CHALMERS

LCA and Methodological Choices for Identification of Improvement Potential

Case Study Bearing Unit

Master of Science Thesis in the Master Degree Programme,

Automation and Mechatronics Engineering

BJÖRN RINDE

Department of Energy and Environment
Division of Environmental Systems Analysis
CHALMERS UNIVERSITY OF TECHNOLOGY
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Environmental Systems Analysis
Chalmers University of Technology
SE-412 96 Göteborg
Sweden
Telephone: +46 (0) 31-7721000

Abstract

The society focus on environmental issues in general and global warming in particular is constantly growing and a further improvement of the studied company's environmental performance is increasingly important. Several corporate environmental targets have been launched and to meet these, new ways to use Life Cycle Assessments (LCA) are sought. A number of LCA's have been performed within the studied company, but with limited utilisation of the results. This may be due to a lack of result credibility caused by diversified methodological choices and a want for recommendations on result use.

In this study an LCA of a specific bearing unit, not a product average, is carried out to increase the knowledge of the product environmental performance from cradle to gate. The studied bearing unit is a high volume product manufactured with materials and processes that allow for generalisation and reuse of results and conclusions within the case study company. The results are related to corporate environmental targets and ways for homogenisation of methodological choices as well as presentation of improvement potential are found.

The major potential environmental impact in the cradle to gate life cycle of the surveyed bearing unit is, for all studied impact categories, caused by the ring production including upstream processes. Steel production is the activity category with dominant contribution to potential environmental impact. When further surveyed it is shown that energy use for steel production is the major contributor to environmental impact. For similar products where average electricity mix is used for in-house processes, the environmental impact from in-house processes is significant as well.

To decrease the sensitivity for choice of allocation methods, environmentally relevant flows should be quantified on channel, rather than facility level. The preferred allocation methods for bearing manufacturing in a system similar to the one surveyed here should be number of pieces and processing time, and not mass as generally used in earlier studies at the company. For channel energy use, further increased system detail by measurement of machine power use for process statuses and calculation of energy use from cycle time data gives a substantial mismatch compared to measurement of energy use on channel level. This methodology is though rewarding when improvement of manufacturing channel energy efficiency is of interest.

It is indicated that the highest improvement of product cradle to gate life cycle environmental performance is achieved by reduction of energy use through reduction of steel content in the product, i.e. operational focus on product development. An improved environmental performance can also be obtained by in-house process development with a focus on energy efficiency in manufacturing, specifically when the electricity supply does not come from low-CO2 sources. For low CO2 electricity supply it shall though be considered that a reduction of energy use will be beneficial from a global perspective, as energy from renewable resources will be made available for other energy users.

Increased added value of LCA's within the studied company can be realised by a homogenisation of methodological choices for LCA's. To ensure that performed studies result in a knowledge build-up, it would be valuable to document studies in a standardised way, and develop guidelines for methodological choices for performing LCA's. The credibility and usability of LCA results can be increased by including factors that have been left out in previous studies. It is also crucial to update and validate datasets with dominant impact on the results, such as electricity mixes and steel production.

Sammanfattning

Uppmärksamheten kring miljöfrågor i allmänhet och global uppvärmning i synnerhet växer konstant. Som reaktion på detta har det studerade företaget fört fram ett flertal miljömål och man letar nu efter nya vägar att tillämpa livscykelanalys (LCA) för att möta dessa mål. Ett flertal LCA:er har genomförts på företaget, men användningen av resultaten har varit begränsad. Anledningen till detta kan härröras till bristande förtroende för resultaten till följd av oklara och skiftande metodval, samt frånvaron av rekommendationer för hur resultaten kan användas i förbättringsarbetet.

I denna rapport kommer en LCA att utföras för en specifik lagerenhet, inte för ett produktgenomsnitt, med målet att öka kunskapen om produktens miljöprestanda från vaggan till grinden, d.v.s. från resursutvinning fram till att den färdiga produkten lämnar fabriken. Den studerade produkten är en högvolymprodukt som tillverkas med material och tillverkningsmetoder som öppnar upp för generalisering och återanvändning av resultaten inom det undersökta företaget. Resultaten kommer att relateras till miljömål på koncernnivå. Förslag på hur metodikval för LCA kan homogeniseras inom företaget förs fram liksom alternativ för hur förbättringspotential kan presenteras på bästa sätt.

Den största potentiella miljöpåverkan från lagerenhetens livscykel, från vaggan till grinden, orsakas för de undersökta påverkanskategorierna av produktionen av ringar inklusive uppströms processer, där stålproduktion är den mest bidragande aktivitetskategorin. Vidare visas det att energianvändning för stålproduktion är den dominerande bidragaren till miljöpåverkan. För produktion av liknande produkter i ett system där nationell genomsnittselektricitet används kommer de interna produktionsprocesserna också att stå för en avsevärd del av miljöpåverkan.

En minskad känslighet for val av allokeringsmetod uppnås genom att flöden kvantifieras på kanalnivå framför fabriksnivå när så är möjligt. De prioriterade allokeringsmetoderna för ett lagerproduktionssystem som det här modellerade bör vara producerade enheter och cykeltid, inte massa som generellt använts i tidigare studier inom företaget. Ökad detaljnivå för energianvändning på kanalnivå genom mätning av effekt på maskinnivå per produktionsstatus och beräkning av total energianvändning med hjälp av cykeltidsdata ger en avsevärd felmarginal. Denna metod är dock lämplig när förbättring av energieffektiviteten i en produktionskanal är av intresse.

Resultaten antyder att en maximal förbättring av produktens miljöprestanda från vaggan till grinden uppnås genom minskad energianvändning för stålproduktion. Detta bör ske genom minskad mängd stål i produkten vilket innebär fokus på produktutveckling. När nationell genomsnittselektricitet används är även processutveckling av stor vikt för att öka energieffektiviteten i interna produktionsprocesser. Det bör dock observeras att minskad energianvändning när energikällor med låg koldioxidintensitet används innebär att energi från förnyelsebara källor globalt frigörs för användning av andra aktörer.

En ökad nytta av LCA:er inom företaget kan uppnås genom en homogenisering av metodikval. Kunskapsuppbyggnad kan säkerställas genom standardiserad dokumentation av tidigare studier och utveckling av riktlinjer för metodikval vid LCA:er. För att vidare öka användbarhet och förtroende för resultaten bör omfattningen av kommande studier utökas och innefatta faktorer som tidigare har utelämnats. Det är också nödvändigt att validera och se över data som har dominerande påverkan på resultaten.

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Thanks also to my examiner, Professor Anne-Marie Tillman, for helping me to stay on track and carrying out a limited review of my work.

I also want to express my appreciation for all help from SKF in general and personnel from Manufacturing Development Centre and the surveyed facility in particular.

The LCA modelling was carried out using GaBi4 software and data base for Life Cycle Engineering, PE INTERNATIONAL GmbH and LBP University of Stuttgart, January 2007 (GaBi4).

I also want to give my thanks to Dionysios Logaras, with whom I carried out much of the data collection, as our theses have many intersecting areas. His work can be found in the M.Sc. Thesis *Life cycle inventory data collection for first tier suppliers: a case study of a bearing unit* (Logaras, 2008).

Björn Rinde

Göteborg, September 2008.

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1 Introduction

In this first chapter a background for the performed study will be given. Furthermore the overarching purpose and goal of the study will be stated.

1.1 Background

The discussions in the world society on the importance of environmental awareness have been accelerating substantially the last years, mainly as a result of statements about the relation between global warming and human activities (IPCC, 2008).

Even though SKF have been showing a keen interest in environmental issues for many years, the drive has been constantly increasing the last years. Several new programmes have been launched, with a primary focus on global warming issues, to meet the expectations from both society and customers (SKF, 2008b). In order to be a manufacturing company with outstanding environmental performance new initiatives must be taken in order to manage these concerns proactively. There must be a focus on the causes before the actual problem has emerged rather than a retrospective focus on treatment of the symptoms, a so called end of pipe approach. Among the incentives for commitment to these issues we have the competitive advantage that can be achieved and the importance of being prepared for legislative changes.

To manage these concerns, the environmental improvement potentials must be found, ways to utilise these potentials must be found, and it must be shown that impact has been reduced. The reliability of the tools and their usability is a prerequisite for the integration of environmental issues into decision making throughout the organisation.

Life Cycle Assessment (LCA) is one of the most recognised methods to perform environmental assessment. However, critique against LCA is often based on the possibility to achieve significantly different results for the same system by using different methodological choices (Baumann and Tillman, 2004). In order to increase result confidence, it is important to develop tools which help keeping the modelling within a well defined framework regarding e.g. system boundaries and allocation. It is also crucial to find the correct level of detail for the data collection to maximise the efficiency in use of resources.

An LCA of a SKF bearing carried out in 2001 (Ekdahl) was given much internal attention and raised the awareness of LCA methodology and the potentials of it. It was, among other things, concluded that the main sources of carbon dioxide emissions associated with SKF operations resulted from energy use and that the major part of these emissions were generated by energy suppliers (SKF, 2002). Since then a number of LCA's have been carried out within SKF but the use of the results has been limited. One reason for this may be a lack of confidence in results since all studies use different methodological choices, e.g. system boundaries and assumptions, without relation to earlier studies. Hence, it is crucial to go towards a standardised process for LCA's within SKF and to find straightforward and ways to communicate the results.

As a step to increase credibility and usability of environmental parameters in decision making, SKF specifically seeks ways to integrate LCA with discrete event simulation (DES) methodologies. The purpose is to find ways to optimise process parameters as well as environmental and economic parameters. As a part of work on these issues, this M.Sc. thesis was initiated. The input data needed for the efforts to integrate LCA and DES methodologies is only related to a cradle to gate life cycle scenario. Hence, this is one of the reasons for modelling the life cycle on a cradle to gate basis.

Furthermore, SKF commits to report CO2 emissions including the third scope (SKF, 2008a) according to Greenhouse Gas Protocol (2008), i.e. emissions from all activities related to the product are included. This induces a need to increase the knowledge about environmental impact from upstream processes. A reporting tool is being developed and is implemented for major direct suppliers, but a lot of work must still be done to find ways to map the entire supplier network from an environmental point of view. To increase the credibility of the results, the use of well known methodologies such as LCA may be a desirable way to go, which further increases the importance of well established processes to performance of LCA's within SKF.

This report is an official report that has been reviewed for confidentiality, but a complete report is available for internal use at SKF.

1.2 Purpose

The overarching purpose of this study is to carry out an LCA for a specific SKF bearing unit. From the LCA results potentials for improvement of the environmental performance of the assessed product, and similar products, will be found. Based on the LCA, methods for performing LCA's and communicating results in the SKF organisation will be evaluated.

The questions to be answered by the LCA are further defined in the goal definition (Section 5.1).

2 System information

In this chapter the studied company and product will be described.

2.1 SKF

It is now over a century since the Swedish engineer Sven Wingquist in 1907 sketched the first self-aligning ball bearing and as the product became a commercial reality, SKF was founded the same year. Since then, the SKF business has grown from 15 employees in Gothenburg, Sweden, to a truly multinational business with 120 manufacturing facilities in 24 countries, representatives in 140 countries and over 41 000 employees.

SKF's vision is "*To equip the world with SKF knowledge*" and in their web site they state; "*The SKF Group is one of the leading global suppliers of products, solutions and services in the area comprising rolling bearings, seals, mechatronics, services and lubrication systems. The Group's service offer also includes technical support, maintenance services, condition monitoring and training.*" (SKF, 2008b)

The SKF business is organised in three divisions; Industrial, Automotive, and Service.

2.2 SKF and Environmental Initiatives

In their marketing SKF call attention to their environmental awareness and one of five drivers is sustainability. The Group is globally certified according to the ISO 14001 environmental standard and the OHSAS 18001 health and safety standard. Lately SKF have launched two ambitious environmental programmes. These are;

- "*Target to reduce carbon dioxide*"
  A target that commits SKF to an annual reduction of carbon dioxide emissions by 5 % irrespective to any changes in production volume.
- "*BeyondZero*™"
  An initiative that aim at eliminating negative environmental impact by comparing the negative impact of producing a product to the benefit of using it, i.e. the benefit of using an SKF product instead of a corresponding product from a competitor.

Furthermore, SKF have committed to work towards reporting and acting "*on as complete a reflection of its global warming impact as is practically possible*". This will be done by expanding the CO2 reporting by adding scope 3 emissions, according to the Greenhouse Gas reporting protocol, published by the World Business Council for Sustainable Development and the World Resource Institute. (SKF, 2008a)

2.3 SKF Bearing Unit

The SKF bearing unit that is assessed with LCA methodology in this master thesis is produced in Italy. It is an assembly of the components and raw material shown in Table 1. The assembly is a sealed unit and does not require any maintenance during its lifetime. An example of a bearing unit is shown in Figure 1.

Component	No. of pieces	Total mass [%]
Bearing Unit	1	100 %
Outer ring (OR)	1	28.1 %
Inner ring (IR)	1	51.8 %
Small inner ring (ID-1)	1	5.4 %
Steel balls	26	5.4 %
Cages	2	0.2 %
Seals	2	0.9 %
Encoder	1	0.7 %
Studs	5	6.9 %
Grease	n/a	0.4 %
ABS sensor	1	1.6 %
Packaging material	n/a	11.7 %

Table 1 - Mass of product parts[1]

Figure 1 – An SKF bearing unit, not the studied product version (SKF, 2008b)

[1] There is a mass mismatch between product mass and the total mass of components and materials that presumably can be derived to use of not fully updated drawings when extracting mass data for this study. The impact on the result from this mismatch is assumed to be negligible.

3 Theoretical Framework

In this chapter the theoretical framework encompassing areas related to this study will be outlined and described.

3.1 Life Cycle Assessment

This summary of the theoretical framework for the LCA methodology is based on Baumann and Tillman (2004) wherever nothing else is stated.

In order to turn the consumer society of today into a more environmentally sustainable direction, comprehensive methods to assess environmental impact from products and services are necessary. The overall framework for environmental systems analysis describes the social, technical and natural systems.

The LCA methodology comprises the whole industrial system involved in production as well as use and waste management. In LCA the product is followed from cradle to grave, i.e. from where the raw materials are extracted to manufacturing, use and end of life. All natural resource use and pollutant emissions are quantified along the way and related to a unit describing the function of the product or service, the so called functional unit. The main steps in the methodology are goal and scope definition, inventory analysis and impact assessment as shown in Figure 2. All these steps are interpretative and iterative. In the goal and scope definition, the product to study and the purpose of study are decided. Thereafter the inventory analysis is carried out, during which the life cycle model is constructed and emissions and resource use are calculated, which means a focus on the technical system. In the impact assessment step, which is further described in Figure 4, the results from the inventory analysis are related to potential environmental consequences through classification and characterisation; i.e. the changes caused in the natural system by the technical system are modelled. The following, voluntary step, is weighting. This means that the environmental impacts are put on the same scale according to the extent to which the social system perceives the changes of the natural system as environmental problems.

In the international standard for LCA (ISO 14040, 1997) the listed application areas for the method are; identification of improvement possibilities, decision making, choice of environmental performance indicators and market claims. But the method is also valuable to map the environmental properties of the system encompassing a product life cycle and learn more about the relationships of the production system (Baumann, 1998).

The main criticism of LCA refers to the fact that diversified methodological choices can result in diversified results for the same system. It has been put forward that LCA's should not be used for promoting purposes until uniform methods have been developed. Even though the international standard (ISO 14040, 1997) gives guidelines, the choices to make are many, which means that variance in results still is an important topic in discussions about the reliability of the methodology.

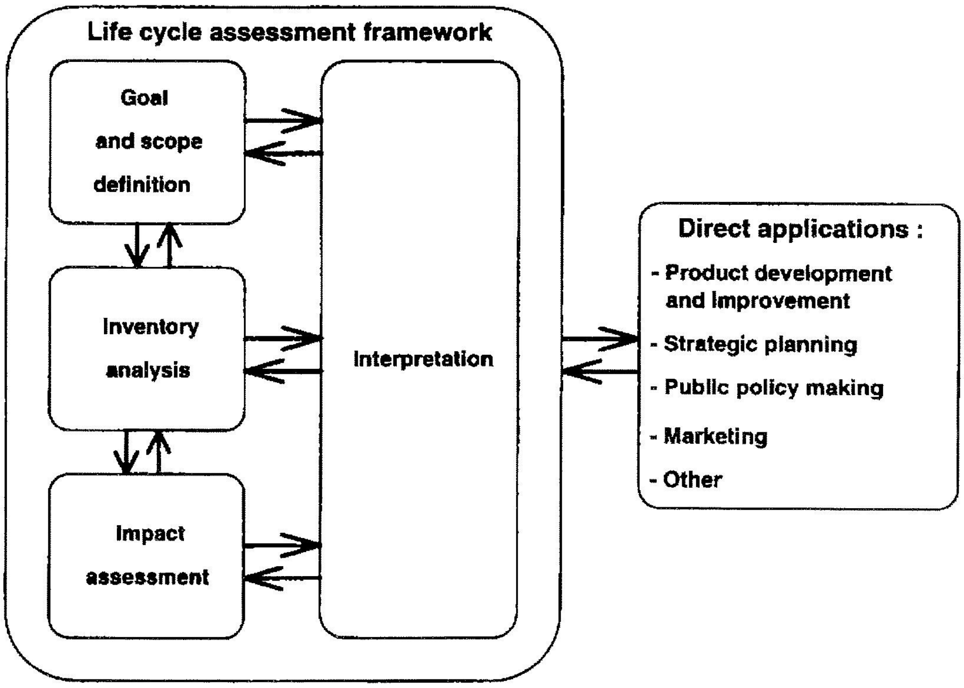

Figure 2 - The LCA Framework (ISO 14040, 1997)

3.1.1 Goal and Scope Definition

In the goal and scope definition the studied product is defined and the purpose of the study is decided. The ISO standard (ISO 14040, 1997) stresses the importance of a clearly stated goal and scope that is thoroughly consistent with the intended application.

3.1.1.1 Goal

In the goal definition the goal and context of the study is outlined. The intended application of the study is stated together with the reason for carrying it out. It shall also be stated who is the intended audience for communication of the results. It is important that the purpose of the study is very well defined with specific questions in order for the correct methodological choices to be made.

3.1.1.2 Scope

The scope and consequently the modelling requirements are based on the goal of the study. The steps to take and methodological choices to make in the scope definition can be summarised in the following points;

- *Options to model*
  Definition of the specific products, designs or process options that are to be surveyed, for example whether a specific product should be modelled or a product group average.
- *System overview flowchart*
  The construction of a general flowchart of the system to be studied to gain a better overview of the system.

- *Functional unit*
  A crucial step that refers to the definition of the flow to which all other modelled flows are to be related. The results can only be related to one specific flow, the functional unit.

- *Impact categories and method for impact assessment*
  It is a necessity in LCA to consider which environmental impacts to take into account. The impact categories listed on a more general level in the ISO standard (ISO 14040, 1997) are resource use, ecological consequences and human health. These must then be translated to more applicable categories such as global warming potential, acidification potential, and resource depletion. Lists of categories like these can be found in ready-made life cycle impact assessment methods that go all the way to weighting.

- *Type of LCA*
  The goal definition will give the background for the methodological choices, and if stand-alone LCA's are left out, the two main types of LCA are generally agreed to be the accounting, or attributional, and the change-oriented, or consequential. The former aims at mapping an existing system, whereas the latter is used when comparing the environmental consequences of changes in a system.

- *System boundaries, in relation to;*

  - *Natural systems*
    Where is the grave and cradle of the product? I.e. where is the raw material extracted and when is the used product deposited? When a flow leaves or enters human control, it also leaves or enters the technical system, and thus it will enter or leave the natural system. The boundary between technical and natural system also represents the boundary between inventory analysis and impact assessment.

  - *Geographical boundaries*
    Where do the production, use and waste treatment of the product take place? Normally different parts of the life cycle take place in different parts of the world and this means differing background systems such as electricity production, waste treatment, etc. Furthermore the sensitivity of the environment is different in different regions.

  - *Time horizon*
    Generally change-oriented LCA's are prospective and accounting LCA's retrospective. Considering for example the use phase for prospective studies, should data for this phase be based on assumptions or should actual present data be used? These choices must be made and explicitly stated depending of the approach of the study.

  - *Production capital, personnel, etc.*
    Buildings, machinery, vehicles, etc, used to produced the studied product are called capital goods. In the case of accounting LCA's the general thought is that the study should be as complete as possible, but production of capital goods is rarely included in LCA's in order to keep the amount of data feasible (Baumann and Tillman, 2004). Maintenance is normally excluded, as the impact seems to be negligible related to the total impact (Rehnström and Månsson, 2004). For buildings, the impact from heating and electricity during the use

phase seems to give non-negligible impact (Li, 2006) and should thus be included if feasible. For change-oriented LCA's capital goods should not be included as long as it is not affected by the change. Cut-off criteria should also be defined regarding both negligible parts of the life cycle and whether the system will be modelled from cradle to gate or if the use phase will be left out in a so called cradle to gate study.

  - *Other products' life cycles and allocation*
    In many cases a number of products share the same processes which results in an allocation problem, i.e. a problem regarding how much of resource use and emissions that should be related to the functional unit. Allocation problems are faced in the three basic cases multi-output, multi-input, and open loop recycling. To manage these problems the ISO standard (ISO 14041, 1998) prescribes that allocation should be avoided through increased level of model detail or system expansion. If that cannot be done, partitioning of environmental loads should be made based on physical causality, and if such relationships can not be established, other relationships between the products should be used as base for allocation, e.g. economical measures. The requirements for Environmental Product Declarations state that allocation should be based on physical causal relationships as far as possible (Swedish Environmental Management Council, 2000).

  - *Division into foreground and background system*
    When studies with a change oriented approach are carried out, it can be useful to divide the modelled system into fore- and background systems. The foreground system here refers to the parts of the modelled system that are under direct influence of the decision maker.

- *Data quality requirements*
  The quality of used data has a substantial impact on the results of an LCA and therefore it is essential to clearly state which level of quality that is dictated by the goal of the study. Increased ambitions for data quality will lead to an increased workload but also to increased reliability. The aspects of data quality listed in the ISO standard (ISO 14041, 1998) are relevance, reliability and accessibility. Relevance concerns the extent to which data represents what it is supposed to represent, whilst reliability describes numerical accuracy and uncertainty. Accessibility encompasses the reproducibility of data and whether it has been collected and documented in a consistent way.

- *Assumptions and limitations of the study*
  Major assumptions should be clearly stated in the goal and scope definition. Regarding for example assumptions in choice of specific data sets, these choices can be stated elsewhere. Limitations that are the result of scope definitions, for example on geographical areas, must be referred to. Limitations can also come up later as a result of for example difficulties to acquire specific data.

- *Reporting*
  According to the ISO standard (ISO 14040, 1997) the goal and scope definition shall contain a specification on the type and format of the report.

- *Critical review*
  The choice on whether or not to carry out a critical review of the study should mainly based on the intended audience and use of the study. If the study is to be public and used for comparative assertion, a critical review shall be carried out. Critical reviews can be of the main types; mandatory ISO review or review of Environmental Product Declaration (EPD). Also the optional internal and external expert reviews are mentioned in the ISO standard (ISO 14040, 1997).

3.1.2 Life Cycle Inventory

In the Life Cycle Inventory, the surveyed system is modelled and emissions and resource use are quantified.

3.1.2.1 Data Collection Requirements

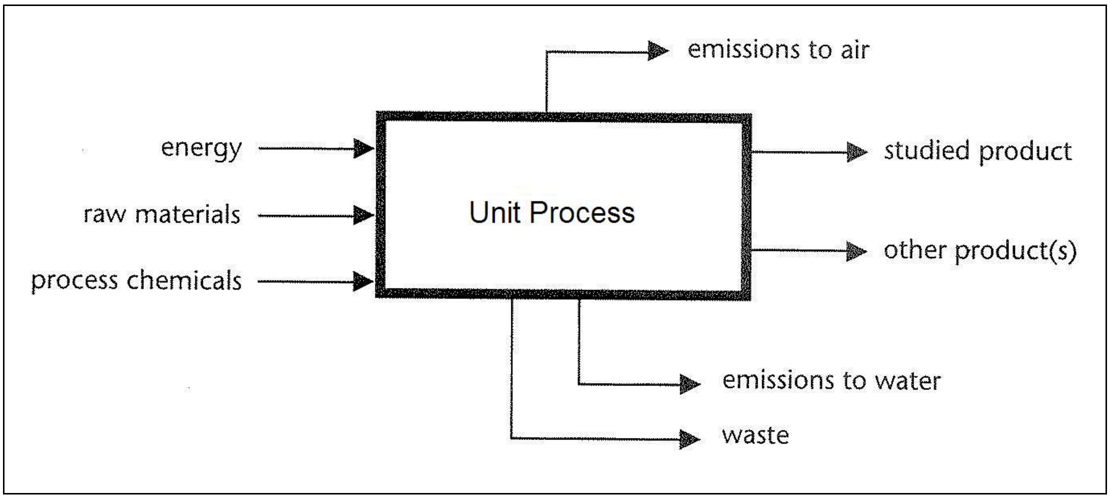

Figure 3 - LCA Unit Process (adopted from Baumann and Tillman, 2004)

During data collection data is collected to cover all in- and outflows from the concerned processes, with exception of the flows or groups of flows that explicitly have been excluded in the goal and scope definition. A unit process is the smallest unit for which in- and outflows are quantified during data collection, and these flows are aggregated into inventory results.

3.1.3 Life Cycle Impact Assessment

In the Life Cycle Impact Assessment (LCIA) the changes caused in the natural system by the technical system are modelled. The steps performed are classification and characterisation, where inventory results are related to potential environmental consequences, and weighting. In the weighting, which is voluntary according to ISO standard, the environmental impact is put on a common scale according to the extent to which the social system perceives the changes in the natural system as environmental problems.

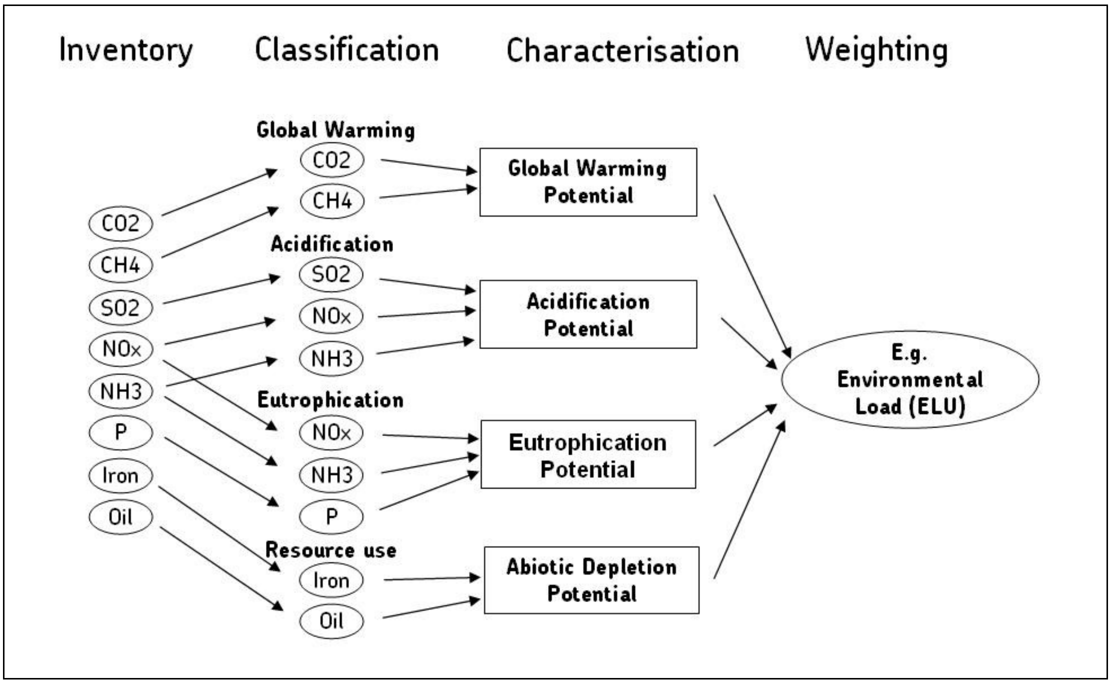

Figure 4 - LCIA methodology

3.1.3.1 Classification

In the classification step the flows listed in the LCI are grouped and a relation is stated to the different impact categories, i.e. this is a qualitative step. This is normally done using published lists where the specific substances are listed per impact category. In some cases a substance can be assigned to several impact categories and if so is done care must be taken to avoid double counting. The use of one substance in more then one impact category can only be done if the effects are independent of each other.

3.1.3.2 Characterisation

Characterisation is a quantitative step where the substances in each impact category, as described in the previous paragraph, are calculated as equivalents of the concerned impact category. E.g. for the impact category global warming potential (GWP), each substance in the category is multiplied by, what in ISO terminology is called a category indicator, to sum up the total carbon dioxide equivalency number. The characterisation methods now existing are well developed for impact categories where the underlying mechanisms are well known, as for acidification, whilst some others are less mature due to more complicated mechanisms, as for eco-toxicity.

Different category indicators are issued as a part of ready-made LCIA packages. These indicators are based on the same underlying mechanisms, but the actual factors used in the calculation might differ. This difference can be both due to unclear mechanism and use of different common denominators; in for example eutrophication the common denominator can be for example nitrogen or phosphate. Due to this it is valuable to compare the results that are obtained from a couple of different LCIA packages, even though weighting is not carried out, in order to find out if the results differ.

3.1.3.3 Weighting

In the weighting procedure, the impact categories are put on the same scale using weighting factors. These weighting factors are based on mainly social sciences, and since these involve ethical and ideological values, it will always be debated what is subjective and objective, and consequently whether it is scientifically correct to use weighting factors. To somewhat reduce the problems induced by this, it is according to ISO standard (ISO 14042, 2000) desirable to several different weighting factors and methods.

3.1.3.4 Ready-made LCIA Methods

Several ready-made LCIA methods exist and these are based on differing classifications, category indicators and weighting valuation preferences.

A number of different LCIA methods should be compared in the presentation of the results, as the findings might differ due to differences in the methods. The category indicators might differ, especially for categories with less well known mechanisms, and above all the values, predominantly social, that the weighting factors are based on are different for different methods which can result in major differences in weighting results.

The below listed methods are presented here as they are used in this study to evaluate the robustness of characterisation results.

- *MSR1999:2, Requirements for Environmental Product Declarations, EPD*
  This readymade LCIA method is a part of the complete guidelines for EPD that have been developed by the Swedish Environmental Council (2000). Using this method, the results are presented as environmental resource use, waste generation and emissions in the impact categories; global warming potential, ozone depletion potential, acidifying compounds, photochemical ozone creation potentials, and eutrophicating compounds
- *CML 2001*
  The CML method has been developed by the Centre of Environmental Science at Leiden University in the Netherlands. The extensive list of characterisation factors is compiled from the characterisation methods that were found to be the best available in an extensive review (Guinée, 2002).
- *EDIP 2003*
  This method was developed to be applied in product development. The used impact categories are; global warming, ozone depletion, acidification, eutrophication, waste, and persistent-, eco-, and human toxicity. The weighting is done for three different categories that are based on varying backgrounds. Danish political targets are used for environmental impact, and for resources the weighting is based on the relation between consumption and regeneration of reserves. The third category is working environment and here the evaluation is based on the probability of work injury and Danish statistics.

3.1.3.5 Other LCIA Procedural Steps

Except for the LCIA steps mentioned in the previous paragraphs, one can also carry out normalisation and grouping before the weighting.

The normalisation is carried when the results from the characterisation are hard to relate to their actual impact on the natural system. In order to achieve a better understanding of the results they are then put in relation to the total impact of the concerned category in a region or country. This will probably not be very meaningful if the comparison is made between functional unit and the total impact in the region, but more so if the comparison is made relating the total impact of the total use of the product to the total impact in the region.

The grouping aims at increasing the usefulness of the results for analysis and presentation and is mentioned in the context of LCIA in the ISO standard. This step consists of a sorting of characterisation results into different sets, which can be for example impacts on a global, regional, and local level, or impacts with a high, medium, and low level.

3.1.4 Interpretation

The interpretation phase in LCA aims at drawing conclusions by assessing the results as well as evaluating the robustness of the drawn conclusions. In the interpretation process, the results from one or both of LCI and LCIA results are combined with the goal and scope definitions to reach conclusions and recommendations (ISO 14040, 1997). The ISO standard (ISO 14043, 2000) defines the main activities of the interpretation as identification of significant issues and evaluation to establish confidence in the results.

3.1.4.1 Identification of Significant Issues

The identification of significant issues normally means finding out which activities or environmental loads that cause the major environmental impact in the life cycle by carrying out one or both of dominance and contribution analysis. A dominance analysis shows which activities in the investigated life cycle that gives the major environmental impact, thus indicating where the improvement potential is highest. A contribution analysis is very much the same as the dominance analysis, but it will instead show which environmental loads that are the main contributors to the total environmental impact.

A decision maker analysis can also be valuable to find the extent to which the commissioner has direct influence over a specific environmental impact. The presentation can be made by for example quantitative presentation of one or more of inventory, characterisation and weighting results. The level of aggregation that is needed depends on at which level the results are conclusive.

3.1.4.2 Evaluation of Result Robustness and Data Quality Analysis

As the amount of data needed for a comprehensive LCA study is immense there will normally be a need to use approximate data. To ensure that results and conclusions are credible the robustness of the results must be surveyed; a step that is called evaluation in the ISO standard (ISO 14043, 2000). Tests that can be used to check robustness are e.g.: completeness and consistency check; uncertainty, sensitivity, and variation analysis; data quality assessment.

The completeness check is performed to find gaps in the inventory and to survey to what extent the impact assessment covers the inventory parameters. To show the completeness of the impact assessment a so called red-flag table can be used, in which flows are listed for which environmental impacts are not described.

In a data quality assessment, the degree of data gaps, approximate data and appropriate data is assessed.

In a consistency check, the adequateness of methodological choices and the used life cycle model is checked. This could for example mean an evaluation of used allocation and characterisation methods.

An uncertainty analysis evaluates how inaccurate data will influence the results. For example, if generic data show that one material is preferable, the other might be a better choice if an environmentally preferred supplier can be used. Such an analysis will though require a lot more data to be collected in order to represent both interval and distribution of the dataset.

Sensitivity analysis is another way of assessing the impact of uncertain data. In this case input parameters are systematically changed. For input parameters where a small change results in a significant change in the results the need of accurate data is highest.

3.1.4.3 Variation Analysis

Effects of alternative scenarios and life cycle models can be assessed in a variation analysis, i.e. case studies are carried out to answer specific questions. This means that parts of the life cycle model are changed to answer identified questions.

3.2 Energy Use Data Collection for Manufacturing Processes

Energy use in manufacturing is often an important contributor to environmental impact and thus the quality of this data is of essence. Regarding collection of data for energy use in production facilities for LCA, no studies with a highly extended system detail level have been found. The use of high system detail level for modelling of in-house systems in a bearing production system may though be questioned as the added value of this will be minor if the steel production is the major energy user (Berg and Häggström, 2002; Ekdahl, 2001). This is also the general situation for manufactured products, i.e. that the production of the materials often dominates the environmental impact, while the assembly only causes a small proportion of these (Baumann and Tillman, 2004).

3.2.1 Energy Use Categories

When modelling manufacturing processes, one generally seeks to develop a model with the minimum amount of data required to achieve a, for the intended purpose, valid model. To achieve this, the modelling of energy use must be made with a proper level of detail, and to do this it is needed to categorise the operations that use energy as well as clearly state the purpose of the model.

Many different methods for allocation of energy use to a product from the overall energy have been used in previous studies. These methods span from allocating overall electricity use by mass, to use of installed power allocated using processing times. The energy categorisation for different types of processes and the resulting system detail level or allocation method has varied. A few different methods are discussed below.

A processing step in a modern manufacturing process does normally include a variety of functions in addition to the basic function of the machine tool. These can for example be; work handling, lubrication, chip removal, tool change, break detection, etc., and these functions can often dominate the energy requirements, especially at low production rates (Gutowski et al, 2006). Furthermore, the energy requirement for start-up and maintaining waiting-mode is generally significant and consequently, the support features rather than the actual mechanism often dominates the electrical energy requirement.

Gutowski (2006) defines $P = P_0 + kv'$, where P is the *total power*, and the *idle power* P_0 is the effect needed for the equipment features required to support the process, *constant* k is related to the physics of the process, and *rate of processing* v'. Even though this divides energy using processes into those directly connected to the basic function and those that are not, it does not give information on how to allocate energy use in for example production of air pressure. That allocation is necessary to be able to assign the correct amount of energy use to the studied product, as well as to find improvement potential.

In a paper on energy use in Swedish plants (Trygg and Karlsson, 2005) the energy use is divided into *production processes*, which are used for producing processes, and *support processes* that are supportive of the production. Production processes consist of processes directly related to the production. In support processes we have for example lighting, ventilation, compressed air, pumping, facility heating, and hot tap water. With this division the problem is that the use of energy and consumables, e.g. process fluids, of many of the support processes are in fact directly dependent of the production even though the production of these supportive functions is central, as for e.g. compressed air. This raises problems with how to allocate the used energy to the different production processes, which is needed in order to find improvement potentials.

In a project on discrete-event simulation of energy intensive production systems (Solding and Petku, 2005), the energy parameters are divided into *overhead, direct,* and *indirect*, but in further work on the same project (Solding and Thollander, 2006) this division has been discarded for the use of a modified version of Trygg and Karlsson's (2001) terminology. Here a subgroup of the support processes has been created to manage the issue of process dependent support processes and support processes that are more similar to overhead processes, with more or less constant energy use such as transformers and pumps. The support processes that have a direct connection to the production process can then be modelled as dynamic, i.e. they can be connected to products; while support processes with variations that cannot be readily associated to a production process can be modelled as continuous flows. This is a new approach since previously the non-producing support processes has been, if included at all, included as a yearly cost (Solding and Thollander, 2006).

3.2.2 Energy Breakdown Method

As described above, the support processes are normally used as an overhead energy use that is allocated by mass, processing time, etc. It is though desirable to, as far possible, increase the system detail to avoid allocation (Baumann and Tillman, 2004). The energy breakdown method that has been introduced at SKF will give opportunities to do this. Using this method, energy use is measured for each machine in operation modes, regarding both electricity and other energy carriers such as process fluids and compressed air, and divided by the time in each operation mode. For fluids and air, the so called system specific power is calculated in order to show the electric power needed to produce one unit of flow. These process energy statuses are here defined as running, waiting and non-manned. Running is when the machine is constantly working with a sufficient inflow of work-pieces, and without subsequent obstructions that interfere with the outflow. In the waiting status, the machine is lacking input or cannot work due to other obstructions such as forward queuing. The level of detail for cycle time data needed to apply this method is much the same as needed for dynamic flow simulation, and thus additional value can be added to each of the methods by combining them. It is though sufficient with average data for the energy mapping in LCA whilst DES requires samples to which statistical distributions can be applied.

3.2.3 Comparison of Methods

The used methods for manufacturing process energy use can be divided into four main groups:

- Allocation of measured figures from facility level, etc., of both production and support process energy by physical causalities or other method, e.g. economical.
- Allocation of production processes from machine level by use of installed power and processing time, and for support processes from factory level by use of physical causalities.
- Measuring of electrical energy use on machine or motor level, allocation as above.
- Measuring of electrical power on machine or motor level, and flows on machine and factory level. Support system electrical energy use allocated using machine flows. Flows and power on machine level allocated by actual time in operation modes.

Except for above-mentioned methods, the energy use could be allocated by use of theoretical calculations on for example chip removal energy (Gutowski et al, 2006). This would indeed give an allocation well based in theory, but for situations where in-house energy use causes a minor part of the environmental impact, the added value of such calculations might be minor. For material removing machining in bearing production operations, the energy related to the actual removing of material has also proven to be minor compared to the energy used for other sub-processes in the machine (Löfgren, 2007).

4 Practical Procedure

In this chapter the practical procedure applied to carry out the survey is described.

After putting together a project plan, goal and scope according to LCA methodology was stated and an initial process overview flowchart was put together, using data acquired at site and by telephone and e-mail from personnel at the manufacturing site. Initial theoretical studies were also carried out, encompassing aspects relevant for the overarching context of the study, such as deeper studies of LCA methodology as well as existing studies of similar systems.

The method for this survey was to start wide, including as many processes and suppliers as possible and as we work put the focus on increasing the level of detail and data quality for those that, in the initial studies, showed to have a major contribution to the environmental impact.

4.1 Data Collection

The data collection was carried out at varying levels of detail. The highest level of detail was used for in-house processes, where machine level measurements were made for electric power use and energy carrier flows, i.e. process fluids and compressed air. The lowest level of detail was used for some upstream processes, where databases datasets were used. The methodology did though stay the same with recording of in- and outflows of unit processes as shown in Figure 3.

The data collection was very much an iterative process, where high variations in the results were observed initially. As more accurate data was acquired, specifically for activities which proved to cause a high environmental impact, e.g. electricity mix and steel production, the variations decreased. Specifically it can be mentioned that it was found out that permanent meters were installed for electricity and compressed air use in the surveyed channel, and this data was therefore used for these flows instead of the machine measurements. It was shown that both methods give approximately the same result, and for finding improvement potential on machine level measurements on machine level are valuable (Löfgren, 2007).

The importance of sufficient sampling length when collecting data was shown in several cases. E.g., data for a couple of weeks was first used for channel electricity and compressed air use. When complete annual data later was acquired, it was shown that the first acquired data gave a mismatch of approximately 20 percent.

4.1.1 Collection of LCI Data from Suppliers

A total flowchart with supplier orientation rather than process orientation was also put together for the products produced in the production channel. From this flowchart, which is not shown here due to confidentiality issues, groups of components were defined and suppliers to visit for collection of site specific data were chosen with the objective to cover all types of processes. Unfortunately all selected suppliers could not be visited due to time constraints, thus database data had to be used for some of the direct suppliers as is shown in each section of the Life Cycle Inventory (Section 6). In total, site specific data was collected from suppliers representing over 60 percent of the components in the product.

For collection of data from direct suppliers of components and materials, the data collection form used by SKF to collect supplier CO2-emission data was used as a basis for developing a questionnaire for gathering information. A modified version was used, with added in- and outflows to account for environmental loads not related to energy use. Data from the direct suppliers was used to find flows of components and materials from secondary suppliers. These flows were used for scaling of datasets used in the modelling of secondary, and further upstream, supplier processes.

The suppliers, for which site-specific data was acquired with the above mentioned questionnaire, were also visited to validate the data. This proved very valuable, as many changes and improvements of figures were made. Discussions were also held with the suppliers regarding preferred allocation method, as the suppliers have a superior technical knowledge of their processes.

4.2 Modelling in GaBi Software

The surveyed system was modelled in the GaBi4 software package for Life Cycle Engineering (2007). The software encompasses datasets from several sources and tools for both modelling and impact assessment.

The model was built with the goal to keep the structure of the model and the actual system as similar as possible, of course regarding dataset representativeness, but also concerning logic in the design of the model. Examples of model design are shown in appendix D. The latter very much increases the intuitiveness of the model and makes it easier to understand as well as to reuse. The aim was also to make it easy to change the background system of the unit processes to facilitate case studies. Performed case studies and analyses using parameter variation were planned ahead in order to include parameters in adequate parts of the model.

5 Goal and Scope definition

In this section the goal and scope of the LCA is defined which will provide a framework for the limitations and aims of the LCA study.

5.1 Goal

This study will survey the system related to the SKF bearing unit and answer the following questions;

- When surveying the product lifecycle with LCA methodology from cradle to gate, which activities cause the major part of the environmental impact, specifically focusing on global warming potential?
- How shall SKF treat problems related to choice of allocation strategy?
- How can the environmental impact during the product cradle to gate life cycle be reduced by changes in in-house activities?

The intended audience is SKF employees working with product and process research and development. The commissioner is SKF Sverige AB, Manufacturing Development Centre.

5.2 Scope

In the following section the scope is stated and methodological choices are made.

5.2.1 Options to Model

The assessed product is a bearing unit produced by SKF in Italy. This study does not refer to a product average; one specific type of bearing unit is modelled. The mass of the one unit is 100 %.

The reasons for modelling the chosen bearing unit are;

- The primary suppliers are located in the relatively immediate surroundings.
- As far as known, no LCA's have been performed for this type of bearing units.
- The product is part of a high-volume product family, which will increase the potential for generalisation and future reuse of data and the report results.
- The product is produced from materials that are used in many other products, which will increase the reusability of data, as well as facilitate the reuse of existing datasets.

5.2.2 System Overview Flowchart

This flowchart (Figure 5) is used to give an overview of the directly product-related system of production processes in the cradle to gate life cycle. Consequently, all parts of the system, e.g. power generation, are not included in the flowchart. The transport activities indicated below are the ones for which data have been collected in this study. There are other transport activities in the life cycle, but these are included in the used database datasets. Flows for bearing rings, steel wire, and steel production up to treated billet are partly grouped in the figure.

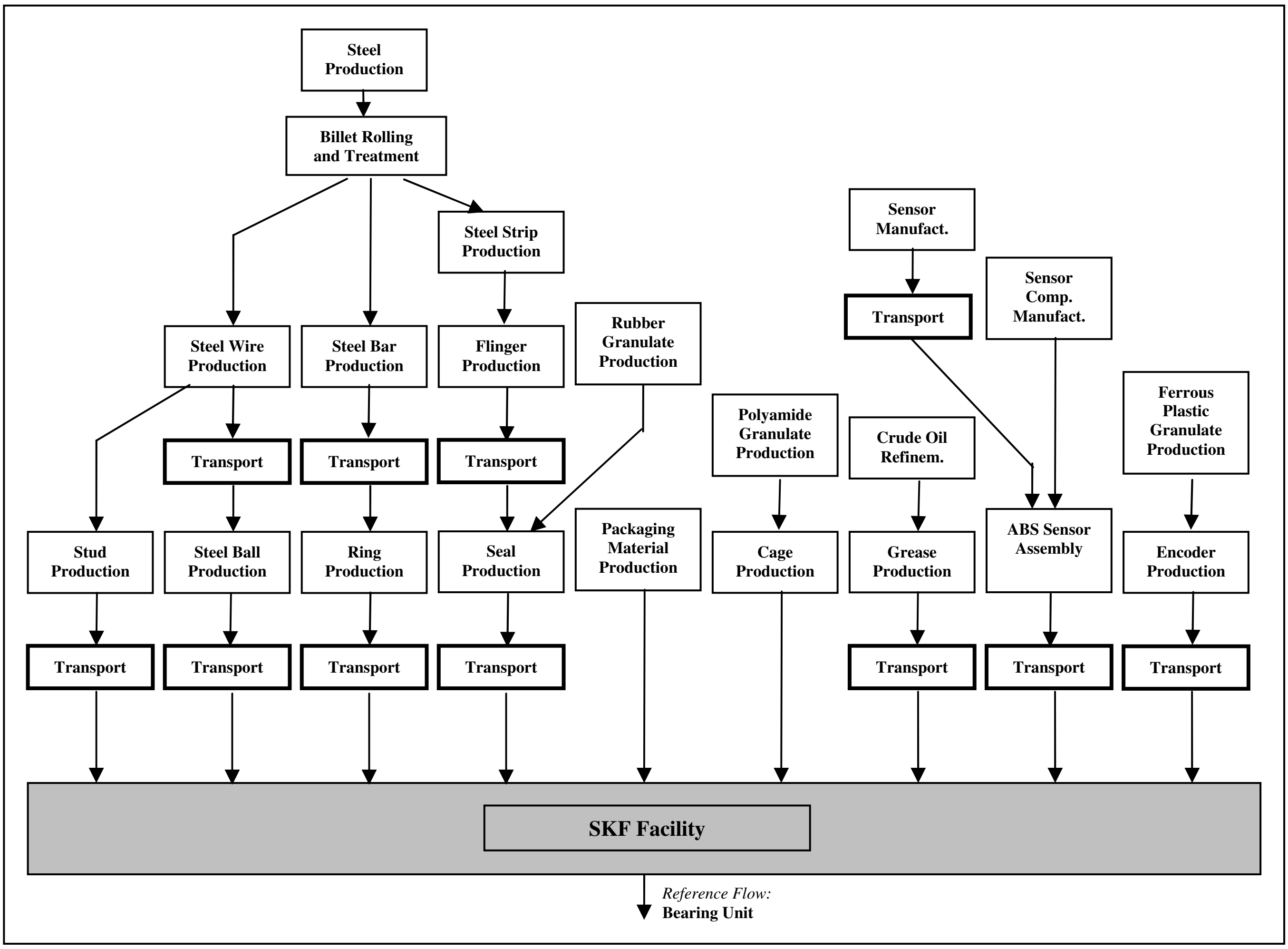

Figure 5 - Production processes for SKF bearing unit, SKF in-house system details in section 6.1

5.2.3 Functional Unit

The functional unit is one packed SKF bearing unit, leaving the manufacturing facility, packed and ready for transport to end-customer. All modelled flows are related to the functional unit unless otherwise stated.

5.2.4 Impact Categories and Method for Impact Assessment

As SKF's environmental targets stresses the importance of reduction of carbon dioxide emissions the main focus regarding impact categories is on global warming potential.

Impact assessment up till characterisation is carried out, which corresponds to ISO standardisation (ISO 14040, 2006). As a preparation for use of Environmental Product Declarations (EPD) within SKF, the characterisation method defined in the report MSR1999:2 (Swedish Environmental Management Council, 2000) is used. The categories in this method do not include resource depletion, but this is included by listing of environmental resource use and waste generation. The used impact categories are;

- *Global Warming Potential - GWP 100 years*
  Characterisation factors for green-house gases, described as Global Warming Potentials (mass basis) for the time horizon 100 years, CO2-equivalents.
- *Ozone Depletion Potential - ODP 20 years*
  Characterisation factors for ozone-depleting gases, described as semi-empirical polar ozone depletion potentials for the time horizon 20 years, CFC-11 equivalents.
- *Acidifying compounds*
  Characterization factors for acidifying compounds, described as mol H+/g, maximum. Stoichiometric formation of H+.
- *Photochemical Ozone Creation Potentials*
  Characterisation factors for gases creating ground-level ozone, described as Photochemical Ozone Creation Potentials (POCP) as ethene-equivalents.
- *Eutrophicating compounds*
  Characterisation factors for eutrophicating compounds, described as g O2/g, maximum.

Normalisation, grouping and weighting is not carried out. As normalisation in this case would describe the relation between one functional unit and the total impact in the region, this step would probably not be very meaningful (Baumann and Tillman, 2004). Weighting involves ethical and ideological values. A survey of the commissioners' preferences for decision making is not within the scope of this study, thus results from weighting is less valuable to the commissioner, i.e. SKF. Weighting does not either give any additional value in relation to SKF's carbon dioxide target, which can be explicitly addressed in the characterisation. Results of weighting will though be presented in an appendix for further analysis by the interested reader.

In order to test the robustness of the characterisation results, comparison will be made to two other LCIA methods which will be EDIP and CML 2001.

5.2.5 Type of LCA

The environmental impact of the cradle to gate life cycle of the product is investigated and the processes that cause major environmental impacts are found. As the intention of the study is to describe the environmental properties of the product cradle to gate life cycle and its sub-systems, the LCA is of accounting type, also called attributional LCA.

5.2.6 System Boundaries

In relation to the natural systems scrap as raw material for steel production is not traced to the cradle. Otherwise all flows are traced to the cradle, i.e. the extraction of raw material, except for flows listed in Appendix C, that have not been included due to the time limitations of this study. Data is acquired for waste flows, but end-of-life is not modelled for site-specific datasets. In the Life Cycle Impact Assessment total waste flows are quantified and resource depletion is taken into account as total flows. Land use is not included. Emissions to air and water are included whenever data can be acquired and calculations can be performed without increased risk of double counting. Double counting can be a problem where theoretical calculations for emissions from e.g. incineration of natural gas are made and these data are hard to tell apart from measurements for the actual emissions.

The geographical boundaries are based on the location of the activities in the product system cradle to gate life cycle. The suppliers that are visited are all located in the same geographical region as the manufacturing site. When the visited supplier is not the same as for the surveyed product, the data is reused with a background system, adapted to the actual manufacturing location for steel, power and thermal energy production.

The time horizon is dependent of the type of LCA performed, and as this one is of accounting type and the data will be retrospective. The used site specific data is mainly from 2006 to 2007 but the measured and estimated data is based on 2007 production. The used data from databases are from 1996 to 2005.

The LCA will be conducted as a cradle to gate scenario, which is decisive for the boundaries of the technical system. The gate is where the finished and packed product leaves the manufacturing facility. The product has a sealed interior which means that it cannot be disassembled, nor can maintenance be carried out. Processes that have a minor effect according to preliminary results are not prioritised during data collection, thus database datasets are used as far as possible to represent these processes. Impact from heating and electricity during building use phase is included for in-house processes and site-specific datasets for direct suppliers. Neither production nor maintenance of capital goods like machines, transport equipment, etc., are included.

The allocation strategy is to, as far as possible, increase system detail. If that is not possible the allocation is be based on physical causalities. As most of the operations within the cradle to gate life cycle of the studied system comprises material forming of different kinds, e.g. forging, moulding, cutting and abrasive machining, etc. the amount of formed material will be the basis of the allocation. The amount of formed material is in most cases directly related to the mass of the concerned component or product hence mass will be the preferred allocation method. Divergences from this strategy will be stated, and explained, in relation to the documentation of each subsystem (Appendix A). In choosing allocation method for upstream data, the issue is discussed with the suppliers in order to take advantage of their superior process knowledge.

The system is subdivided into in-house system, direct suppliers, and other suppliers. Direct suppliers are related to as tier 1 suppliers. Relating to the terminology of fore- and background systems, SKF in-house systems can be denoted foreground system and other parts of the system as background system. In this report the so called background system relates to unit processes supplying in-flows to gate-to-gate datasets, such as power generation. The processes in the foreground system are the processes that are changed in the case studies in order to find improvement potential by changing SKF in-house processes. The in-house processes are modelled at a high level of detail, as many flows as possible on either one of product and machine level, or both. The first level of upstream processes, so called tier 1 suppliers, are modelled at product category level for directly product related flows, and at facility level for auxiliary flows. Some of the tier 1 suppliers in this study are SKF operations, but treated as external suppliers in the modelling. Regarding some of the tier 1 suppliers' site-specific data will not be acquired due to time constraints. For these, and for further upstream processes, such as for example electrical energy, database datasets are used. Database data will be acquired from databases supplied with GaBi4 software (2007) as well as from SPINE@CPM (2007) and previous LCA's (Ekdahl, 2001).

5.2.7 Data Quality Requirements

Data quality requirements are highest for in-house processes, as these flows are decisive for all upstream flows. Thus site specific data is acquired for these processes. For tier 1 suppliers, site-specific data is acquired from one supplier of bearing unit components for each component group, with some exceptions as stated in the Life Cycle Inventory (Section 6). Data for the background system is taken from databases or collected from suppliers. Annual data is used as far as possible, but if not available, estimations of the annual use will be made from shorter samples. Due to resource limitations of this study a full documentation of all flows and processes according to ISO standard (ISO 14040, 2007) is not carried out. Data will be documented as collected before being used in the GaBi model. Filled out questionnaires from data collection will be preserved.

For each dataset area and time referring to the data collection of the original dataset is stated, and it is described to what extent the technique of the used dataset correspond to the actual process, using the terminology as defined in the GaBi4 software (GaBi, 2007);

- *Completely representative* - Same facility or documented standardised technique that reflects the facility where data was collected.
- *Partly representative* - Similar technologies are used, but there is no documentation stating this fact. Or; if no information about the actual processes used exists, it can be assumed that they are similar.
- *Not representative* - It is documented that the processes used are not similar/representative to the data collection. The main output product does though have a reasonable likeness with the main output from the original process.
- *No statement* - Unknown processes and no qualified assumptions can be made.

5.2.8 Assumptions and Limitations of the Study

Transportation distances are estimated using tools available in the World Wide Web (Michelin, 2007; Maporama International, 2007; World News Network, 2007; Petromedia Ltd, 2007) and means of transport are assumed; e.g. heavy truck for long distance land transportation. Transports are included with specific data for inbound transport of components and materials to in-house production. For other transports, the environmental impact is included whenever transports are included in the used datasets. Data on electricity and production of thermal energy is taken from national averages where no specific data is available. It is assumed that the production methods for production of steel bars from steel scrap have not changed substantially since Ekdahl's (2001) study. Further assumptions are described for concerned processes in the inventory analysis (Section 3.1.2). The study is limited to one specific type of bearing from the concerned channel in the production facility, as a modelling for the complete supplier network would be unmanageable in the time frame for this study.

5.2.9 Report

The report structure is based on the ISO LCA standard (ISO 14044, 1998) and the layout is based on guidelines from Chalmers University of Technology (1998).

5.2.10 Critical review

According to the ISO standard (ISO 14040, 2006) the report must be reviewed if it is to be open to the public with an intended use as a comparative assertion. This is not carried out here, but limited expert reviews (Baumann and Tillman, 2004) are carried out internally at SKF by the master thesis industrial supervisor and externally regarding solely methodology issues by Professor Anne-Marie Tillman at Chalmers University of Technology.

6 Life Cycle Inventory Analysis

In this section the Life Cycle Inventory Analysis is carried out and modelled processes are described.

The bearing unit is assembled at manufacturing facility in Italy from the parts as described in section 2.3.

The processes included in the production of each component, or material, are described below, as well as the processes performed at the manufacturing site. An overview of the major flows in the system has been presented earlier in Figure 5. Some of the flows that include similar processes have been grouped in the flowchart. The grouped flows are bearing rings, steel wire, and steel production up to treated billet.

Transports are explicitly calculated where transport processes are included in flowcharts. Transports included in datasets from databases are though not denoted in the flowcharts.

In the tables defining the used datasets, area and time refer to the data collection of the original dataset, and the column technique representativeness refers to the extent to which the used data correspond to the actual process.

6.1 Manufacturing of Bearing Unit

The bearing unit is manufactured in the facility in Italy from ten different, directly product related, incoming flows of components and materials. The components are listed in section 2.3, and the inventories for these components are described below in this section. The studied product is manufactured in a production channel together with several other types of bearing units. They are all of similar size, mass and complexity. The other products manufactured in the facility are bearing units of other generations and types, but all relatively similar regarding machining processes and complexity. The product mass and amount of removed material are both varying substantially, the mass from 8 to 134 % of the mass of the assessed bearing unit. As processes and complexity are similar but the mass and thus the amount of formed metal are varying, the product mass is chosen for allocations where the detail of modelling can not be increased. The used electricity is from sources with low carbon dioxide emissions and data for this is provided in a certificate from the supplier.

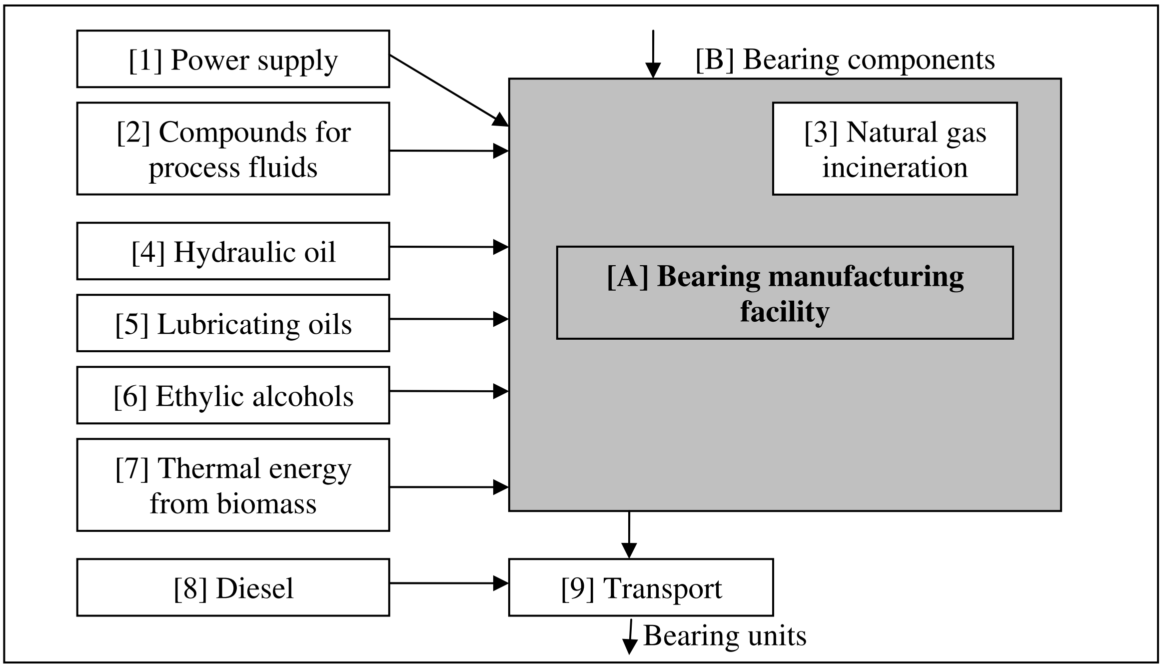

Figure 6 – Bearing unit manufacturing processes, cradle to gate; numbers refer to datasets shown below

	Dataset	Year	Database	Technique representa-tiveness
A	Bearing unit manufacturing	2007	SKF (Section 6.1.1)	Completely
B	Bearing components	n/a	n/a (See Table 1 and Figure 5)	n/a
1	Power grid mix; low CO2	2007	SKF (Appendix A.7)	Completely
2	Propylene glycol (via PO-hydrogenation)	2005	PE	Partly
2	Sodium chloride	1996	BUWAL	Partly
2	Ethylene glycol (from ethene and oxygen via EO)	2005	PE	Partly
2	Ethylene oxide (EO)	2005	PE	Partly
2	Naphtha at refinery	2003	PE	Partly
2	Lubricants at refinery	2003	PE	Partly
3	Thermal energy from natural gas	2002	PE	Completely
4	Lubricants at refinery	2003	PE	Partly
5	Lubricants at refinery	2003	PE	Partly
6	Ethanol (96%, hydrogenation with nitric acid)	2005	PE	Completely
7	Thermal energy from wood BUWAL	1996	BUWAL	Partly
8	Diesel at refinery	2003	ELCD/PE-GaBi	Completely
9	Truck-trailer > 34 – 40 total cap / 27t payload / Euro 2	2005	PE	Completely

Table 2 - Bearing manufacturing; used datasets

6.1.1 In-house Processes

General documentation for in-house processes is presented here. More thoroughly data is available in Appendix A.1.

6.1.1.1 Product Level

The system is modelled on product level for component and material inflows that are directly related to the product. These flows are calculated from required number of pieces for components, and mass for grease, including compensation for scrap rate, i.e. the number of scrapped components due to defects from suppliers and problems related to the manufacturing. The scrap rates used are channel averages.

6.1.1.2 Manufacturing Channel Level

The manufacturing process is carried out in three flows, one for each ring, and after that the parts are assembled to one unit in several steps. An overview of the processes in the channel is presented in Figure 7.

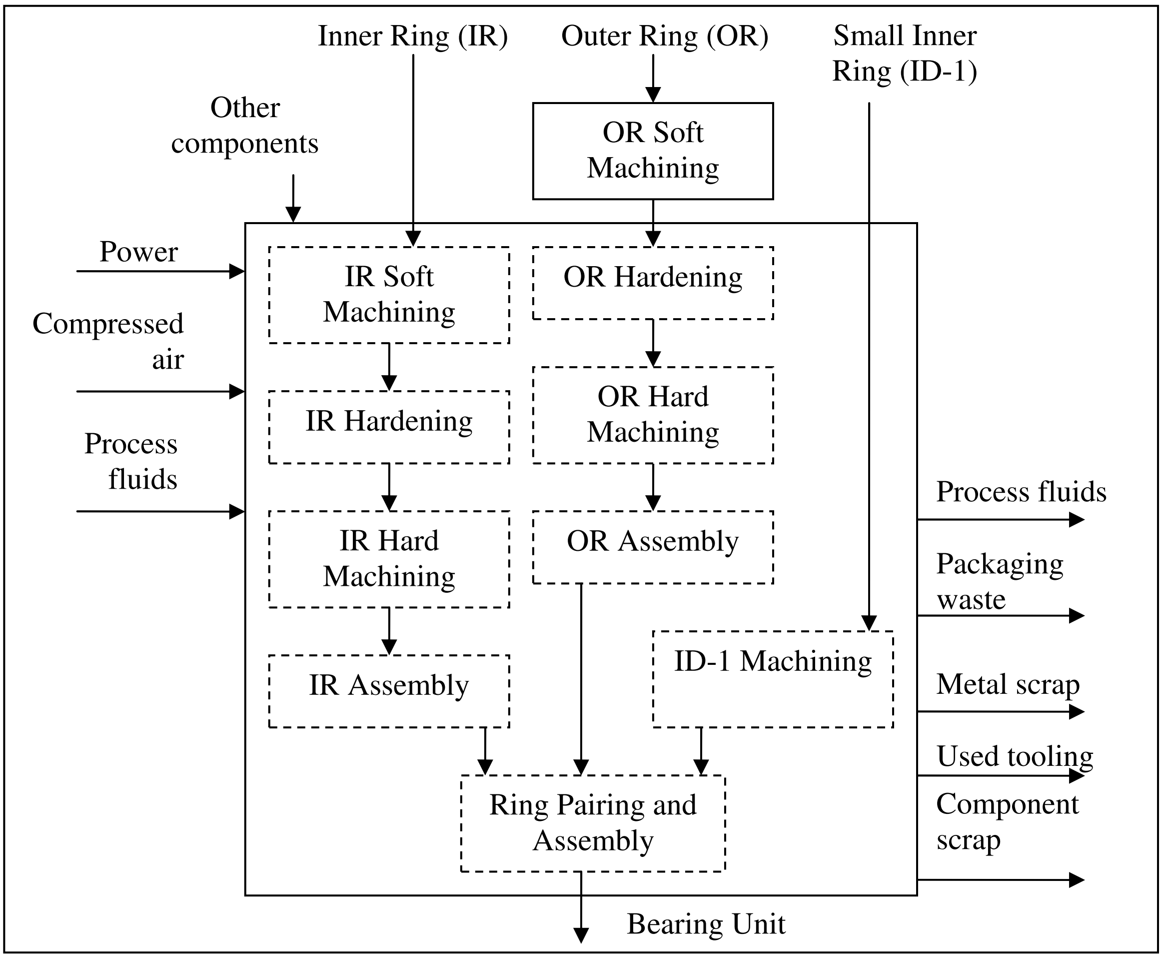

Figure 7 - Manufacturing of bearing unit, channel level (dashed rectangles represent groups of processes, not unit processes, i.e. no data collected on this level)

The inner ring (IR) flow consists of the basic steps;

- Soft machining
  - 1st phase soft machining
- Hardening
  - Induction hardening
- Hard machining
  - 2nd phase hard machining
  - Washing
  - Grinding and honing
  - Washing
- Assembly

The outer ring (OR) flow consists of the basic steps;

- Soft machining
  - 1st phase soft machining, at external company
- Hardening
  - Induction hardening
- Hard machining
  - 2nd phase machining
  - Washing
  - Grinding and honing
  - Washing

The small inner ring flow consists of the basic steps;

- Grinding and honing
- Washing

The assembly flow consists of several different machines used for assembly of the specific parts, test and inspection stations, and a packaging area where the finished product is packed and loaded in pallets for transport to a central warehouse.

Electric energy and compressed air volume is measured on channel level whilst the inflows of process fluids are measured on channel level and the inputs to these systems are allocated to channel level by proportion of the total flow. Motor cooling water is allocated to channel level by removed material.

6.1.1.3 Total Facility Level

The manufacturing channel is supported by various systems that are either directly production related, such as process fluids, or common functions, such as office areas.

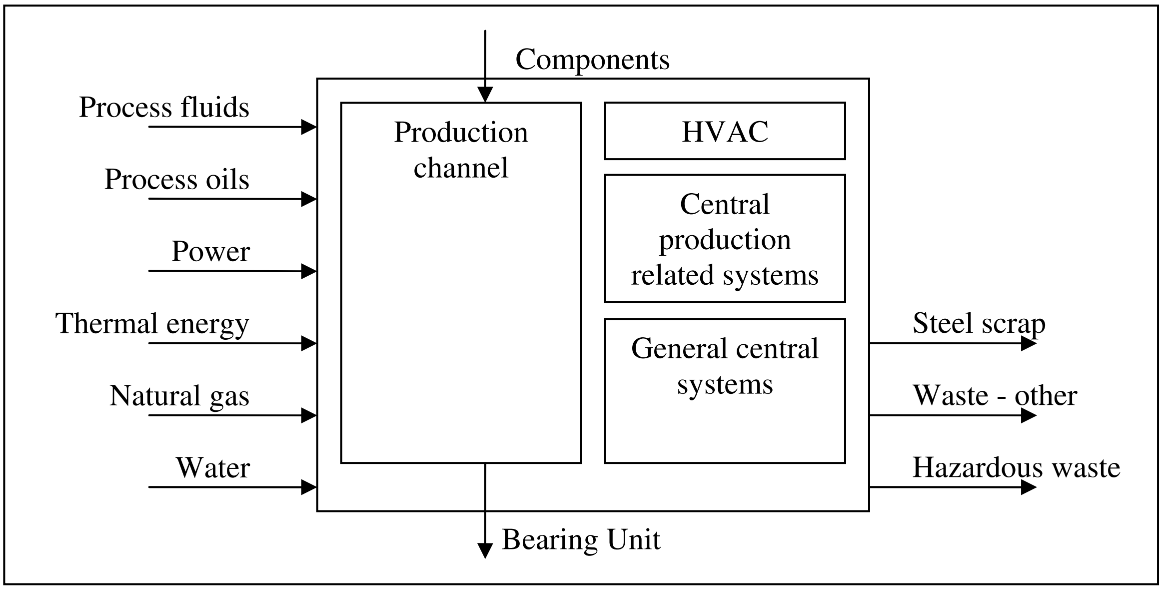

Figure 8 - Manufacturing of bearing unit, total facility level

For the production related support systems, flow data is acquired from permanent meters for electric power consumption, and from meters and charts for fluid use. The outgoing flow is assumed to be the rated flow according to pump specifications, and the allocation to the manufacturing channel is made using the measured inflow to the channel for all systems except motor cooling water. The channel level volumes are calculated from flow measurements, made with a permanent meter for compressed air and with mobile measuring equipment for grinding, honing, turning and washing fluids. For motor cooling water, no measurements on manufacturing channel level are available and therefore removed material is used as allocation basis from the support system.

For heating and ventilation, the inputs of electricity, natural gas and thermal energy from biomass are measured and allocated to channel level using floor area. The use of electricity for general functions such as offices, maintenance shop, etc., is also allocated using floor area.

The quantities of all waste flows are acquired on total facility level, except for total steel scrap generation. This flow has been calculated from scrap rates and the amount of removed material, the latter acquired from calculations from drawing figures. The use of tooling, i.e. grinding wheels, honing stones and cutting tooling, is not included due to problems with acquiring data for these flows.

Complementary flowcharts and inventory data are presented in appendix A.1.

6.2 Cage Production

The cage is a plastic component used to hold the steel balls in their positions.

The two cages used in the assembly are produced in a European country. The data used for the cage production is collected from a supplier with similar processes in Italy, but the background system is adjusted to fit the nation-specific situation in the concerned manufacturing country.

The cages are produced using an injection moulding process where an input of polyamide granulate is formed to cages. For further information on the dataset, see appendix A.2.

The cage production system is formed as shown below in Figure 9, where the numbers refer to the respective datasets in Table 3.

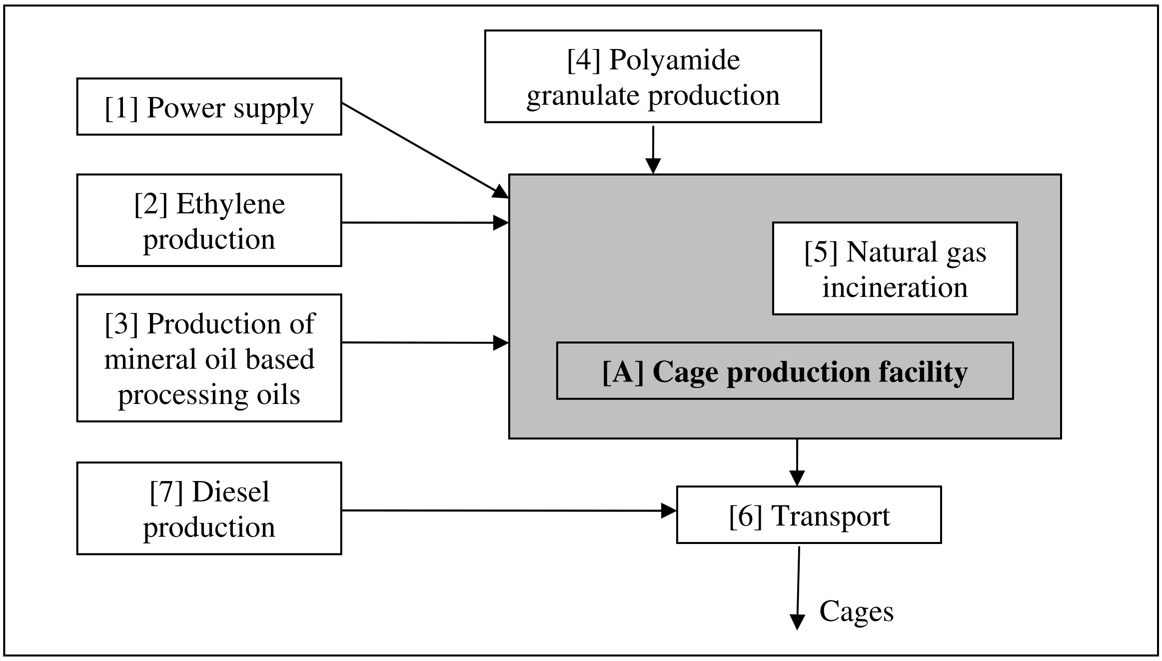

Figure 9 - Cage production unit processes, cradle to gate; numbers refer to datasets shown below

The used background datasets are from cradle to gate, consequently the flows entering the system are flows from the natural to the technical system.

	Dataset	Year	Database	Technique representa-tiveness
A	Cage production	2007	SKF (Appendix A.2)	Completely
1	Power Grid Mix	2002	ELCD/PE-GaBi	Completely
2	Ethylene BUWAL	1996	BUWAL	Partly
3	Lubricants at refinery	2003	PE	Partly
4	Polyamide 6 GF30 (PA 6 GF30)	2005	ELCD/ PlasticsEurope	Completely
5	Thermal energy from natural gas	2002	PE	Completely
6	Truck-trailer > 34 – 40 total cap / 27t payload / Euro 2	2005	PE	Completely
7	Diesel at refinery	2003	ELCD/PE-GaBi	Completely

Table 3 - Cage production; used datasets

6.3 Seal Production

The seals are used to seal the unit and keep dirt out as well as contain the grease.

The two seals used in the assembly are produced in Italy. The data used for the seal production is site specific. The used electricity is from sources with low carbon dioxide emissions and data for this is provided in a certificate from the supplier.

The seals are produced from two major inflows which are metal inserts/flingers and rubber. The incoming material flows are treated separately before they are joined to the product using carousel compressing moulding. The process is further described in appendix A.3.

The seals production system is formed as shown below in Figure 10 where the numbers refer to the respective datasets in Table 4.

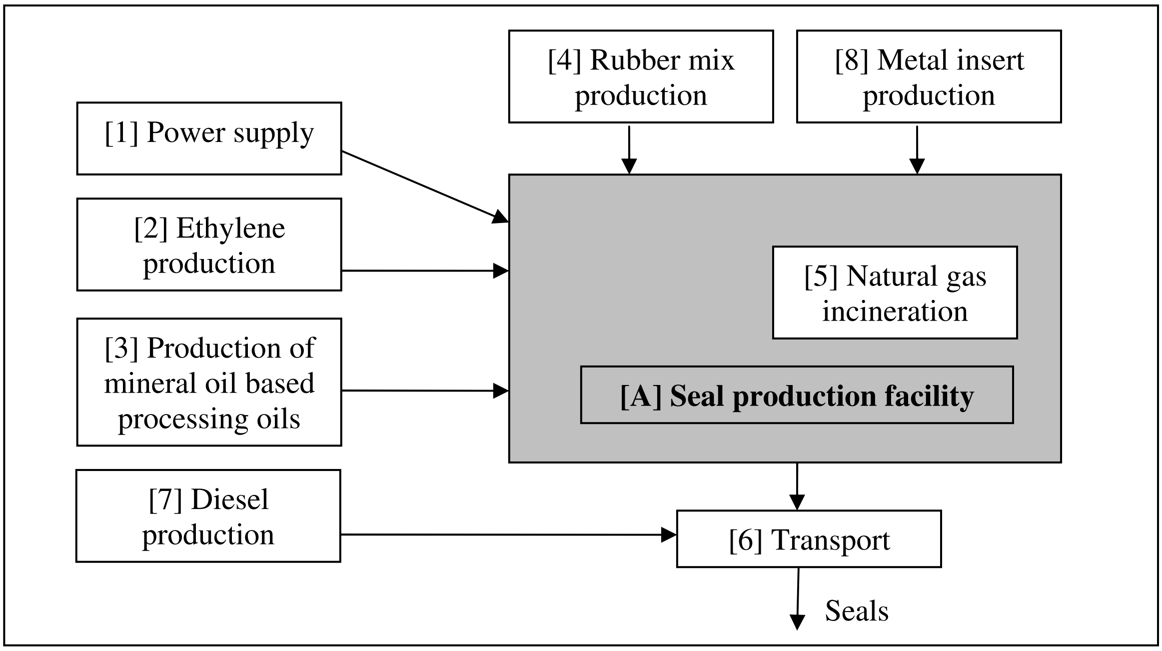

Figure 10 - Seal production unit processes, cradle to gate; numbers refer to datasets shown below

The used background datasets are from cradle to gate, consequently the flows entering the system are flows from the natural to the technical system.

The used datasets are listed in Table 4. The dataset for metal insert/flingers is site-specific and collected at the concerned supplier in Italy. For further information on this dataset, see appendix A.3.

	Dataset	Year	Database	Technique representa-tiveness
A	Seal production	2007	SKF (Appendix A.3)	Completely
1	Power grid mix with low CO_2	2007	SKF (Appendix A.7)	Completely
2	Ethylene BUWAL	1996	BUWAL	Partly
3	Lubricants at refinery	2003	PE	Partly
4	Styrene-butadiene rubber mix (SBR)	2005	PE	Partly
5	Thermal energy from natural gas	2002	PE	Completely
6	Truck-trailer > 34 – 40 total cap / 27t payload / Euro 2	2005	PE	Completely
7	Diesel at refinery	2003	ELCD/PE-GaBi	Completely
8	Metal insert/flinger production	2007	SKF (Appendix A.4)	Completely

Table 4 – Seal production; used datasets

6.4 ABS Sensor Production

The ABS sensor is the part of the anti-lock breaking system that senses the movement of the encoder, which is joined to the moving wheel.

The ABS sensor is assembled in Italy from four different parts, one of these, the actual sensor, is delivered from two different locations.

The sensor and the sensor carrier are produced by injection moulding with metal inserts, while the actual processes for the screw and o-ring are unknown. For the two latter products, they are not modelled as easily accessible data could not be found, and their mass is negligible compared to other components. Neither are the metal inserts in the sensor and sensor carrier are included, as their relative mass is negligible. It is assumed that these components cause a minor impact on the result.

The assembly process is documented in appendix A.5.

The ABS sensor production system is formed as shown in Figure 11, where the numbers refer to the respective datasets in Table 5.

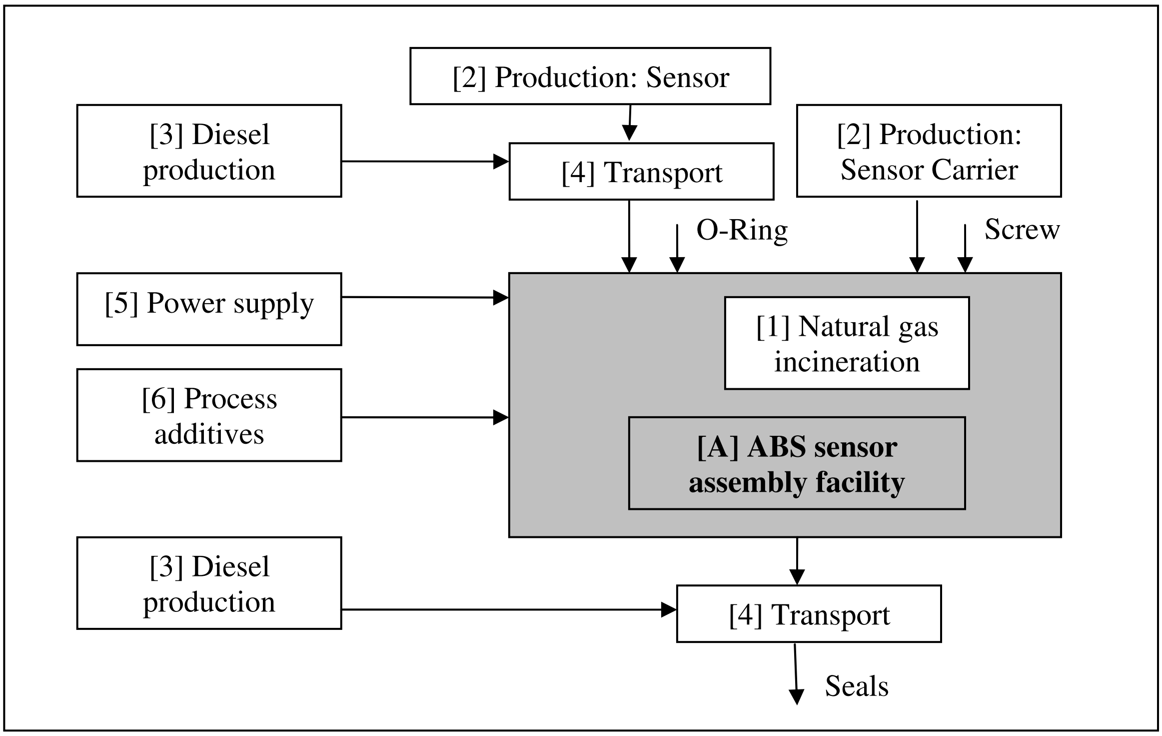

Figure 11 - ABS sensor production unit processes, cradle to gate; numbers refer to datasets shown below

The used background datasets are from cradle to gate, consequently the flows entering the system are flows from the natural to the technical system.

The used datasets are listed in Table 5.

	Dataset	Year	Database	Technique representa-tiveness
A	ABS Sensor assembly	2007	SKF (Appendix A.5)	Completely
1	Thermal energy from natural gas	2002	PE	Completely
2	Polypropylene injection moulding part (PP)	2005	PlasticsEurope	Partly
3	Diesel at refinery	2003	ELCD/PE-GaBi	Completely
4	Truck-trailer > 34 – 40 total cap / 27t payload / Euro 2	2005	PE	Completely
5	Power Grid Mix	2002	ELCD/PE-GaBi	Completely
6	Styrene-butadiene rubber mix (SBR)	2005	PE	Partly
6	Epoxy resin	2005	PlasticsEurope	Partly

Table 5 - ABS sensor production; used datasets

6.5 Steel Ball Production

The steel balls are the rolling elements in this bearing product.

The 26 steel balls used in the assembly are produced in a European country. The data used for the steel ball production, cradle to gate, is average data for Europe. In this case the steel wire production takes place in another European country than the ball production.

The balls are produced from steel wire which is produced from steel scrap. The main steps in the production of steel balls from steel wire are;

- Phosphate treatment
- Cold forming
- Heat treatment
- Grinding
- Honing
- Preservation

The ball production system is formed as shown below in Figure 12, where the numbers refer to the respective datasets in Table 6.

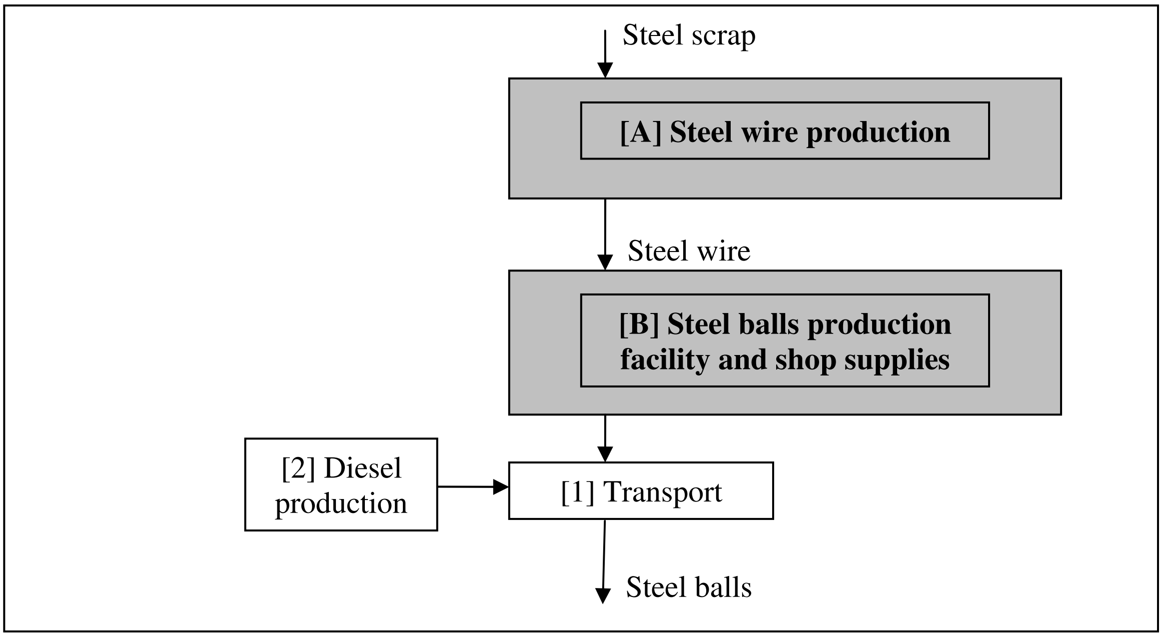

Figure 12 - Steel ball production unit processes, cradle to gate; numbers refer to datasets shown below

The used datasets are from cradle to gate; consequently the flows entering the system are flows from the natural to the technical system, except for steel scrap which enters the modelled system from another technical system.

The used datasets are listed in Table 6.

	Dataset	Year	Database	Technique representa-tiveness
A	Steel wire production	2006	NN Balls (2006)	Completely
B	Ball production and shop supplies	2006	NN Balls (2006)	Completely
1	Truck-trailer > 34 – 40 total cap / 27t payload / Euro 2	2005	PE	Completely
2	Diesel at refinery	2003	ELCD/PE-GaBi	Completely

Table 6 - Steel ball production; used datasets

6.6 Stud Production

The studs are fasteners, used to assemble the unit in the final product.

The studs used in the assembly, five for each functional unit, are produced in three different locations in Europe. The proportion from each location is established by qualified estimations. No site-specific data is collected for the stud production, instead adequate datasets are used. The datasets used for manufacturing of the studs are used with background data according to the situation for each location.

The studs are produced from steel wire which is produced from steel slabs which are produced from virgin steel and recycled steel. The basic steps in the production of studs from steel wire are (Revifa S.P.A., 2007);

- Pressing in 4-5 steps
- Thread rolling
- Heat treatment
- Inspection and packaging

The stud production system is formed as shown below in Figure 13 where the numbers refer to the respective datasets in Table 7.

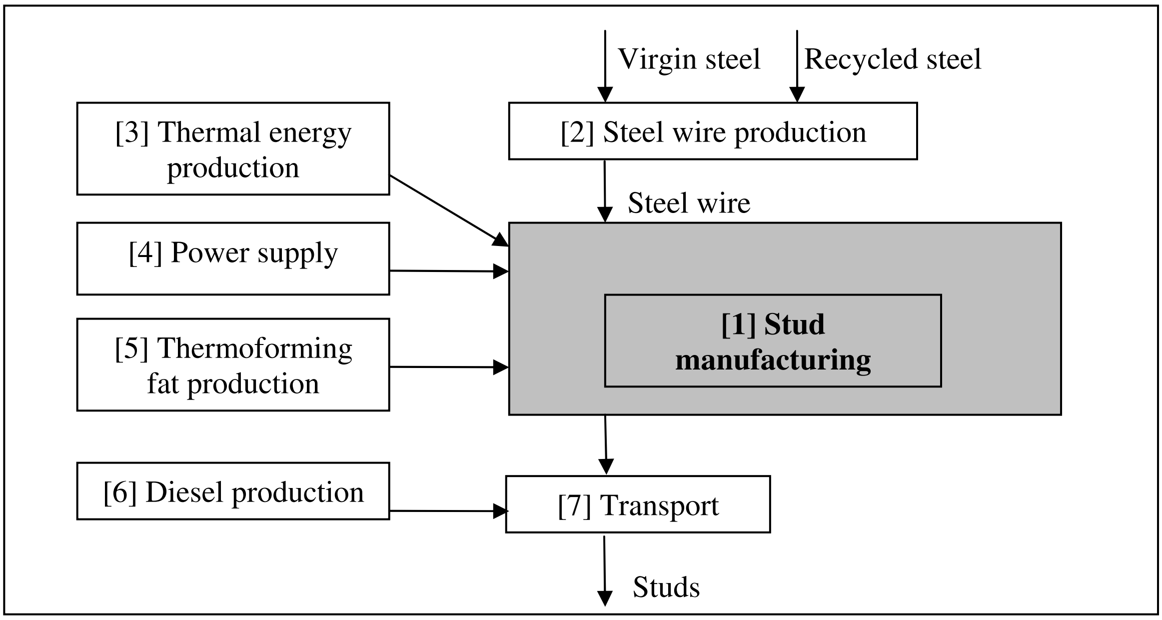

Figure 13 - Stud production unit processes, cradle to gate; numbers refer to datasets shown below

The used background datasets are from cradle to gate; consequently the flows entering the system are flows from the natural to the technical system.

The used datasets are listed in Table 7.

	Dataset	Year	Database	Technique representa-tiveness
1	Steel sheet deep drawing (multi-level)	2005	PE	Not
2	Steel wire (St)	2004	PE	Partly
2	Steel wire production	2006	NN Balls (2006)	Partly
3	Thermal energy from natural gas	2002	PE	Partly
3	Thermal energy from light fuel oil	2002	PE	Partly
4	Power grid mix	2002	ELCD/PE-GaBi	Completely
4	Power grid mix	2002	ELCD/PE-GaBi	Completely
5	Lubricants at refinery	2003	PE	Partly
6	Diesel at refinery	2003	ELCD/PE-GaBi	Completely
7	Truck-trailer > 34 – 40 total cap / 27t payload / Euro 2	2005	PE	Completely

Table 7 - Stud production; used datasets

6.7 Inner and Outer Ring Production

The inner and outer rings are the main bodies of the product.

The inner and outer rings, one of each, are produced in a European country. Site specific data for the production of the rings from steel bars is collected from a supplier in Italy with processes similar to the ones used in the modelled production site. The gate-to-gate data used for the production of steel bars is data for Sweden. The applied background system is adjusted to the situation in the production country.

The rings are produced from steel bars which are produced from steel billets produced from recycled steel only.

For a closer description of the process at the tier 1 supplier, see flowchart in appendix A.6.

The ring production system is formed as shown below in Figure 14 where the numbers refer to the respective datasets in Table 8.

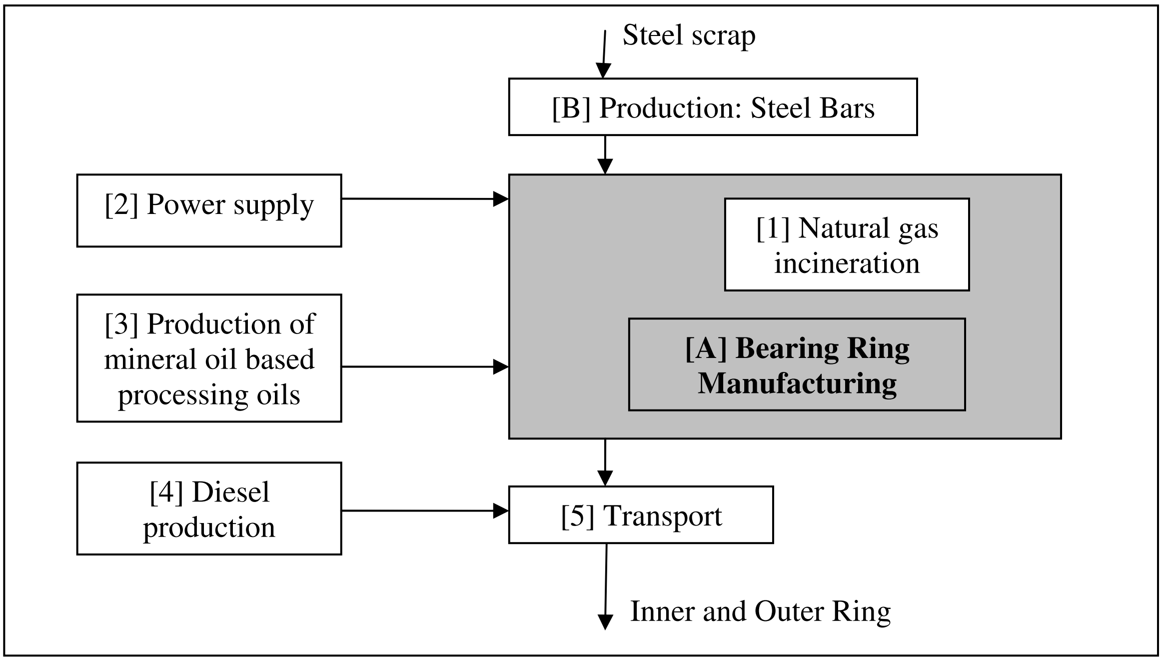

Figure 14 – Inner and outer ring production unit processes, cradle to gate; numbers refer to datasets shown below

The used background datasets are from cradle to gate; consequently the flows entering the system are flows from the natural to the technical system.

The used datasets are listed in Table 8.

	Dataset	Year	Database	Technique representa-tiveness
A	Bearing Ring Manufacturing	2007	SKF (Appendix A.6)	Completely
B	Steel Bar Production	n/a	See section 6.7.1	n/a
1	Thermal energy from natural gas	2002	PE	Partly
2	Power grid mix	2002	PE	Completely
3	Lubricants at refinery	2003	PE	Partly
4	Diesel at refinery	2003	ELCD/PE-GaBi	Completely
5	Truck-trailer > 34 – 40 total cap / 27t payload / Euro 2	2005	PE	Completely

Table 8 – Inner and outer ring production; used datasets

6.7.1 Steel Bar Production

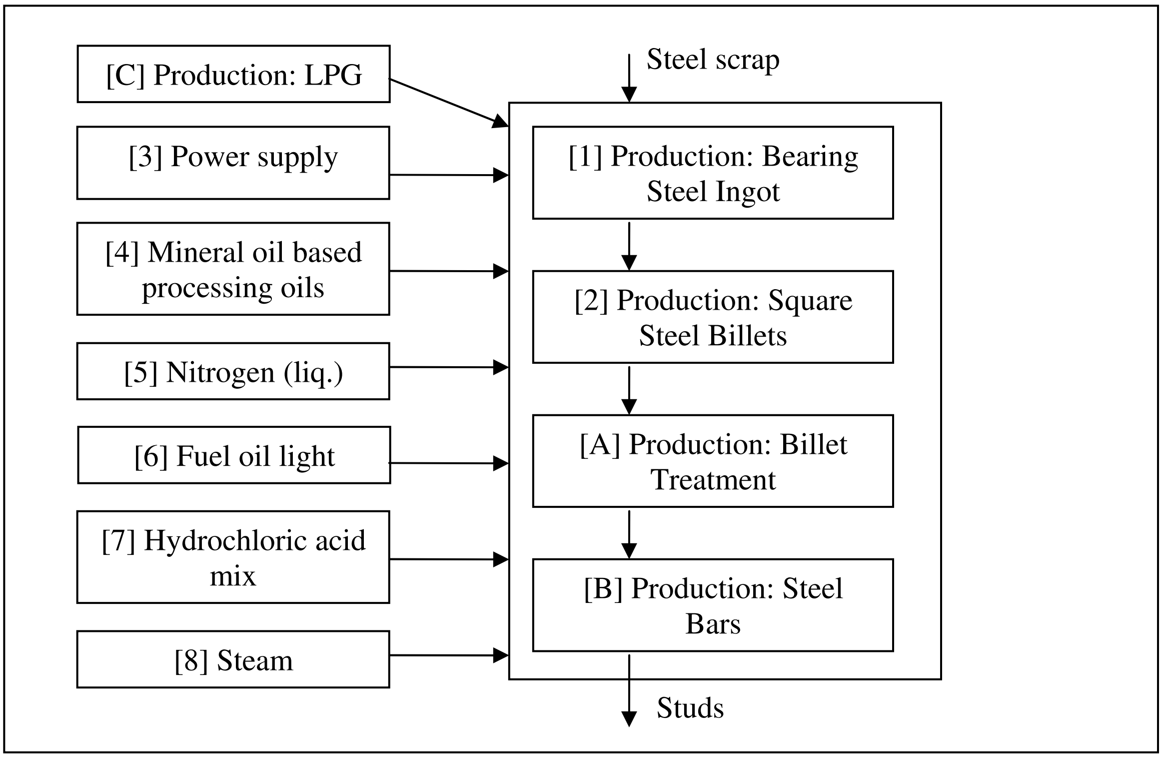

Figure 15 - Steel bar production unit processes, cradle to gate; numbers refer to datasets shown below

	Dataset	Year	Database	Technique representa-tiveness
A	Billet treatment	1998	Ekdahl (2001)	Completely
B	Production of hot rolled bars, 60mm	1998	Ekdahl (2001)	Completely
C	Production: LPG	n/a	See section 6.7.2	n/a
1	Production of Bearing Steel	1998	SPINE@CPM	Completely
2	Manufacturing of Hot Rolled Square Billets, 150 mm	1998	SPINE@CPM	Completely
3	Power grid mix	2002	PE	Completely
4	Lubricants at refinery	2003	PE	Partly
5	Nitrogen (liquid)	2005	PE	Completely
6	Fuel oil light at refinery	2003	ELCD/PE-GaBi	Completely
7	Hydrochloric acid mix (100%)	2005	PE	Completely
8	Steam (mp)	2005	PlasticsEurope	Partly

Table 9 - Steel bar production, used datasets

6.7.2 Liquid Petroleum Gas (LPG) Production

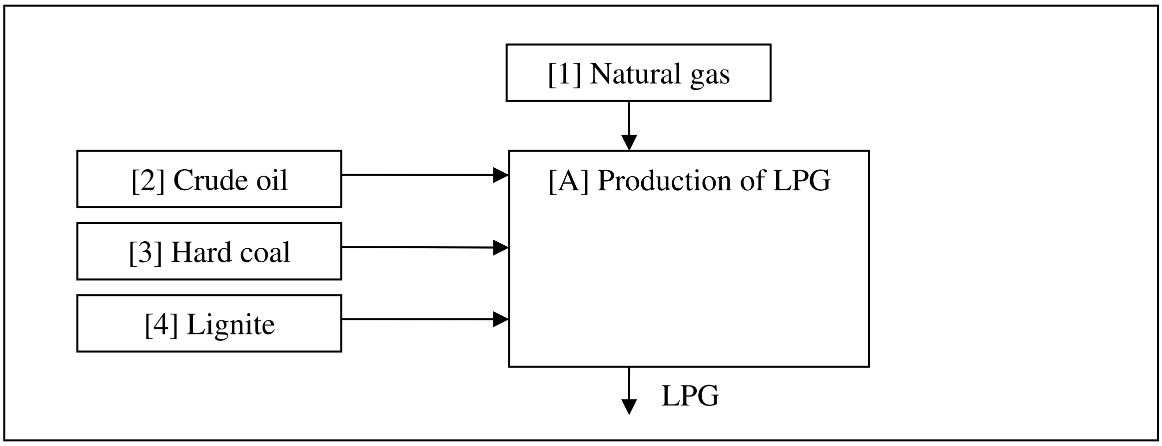

Figure 16 - LPG production unit processes, cradle to gate; numbers refer to datasets shown below

	Dataset	Year	Database	Technique representa-tiveness
A	Production of LPG	<2001	Ekdahl (2001)	No statement
1	Natural gas mix	2002	PE	Completely
2	Crude oil mix	2002	PE	Completely
3	Hard coal mix	2002	PE	Completely
4	Lignite mix	2002	PE	Completely

Table 10- LPG production; used datasets

6.8 Small Inner Ring Production

The small inner ring encompasses one of the inner raceways for the balls.

The small inner ring is produced in Italy from steel bars produced in another European country. Site specific data for the production of the rings from steel bars is collected from the actual supplier in Italy. The used electricity is from sources with low carbon dioxide emissions and data for this is provided in a certificate from the supplier. The data used for the production of steel bars from steel billets is data for Sweden, adjusted to background system in the production country. The billet is produced in the same country as the steel bars, from 25 percent recycled steel, but the used dataset is for production of the same steel alloy billet in another European country, though from virgin steel only, i.e. not completely representative.

For a closer description of the process at the tier 1 supplier, see the flowchart in appendix A.6.

The ring production system is formed as shown below in Figure 17 where the numbers refer to the respective datasets in Table 11.

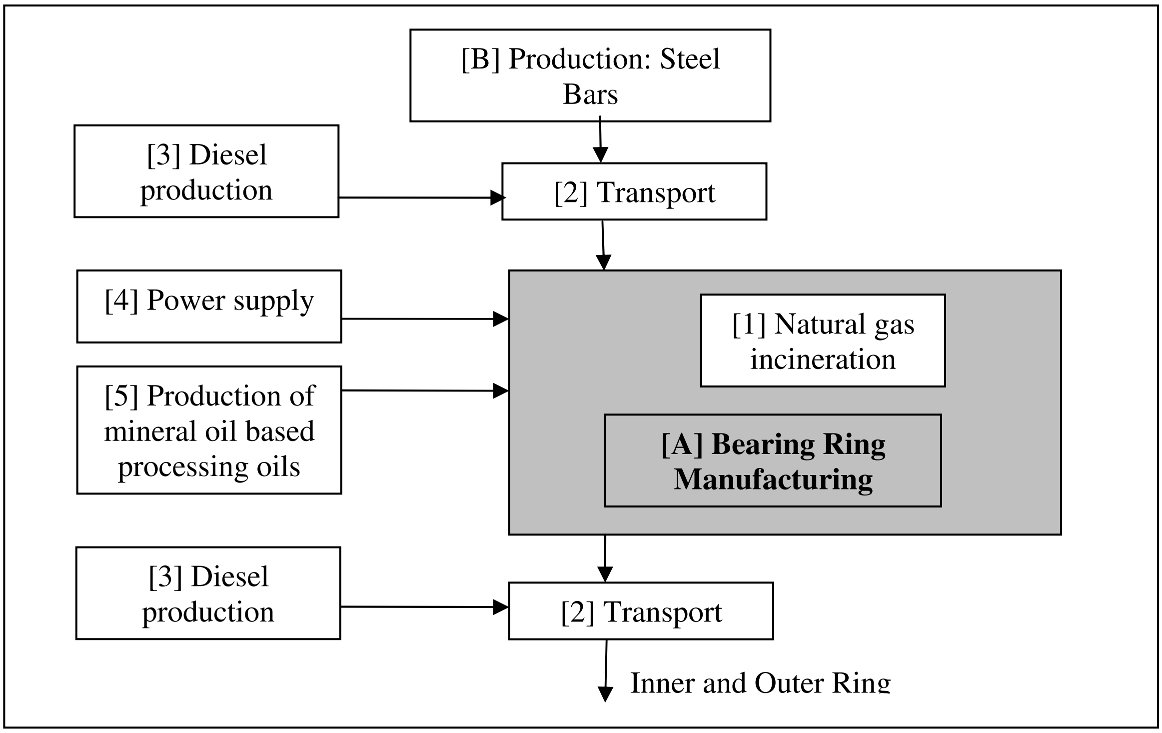

Figure 17 – Small inner ring production unit processes, cradle to gate; numbers refer to datasets shown below

The used background datasets are from cradle to gate; consequently the flows entering the system are flows from the natural to the technical system.

The used datasets are listed in Table 11.

	Dataset	Year	Database	Technique representa-tiveness
A	Bearing Ring Manufacturing	2007	SKF (Appendix A.6)	Completely
B	Steel Bar Production	n/a	See below (Section 6.8.1)	n/a
1	Thermal energy from natural gas	2002	PE	Partly
2	Truck-trailer > 34 – 40 total cap / 27t payload / Euro 2	2005	PE	Completely
3	Diesel at refinery	2003	ELCD/PE-GaBi	Completely
4	Power grid mix with low CO2	2007	SKF (Appendix A.7)	Completely
5	Lubricants at refinery	2003	PE	Partly

Table 11 - Small inner ring production; used datasets

6.8.1 Steel Bar Production

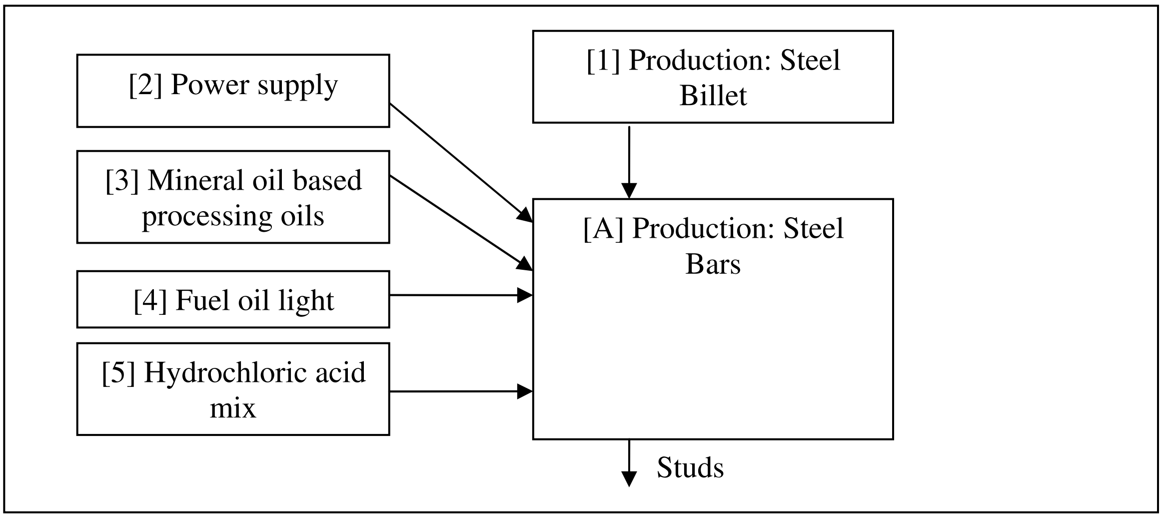

Figure 18 - Steel bar production unit processes, cradle to gate; numbers refer to datasets shown below

	Dataset	Year	Database	Technique representa-tiveness
A	Production of hot rolled bars, 60mm	1998	Ekdahl (2001)	Completely
1	Steel Billet (100Cr6)	2004	PE	Partly
2	Power grid mix	2002	PE	Completely
3	Lubricants at refinery	2003	PE	Partly
4	Fuel oil light at refinery	2003	ELCD/PE-GaBi	Completely
5	Hydrochloric acid mix (100%)	2005	PE	Completely

Table 12 - Steel bar production; used datasets

6.9 Grease Production

The grease is used to reduce friction between the moving elements in the bearing.

The grease is supplied from SKF's central warehouse in Belgium. The mixing of the grease as well as the production of additives is left out due to the time-limitations of this study. The additives represent a minor proportion of the grease mass, but the impact from these chemicals is unknown. The mixing of the grease is assumed to be a minor energy consumer compared to the refinement of the mineral oil, and is thus left out while the required data cannot be acquired within the timeframe of this study.

The choice of less representative dataset is further motivated by the fact that preliminary results showed that the impact of the grease in the total cradle to gate life-cycle is minor.

The basis of the grease production system is formed as shown below in Figure 19 where the numbers refer to the respective datasets in Table 13.

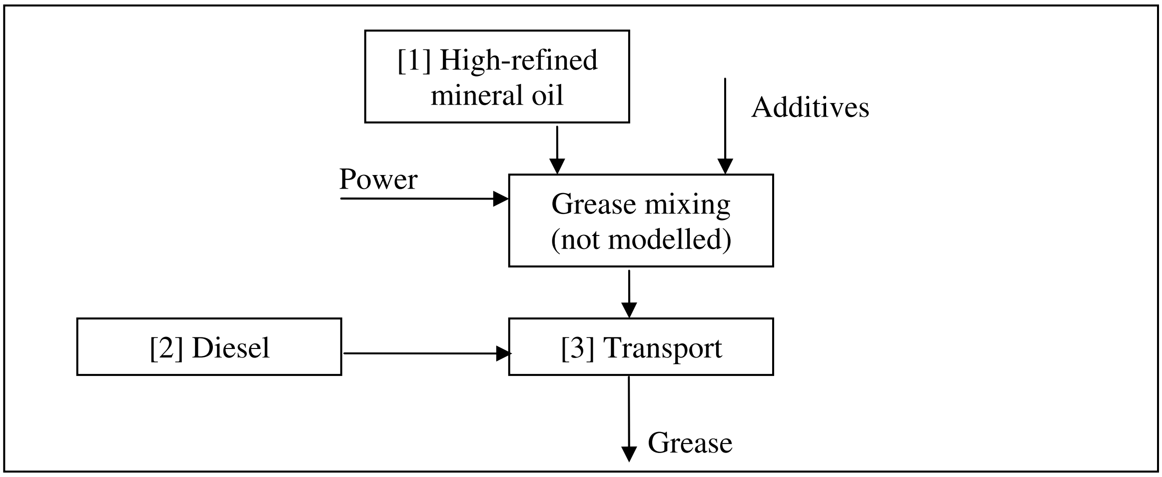

Figure 19 - Grease production unit processes, cradle to gate; numbers refer to datasets shown below

The used background datasets are from cradle to gate; consequently the flows entering the system are flows from the natural to the technical system.

The used datasets are listed in Table 13.

	Dataset	Year	Database	Technique representa-tiveness
1	Lubricants at refinery	2003	PE	Partly
2	Diesel at refinery	2003	ELCD/PE-GaBi	Completely
3	Truck-trailer > 34 – 40 total cap / 27t payload / Euro 2	2005	PE	Completely

Table 13 - Grease production; used datasets

6.10 Encoder Production

The Encoder, also called Impulse Ring, is the part of the assembly that gives input to the ABS Senor on the movement of the wheel.

The encoder is produced by a supplier in Italy from a ferrous plastic granulate by use of compression moulding, i.e. the raw material is heated to a semi-liquid state and pressed in a mould. The used dataset for the forming is based on injection moulding and does consequently not represent a completely equal process. As the raw material is heated to a liquid state in the injection moulding process, apart from a semi-liquid state in the compression moulding process, it is though highly likely that the latter process does have lower energy consumption and thus the choice of dataset is conservative. The background system is adjusted to the Italian nation-specific situation. The used electricity is from sources with low carbon dioxide emissions and data for this is provided in a certificate from the supplier. Regarding the raw material input, ferrous plastic, no representative data is acquired, but data on a pure plastic granulate is used, leaving some metal input, existent in the actual system, out of the system model.

The choice of less representative dataset is further motivated by the fact that preliminary results showed that the encoder have a minor impact in the total cradle to gate life-cycle in the context of this study.

The basis of the encoder production system is formed as shown below in Figure 20 where the numbers refer to the respective datasets in Table 14.

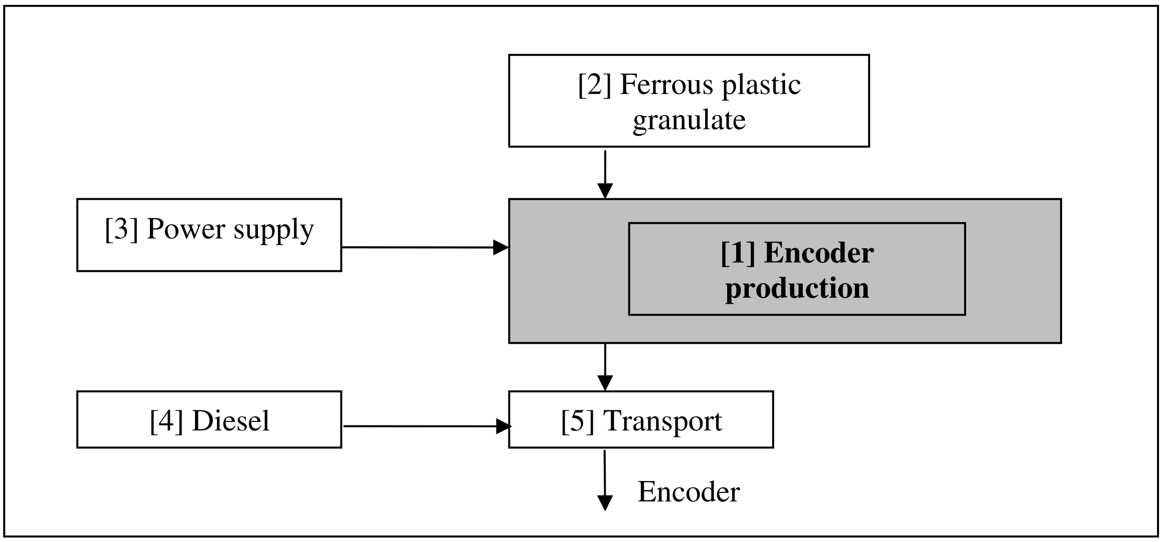

Figure 20 - Encoder production unit processes, cradle to gate; numbers refer to datasets shown below

The used background datasets are from cradle to gate; consequently the flows entering the system are flows from the natural to the technical system.

The used datasets are listed in Table 14.

	Dataset	**Year**	**Database**	**Technique representa-tiveness**
1	Plastic injection moulding part (unspecific)	2005	PE	Partly
2	Polystyrene granulate (PS)	2005	ELCD/ PlasticsEurope	Partly
3	Power grid mix with low CO2	2007	SKF (Appendix A.7)	Completely
4	Diesel at refinery	2003	ELCD/PE-GaBi	Completely
5	Truck-trailer > 34 – 40 total cap / 27t payload / Euro 2	2005	PE	Completely

Table 14 - Encoder production; used datasets

6.11 Packaging Production

The packaging material is used to protect the product and facilitate the transportation to the customer.

The packaging material consists of several different parts that are used for one or several functional units. The pallets used for packing the units are the size of half an EU pallet and in the calculation of their use; the number of reuse cycles is estimated and taken into consideration. The materials used for the packaging material is wood, metal, cardboard, carton, polyethylene and plastic.

No specific data is collected for the production of packaging material, but adequate datasets are used, representing only the material use. Due to limitations of the study the production of wood packaging material, i.e. wooden pallets, is not included as datasets representing this was not readily accessible.

The modelled system for packaging material looks as follows in Figure 21.

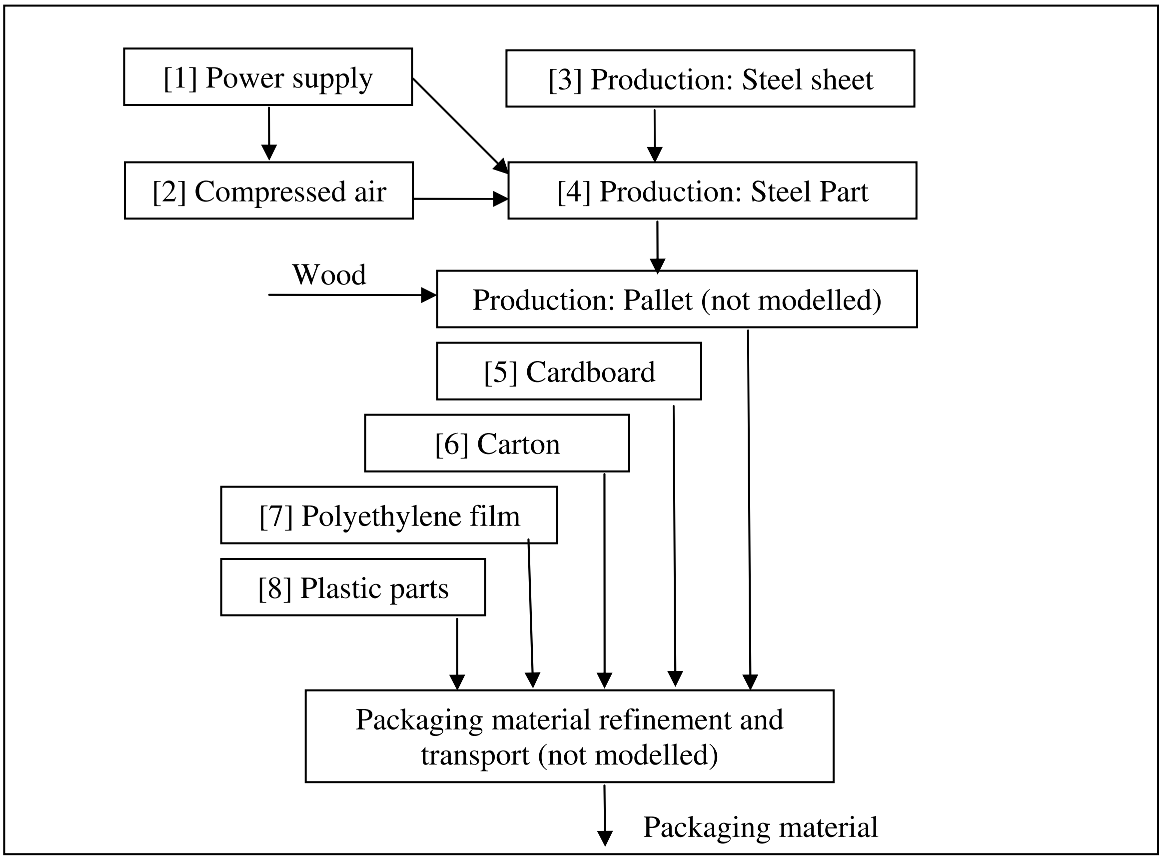

Figure 21 - Packaging material production unit processes, cradle to gate; numbers refer to datasets shown below

The used background datasets are from cradle to gate; consequently the flows entering the system are flows from the natural to the technical system. The used datasets are listed in Table 15.

	Dataset	Year	Database	Technique representa-tiveness
1	Power grid mix	2002	PE	Completely
2	Compressed air 7 bar (low power consumption)	2002	PE	Partly
3	Steel cold rolled	2004	PE	Partly
4	Steel sheet stamping and bending (5% loss)	2005	PE	Partly
5	Corrugated cardboard	1996	BUWAL	Completely
6	Paper woody coated	1996	BUWAL	Partly
7	Polyethylene film	2005	(PE-LD) PlasticsEurope	Completely
8	Polystyrene part (PS, thermoformed)	2005	PlasticsEurope	Partly

Table 15 - Packaging material production; used datasets

7 Life Cycle Impact Assessment

In this study the LCIA is limited to classification and characterisation. Further check of data quality will be performed through the methods applied in the interpretation step in section 8.

The classification and characterisation will be carried out using the classifications and category indicators as stated by the Swedish Environmental Management Council (2000) in the publication MSR1999:2.

This will encompass the global warming potential which in the current context is the most interesting category for the commissioner. In order to include the use of resources in the result, resource use will be included as recommended in the above mentioned publication (Swedish Environmental Management Council, 2000).

Environmental indicators, related to F.U.		
Acidifying compounds	[mol H+ equiv.]	6.127E+00
Eutrophicating compounds	[kg O2 equiv.]	3.410E-01
Global Warming Potential (GWP 100 years)	[kg CO2 equiv.]	1.063E+01
Ozone Depleting Potential (ODP 20 years)	[kg R11 equiv.]	5.036E-07
Photochemical Ozone Creation Potentials	[kg C2H4 equiv. to air]	1.037E-02

Table 16 - Environmental indicators MSR1999:2, cradle to gate

Environmental resources, related to F.U.			
With energy content [MJ]	**Total renewable**		**13.1%**
	Non-renewable	Crude oil	20.9 %
		Hard coal	16.1 %
		Lignite	11.4 %
		Natural gas	18.7 %
		Uranium	19.7 %
		Others	0.0 %
		Total	86.9 %
	Gross energy requirements		**100 %**
	Of which electricity in SKF facility		*
Without energy content [kg]	Total renewable (steel scrap)		*
	Total non-renewable		*
	Water		*

Table 17 - Resource use, cradle to gate (* - removed due to confidentiality)

Waste generation, related to F.U.		
Non-hazardous	Of which steel scrap Unspecified Other	* * *
	Total non-hazardous Total hazardous **TOTAL**	* * **100.0 %**

Table 18 - Waste generation, cradle to gate (* - removed due to confidentiality)

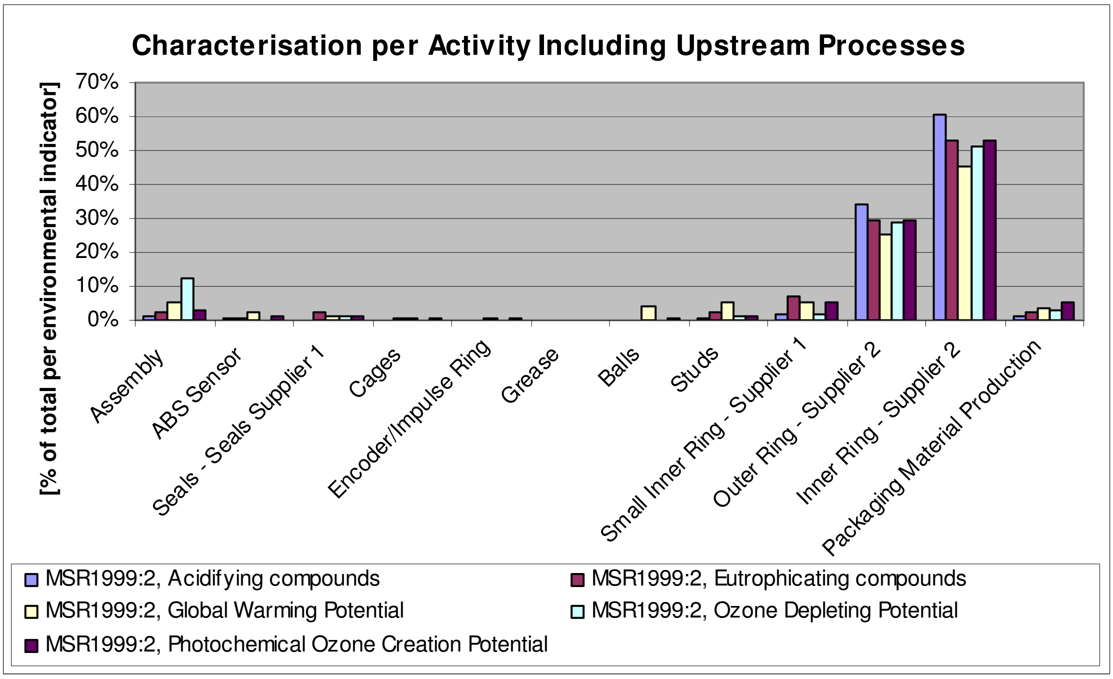

Figure 22 - Impact categories per activity including upstream processes

It can be seen in Figure 22 that the ring production activities including upstream processes are the major contributors to all considered potential environmental impact categories. If adding up ring production activities with balls and studs, it is seen that production of components manufactured from steel are the activities including upstream processes that accounts for the main potential environmental impact. The relation between the figures is approximately the same for all impact categories when comparing the activities. Some exceptions that are relatively easy observed can be commented, all related to electric power generation;

- *Balls and Studs*
  Balls and studs show a noticeably higher contribution to the total GWP than to the other impact categories, while other activities including upstream processes have a relatively similar contribution to all impact categories. This pattern is present for production that mainly takes place in Italy. The major part of electric power generation for the Italian national average power grid mix comes from fossil fuel sources, which results in a contribution to GWP that is high compared to the other impact categories. As mentioned in previous paragraph, nuclear power generation causes relatively high impact on ODP, and as nuclear power is not included in the power grid mix, this keeps the contribution to ODP low.

- *Bearing Unit Assembly*
  The reason that this activity, including upstream processes, gives a high contribution to the total ODP impact, while the contribution to the other impact categories is low, is that an electricity mix with low CO2 intensity is used. This results in lower emissions to all impact categories except for ODP. It can be seen in the detailed results that the nuclear power generation in the electricity mix for this process is a major contributor to the relatively high level of ODP.

- *Small Inner Ring*
  As the steel content in the components balls, studs and small inner ring are of the same magnitude; one could expect the contribution to potential impacts to be quite similar. We can though see that the contribution to eutrophication potential is relatively high for the small inner ring. This is because the impact from the so called Supplier 2, i.e. Inner and Outer Ring, including upstream processes, account for the major contribution to all included impact categories and thus it is to these activities, including upstream processes, that the contribution from other activities, including upstream processes, will be compared in Figure 22. The major contributing activity to all impact categories related to Supplier 2 is steel billet production and the used dataset does not include direct emissions to water. In the case of activities related to Small Inner Ring, the used dataset for steel billet production does include emissions to water. As emissions to water is the major contributor to eutrophication, this will result in a relatively high contribution to the total eutrophication potential for Small Inner Ring. We can also see a high relative potential impact for POCP, but the reason for this is more unclear, and whilst the focus of the study is on GWP, a further survey of this will not be carried out.

- *Packaging material production*
  It is noticeable that the impact from packaging material production is of the same magnitude as balls, studs and small inner ring. It should be noted that no site-specific data is used for this activity including upstream processes. An increased data quality for this activity including upstream processes cannot be achieved with the time-resources available for this study, but could be investigated in further studies.

8 Interpretation

In the interpretation section the results are related to the goal of the study and the credibility of the results is assessed.

8.1 Identification of Significant Issues

This section on identification of significant issues aims at finding activities as well as emissions and resource use that causes the major environmental impact. The focus is on answering the questions asked in the goal definition.

8.1.1 Dominance Analysis

The dominance analysis is carried out to find activities with major environmental impact in the cradle to gate life cycle and therefore should be considered for improvement activities. The focus is on global warming potential, which is well in line with SKF's CO2 target. The relation between global warming potential and CO2 is further assured in Figure 26. Furthermore, we have seen in the LCIA (Figure 22) that the production of inner and outer rings, including upstream processes, is the activity that is dominant for all the used impact categories. Contribution to global warming potential from different activities, including all upstream activities, is shown in Figure 23.

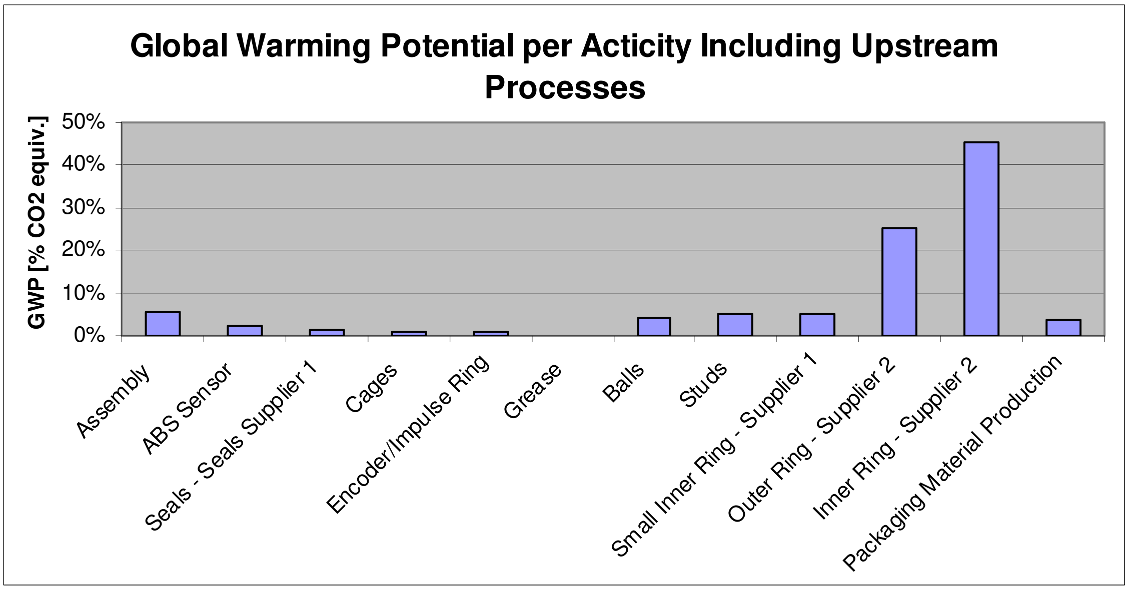

Figure 23 - Global Warming Potential, MSR1999:2, per activity including upstream processes

It can be seen that activities related to steel intensive parts, i.e. rings, balls, and studs, accounts for the major impact during the cradle to gate life cycle, which can be seen even more straightforward in Figure 24. It is clear that ring production give the absolutely highest impact during the cradle to gate life cycle. Weighting is not a part of the scope of this study, but for the interested reader the results of weighting according to the Environmental Priority Strategies in Product Design (EPS) can be found in appendix B.2. In that weighting, it can be seen that the impact on resource use is much higher when virgin steel is used instead of recycled steel, as is the case for the small inner ring.

In this specific study, the potential environmental impact does not correlate to energy use for the specific activities, since a so called low carbon dioxide power mix is used for SKF Italy, i.e. the activities SKF in-house, and the tier 1 part of Seals, Encoder and Small inner ring. Consequently, it must be noted that the relation between activities might be substantially different for a similar product if the background system regarding power grid mix is different. In such a situation the priorities for environmental performance improvement actions might be different, with a higher focus on e.g. in-house electricity use. This is further discussed in the sensitivity analysis (Section 8.2.5).

To get an idea about which type activities in the upstream flows that cause the major part of the environmental impact, the total global warming potential is shown in Figure 24 divided into the categories; Steel production, Other, SKF in-house, tier 1 and In-bound transports.

- *Steel production*
  In this category, steel production and all activities directly related to the steel production are accounted for. This means also energy generation and other related activities.
- *Other*
  Includes production upstream of tier 1 suppliers except for steel production, e.g. production of plastic granulates and grease. Packaging production is also included in this category.
- *SKF in-house*
  The SKF in-house activities consists of activities related to the bearing unit life-cycle performed in SKF's facility and includes all non-product related upstream flows. Consequently, power generation, hydraulic oil, etc., are accounted for, but components and materials for the product are not.
- *TIER1*
  The tier 1 category refers to the first level of suppliers, in this case only suppliers of directly related components and materials. As for SKF in-house, only upstream flows of non-product related flows are included in this category. The suppliers of seals, small inner ring, and encoder are SKF companies.
- *In-bound transport*
  In the in-bound transport category, transports from tier 1 suppliers to SKF's facility are included. Also transports from steel bar producers to the bearing ring manufacturers are included.

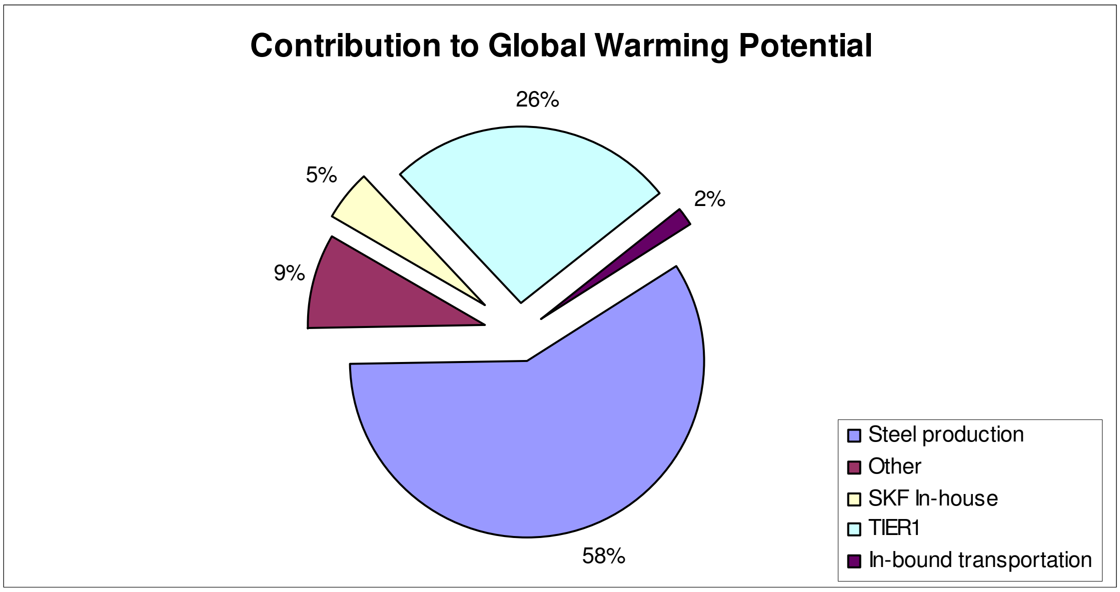

Figure 24 - Global Warming Potential, MSR1999:2, per activity category

It is clear that steel production is the dominant contributor to global warming potential and according to the pattern in Figure 22 also other environmental impact. The proportion of recycled steel has a major impact on the results, as production of virgin steel is much more energy demanding than use of recycled steel. In a theoretical comparison, with scrap as raw material for steel production not traced back to the cradle, the emissions of carbon dioxide from steel billet production from recycled steel are only 36 % of the emissions when virgin steel is used (GaBi, 2007). In this study, the major part of the used steel originates from scrap steel, but virgin steel is still used.

The major environmental impact is caused by non-SKF operations and will not be reported in the current CO2 reporting scheme, which only includes scope 1 and 2. Thus, SKF's commitment to report CO2 emissions including scope 3 emissions according to the Greenhouse Gas Protocol is fully in line with the products' environmental performance. (Greenhouse Gas Protocol, 2008)

In Figure 25 Ring Supplier 2 is used as comparative example, having a high similarity to all ring production, to show which types of activities that cause the major environmental impact from ring production including upstream processes. The chart is grouped into:

- *Steel production*
  Steel production including direct emissions and upstream processes except for production and conversion of energy carriers, e.g. electric power generation and oil refinement.

- *Energy conversion*
  Emissions from electric power generation and other refinement of energy resources.

- *Ring supplier 2*
  Ring supplier 2 direct emissions and upstream processes except for directly product related steel production as well as production and conversion of energy carriers, e.g. electric power generation and oil refinement.

- *In-bound transportation*
  Direct emissions from in-bound transportation, energy conversion excluded.

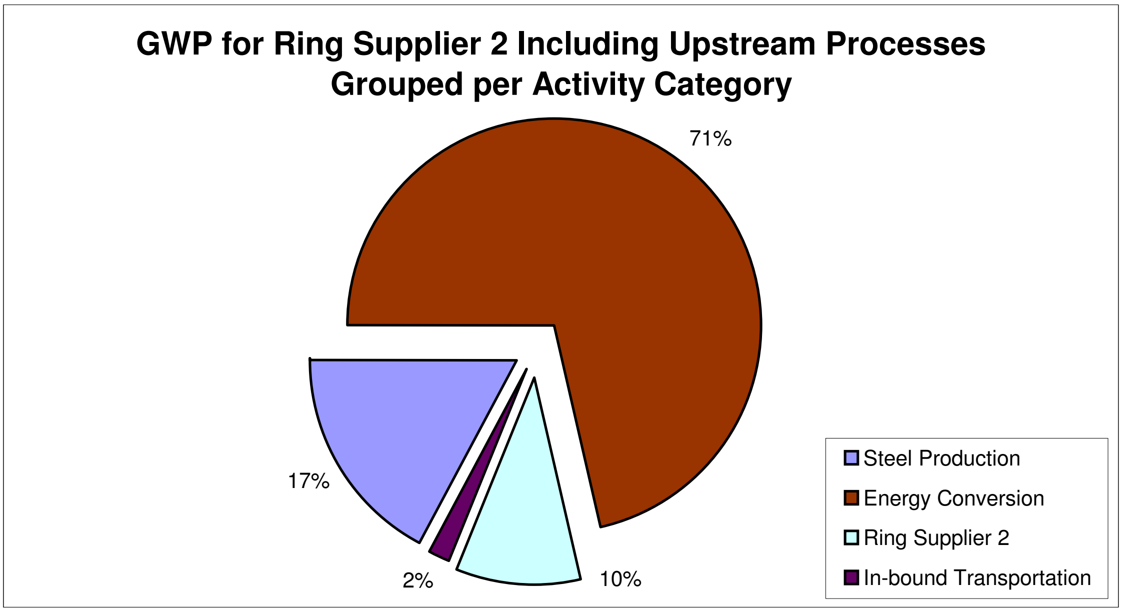

Figure 25 – Global Warming Potential, MSR1999:2, for Ring Supplier 2 including upstream processes, grouped per type of activity (legend explanations above)

It can be concluded from proportion of Energy Conversion that energy use is the major contributor to environmental impact from the ring production. It is likely that much of the impact in the Steel Production category also comes from energy use, e.g. incineration of LPG for production of thermal heat for the steel treatment process. Consequently, energy use for steel production is the type of activity that causes the greatest environmental impact during the cradle to gate life cycle of the bearing unit.

8.1.2 Contribution Analysis

The purpose of the contribution analysis is to show what emissions that are the major contributors to an impact category. In Figure 26 it is shown which emissions that are the major contributors to global warming potential. Three different ready-made LCIA methods are used to clarify if there are differences in the category indicators.

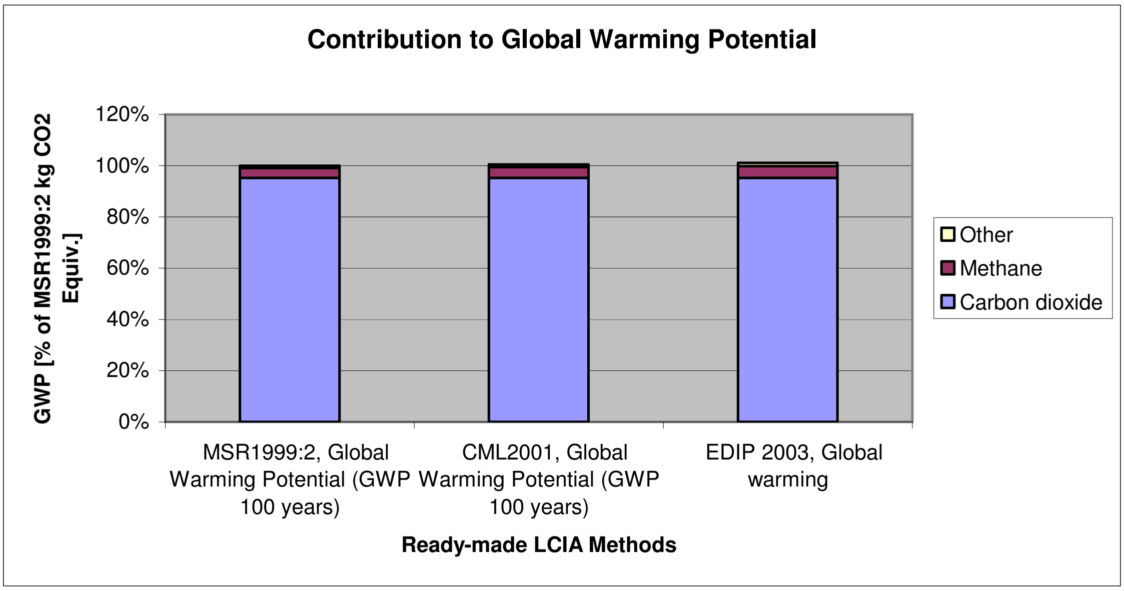

Figure 26 - Emissions contributing to GWP per LCIA method

It can be seen that carbon dioxide gives the absolute majority of the contribution to global warming potential for all three cases. As can be seen in Figure 25, energy use is the dominant activity regarding emissions contributing to global warming potential. Reflecting on the high proportion of fossil fuels used for electric power generation in the concerned geographical area, the dominance of carbon dioxide in global warming potential is expected. This goes well in line with SKF's decision to report only carbon dioxide to account for greenhouse gas emissions related to their operations.

8.2 Evaluation of Result Robustness

In order for the results to be credible, methodological choices and quality of data with significant impact on the results are evaluated. These evaluations are focused on meeting the questions asked in the goal definition.

8.2.1 Completeness Check

The completeness check is carried out to ensure that all important flows are included in the LCI and LCIA. Among the tools, material balance can be mentioned. Total values for material in- and outflows do not correspond very well in the used model. Due to time limitations this has not been further investigated, but for example is data collected for all waste flows from in-house activities, whilst complete data for inflows to the facility is not easily acquired, which result in a major discrepancy. Most flows that can be assumed to have a non-negligible environmental impact are though included. Among the exceptions that can be mentioned for SKF in-house processes we have lack of data for inflows of grinding wheels and honing stones. To have an overview of this kind of flows that are known to exist but are not quantified, a list of valuables not accounted for is shown in appendix C.

A so called red flag table show what flows that are not included in any impact category and thus will be left out of the LCIA. A red flag table is not included in the report as the use of very comprehensive datasets from the used software database (GaBi, 2007) resulted in an unmanageable number of flows to list. A list has though been generated and assessed with the conclusion that the quantities of listed flows are very small and thus can be assumed to have minor environmental impact.

8.2.2 Data Quality Analysis

To assess the quality level of the used data, a comparison with an LCA of a similar product is carried out. To make the results comparable, a national average power grid mix is applied for SKF Italy in the scenario denoted *Average Electricity Mix*. As other parts of the cradle to gate life cycle take place in different parts of Europe, the average background system will correspond relatively well to applying an average European background for the whole system, which was not carried out due to time limitations. The results are then compared to results obtained when applying an average European background system on Ekdahl's (2001) LCI data in the scenario called *Ekdahl EU Background*. Changes in the background system have only been made for energy inputs and use. The results are shown in Figure 27.

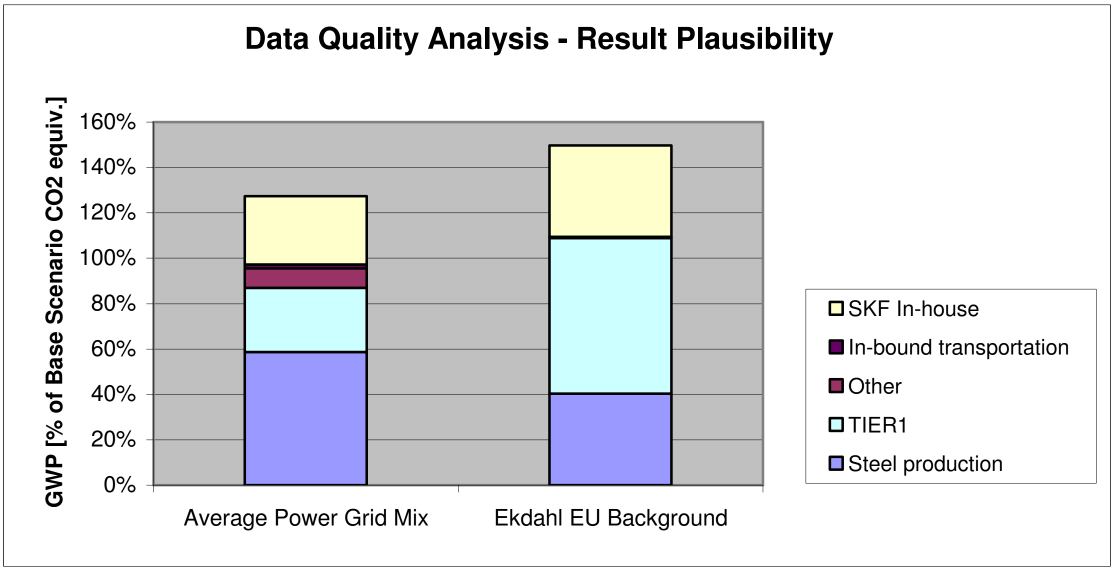

Figure 27 - Global Warming Potential, MSR1999:2, assessment of result plausibility by comparison with results from LCA of similar product

The difference in the results is very much explained by differences in processes. The bearing unit assessed by Ekdahl (2001) use rollers instead of steel balls, and, above all, the whole rings are heat treated in a furnace, whilst the bearing unit in this survey is heat treated only for the raceways with induction hardening. Regarding the relation between types of activities in the datasets, the differences can partly be explained by slight differences in the definitions of activities, i.e. where the system limits are drawn. The main reason for the tier 1 category being relatively dominant in the Ekdahl example is that roller production is included there, and roller production is a much higher user of energy than the steel ball production in the bearing unit example for average power grid mix. Over all, when taking the differences in processes into account, it can be concluded that the two systems show a high equivalence which indicates good result accuracy.

8.2.3 Consistency Check - Characterisation Methods

As the underlying mechanisms are less well-known for some of the impact categories, it is interesting to compare several sets of category indicators in order to find out whether the results from the characterisation correspond to each other. The category indicators are defined in the ready-made LCIA-methods, but the category indicators included in the categories and their relative contribution might differ why an analysis of this is interesting. Furthermore, category indicators for the ready-made LCIA method MSR1999:2 are put into the GaBi4 software by hand. Thus, it is important to do comparison to identify mistakes that might have been made when entering the data.

In appendix B.1 graphs are shown, comparing the results using category indicators from three different ready-made LCIA methods. The used LCIA methods are briefly described in section 3.1.3.4. The only divergences from a similar pattern for the methods are for EDIP2003 for Eutrophication and Photochemical Ozone Depletion Potential. This may be derived to the fact that these two impact categories are the ones that are most dependent of the local geographical situation (Baumann and Tillman, 2004). I.e. the results might differ because the category indicators are developed with the environmental characteristics of a specific region in mind. Even though the divergence is apparent, it does not change the actual relation between activities. Consequently, it can be assumed that the used category indicators give a good picture of the situation.

8.2.4 Consistency Check - Allocation Methods

Allocation methods are here evaluated for in-house processes. Allocation of in-house activities will not influence directly product-related upstream flows of components and materials, since these are known for the specific type of product. Evaluation of the situation regarding allocation of upstream processes is not carried out, whilst data is not readily acquirable. In the case of suppliers, the superior process knowledge of the suppliers has been trusted.

In Figure 28 a comparison of allocation methods for in-house processes is made. Evaluation is also made for impact of level of detail for data collection where the simplified scenario refer to data collection on solely factory level for all flows that are not directly product related. The base scenario refers to the methodological choices and cut-off rules as defined in the goal and scope for this study. The used allocation methods are;

- *Mass*
  The mass of one F.U. is divided by the mass of the total delivered pieces from the production channel and factory, respectively.
- *No. Pcs.*
  The number of pieces per F.U., i.e. one, is divided by the total number of delivered pieces from the production channel and factory, respectively.
- *Value Added*
  The added value per F.U. for SKF in-house processes is divided by the total added value in the production channel and factory, respectively. Value added describes the economic resources needed to produce a product which is, in this case, mainly related to physical causalities such as processing time and material use. Overhead, not directly production-related, costs are a minor part of the total

value added in this case. Thus, value added as allocation method is in this case not an economical allocation, but describes weighted physical causalities.

- *Removed Material*
  The material that is removed in SKF in-house machining processes per F.U. is divided by the total removed material in the production channel and factory, respectively.
- *Process Time*
  The bottleneck time for the surveyed production channel, i.e. the time between finished F.U.'s, is divided by the running time, i.e. the total time when production takes place, for the concerned channel and the total of all channels, respectively.

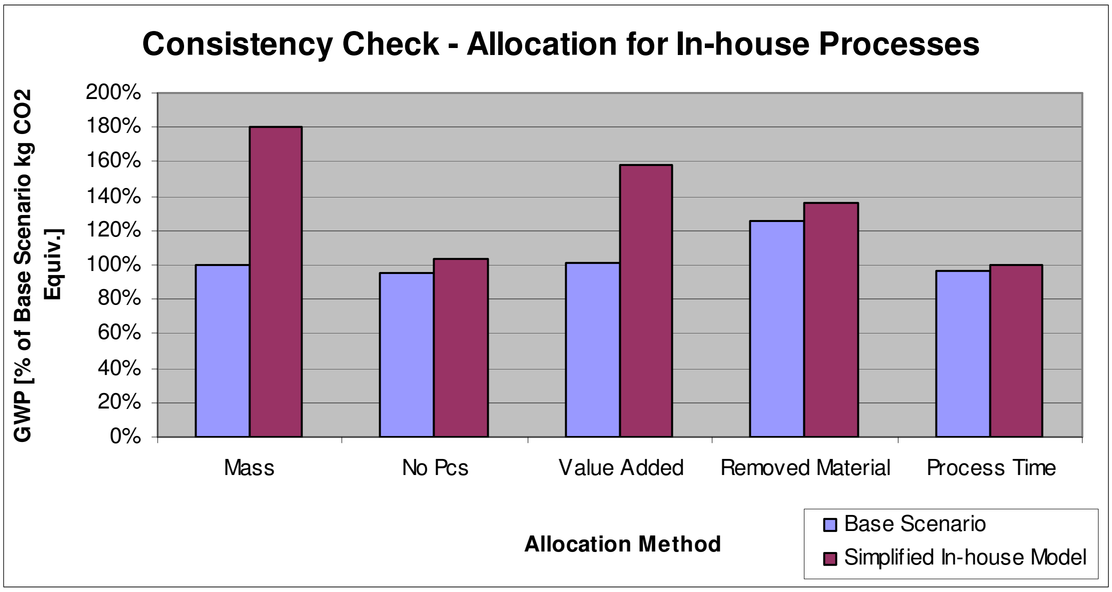

Figure 28 – Global Warming Potential, MSR1999:2, impact of allocation methods for in-house processes

Increased detail level in model will decrease the sensitivity for choices of allocation methods. This can be seen in Figure 28 where the variation of the result is much less for the Base Scenario with high level of detail compared to the Simplified Scenario. For example regarding allocation by mass the difference in mass per piece is not very high when comparing the types of bearing unit produced in the specific channel. On the other hand, in the case of the simplified modelling of in-house processes, all flows, except components for the product, are allocated from facility level. Using allocation by mass, the difference between the average mass per delivered piece and the mass per piece for the modelled type of bearing unit is quite high. The result for allocation by mass from facility level is therefore significantly different from the result when using another allocation method, e.g. number of pieces, where the relation between facility and channel level is different.

Mass is the primarily used allocation method in this study, and according to findings from Figure 28, it is a reliable choice. The result can be concluded to be reliable because the results for the Base Scenario, i.e. when data is collected on a high level of detail, is of the same magnitude as for any of the other allocation methods, except for allocation by removed material which gives an approximately 25 % higher GWP than allocation by mass. It should be noted, as seen in Figure 28, that mass it not a good choice when data is collected on a lower level of detail, i.e. the Simplified Scenario.

8.2.5 Sensitivity Analysis

The sensitivity analysis aims at evaluating whether unit processes with insecure data have a high impact on the result. The focus is put on processes with a major contribution to the environmental impact.

8.2.5.1 Electricity Mix

The first point of focus is the used power grid mix. This dataset is used as replacement for the national average power grid mix for Italy, which is the initially used dataset for SKF's processes in Italy. As it became clear, at a late stage of the study, that a so called green power grid mix is used, the results from an updated model showed significantly different results. Therefore the impact of the used power grid mix for SKF Italia is clarified here. The focus on this dataset is of high importance, as it is important for the potential reuse of the results. In other situations with production of similar products it may be that electrical power corresponding to the average national power grid mix is used for most processes, including SKF processes, and in that case the pattern will be different form the results of this study, which is shown in Figure 29.

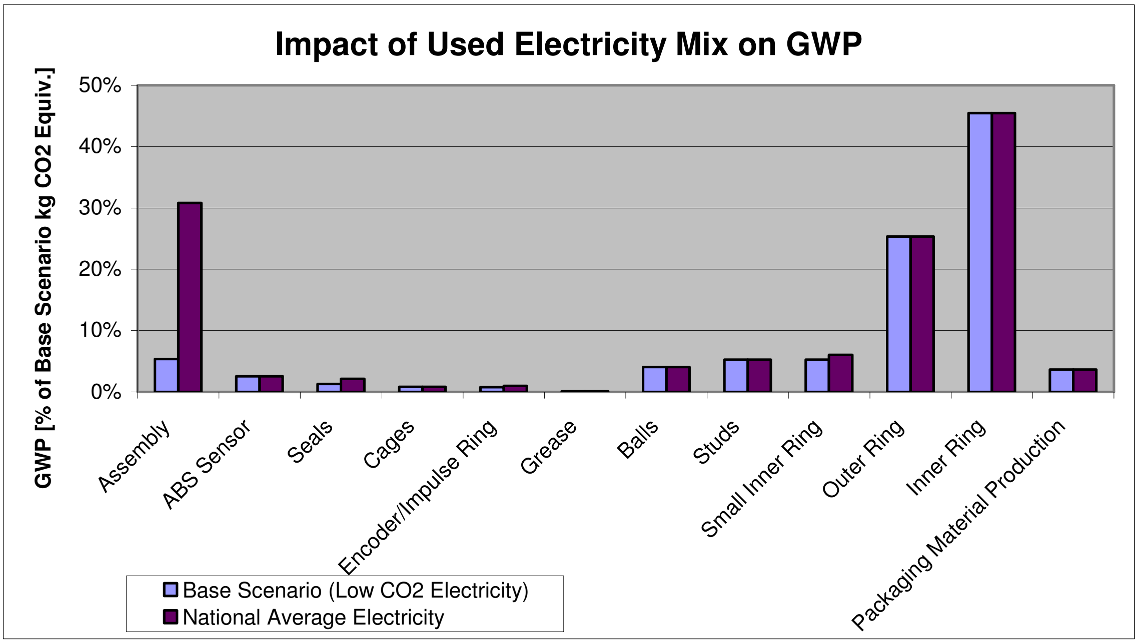

Figure 29 – Global Warming Potential, MSR1999:2, sensitivity analysis per activity including upstream processes; Comparison of national average versus low CO2 electricity mix for SKF operations.

It is seen in Figure 29 that the used power grid mix has a major impact on the pattern for activity dominance in the cradle to gate life cycle, i.e. the use of low CO2 electricity mix will result in a minor impact from in-house assembly processes. It can also be seen in that the total impact, in this case as global warming potential, will increase significantly if a national average power grid mix is used for SKF Italia. This is an expected situation, as the purpose of choosing a so called green power grid mix is to decrease carbon dioxide emissions, and thus also the global warming potential will decrease.

Further survey of this issue is shown in Figure 30 where a European energy background system is applied to Ekdahl's (2001) energy related LCI-data and compared to the results of this study.

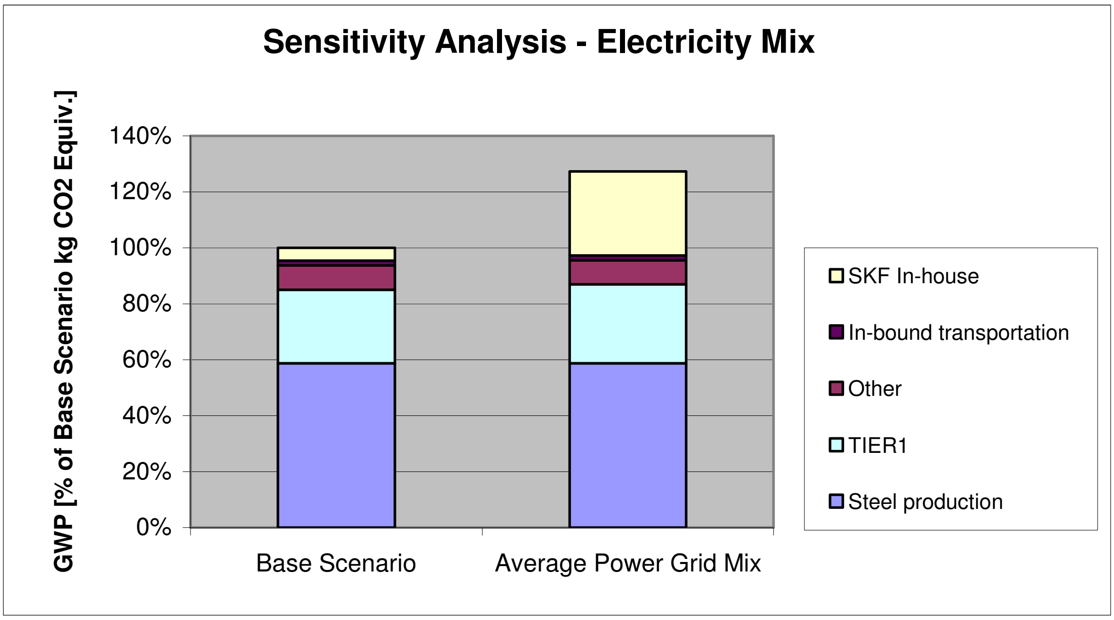

Figure 30 – Global Warming Potential, MSR1999:2, sensitivity analysis; Comparison between base scenario and use of average electricity mix

It is clear from Figure 30, comparing the *Base Scenario* with *Average Grid Mix*, that the use of a so called green electricity mix has a substantial impact on the result, specifically for SKF in-house processes. This quality of this dataset is thus very important to the result of the study. As exact data for the actual composition of the electricity mix is available as well as datasets representing the concerned types of power generation processes, it is assumed that the dataset has sufficient quality in relation to the scope of this study.

8.2.5.2 Steel Production

The second focused activity is production of steel bars from recycled steel. It is shown in Figure 23 that the activities related to Inner and Outer Ring production are dominant in the cradle to gate life cycle, and that steel production is the dominant activity category is shown in Figure 24. To assure that the used data is reliable, the energy use in the used datasets is compared with each other and with other relevant data to assure that the energy flows are of similar magnitude when so is expected. In this case the following data is adjusted to equal mass of steel and compared;

- *Results from this study;* Base Scenario
- *Results from Ekdahl (2001);* Ekdahl EU Background.
- *Steel energy data;* collected from one of SKF's major steel suppliers with the Supplier CO2 reporting questionnaire.
- *Theoretical energy data;* calculated values for steel heating and treatment.

The results showed that the data is of similar magnitude and thus the used datasets should be relatively reliable.

8.3 Variation Analysis

The case studies in the variation analysis, where different input parameters are varied, will answer the questions specified in the goal definition that are not answered through analyses carried out as part of the previous steps of the interpretation phase.

8.3.1 Reduced Environmental Impact by In-House Changes

In the dominance analysis (Section 8.1.1) it is shown which activities that cause a major environmental impact during the cradle to gate life cycle. The question is how SKF can influence these processes. To answer the questions defined in the goal, it must be shown which changes in SKF's in-house processes that will give a major improvement of the environmental performance of the product. To do this, four scenarios are evaluated apart from the base scenario. Considering the findings on impact from steel related activities, changes influencing material use, mainly steel, will be surveyed. Furthermore it is examined what environmental impact a reduction of SKF's in-house steel use will have on the product cradle to gate life cycle environmental performance. For each scenario a change of ten percent is applied and the impact is evaluated. The scenarios that are evaluated and compared to the base scenario are;

- *Reduction of scrap rate*
  This means reduction of the amount of components and finished products that are scrapped due to defects from suppliers or process-caused failures.
- *Reduction of SKF in-house electricity use*
  Higher energy efficiency can be achieved through improvement of production processes and support systems, and lead to a lower use of electric energy.
- *Reduction of the removed material in SKF in-house processes*
  By working further towards a so called near-net shape for forged rings, the material that need to be removed in machining processes can be reduced. This gives reduction of in-house processing as well as reduction of upstream steel processes.
- *Reduction of the input mass of steel components*
  Actually, this more refer to reduction of product mass, which consequently gives less input mass of steel. To do such a change, product development efforts are required.

The scenarios give very different results and the change in GWP per scenario in percent is shown in Figure 31.

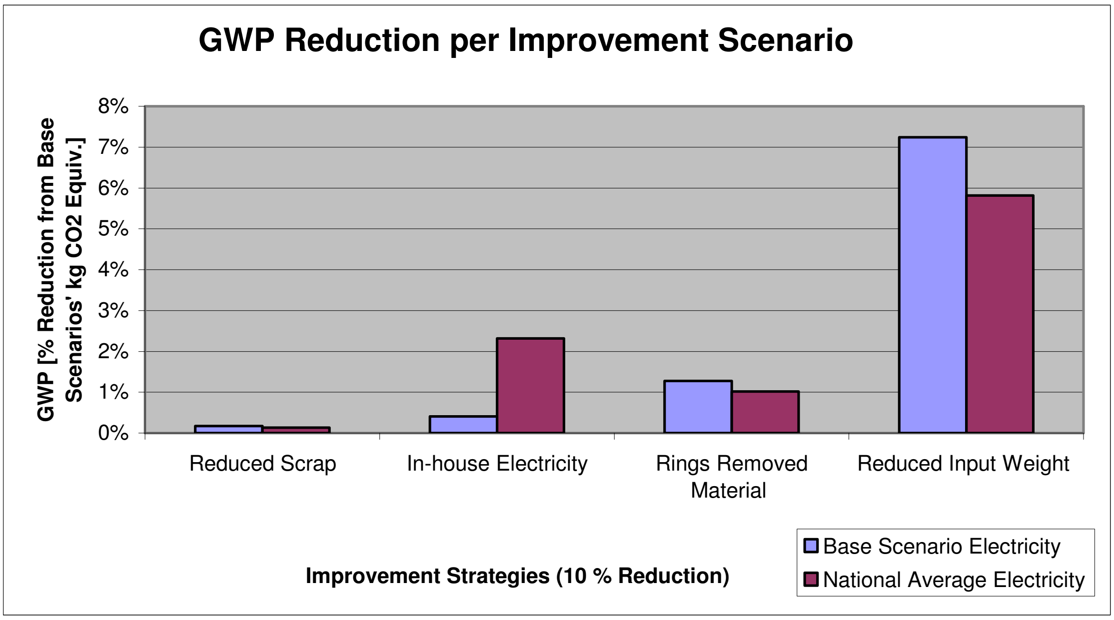

Figure 31 – Reduction of GWP per Improvement Scenario

For the situation in the base scenario, a reduction of the input mass of steel is the improvement scenario with highest impact on GWP. This is very much related to the energy intensity of steel production. Improvement according to this scenario refers to product development, since product redesign is required to achieve these changes. To reduce the removed material on rings, i.e. reduce the mass of input forged rings, the capability of the process must be increased. This scenario consequently corresponds to a focus on process development. The very low impact of reduction of in-house electricity use can be explained by the use of a so called green electricity mix, i.e. low CO2 per energy unit. The improvement scenario focused on less scrap gives an almost negligible impact, much because the scrap rate already is very low.

If national average electricity is used for all processes, the situation will be different. In that case reduction of in-house electricity use will be a rewarding improvement scenario as well.

9 Results

Here, results are concluded and related to the questions stated in the goal (Section 5.1)

9.1 Activities with Major Environmental Impact

Statements in this section are related to the cradle to gate life cycle of the product.

- Production of bearing rings is the production activity with the dominant contribution to environmental impact, accounting for 76 % of global warming potential.
- Steel production is the major contributing type of activity, accounting for 58 % of global warming potential.
- SKF in-house processes are a minor contributor in this specific case, with a contribution to global warming potential of 5.4 %.
- If a national average power grid mix would have been used instead of a so called green electricity mix for SKF in-house processes, the contribution to global warming potential would have been 24 %.
- The major environmental impact is caused by non-SKF operations and will not be reported in the current CO2 reporting scheme. Thus, SKF's commitment to report CO2 emissions including scope 3 emissions according to the Greenhouse Gas Protocol is fully in line with the products' environmental performance.

9.2 Allocation Strategy

- SKF's Energy Breakdown Method gave a mismatch of 16 % for channel energy use.
- Data should as far as possible be collected on channel level rather than factory level to reduce the sensitivity for choice of allocation method.
- For the concerned type of bearing unit, produced in a production system where the multi-output products are of similar complexity, the least sensitive allocation methods are allocation by number of pieces and processing time.

9.3 Reduced Environmental Impact by In-house Changes

- The main potential for improvement of product cradle to gate life cycle environmental performance can be seen in reduction of steel content of the product, which refers to focus on product development.
- In a case where national average power grid mix is used for in-house processes, reduction of in-house electricity use is a rewarding improvement scenario.

Development towards near-net-shape for incoming steel components by means of increased process capability will give approximately 1 % reduction of GWP per 10 % decreased mass of removed material.

10 Discussion

In this section the results are related to the overarching purposes of the study and it is discussed how the results can be applied in SKF.

10.1 Activities with Major Environmental Impact

The results show that ring production is the upstream flow with the highest environmental impact in the cradle to gate life cycle for the product, whilst steel production is the activity category with the highest environmental impact. These results are clear and the relation to other activities appear to be indubitable; activities related to steel production and processing are the major contributors to environmental impact.

The picture can though change quickly in the iterative process of acquiring new data, as for the electricity mix used for SKF in-house processes. As long as national average electricity mix was used, in-house processes accounted for a substantial part of environmental impact, but when this was adjusted to a low CO2 electricity mix, the proportion fell from 24 % to 5.4 % of global warming potential. This show that preliminary results can be substantially inaccurate and that datasets that could amount for a potentially higher impact must be thoroughly evaluated for accuracy. The electricity mix should also be further evaluated to ensure that the used allocations are representative.

A similar scenario was experienced for studs, which initially were assumed to be produced from virgin steel. At a late stage it became clear that the major part of steel wire supplies for stud production came from recycled steel. As studs is a minor product compared to ring production, the impact of this change was not too big, but issues like this can have a major impact, in this case mostly due to the much higher energy requirements for producing steel components from virgin rather than recycled steel. It can also be mentioned that the impact from small ring production is not completely representative as the used dataset is based on the use of virgin steel only, whilst the actually used steel is produced from 25 % recycled steel. Consequently, the used dataset represent a conservative scenario and the results from the modelled system will show a higher environmental impact than the actual environmental impact.

Due to its major contribution to the environmental impact, the dataset to which the result is most sensitive is the steel bar production and flows and processes upstream of this. The data for the currently used steel bar dataset was acquired nine years prior to the base year of this system model, i.e. 1998 related to 2007. Furthermore, emissions to air and water are not completely accounted for in the used datasets for steel bar production. Consequently it is uncertain whether this is still representative or if process changes have resulted in a different pattern for resource use and emissions. On the other hand, the functional unit of the used dataset is more or less equal to the actual system which may not be possible to achieve if another dataset is used. This must be further investigated, and preferably site-specific data should be collected for future studies. This uncertainty should not cause any changes in the conclusions and results of this report, as the shown patterns are very apparent.

The reasons for inaccuracy in datasets can be many, including erroneous assumptions or information resulting in the use of non-representative datasets, as initially was the case for the in-house electricity use. Another potential source of errors can be whether all emissions to air and water are included or not. This might be an issue regarding the results of this report, as a thoroughly evaluation of the contribution to environmental impact from these emissions have not been performed in the cases where they are not included. This primarily refers to the direct supplier for which site-specific data has been collected. For these direct emissions from the facility to air and water are only included for incineration activities. For SKF in-house processes emissions to water are not included. Since emissions of CO2 are included for all incineration of fossil fuels the credibility of results for global warming potential is high and that is where the focus of the analysis is for this report, which further strengthens the overall results and conclusions. It would be valuable to survey the impact of other emissions to air and water in further studies.

One other aspect that is not included to a very high extent due to lack of easily accessible data is the production of chemical compounds. Data for the flows is acquired in most cases but no upstream processes are connected, i.e. this part can be relatively easily updated when suitable datasets are acquired.

In general, an increase of the proportion of site-specific data would be valuable. If that is not possible, shorter supplier visits will lay down the representativeness of used datasets and ensure that flows are of a magnitude corresponding to the actual system.

10.2 Allocation Strategy

In general, the lower the level of detail, i.e. the more aggregated flows that is acquired, the higher the importance of a correct allocation methodology. This shows the added value of increased level of detail in energy data collection. The uncertainty and the dependence of choice of allocation method will decrease with increased level of detail in the model. An increase in level of detail for data acquisition will result in rapidly growing amounts of data which may be hard to manage in an efficient way. It is crucial to find the level of detail for data collection that is sufficient to be able to answer the goals of the study. It is likewise crucial to not exceed that level of detail whilst this will complicate and prolong the modelling of the product life cycle.

An increased level of detail will reduce the risks with allocation, but use of measured electricity and other energy carriers such as process fluids and compressed air on machine level will not pay off for an LCA aiming at identification of improvement potential. The energy breakdown method is very valuable to identify energy waste and improve energy efficiency on machine level, but the results are not satisfying for accounting LCA purposes. The result from energy breakdown method gives a 10 % lower electric energy use than measurements for the whole channel. From the results shown in this report, it is suggested that such a method shows a lower energy use than the actual case.

The mismatch is probably a result of incorrect calculations of the time in the different statuses, but irrespective of the reason for the mismatch, it indicates that also calculation of energy use from installed power and running time may give incorrect results. The reasons for the error between calculation and measurement might comprise;

- Machines not to entering waiting status immediately after running cycle
- Errors in data or calculation of cycle time
- Increased values for permanent meter because the electrical distribution system is not well documented and limited to the specific channel
- Rework and scrapping that result in that the number of processed work pieces is higher than the delivered, where the delivered pieces are used for the calculation.

Some questions are still present for specific allocation choices. For example regarding process fluids, it is quite straightforward to use the volume supplied to a production channel as basis for allocation to channel level. It is though uncertain if the flows to all channels add up to the total flow of the central systems. For example the use of bypass flows to regulate the system may result in flows not accounted for and thus in inaccuracy of the model. As long as the actual distributed flow is not measured it is unknown, and thus it is hard to know the distributed volume to which power use is allocated actually correspond to the total volume distributed to the channels.

When flows are allocated to channel level, as described for process fluids above, it must be decided how to allocate to F.U.. Many allocation strategies can be used, but according to the ISO standard physical causalities should be utilised the primarily used strategy. When assessing a bearing product the main work carried out is related to the amount of deformed material and consequently also to removed material, as material must be deformed to be removed. Consequently it seems viable to use the mass of the product, or component, or the amount of removed material, as basis for allocation. When assessing the results from the allocation comparison it does though become clear that the sensitivity of these allocation methods is high, i.e. the result is very different depending of the level from which the allocation is performed. The reason for this seeming low causality between manufacturing process resource use and amount of deformed material, i.e. mass or removed material, may be derived to the pattern of machine energy use. When looking into data for electricity and process fluid use it is seen that the levels are quite high even when processing is not under way and that the difference between running and waiting status often is quite small. This indicates that the proportion of machine energy use that is actually related to the material deformation is relatively small which explains the high sensitivity of the allocation methods that are directly related to material deformation causalities. It seems that allocation methods more related to product complexity and equipment utilisation, such as number of pieces and processing time, are less sensitive to level of detail of data collection and thus are more reliable. It must though be stressed that this is the case for the surveyed production system, where the products are of equal type and complexity, the situation will most certainly be different in cases where the output from a production system is more diversified in terms of product complexity and manufacturing processes.

Allocation for the suppliers from which site-specific data is collected has not been thoroughly surveyed. Primarily the superior process knowledge of the suppliers is trusted, but it is unclear whether lacking insight in LCA methodology from the suppliers is a reason for use of non-preferable allocation methods. Due to time restraints and problems to acquire data different allocation methods are not evaluated. In most cases the upstream flows are well known and data for these collected on product level and thus the risk of further propagation of errors caused by allocation uncertainty should be limited.

The methodological choices are many and in order to achieve a homogenisation of allocation strategies for LCA's within SKF the first step is to make sure that acquired knowledge and experiences from LCA studies is documented in a standardised way. This data can then be used to continuously develop and improve guidelines for the direction of the methodological choices.

10.3 Reduced Environmental Impact by In-house Changes

The comparison of improvement scenarios to reduce environmental impact by in-house changes is made with a ten percent reduction of different factors. This reduction is a purely hypothetical value that is not related to the actual difficulties in achieving changes for the factors. Each improvement scenario does also correspond to a specific part of the organisation, which is further described for each improvement scenario below.

Regarding reduction of final product mass, this is of high importance to product performance and even more important with the raising steel prices of today, and thus it can be assumed that focus has already been on this aspect for quite some time. Consequently it will probably be hard to achieve quick improvements of this parameter. The final product mass is a parameter that is directly related to product development and thus improvement of this will have to start with product development which means that the time perspective is relatively long compared to e.g. reduction of in-house electricity use.

For reduction of in-house electricity use it can be assumed that a lot of work is still to be done as energy costs have been a relatively low up until today but can be expected to raise due to scarcity of energy resources. As shown in the results, the impact on global warming potential from a reduction of in-house electricity use is relatively low with the methodological choices used in this study. This is due to the low CO2 electricity mix that is used for in-house processes. It should though be noted that the situation will be different for other production systems where a national average electricity mix is used. If seeing the picture on a global level, a reduction of energy use for processes using a low CO2 electricity mix will though increase the available energy from renewable resources and decrease the marginal use of fossil energy sources. The focus area to achieve a reduction of in-house electricity use should be process development.

For reduction of the amount removed material, an increase in capability of the process could allow further changes towards near-net-shape for the incoming material. Consequently a process focus is the way to improve this factor. Just as for product mass, steel prices are driving improvement in this direction. A reduction of removed material also means a reduction of mass of incoming material, and thus this will influence the whole upstream flow.

When it comes to reduction of scrap rate, this is naturally also a work that has been in focus for a long time, both for cost and quality reasons. The impact of reduction of scrap-rate is in this case very low, much due to an already low rate. Further improvement will request focus on supplier development to reduce defects for incoming goods, and also focus on process development to reduce scrap due to process errors.

In order to communicate and make sure that proposed improvements are carried out, the way the results are presented is crucial. It is also important to make sure that proposed improvements are well founded with the function that are to act upon them, to increase the credibility of the recommendations in their eyes. A reduction of the different factors by ten percent give different impact on global warming potential, but even more guidance can be given if a price is put on the changes, or if the changes can be related to the complexity of carrying them out. We want to maximise the reduction of global warming potential per invested amount. Further, it can be discussed whether an upstream process with an environmental impact that is directly dependent of in-house activities, e.g. removed material and scrap generation, should be accounted to the in-house activities. This would mean that a certain proportion of the pollutants emitted by e.g. the ring producer should be accounted to the in-house processes because this part of the emissions can be reduced by in-house changes. Or, put differently, environmental impacts should be accounted to the function in the life cycle that has the highest potential to influence it.

11 Recommendations

To achieve an increased homogenisation of methodological choices for LCA's within SKF, consider following;

- Implement the use of LCA project white-books to document knowledge and experiences from performed LCA's.
- Continuously evaluate methodological choices in LCA's and use this to develop guidelines for performing LCA's within SKF.
- Whenever an increase of level of model detail is inappropriate, process time and number of pieces should be the primary allocation methods for in-house processes if the system has a high likeness to the system in this study.
- SKF's Energy Breakdown Method is not suitable for LCA data collection unless improvement of in-house energy efficiency is a surveyed issue. In that case the method will give valuable information about how to decrease energy use for the manufacturing channel.

The credibility and usability of LCA results can be improved through;

- Broaden scope of LCA's by including; production of chemicals and abrasives, emissions to air and water whenever so is not already done, and end of life and waste treatment.
- Further survey how calculations should be performed for the used electricity mix where low CO2 energy sources used.
- Review and update data for dominant parts of life cycle, especially steel bar production.
- Perform a corresponding study, or expand this one, to include use phase and relate the results to SKF's BeyondZero initiative.

The environmental performance for the bearing unit cradle to gate life cycle can be achieved by;

- Focus on product mass reduction in product development.
- Improvement focus on reduction of in-house electricity use should be evaluated, especially where a national average electricity mix is used, i.e. focus on process development.
- Reduce the mass of removed material by means of process development towards near-net-shape.
- Further evaluate improvement scenarios by relating them to cost and level of difficulty.

New focus areas for improvement of product life cycle environmental performance in future LCA's can be found by;

- Include production of chemicals to a higher extent.
- Acquire more comprehensive data for direct emissions.
- Include use phase and end of life treatment.

12 References

12.1 Publications

Baumann, H. (1998) *Life cycle assessment and decision making. Theories and practices.* PhD thesis, Chalmers University of Technology, Göteborg, Sweden. ISBN 91-7197-600-0, ISSN 0346-718X

Baumann, H. and Tillman, A-M. (2004) *The hitchhiker's guide to LCA : an orientation in life cycle assessment methodology and application*. Lund: Studentlitteratur. ISBN 91-44-02364-2

Chalmers University of Technology (1998) *Skrivregler och typografiska råd.* Swedish. Informationsavdelningen Chalmers tekniska högskola

Ekdahl, Å. (2001) *Life Cycle Assessment on SKF's Spherical Roller Bearing*. Report 2001:1. Göteborg, Sweden. Chalmers University of Technology, Department of Environmental Systems Analysis. ISSN 1400-9560

Gutowski, T.,J. Dahmus, and A. Thiriez (2006). *Electrical Energy Requirements for Manufacturing Processes*. In 13th CIRP International Conference on Life Cycle Engineering,
Leuven, May 31st – June 2nd, 2006

Guinée, Jeroen B. (Ed.) (2002) *Handbook on Life Cycle Assessment - Operational Guide to the ISO Standards Series: Eco-Efficiency in Industry and Science*, Vol. 7, 708 p., ISBN 978-1-4020-0557-2

Gäbel, K. (2001) *A life cycle process model - Simulation of environmental, production and economic performance in cement production*. Report 2001:1. Göteborg, Sweden. Chalmers University of Technology, Department of Environmental Systems Analysis.

ISO 14040: 2006 (2006) *Environmental management -- Life cycle assessment -- Principles and framework*. International Organization for Standardization

ISO 14044: 1998 (1998) *Environmental management - Life cycle assessment - Requirements and guidelines*. International Organization for Standardization

Li, Y. (2006) *The importance of buildings' environmental impact in life cycle assessment : a case study of SKF's spherical roller bearing 24024*. Report 2006:15. Göteborg, Sweden. Chalmers University of Technology, Department of Environmental Systems Analysis. ISSN: 1404-8167

Logaras, D. (2008) *Life cycle inventory data collection for first tier suppliers : a case study of a bearing unit.* Report 2008:11. Chalmers University of Technology, Department of Environmental Systems Analysis.

Löfgren, Birger (2008) *Added value of following ISO14044 allocation rules for electricity use in manufacturing industry*. SETAC Europe 14th LCA Case Studies Symposium, Göteborg.

Solding, P. and Petku, D. (2005) Applying energy aspects on simulation of energy-intensive production systems. *Proceedings of the 2005 Winter Simulation Conference*, Orlando, FL, USA, Dec 4-7 2005, pp 1428-1432. ISBN 0-7803-9519-0

Solding, P. and Thollander, P. (2006) Increased energy efficiency in a Swedish iron foundry through use of discrete event simulation. *Proceedings of the 2006 Winter Simulation Conference*, Monterey, CA, USA, Dec 3-6 2006, pp 1971-1976. ISBN 1-4244-0501-7

12.2 World Wide Web

Chalmers University of Technology (2007) *SPINE@CPM Database*
http://cpmdb.imi.chalmers.se/SpineAtCPM/database/start.asp (2008-09-04)

Greenhouse Gas Protocol (2008) *The Greenhouse Gas Protocol Initiative – The foundation for sound and sustainable climate strategies*. http://www.ghgprotocol.org/ (2008-02-11)

IPCC (2008) *IPCC – Intergovernmental Panel on Climate Change*.
http://www.ipcc.ch/ (2008-02-11)

Michelin (2007) *ViaMichelin: street map, maps,…*
http://www.viamichelin.com/ (2007-11-01)

Maporama International (2006) *Welcome to Maporama.com*
http://www.maporama.com/ (2007-11-01)

NN Europe (2006) *EPD Environmental Product Declaration of Bearing Steel Balls*
http://www.environdec.com/reg/epd43e.pdf (2007-10-30)

Petromedia Ltd (2007) *PORTWORLD - Ship Voyage Distance Calculator*.
http://www.portworld.com/map/ (2007-11-01)

Revifa S.P.A. (2007) *REVIFA*
http://www.revifa.it/UK/homeUK.html (2008-01-08)

SKF (2002) *SKF Annual Report 2002 including Sustainability Report*
http://investors.skf.com/files/press/skf/SKF_annual2002_en.pdf (2007-11-25)

SKF (2008a) *SKF Annual Report 2007 including Sustainability Report*
http://investors.skf.com/files/press/skf/SKF_Annualreport2007_eng.pdf (2008-03-12)

SKF (2008b) *Welcome to the SKF Group – SKF.com*
http://www.skf.com (2008-01-30)

Swedish Environmental Management Council (2000). *Requirements for Environmental Product Declaration, EPD*. MSR 1999:2.
http://www.environdec.com/documents/pdf/e_epd_msr19992.pdf (2007-11-20)

World News Network (2007) *World Port Distances*.
http://www.distances.com/ (2007-11-01)

12.3 Personal Communication

Löfgren, Birger (2008) PhD Candidate. Chalmers University of Technology, Department of Energy and Environment, Division of Environmental Systems Analysis.

Tillman, Anne-Marie (2008) Professor. Chalmers University of Technology, Department of Energy and Environment, Division of Environmental Systems Analysis.

12.4 Other

GaBi4 (2007) Software and data base for Life Cycle Engineering, PE International GmbH and University of Stuttgart.

A Appendix – Inventory Datasets

This section include additional inventory data for the unit processes for which site-specific data has been acquired.

A.1 SKF In-house Facility

The SKF in-house facility is where the bearing unit is manufactured and assembled from upstream components and materials.

A.1.1 Flowchart

Here the main flows related to the in-house production system are presented.

A.1.1.1 HVAC System

The HVAC system is based on hot water as energy carrier. The water is heated by thermal energy from an adjacent biomass plant as well as from internal natural gas boilers. The hot water is distributed by a system of ventilation cabinets, supplying hot air throughout the factory through air ducts. A second system of small fans distributed around the facility is also supplied with thermal energy from the hot water system. The latter system does also run for ventilation during the warmer months.

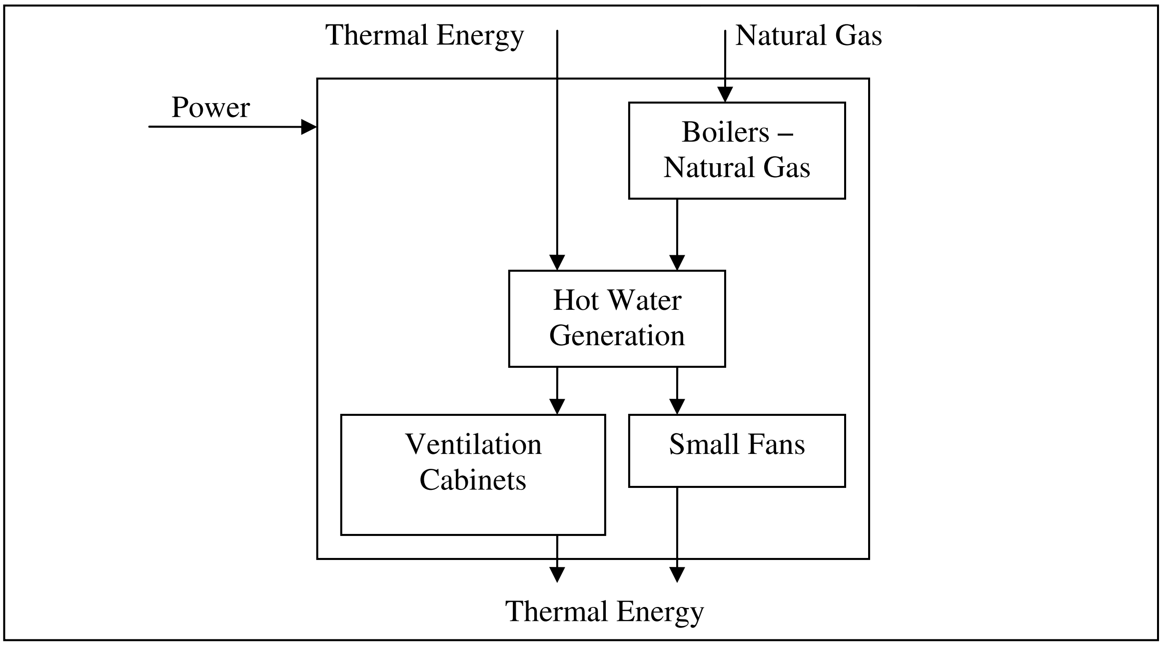

Figure 32 - SKF in-house; HVAC system

A.1.1.2 *Central Production Related Systems*

The central production related systems provide support functions directly related to production processes.

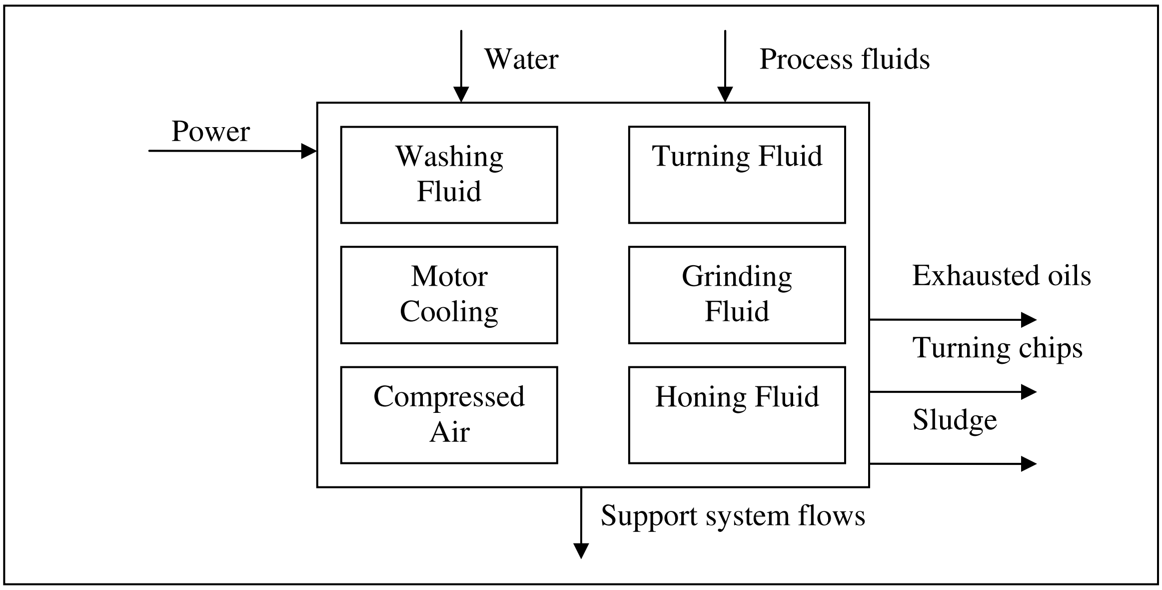

Figure 33 - SKF in-house; central production related systems

A.1.1.3 *General Central Systems*

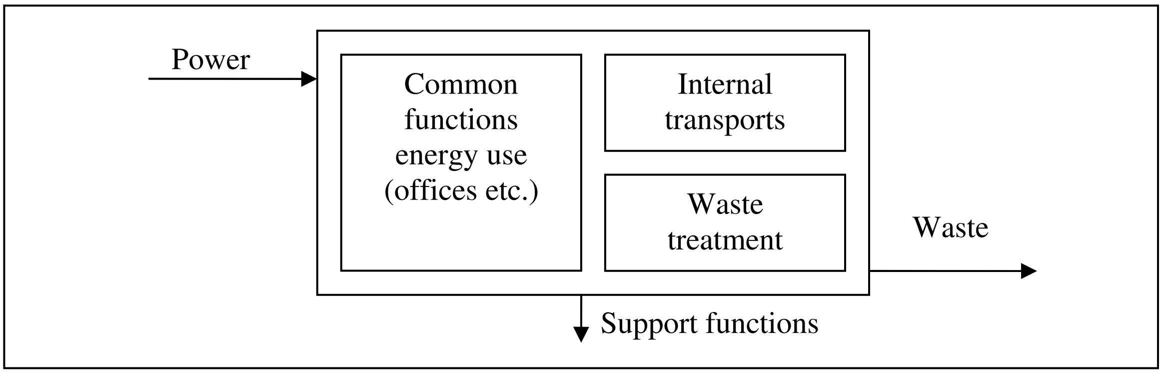

Figure 34 – SKF in-house; general central systems

A.1.2 Dataset documentation

A.1.2.1 *Product*

The product is a bearing unit.

A.1.2.2 *Functional Unit*

The functional unit is one kg of bearing unit manufactured in Italy and ready for delivery from the facility to the customer.

A.1.2.3 Time Horizon

Mainly annual averages calculated from data collected for the first three quarters of 2007. Some of the production data is based on 2007 production plan. Waste data and some other data are from 2006.

A.1.2.4 System Boundaries

This is a gate-to-gate dataset, to which adequate data for upstream processes must be related. The inventory data is though calculated without influence from these upstream processes.

The data is collected from SKF's facility in Italy. The background system can be adjusted to fit the system in other countries.

A.1.2.5 Allocation methods

The allocation is mainly based on mass.

For directly product related inputs, i.e. raw material and components, specific data is used.

Electricity is measured on channel level. Compressed air and process fluids except for motor cooling water are measured on channel level and assigned a calculated proportion of the respective central system resource use. Motor cooling water is allocated to by removed material to channel level. All these flows are thereafter allocated to F.U. from channel level by mass.

Electricity use for respective central system and HVAC are measured separately.

Other support flows and waste flows are allocated from facility level.

$$\text{Input support and waste per kg bearing unit} = \frac{\text{Input for entire facility}}{\text{Delivered bearing unit [kg]}}$$

A.1.2.6 Additional Information

Emissions to air are included, calculated from data for each chimney, but emissions to water are not.

Electricity and thermal energy for support operations, i.e. administration etc., are included in the dataset.

A.1.3 LCI Results from Gate-to-Gate

Removed due to confidentiality

A.2 Cage production

Cages for the bearing unit are produced by injection moulding of polyamide granulate.

A.2.1 Flowchart

Here the main flows in the cage production system are presented.

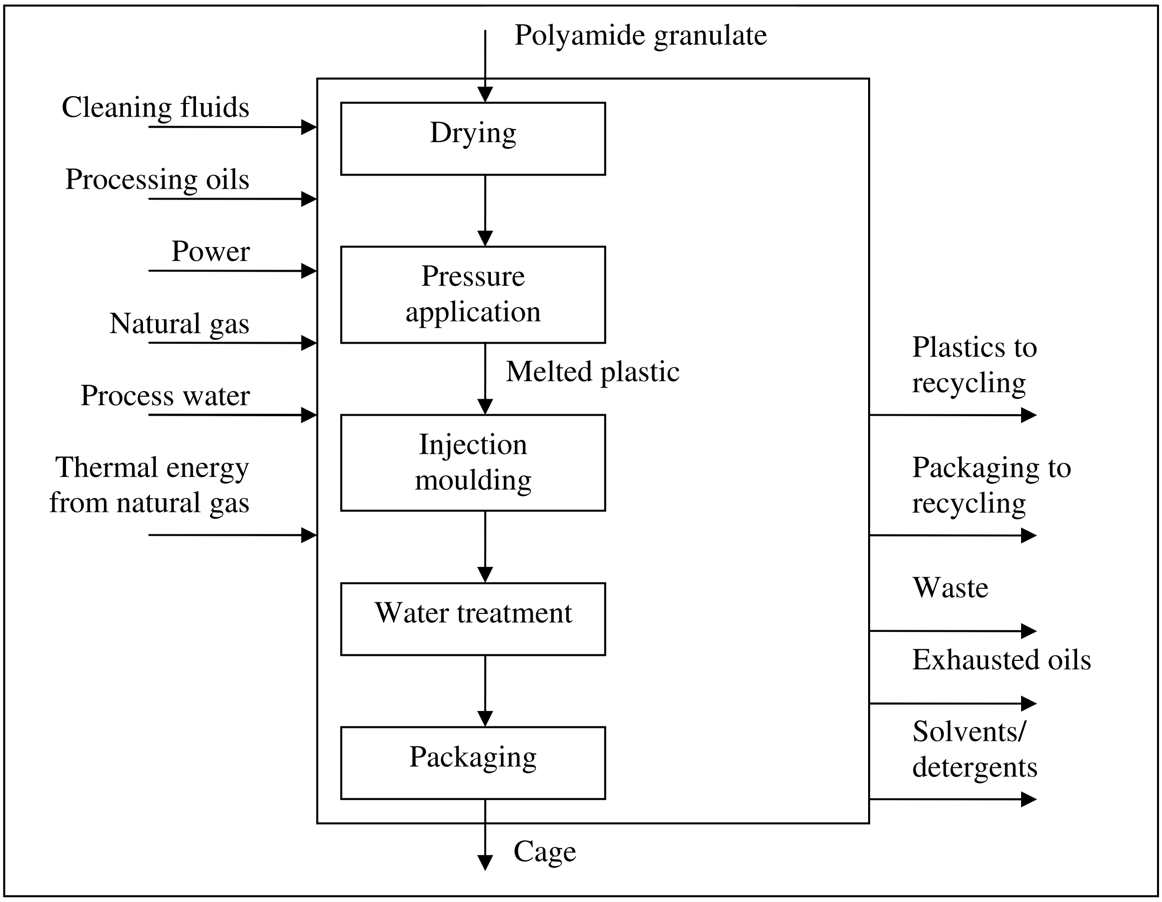

Figure 35 - Cage production; modelled gate-to-gate system

A.2.2 Dataset Documentation

A.2.2.1 Product

Injection moulded bearing cages for bearing unit produced from polyamide granulate.

A.2.2.2 Functional Unit

The functional unit is one kilogram of bearing cage bearing units.

A.2.2.3 Time Horizon

Annual averages calculated from data collected for the first three quarters of 2007.

A.2.2.4 System Boundaries

This is a gate-to-gate dataset, to which adequate data for upstream processes must be connected. The inventory data is though calculated without influence from these upstream processes.

The data is collected from a manufacturer in Italy. The background system can be adjusted to fit the system in other countries.

A.2.2.5 Allocation Methods

The allocation is based on mass.

Directly product related inputs, i.e. raw material, are allocated from product type level.

$$\text{Input raw material per kg cage} = \frac{\text{Input raw material for cages [kg]}}{\text{Delivered cages [kg]}}$$

Support and waste flows are allocated from facility level.

$$\text{Input support and waste per kg cage} = \frac{\text{Input for entire facility}}{\text{Delivered cages [kg]}}$$

The contribution from the moulding part of the facility is estimated from facility totals by qualified personnel at the concerned company.

A.2.2.6 Additional Information

Emissions to air and water are not included, whilst complete data was not available.

Electricity and thermal energy for support operations, i.e. administration etc., are included in the dataset.

A.2.3 LCI Results from Gate-to-Gate

Removed due to confidentiality

A.3 Seal production

The Seals are produced from a metal insert and rubber in a compression moulding process.

A.3.1 Flowchart

Here the main flows in the seal production system are presented.

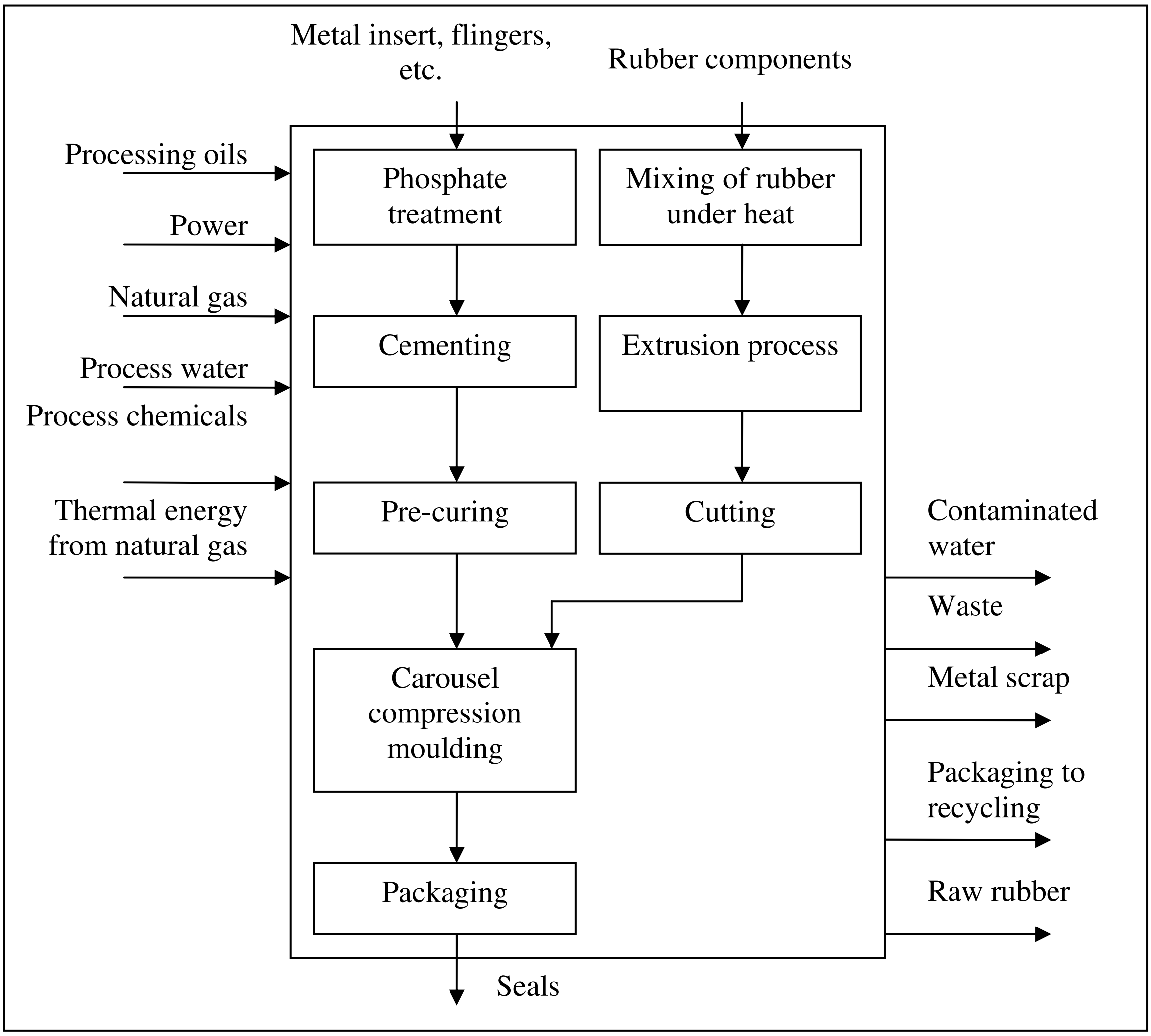

Figure 36 - Seal production; modelled gate-to-gate system

A.3.2 Dataset Documentation

A.3.2.1 Product

Compression moulded seals for bearing units produced from metal insert and rubber.

A.3.2.2 Functional Unit

The functional unit is one kilogram of bearing seal for bearing units.

A.3.2.3 Time Horizon
Annual averages calculated from data collected for the first ten months of 2007.

A.3.2.4 System Boundaries
This is a gate-to-gate dataset, to which adequate data for upstream processes must be connected. The inventory data is though calculated without influence from these upstream processes.

The data was collected from a manufacturer in Italy. The background system can be adjusted to fit the system in other countries.

A.3.2.5 Allocation Methods
The allocation is based on mass. All production in the facility concerns the same type of processes, but the products are of differing dimensions. The processing mainly comprises material forming processes, and thus the used energy depends on the amount of formed material, consequently mass should be an adequate allocation method.

Directly product related inputs, i.e. raw material, are allocated from product type level.

$$\text{Input raw material per kg seal} = \frac{\text{Input raw material for seals [kg]}}{\text{Delivered seals [kg]}}$$

Support and waste flows are allocated from facility level.

$$\text{Input support and waste per kg seal} = \frac{\text{Input for entire facility}}{\text{Delivered seals [kg]}}$$

A.3.2.6 Additional Information
Emissions to air and water are not included, whilst complete data was not available.

Electricity and thermal energy for support operations, i.e. administration etc., are included in the dataset.

A.3.3 LCI Results from Gate-to-Gate

Removed due to confidentiality

A.4 Metal Insert / Flinger Production

Metal inserts and flingers are used as components in the production of seals. They are produced by pressing of stainless steel strip.

A.4.1 Flowchart

Here the main flows in the metal insert / flinger production system are presented.

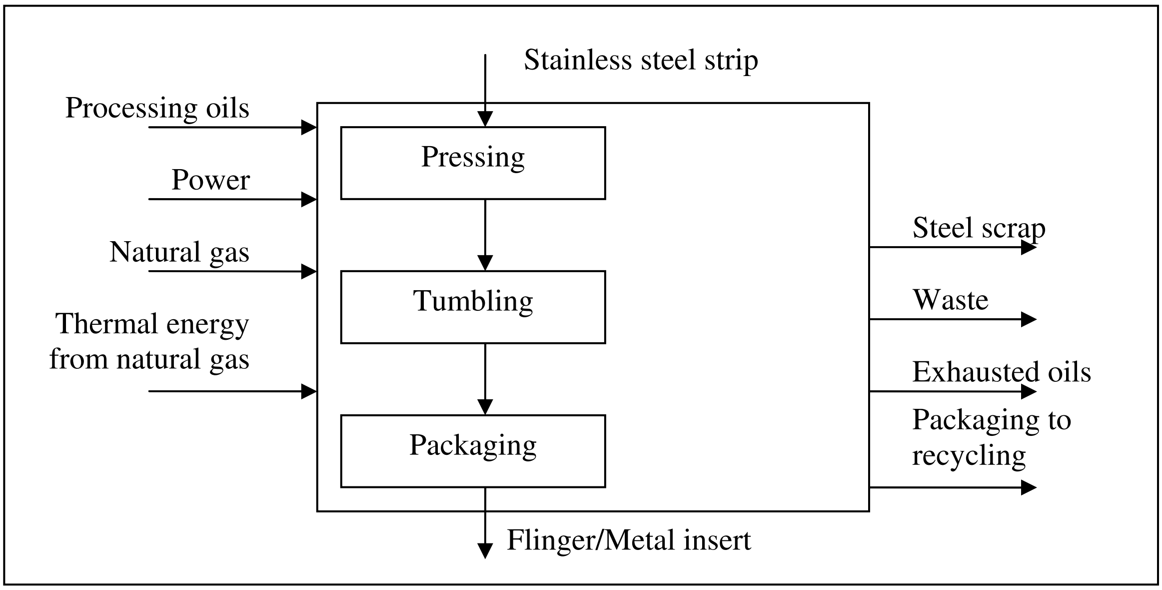

Figure 37 - Metal insert/ flinger production; modelled gate-to-gate system

A.4.2 Dataset Documentation

A.4.2.1 Product

Metal inserts and flingers for use in bearing units, both as components for seals and as free-standing components.

A.4.2.2 Functional Unit

The functional unit is one kilogram of metal insert / flinger for bearing unit applications.

A.4.2.3 Time Horizon

Annual averages calculated from data collected for the first three quarters of 2007.

A.4.2.4 System Boundaries

This is a gate-to-gate dataset, to which adequate data for upstream processes must be connected.

The data was collected from a manufacturer in Italy. The background system can be adjusted to fit the system in other countries.

A.4.2.5 Allocation Methods

The allocation is based on mass.

Directly product related inputs, i.e. raw material allocated from product type level.

$$\text{Input raw material per kg product} = \frac{\text{Input raw material for flingers [kg]}}{\text{Delivered flingers [kg]}}$$

Support and waste flows are allocated from facility level. Also here mass would be preferable, as the energy use is directly related to the amount of formed material, but due to lack of data this allocation of facility totals to product is done based on produced pieces.

Other flows and waste per kg flinger =

$$\frac{\text{Input for entire facility}}{\text{Delivered products [No. pcs.]}} * \text{Flingers [No. pcs. / kg]}$$

A.4.2.6 Additional Information

Emissions to air and water are not included, whilst complete data was not available.

Electricity and thermal energy for support operations, i.e. administration etc., are included in the dataset.

A.4.3 LCI Results from Gate-to-Gate

Removed due to confidentiality

A.5 ABS Sensor Production

ABS sensors for bearing units are produced from four components, the main parts produced by injection moulding.

A.5.1 Flowchart

Here the main flows in the ABS sensor production system are presented.

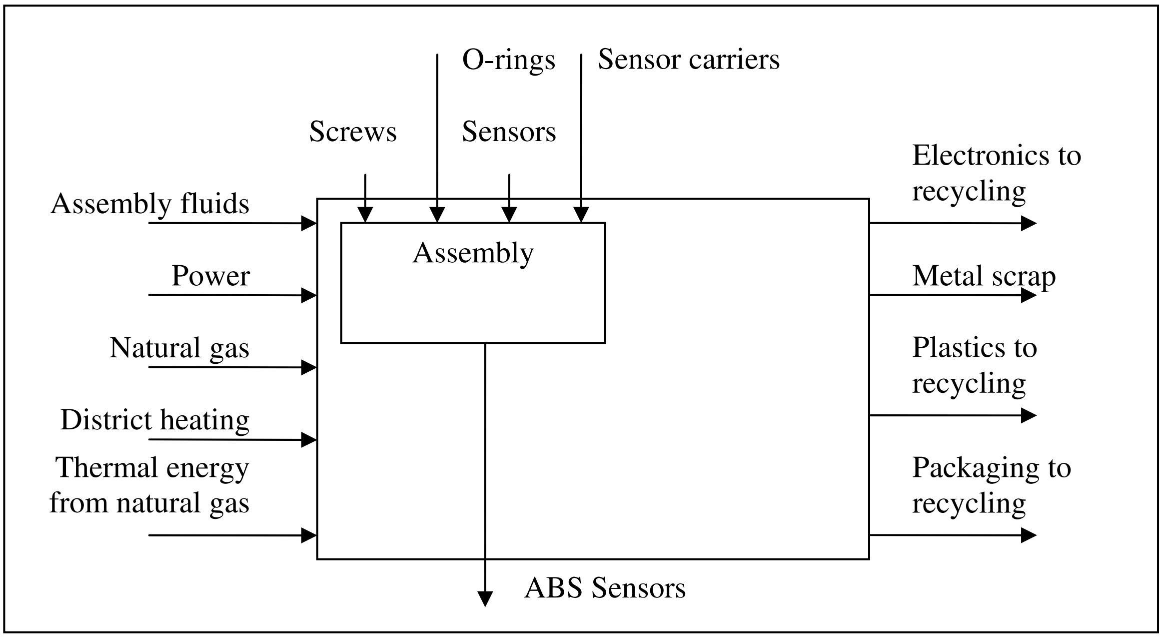

Figure 38 - ABS sensor production; modelled gate-to-gate system

A.5.2 Dataset Documentation

A.5.2.1 Product

Assembled ABS sensors for bearing units.

A.5.2.2 Functional Unit

The functional unit is one kilogram of ABS sensor for bearing units.

A.5.2.3 Time Horizon

Annual averages for 2007.

A.5.2.4 System Boundaries

This is a gate-to-gate dataset, to which adequate data for upstream processes must be connected.

The data was collected from a manufacturer in Italy. The background system can be adjusted to fit the system in other countries.

A.5.2.5 Allocation Methods

The directly product related inputs of components are not allocated, the level of detail represent the actual situation for the concerned type of ABS sensor.

Support and waste flows are allocated from flows related to the ABS sensor assembly line. These flows are allocated using number of pieces, as the ABS sensors are of similar complexity and the complexity is the major cause of resource use in the assembly process.

$$\text{Input support and waste per ABS sensor} = \frac{\text{General flows for ABS sensor assembly line}}{\text{Delivered ABS sensors [No. pcs.]}}$$

The contribution from the ABS sensor assembly line is estimated from facility totals by qualified personnel at the concerned company.

A.5.2.6 Additional Information

Emissions to air and water are not included, whilst complete data was not available.

Electricity and thermal energy for support operations, i.e. administration etc., are included in the dataset.

A.5.3 LCI Results from Gate-to-Gate

Removed due to confidentiality

A.6 Ring Production

The three rings used in the bearing unit are produced in a similar way. Basically steel bars are cut and forged.

A.6.1 Flowchart

Here are the main flows in the bearing ring production system presented.

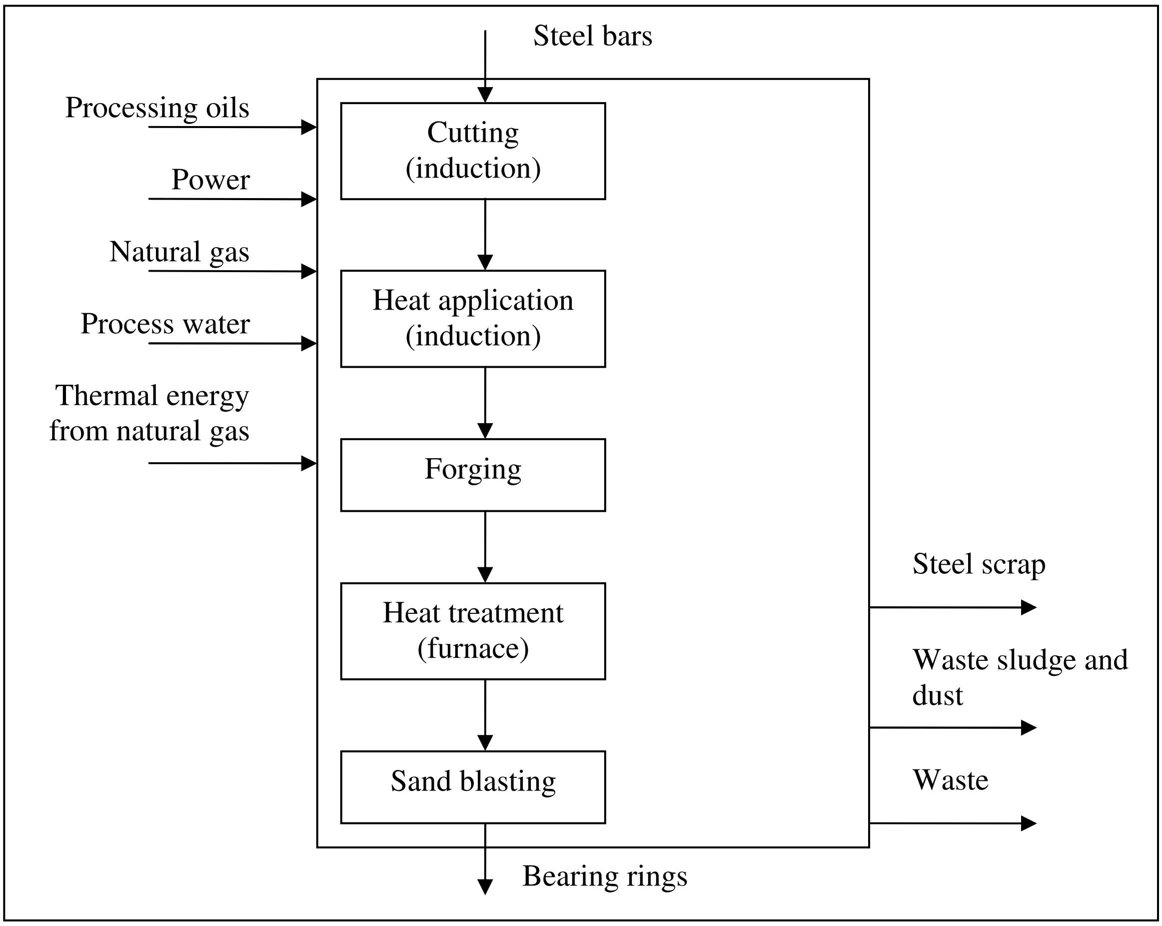

Figure 39 - Ring production; modelled gate-to-gate system

A.6.2 Dataset Documentation

A.6.2.1 Product

Forged rings for bearing unit produced from steel bars.

A.6.2.2 Functional Unit

The functional unit is one kilogram of bearing ring for bearing units.

A.6.2.3 Time Horizon

Annual averages calculated from data collected for the first three quarters of 2007.

A.6.2.4 System Boundaries
This is a gate-to-gate dataset, to which adequate data for upstream processes must be connected.

The data was collected from a manufacturer in Italy. The background system can be adjusted to fit the system in other countries.

A.6.2.5 Allocation Methods
The allocation is based on mass.

Data is collected for the concerned specific parts of the facility and all flows can therefore be related to the output of forged steel parts, produced from steel bars.

$$\text{Flows per kg ring} = \frac{\text{Total flows in forging department (and related functions)}}{\text{Delivered forged parts from steel bars [kg]}}$$

A.6.2.6 Additional Information
Emissions to air and water are not included, whilst complete data was not available.

Electricity and thermal energy for support operations, i.e. administration etc., are included in the dataset.

A.6.3 LCI Results from Gate-to-Gate

Removed due to confidentiality

A.7 Power Grid Mix; Low CO2

Some of the production sites utilise electricity sourcing, i.e. electricity from sources with low emissions of carbon dioxide per energy unit is used.

Data is provided from the supplier regarding the proportions of different power generation techniques. Datasets are used as shown in the flowchart below.

A.7.1 Assumptions

No data is given on the relative proportions of wind and hydropower, so this is assumed to be the same as the relation between these two sources in the national average power grid mix (GaBi, 2007). No data is available for cogeneration from methane, so a natural gas dataset is used and adjusted to cogeneration according to the relative amounts of carbon dioxide emissions from the dataset and the data acquired from the electricity supplier.

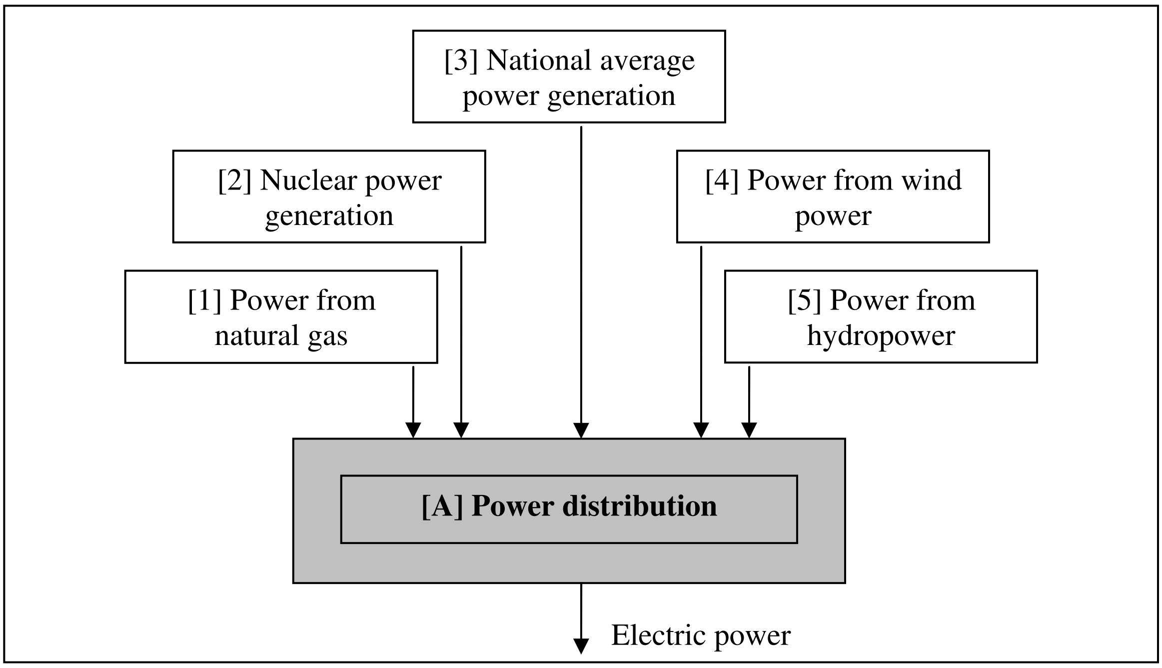

Figure 40 - Power grid mix (low CO2) unit processes, cradle to gate; numbers refer to datasets shown below

	Dataset	Year	Database	Technique representa-tiveness
A	Power distribution; low CO2 mix	2007	SKF	Completely
1	Power from nuclear power plant	2002	PE	Partly
2	Power grid mix	2002	ELCD/PE-GaBi	Completely
3	Power from wind power	2002	PE	Partly
4	Power from hydropower	2002	PE	Completely
5	Power from natural gas	2002	PE	Completely

Table 19 – Power grid mix (low CO2); used datasets

B Appendix – Complementary LCIA Results

Here, LCIA results are presented, that are of interest for the more interested reader.

B.1 Comparison of Category Indicators

The comparison of category indicators from different ready-made LCIA methods is made in order to further survey the robustness of characterisation results (Section 8.2.3).

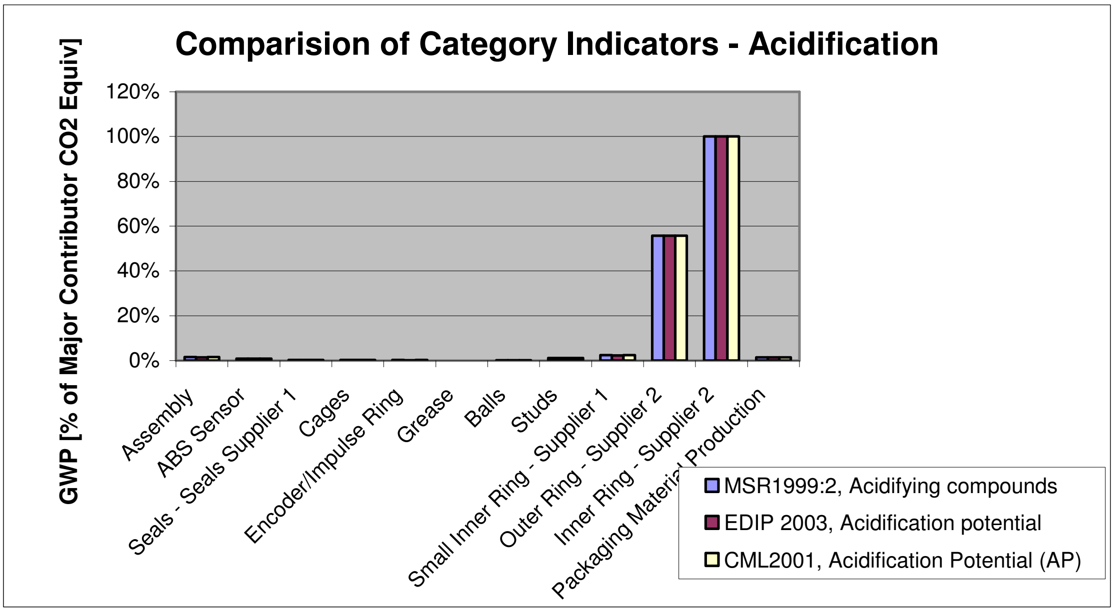

Figure 41 – Comparison of category indicators for acidification

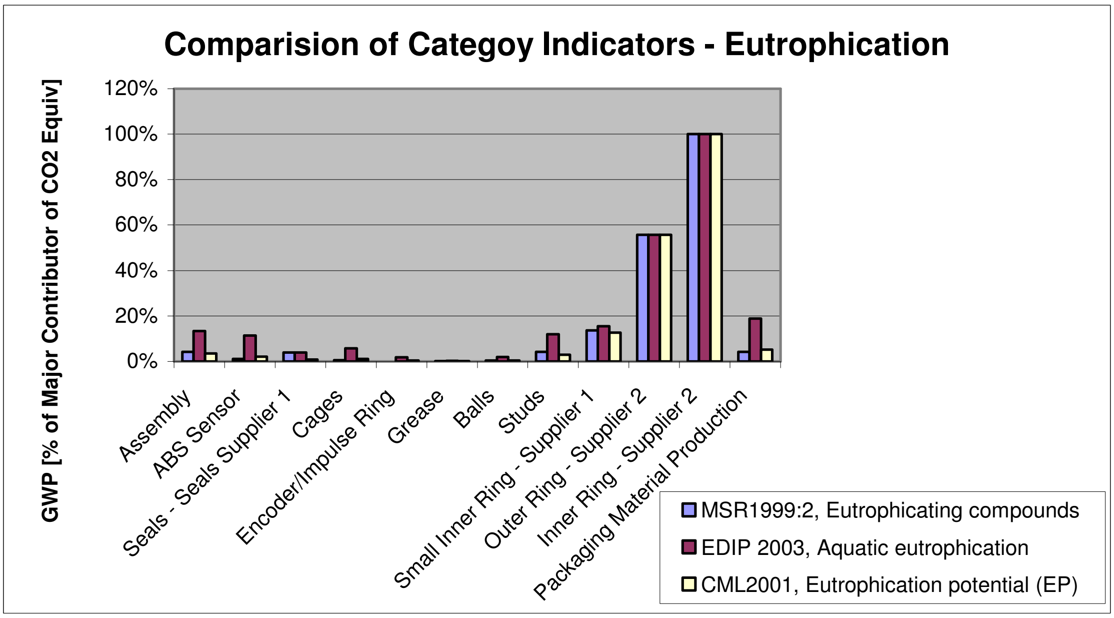

Figure 42 – Comparison of category indicators for eutrophication

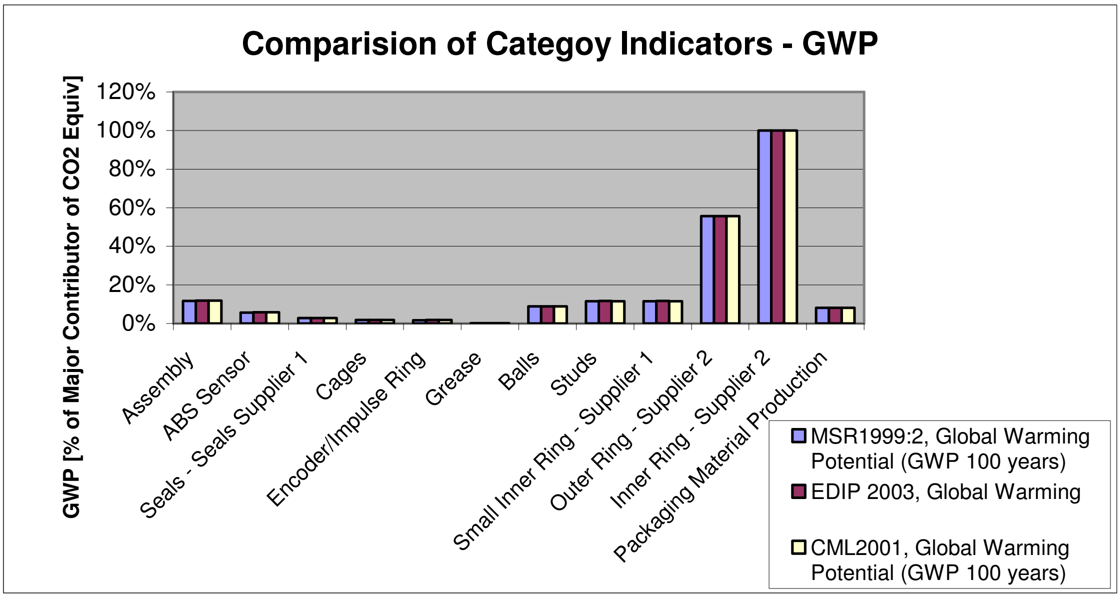

Figure 43 - Comparison of category indicators for global warming potential

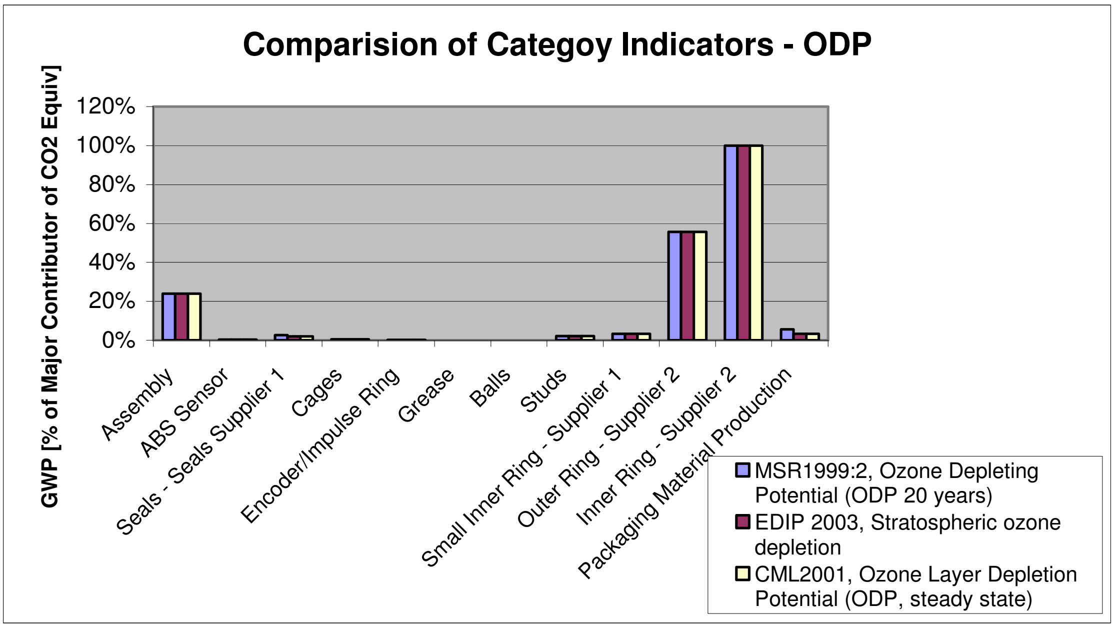

Figure 44 - Comparison of category indicators for ozone depletion potential

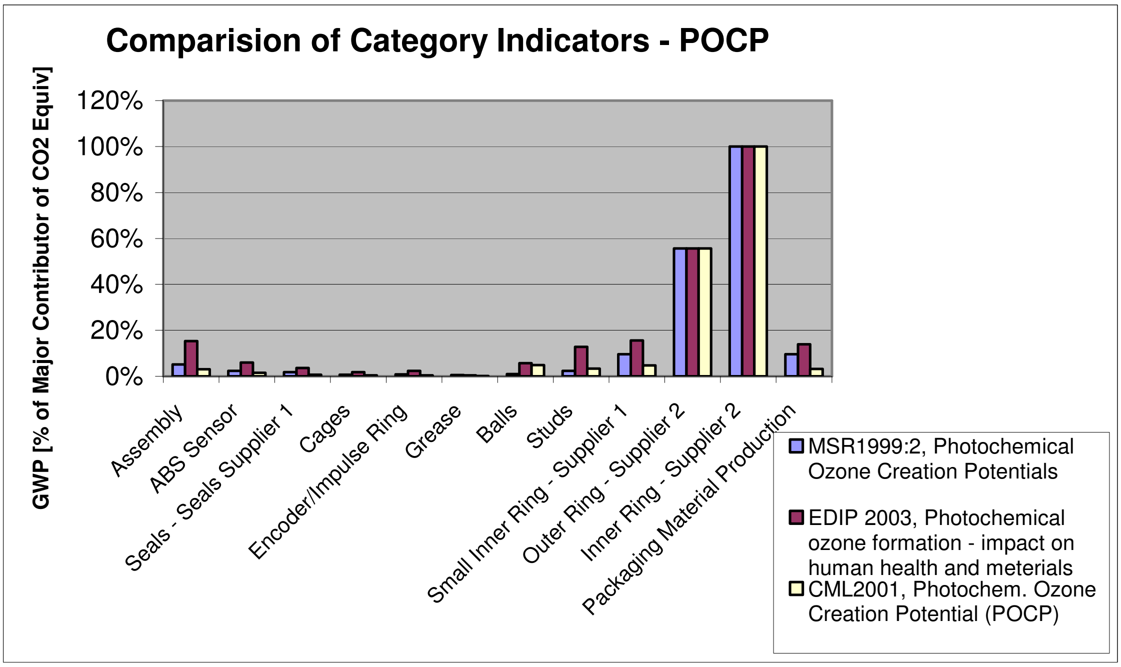

Figure 45 - Comparison of category indicators for photochemical ozone creation potential

B.2 Results from Weighting

These weighting results according to Environmental Priority Strategies (EPS) are shown to give the interested reader more information. Weighting is not included in the scope of the study and as an analysis of the weighting results and credibility is time consuming, the graphs are just shown and the analysis is left for the well-informed reader.

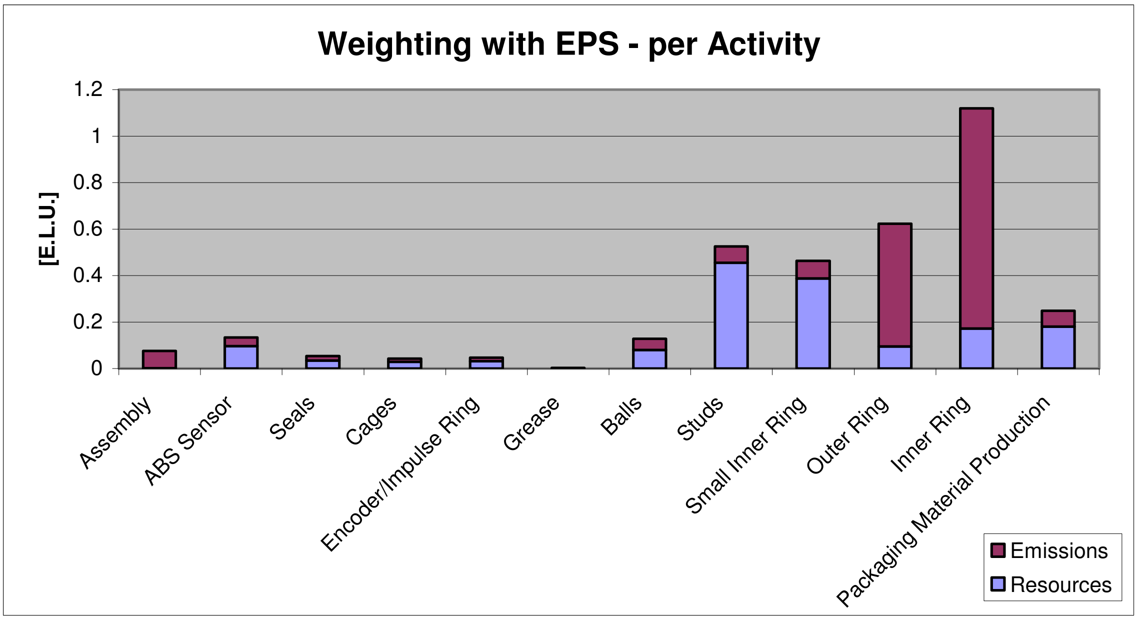

Figure 46 – Weighting with EPS per activity including upstream processes

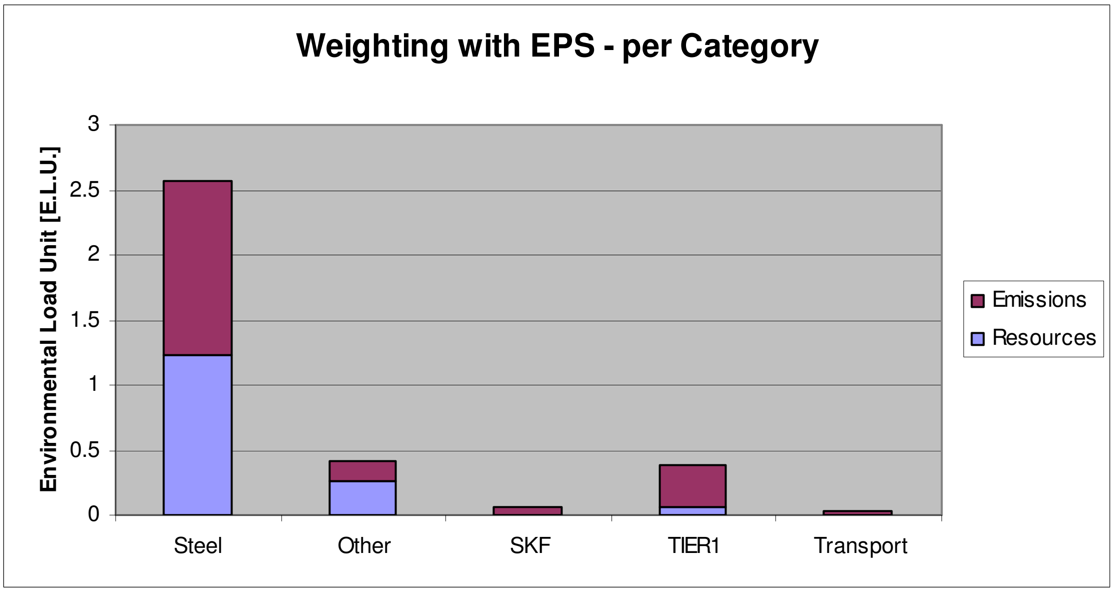

Figure 47 – Weighting with EPS per activity category

C Appendix – Flows of Valuables Not Accounted For

This section presents the flows of valuables that are known, but for which upstream data has not been included in the model.

Petroleum Destillate CAS 64742-46-7 [Operating materials]
Sulphonate, Synthetic [Flows]
3,3-Methylene bis [Flows]
Petroleum Destillates CAS 64741-89-5 [Flows]
Base oil (unspecified) [Flows]
Morpholine [Organic intermediate products]
Amines, coco alkyl, ethoxylated [Organic intermediate products]
Methylenebismorpholine [Organic intermediate products]
Alkanolamines (unspecified) [Organic intermediate products]
IODO-PROPYNYL BUTYLCARBAMATE [Flows]
Undecanedioic acid [Flows]
Grinding wheels [Operating materials]
Hard tooling [Operating materials]
Honing stones [Operating materials]
Sodium suphide [Inorganic intermediate products]
Lubricating oil vegetable [Operating materials]
Diethylamine [Organic intermediate products]
Diethylene glycol [Organic intermediate products]
Ethylenediamine [Organic intermediate products]
Methyl amine [Organic intermediate products]
boric acid, anhydrous, powder, at plant [inorganics]
monoethanolamine, at plant [organics]
ethoxylated alcohols, unspecified, at plant [Surfactants (tensides)]
Fatty acid, free [Materials from renewable raw materials]
Resources Non-renewable without energy content [Flows]
Steel scrap (St) [Waste for recovery]
Triazole derivative [Flows]
Phosphoric acid [Inorganic intermediate products]
Detergent [Operating materials]
Screw [Flows]
O-Ring [Flows]
Wooden pallet (one way) [Materials from renewable raw materials]
Tall oil [Organic intermediate products]
Turpentine [Organic intermediate products]
Thermal energy (MJ) [Thermal energy]
Springs [Flows]
Phosphating products [Flows]
Steel scrap (St) [Waste for recovery]
Cement [Minerals]
Cement (average) [Minerals]
Steel sheet (ECCS low grade) [Metals]
Grease [Flows]
Steel scrap (St) [Waste for recovery]
Uranium (enriched) [Other fuels]
Biomass [Renewable energy resources]

Table 20 – Flows of valuables not accounted for

D Appendix – Examples of Modelling in GaBi4

The figures in this section show how the structure of the model in GaBi was built.

D.1 Cradle to Gate Total System

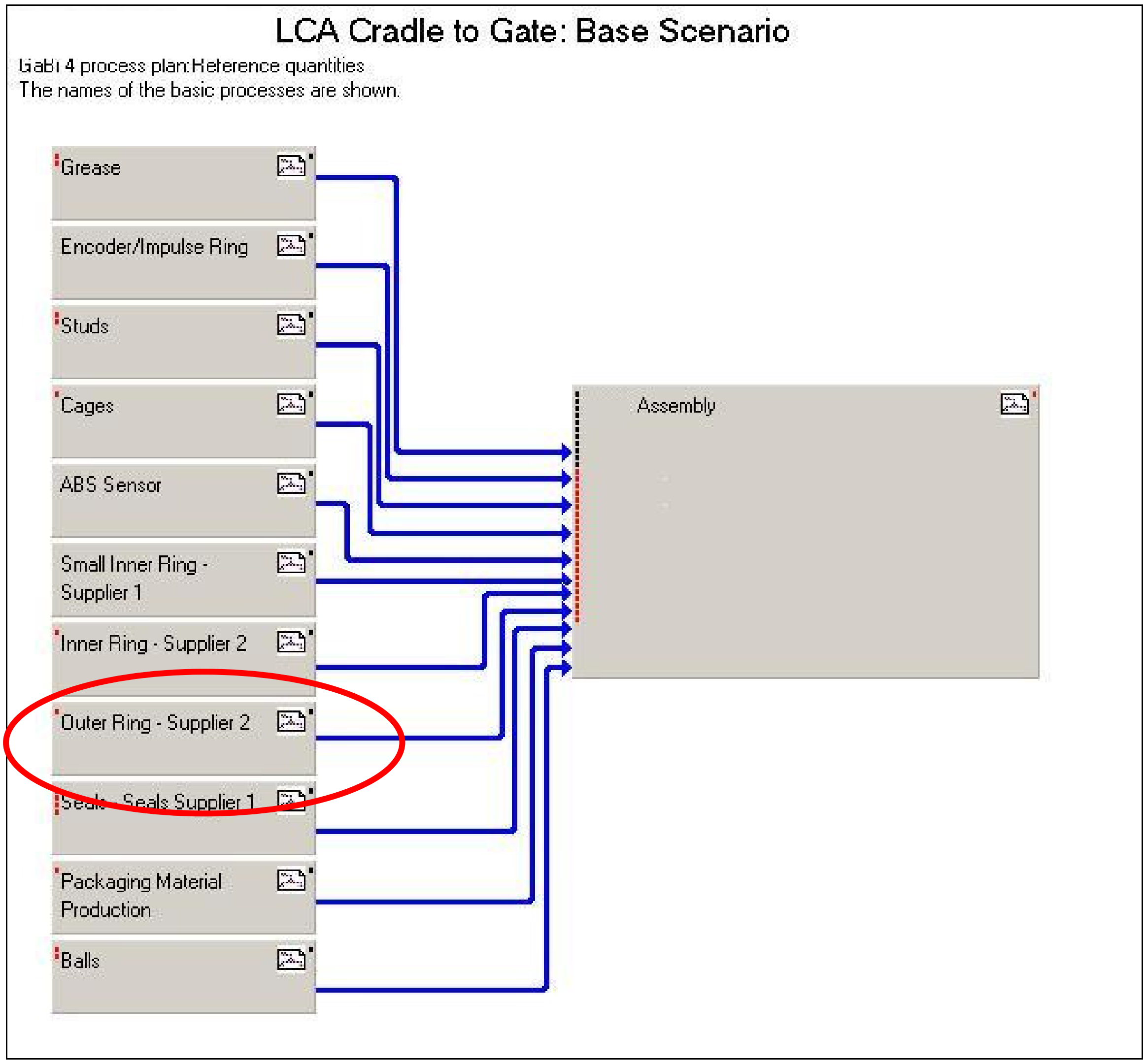

Table 21 – GaBi model, cradle to gate for the total system

D.2 Cradle to Gate - Outer Ring Supplier 2

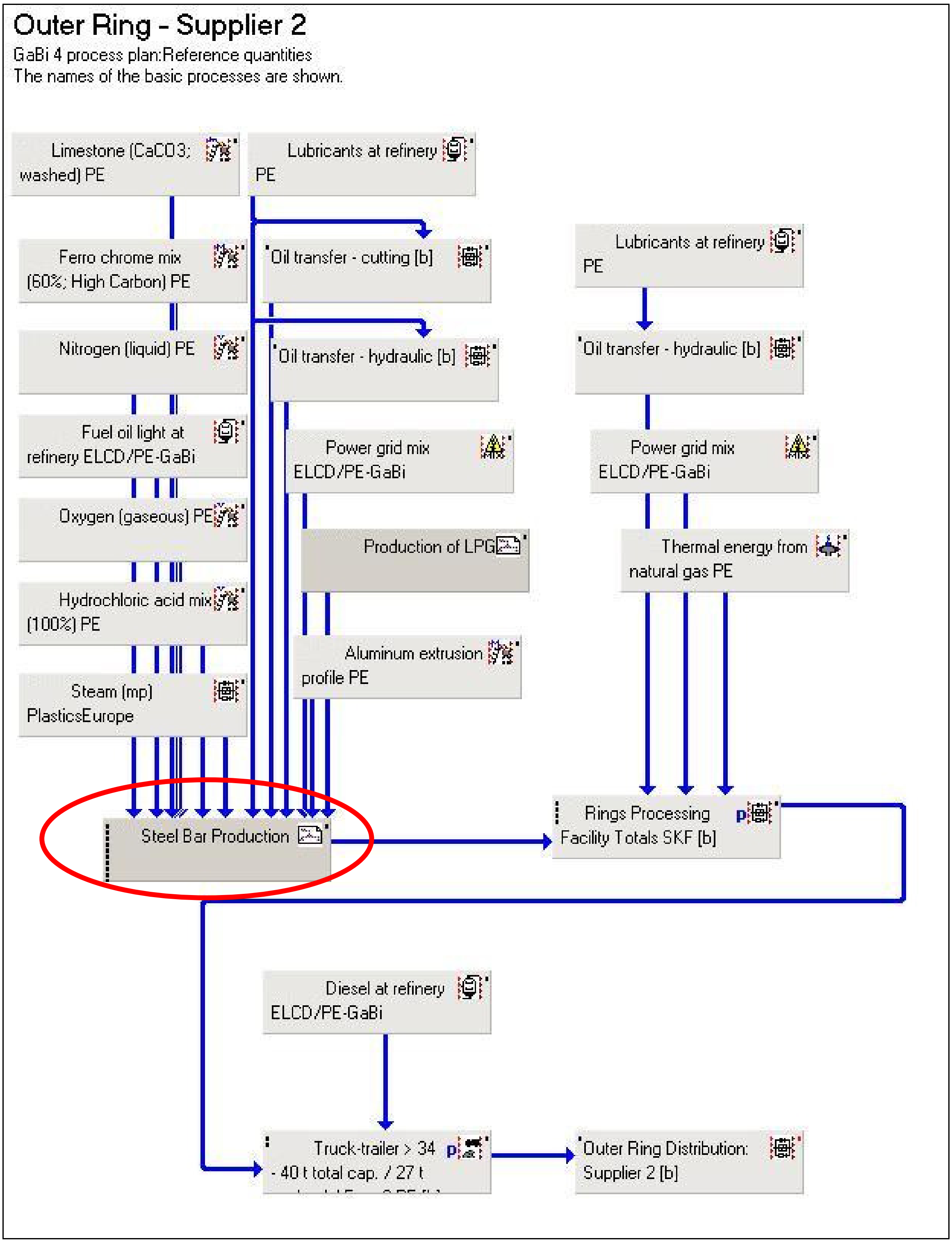

Table 22 - GaBi model, cradle to gate for the outer ring, ring supplier 2

D.3 Gate to Gate - Steel Bar Production

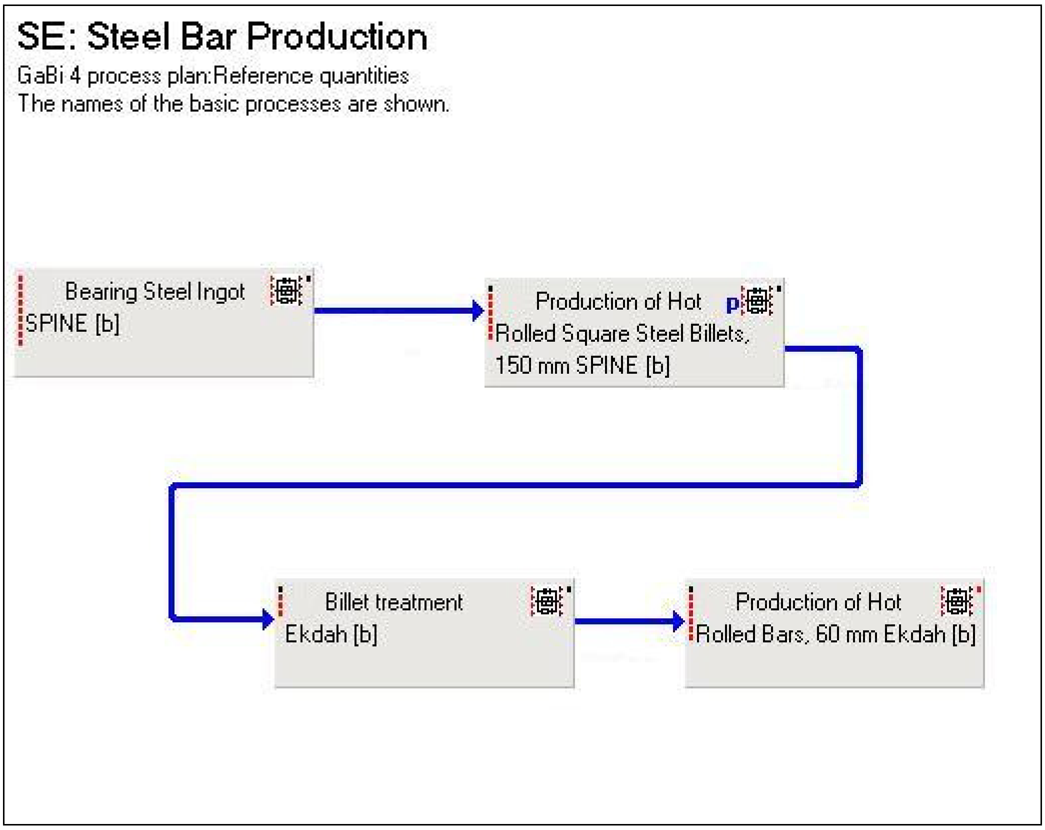

Table 23 - GaBi model, cradle to gate for the production of hot rolled bars