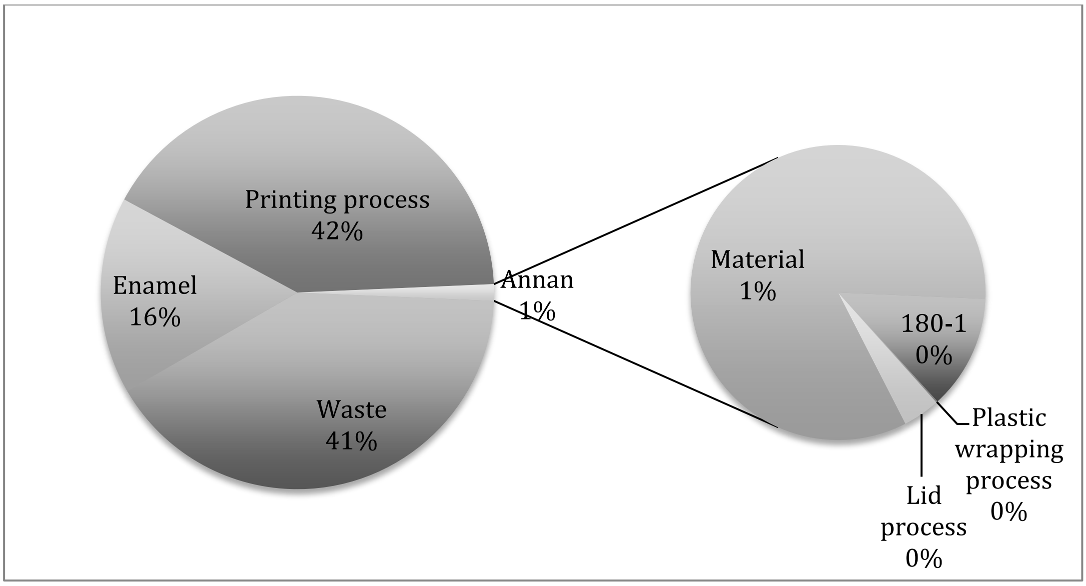

Figure 21 The impact of the variation of GWP value for one can size

6.2.1 Analysis of in house contributions

As can be seen in figure 10 a large proportion of the in house GWP contribution is due to waste. Figure 11 shows that waste due to the lid and bottom production is a much larger than waste due to the mantel area. This is explained by intuitive geometry were cutting a round circle from a square leaves much more unused area than cutting a square area from a square metal sheet.

The overhead waste, which is distributed by the time per can in the main production line, comes from all parts of production.

Figure 21 shows that the enamel process followed by printing process is the processes that have the biggest impact on the GWP. This is because of combustion of enamel and LPG produces large amounts of CO_2. Other processes such as bottom process, plastic wrapping process and ear process only consumes electrical energy and compressed air that has a fairly low impact on the GWP result.

The heating of the facility has a very low impact on the GWP result. This is because of the ovens at the enamel process and the printing process produces a lot of heat to the rest of the factory. Because of this the facility don´t need any additional heating when the average temperature for one day and night is above four degrees. If one of these processes would be changed to a process that don´t use the same heating process the GWP impact for heating the facility would be more significant.

6.2.2 Analysis of material contribution

The material used has a much bigger impact on the GWP value than the In House contributions. Chart 17 shows that almost all of the material contribution is because of the steel for mantel, lid and bottom. Of the GWP contribution due to the materials 14% is because of transportation from the supplier to Emballator.

7. Discussion

The discussion will handle the method for evaluation, the evaluation result and the result from the model.

7.1 Evaluation method discussion

The field notes method was adapted according to the questions asked in the problem formulation. It was also an “evaluating by doing” method which will affect the result. The risk with the chosen method is subjectivity and lack of quantifiable or measurable results. It is possible that problems or difficulties with the EcoProIT method where missed because of this.

The evaluation was very dependent on the current situation at Emballator and as a result of this certain problems with the EcoProIT method where highlighted while others might not show themselves. It is a fact that this is one case and cannot stand for the entire evaluation of the EcoProIT method but it does give an indication of the difficulties that need to be tackled, e.g. the EcoProIT method’s weaknesses when there is contradicting objectives (production and environmental). These would not have been as clear if the case had been performed at another company.

Factors that might have contributed to a better result is more knowledge or experience of performing a LCA to be able to more accurately compare the input data management in this case.

7.2 Evaluation result discussion

As have been said before the processes at Emballator have a limited or no impact on each other and therefore not each other’s GWP impact. If on the other hand the enamel and printing press where built as a line and a stop in the enamel meant both ovens running empty, they would have a dynamic impact on each other. A driven line such as one traditionally in the automotive industry would have a high dynamic impact on each other and therefore also a dynamic impact on the GWP value. But it is important to recognize the limited affect an electricity driven process have on the GWP value. It would take a high impact (such as LPG) process and a dynamic process to show EcoProIT’s advantages. The majority of the impact comes from the material and its combinations and waste, as mentioned before. This would be the important focus if a similar studies where to be done in for example an automotive manufacturing process. The impact of time spent in buffer for the material is less important.

When combining several EcoProIT models an insufficient representation of the GWP impact from one production system would affect several others. This is one of EcoProIT’s week points. Especially if there are systems not suitable, possible or economically viable for a DES model. A possible solution to this is to look for suitable substitutes to a simulation model. Maybe using statistics and probability to get a dynamic value. This situation would be suitable in a more static system, like that at Emballator, than a dynamic system where the processes have a high GWP impact. A suggestion to the developers of EcoProIT method is to investigate the possibility of combining EcoProIT with more than one model of simulation. This would give more credibility to the results from the EcoProIT project and also more flexibility to handle different types of production systems.

The suggested Pre-Study would add time to an already time consuming and data intensive method which could be viewed as a drawback. The Pre-Study would decrease time spent on input data management later in the project and unnecessary iteration can be avoided. In addition the data collected will still be needed in the project.

Further research should be performed on developing a input data management method more adopted to the EcoProIT methods needs, seeing as this is a more data intensive process than in a traditional DES project. The risk of compromising both the environmental and production analysis is high if these requirements are not investigated beforehand. It is also important to remember that the EcoProIT method demands that a DES model should be possible and economically viable to build.

The risk of modifying a DES-model is that it might grow large and the software might limit the possibilities. This was actually a fact in this project. In this case one solution could have been to make the order the functional unit instead of the can, or instead of using non 180-1 loads, try to make distributions corresponding to non available time for the 180-1 production line. This would increase the possibilities to model the entire system, but it would also affect the level of detail in the enamel and printing press, two of the high GWP impact processes.

7.3 GWP result discussion

All GWP results have large uncertainties. It is difficult to find correct LCI data for all materials and processes and it is difficult to find out the exact stoichiometry in the ovens. The results should only be considered as hint of the correct result and not exact values.

Chapter *2.4 Ecolabeling* mentions different types of Ecolabel but none of them can be used with figures from this master thesis. Ecolabel type I must be approved by a third party. To use a Ecolabel type III a certain methodology must be followed. Ecolabel type II is perhaps the one that is easiest to apply for the result from this master thesis. However, because of the uncertainties of the results it is not recommended to use these without further investigation.

The GWP results are calculated for a can until it reaches the gate at Emballator. What happens after gate is not a part of the scope for this master thesis. However, chapter *2.3 Steel industry* mentions that much of the steel consumed in Sweden are recycled even though it is difficult to know the percentage of steel products produced today that will recycled that product is effetely. Since there is a massive saving in energy consumption when using recycled steel rather than using iron ore to produce new products it can be assumed that in a life cycle perspective the steel contribution to the GWP value will be much lower. Since the steel has such a big impact on the total GWP this is an important factor to consider.

Figure 15 in chapter *5.3 Waste Contribution* shows that 18 % of the material used is waste material. This might be even bigger since this master thesis has only taken metal waste into consideration. There might be even more waste material of enamel, paint, plastic handles etc. To address the problem an analysis of where the waste arises, how much and why should be carried out.

The other big contributor to the in house GWPs is the processes. The two most significant processes are the enamel process and the printing process. Perhaps it will be possible to decrease the GWPs from these processes by reducing failure and set up times.

8. Conclusions and recommendations

In this chapter the conclusions and recommendations from this master thesis is presented.

8.1 Conclusions and recommendations regarding the EcoProIT method

Taking the analysis and discussion into consideration it can be concluded that:

- The EcoProIT method need to be modified or revised as suggested in chapter *6.1.3 Suggested improvements* to get a high quality result.
  - o A pre-study should be performed to identify the important parameters and accuracy requirements regarding the system intended for the EcoProIT model.
  - o An existing DES-model should be studied with this pre-study in mind before considering the EcoProIT method.
- The existing difficulties with ABC, DES and LCA are present in the EcoProIT method.
- Validation of environmental factors is difficult due to lack of comparable LCI data.
- EcoProIT is more time consuming than a traditional DES and more data intensive.
- Building a DES with production perspective and environmental objectives (no production objectives) compromises the quality of the results of the model.

Additional research should focus on the following areas:

- Is an EcoProIT project performed solely with environmental factors in mind economically viable?
- The EcoProIT method should be evaluated by using an existing DES model built to satisfy objectives set for a production analysis.
- Investigating the possibility of combining the EcoProIT method with other models than a DES (when production analysis is not needed or desired).

8.2 Conclusions and recommendations from model result

Table 5 in chapter *6 GWP result from model* shows that the average GWP value for a can produced in 180-1 process line varies between ~2,37 GWPs for a 2,5 litres can to ~4,35 for a 6 litres can. The model presented in his master thesis shows that the variation for one can is quite large. As an example a 2,5 litres varies between ~2,19 and ~2,88 GWPs.

The most significant in house contribution to the GWP value is waste materials and processes. Of these two sources our recommendation is to further analyse the wastes in the production flow to see if it is possible to make any cuts. The enamel process and printing process has a large impact on the in house GWPs. By reducing set up times and stop times for these processes it will be possible to lower the total GWP value.

It is not recommended to use the result in this master thesis for an ecolabel. However, the results can be used as a hint of the result and as a pre-study for further studies.

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Appendix I

GWP values

Appendix I presents the GWP values used in the EcoProIT model performed at Emballator.

Electricty for transportation by train.

ELCD data created by PE International for JRC-IES, Italy.

Comment: Use advice for data set: Use by medium voltage electricity customers without own electricity generators or transformers (e.g. at industry and SME), which use electricity directly from the grid. The data set can be used for all LCI/LCA studies where electricity is needed.; Technical purpose of product or process: Medium voltage (1kV - 60kV) electricity for final consumers.; Technology description including background system: The Swedish electricity consumption mix is provided by multiple energy carriers. The Swedish specific mix is shown in the pie chart 'Power Grid Mix - SE'. The electricity is either produced in energy carrier specific power plants and / or energy carrier specific heat and power plants (CHP). The Swedish-specific fuel supply (share of resources used, by import and / or domestic supply) including the Swedish-specific energy carrier properties (e.g. element and energy contents) are accounted for. Furthermore Swedish specific technology standards of power plants regarding efficiency, firing technology, flue-gas desulphurisation, NOx removal and dedusting are considered. The Swedish electricity consumption mix is modelled as shown in the flow diagram 'Modelling of Power Consumption Mix'. It includes imported/exported electricity, distribution losses (in %) and the own use by energy producers. The data set considers the whole supply chain of the fuels from exploration over extraction and preparation to transport of fuels to the power plants. The background system is addressed as follows: Transports: All relevant and known transport processes used are included. Overseas transports including rail and truck transport to and from major ports for imported bulk resources are included. Furthermore all relevant and known pipeline and / or tanker transport of gases and oil imports are included. Energy carriers: Coal, crude oil, natural gas and uranium are modelled according to the specific import situation. Refinery products: Diesel, gasoline, technical gases, fuel oils, basic oils and residues such as bitumen are modelled via a country-specific, refinery parameterized model. The refinery model represents the current national standard in refinery techniques (e.g. emission level, internal energy consumption,...) as well as the individual country-specific product output spectrum, which can be quite different from country to country. Hence the refinery products used show the individual country-specific use of resources. The supply of crude oil is modelled, again, according to the country-specific crude oil situation with the respective properties of the resources.;

The GWPs in table 1 below are calculated for 1 kWh.

Greenhouse gas	Amount (kg)	GWP 20 yr	GWP 100 yr	GWP 500 yr
Methane	7,85954E-05	0,005658867	0,001964884	0,000597325
Carbon dioxide	0,101526111	0,101526111	0,101526111	0,101526111
Dinitrogen monoxide	1,58193E-06	0,000457178	0,000471415	0,000242035
Ethane, 1,1,1,2-tetrafluoro-, HFC-134a		0	0	0
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-, CFC-113		0	0	0
Ethane, 1,1-difluoro-, HFC-152a		0	0	0
Ethane, 1,2-dichloro-1,1,2,2-tetrafluoro-, CFC-114	8,33799E-08	0,000670375	0,000833799	0,000727907
Ethane, hexafluoro-, HFC-116		0	0	0
Methane, bromochlorodifluoro-, Halon 1211		0	0	0
Methane, bromotrifluoro-, Halon 1301		0	0	0
Methane, chlorodifluoro-, HCFC-22	1,91332E-08	9,87275E-05	3,46312E-05	1,05041E-05
Methane, dichlorodifluoro-, CFC-12	1,75049E-08	0,000192554	0,000190803	9,10254E-05
Methane, trichlorofluoro-, CFC-11	8,1418E-08	0,000547943	0,000386736	0,000131897
Methane, trifluoro-, HFC-23		0	0	0
Sulfur hexafluoride	6,78424E-11	1,10583E-06	1,54681E-06	2,21166E-06

Table 2 GWP values for transportation by train.

Boat transportation

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Included processes: The module calls the modules addressing: operation of vessel; production of vessel; construction and land use of port; operation, maintenance and disposal of port.

Remark: Inventory refers to the entire transport life cycle. Port infrastructure expenditures and environmental interventions are allocated based the yearly throughput (0.37). Vessel manufacturing is allocated based on the total kilometric performance (2'000'000km) and its transport performance (50000/unit). For each transport activity 2 ports are required.; Geography: Data from one port in Netherlands is employed as an estimate for international water transportation.

The GWPs in table 2 below are calculated for 1 tkm.

Greenhouse gas	Amount (kg)	GWP 20 yr	GWP 100 yr	GWP 500 yr
Methane	7,86776E-06	0,000566479	0,000196694	5,9795E-05
Carbon dioxide	0,01048319	0,01048319	0,01048319	0,01048319
Dinitrogen monoxide	2,69508E-07	7,78878E-05	8,03134E-05	4,12347E-05
Ethane, 1,1,1,2-tetrafluoro-, HFC-134a	4,01212E-11	1,53664E-07	5,73733E-08	1,74527E-08
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-, CFC-113	8,35E-16	5,4609E-12	5,11855E-12	2,2545E-12
Ethane, 1,1-difluoro-, HFC-152a	1,3993E-12	6,11494E-10	1,73513E-10	5,31734E-11
Ethane, 1,2-dichloro-1,1,2,2-tetrafluoro-, CFC-114	1,8535E-11	1,49021E-07	1,8535E-07	1,61811E-07
Ethane, hexafluoro-, HFC-116	6,34664E-12	5,47715E-08	7,7429E-08	1,15509E-07
Methane, bromochlorodifluoro-, Halon 1211	9,0733E-12	4,30982E-08	1,71485E-08	5,21715E-09
Methane, bromotrifluoro-, Halon 1301	1,04267E-10	8,84187E-07	7,44469E-07	2,87778E-07
Methane, chlorodifluoro-, HCFC-22	4,27635E-11	2,2066E-07	7,7402E-08	2,34772E-08
Methane, dichlorodifluoro-, CFC-12	5,8407E-14	6,42477E-10	6,36636E-10	3,03716E-10
Methane, trichlorofluoro-, CFC-11	4E-17	2,692E-13	1,9E-13	6,48E-14
Methane, trifluoro-, HFC-23	7,847E-15	9,4164E-11	1,16136E-10	9,57334E-11
Sulfur hexafluoride	2,42075E-10	3,94582E-06	5,51931E-06	7,89165E-06

Table 3 GWP values for 1 tkm of boat transportation.

Truck transportation

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Included processes: operation of vehicle; production, maintenance and disposal of vehicles; construction and maintenance and disposal of road.

Remark: Inventory refers to the entire transport life cycle. For road infrastructure, expenditures and environmental interventions due to construction, renewal and disposal of roads have been allocated based on the Gross tonne kilometre performance. Expenditures due to operation of the road infrastructure, as well as land use have been allocated based on the yearly vehicle kilometre performance. For the attribution of vehicle share to the transport performance a vehicle life time performance of 540000 vkm/vehicle has been assumed.; Geography: The data for vehicle operation and road infrastructure reflect Swiss conditions. Data for vehicle manufacturing and maintenance represents generic European data. Data for the vehicle disposal reflect the Swiss situation.

The GWPs in table 3 below are calculated for 1 tkm.

Greenhouse gas	Amount (kg)	GWP 20 yr	GWP 100 yr	GWP 500 yr
Methane	0,000241391	0,01738018	0,006034785	0,001834575
Carbon dioxide	0,176445476	0,176445476	0,176445476	0,176445476
Dinitrogen monoxide	6,19746E-06	0,001791066	0,001846843	0,000948211
Ethane, 1,1,1,2-tetrafluoro-, HFC-134a	4,03398E-07	0,001545016	0,00057686	0,000175478
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-, CFC-113	2,1607E-12	1,4131E-08	1,32451E-08	5,83389E-09
Ethane, 1,1-difluoro-, HFC-152a	1,1537E-11	5,04167E-09	1,43059E-09	4,38406E-10
Ethane, 1,2-dichloro-1,1,2,2-tetrafluoro-, CFC-114	2,527E-10	2,03171E-06	0,000002527	2,20607E-06
Ethane, hexafluoro-, HFC-116	2,53849E-09	2,19072E-05	3,09696E-05	4,62005E-05
Methane, bromochlorodifluoro-, Halon 1211	9,1738E-11	4,35756E-07	1,73385E-07	5,27494E-08
Methane, bromotrifluoro-, Halon 1301	2,34721E-09	1,99043E-05	1,67591E-05	6,47829E-06
Methane, chlorodifluoro-, HCFC-22	4,40798E-10	2,27452E-06	7,97844E-07	2,41998E-07
Methane, dichlorodifluoro-, CFC-12	5,98706E-12	6,58577E-08	6,5259E-08	3,11327E-08
Methane, trichlorofluoro-, CFC-11	2,3124E-14	1,55625E-10	1,09839E-10	3,74609E-11
Methane, trifluoro-, HFC-23	4,5322E-12	5,43864E-08	6,70766E-08	5,52928E-08
Sulfur hexafluoride	1,54521E-09	2,5187E-05	3,52309E-05	5,0374E-05

Table 4 GWP values for1 tkm of truck transportation.

Steel Wire

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Included processes: Includes the process steps pre-treatment of the wire rod (mechanical descaling, pickling), dry or wet drawing (usually several drafts with decreasing die sizes), in some cases heat treatment (continuous-/discontinuous annealing, patenting, oil hardening) and Finishing. Does not include coating and the material being rolled

Remark: Wire drawing is a process in which wire rods/wires are reduced in diameter by drawing them through cone-shaped openings of a smaller cross section, so called dies. The input usually is wire rod of diameters raging from 5.5 to 16 mm obtained from hot rolling mills in form of coils. The final diameter size of dry drawn wire is between one and two millimetres, wet drawn wire has an even smaller diameter.; Geography: Data-set is representative for European Union

Technology: Average technique for EU. The processes of steel and stainless steel aren't fundamentally different, thus this module covers both materials

The GWP values in table 4 below are calcuted for 1 kg of steel wire.

Greenhouse gas	Amount (kg)	GWP 20 yr	GWP 100 yr	GWP 500 yr
Methane	0,000493042	0,035499034	0,012326054	0,00374712
Carbon dioxide	0,386365428	0,386365428	0,386365428	0,386365428
Dinitrogen monoxide	5,1801E-06	0,001497049	0,00154367	0,000792555
Ethane, 1,1,1,2-tetrafluoro-, HFC-134a	1,18824E-08	4,55097E-05	1,69919E-05	5,16886E-06
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-, CFC-113	1,5644E-12	1,02312E-08	9,58977E-09	4,22388E-09
Ethane, 1,1-difluoro-, HFC-152a	7,7636E-11	3,39269E-08	9,62686E-09	2,95017E-09
Ethane, 1,2-dichloro-1,1,2,2-tetrafluoro-, CFC-114	1,0484E-09	8,42914E-06	0,000010484	9,15253E-06
Ethane, hexafluoro-, HFC-116	8,3977E-10	7,24722E-06	1,02452E-05	1,52838E-05
Methane, bromochlorodifluoro-, Halon 1211	1,1886E-09	5,64585E-06	2,24645E-06	6,83445E-07
Methane, bromotrifluoro-, Halon 1301	4,4717E-10	3,792E-06	3,1928E-06	1,23419E-06
Methane, chlorodifluoro-, HCFC-22	4,80024E-09	2,47692E-05	8,68843E-06	2,63533E-06
Methane, dichlorodifluoro-, CFC-12	9,05991E-12	9,9659E-08	9,8753E-08	4,71115E-08
Methane, trichlorofluoro-, CFC-11	1,8294E-14	1,23119E-10	8,68965E-11	2,96363E-11
Methane, trifluoro-, HFC-23	3,5855E-12	4,3026E-08	5,30654E-08	4,37431E-08
Sulfur hexafluoride	1,31668E-08	0,000214619	0,000300204	0,000429238

Table 5 GWP values for production of 1 kg of steel wire.

Steel

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Included processes: Mix of differently produced steels and hot rolling

Remark: represents Average of World and European production mix. This is assumed to correspond to the consumption mix in Europe; Geography: Data relate to plants in the EU

The GWP values in table 5 below are calculated for 1 kg of steel.

Greenhouse gas	Amount (kg)	GWP 20 yr	GWP 100 yr	GWP 500 yr
Methane	0,010506493	0,756467462	0,262662313	0,079849343
Carbon dioxide	4,265212026	4,265212026	4,265212026	4,265212026
Dinitrogen monoxide	6,8531E-05	0,019805459	0,020422238	0,010485243
Ethane, 1,1,1,2-tetrafluoro-, HFC-134a	9,11808E-08	0,000349223	0,000130389	3,96637E-05
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-, CFC-113	4,1812E-12	2,7345E-08	2,56308E-08	1,12892E-08
Ethane, 1,1-difluoro-, HFC-152a	9,0997E-10	3,97657E-07	1,12836E-07	3,45789E-08
Ethane, 1,2-dichloro-1,1,2,2-tetrafluoro-, CFC-114	1,2238E-08	9,83935E-05	0,00012238	0,000106838
Ethane, hexafluoro-, HFC-116	4,49906E-08	0,000388269	0,000548885	0,000818828
Methane, bromochlorodifluoro-, Halon 1211	2,3793E-08	0,000113017	4,49688E-05	1,3681E-05
Methane, bromotrifluoro-, Halon 1301	6,4728E-09	5,48894E-05	4,62158E-05	1,78649E-05
Methane, chlorodifluoro-, HCFC-22	8,98397E-08	0,000463573	0,00016261	4,9322E-05
Methane, dichlorodifluoro-, CFC-12	1,04163E-10	1,14579E-06	1,13538E-06	5,41648E-07
Methane, trichlorofluoro-, CFC-11	6,4745E-14	4,35734E-10	3,07539E-10	1,04887E-10
Methane, trifluoro-, HFC-23	1,2689E-11	1,52268E-07	1,87797E-07	1,54806E-07
Sulfur hexafluoride	7,04825E-08	0,001148865	0,001607002	0,002297731

Table 6 GWP values for production of 1 kg of steel.

Polyethane

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Included processes: This dataset contains the transports of the monomers as well as the production (energy, air emissions) of the PUR foam

Remark: Dataset represents just one possible composition for a rigid PUR foam.

The GWP values in table 6 below are calcutaed for 1 kg of polyethane.

Greenhouse gas	Amount (kg)	GWP 20 yr	GWP 100 yr	GWP 500 yr
Methane	0,032028726	2,306068301	0,80071816	0,243418321
Carbon dioxide	3,559041148	3,559041148	3,559041148	3,559041148
Dinitrogen monoxide	2,61638E-05	0,007561339	0,007796813	0,004003062
Ethane, 1,1,1,2-tetrafluoro-, HFC-134a	5,77528E-08	0,000221193	8,25865E-05	2,51225E-05
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-, CFC-113	2,8926E-11	1,89176E-07	1,77316E-07	7,81002E-08
Ethane, 1,1-difluoro-, HFC-152a	1,9923E-10	8,70635E-08	2,47045E-08	7,57074E-09
Ethane, 1,2-dichloro-1,1,2,2-tetrafluoro-, CFC-114	2,6888E-09	2,1618E-05	0,000026888	2,34732E-05
Ethane, hexafluoro-, HFC-116	1,42294E-08	0,0001228	0,000173599	0,000258975
Methane, bromochlorodifluoro-, Halon 1211	1,2713E-09	6,03868E-06	2,40276E-06	7,30998E-07
Methane, bromotrifluoro-, Halon 1301	9,52521E-10	8,07738E-06	6,801E-06	2,62896E-06
Methane, chlorodifluoro-, HCFC-22	7,06333E-09	3,64468E-05	1,27846E-05	3,87777E-06
Methane, dichlorodifluoro-, CFC-12	8,04787E-11	8,85266E-07	8,77218E-07	4,18489E-07
Methane, trichlorofluoro-, CFC-11	3,105E-13	2,08967E-09	1,47488E-09	5,0301E-10
Methane, trifluoro-, HFC-23	6,0855E-11	7,3026E-07	9,00654E-07	7,42431E-07
Sulfur hexafluoride	3,43168E-08	0,000559364	0,000782423	0,001118728

Table 7 GWP values for production of 1 kg of polyethane.

Enemaling

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Included processes: The basic inventory is split up into the major process stages degreasing, corroding, cleaning and firing as well as an inventory for the materials used for enamelling. All stages of enamelling are summed up not including the metal sheets treated. Data for infrastructure and land are estimated roughly with data for a metal coating plant.

Remark: Enamel is a glass of a particular chemical composition and physical nature determined for the surface protection of metal.; Geography: The inventory has been elaborated for the European situation based on data investigated in Germany.

The GWP values in table 7 below calculated for a enamel layer with 600 g/m^2.

Greenhouse gas	Amount (kg)	GWP 20 yr	GWP 100 yr	GWP 500 yr
Methane	0,01478115	1,0642428	0,36952875	0,11233674
Carbon dioxide	8,449917224	8,449917224	8,449917224	8,449917224
Dinitrogen monoxide	0,000308268	0,089089452	0,091863864	0,047165004
Ethane, 1,1,1,2-tetrafluoro-, HFC-134a	7,6185E-08	0,000291789	0,000108945	3,31405E-05
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-, CFC-113	7,3043E-12	4,77701E-08	4,47754E-08	1,97216E-08
Ethane, 1,1-difluoro-, HFC-152a	6,1814E-09	2,70127E-06	7,66494E-07	2,34893E-07
Ethane, 1,2-dichloro-1,1,2,2-tetrafluoro-, CFC-114	8,1992E-08	0,000659216	0,00081992	0,00071579
Ethane, hexafluoro-, HFC-116	3,56077E-08	0,000307294	0,000434413	0,000648059
Methane, bromochlorodifluoro-, Halon 1211	4,316E-08	0,00020501	8,15724E-05	0,000024817
Methane, bromotrifluoro-, Halon 1301	1,1539E-08	9,78508E-05	8,23886E-05	3,18477E-05
Methane, chlorodifluoro-, HCFC-22	2,03543E-07	0,001050283	0,000368413	0,000111745
Methane, dichlorodifluoro-, CFC-12	2,5312E-10	2,78432E-06	2,75901E-06	1,31622E-06
Methane, trichlorofluoro-, CFC-11	2,5918E-13	1,74428E-09	1,23111E-09	4,19872E-10
Methane, trifluoro-, HFC-23	5,0797E-11	6,09564E-07	7,51796E-07	6,19723E-07
Sulfur hexafluoride	1,07059E-06	0,017450552	0,024409361	0,034901104

Table 8 GWP values for an enamel layer with 600g/m^2.

Alkyd

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Included processes: Transport of raw materials and production of paint. Packaging is neglected.

Remark: Alkyd paints can be made of many different resins. This dataset stands for one specific long oil alkyd as used in architectural paints of white colour and should not be used for other alkyds if it's contribution to the overall result is important. The data quality is not sufficient to allow for e.g. a comparative assessment of different paints.

The GWP values in table 8 below are calculated for 1 kg of alkyd.

Greenhouse gas	Amount (kg)	GWP 20 yr	GWP 100 yr	GWP 500 yr
Methane	0,008086274	0,5822117	0,20215684	0,061455679
Carbon dioxide	2,476859324	2,476859324	2,476859324	2,476859324
Dinitrogen monoxide	0,000713644	0,206243119	0,212665915	0,109187534
Ethane, 1,1,1,2-tetrafluoro-, HFC-134a	2,07629E-07	0,000795219	0,00029691	9,03186E-05
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-, CFC-113	7,9755E-11	5,21598E-07	4,88898E-07	2,15339E-07
Ethane, 1,1-difluoro-, HFC-152a	6,0393E-10	2,63917E-07	7,48873E-08	2,29493E-08
Ethane, 1,2-dichloro-1,1,2,2-tetrafluoro-, CFC-114	8,4172E-09	6,76743E-05	0,000084172	7,34822E-05
Ethane, hexafluoro-, HFC-116	4,29044E-08	0,000370265	0,000523434	0,00078086
Methane, bromochlorodifluoro-, Halon 1211	2,5696E-08	0,000122056	4,85654E-05	1,47752E-05
Methane, bromotrifluoro-, Halon 1301	2,7686E-08	0,000234777	0,000197678	7,64134E-05
Methane, chlorodifluoro-, HCFC-22	9,57528E-08	0,000494084	0,000173313	5,25683E-05
Methane, dichlorodifluoro-, CFC-12	4,06367E-10	4,47004E-06	4,4294E-06	2,11311E-06
Methane, trichlorofluoro-, CFC-11	8,5738E-13	5,77017E-09	4,07256E-09	1,38896E-09
Methane, trifluoro-, HFC-23	1,6804E-10	2,01648E-06	2,48699E-06	2,05009E-06
Sulfur hexafluoride	1,01529E-07	0,001654917	0,002314854	0,003309835

Table 9 GWP values for 1 kg of alkyd.

Polystyren

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Included processes: Aggregated data for all processes from raw material extraction until delivery at plant

Remark: Data are from the Eco-profiles of the European plastics industry (PlasticsEurope). Not included are the values reported for: recyclable wastes, amount of air / N2 / O2 consumed, unspecified metal emission to air and to water, mercaptan emission to air, unspecified CFC/HCFC emission to air, dioxin to water. The amount of "sulphur (bonded)" is assumed to be included into the amount of raw oil.

Technology: polymerization out of ethylene and benzene by free radical processes

The GWP values in table 9 below are calcutaed for 1 kg of polystyren.

Greenhouse gas	Amount (kg)	GWP 20 yr	GWP 100 yr	GWP 500 yr
Methane	0,030408117	2,189384421	0,760202924	0,231101689
Carbon dioxide	2,768819043	2,768819043	2,768819043	2,768819043
Dinitrogen monoxide	7,05953E-07	0,00020402	0,000210374	0,000108011
Ethane, 1,1,1,2-tetrafluoro-, HFC-134a	8,24434E-10	3,15758E-06	1,17894E-06	3,58629E-07
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-, CFC-113	7,0394E-14	4,60377E-10	4,31515E-10	1,90064E-10
Ethane, 1,1-difluoro-, HFC-152a	1,7653E-12	7,71436E-10	2,18897E-10	6,70814E-11
Ethane, 1,2-dichloro-1,1,2,2-tetrafluoro-, CFC-114	2,8145E-11	2,26286E-07	2,8145E-07	2,45706E-07
Ethane, hexafluoro-, HFC-116	8,53795E-11	7,36825E-07	1,04163E-06	1,55391E-06
Methane, bromochlorodifluoro-, Halon 1211	1,7654E-11	8,38565E-08	3,33661E-08	1,01511E-08
Methane, bromotrifluoro-, Halon 1301	7,1632E-11	6,07439E-07	5,11453E-07	1,97704E-07
Methane, chlorodifluoro-, HCFC-22	1,49886E-08	7,73411E-05	2,71293E-05	8,22873E-06
Methane, dichlorodifluoro-, CFC-12	2,95355E-13	3,24891E-09	3,21937E-09	1,53585E-09
Methane, trichlorofluoro-, CFC-11	7,85E-16	5,28305E-12	3,72875E-12	1,2717E-12
Methane, trifluoro-, HFC-23	1,5391E-13	1,84692E-09	2,27787E-09	1,8777E-09
Sulfur hexafluoride	2,79502E-10	4,55588E-06	6,37265E-06	9,11177E-06

Table 10 GWP values for 1 kg of polystyrene.

LPG production

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Included processes: Dataset includes LPG production and distribution. Filling station is considered. Losses at loading, unloading and refuelling are included.

Remark: The LPG production mix represents the average of 1999 until 2008 and is based on Swiss trade statistics.; Geography: Switzerland

Technology: Average data for the used technology

The GWP values in table 10 below are calcutaed for production of 1 kg of LPG.

Greenhouse gas	Amount (kg)	GWP 20 yr	GWP 100 yr	GWP 500 yr
Methane	0,00574335	0,413521196	0,143583749	0,04364946
Carbon dioxide	0,560104623	0,560104623	0,560104623	0,560104623
Dinitrogen monoxide	7,4973E-06	0,00216672	0,002234196	0,001147087
Ethane, 1,1,1,2-tetrafluoro-, HFC-134a	4,10555E-08	0,000157243	5,87094E-05	1,78591E-05
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-, CFC-113	5,555E-13	3,63297E-09	3,40522E-09	1,49985E-09
Ethane, 1,1-difluoro-, HFC-152a	6,435E-11	2,8121E-08	7,9794E-09	2,4453E-09
Ethane, 1,2-dichloro-1,1,2,2-tetrafluoro-, CFC-114	1,0244E-09	8,23618E-06	0,000010244	8,94301E-06
Ethane, hexafluoro-, HFC-116	1,07367E-09	9,26576E-06	1,30988E-05	1,95408E-05
Methane, bromochlorodifluoro-, Halon 1211	4,1126E-10	1,95349E-06	7,77281E-07	2,36475E-07
Methane, bromotrifluoro-, Halon 1301	5,7639E-08	0,000488779	0,000411542	0,000159084
Methane, chlorodifluoro-, HCFC-22	1,88501E-09	9,72666E-06	3,41187E-06	1,03487E-06
Methane, dichlorodifluoro-, CFC-12	4,2335E-12	4,65685E-08	4,61452E-08	2,20142E-08
Methane, trichlorofluoro-, CFC-11	7,322E-15	4,92771E-11	3,47795E-11	1,18616E-11
Methane, trifluoro-, HFC-23	1,4351E-12	1,72212E-08	2,12395E-08	1,75082E-08
Sulfur hexafluoride	1,03677E-08	0,000168993	0,000236383	0,000337987

Table 11 GWP values for production of 1 kg of LPG.

LPG combustion

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Included processes: unspecified

Remark: Important note: although most of the data in the US LCI database has undergone some sort of review, the database as a whole has not yet undergone a formal validation process

Technology: LPG combustion in average industrial boiler.

The GWP values in table 11 below are calculated for combustion of 1 kg of LPG.

Greenhouse gas	Amount (kg)	GWP 20 yr	GWP 100 yr	GWP 500 yr
Methane	0,000026025	0,0018738	0,000650625	0,00019779
Carbon dioxide	1,724	1,724	1,724	1,724
Dinitrogen monoxide	0,00011711	0,03384479	0,03489878	0,01791783
Ethane, 1,1,1,2-tetrafluoro-, HFC-134a		0	0	0
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-, CFC-113		0	0	0
Ethane, 1,1-difluoro-, HFC-152a		0	0	0
Ethane, 1,2-dichloro-1,1,2,2-tetrafluoro-, CFC-114		0	0	0
Ethane, hexafluoro-, HFC-116		0	0	0
Methane, bromochlorodifluoro-, Halon 1211		0	0	0
Methane, bromotrifluoro-, Halon 1301		0	0	0
Methane, chlorodifluoro-, HCFC-22		0	0	0
Methane, dichlorodifluoro-, CFC-12		0	0	0
Methane, trichlorofluoro-, CFC-11		0	0	0
Methane, trifluoro-, HFC-23		0	0	0
Sulfur hexafluoride		0	0	0

Table 12 GWP values for combustion of 1 kg og LPG.

Hydroelectric power

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Included processes: This module describes the average operation of major Swiss dams. It includes the area occupied; a preliminary estimation of greenhouse gas emissions out of the water reservoir (as biogenic methane); lubricant oil; volume of the reservoir; mass of water passing through the turbines.
Remark: This study adresses Swiss dams only. The data have been applied for an extrapolation to preliminary describe dam-mixes in Finland. A representative sample of Swiss dams with a height of more than 30 metres is taken into account for calculating the input. Data are the same for reservoir and pumped storage power plants. Lifetime is assumed to be 150 years for the structural part and 80 years for the turbines. Net average efficiency, including pipe losses, is 78% (best efficiency can be 84%). The results of this module cannot be applied to describe a single unit.; Geography: Data were extrapolated from the average Swiss reservoir hydropower plant.

Technology: The module describes average installed technology with an efficiency of 78%, including pipe losses (best technology has 82%).

The GWP values in table 12 below are calculated for 1 kWh.

Greenhouse gas	Amount (kg)	GWP 20 yr	GWP 100 yr	GWP 500 yr
Methane	0,001437079	0,103469656	0,103469656	0,103469656
Carbon dioxide	0,005216744	0,005216744	0,005216744	0,005216744
Dinitrogen monoxide	1,17284E-07	3,38951E-05	3,38951E-05	3,38951E-05
Ethane, 1,1,1,2-tetrafluoro-, HFC-134a	5,09045E-10	1,94964E-06	1,94964E-06	1,94964E-06
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-, CFC-113	4,677E-15	3,05876E-11	3,05876E-11	3,05876E-11
Ethane, 1,1-difluoro-, HFC-152a	8,6781E-13	3,79233E-10	3,79233E-10	3,79233E-10
Ethane, 1,2-dichloro-1,1,2,2-tetrafluoro-, CFC-114	1,4527E-11	1,16797E-07	1,16797E-07	1,16797E-07
Ethane, hexafluoro-, HFC-116	5,00387E-11	4,31834E-07	4,31834E-07	4,31834E-07
Methane, bromochlorodifluoro-, Halon 1211	8,081E-12	3,83848E-08	3,83848E-08	3,83848E-08
Methane, bromotrifluoro-, Halon 1301	2,1078E-11	1,78742E-07	1,78742E-07	1,78742E-07
Methane, chlorodifluoro-, HCFC-22	3,43365E-11	1,77176E-07	1,77176E-07	1,77176E-07
Methane, dichlorodifluoro-, CFC-12	5,3379E-14	5,87169E-10	5,87169E-10	5,87169E-10
Methane, trichlorofluoro-, CFC-11	7,1E-17	4,7783E-13	4,7783E-13	4,7783E-13
Methane, trifluoro-, HFC-23	1,3918E-14	1,67016E-10	1,67016E-10	1,67016E-10
Sulfur hexafluoride	1,26055E-10	2,05469E-06	2,05469E-06	2,05469E-06

Table 13 GWP values for 1kWh of hydroelectric power.

Appendix II

Material

Description	GWP contribution	Share of GWP contribution
GWP Steel mantel manufacturing	0,942976918	34,6297%
GWP Steel mantel Transportation boat	0,043726409	1,6058%
GWP Steel mantel transportation Truck	0,004216385	0,1548%
GWP Steel mantel manufacturing WASTE	0,018142687	0,6663%
GWP Steel mantel Transportation boat WASTE	0,000841287	0,0309%
GWP Steel mantel transportation Truck WASTE	8,11224E-05	0,0030%
GWP Steel bottom manufacturing	0,247641458	9,0943%
GWP Steel botom transportation boat	0,197299482	7,2456%
GWP Steel Bottom Transportation Truck	0,001107293	0,0407%
GWP Steel bottom manufacturing WASTE	0,050254923	1,8456%
GWP Steel bottom transportation boat WASTE	0,002330351	0,0856%
GWP Steel Bottom Transportation Truck WASTE	0,000224708	0,0083%
GWP Steel lid manufacturing	0,396341003	14,5551%
GWP Steel lid transportation boat	0,007232974	0,2656%
GWP Steel lid Transportation Truck	0,001772182	0,0651%
GWP Steel lid manufacturing WASTE	0,155981873	5,7282%
GWP Steel lid transportation boat WASTE	0,007232974	0,2656%

GWP Steel lid Transportation Truck WASTE	0,00069745	0,0256%
GWP Gripping wire manufacturing	0,007210573	0,2648%
GWP Gripping wire transportation	0,00038959	0,0143%
GWP Plastic handles manufacturing	0,000301647	0,0111%
GWP Plastic handles transportation TRUCK	2,84601E-06	0,0001%
GWP Steel ears manufacturing	0,011486888	0,4218%
GWP Steel ears Transportation boat	0,000532654	0,0196%
GWP Steel ears transportation truck	5,1362E-05	0,0019%
GWP Steel ears manufacturing WASTE	0,006004094	0,2205%
GWP Steel ears Transportation boat WASTE	0,000278413	0,0102%
GWP Steel ears transportation truck WASTE	2,68464E-05	0,0010%
GWP Plastic layers	0,00286942	0,1054%
GWP Plastic layer transportation train	5,73962E-05	0,0021%
GWP Plastic layer transportation truck	1,33656E-05	0,0005%

Enamel Process

Description	GWP contribution	Share of GWP contribution
GWP Electricity	0,000471632	0,0173%
GWP Compressed air	0,00014149	0,0052%
Transportation of Enamel Train	1,03109E-05	0,0004%
Transportation of enamel Truck	0,000120568	0,0044%
GWP for production and combustion of enamel.	0,088259081	3,2412%
GWP electricity	9,19327E-05	0,0034%
GWP compressed air	9,19327E-05	0,0034%

Transportation of Enamel Train Bottom	1,4094E-06	0,0001%
Transportation of enamel Truck Bottom	1,64805E-05	0,0006%
GWP for production and combustion of enamel. Bottom	0,012064192	0,4430%
GWP electricity	0,000133769	0,0049%
GWP compressed air	4,01306E-05	0,0015%
Transportation of Enamel Train LID	1,96426E-06	0,0001%
Transportation of enamel Truck LID	2,29685E-05	0,0008%
GWP for production and combustion of enamel. LID	0,016813641	0,6175%

Print Process

Description	**GWP contribution**	**Share of GWP contribution**
GWP Electricity	0,002244515	0,0824%
GWP Compressed air	0,000353511	0,0130%
GWP Production paint	0,000392362	0,0144%
GWP Transportation paint Train	2,35828E-07	0,0000%
GWP Transportation Paint Truck	2,50691E-08	0,0000%
GWP Production LPG	0,012370306	0,4543%
GWP Combustion LPG	0,119827758	4,4005%
GWP Production LPG	0,003111634	0,1143%
GWP Combustion LPG	0,015281764	0,5612%

180-1 process

Description	**GWP contribution**	**Share of GWP contribution**
Electricity GWP	0,003624433	0,1331%
Preassured air GWP	0,00073896	0,0271%

Plastic wrapping process

Description	**GWP contribution**	**Share of GWP contribution**
GWP Electricity	4,66517E-05	0,0017%

Ear process

Description	GWP contribution	Share of GWP contribution
GWP Electricity	5,49117E-06	0,0002%

Lid process

Description	GWP contribution	Share of GWP contribution
GWP Electricity lid	0,002339562	0,0859%
GWP compressed air lid	0,000545299	0,0200%

Bottom Process

Description	GWP contribution	Share of GWP contribution
GWP Electricity Bottom	0,000362417	0,0133%
GWP compressed air Bottom	0,000365317	0,0134%

Transportation (Overhead costs)

Description	GWP contribution	Share of GWP contribution
AGV 1 GWP	2,53841E-06	0,0001%
AGV 2 GWP	3,285E-06	0,0001%
AGW 3 GWP	3,43432E-06	0,0001%
GWP Print forklifts	3,54244E-05	0,0013%
GWP Production fork lifts	0,000138617	0,0051%
GWP Buffer fork Lifts	4,35038E-05	0,0016%
GWP Raw Buffer forklifts	6,21211E-05	0,0023%
GWP Mopeds	3,61081E-05	0,0013%

Heating (Overhead costs)

Description	GWP contribution	Share of GWP contribution
GWP Can Production line manufacturing	0,00040527	0,0149%
GWP Can Production line combustion	0,001990351	0,0731%
GWP Enamel & Paint Machine manufacturing	4,66862E-05	0,0017%
GWP Enamel & Paint Machine combustion	0,000229284	0,0084%
GWP Enamel sheets storage manufacturing	4,15873E-05	0,0015%
GWP Enamel sheets storage combustion	0,000144329	0,0053%

GWP Printed sheets storage manufacturing	3,57835E-05	0,0013%
GWP Printed sheets storage combustion	0,000175739	0,0065%
GWP Raw material Storage manufacturing	8,32115E-05	0,0031%
GWP Raw material Storage combustion	0,000408666	0,0150%
GWP Finished goods storage manufacturing	0,000488231	0,0179%
GWP Finished goods storage combustion	0,002397787	0,0881%
GWP Press operations manufacturing	0,000320387	0,0118%
GWP Press operations combustion	0,001573476	0,0578%
GWP Offices and other manufacturing	0,000111047	0,0041%
GWP Offices and other combustion	0,000545372	0,0200%

Electricity (Overhead costs)

Description	GWP contribution	Share of GWP contribution
GWP Electrical energy OH cost per can	0,009577571	0,3517%

Water (Overhead costs)

Description	GWP contribution	Share of GWP contribution
GWP water	0,001805018	0,0663%

Waste (Overhead costs)

Description	GWP contribution	Share of GWP contribution
GWP WASTE Steel OH manufacturing	0,167454132	6,1495%
GWP WASTE STEEL OH transportation boat	0,007764949	0,2852%
GWP WASTE STEEL OH transportation truck	0,000748747	0,0275%

Stops enamel process (Overhead costs)

Description	GWP contribution	Share of GWP contribution
GWP Manufacturing of LPG	0,014178014	0,5207%
GWP combustion of LPG	0,069630634	2,5571%
GWP Consumed electrical energy	0,01331617	0,4890%
GWP Consumed compressed air	0,000614642	0,0226%
GWP Transportations of LPG	0,002377968	0,0873%
GWP combustion of LPG	0,011678604	0,4289%
GWP Consumed electrical energy	0,002233418	0,0820%
GWP Consumed compressed air	0,000103089	0,0038%
GWP Transportations of LPG	0,003460129	0,1271%
GWP combustion of LPG	0,016993281	0,6241%
GWP Consumed electrical energy	0,003249797	0,1193%
GWP Consumed compressed air	0,000150003	0,0055%

Stops printing process (Overhead costs)

Description	GWP contribution	Share of GWP contribution
GWP Production LPG	0,000440043	0,0162%
GWP Combustion LPG	0,00062271	0,0229%
GWP Consumed electrical energy	7,9843E-05	0,0029%
GWP Consumed compressed air	1,25753E-05	0,0005%