CHALMERS

Life Cycle Inventory Data Collection for First Tier Suppliers

-- A case study of a bearing unit

Master of Science Thesis in the Master Programme, Industrial Ecology

DIONYSIOS LOGARAS

Department of Energy and Environment
Division of Environmental Systems Analysis
CHALMERS UNIVERSITY OF TECHNOLOGY
Göteborg, Sweden, 2008
ESA Report No 2008:11 , ISSN:1404-8167

Life Cycle Inventory Data Collection for First Tier Suppliers

-- A case study of a bearing unit

DIONYSIOS LOGARAS

Master of Science Thesis
In the Master Degree Programme, Industrial Ecology

Environmental System Analysis
Department of Energy and Environment
CHALMERS UNIVERSITY OF TECHNOLOGY
Göteborg, Sweden 2008

Life cycle inventory data collection for First Tier suppliers
--A case study of a bearing unit

DIONYSIOS LOGARAS

ESA Report No 2008:11
ISSN: 1404-8167

Environmental System Analysis
Chalmers University of Technology
SE-412 96 Göteborg
Sweden
Telephone: +46 (0) 31-7721000

Abstract

The purpose of this report is to evaluate the importance of collecting site-specific data for the First Tier suppliers in a Life Cycle Inventory (LCI) study as compared to use data from an LCI database and point out other highly polluting life-cycle stages where site-specific data should be collected. Data collection strategies will be analysed and recommendations will be given for future Life Cycle Assessment (LCA) studies in SKF.

The case study of a specific bearing has been applied. The type of the product is manufactured at one of SKF's factory.

As already mentioned, this report is focused on the suppliers of SKF that provide products directly to SKF’s manufacturing facility, called First Tier suppliers. Due to time and data quality limitations, site specific data were collected only for the main local First Tier suppliers with the use of a data collection form developed specially for the purpose. These data comprise information for the raw materials and energy inputs along with waste and emissions outputs.

An analysis is performed to assess the qualitative and quantitative difference of using "real" data collected from the First Tier suppliers in opposition to the LCI data of a database. For this purpose, two simplified LCI models are established by using the GaBi LCA software program. The first models site-specific data for the processes of the First Tier suppliers and the second applies LCI data offered from the GaBi’s database. Then, a thorough dominance analysis is conducted to indicate important life-cycle stages in the bearing’s production that cause major environmental impact. The interpretation of the results, in both cases, has been done by comparing the LCI results. Finally, the benefits and drawbacks of the data collection strategy are realized after a comparison to the ISO standard guidelines, other LCA studies and personal reflections.

This report indicates that the two different data sources (site-specific and GaBi data), change evidently the LCI results for the total environmental load generated by the bearing’s production. These changes fluctuate up to 30 % between the two models. They are caused mainly by the quality and unavailability of inventory data in the database used. The steel production and more specifically the steel billet (used for steel bars, the raw material of rings) causes the highest environmental impact in the technical system of the analysed bearing. Regarding the data collection strategy, it proved to be quite efficient, reliable and transparent for the purpose of this study, since the most important data for the First Tier suppliers have been collected and data gaps were of minor importance to the results of the study.

Future LCA studies in SKF should focus on LCI data collection for processes that influence significantly the life cycle of a product. Database data may be used cautiously for products of minor importance to the environmental performance of the investigated technical system. The data collection strategy should be based on a data questionnaire and good preparation for the site visits of the targeted companies.

Acknowledgements

I would like to give my thanks to all the people who have helped me with different ways to finish this report.

First of all, my supervisor and Ph. D. candidate Birger Löfgren for his valuable guidance and support, all through my study. You have helped me very much to carry out the study and draw the right conclusions. Our collaboration has given me a lot of experience in LCA and not only.

Also, I am thankful to my examiner, Professor Anne Marie Tillman, for her interesting and helpful feedback during my report writing.

My thanks also to the employees of SKF in the department, where I carried out my thesis, for their help on various issues.

I would like also to express my thanks to Björn Rinde with whom I worked together and collected-organised much of the data of this study. You have helped me very much to analyze and carry out this study with your special knowledge on manufacturing issues and not only.

Finally, I would like to thank my family that helped me and supported me all through the period of my master thesis.

Dionysios Logaras

Göteborg, 2 June 2008.

Table of Contents

1 Introduction

In this chapter an introduction to the report is given by stating the background, purpose and delimitations of the study.

1.1 Background

Life Cycle Assessment (LCA) is an emerging tool in the industry sector for environmental evaluation of products and services. It is used to model production processes and calculate the environmental load generated by the technical system under study. The pressure coming from national and international environmental regulations for the manufacturing industry makes necessary the need for action to be taken by each company. Therefore many start to use LCA for various applications such as eco-design, procurement or "greening" their supply chain.

Life Cycle Inventory (LCI) data collection is the most time consuming part for an LCA project. The analyst must gather all the necessary data to carry out his/her project. Depending on the goal and scope of the project, the practitioner defines from the beginning where in the product's life cycle will collect site specific or average data. Many times assumptions would have to be made for information that was not time or source to find them. Moreover time limitations can make unavoidable the use of data from a database. These methodological choices influence the results of the LCA study and therefore its transparency and reliability.

Many databases have been developed through the years that provide several types of data for LCA studies. They can offer quantitative information for the production of various kinds of products, services (e.g. electricity), waste, emissions etc. Often these correspond to a specific region or country and represent average data for a certain time period. It depends from the data requirements of the respective LCA project if one of these databases can be used. This report indicates how important is to use data from these sources or site-specific data.

Sometimes LCI databases are included in special software programs that help to carry out an LCA project. These programs have calculation and modelling functions, which ease the working load of the analyst. The data usually included in these programs are thoroughly documented for reasons of transparency and representativeness. At the end, results are generated and many options are available for their interpretation. Widely used LCA software is GaBi, which has been purchased by SKF Sweden AB for employment to related environmental studies.

As a leading bearing manufacturing industry, SKF wants to build the knowledge within its various divisions of the LCA concept. This will help the respective company to fulfil its environmental and sustainability targets (e.g. reductions in CO_2 emissions by 5% annually). One of SKF's intentions is to include also supply chain processes in the analysis and implement their environmental objectives to their suppliers also. This aim constitutes an application of an LCA study, which it makes possible to identify the "dirtiest" stages in a product's life cycle.

Due to these targets, an LCA project has been initiated by SKF to analyse the environmental performance of a specific bearing unit, manufactured at one of their facilities. Its results will indicate improvement possibilities in their manufacturing processes and supply chain, from an environmental point of view. The specific report highlights the suppliers and upstream processes, involved in the production of the investigated bearing, that generate the highest environmental impact and therefore, need precise LCI data to be collected.

In this study the LCA modelling has been carried out with the GaBi4 software and database for Life cycle Engineering, PE INTERNATIONAL GmbH and LBP University of Stuttgart, January 2007 (GaBi4).

1.2 Purpose of the study

The purpose of this report is to evaluate the importance of collecting site-specific data for the First Tier suppliers in a Life Cycle Inventory (LCI) study as compared to use data from an LCI database and point out other highly polluting life-cycle stages where site-specific data should be collected. Proper data collection strategies will be also recommended. The product to be investigated is a bearing unit, manufactured at an SKF facility.

1.3 Delimitations of the study

There are various LCI datasets offered in the market. A general research of LCI databases with relevant (to the purpose of this project) datasets is shown in the 11.4 section of the Appendix. In this study, only the GaBi database, purchased by SKF and its LCI data have been used. Occasionally, these data proved to be insufficient to represent adequately the production processes of the First Tier suppliers. In addition, there were gaps in the LCI data collected by the suppliers. These kinds of issues have been encountered by proper methodological choices such as assumptions or cut-off decisions. A detailed explanation of these options is given in the Goal and Scope and Inventory analysis chapters (chapters 5 and 6).

2 Theoretical Framework

In this chapter, the three LCA phases (Goal and Scope definition, Inventory Analysis and Interpretation of the results) that characterise an LCI study are briefly described. More information is also given concerning LCI data requirements, collection and quality indicators.

2.1 LCA methodology

2.1.1 Goal and Scope definition

The goal and scope definition constitutes the first phase of an LCA project, where its context is defined and the project is planned. It's an interactive step between the practitioner and commissioner of the study where discussions are carried out and conclusions are drawn for its intention and methodological choices.

As shown in the figure, all the phases of an LCA interact with each other, which mean that it is an iterative process. The goal and scope must be clearly defined from the beginning and be consistent with the intended application of the study so that later changes can be avoided.

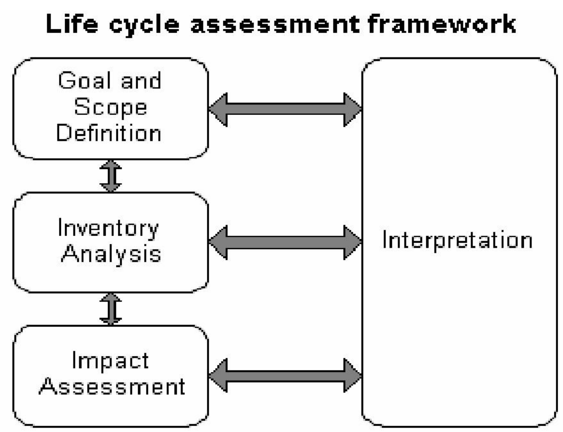


Figure 1 Phases of LCA

The purpose of an LCA project is stated in the "goal" definition phase along with decisions about the specific product that will be analysed. Thereafter, in the "scope" definition phase, modelling and procedural aspects such as system boundaries, functional unit, reporting etc. are described that will be applied in the subsequent phases.

Goal of the project

The purpose of the study is set here by answering the following questions:

- **Why** are we doing this study?
- To **whom** will the results be communicated?
- **What** product or process will be studied?

In other words, the goal definition "shall unambiguously state the intended application, the reason for carrying out the study and the intended audience" (ISO 14041 1998). The outcome of this phase will constitute the basis on which the next phases of the LCA project will rely on and the right methodological choices will be done.

Scope of the project

After defining the goal of the project, the modelling and procedural aspects of an LCA study must be decided. Scoping is a necessary and important step before conducting an LCA to ensure (Joel Ann Todd,1999):

- The breadth and depth of analysis are compatible with and sufficient to address the goal of the LCA.
- All boundaries, methodologies, data categories, and assumptions are clearly stated, comprehensible, and visible.

The modelling choices made in the scope definition comprise:

- Product or process definition to be modelled
- Type of LCA
- Initial flowchart
- Functional unit selection
- Selection of impact categories and impact assessment method and subsequent interpretation to be used
- Definition of system's boundaries
- System subdivision
- Designation of data requirements for the study
- Assumptions and limitations of the study

Regarding the procedural aspects, these are:

- Reporting specifications
- Critical reviewing
- Actors identification
- Project planning

The decisions taken for all of these aspects are based on the goal of the study set earlier. So it is necessary to understand its content and the intended applications of the specific project in order to find the most suitable parameters and requirements and ensure valid and qualitative results. In the following some important modelling aspects are described briefly.

Which options to model

First, it has to be decided and defined what specific products, product designs or process options are to be investigated (Baumann and Tillman, 2004). This step is very crucial since the practitioner will make clear where the LCA will be applied and start planning and organizing the following steps of the scope definition.

Type of LCA

The type of LCA must be defined in this phase. There are three types of LCA:

- Accounting type
- Change oriented type
- Stand-alone

The accounting LCA type is comparative and retrospective (looks back in time). Its main applications are to evaluate the environmental performance of a product, identify environmental improvements that can be made along its whole life cycle and serve the basis to compare products or processes from an environmental point of view. The change oriented LCA type is also comparative but prospective (looks forward in time). It mainly shows how the life cycle of a product system would be affected by changes (in raw materials, processes etc.) made from an environmental point of view. The stand alone LCA type has as a main application to identify the "hot spots" in a product's life cycle or generally quantify its environmental performance without making comparisons with other products or modelling effects of changes.

The suitable selection of the type of LCA to be established is made according to the goal of the study and its intended applications. Knowing which type of LCA is being done helps when making methodological choices such as what system boundaries to choose, what data requirements to have, allocation methods etc. (Baumann and Tillman, 2004).

Initial Flowchart

A flowchart is a flow model where mass and energy flows along with the main activities in the life cycle of the analysed product system are described. During the scope definition, the practitioner can develop a primary flowchart where he/she can illustrate the main processes of the whole life cycle and use it for further steps of this phase. It would be a merit if, from this early stage, the flowchart could be as much as complete so that the practitioner will be able to start planning with a better precision other important methodological aspects such as data requirements, system boundaries, allocation methods etc.

Functional Unit

A very important modelling specification is the definition of the functional unit. The term functional unit refers to the expression of the system's main function in quantitative terms such as "litres of packaged drink" for beverage packaging etc. It corresponds to a reference flow to which all other modelled flows of the system are related and it has to be pointed out on the flowchart (Baumann and Tillman, 2004). The project team must carefully make the selection of the functional unit for being meaningful to the goal of the study (Joel Ann Todd,1999) and serve the basis for the upcoming calculations in the inventory phase.

System Subdivision

System subdivision makes sense for change oriented LCA studies where the analysed system is divided into two sub-systems: the foreground and the background. The distinction between them has to do with what part of the system is under the direct influence of the decision maker or commissioner of the study (Baumann and Tillman, 2004). More specifically, the foreground system comprises the processes that can be affected directly by measures taken form the commissioner while the background system includes all the other modelled processes that can be affected indirectly. This subdivision of the system has no relation with the environmental importance of the effects that these measures would cause since they can be largest in the foreground or the background system (Mikkel Thranne,2005).

System Boundaries

One of the most crucial aspects set in the goal and scope definition of the project are the boundaries of the analysed system. They define the unit processes or activities that will be included in the study (Joel Ann Todd,1999). Moreover, the criteria used in establishing the system's boundaries shall be identified and justified in this phase (NSF International, 1997). All the next phases will be based on these choices such as data requirements, impact assessment method etc. Furthermore the LCA practitioner must specify these boundaries in several dimensions (Baumann and Tillman, 2004):

- *In relation to natural system*

  The boundary between the modelled technical system and the surrounding natural system must be identified. The main reason for doing this distinction is to understand which of the modelled processes or flows are affected by the technical system (by human) and which of them influence that.

- *Geographical boundaries*

  Geography matters in LCA because different parts of the life cycle occur in different places of the world, infrastructure (electricity production, transport systems etc.) varies between different regions and, also, the sensitivity of the environment to different pollutants changes in different geographical areas (Baumann and Tillman, 2004).The geographical boundaries of the modelled system depend on the location of the production site and its suppliers and customers.

- *Time boundaries*

  Depending on the goal of the study and the type of LCA that will be established, time boundaries can be defined. An accounting LCA type is retrospective (looks backwards in time) while a change-oriented type is prospective (looks forwards in time). It constitutes an important aspect since the practitioner will set the requirements for the data that will be collected and used later in the study.

- <u>*Boundaries within the technical system*</u>

  Another modelling aspect that has to be taken seriously into account is the boundaries within the technical system such as cut off processes and allocation method due to other products' life cycles. The selection of these methodological parameters must be consistent with the goal of the study.

  - *Related to production capital, personnel, etc. Cut-off criteria*

    It is the practitioner's decision to exclude or "cut off" processes with minor environmental impact from the system's model for the sake of simplicity. Relevance is another aspect since some processes might not be affected by a change in the system (for change oriented LCA). Capital goods (machinery, buildings etc.) and personnel also are causing environmental impacts. The choice to include these aspects in the model depends from the goal of the study. Usually for accounting LCA types, they are not taken into account while in a change-oriented study depends whether they are influenced by the changes made.

  - *In relation to other products' life cycles*

    Occasionally, several products share the same processes. If the environmental load of those processes is to be expressed in one function only then there is an allocation problem (Baumann and Tillman, 2004). This problem mainly comes from processes that produce different products (multi-output), processes that receive input from different sources (multi input) or when open loop recycling (product recycled to a new product) takes place.

    The ISO standard recognizes two allocation methods: partitioning and system expansion. Partitioning means that the environmental loads (resource consumption and emissions) related with the multiple process and the upstream processes are divided between the two products while in system expansion the analysed system is credited with the avoided production of the shared product by another source (Baumann and Tillman, 2004). The first method is used in accounting types of LCA while the latter is applied in change-oriented types. The recommendations of the ISO standard for allocation methods is first, if possible to be avoided by increased level of detail in the study, then system expansion is favourable than partitioning and finally as a last option allocation based on other values such as weight, price etc.

Data quality requirements

Deciding on data quality requirements is an important activity during the goal and scope definition (Baumann and Tillman, 2004). The practitioner of the study sets these requirements according to general guidelines that are relevance, reliability and accessibility. They must always be consistent with the goal of the study but as LCA is an iterative process they may be changed due to limitations faced later on in the project. The most crucial aspects to be taken into account are time and geographical related coverage, precision, consistency and completeness. Furthermore, the type of data, meaning average or marginal, must be based on the purpose of the study. Usually, average data are used more in accounting LCA types while marginal are used more in change -oriented types.

Assumptions and limitations of the study

Often many assumptions are made during an LCA project such as for electricity production, transportations etc. The practitioner must state them in the goal and scope phase so that his or her study will be as much credible and transparent possible. Limitations faced along the study should also be mentioned for the intended audience to know about the problems encountered by the analyst and to explain the possible "bad" data quality.

2.1.2 Life Cycle Inventory Analysis (LCI)

This phase of LCA follows after the definition of the goal and scope of the study. Both of them are mutually connected either by changing initial decisions taken in the former phase based on new information acquired in the latter one or by following guidelines set in the first one.

In the previous stage, the purpose of the study and its methodological and procedural aspects have been set by the LCA analyst and now he/she will go into a more detail study about the investigated technical system.

The main steps in the inventory analysis contain: (Baumann and Tillman, 2004)

- Flowchart construction
- Data collection – documentation of collected data
- Calculation of the environmental loads in relation to the functional unit

Construction of the flowchart

At first, the construction of the flow model is established, always in relation to the definitions made in the goal and scope of the study. System boundaries set before are taken into account for what processes and flows to include. Therefore, the flowchart’s detail, concerning especially up stream or end use activities, depends on where the practitioner set the limits of the study.

The initial flowchart designed in the scope sub-phase is now further developed into a more detailed diagram, showing almost all of the processes and flows happening in the modelled system (Baumann and Tillman, 2004). Each unit process will show all the input and output flows related with each activity in the system under study.

This LCA phase constitutes an iterative process where the analyst might have to return later and add more processes or even “cut-off” others according to additional information gathered in subsequent phases. Usually the initial flowchart (from the previous phase) shows just the main processes of the technical system so that the analyst can start planning the data requirements and the way to collect them.

Data collection - documentation

After the construction of the flowchart, the most time consuming step of an LCA study follows, that is the data collection for each unit process of the investigated product's life cycle.

The type and strategy for the data to be collected is already starting to be planned at the goal and scope phase of the project. The flowchart of the investigated system, developed previously, will help to set this strategy. Depending on the foreground and background system of the study, the practitioner can decide to acquire site-specific data for important processes and average data for other less crucial processes in the life cycle. Usually average data are taken from available LCI databases while the obtainment of site-specific data takes more time since it involves many different actions such as measurements, getting in contact and try to reach different people etc.

Another aspect, which makes this phase so time consuming, is the unfamiliarity of the LCA analyst with all the processes of the analysed technical system. Therefore the practitioner needs time to understand what is happening so that he/she can gather the best possible data for the study. These data can be numerical or qualitative data depending on the demands set previously in the goal and scope phase.

A classification of the data collected related to their sources and types are: (Bo P.Weidema, 2003):

- *Primary data* are data gathered by direct measurement, estimations or calculation from the original source. Measured data can be up-to-date and specific while calculated data are based on theoretical models and they are not affected by possible errors of individual measurements.
- *Secondary data* are data collected from literature and other published sources.

Usual issues to be considered when ***planning*** for data collection are (Bo P.Weidema, 2003):

- ***Objectives*** of the data collection system
- ***Data requirements***
- ***Data gaps*** (identification and treatment)
- Required ***frequency*** of data collection, ***location*** of data collection points, data collection ***methods*** and ***units***
- Required ***documentation, validation and communication*** of the data to fulfil the objective
- ***Personnel*** involved (at management and operational level, they must have appropriate knowledge of the procedures they gather data).

The documentation of data must be done very carefully and thoroughly so that the transparency of the results will be in the highest level as possible. The sources of different kind of data must be stated and also the way these data were acquired. In the case of estimated data, the LCA practitioner needs to mention the reasons and validity of them.

Finally, ISO standard requires a validation of data to be done in order to realize the precision and completeness of the data collected. Therefore a comparison with the goal of the study and other valid data sources can be done to draw some useful conclusions.

Calculation of the environmental loads

After the completion of the flowchart and the collection of all the necessary data, the calculation of the environmental loads, caused by each unit process of the analysed technical system, can be started.

These calculations comprise a number of different steps (Baumann and Tillman, 2004):

- **Normalization** of the data for all the activities of the product's life cycle. Usually the data that the practitioner receives are in various units so they must be converted to other units that are more appropriate for the goals of the study.
- **Calculation** of the flows linking the activities in the flowchart by using the flow that represents the functional unit as a reference. In other words, each of the data that have been collected is going to be related with the functional unit of the current study.
- **Calculation** of the flows passing the system boundary with relation to the reference flow.
- **Summary** of the resource use and emissions to the environment for the whole system.
- **Documentation** of the calculations.

Often an LCA software program is used for the establishment of these calculations and further analysis (Impact Assessment, etc.) of the technical system. When an LCA is small (meaning that does not involve many activities), the analyst can carry out the calculations without the help of a software but usually for bigger projects the companies are buying programs such as GaBi or SimaPro for more convenient and fast results. Still the practitioner must be very careful on how to handle the data of the software since sometimes their sources are not thoroughly stated.

2.1.3 Interpretation of the results

The final phase of an LCA project is the interpretation of the results. It is basically the conclusion on the study, but besides a presentation of the key results it must include a critical reflection about the study, uncertainty, sensitivity and methodological choices (Mikkel Thranne,2005).

The results presentation is based on various kind of diagrams with LCI results, impact assessment characterisation and weighted results or even qualitative assessments of the results. From these diagrams many conclusions can be drawn depending on the goals of the project (e.g. identification of the most "dirty" products in comparative studies).

Various types of analyses exist and can be applied based on the aim of the specific LCA study. These are (Baumann and Tillman, 2004):

- Dominance analysis: Identifies the stage in a product's life cycle that causes the major environmental impact
- Contribution analysis: Discovers the worst environmental impact in the system.
- Break-even analysis: Used to compare two different kinds of products e.g. short-lived versus long-lived etc.
- Decision maker analysis: assess the influence of the commissioner of the study to the different stages of a product's life cycle and their environmental impacts.
- Uncertainty analysis: checks the effect of uncertain data
- Sensitivity analysis: Change crucial data and explore how they affect the results of the study
- Variation analysis: change processes or flows in the life cycle and find the effects

The aim of interpretation is to reduce the number of quantified data and/or statements of the inventory analysis and/or impact assessment to the key results to facilitate a decision making process based on, among other inputs, the LCA study (Allan Astrup Jensen,1997). At the end, all these new valuable information gained from this last phase will help the LCA analyst to answer with reliable and transparent arguments his/her research questions.

2.2 Data requirements in LCA

LCA data refer primarily to the environmental inputs and outputs of the system but in order to be meaningful, data must also be available that describe the processes which are the destination and origin of these inputs and outputs as well as data describing the product system that results from a specific combination of these processes. Additionally, the translation of "inputs and outputs" into environmental impacts requires data that describe the environmental mechanisms in the ecosystems (Bo P.Weidema, 2003).Site-specific data must be used for these unit processes that contribute the majority of the mass and energy flows in the system or considered to have environmentally relevant emissions (Allan Astrup Jensen,1997).

LCI data are data that describe a process from its environmentally relevant perspective. An LCI data item consists of a definition of the process, its boundaries etc. and its inputs and outputs. Changes in stocks of raw materials, components and produced goods are usually not part of LCA data (LCA methodology considers inputs and outputs only) but they can help indirectly to find the data of inputs and outputs (Bo P.Weidema, 2003).

Issues to consider when thinking about data requirements (Bo P.Weidema, 2003):

- What kinds of questions are to be answered by obtaining the data?

- What analyses or assessments need to be done to answer these kinds of questions?
- What data are needed to perform these analyses and in what quality?
- What data are already available and is their quality adequate?
- What data is it necessary to collect and with what quality and in what priority?

Data needs can be specified in terms of product and process specifications, market trends, elasticity and production costs of these products and processes, their important inputs and outputs, and their characterization and weighting factors. Data quality requirements can be determined by estimates of importance and uncertainty. Doing a comparison of the needs with the available data from the current data collection system, results in a prioritized list of data that need to be collected (Bo P.Weidema, 2003). Moreover, the data that have been collected can be checked (during the LCI and LCIA phase), according to the requirements set in the goal and scope definition and if they don't meet these requirements then they must be collected again or change the requirements.

Data for (Svoboda, 1995):

- **Raw materials acquisition** must include all activities (inputs of energy, materials, and equipment) required to obtain raw material, including transportation of the materials to the point of manufacture. Insignificant contributions must not be included in the inventory so that the complexity of the study won't increase dramatically. It is preferable to include the measurable environmental effects in the inventory while other kind of effects can be in a more qualitative impact assessment. Energy data for these processes must concern not only emissions and energy use by them but also the same numbers corresponding to the energy production.
- **Manufacture - fabrication** must include all energy, material or water inputs and environmental releases happening during the manufacturing processes. Data for final product fabrication should describe the consumption of inputs and the emissions (inputs and releases associated with filling and packaging operations) required converting all materials into the final product.
- **Transportation - distribution** can be simplified by using standards for the average distance transported and the typical mode of transportation used.
- **Consumer use - disposal** cover consumer activities including use, maintenance and reuse. Disposal may include reuse, recycling, composting, incineration and land filling. Transportation and collection of post-consumer waste should also be included.

The data quality requirements in an LCA study follow the stated guidelines in the next table : (Baumann and Tillman, 2004) & (Allan Astrup Jensen,1997)

Relevance	***Reliability***	***Accessibility***
Time-related coverage*	Precision*	Reproducibility*
Geographical coverage*	Consistency*	Consistency*
Technology coverage*		
Completeness*		
Representativeness*		

Table 2 Data quality requirements in an LCA study

Time - related coverage: the desired age and the minimum length of time
Geographical coverage: geographical area from which data for unit processes should be collected to satisfy the goal of the study
Technology coverage: nature of the technology mix, type of the technology
Completeness: percentage of locations reporting primary data from the potential number in existence (for each data category in a unit process).
**Representativeness:* qualitative assessment of the degree to which the data set reflects the true population of interest (geography, time etc.)
**Precision*: measure of the variability of the data values for each data category expressed, numerical accuracy and uncertainty of data
**Consistency*: qualitative assessment of how uniformly the study methodology is applied to the various components of the analysis
**Reproducibility:* extent to how the data values and used methodology may be reproduced by an independent practitioner

The data quality goals set in the goal and scope are reviewed continuously during the data collection phase so that the LCA analyst can control the data gaps or return to the beginning and change these requirements.

2.3 Data Collection in LCA

Data collection is the acquirement of numerical and/or qualitative data for the processes of the modelled system either by measurement, interviews, estimations or calculations (Bo P.Weidema, 2003). Qualitative data may be used for environmental aspects or single steps in the life cycle that cannot be quantified or if the goal and scope allows a qualitative description of a process or a condition (Allan Astrup Jensen,1997). Data collection is a complex process because of missing or incomplete data, differences in data collection way, variations in technologies, and the number, diversity and potential interaction of the processing steps. Together with data requirements, they constitute two iterative "processes" of an LCA study since both have to be revised, checked and even changed during the different phases of an LCA.

Sources of data can be government documents, federal regulations, technical literature, industry reports, published studies, plant visits, databases, etc. The selection of the data sources can affect the inventory results and any analysis should include complete documentation of sources, assumptions, limitations and omissions (Svoboda, 1995). Practical constraints also should be considered in the scope and documented in the study report (NSF International, 1997). Whenever data for a product or a process are missing, then the same kind of data can be obtained from other similar products or processes when the differences between them are minor and they don't have significant environmental impacts (Joel Ann Todd,1999).

It is necessary to select data categories (data groups for inputs and outputs in the modelled system) and corresponding parameters in order to initialize the collection process. Then the practitioner can start by collecting data for the most important processes and move towards less important (Kun-Mo Lee, 2004). The flowchart can give a path that has to be followed concerning the kind of data needed to describe all the processes (Svoboda, 1995). Moreover, the designation of the system's boundaries during the scope definition is important for the data collection phase, because they will determine the amount of the work to be done.

The procedures followed in data collection vary depending on the scope of the study, unit process or the intended application of the study (NSF International, 1997). The choice of ***data collection method*** depends on (Bo P.Weidema, 2003):

- the required precision for the data
- the type of data to be obtained
- the required skills of the data collection personnel
- the acceptance of the method by the intended audience

The more usual method to collect on site data is by creating and filling a data questionnaire describing the main characteristics of the unit processes. A generic data questionnaire can contain the following information (Kun-Mo Lee, 2004):

- Process description
- Time of data collection
- Product type
- Name of company
- Input - output parameters such as unit, quantity, data quality, country of origin etc.

As it was noted before, background data can be obtained by LCI databases. But it is very important to take into consideration that system boundary and assumptions made while developing the respective database might be different than the ones suited for the current study. Therefore, each time data are used from a database these aspects must be taken into account (Kun-Mo Lee, 2004).

2.4 Data Quality Indicators for LCA

The quality of data used in a Life Cycle Assessment plays a major role for the results of the study. For the realization of their quality, indicators are suggested by various sources. In this part, the recommendations by ISO standard and other LCA experts are summarized in table 3 and discussed.

The specifications suggested by ISO, when thinking about data quality requirements, are covering all the necessary aspects of environmental information that must be considered. By comparing the data in an LCA study with these guidelines, its reliability and transparency will be at the highest grade together with its results. Moreover they can give a certain path for the practitioner to follow during data collection either by helping to manage the data gaps emerged in this phase or even return and change the study’s data requirements. ISO makes it clear for each published LCA study that is required to take into consideration each of these aspects.

ISO Standard	**Bo P.Weidema, Marianne S.Wesnaes (1996)**	**Pålsson (1999)**	**Bo Von Bahr & B.Steen (2003)** **Bo Von Bahr et al. (2003)**
• Time –relation * • Geography * • Technology * • Precision • Completeness • Representativeness • Consistency • Reproducibility • Data sources • Uncertainty	• Reliability • Completeness • Time • Geography • Technology	• Reliability • Accessibility • Relevance	• Emission characteristics • Hypotheses - questions

* Coverage of data with respect to these aspects

Table 3 Data Quality indicators by various sources

Bo P.Weidema and Marianne S.Wesnaes (1996), in their article for data quality management in LCA, suggest five data quality indicators, as shown in the above table. A specific structured form is given in this paper called "pedigree matrix" (see 11.1 in Appendix), where these indicators, a score scale from 1-5 and respective directions for each category are outlined. According to them, they can be used to:

- Revise the data collection strategy for the improvement of the quality of the collected data
- In combination with uncertainty estimates, to give a better assessment of the reliability of the result.

Despite the older origin of these data quality indicators, they are consistent with the ISO standard and can be used (with modifications due to a practitioner's preferences) for the proper control of the information gathered during the inventory stage. However some other ISO aspects such as precision, reproducibility and consistency are not included and have also to be considered.

According to the Centre for Environmental Assessment of Product and Material Systems (CPM) and its report 1999:1 by Ann Christin Pålsson, the data quality indicators of reliability, accessibility and relevance are suggested and used in their database. A special format has been developed and applied for the documentation of their LCI data called SPINE. The specific quality indicators were related to the aspects of data quality set by the ISO standard (ISO 14041) with:

- Relevance covering the time relation, geography, technology, completeness and representativeness
- Reliability covering precision and consistency
- Accessibility covering reproducibility and consistency.

Therefore, the CPM data quality requirements totally agree with the ISO standard and include all the perspectives that ought to be thought during collection of LCI data.

Finally, Bo Von Bahr & B.Steen (2003) recommend considering the specific characteristics of emissions and the governing factors that influence each type of emission. They suggest a certain methodology which comprises three different stages:

- Primary emission mechanism that corresponds to the sources of the emissions
- Conversions in process, that correspond to the reductions of emissions (because of chemical reactions) in the process of origin
- End-of-pipe measures (e.g. filters, catalysts etc.)

With this course of action, the practitioner will comprehend the aspects that rule the generation and final discharge of a polluting substance in order to realize the relevance of the data collected with the real conditions and direct the right questions for the LCI processes under investigation. Another article by Bo Von Bahr et al. (2003), which outlines the experiences of environmental performance evaluation in the cement industry, applies hypothetical statements to explore the data quality of the emission factors (emission/product). These statements refer to questions about average values, variations etc. and can serve the basis for the appreciation of the information used.

All the various data quality indicators mentioned and discussed above, can help an LCA analyst to evaluate, explore or organize the inventory data applied in his/her study. However the use of each of them must be done in accordance to the ISO standard.

3 Methodology

In this chapter methodological approaches are described, first for the two simplified LCI models done for the purpose of the study and then for the data collection of the First Tier suppliers.

3.1 Simplified LCI models

The methodology that is followed to discover the difference of using two sources of data (site-specific and database data) will be based on two simplified LCI models, each built with the respective type of data. For this purpose, the case study of a bearing unit manufactured by SKF will be used. In the end various inventory result categories will be compared to reach valuable conclusions.

These two models will be developed with the help of the GaBi software program. Its database has an extensive range of LCI data that covers many products and processes such as steel products, electricity production, fossil fuels etc.

The “core” of these simplified LCI models is the bearing’s production process with site-specific data collected by SKF. These data correspond to annual total factory data and comprise mainly energy inputs and waste outputs (source is SKF’s environmental reports). In both models, the main (local) First Tier suppliers of the major supplied components will be modelled with their relevant processes. These supplied parts are:

- Flinger
- Seal
- Ring
- Cage
- ABS Sensor
- Steel ball
- Stud
- Grease

The structure of the GaBi models includes a "central" GaBi plan (see 6.1 for explanations of GaBi functions) with the main unit process of the bearing production and the respective GaBi plans of the First Tier suppliers connected to this process through their output flows (see Figure 3).

In both cases, the output of the supplier’s production processes is chosen to be the weight of their products needed for the production of the analysed bearing (functional unit of the two models). Methodological choices such as functional unit, allocation method, system boundaries etc., are explained thoroughly in the Goal and Scope chapter of the report. In order to make the GaBi models as simple as possible, it has been decided to include other upstream processes such as raw material production, energy - fuel supply and transports in the respective supplier GaBi “plan”, as shown in figure 3.

The model with data taken from GaBi's database will include flows and processes similar to the real ones, which take place in the supplier's facilities. For the other model, with site-specific data of the First Tier suppliers, the inputs and output flows of their processes will be allocated according to the study’s functional unit and represent their production. Processes and flows in other stages of the product's life cycle (e.g. steel production or energy supply) will remain as before by using GaBi data. Furthermore, data quality aspects are stated such as origin of data, integrity, location -time aspects etc.

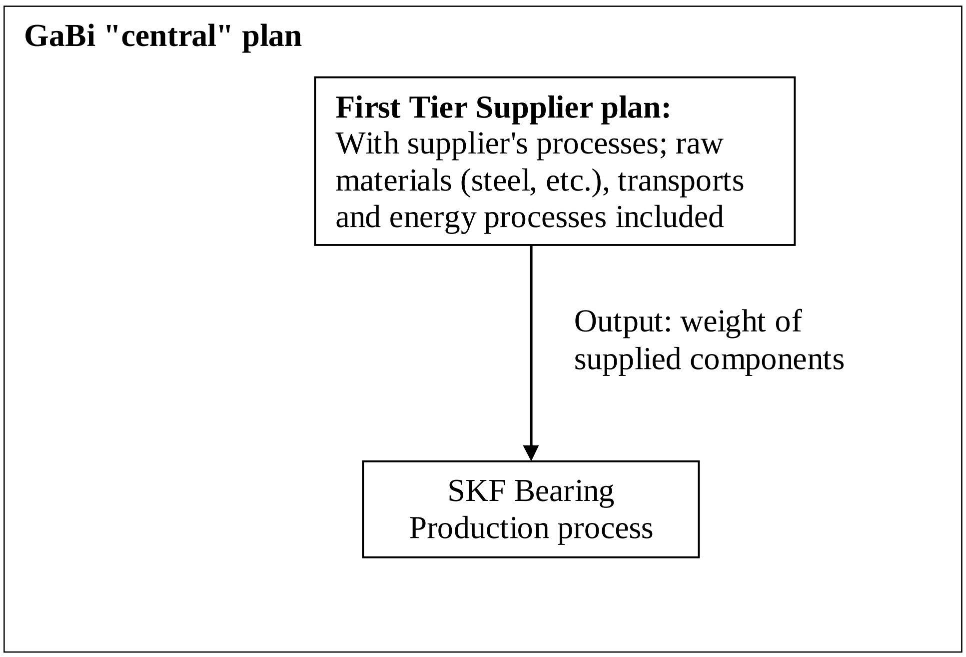


Figure 3 Structure in GaBi of the two LCI models

As mentioned earlier, there will be a comparison of the LCI results from each model to discover the qualitative and quantitative difference of using the two data sources. For this reason, GaBi “balances” (special function of GaBi calculating the inventory results) of each “plan” will be used in order to analyse the LCI results with the help of diagrams and examine the main variations.

Finally a dominance analysis will be performed to evaluate the importance of collecting data for the First Tier suppliers rather than gathering site-specific data for other stages of the specific product's life cycle.

3.2 Data Collection strategy for First Tier Suppliers

A very "vital" stage of an LCA project is the data collection and furthermore the method that will be followed in order to gather the required data for the completion of the study.

In this section the strategy followed and every step will be described analytically since the beginning of the project in SKF. A first overview of the data collection strategy is shown in the following figure:

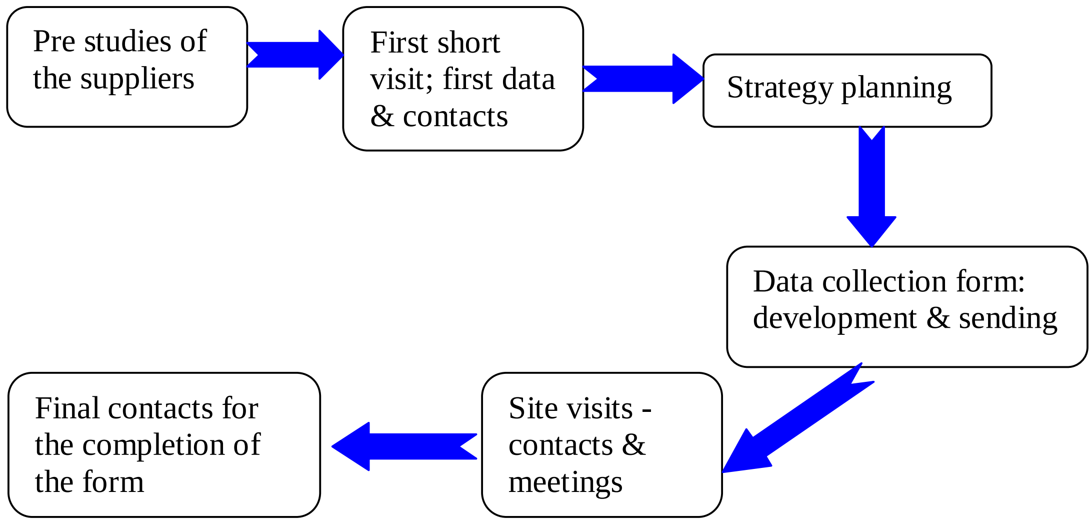


Figure 4 Data collection strategy

Like in many cases, at the beginning of a project the practitioner needs to become familiar with the processes involved in his/her study. In the respective case, general pre studies have been made, such as for steel production, because of the lacking knowledge for the main suppliers and the specific components. These were based on web based studies mainly and older reports.

The data collection guidelines for an LCA have been studied in order to set the most efficient strategy to be followed later. In this research, literature recommendations have been taken into consideration such as in the book "The Hitch Hikers Guide to LCA" (Anne-Marie Tillman & Henrikke Baumann, 2004) together with published articles by Bo P.Weidema (2003), Allan Astrup Jensen (1997), Svoboda (1995), Joel Ann Todd (1999) and Kun-Mo Lee (2004). Additionally other sources of information were older LCA reports of SKF by Yunfeng Li (2006), Åsa Ekdahl (2001), J. Nilsson (2001) and K. Jonasson (2003) where their data collection methods have been investigated. As supplementary information the guidelines of an EPD were taken into consideration. Finally all the findings have been discussed to organize an initial strategy.

A short visit to SKF's factory took place (after six weeks almost since the start of the project) to establish the right contacts with the people working there. Another reason of this visit was to agree on a period of two weeks for the next visit when the collection of the data from the First Tier suppliers would occur. This first visit lasted for 3 days where a presentation of the project has been done with the intention that they will have a first idea of the data needed. Some crucial data were collected such as a plan with all the in-house processes happening in the factory and a list of their main suppliers.

An initial flowchart of the technical system under study was constructed with all the known upstream and in-house processes. The specific flowchart made possible together with the provided data from the supply chain manager of the facility to identify all the suppliers, local and global. Specific pre studies of their processes have followed to enhance the knowledge and prepare as much possible for the site visits later on. These studies involved visits to their websites, web based research on similar products and literature study mainly from the previously mentioned older LCA studies of bearings.

Thereafter the data collection strategy for the First Tier suppliers started to be planned by doing a distinguishing of the "big" suppliers and what type of data should be collected by each one (total factory data or product specific data for example). A data collection form was developed, specially adjusted to the data needed by the suppliers. This form would constitute the basis on which the data collection will be relied on. It included two main sections, the inputs and the outputs, together with information for the product and its manufacturing processes (see 11.2 in the Appendix).

A selection of the suppliers has been done for reasons of time limitations and data quality requirements. Only the main local First Tier suppliers have been chosen to collect site-specific data and fill in the form. Then a validation of the form has been done to assess its functionality and flexibility so that it can be as much as possible easy to fill in. It was carried out with the use of data from the facility of SKF related to the production of this study's analysed bearing unit.

After all these preparations the site visit at SKF took place where all the data would be acquired. Interviews within SKF have been made to collect numerical data for the supplied components and specific information of their manufacturing processes. Then, in the meeting with the purchasing manager of the respective SKF facility, the site visits to the local First Tier suppliers were organised with the contact (by phone or e mail) of the right persons through the manager. Finally the data collection form was sent by email to each of these suppliers together with instructions of the way to fill in the form.

During the site visits to the suppliers, meetings with the factory managers and other employees, such as environmental managers, occurred. First of all a presentation of their companies have been showed to provide general information of their products and business activities. A presentation of the LCA project followed, with a description of the LCA concept and methodology along with the type of data needed. Afterwards more extended discussions followed on practical matters concerning the completion of the data form. Later on, in each visit, "tours" inside the facility were made to observe and understand their in house processes. At the end of each visit, contact information with the people met was ensured for subsequent communication.

Finally, the suppliers completed the data form after the visits and sent it by e-mail. Data gaps have been filled with continuous contact of the suppliers. Reflections and analysis of the benefits and drawbacks of this strategy along with recommendations for future LCAs will be discussed later on in this report.

4 Bearing Unit Case study

4.1 General information for the analysed bearing unit

The product under investigation in this study is a specific bearing unit that is manufactured in an SKF facility. There are various types of this bearing with the following components utilised for their production:

- ABS Sensor
- Steel balls
- Cages
- Cup
- Encoder
- Flinger
- Grease
- Inner flanged ring
- Inner ring
- O-ring
- Outer flanged ring
- Screw
- Seal
- Sensor carrier
- Studs

The production line in SKF factory comprises two main processing lines, one for the inner ring and one for the outer ring, one small processing line for the inner half ring and finally the assembly line. Each one of the above components is inserted in the production line in different stages of the process. The various types of the investigated bearing product have different characteristics (e.g. different weight or different components etc.) which depend on the customer's needs. For example in 2007, fourteen different types of this bearing have been produced in the respective SKF facility.

4.2 First Tier Suppliers

Each component of the analysed bearing can have more than one supplier. The majority of the First Tier suppliers are local but there are also parts coming from other European or Asian countries. In table 4, the origin of the First Tier suppliers is shown. The manufacture processes of the suppliers that site-specific data were collected and are modelled in this study are illustrated in the 11.3 section of the Appendix.

Component	Country
ABS Sensor	Hungary
	Italy
Steel ball	Italy
	UK
Cage	Italy
	UK
Cup	Italy
Encoder	Italy
	Italy
Flinger	Italy
	Japan
Grease	Belgium
Inner Flanged Ring	Italy
	Italy
	Germany
	Korea
Inner Ring	Italy
	Korea
	China
O-Ring	Italy
Outer Flanged Ring	Korea
	Italy
	Germany
Screw	Italy
Seal	Italy
	Japan
Sensor Carrier	Italy
Stud	Spain
	Italy
	Germany
	Italy

Table 4 Geographical location of First Tier suppliers of the analysed bearing

5 Goal and Scope of the study

In this chapter the goal and scope of the present study will be outlined thoroughly.

5.1 Goal of the study

The goal of this study is to investigate and evaluate the quantitative and qualitative difference, in an LCI study, of using site-specific data as compared to LCI data of a database for the First Tier suppliers in a product's chain. Furthermore, a dominance analysis will be carried out in order to investigate the importance to focus for data collection on other life cycle stages than the First Tier suppliers. The case study of a bearing unit, manufactured in a specific site of SKF, has been chosen to model.

Data collection strategies followed in this case study will be discussed and reflected with standard guidelines (ISO) or older LCA reports, so that recommendations can be given for future LCA studies.

Life Cycle Impact Assessment (LCIA) has not been conducted for the specific study and the reason is related with its purpose. The analysis of specific categories of the LCI results, without aggregating them into impact categories, shows effectively the real differences between the models with different data sources and points out the most polluting life-cycle stage in the modelled product system. This selection is based on their quantitative importance in the analysed system.

The intended application of this study is to investigate data collection strategies, specifically the importance of site-specific data from First Tier suppliers. The report is written for SKF Sverige AB and Chalmers University of Technology.

5.2 Scope definition

In this section the methodological choices of this study are stated for the two LCI models that will be developed (site-specific data model and "GaBi" data model).

Options to be modelled

In both of the models, the product under investigation is a bearing unit, manufactured by SKF.

Type of LCI

The specific type of the LCI models in this study is of the accounting type, where the environmental loads generated by the production of the investigated bearing are going to be compared between the two models. The data used in this project comprise annual average (GaBi model) and total factory data (site-specific model). Finally the allocation method used is partitioning, as it will be explained more thoroughly later in the scope definition.

Initial Flowchart

A general and initial flowchart showing the life cycle "from cradle to gate" of the analysed bearing is:

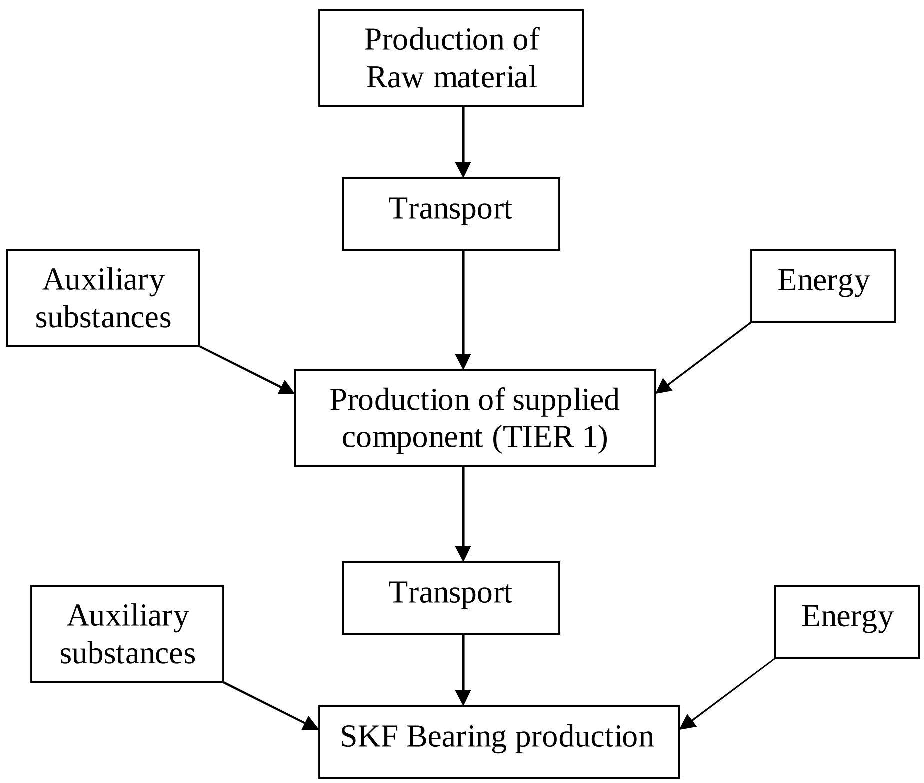


Figure 5 General flowchart of the analysed bearing's production

These flows and processes are going to be included in the two models that will be compared at the end. Their only difference will be the origin of the First Tier supplier's data.

Functional unit

In both models, the functional unit is selected to be one final "average" bearing unit. As pointed out earlier, the bearing analysed in this study is produced in different types. With the term "average" it is meant that this bearing has an average weight (from all the different types of bearings produced) and uses the average number of components (First Tier supplied products) for its manufacturing processes. This number of components corresponds to the parts that are used by the majority of the bearings produced. For reasons of simplification, components with minor use have been excluded from the models (more will be explained in the cut-off criteria).

System boundaries

The boundaries set in the two models are described below:

- In relation to natural system: the study's general boundary is "from cradle to gate" meaning that it includes (whenever possible or available) the relevant flows and processes from the extraction of raw materials until the production of one bearing (as shown in the initial flowchart earlier). Moreover the emissions to air and water, waste and land resources related with the production of the raw materials, transports, fuel production, energy generation and use, are given from the GaBi software program and its database. Concerning the production processes of the First Tier suppliers, in the model with site-specific data, emissions and waste are included when available, while in the "GaBi" model these flows are provided from its database respective processes. Finally in both models, the waste involved with the bearing's production is taken from the environmental reports of SKF in 2006 and 2007.

- Geographical boundaries: In the model with site-specific data, the main local suppliers have been modelled which were located in the surrounding geographical area of SKF's facility (in the same country). About the production of raw materials, GaBi relevant processes have been chosen taking place within the European continent (mostly Germany because of the origin of the program). In some cases, site-specific data were available and have been used for other suppliers higher in the bearing's production chain (than the First Tier) e.g. for seal's flinger and ABS Sensor carrier. Regarding energy generation and use (electricity, natural gas etc.) national data of the country where the specific bearing is produced, have been used for the investigated suppliers (available from GaBi's database).

  Energy and land resources utilised for the production of the raw materials have a global origin since they're coming from different regions of the world, as documented in the software's database.

  For the GaBi model, relevant unit processes have been chosen to represent the production of the First Tier suppliers, when available. The majority of these processes are mainly coming from Germany along with processes for the raw materials. The energy processes used in this model correspond to average European data.

  As for transports and fuel production, the global and European GaBi's general data were included in both models, respectively. Concerning auxiliary substances in the models, such as oils, average European data have been taken into account. Finally, for the main process of the bearing's production, national average data were used for the electricity and natural gas generation (due to the country of bearing's manufacture).

- Time boundaries: As mentioned before this LCI study is of the accounting type, meaning that the data used in both models are coming from previous years (retrospective).

More specifically in the first model, the site-specific data gathered by the suppliers are based on their 2006 and 2007 production. Thereafter the data taken from GaBi for the background system (energy, transports, and raw materials) are varied between 2001 and 2005.

In the second model with GaBi's data, all the processes selected for the First Tier suppliers, raw materials, transports and energy correspond to the time space of 2002 to 2005.

Finally in both models, the data for the bearing’s production were taken from the environmental reports of 2006 and 2007, as mentioned earlier.

- Cut off criteria: Based on the fact that, for the purpose of this study, two "simplified" LCI models will be developed, it is necessary to state the criteria of these simplification choices.

  First of all, the productions of the capital goods have not been taken into account (Baumann and Tillman, 2004). For the bearing product it was decided to use the average weight, as calculated from SKF's 2007 production data.

  As mentioned earlier, some components have been excluded from the two LCI models because of lack of data and their minor use in the investigated bearing. These correspond to the cup, encoder and screw. From the fourteen types of the analysed bearing produced in 2007, only one uses cup, four use encoder and two use screws.

  For the cases of steel balls, studs and grease, where different amount of pieces or weight (for grease) is applied to the bearing’s manufacturing process, their average was calculated and taken into account for the two models (more will be explained in the inventory analysis).

  In the model with site-specific data, few data sets were excluded or "cut-off" because of data gaps and irrelevance. In the case of emissions, some supplier’s data have been also excluded because of their very small amounts (compared to the national limits of the production location). These are stated below:

Component - Supplier	**Data set**
Seal	Emissions to water Hazardous waste Alkalinity
Cages	Auxiliary materials Emissions to air
ABS Sensor Carrier “Sensor Carrier 2”	Raw and auxiliary materials Energy use Waste
Steel Balls	Acidification Potential

Table 5 Data excluded in the model with site-specific data

A more detailed explanation for each excluded data set is given in the Inventory Analysis chapter, where each model is described.

- Allocation choice: In both of the models the average data used for the production of the investigated bearing correspond to the total factory data, as mentioned earlier. Also the First Tier suppliers, where site-specific data were collected, have provided their factory total data from 2006 or 2007 production. All of these factories produce several products so there was a multi-output problem. For this reason, allocation was necessary to be applied in order to find out the amount of these data related to the functional unit of the study.

  The method of allocation used is partitioning by weight. Another option was to use the number of pieces produced but weight represents in a better way the relationship of the respective products and the related manufacturing processes. This statement is based on the fact that the various products have different weights and depending on the weight of the final product differences may occur in a range of activities such as more or less energy consumption, use of raw materials, waste generation etc. Moreover, according to the ISO standard guidelines, the chosen allocation method should reflect the way in which the inputs and outputs are changed by quantitative changes in the products delivered by the system (ISO 2001). So using weight does not only take into account possible changes in the final production of the respective facility but also individual changes of the modelled product. Hence the main reason of selecting weight as allocation-partitioning factor is the added quality of the inventory results instead of using the number of pieces as the basis of the allocation.

  Concerning the allocation in the GaBi model, for the bearing production the same type of data have been used as in the previous model, so the same allocation method has been used. At the First Tier supplier processes, where GaBi processes were applied, all the flows are related to the product’s weight of the respective supplier. The input and output data of the GaBi's unit processes are also automatically normalised to this number by their "scaling factor" (in GaBi "scaling factor" is a parameter of each unit process that normalises all the input and output data, when changes are made, to remain in relation with the functional unit).

Data quality requirements

The data requirements of this study are consistent with its goal. So the actual differences of the data used in the two models are focused on the First Tier suppliers and their processes.

Concerning the data that will be used for the background system of the study (raw materials, electricity, transports and fuels) they must be originated from an LCI database (in our case that would be GaBi’s) and correspond to the same type of product (technology representative). They should be average with geographical boundaries depending on the model that they will be included. These will be altered between the two models, in order to comply with the goal of the study (changes are stated in the inventory analysis).

Regarding the First Tier suppliers, the data to represent their processes must be site-specific in the one model and of database origin in the second one. The site-specific data must correspond to the respective production processes and indicate all the environmentally relevant flows. The database data must represent adequately the particular product of the supplier and its manufacture processes.

Finally for the production process of the analysed bearing, the same type of data must be used in order to ensure equal conditions for comparison of the two models. Therefore the same input flows for the supplied components must be taken into account to be the same between the two models.

Major assumptions

The choice to consider the "average" bearing, as the functional unit of the study constitutes a significant assumption made for reasons of simplification. As explained, in the description of the functional unit, it has the average weight (calculated by all the different types produced) and uses the average number of supplied components, meaning the average parts that are utilised by all the various types of the particular bearing products.

Other assumptions made for individual data sets will be stated in the inventory analysis where the calculation procedures are going to be illustrated.

Interpretation of the results

Since there is not going to be conducted a Life Cycle Impact Assessment, the inventory results are going to be compared between the two models. Categories that will be used as a basis of the comparison are:

- Material resources (input flows)
- Energy resources (input flows)
- Emissions to air
- Emissions to water
- Production residues in life cycle (waste for disposal or recovery, hazardous waste)

By these categories the fluctuations of the inventory results are going to be observed and conclusions will be drawn. Finally, a dominance analysis will be established (as stated in the goal of the study) in order to discover the importance of the First Tier suppliers as compared to other life cycle stages.

Procedural aspects

The format of the report will be based on the ISO standard for reasons of transparency. The report is going to be reviewed by supervisors at SKF Sverige AB and Chalmers University of Technology.

6 Life Cycle Inventory Analysis

In this chapter, the two models will be described in detail with the methodological choices and the calculations done for individual data sets. Moreover pictures of the GaBi flowcharts in each case will be shown for additional comprehension of the two models and their differences. Previously general information will be given for functions and concepts of the GaBi software program, for a better understanding of the subsequent sections.

6.1 GaBi software program: Concepts and functions

The GaBi software program has its own glossary and terms for the LCA definitions. Therefore it was considered necessary to make a short description so that the reader will be able to comprehend the next sections of this study.

- **GaBi "plan":** In a GaBi "plan" the life cycle of the modelled product is shown. This means that the entire unit processes (with their input and output flows) of the modelled technical system are included and connected with each other. An additional function of GaBi is the "plan nesting" where a plan can be used into another plan, if necessary. In that case the main output (product) of this plan will be connected to the inputs of another process (or even plan).

- **GaBi process:** A GaBi process corresponds to a unit process, in a life cycle, with its input and output flows (they are depicted by the boxes in each flowchart). For example the GaBi process "Steel wire" refers to the production of steel wire and includes the inputs and output flows of this process such as raw materials, energy, waste and emissions flows. The GaBi processes are connected in a GaBi "plan" through their main output flow.

  Some processes have parameters that define one or several input-output flows. For instance, each transport process in the program has a parameter for distance that recalculates inputs and output flows (e.g. fuel use, waste, emissions etc.) according to the distance of transportation.

  Moreover a process has its standard and "local" settings (inputs, outputs, parameters etc.). The standard settings are the initial settings in the GaBi's database and the "local" correspond to a specific GaBi "plan". The program gives the possibility to change the "local" settings without influence the standard ones. When a change in the "local" inputs or outputs happens, there is a function called "scaling factor" that normalises automatically all the data (in order to remain in relation with the functional unit).

- **GaBi flow:** A flow in the GaBi program is used by a GaBi process as input or output and refers to a specific quantity such as mass, energy, volume etc for a particular product or service. These flows are categorised as valuable material flows (corresponds to material or energy carriers used in other processes), elementary flows (flows taken directly from the environment or released to it e.g. emissions or ore) and waste flows (waste treated in other processing steps and decomposed into elementary flows). The GaBi flows are used to connect consecutive unit processes.

- **GaBi "balance":** It makes the calculation of the inventory results in a specific GaBi "plan". These results are related to the inputs and outputs of each unit process included in the respective "plan". By this function the practitioner is able to compare the inputs and outputs of the modelled system and make analytical assessments of the results such as view the results with various impact assessment methods and units, sensitivity analysis, dominance analysis etc.

6.2 Model with site-specific data of the First Tier suppliers

As mentioned in the methodology chapter, both of the models have a "central" GaBi plan of the SKF bearing production. Thereafter all the respective GaBi plans of the First Tier suppliers are connected to the main process of "SKF Bearing production" through their outputs.

The SKF's annual total factory data used in the two models for the bearing production are coming from their environmental reports of 2006 and 2007. Because of the lack of data for the last quarter of 2007, it was necessary to use the data of the 2006's last quarter in order to account for one-year data. The total data taken into account were very similar to the ones from 2006 production.

According to the weight supplied of each modelled component for the production of one bearing, their relation is shown in the following table:

Component (TIER 1 Supplier)	Supplied amount (%)
Flinger	0.26
Seal	0.35
Rings	88.1
Cages	0.16
ABS Sensor	1.45
Steel balls	4.24
Stud	5.05
Grease	0.36

Table 6 Supplied amounts of the modelled components for the production of one bearing

For steel balls, studs and grease, their average number has been used in the model (more information will be given later). An overview of the "central" GaBi plan for this model can be seen in figure 6.

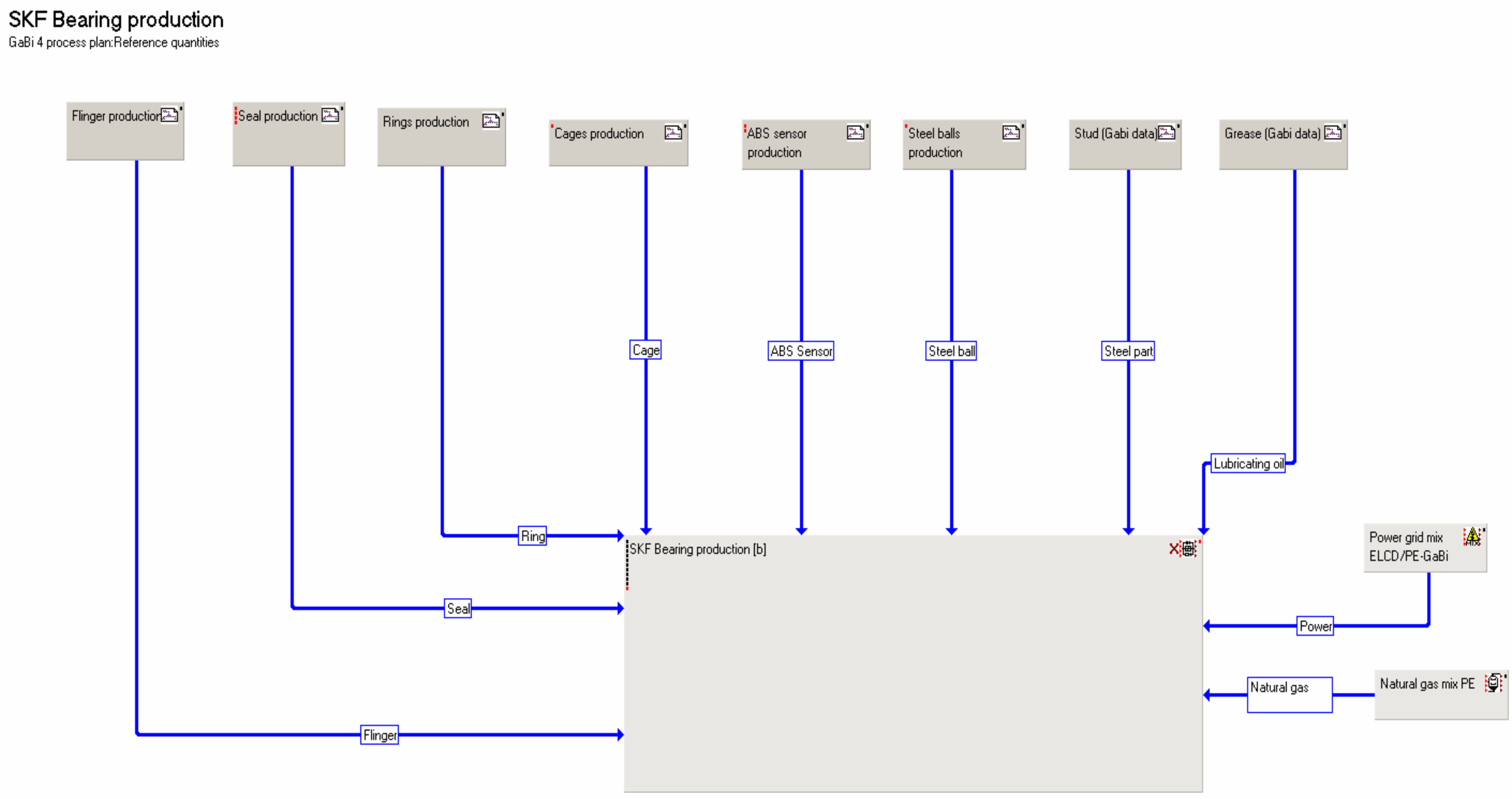


Figure 6 GaBi model for the production of the analysed bearing

The unit processes for power supply from electricity and natural gas were taken from GaBi database and correspond to the country where the bearing is produced (except for some further upstream processes where general European data have been used). As for transportation, the GaBi processes used were based on the total weight and distance transported.

Concerning other upstream suppliers, the most relevant unit processes of the GaBi database were used in the model. Their selection was based on the specific information collected from the First Tier suppliers.

As mentioned in the goal and scope, the allocation in the study has been done by weight. The formula used for the allocation of SKF and supplier's data is:

$\frac{\textit{Factory data}}{\textit{Factory production}} * W_{\text{av. bearing}}$. The factory's data correspond to the data gathered for raw materials, energy and auxiliary inputs along with product, waste and emissions outputs. The factories production in Kg has been used for this allocation. In the case of the suppliers this corresponds to the respective component's production or the total factory production depending on the type of the supplier data (sometimes the supplier provided data related only to the specific component for SKF and other times the total factory data have been given). Finally the average weight of the analysed bearing has been used to relate the data to the functional unit of the study.

All the Gabi flows and processes used in this model are stated in the Appendix section 11.5.1.

Flinger production

For the production of flinger, the total data of the supplier's factory were given. For the allocation procedures, it was necessary to calculate the total production of the respective supplier. This was done with the help of the specific company's general production data.

For reasons of simplification the total of oils (pressing-emulsion-hydraulic) is taken into account as lubricating oil. According to availability of site-specific data, the "steel mix disposal" GaBi process was used for the representation of the steel scrap disposal by a particular local company that receives this waste and then sends it to foundries. An overview of the GaBi plan for the flinger production is shown in figure 7.

Seal production

The data provided by the seal manufacturing company were total factory data except the raw materials that they use which correspond to the specific type of seal used in the analysed bearing. For the allocation of the factory total data, it was needed to calculate the total weight of the seals produced in the facility. This number was found by the electricity data that were given. An overview of this GaBi plan is shown in the figure 8.

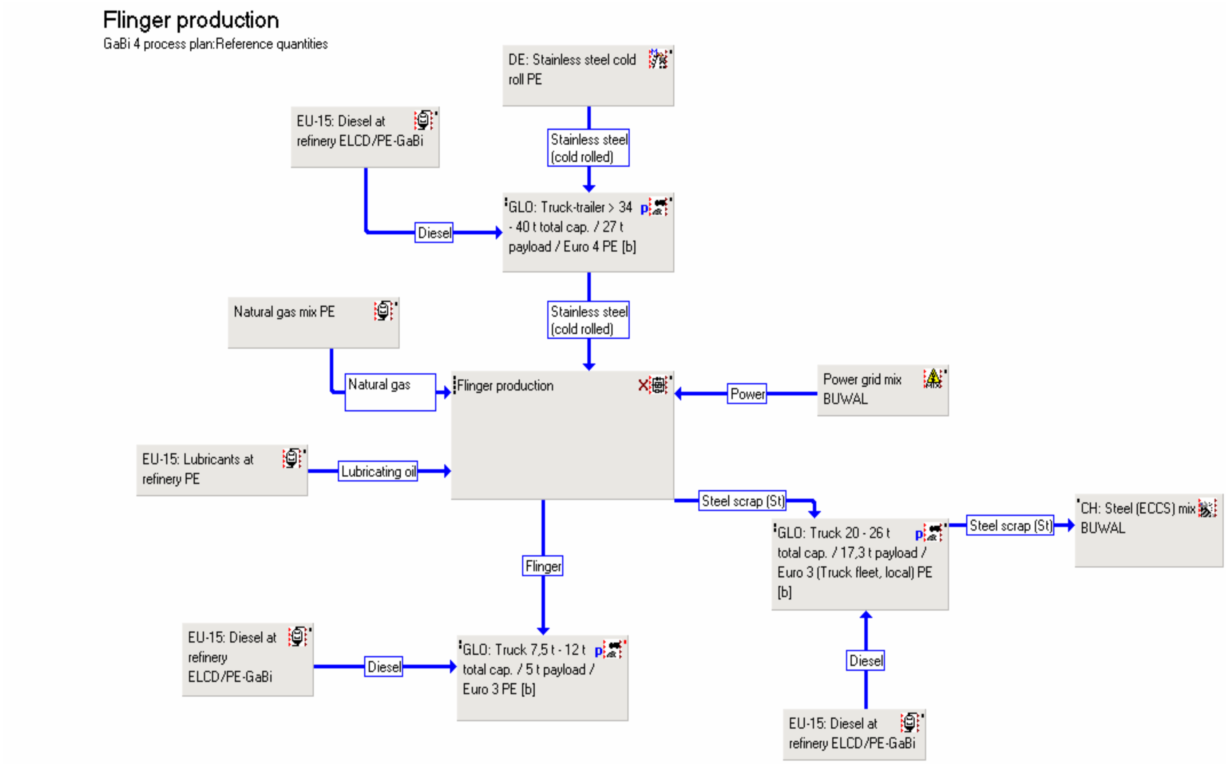


Figure 7 GaBi model for flinger production

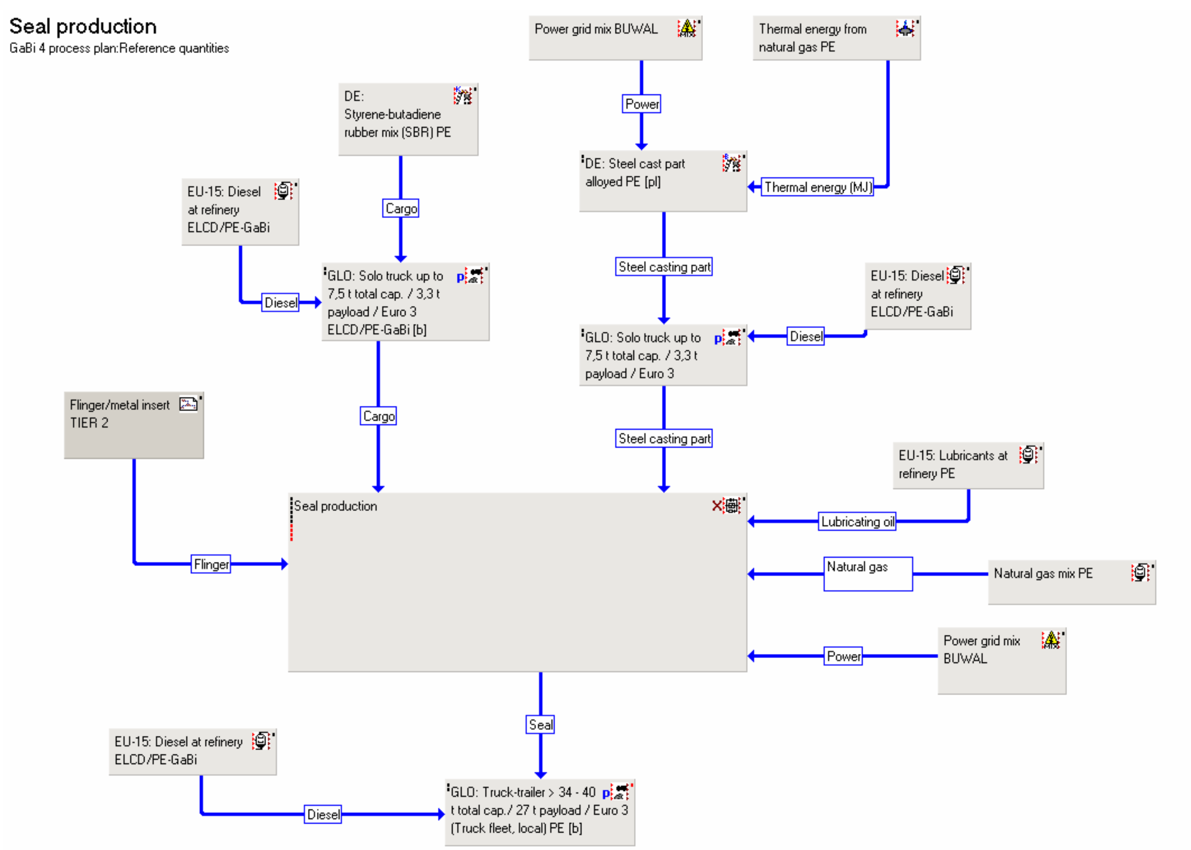


Figure 8 GaBi model for seal production

Concerning the raw materials used for the seal production, the flinger and metal insert inputs are added and their total weight has been taken into account. This choice is done for reasons of simplification and is based on the fact that both of these inputs were coming from the same company that supplies also flinger to SKF and produces the same type of metal products. So in the GaBi model for seal production, this input material is represented by the same GaBi model - plan as used before for flinger (only this time renamed as "Flinger/Metal insert TIER 2" plan and with the respective flinger output). As for other processing input materials such as cement, spring or phosphate products, they are included in the model as flows but they are not linked to upstream processes because of their minor numerical importance and lack of GaBi relevant processes.

The emissions to air from the seal production are included in the model (except alkalinity where was no specific information about the type of alkali metal emitted), but an assumption was necessary to be done in order to convert their unit from kg/h to kg. So it was assumed 300 working days per year, excluding Sundays and national days of the respective country. Then the emissions were calculated for the respective period of the data collected. Concerning the emissions to water and hazardous waste, they are not included in the model because of data gaps such as unit missing (for hazardous waste) or lack of water flux specific data (for the emissions to water).

Rings production

According to data collected from the rings manufacturing company, they supply two kinds of rings for the production of the analysed bearing. These are the inner-flanged ring and the outer-flanged ring. In the model, as output of the "Ring production" plan is chosen the total of the average weights of these two rings. Therefore all the input and output flows in the allocation calculations are related to this number. The data used to find the average weight of these rings are taken from the forged ring drawings (acquired by SKF facility).

For the production of these rings, hot rolled steel bars (of 55-60 mm) are utilised and forged into the respective ring shapes. The data set for the production of these steel bars is taken by the LCA study of Ekdahl for another kind of bearing that uses this type of steel bars (2001). For the allocation of these data to this study’s functional unit, it was necessary to find out the weight of the steel bars used for the production of that product and then with the help of GaBi’s “scaling factor” all the flows were related to the current functional unit.

The steel scrap amount stated by the respective supplier’s total data corresponds to the total scrap including the turning operations. But in the case of the studied SKF factory, the turning of the rings takes place in another company so the steel scrap was calculated by excluding this phase.

An overview of the two GaBi plans developed for the modelling of rings and steel bars production is given in the figures 9 and 10.

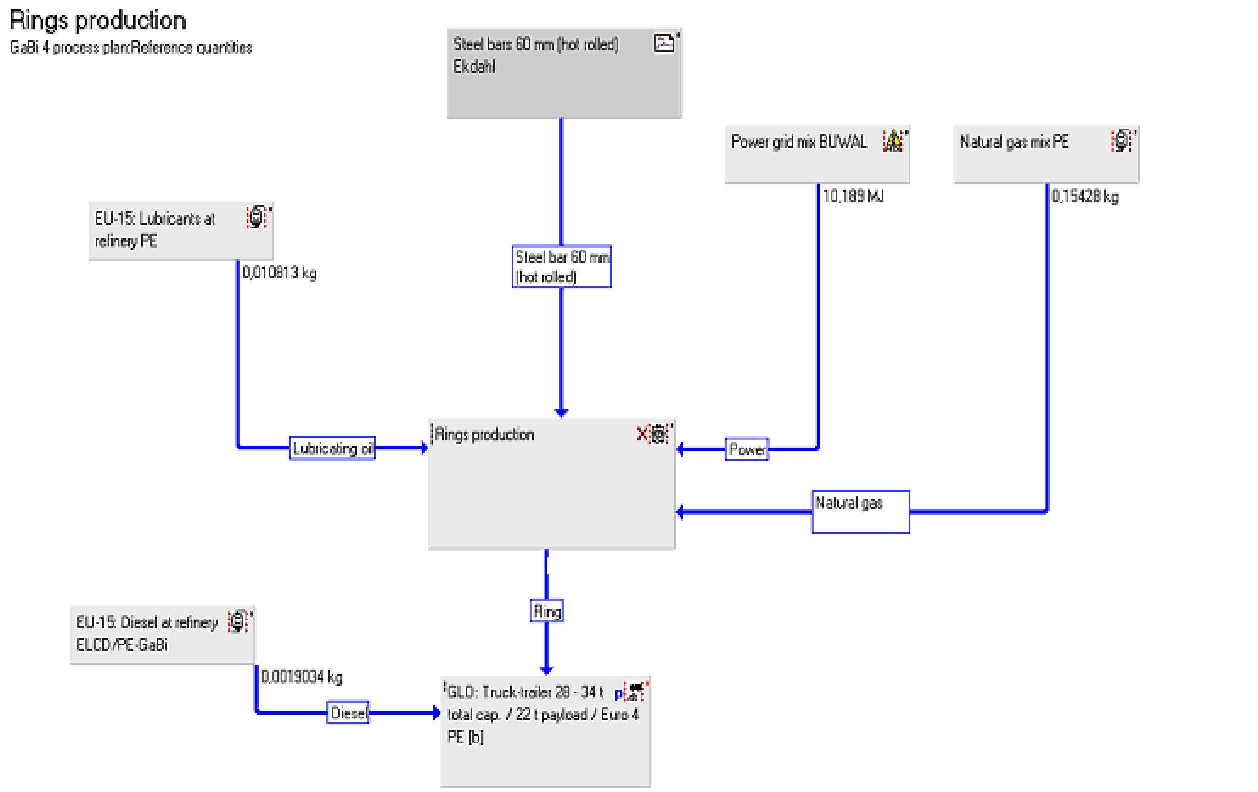


Figure 9 GaBi model for rings production

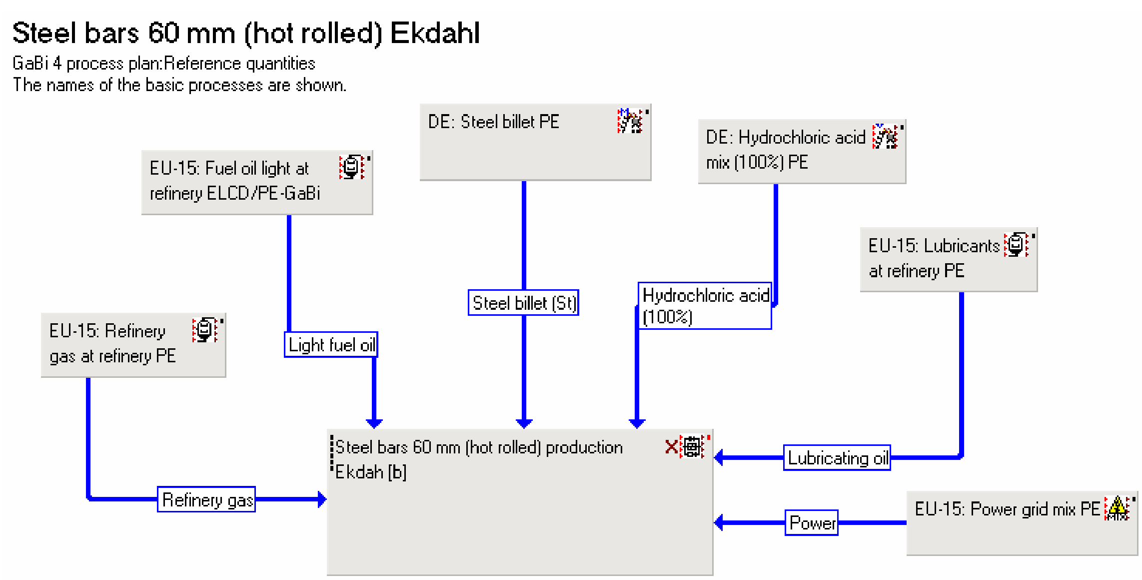


Figure 10 GaBi model for the steel bars production

Cages production

The analysed bearing uses two plastic cages. The site-specific data provided by the specific supplier correspond to their factory's total production, except for the plastic raw material used for the production of the respective cage. For the allocation of these data according to the functional unit (one final bearing), their total production amount (weight) has been used and then all the input and output flows are related to the total weight of the two cages. An overview of the model is shown in figure 11.

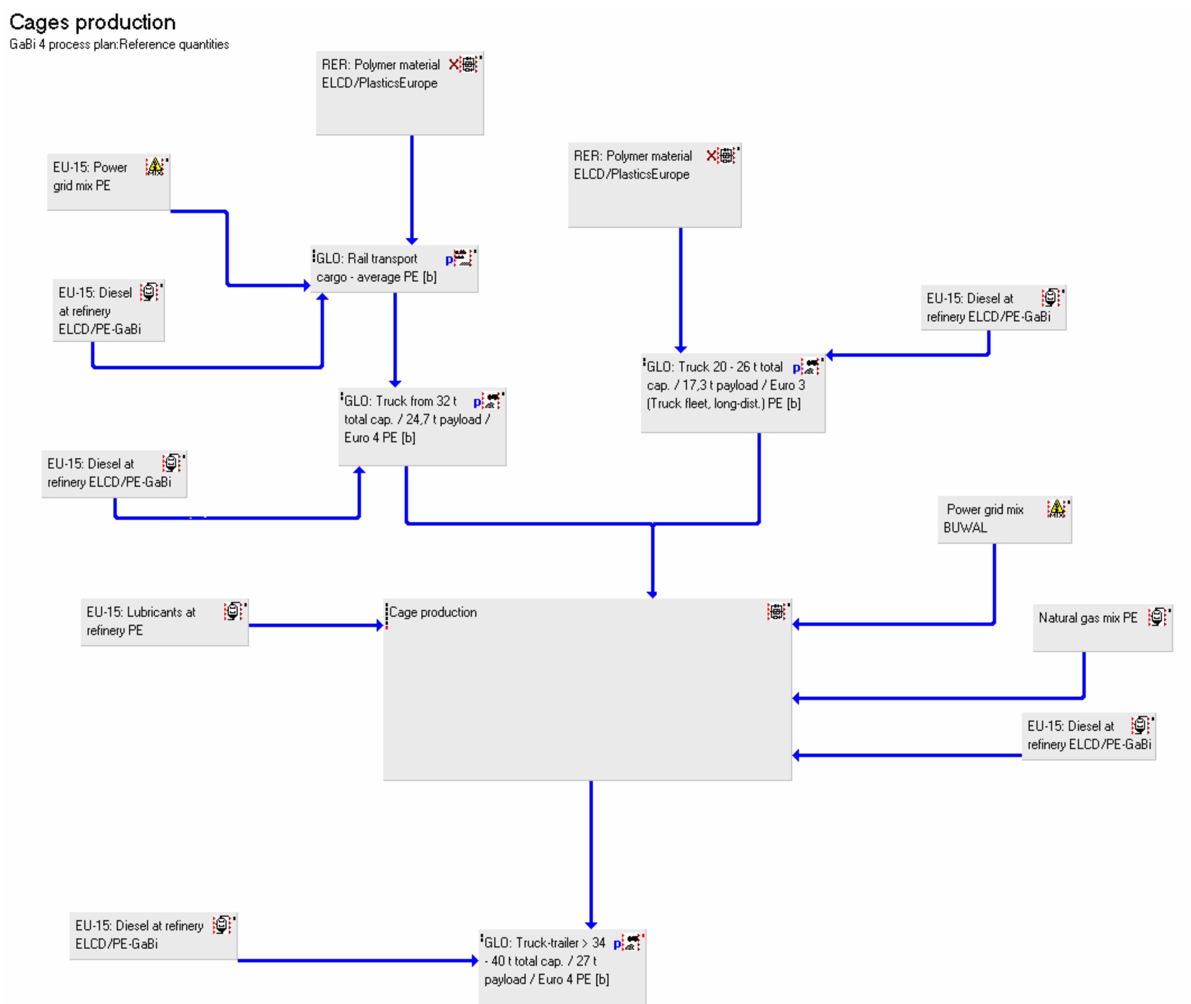


Figure 11 GaBi model for cages production

Polymer material is the main raw material for the production of cages. In relation to the collected data, the origin of this material was coming from two different locations. Therefore the GaBi's unit process for this polymer material is used twice in the model with the respective amounts and transport processes (according to weight and distance transported).

The total amount of oils (lubricating and emulsion oil) was taken into account for reasons of simplification. Auxiliary materials such as solvents and cleaning fluids are not considered because of their very small amounts (in relation to the use of other materials such as oils). Finally, emissions to air had a very insignificant contribution (80% lower than the national limits) and have been also excluded from the model.

ABS Sensor production

The supplier that produces the ABS Sensors does an assembly of semi-finished products. These products comprise metal insert (“O-ring”), studs and micro-coils (“Sensor carrier”). In the site-specific collected data, the amounts of these products were not included but have been gathered later when our data collection form was sent to their suppliers.

They receive Sensor carriers by two companies and metal insert by the same company that provides flinger to SKF facility. For an easier description, the two companies that supply Sensor Carriers from now on will be called “Sensor Carrier 1” and “Sensor Carrier 2”.

The data from these suppliers comprise their raw materials and energy use mainly (for the metal insert the same total factory data as for the flinger production have been provided). “Sensor Carrier 2” gives products for only two types of ABS Sensor (of the ten different types) delivered to SKF. For reasons of simplification it was decided not to be included in the model. Moreover data have not been gathered for the studs, so they are also excluded from this model.

All of the data collected by the First Tier supplier are related to the amount of ABS Sensors supplied to SKF. With the help of specific weight data, the average weight of one ABS Sensor has been calculated and used for the allocation.

For the metal insert component, the same GaBi model has been used, as for flinger production, but this time renamed as "Flinger TIER 2 ". This means that the same upstream processes and input-output flows are included but their amounts are adjusted to the new output quantity (through the “scaling factor”).

Concerning the Sensor Carriers supplied by “Sensor Carrier 1” company, a new GaBi model is created where all the flows and upstream processes, related with the production of these products and the data gathered, are included. Furthermore, assumptions were necessary to be made because of lack of specific information for their supplied components.

Overviews of the two GaBi plans for ABS Sensor production and Sensor Carrier (micro-coil) production are shown in figures 12 and 13.

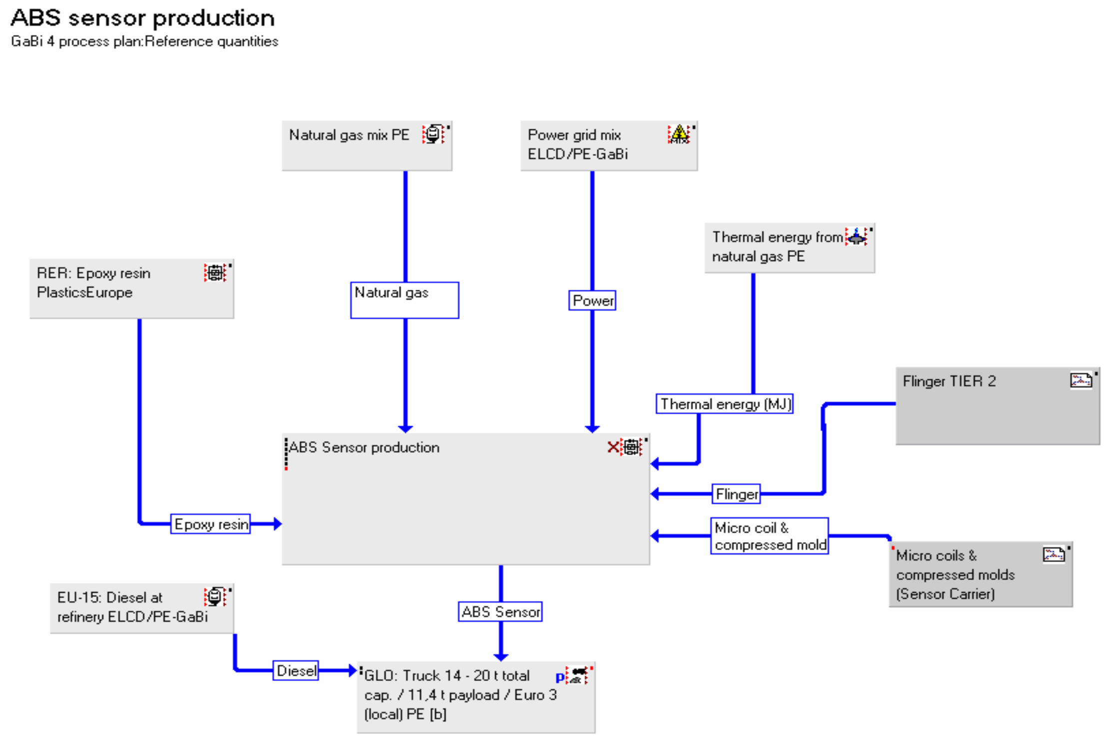


Figure 12 GaBi model for ABS Sensor production

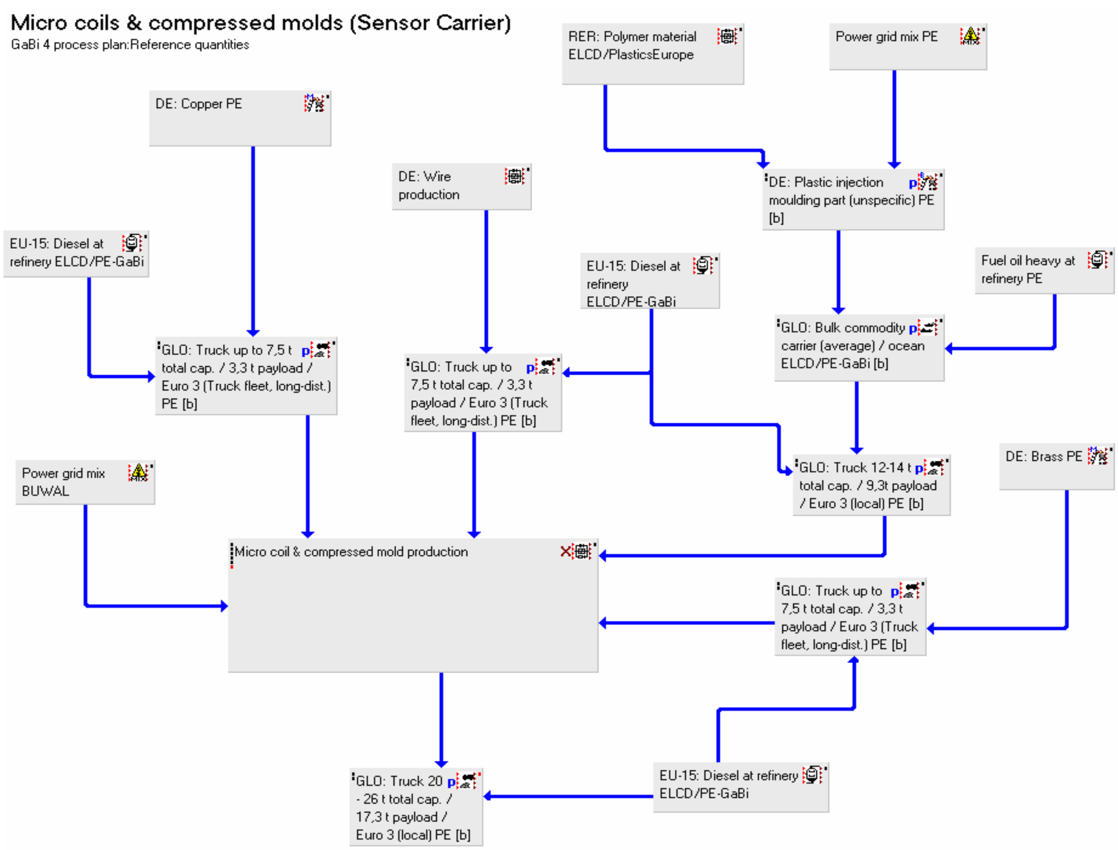


Figure 13 GaBi model for micro-coil (Sensor carrier) production

Steel balls production

As mentioned earlier, the number of steel balls used by each type of the analysed bearing varies. In this study the average number of steel balls is considered and its calculation is based on the number of bearings and steel balls utilised for their production. The formula used for this calculation is:

$$\frac{\sum_i Q_{bearing_i} * Q_{balls}}{\sum_i Q_{bearing_i}}$$

. Q stands for the number of steel balls and bearings.

The site specific data collected by the respective First Tier supplier are originated from their EPD. These data correspond to their average European plant and comprise energy and material resources, emissions (in the form of characterization results) and waste data. They refer to the steel ball production, steel production and shop supplies. For reasons of simplification, it was decided to account for the total of supplier data meaning that their total amounts have been used in this model.

In their EPD a specially developed geometrical unit had been used as a functional unit, which describes the weight and the dimensions of the steel balls ($\sqrt{t * m^2}$).In order to allocate their data in relation to one bearing, first this geometric unit is calculated with the weight and diameter of one steel ball used for the specific bearing. Then the number of functional units ($\sqrt{t * m^2}$) that correspond to the utilised average number of steel balls was found and used for this study's allocation.

The specific energy data stated in their EPD refer to the energy content of resources used such as coal, oil, natural gas etc. In the GaBi model, power plant processes are taken where, in their "local" settings, the respective energy input amount is changed due to the new data. Regarding the renewable resource its origin was not stated so the hydropower is taken into account (since it's also the main source of renewable energy in the country where this study's SKF factory is located).

Concerning the steel input, a new GaBi "plan" is created which includes the total data of the suppliers and has as a main output the steel wire. The origin of the steel wire is steel scrap, according to the information collected.

Finally all the emission data have been taken into account, except the Acidification Potential. The reason of this exclusion is based on the strong dependence of this impact by the location (the average European data are not representative) and the unknown source of the hydrogen ions. Overviews of the two GaBi models can be seen in the figures 14 and 15.

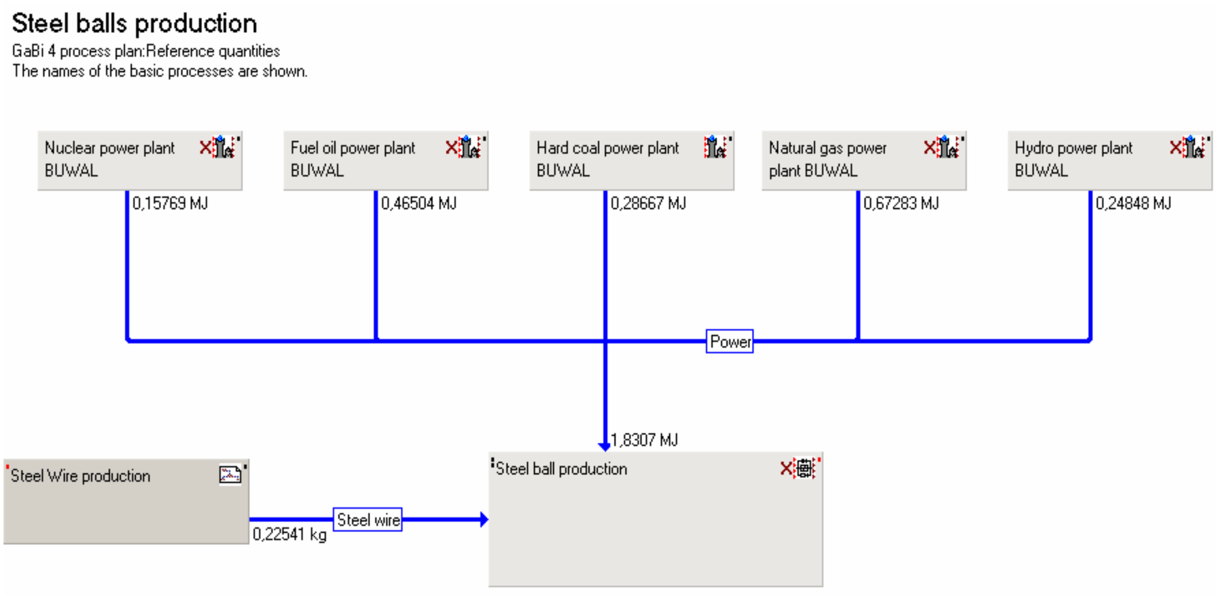


Figure 14 GaBi model for steel balls production

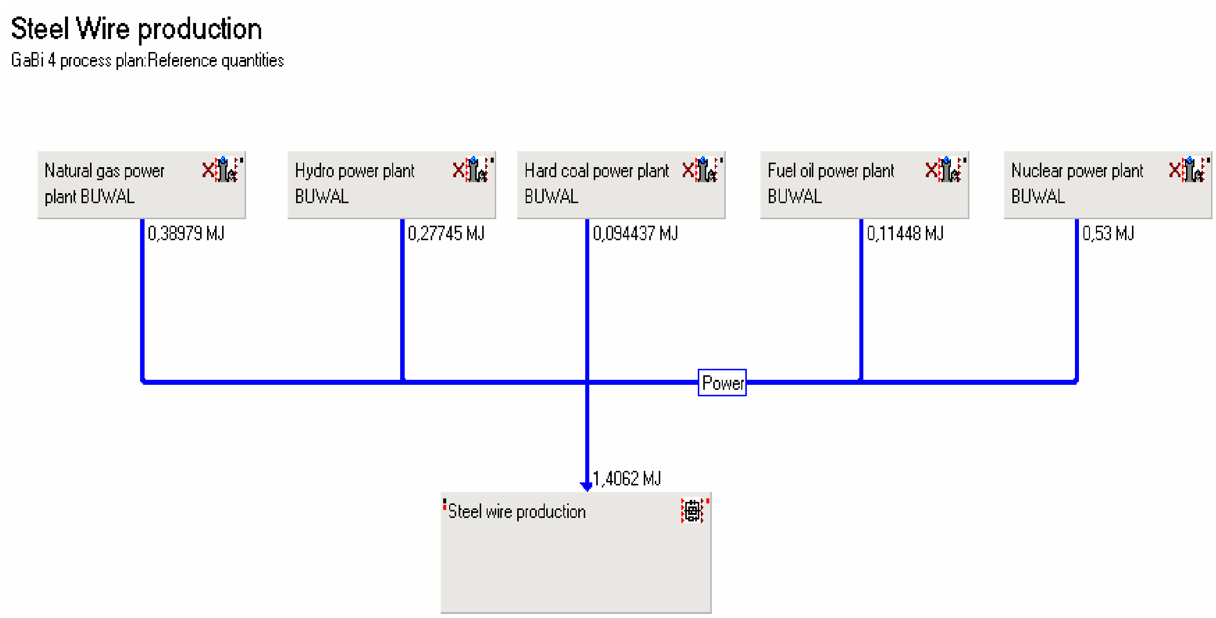


Figure 15 GaBi model for steel wire production

Studs production

As in the case of steel balls, different types of the analysed bearing use different number of studs for their assembly. Since there was not any site-specific data available for these components, the average number and weight of studs has been calculated by SKF's data. The logic of these calculations is the same as for steel balls.

Because of lack of site-specific data, GaBi's flows and processes were used for the modelling of steel studs. Concerning the production of steel studs, the "Steel sheet stamping and bending" process was included as the most relative of GaBi's processes. This choice was based on web-based information by one of the main local suppliers for their manufacturing processes (pressing machines used) and on further research for production of bearing studs. Then all the relevant GaBi's flows were linked with their respective upstream processes.

Grease

The main supplier of grease, which is used as a lubricating material for the bearing, is transported by truck to SKF. In this case also there was a problem of the weight of grease used by each type of bearing. So like for the two previous components the average weight of grease is calculated and taken into account. In the respective GaBi model the transport process by truck is included.

Overview of the GaBi model for studs is shown in the following figure:

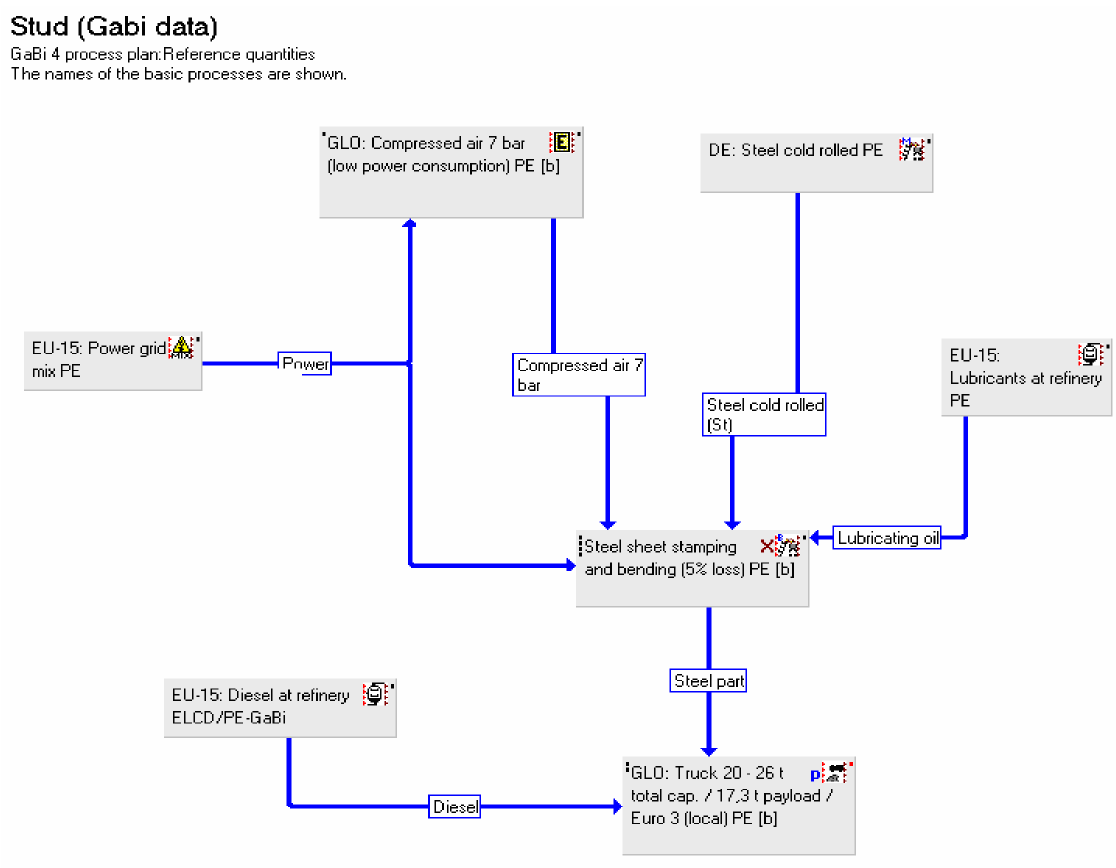


Figure 16 GaBi model for studs production

6.3 Model with GaBi data

The logic of this model is the same with the previous one but now the data set used for the processes of the First Tier suppliers are based on the GaBi database. The functional unit of this model is, also, one final “average” bearing unit.

Concerning the central GaBi “plan” of SKF bearing production (see figure 17), the same input and output flows of energy, supplied products and waste are used. So the GaBi plans of the First Tier suppliers remain with the unchanged output of their products (related to the functional unit) but their processes have been altered.

In this model the background system, regarding electricity supply, is changed due to the goal of the study (compare the differences of site-specific than database data). Relevant processes have been used to agree with the specific boundaries of the GaBi processes used for the First Tier suppliers (e.g. Germany’s power grid mix in the cages production model). As for the transport processes (when included), the same type of transports were used but without the specific distance numbers.

The GaBi’s database did not include relevant production processes for some of the First Tier supplier’s products. In the following table the available and non-available processes are listed:

Product	Not available GaBi process	Available GaBi process
ABS Sensor	ABS Sensor production (Assembly)	Raw material production: Plastic (injection moulding)
Cage	-	Cage production (injection moulding)
Flinger	-	Flinger production (Steel sheet stamping and bending)
Rings	Ring production (forging – annealing)	Steel bars production (Ekdahl) Steel billet (GaBi)
Seal	Seal production (Compression moulding)	Raw material production: Rubber and metal insert
Steel ball	Steel ball production (pressing-grinding-heat treatment)	Raw material production: Steel wire

Table 7 Available and not available processes by GaBi

In the following paragraphs the methodological choices done for each of the First Tier supplier GaBi “plans” are described. As for the previous model, all the GaBi flows and processes used in this model are stated in the 11.5.2 section of the Appendix. For the studs production and grease supply the same GaBi plans have been used as in the previous model.

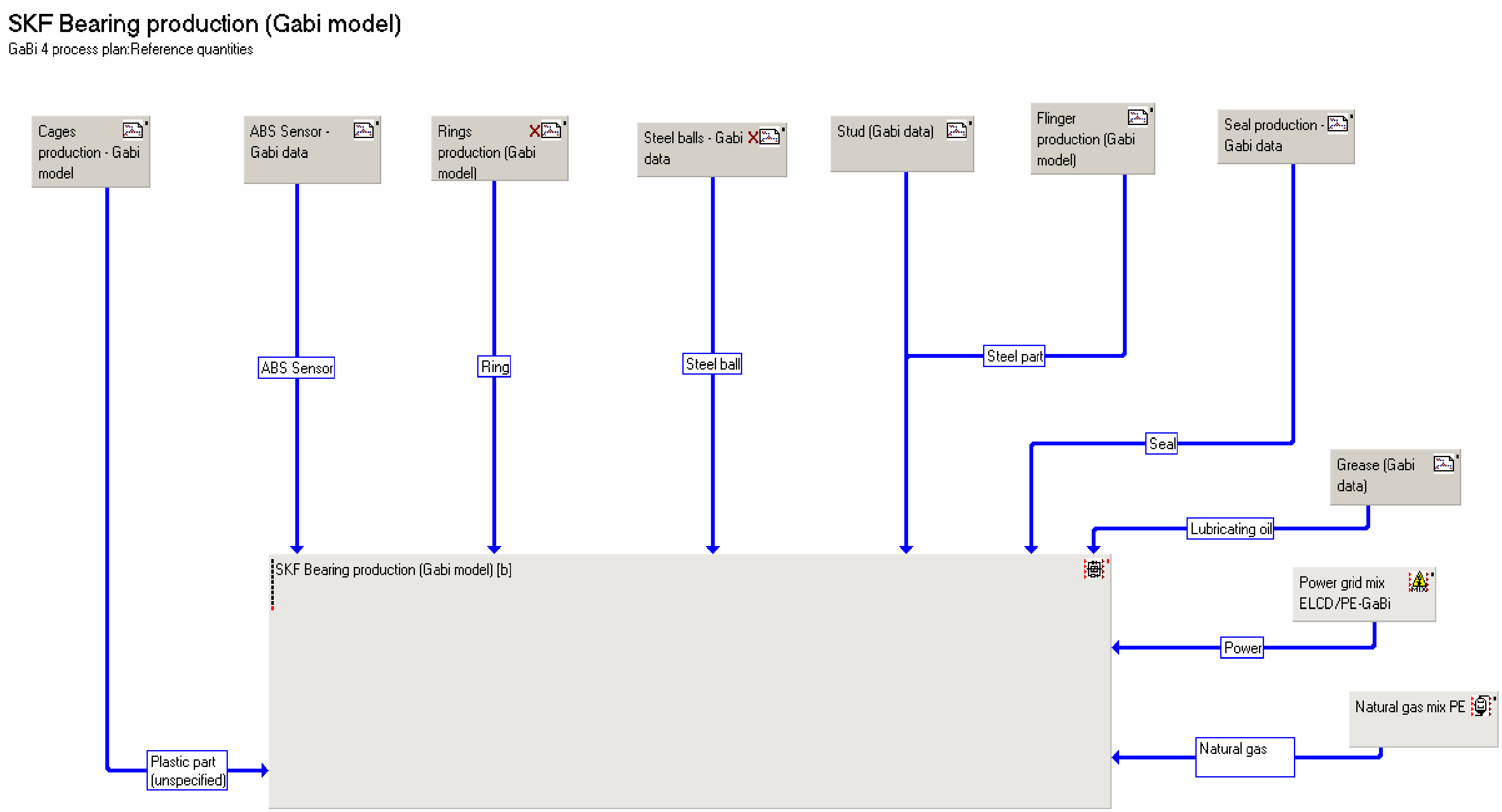


Figure 17 GaBi model for the bearing’s production

For the **flinger production** the GaBi process “Steel sheet stamping and bending (5% loss)” is used. This process is the only relevant found in the GaBi’s database with the real manufacturing method for flinger (the supplier stated the use of pressing with “punching” operations and then tumbling of the raw metal strip). GaBi’s process though is not the most representative since the portion of steel scrap is only 5% while in the reality it can exceed the 50 % (this means also a change in the amount of input steel). Therefore, the GaBi plan is same with the one of stud’s production in figure 16 but the quantities are now adjusted to the output of flinger. It should be mentioned that the output GaBi flow of the respective “plan” for flinger is “Steel part”. This justifies the connection of the outputs from the flinger and the studs at the central GaBi “plan” of SKF Bearing production.

For the **seal production** there was not any available process by GaBi software program similar to the compression moulding manufacturing method. So a new GaBi process was created where only the input flows of raw materials, rubber and metal insert (same processes as for flinger), and the output flow of seal are included. According to the functional unit, one seal is the output of this process. The input amounts chosen for rubber and metal insert were half of the final amount of seal, respectively. This decision was based on the fact that, in the reality, about the 50 % of the seal’s final weight corresponds to the metal insert component. It was assumed that the rest of the seal’s weight is related to rubber (an amount not close to the real site-specific data). By these methodological choices the amount of input raw materials has been also affected. These changes will help to understand the value of collecting site-specific data for the First Tier suppliers.

For the **rings production** plan, there was also not any GaBi process available that was analogous to the manufacturing processes of rings (induction heating, forging of steel bars to rings, annealing). In order to have as an output of this GaBi “plan”, the amount of ring needed for a bearing, a new GaBi process was created (“Ring production-GaBi model”) which has as the only input the steel bars and output the rings. The amount used for the steel bars input is the same with the output ring since no energy, waste and emissions data are included in the ring production process. So the amount of steel bars used now is less than in the real case (10% almost lower). As in the model with site-specific data, the same GaBi “plan” of “Steel bars (60 mm) hot rolled” is used with the data set from the LCA report of Ekdahl (2001). Overview of the GaBi “plan” for rings production is shown in figure 18.

For the **cages production** GaBi “plan”, the most similar GaBi process that was taken into account is the “DE: Plastic injection moulding part (unspecific)”. The selection of this process is based on the specific knowledge for the supplier’s manufacturing processes (injection moulding). As mentioned earlier, the unit process for electricity supply depends on the boundaries of the manufacturing process so in this case it’s the Germany’s power grid mix which has been applied.

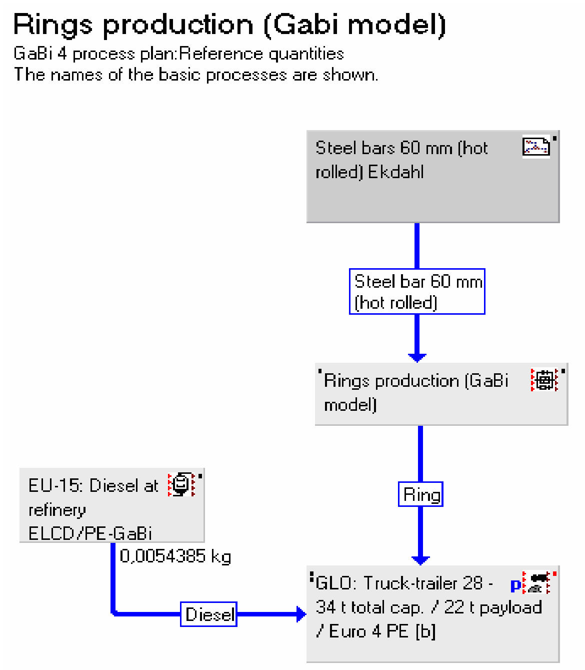


Figure 18 GaBi model for rings production

For the **ABS Sensor production** there was also not any available process from GaBi's database, similar with its real production process (assembly of semi-finished products). Based on the fact that plastic is the main material of an ABS Sensor (O-Ring and studs have a smaller portion in the weight of one ABS Sensor) it was decided to take into account only the plastic as raw material in this GaBi "plan". The injection moulding process of GaBi is used to represent its production. Using the same logic like in the rings production, a new GaBi process for ABS Sensor production is created where the only input is the plastic part and output is the ABS Sensor. There is no energy, auxiliary materials, waste and emissions flows included in the respective process, just the amount of plastic and the same amount of output ABS Sensor, needed for the production of one bearing. Moreover the respective upstream (Polymer production, Germany's electricity mix) and transport processes have been included in the model. An overview of this GaBi "plan" can be seen in the figure 19.

The manufacturing process for **steel balls** comprises cold forming (pressing) of the raw steel wire, grinding and heat treatment. As in the two previous components, there was not any similar process in GaBi to represent adequately the production of steel balls. So the process "Steel balls production" is created where the only input flow is steel wire and its output is steel ball. The amount of steel wire used is the same amount as the output of the steel balls (same logic as for rings and ABS Sensor), needed for the production of one bearing (less raw steel wire by 20% almost than the real case). For the steel wire production, the GaBi analogous process has been taken into account which this time includes LCI data such as raw materials extraction, transports, energy resources etc. Furthermore transport types are selected randomly. An overview of this GaBi "plan" can be seen in the figure 20.

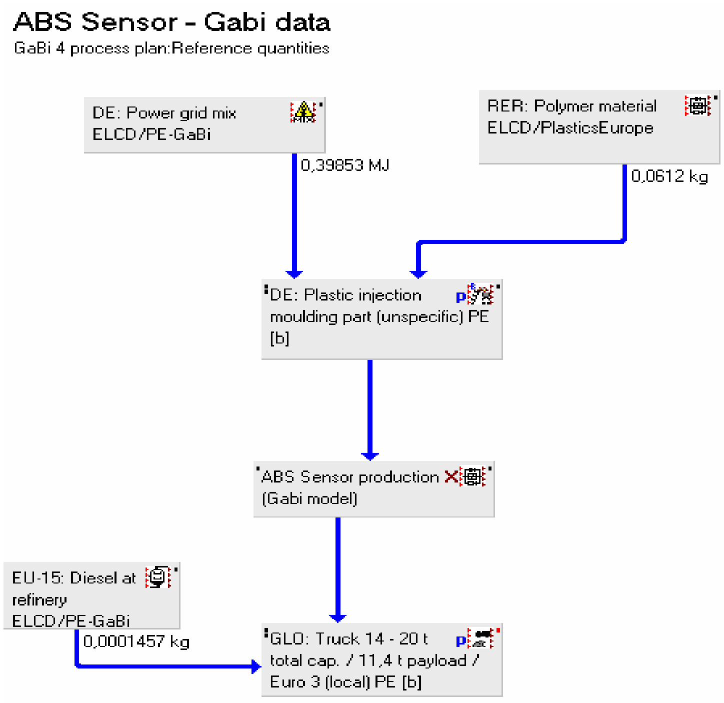


Figure 19 GaBi model for ABS Sensor production

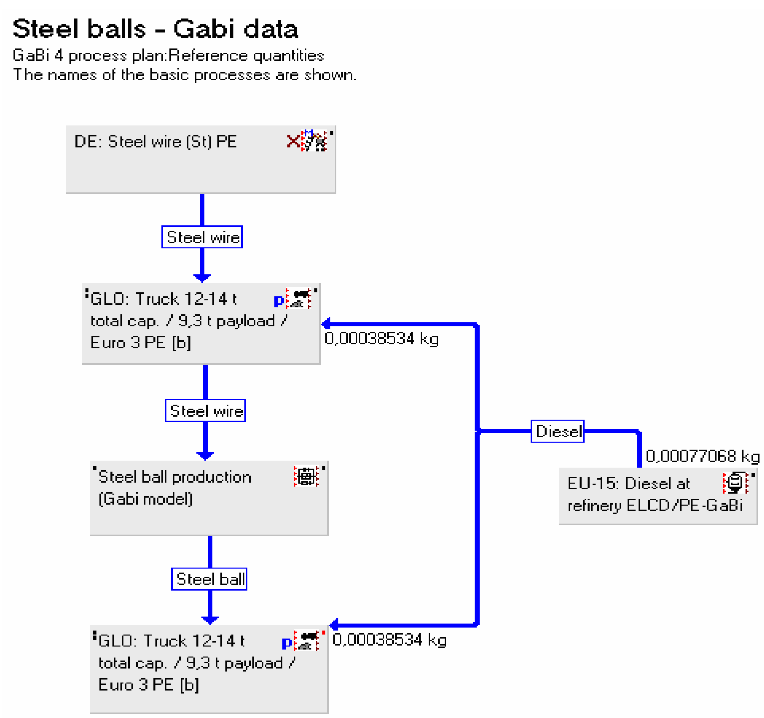


Figure 20 GaBi model for steel balls production

7 Analysis

In this chapter the analysis of the inventory results will take place with the comparison between the two models and the dominance analysis. In the last paragraph, the data collection strategy is analysed.

7.1 Selection of LCI data

As mentioned in the goal definition of the study, specific type of LCI data will be selected for the comparison of the two models and the dominance analysis. This selection is based on their quantitative importance and their influence on the environment for the whole technical system of the bearing's production (in both models).

In the scope definition the general categories that will be analysed have been stated. The chosen LCI data in each of these categories are:

- **Raw material resources**: These comprise non-renewable and renewable resources. From an environmental perspective, the use of non-renewable resources is the most important. It has been found that inert rocks is the most used resource in the technical system under study with a share of 80%, and, then iron ore with 13% approximately. Therefore these two categories will be used for the analysis.
- **Energy resources**: The non-renewable energy resources constitute the sources of energy of the bearing's production system. From the various types of these resources (hard coal, crude oil, natural gas, uranium, lignite), the most used is the hard coal resource with a share of 40% approximately from the total. This resource has been used for this category.
- **Emissions to air**: In this category the highest amount of emissions was coming by the inorganic emissions. From this emission types, the CO_2 emissions account for the 55% more or less. Therefore these emissions among with the SO_2 and NO_x emissions, which are important from an environmental point of view, are analysed.
- **Emissions to water**: The emissions to water are grouped in GaBi into two sub-categories, the emissions to sea water and fresh water. The latter group has the biggest contribution with chloride accounting for 65% in this group. This inorganic emission will be taken into account for this category.
- **Production residues in life-cycle:** The sub-categories of hazardous waste (for disposal and recovery) and ordinary waste (for disposal and recovery) are comprised. The 95% of the production residues in the investigated technical system is ordinary waste for recovery. So this type of waste is taken into account that mostly comprises steel scrap (75%) and slag (15%).

7.2 Comparison of the results

In this section the inventory results (as calculated by GaBi software program) of the two different models will be compared. First, this comparison will be made between the First Tier suppliers and then a total evaluation of the results will be done for the whole technical system of the bearing's production.

7.2.1 First Tier Suppliers

According to the goal of this study, the production processes of the First Tier suppliers have been changed between the two models. This alteration has influenced their results in various aspects. Their differences are going to be shown and discussed below, with the help of comparative diagrams for each of the chosen type of LCI data, stated in 7.1.

7.2.1.1 Raw material resources

As already shown and mentioned, each of the GaBi "plans" for the First Tier suppliers includes all the upstream processes (background system) related with the raw material production (e.g. steel or plastic production), energy carriers (e.g. electricity, fuels etc.) and auxiliary substances (mainly oils). Through the software's functions (GaBi "balance"), all the raw material resources (except the energy resources that are given differently and will be analysed afterwards), used for these processes, are calculated in each case. The most important data of inert rock and iron ore are compared in the figures 21 and 22.

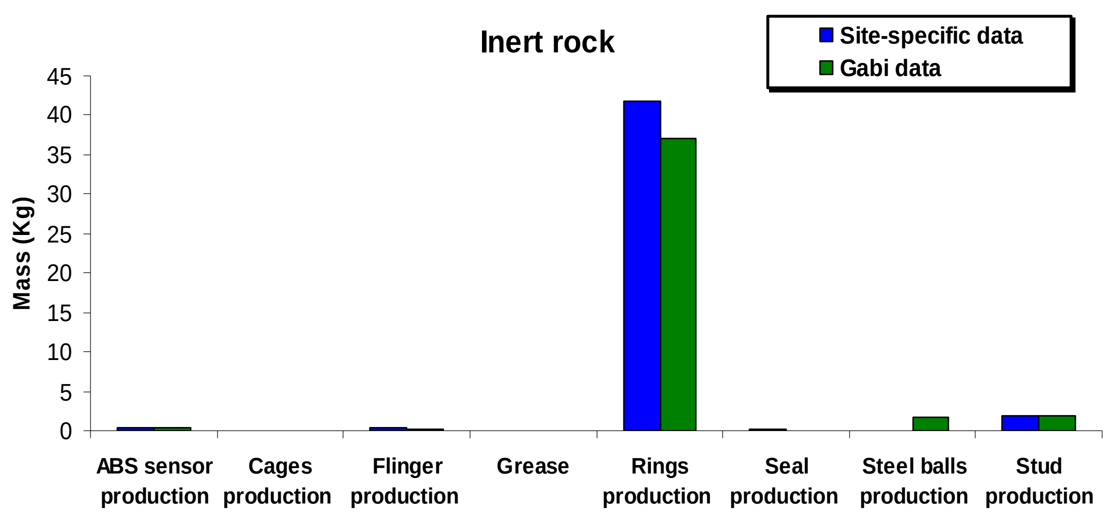


Figure 21 Comparison of the amounts of inert rock used by the First Tier suppliers

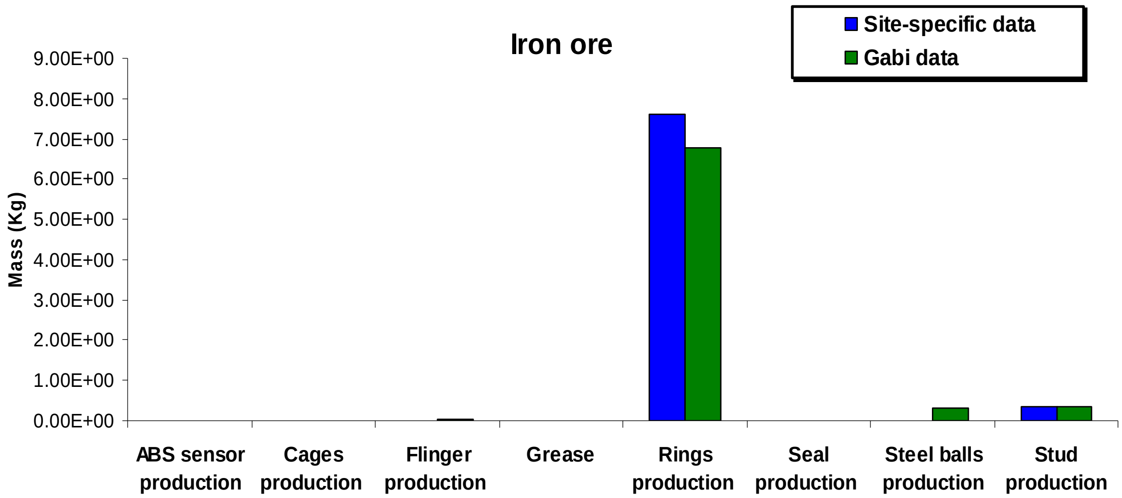


Figure 22 Comparison of the amounts of iron ore used by the First Tier suppliers

As we can see from this diagram, some differences can be observed between the two models. More specifically, in the GaBi data model the amount of steel bars used along with the absent energy inputs for the obviously dominant rings production process generate this variance of the results (around 11% lower than the real case). In the case of steel balls, the higher raw material resources in the GaBi model correspond to the respective GaBi process used for steel wire production, where steel scrap is not the only raw material as in the real case (see inventory analysis for further description of these flows and processes). For the other products, divergences in the inventory results exist but do not affect the overall raw material resource use of the bearing's production system.

7.2.1.2 Energy resources

An important category to compare, that has a strong influence on the environmental impact caused by each product, is the energy resources used. These amounts are calculated by GaBi software for each production process and they are related with the respective resource use by various upstream processes (background system) such as raw material production, electricity production, fuel production, auxiliary material production. A comparative diagram for the most used hard coal resource is shown in the figure 23 for the two models.

As in the previous case, the most obvious variation exists for the rings production. Generally, the most of the hard coal is used in the production of the raw materials such as steel or plastic. Therefore depending on the differences of the raw material input amount in each process there will be the analogous variances for the specific resource use among the two models. In the rings and steel balls production differences of 15% and 30% are realized respectively. These variations are based on their different raw material inputs (steel bars and steel wire respectively) and the missing energy inputs in the GaBi data model.

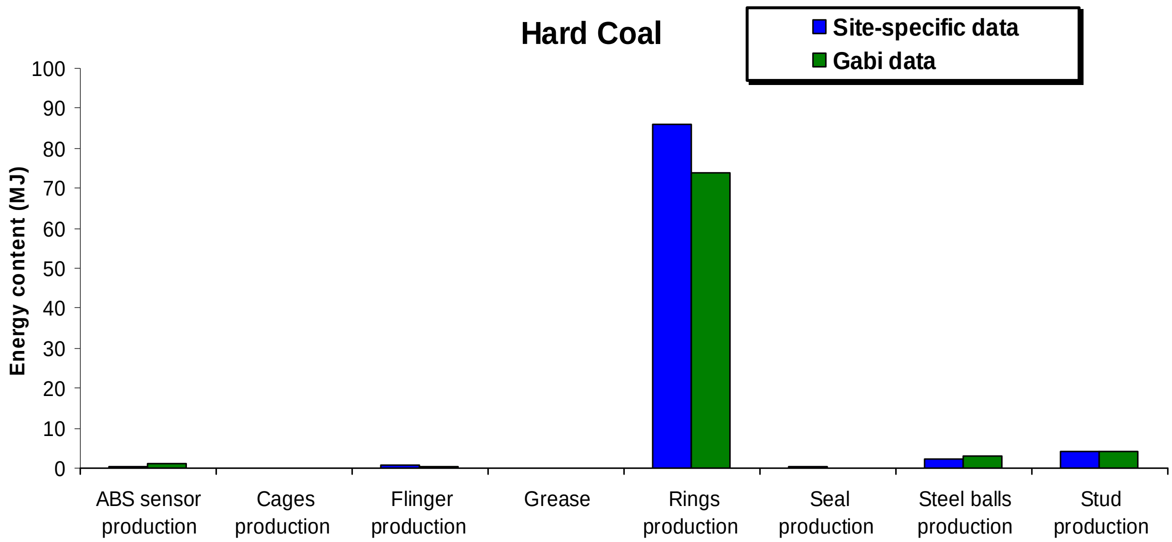


Figure 23 Comparison of hard coal used by the First Tier suppliers

7.2.1.3 Emissions to air

Regarding the output flows by each production process, it is vital to compare the emissions to air. The results of this category are connected with the previous input categories and the differences observed there. So these amounts of emissions are related with the respective First Tier production process and its background system (transports, electricity production, fuel and energy carrier production, etc.). Diagrams of the CO_2, NO_x, and SO_2 emissions to air are shown in figures 24, 25 and 26.

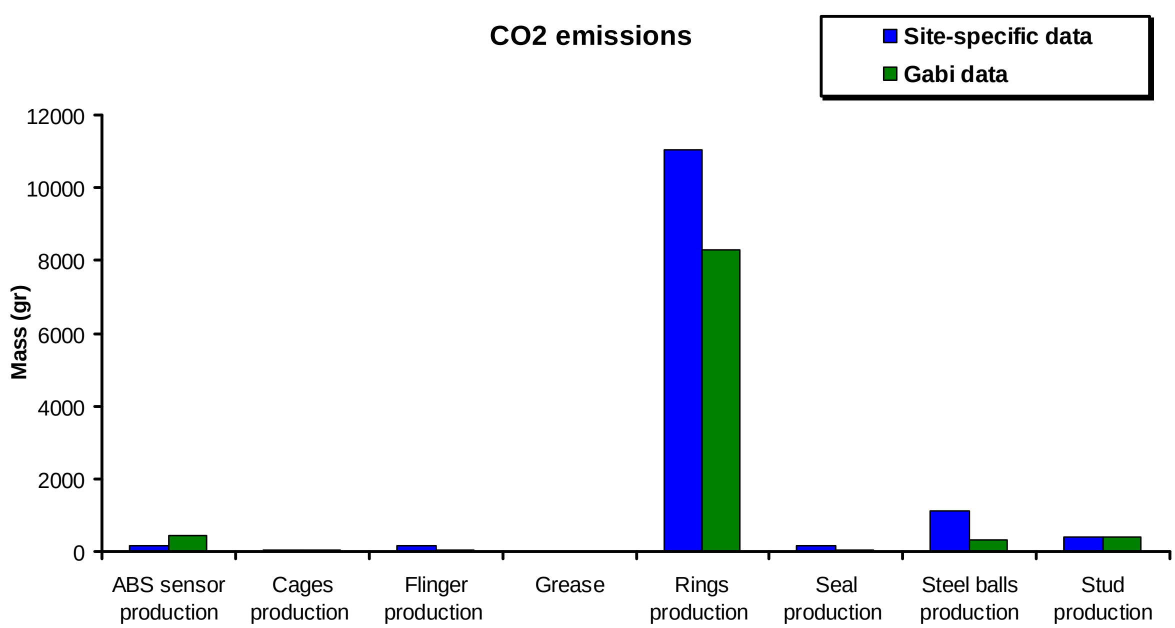


Figure 24 Comparison of the CO_2 emissions by the First Tier supplier's processes

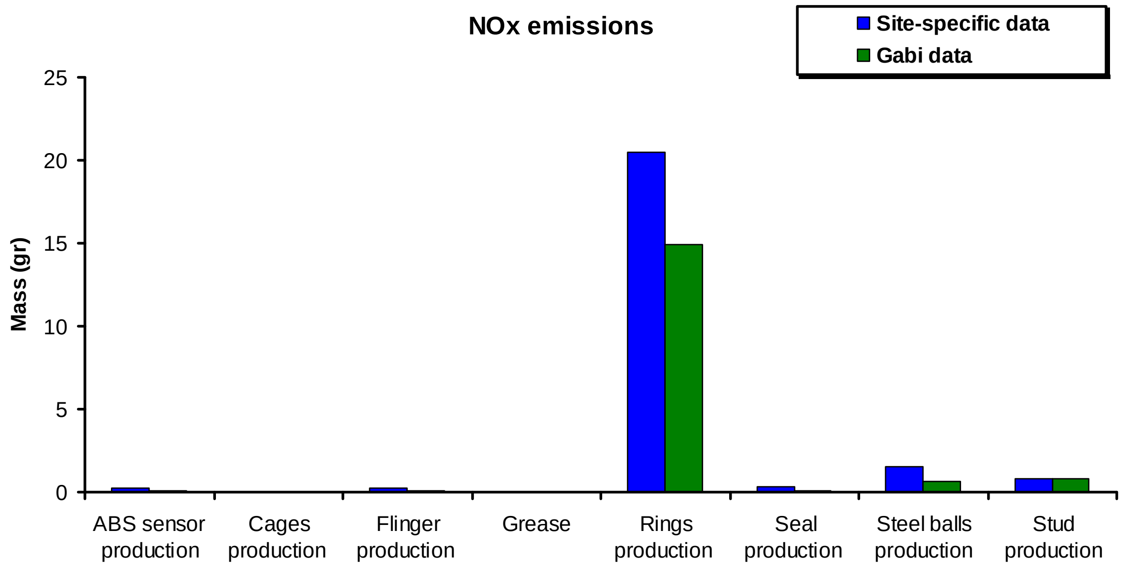


Figure 25 Comparison of the NO_x emissions by the First Tier suppliers

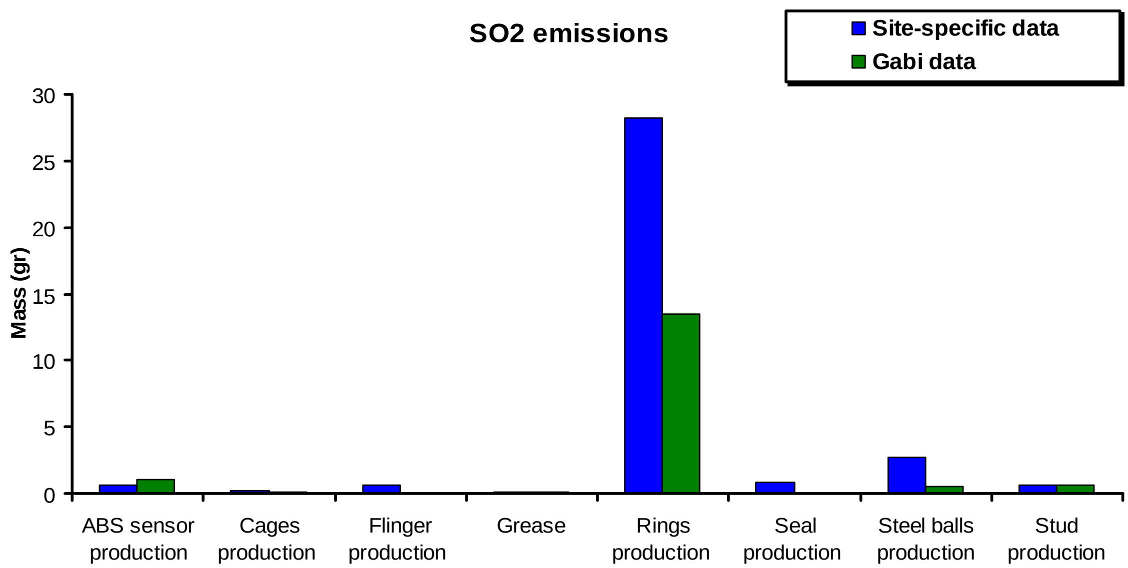


Figure 26 Comparison of the SO_2 emissions by the First Tier suppliers

These emissions to air are mainly depending on the amounts of raw materials and energy inputs used for the production processes of the First Tier suppliers. So the variances of the results among the two models are based on the changes of the respective input flows. It is clear that there are differences in this category but the most observable again corresponds to the dominant rings production process. The variation in CO_2 emissions is approximately 25%, in NO_x emissions almost 30% and finally the most evident difference appears in SO_2 emissions where it is almost 50%.

7.2.1.4 Emissions to water

The amounts of the chloride emissions are depicted in the following diagram:

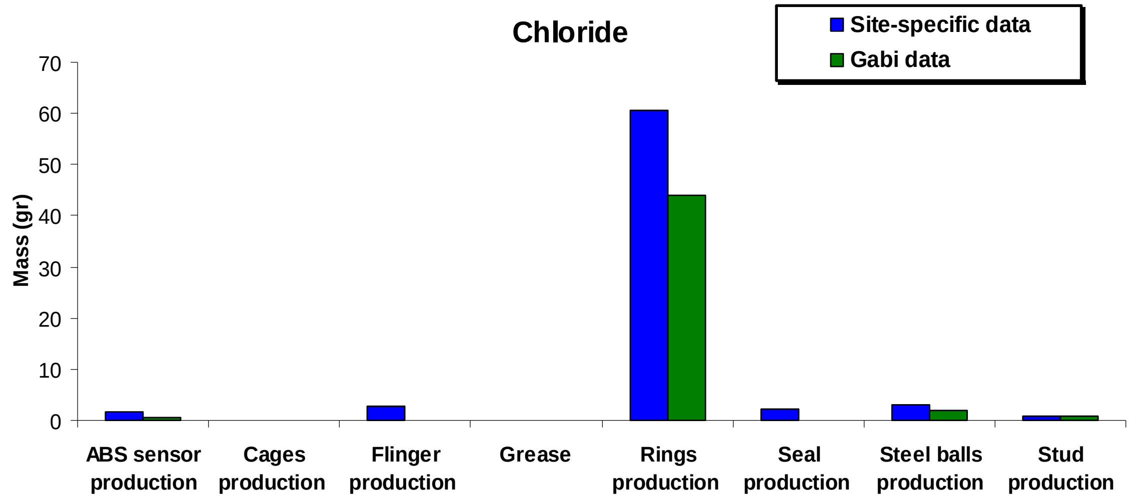


Figure 27 Comparison of the chloride emissions by the First Tier supplier's processes

As before, the results correspond to the specific production processes and their analogous background system. It is apparent that the results are similar to the previous category where the discrepancies occur at the processes of the First Tier suppliers with the biggest changes for their input flows. As shown in the diagram, the model with site-specific data appears to have higher amounts of chloride emissions with the difference in the most dominant category of rings production being about 30%. All these variations are caused by the higher amounts of raw material used and the additional data for energy inputs and auxiliary materials in the site-specific data model. The production of these materials or services credits more emissions to the respective model.

7.2.1.5 Production residues

The waste generated by each process (and its background system) can also vary between the two models depending mainly on the raw materials (and the other auxiliary materials used). The differences in steel scrap among the two models are shown in figure 28.

It should be mentioned that some production processes of the First Tier suppliers do not involve steel (such as cages) or GaBi did not include steel scrap data for some steel production processes. These facts together with other methodological choices (e.g. lower amounts of input raw material used in the GaBi data model) generate the differences in this category. A quite big difference is observed for the rings production (around 50%), because of the missing steel scrap data from the First Tier's respective production process. In the case of ABS Sensor there is only steel scrap in the site-specific data model because of the presence of the metal insert part (more explained in inventory analysis).

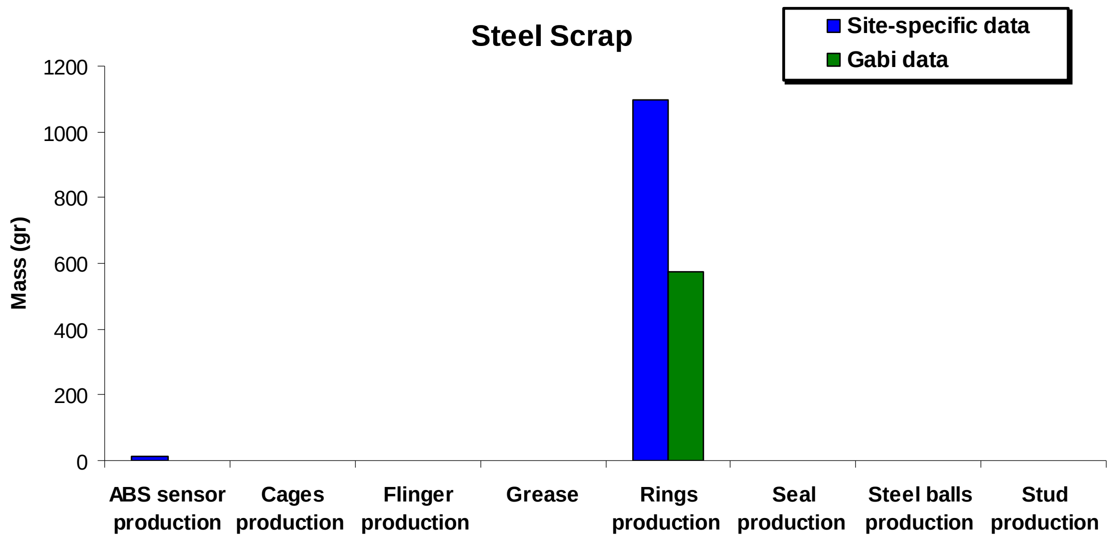


Figure 28 Comparison of steel scrap by the First Tier supplier's processes

7.2.2 Bearing production

In order to answer the main research question of this study, it is needed to find out the major differences of the results between the two models. So the same type of inventory results will be compared, but now the process of SKF Bearing production will be taken into account. Since the two different models have the same input and output flows for this process, the variances are based on the data changes made for the First Tier suppliers. The comparative diagram can be seen in the figure 29. The values in that are normalized for a better illustration of the results. It is important to mention that this diagram is just for comparison of the inventory results in each category of the two models so the unit varies among the compared categories. Hence the hard coal energy resource is accounted in MJ, the inert rock, iron ore and CO_2 emissions in Kg and, finally, the chloride emissions to water and the steel scrap are in gr.

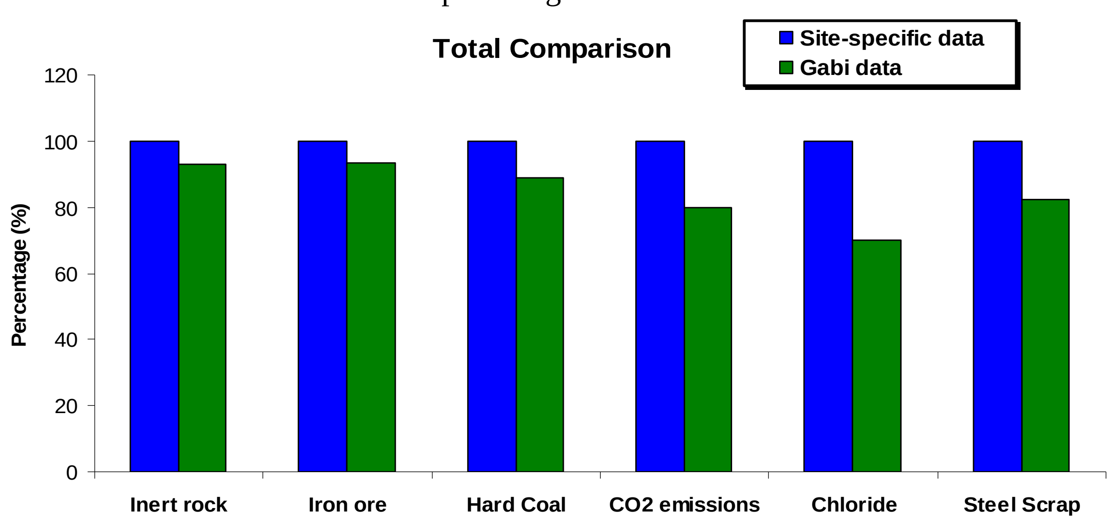


Figure 29 Comparison of the two SKF Bearing production models

It is clear that there are fluctuations, relatively small for most of the categories except the chloride emissions. Concerning the input flows, the non renewable raw material resources of inert rock and iron ore have a very small variation close to 10%. This is connected to the previous observations in the section 7.1.1.1.

In the other input category of the hard coal resource use, divergences can be observed due to the higher amounts of raw material inputs in the site-specific data model (as mentioned earlier the most of the energy resources are used for the raw material production) or the absent energy inputs for some production processes in the GaBi data model such as for rings, steel balls, ABS Sensor and seal.

Regarding the CO_2 emissions, a 20% difference can be realized with a dominance of the site-specific data model. As explained earlier, the rings production and mostly its background system (steel production) defines these variances.

In the category of the chloride emissions (in gr), the biggest difference exists (about 30%). As illustrated in the respective categories of the First Tier suppliers, these differences are coming mainly from:

- the altered raw material inputs between the two models (raw materials production cause the majority of the emissions)
- and the supplier's data (e.g. energy, auxiliary materials, waste etc.) that were collected and taken into account in opposition to the absence of the analogous flows in the GaBi data model (stated in inventory analysis).

In the steel scrap, there is also an obvious difference with the rings production and its background system to cause this divergence, as illustrated in 7.1.1.5.

All these variances are also affected by the different process used in the two models to represent the production of the modelled supplier. This process might include different input or output flows e.g. in the GaBi data model, the flinger production process is represented by GaBi's process "Steel sheet stamping and bending (5% loss)" which have as steel scrap only the 5% of the steel input used as compared to the real process with 40-70% steel scrap waste.

So the different data sources generate variations in the inventory results of the two models, which depend mostly on the dominant process of rings production (mostly from its background system), and can change the overall picture of the technical system under study. Most of the categories, generally, have small differences except the chloride emissions to water with the most visible alteration.

7.3 Dominance Analysis

In this section the analytical dominance analysis, which is carried out for the model with the site-specific data (of the First Tier suppliers) will be illustrated. The specific source of data has been chosen (than the model with GaBi data) to be used for this analysis since they represent better the analogous production processes of the modelled technical system.

The specific investigation will be performed in two different phases. First the raw materials and their relationships with the production processes of the First Tier suppliers will be analysed. Finally the results will be aggregated in order to identify the most polluting life-cycle stages of the whole technical system under study.

7.3.1 Raw materials

The main raw materials used either directly from the First Tier suppliers or by other upstream suppliers are mainly:

- Steel, which is involved in the production processes of almost every First Tier supplier (except for cages)
- Polymer material, which is used for ABS Sensor (through the production of the Sensor carrier) and cages
- Rubber, which is used for the seal production
- Copper and brass that is used for the production of micro-coils (Sensor carrier).

As already mentioned, the data which represent these processes (in both models) are taken from GaBi's database or the LCA report of Ekdahl (2001) for the case of steel bars production (except for the steel wire where site-specific data have been used). Steel production dominates in all the important LCI data categories of the SKF Bearing production system. Almost 99% of the hard coal resource use corresponds to steel production (steel dominates in almost all the categories of non-renewable resources). As a result, the majority of the CO_2, SO_2 and NO_x emissions, related with the production of these raw materials, are coming from the steel production. A diagram to depict this dominance is shown in the figure 30. The data are normalized with the emissions of steel production set equal to 100% (initial data used were mass in gr) and all the other compared materials related to this number.

This dominance of steel is mainly based on the fact that its production processes are energy intensive and it is mostly involved in every product, manufactured by the First Tier suppliers. Components that constitute the main "body" parts of the analysed bearing, such as rings and steel balls, are made of steel and they use quite big amounts of steel. It should be reminded that the LCI results of the raw materials correspond to the production process of the respective material and its background system (e.g. transports, electricity and fuel production etc.).

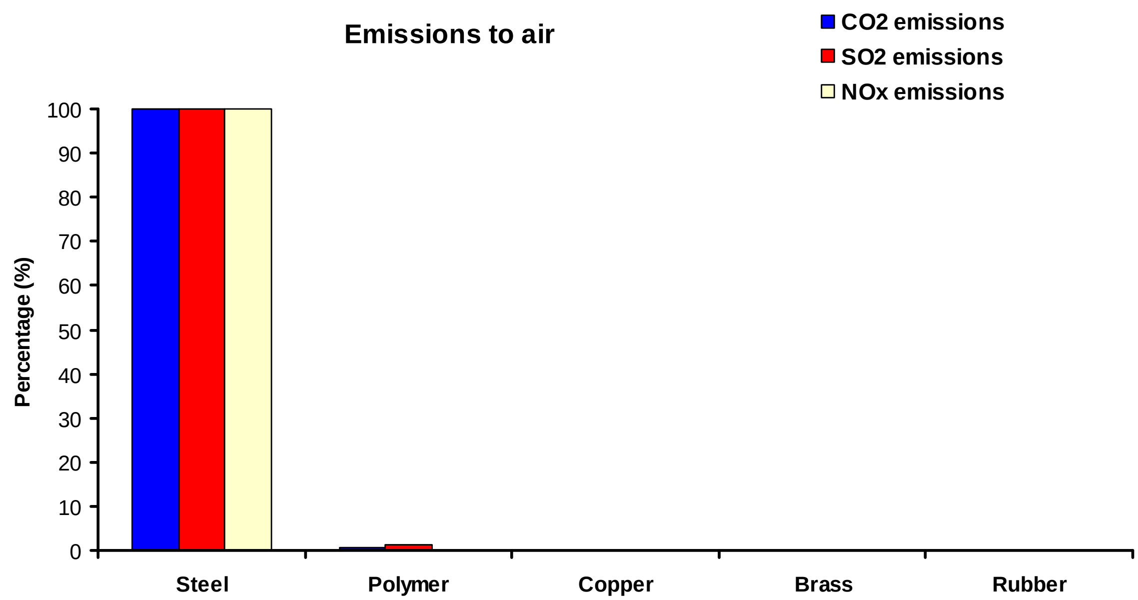


Figure 30 Comparison of the emissions to air by raw materials production

Based on these observations, it is decided to make a separate dominance analysis to discover the most polluting steel type that is used as input in the processes of the First Tier suppliers or other upstream processes. So the steel products to be compared are:

- Steel billet used for the steel bars production
- Steel bars used for the rings production
- Steel wire used for the steel balls production
- Stainless steel (cold rolled) used for flinger production and involved in the seal production (through the metal insert part)
- Steel (cold rolled) for studs production

These materials will be compared for the hard coal resource used and the CO_2 emissions generated, by their production processes (and of course their background system). In the figures 31 and 32, it is apparent that the most energy intensive and, therefore, most CO_2 emitting is the steel billet (raw material of the steel bars which are utilised for rings production). The basis of this result is the amount of the steel billet which is the highest amount of steel used as raw material in the bearing's production system (accounts for the 90%). The second most CO_2 polluting production process corresponds to the steel bars used for the rings production and, then, the steel wire for steel balls production (significantly lower from the steel billet). Finally, the impacts by the steel used for the other components are negligible.

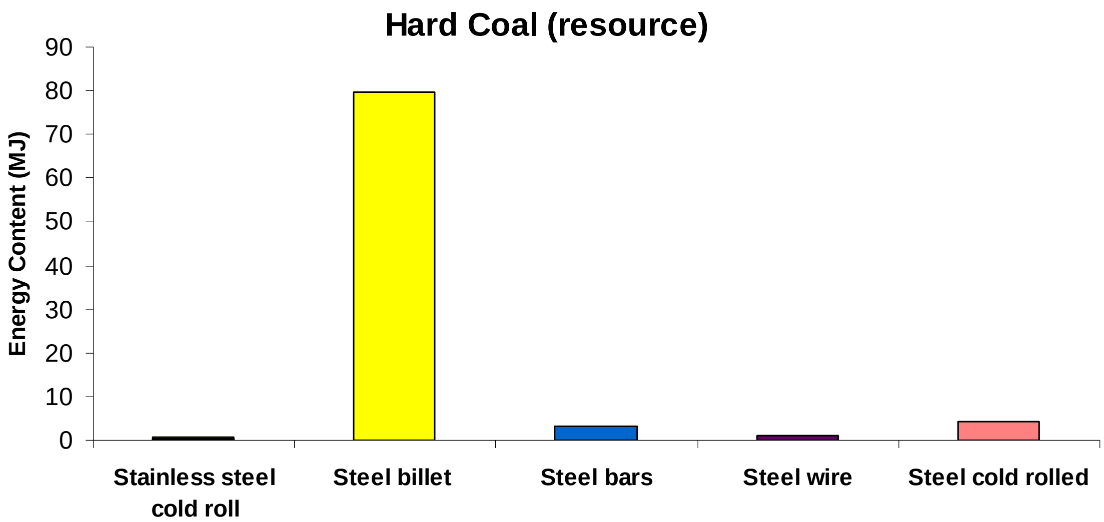


Figure 31 Comparison of the hard coal resource used for various steel products

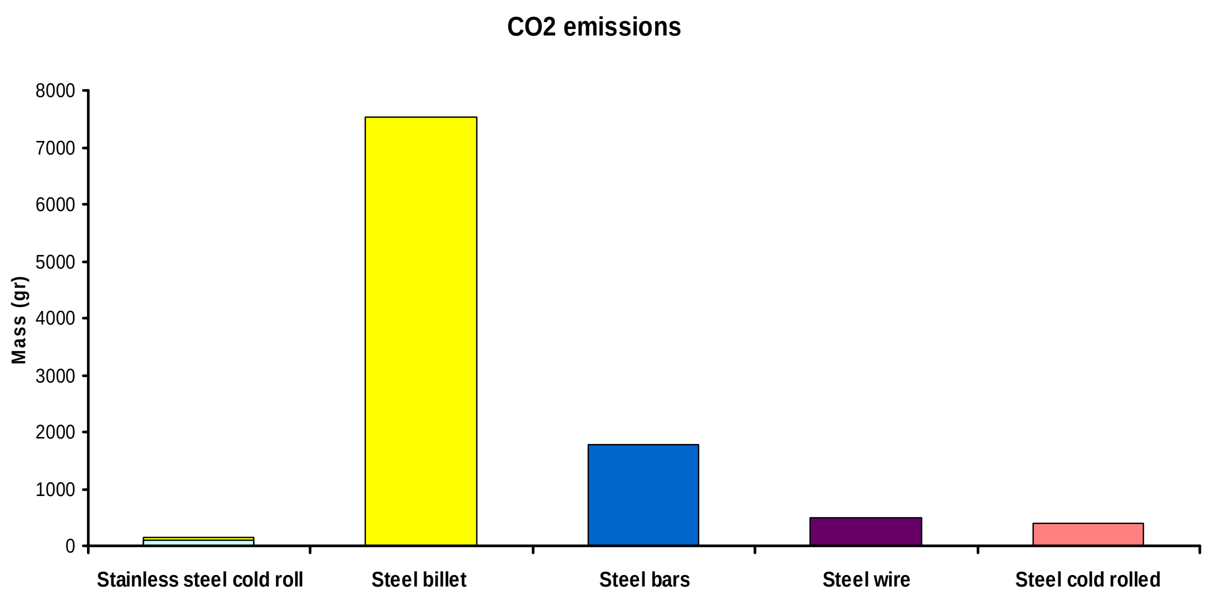


Figure 32 Comparison of the CO_2 emissions by production of various steel products

7.3.2 Raw materials and First Tier suppliers

In this section the relation of the production processes corresponding to the First Tier suppliers and their utilized raw materials will be examined. By analyzing the LCI data of hard coal resources, CO_2 emissions and ordinary waste for recycling, it will be concluded which of these processes cause the most environmental impact. In the following diagrams these relationships are depicted for each of the modelled suppliers. They should not be used for comparison between the different suppliers but only for each supplier and its raw materials. For easier comparison, the values in each supplier are normalized and related to the process with the higher amount.

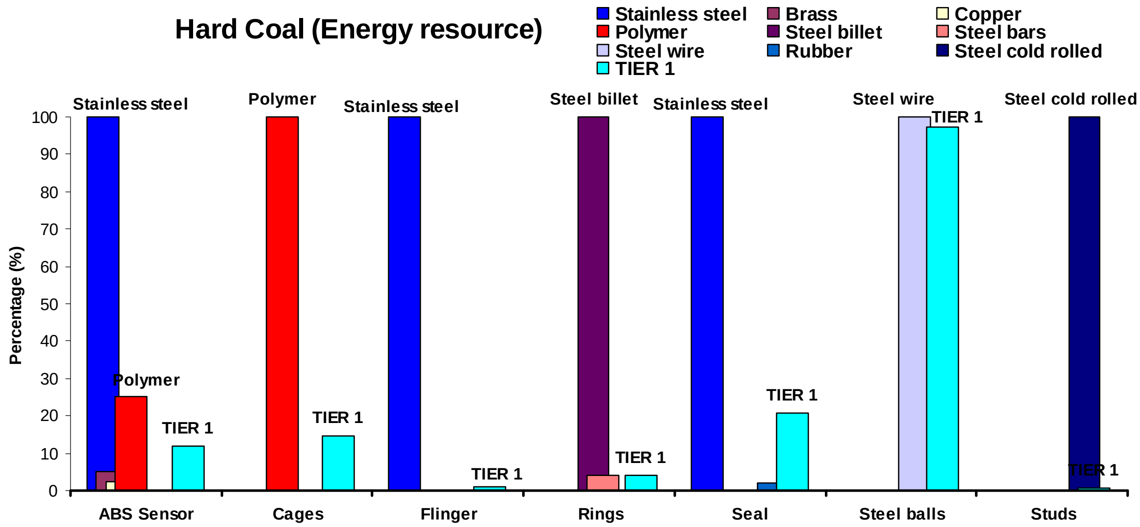


Figure 33 Comparison of the hard coal resource use by the First Tier suppliers and their respective raw materials (normalized data in MJ)

The conclusion drawn from the above diagram is that the raw materials production for each product of the First Tier suppliers is using the most of the hard coal energy resource. Steel, as expected, dominates in the ABS Sensor (through the metal insert part), seal, rings, flinger, steel balls and finally, studs production. On the other hand, polymer material is the main material for cages and its production consumes higher hard coal resources than the latter one. All of the above observations are caused by the background system of each respective process and its boundaries. For example, the main energy resource used for the Germany's electricity grid mix is hard coal while for the country where SKF facility and its suppliers located, is natural gas. Therefore these geographical dependences create these differences.

The comparison for the CO2 emissions is shown in figure 34. It is evident that the results follow the variations in the previous category. As observed before the raw materials are using the majority of the hard coal energy resources therefore generate the most of the emissions. While the all of the products consent to the previous remark, it is interesting to see that the emissions to air by steel balls production do not totally agree with the previous results. The steel balls production emits higher amounts than the steel wire despite the latter's higher energy use. This is the consequence of the different energy resources used (based on site-specific information) with the ones corresponding to steel balls production coming mainly from fossil resources.

Finally, in the figure 35, the LCI results for the most important of the various waste categories (see 7.1) are analysed for each of the components and their raw materials. The ordinary waste for recycling corresponds to:

- Steel scrap and slag for all the raw materials, except the rubber material with cooling water being its main waste

- Steel scrap and slag for the First Tier processes of rings, steel balls, studs and flinger; rubber waste for the seal production, carton for cages and finally, plastic for ABS Sensors.

The results of the diagram vary. They depend mainly on the specific manufacturing procedures and the type of the final product. So ABS Sensor, steel balls and studs production generate higher amount of waste, cages production give almost equal amounts and, lastly, flinger, rings and seal production discard lower matter than their raw materials production. Therefore the actual impact of the various production residues depends on their type and their effects to the environment.

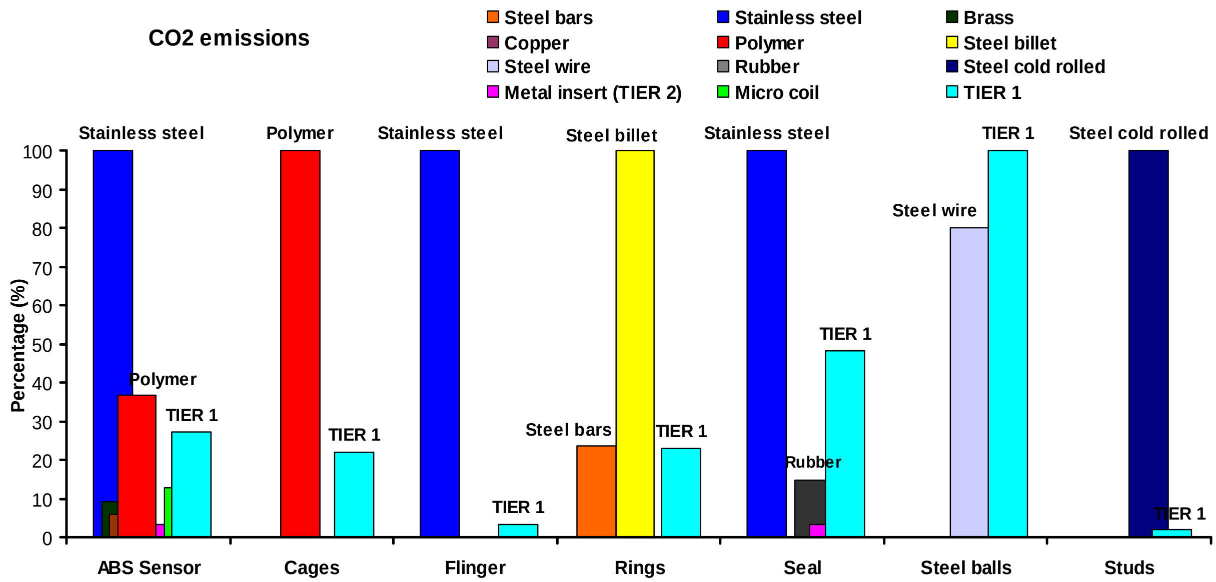


Figure 34 Comparison of the CO_2 emissions by the First Tier suppliers and their respective raw materials (normalized data in gr)

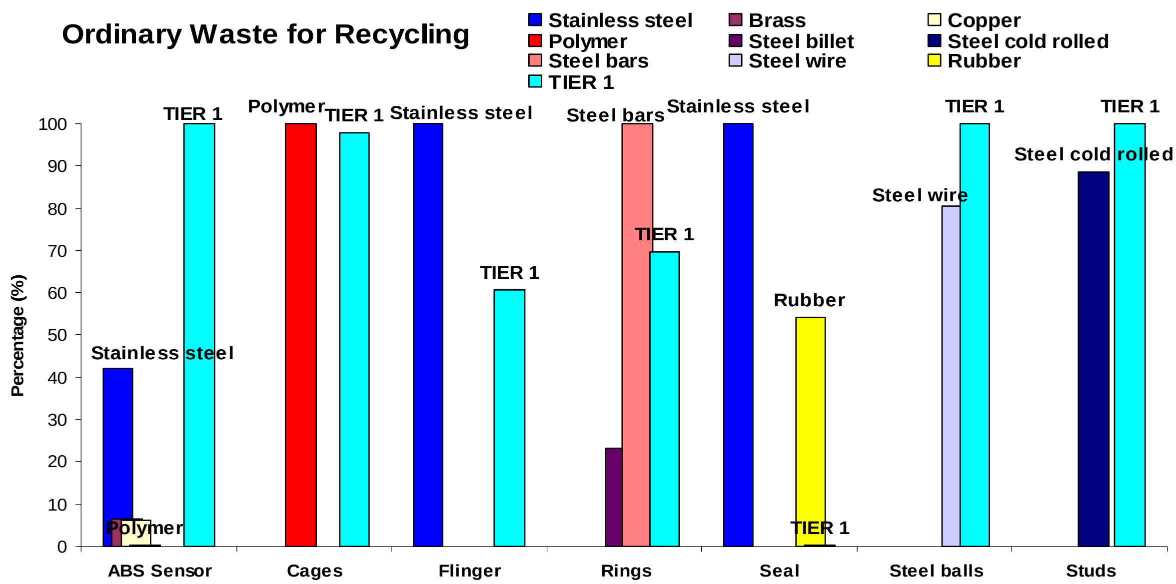


Figure 35 Comparison of the waste by the First Tier suppliers and their respective raw materials (normalized data in Kg)

7.3.3 Total Dominance in SKF bearing production

In this part all the previous results will be used to compare them with the respective information for the production of the analysed bearing. These three production processes (raw materials, first Tier supplier and SKF Bearing) will be weigh against each other for the hard coal energy resources used, CO_2, SO_2, NO_x emissions and ordinary waste for recycling. The values in the figure 36 are normalized with the raw materials set equal to 100% and the two other categories related to the former.

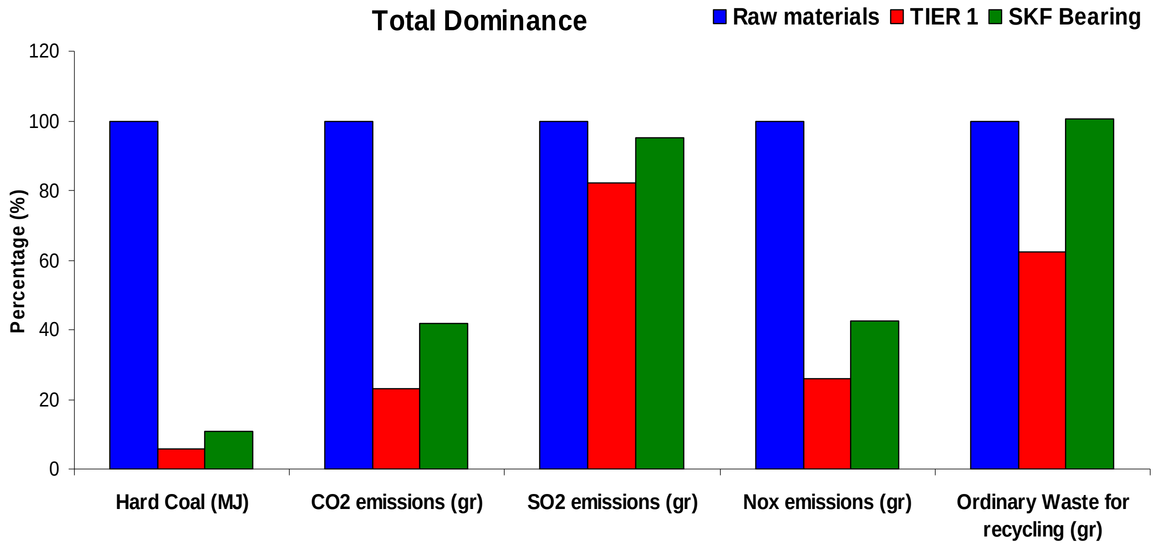


Figure 36 Total comparisons for the bearing's production system

As expected the raw materials are the dominant in almost every category except the waste. The second most important category is the SKF Bearing production process (including its background system) and last is the First Tier suppliers.

Regarding the most used energy resource, hard coal, it is obvious that the raw materials production processes are by far using the most of them. As shown earlier, this is caused mainly by the steel production and more specifically by the steel billet manufacturing processes. The other two categories of the bearing production and the First Tier suppliers are by far using less hard coal resources because of the different types of the utilised energy resources (where again steel dominates).

The results for the compared types of emissions to air are connected with the previous category with the raw materials playing also here the most important role. Steel is responsible for the majority of the emissions. The bearing's production is second in these categories also, with its generated emissions caused by the energy use mainly. It is worth noting that the SO_2 emissions from the bearing's production are quite close to the ones from raw materials. This is caused by the nature of the local power grid mix process (by GaBi) which uses mainly oil and natural gas resources (they generate high amounts of

SO_2 emissions). The First Tier suppliers are again less important (compared to the other two production processes).

Last but not least, the only category where raw materials are not dominating is the ordinary waste that goes for recycling. In 7.3.2, it was pointed out which kind of waste is included in this category for the raw materials and the First Tier suppliers. Regarding the SKF Bearing production, steel scrap is its main waste for recovery. As shown, the amounts between raw materials and bearing production are almost equal. This result can be justified by the type of processes for the bearing production and the high amount of steel scrap generated by its manufacturing procedures. The First Tier suppliers again have less important amounts of this type of waste by their production processes.

It can be concluded from all this systematic dominance analysis that the life-cycle stage of the modelled technical system causing the major environmental impact is the steel production and, more specifically, the steel billet which is used as raw material for the steel bars (by which the rings of the analysed bearing are manufactured from).

7.4 Analysis of data collection

In this section, the procedure followed for the data collection by the First Tier suppliers will be analyzed through comparison made with the ISO standard and, generally, other guidelines or older LCA reports of SKF. By this investigation, the benefits and drawbacks of the method used in this report's case study will be appreciated in order to recommend, later on in the report, better and more efficient data collection methods.

7.4.1 Comparison with ISO standard and other references

In the table 8, the ISO standard guidelines for data collection are stated, together with strategies followed in older LCA reports.

Concerning the ISO standard, the steps suggested have been thoroughly followed for the specific's study data collection strategy (as explained in the methodology chapter). First, the pre-studies of the modelled bearing's components together with the strategy planning and, then, the development of the data collection sheet with all the needed input and output flows comply precisely with the ISO's recommended actions. The flows included in this sheet, agree also with the categories summarized by the standard. As for the validation of data, all the data gathered were first checked if they consent to the data quality requirements of the study and then have been tested with the help of mass or energy balances (made mostly in GaBi software) and literature or older company reports (e.g. for rings, the respective company's environmental report of 2006 have been used to check the energy data).

It is obvious that the main method for gathering data in older LCA reports were interviews and direct contact with the responsible people. The same strategy has been followed for the current study with its "core" being the data collection form. As mentioned earlier, the form has been sent in advance to the suppliers so that further instructions can be given to them during the site visits. Literature data were used as secondary sources for data gaps and pre-studies while the databases (GaBi's) has been used as the main data source for the one of the two models(goal of the study). Finally measurements, estimations and calculations have not been employed in this study (only whenever necessary assumptions were made).

Source	Data collection Strategy
ISO Standard (stands for EPD also)	• Preparations for data collection: ➢ Understand – study the products systems to be modelled: ▪ Draw unspecific flow diagrams ▪ Comprehend each unit process and the type of data needed ▪ Consider data collection techniques • Data collection sheet: ➢ Description of unit process ➢ Raw materials – energy – ancillary inputs ➢ Products, Co-products and waste ➢ Releases to air, water and soil ➢ Other environmental aspects • Validation of data
The importance of buildings' Environmental Impact in Life Cycle Assessment -A case study of SKF's SRB 24024 (Yunfeng Li, 2006)	• Interview on-site • Phone interviews, mail, fax, email • Literature • databases
Life Cycle Assessment on SKF's Spherical Roller Bearing (Åsa Ekdahl, 2001)	• Interviews • Literature
LCA for the plain bearing GE30, manufactured from steel tubes (J.Nilsson, 2001)	• Interviews • Literature • Measurements • Database
Environmental aspects of the Use-phase for bearings in trains (K.Jonasson, 2003)	• Interviews on site • Literature • Estimations by responsible personnel • Calculations

Table 8 Data collection strategies

Taking into consideration other guidelines from various LCA experts, Bo P. Weidema et al. (2003) outline some procedural aspects to be considered when planning for data collection. In the present study the majority of them were thought about, such as its data requirements, locations of the suppliers, documentation and communication issues, knowledge of the targeted people about LCA, possible data gaps and treatment etc. Other advices given by Kun-Mo Lee and Atsushi Inaba (2004), such as the selection of data categories needed and the use of a questionnaire for on site data collection, are precisely correspond to the strategy followed. Finally, the general flowchart of the bearing's product system has helped to identify the main suppliers and the data needed to gather, a recommendation given by Svoboda (1995).

7.4.2 Benefits and drawbacks

As described earlier, the LCI data collection strategy for the First Tier suppliers of the analysed bearing is consistent with the ISO guidelines, older LCA strategies and other suggestions. The benefits and drawbacks will be illustrated here based mainly on personal experiences and the previous remarks. The following table summarizes them:

Benefits	Drawbacks
• Data collection form ➢ Structure ➢ Assignment to the suppliers • Pre-studies and preparation • First visit ➢ Initial establishment of contacts ➢ Acquirement of initial information • Supplier selection	• Data collection form ➢ Data gaps • Time constraints ➢ Communication with the suppliers ➢ Short visits

Table 9 Benefits and drawbacks of the data collection strategy

Starting with the data collection form, it comprises mostly advantages. First of all, the structure of the form has been created as simpler as it could be. All the needed data categories (inputs and outputs) for the specific LCA study were included with the most straightforward information "boxes" to be filled in e.g. for raw material inputs it was asked:

- Type
- Quantity amount used and its unit
- weight of raw material initially delivered to the facility
- their supplier and its location

The whole planning of the form has been focused on the suppliers ease to gather the data and report them in this sheet. Furthermore, it was very helpful the fact that an example showing how to complete the form together with specific instructions for each data category have been included in this form. The assignment of the form to the suppliers, before the visit took place, has been a wise action as it was proved later. During the visits, the most of the suppliers have already started to gather the required data and it was much easier to give them the right directions.

However the data gaps were not missing after the reception of the completed form by each supplier. More specifically, some units were missing or mistakes have been done. Therefore it was necessary to contact many times the particular company and our contact person to correct the data. The most of the data have been corrected but, occasionally, assumptions were necessary to be made. Additional data were also necessary from time to time, because of allocation problems or other requirements realized on the way. Again, the majority of the needed information has been collected but not completely.

The preparation for the data collection (pre-studies) proved also to be quite helpful. The knowledge for supplier processes was acquired by literature studies and the information provided by SKF personnel. Based on this research, specific questions for each supplier (especially for their processes) have been written down to be asked during the visits.

Regarding the first short visit to the SKF facility, it also turned out to be very “fruitful”. The initial contacts established then have helped to obtain the first data for the investigated bearing’s manufacturing processes and its suppliers. These comprised vital information such as the process flowchart and the components of the respective bearing, identification of major suppliers and very detailed information about each component (e.g. weight and number of parts used and delivered, supplier, location etc.) used for the various types of the analysed bearing.

The above mentioned data have facilitated the decision of which suppliers to visit and collect site-specific data. All through the period of the strategy planning, the time aspect and the data quality has been the most thoughtful issue. Due to time limitations of the study, it was decided to visit and gather specific data only by the main local suppliers of the respective SKF facility. As this production unit of SKF had several suppliers around the world, the quality of data would be lower and their collection might need quite a long time to be completed. Consequently, the decision to focus on the local suppliers gave a better data quality to this study within the assigned time period.

The time constraints of the study influenced its data quality. First and most important was the time when the visits were organized. Through the contacts of a specific person working in the facility of SKF, these visits have been arranged just one week earlier. As a result, some companies have not been able to find an available day, during the week asked, and site-specific data could not be gathered by them (e.g. a steel company and a stud’s First Tier supplier). This fact could of course give higher quality to the results of the study. Another problem, due to time limitations, was the short visits to the suppliers. Many things had to been done during this time space, such as presentation of the particular company and its business activities, then presentation of the LCA project, directions for the filling of the data collection form and finally, short factory tour. It is obvious that the schedule was quite hectic with limited time by both sides. However, in most of the companies there was not need for longer stay because of their preparation for our visit.

8 Discussion

Regarding the data quality of the study:

- The data sources, as already known, for the raw material production in both models are taken from the GaBi's database. The geographical boundaries of these processes are different than the real locations where they took place. This choice was based on the goal of the study where the main interest is to find the differences of the two models with a focus on the source of information for the First Tier suppliers. Nevertheless there were not any available GaBi processes to use, with the same geographical boundaries as in reality. Therefore the same types were used in each model, so that the results will not be affected.

- After the completion of this study, late information came that the SKF group in the country where the analysed bearing is produced, uses "green" electricity as the main source of energy. This group comprises the SKF facility (which produces the bearing), the rings suppliers and the seal suppliers. In the model with site-specific data, the power grid mix GaBi process has been used for the country where SKF produces this bearing. This mostly comprised natural gas and oil as energy resources. The specific data stated as the main source of electricity, the hydro power and then, cogeneration through methane, nuclear and national power grid, respectively. Also the amount of CO_2 emissions, generated by the production of this electricity, has been given. A quick calculation has been done to estimate the effects at the results:

    - For the bearing's production in SKF facility, the quantity of CO_2 emissions would have been approximately 90% lower.
    - For the rings and seal production, the CO_2 emissions would be about 88% lower.

  It is obvious that these new data would have caused some changes at the results of the study. However, the final conclusions from the comparison of the two models would not be affected because:

    - The type of process for electricity generation, used in SKF Bearing production, is the same in both models
    - The main variations were caused by the raw materials and other modelling options such as different energy and raw materials inputs, type of processes used etc.

  As for the result of the dominance analysis, the steel billet would still be the most polluting production process (just the difference with the bearing's and rings production would be higher, if the new information was considered). Regarding the First Tier suppliers, the rings production would still be the most energy intensive but not the most polluting because of the type of electricity. Steel balls production has been found to emit, in that case, the most of the CO_2 emissions.

- The data used to represent the production of the investigated bearing have been taken from the environmental reports of 2006 and 2007. For the modelling of the in-house processes, specific measurements have been made (e.g. for compressed air used) and analytical data sheets for waste, energy use, emissions etc. were acquired, all related to the specific production line of the SKF factory, where the respective bearing is produced. These data have not been used in this study because of its simplified nature. The used information from their reports meets the data requirements of this project and serves the basis to draw the right conclusions.

- In the GaBi model with database data for the First Tier suppliers of SKF, there were not available processes offered by GaBi to represent all of them. So it was decided to create "blank" unit processes for the production of these components. As described before, these processes had as only input the raw material and output the product, with the same amount of input as the weight of the final product (meaning that no waste data were included). Energy and emissions also were not included. This choice was done to keep the structure of the specific model same as in the other model and have the same conditions for equal comparison of their results.

- After a sensitivity analysis done in relation to the previous remark, some interesting conclusions have been drawn. It is found that the application (in the GaBi model) of an 8% steel scrap rate (30% lower than the real scrap rate) and with the same energy inputs as in the real case for the dominant rings production process, the average variation of the total LCI results between the two models (in the compared categories) will be about 5.5% (65% lower than the initial average variation). The same scrap rate as in the real case for the rings production would not cause a big change from the previous scenario (average variation would be 5.3%).

  The best case has been observed if together with the previous data for rings production (8% scrap rate and energy inputs), the same waste and energy data (as in real case) are taken into account for the steel balls production. Then the average difference of the total LCI results would be 3.5% (lower by almost 80%). So with site-specific data collection by the two most dominant First Tier suppliers, the LCI results can be of a very good quality and very close to the case where site specific data are collected also by the rest First Tier suppliers.

- Taking into consideration the simple character of this study, it was quite reasonable to use the average number of the bearing's components such as for steel balls or studs and do not consider parts used in few types of this bearing (e.g. encoder, screw or cup). Even if the production of the latter components has been included in the models (would be represented by GaBi processes, since site-specific data are not available) it would a have a negligible impact on the results, based on their characteristics and usage in bearings as compared to their main body parts and their production processes (e.g. rings, steel balls, etc.).

- As mentioned in the chapter 4, the suppliers of SKF are not only local but also other European or even Asian companies. In this study only the local suppliers of the main components (used for one "average" bearing) have been modelled. This decision has been taken in accordance with its goal (to compare the two different models) and based on the fact that only for the main local suppliers site-specific data were available.

- Assumptions for individual site-specific data sets of the First Tier suppliers (e.g. for emissions or auxiliary materials) proved that did not affect the final results of the study. The main reason was their minor amounts and their impacts on the environment as compared to the major source of pollution, the raw materials production. The same conclusion stands for emissions or other minor importance data that have been cut-off from the models.

9 Conclusions and recommendations

In this chapter the conclusions of the study will be summarized for each of the research questions stated in the goal of the study. Then, some recommendations will be given for future LCA studies in SKF.

9.1 Conclusions of the study

The following conclusions have been drawn:

- The effects on the LCI results of the two different data sources (site-specific and GaBi data), used in the two models, are observable. Their variations are caused mainly by the unavailability of relevant processes, in the LCI database used (GaBi), to represent the production of some of the First Tier suppliers. These missing inventory data have influenced the results with the site-specific data model having higher amounts in the compared categories. More specifically, the differences for the most important raw materials and energy resources used in the bearing's production system (inert rock, iron ore and hard coal) were around 10%. CO_2 emissions fluctuate by 20% and steel scrap less than 10%. The biggest difference has been observed for the chloride emissions to water with a variation of 30%. So it can be concluded that this LCI data exchange, between the two models, affects the overall picture of the analysed bearing's production system, regarding its environmental impacts. When quality issues are brought up, the data exchange matters even more, since site-specific data are more representative and reliable than database sources.

- As illustrated in the dominance analysis, the raw materials (steel, polymer, rubber) production dominates in the majority of the compared categories. The only exception involved the waste data where the bearing's production process was equally important. After the comparison of the various raw materials used, the steel billet (used for steel bars, the raw material of rings) production has been found to cause the highest environmental impact.

- The data collection strategy followed, for the acquirement of site-specific data by the First Tier suppliers, has been very reliable and practical. The most important data for their processes have been collected through the use of a data collection sheet, site-visits and proper preparation. Data gaps were of minor importance to the results of the study.

9.2 Recommendations to SKF

Based on these interesting conclusions, recommendations can be given for future LCA studies within SKF, regarding data sources and data collection strategies for an LCA study.

9.2.1 Data sources in an LCA project

As already mentioned, the data collection in an LCA project is the most crucial and time consuming part. The results of the study depend mostly on the data quality. Therefore the data sources selected, to carry out a specific project, are the most critical choices done during the methodology planning.

The two main choices for data are to use site-specific or database data. Generally it is preferable to gather and apply site-specific data to the inventory analysis stage of an LCA. This type of information would of course give a higher transparency and representativeness to a project. However, there is another important aspect that must be considered in one LCA study and that is the time constraint. Companies usually want to have quick results for several reasons. One of them is the business target to gain a competitive advantage in the market over other "opponent" industries. Another reason also is the cost that an LCA project would cause, regarding the occupation time spent by the employees. Therefore the time pressure, combined with the time-consuming activity of collecting specific data, increases the interest of using ready inventory data by an LCI database.

Based on the results of this study, the choice of LCI data can affect in a small or a big grade the total picture of the final results, depending on the life-cycle stage of the product. Using lower quality data for processes that do not cause major environmental impacts would not have big effects on the results. Hence this choice is connected with the awareness of the most dominant stage in the production system investigated. If the stage of the life cycle, where database data are used, has a secondary impact on the results and the commissioner of the project would like to have as fast as possible the results, then inventory data from this source could be used with careful selection of flows and processes together with proper statement of the data origin.

The employment of these data in an LCA study is mostly a quality issue. If a company needs to look into more detail their supply chain and what is the environmental load by each of their suppliers, then site-specific data must be used. The database data will not be totally representative either because of their different boundaries or relation with the modelled product to be applied.

In this specific study for the production of a specific bearing, the two different data sources used for the processes of the First Tier suppliers, cause variations in the inventory results. As proved, these differences have been caused by the processes that influence most the analysed technical system that is the steel production. Therefore, it is preferable to collect and use LCI data for the most polluting life-cycle stages in order to increase the quality of an LCA study. Database data could be used instead for products or services of minor importance (quantitative and qualitative) to the results of the project.

9.2.2 Data collection strategies

The strategy that can be followed during the data collection in an LCA study depends mainly on its practitioner and several other aspects (time limitations, data requirements etc.). In all cases the most efficient strategy, which serves the purpose of the respective project, must be found and applied.

As realized by the results of the specific study, the current data collection strategy followed for the suppliers of the analysed bearing was quite fruitful and reliable. The most crucial issue was the development of the data collection sheet. In every LCA study, the necessary site-specific data must be written down and summarized into a collective sheet. By this way, the practitioner would not forget any data and their documentation will be easier at the end. The structure of the form must be as simple and clear as it can be for the people who will provide the data. It is also wise to send this sheet as soon as possible to the targeted companies, preferably before the site visits. Such action would prepare the upcoming meetings with the responsible persons and save time for both sides.

When an LCA project is initialized, the proper preparations should be made for the site visits. The LCA expert should study as much possible the companies that he or she is going to gather data from, so all the essential information for his/her study would be gathered. It is an advantage if some contacts have been established before the visits, so that some initial data can be acquired. This action would give a better idea for the processes or the products to be modelled.

Data quality is another issue that has to be considered. When various materials or industries are involved in the production of a product, then a selection of the most important (to the purpose of the study) can be made in order to focus only on their processes for collection of site-specific data. The criteria for such selection may be the impact that would have to the final results, the ease of the data collection, the data requirements and finally the time limitations of the particular project. Then LCI data for products of secondary importance or where site-specific data are not available may be taken from databases or even reuse data by LCA studies of similar products. This has happened for the specific LCI study where the main local suppliers have been chosen to gather data from and then use database data for components that site-specific data were missing.

Finally, time can be the most crucial factor in the establishment of every LCA study. Therefore, the planning for data collection strategy ought to take into account, the time constraints and difficulties that may be faced later on. Issues, such as communication with the companies and their people who will provide data among with the duration of the site visits, must be thought in advance. In that way, the proper organization of the meetings and the collection of the required data would be succeeded.

10 References

10.1 Publications

Baumann Henrikke, Tillman Anne-Marie (2004).The Hitch Hiker's Guide to LCA. Studentlitteratur.

Ekdahl, Åsa (2001). Life Cycle Assessment on SKF's Spherical Roller Bearing. Department of Environmental System Analysis. Göteborg, Chalmers University of Technology. **Master:** 75.

ISO 14044 (2006) Environmental Management – Life cycle assessment – Requirements and guidelines. International Organization for Standardization, Geneva, Switzerland.

Jensen Allan Astrup , Hoffman Leif , Møller Birgitte T. ,Schmidt Anders ,Christiansen Kim ,Elkington John ,Van Dijk Franceska (1997). Life Cycle Assessment. A guide to approaches, experiences and information sources. Environmental Issues, European Environment Agency**:** 116.

Jonasson, Karl (2003). Environmental Aspects of the Use-Phase for Bearings in trains. Department of Environmental Systems Analysis. Göteborg, Chalmers University of Technology **Master:** 37.

Kun-Mo Lee, Atsushi Inaba (2004). Life Cycle Assessment: Best practices of ISO 14040 series. Centre for Ecodesign and LCA (CEL), Ajou University, Korea.

Li, Yunfeng (2006). The Importance of Buildings' Environmental Impact in Life Cycle Assessment. Department of Environmental System Analysis. Göteborg, Chalmers University of Technology. **Master:** 53.

Nilsson, Jesper (2001). LCA for the plain bearing GE30, manufactured from steel tubes. Department of Environmental System Analysis. Göteborg, Chalmers University of Technology. **Master:** 87.

NSF International (1997). Environmental management-Life cycle assessment-Principles and framework. **ANSI/ISO 14040:** 16.

Pålsson Ann-Christin (1999). Introduction and guide to LCA data documentation using the CPM documentation criteria and the SPINE format. CPM report 1999:1, Centre for Environmental Assessment of Product and Material Systems (CPM), Chalmers University of Technology, Göteborg, Sweden.

Seo, Seongwon (2002). International review of environmental assessment tools and databases, CRC Construction Innovation**:** 76.

Svoboda, Susan (1995). Note on Life Cycle Analysis, National Pollution Prevention Centre For Higher Education, University of Michigan**:** 9.

Thranne Mikkel, Schmidt Jannik (2005) Life Cycle Assessment (LCA). Chapter 4A: 28

Tillman Anne-Marie, Ekvall Tomas, Baumann Henrikke, Rydberg Tomas (1993). Choice of system boundaries in life cycle assessment. Journal of Cleaner production **2**(1): 9.

Tilmann, Anne-Marie (2000) Significance of decision making for LCA methodology. Environmental Impact Assessment Review 20: 11

Todd Joel Ann, Curran Mary Ann (1999). Streamlined Life-Cycle Assessment: A Final Report from the SETAC North America Streamlined LCA Workgroup, SETAC North America**:** 31.

Weidema Bo P. , Cappellaro Francesca , Carlson Raul ,Notten Philippa ,Pålsson Ann-Christin ,Patyk Andreas ,Regalini Emanuele ,Sacchetto Francesco ,Scalbi Simona (2003) Procedural guideline for collection, treatment and quality documentation of LCA data. 2.-0 LCA consultants, Standards for modelling LCA data, CASCADE: 64

Weidema Bo P., Wesnaes Marianne S.(1997). Data Quality management for Life Cycle Inventories - An example of using data quality indicators. Journal of Cleaner production **4**(3-4): 167-174.

Von Bahr B., Hanssen O.J., Vold M., Pott G., Stoltenberg-Hansson E., Steen B. (2003). Experiences of environmental performance evaluation in the cement industry. Data Quality of environmental performance indicators as a limiting factor for Benchmarking and Rating. Journal of Cleaner production **11**: 13.

Von Bahr B., Steen B. (2004). Reducing epistemological uncertainty in life cycle inventory. Journal of Cleaner production **12**: 20.

10.2 Internet addresses

Boustead consulting
URL address: http://www.boustead-consulting.co.uk/ (1 November 2007)

Dictionary of automotive terms abbreviations
URL address: http://www.motorera.com/dictionary/AA.HTM (25 January 2008)

Eco-Invent database
URL address: http://www.ecoinvent.ch/ (17 December 2007)

EPD (Environmental Product Declarations)
URL address: http://www.environdec.com/ (12 September 2007)

EIA - Energy Information Administration
URL address: http://www.eia.doe.gov/ (5 February 2008)

European Confederation of Iron and Steel Industries
URL address: http://www.eurofer.org (29 October 2007)

European Union, platform for LCA (LCI databases)
URL address: http://lca.jrc.ec.europa.eu/ (22 October 2007)

GaBi software
URL address: http://www.gabi-software.com/ (15 October 2007)

Global Spec, engineering search and industrial supplier catalogues
URL address: http://www.globalspec.com/ (25 January 2008)

How products are made
URL address: http://www.madehow.com/ (16 September 2007)

How stuff works
URL address: http://www.howstuffworks.com/ (16 September 2007)

IEA - International Energy agency
URL address: http://www.iea.org/index.asp (22 October 2007)

IISI - International Iron and Steel Institute
URL address: http://www.worldsteel.org (29 October 2007)

ISO - International Organization for Standardization
URL address: http://www.iso.ch/ (5 September 2007)

Library of Chalmers University
URL address: www.lib.chalmers.se (16 September 2007)

Life Cycle Assessment frame
URL address: http://www.life-cycle.org/ (10 September 2007)

Online metal fabricating information source
URL address: http://www.thefabricator.com/Default.cfm (18 February 2008)

Plastics Europe
URL address: http://www.plasticseurope.org/ (10 February 2008)

Science Direct
URL address: www.sciencedirect.com (16 September 2007)

Scientific Journal

URL address: www.scientificjournal.com (16 September 2007)

Sima Pro and Pre Consultants
URL address: http://www.pre.nl/ (15 October 2007)

SKF website
URL address: http://www.skf.com (5 September 2007)

Via Michelin
URL address: http://www.viamichelin.com/ (22 January 2008)

11 APPENDIX

11.1 Data quality Indicators

Table 1 *Pedigree matrix with guidelines for scoring the DQIs (Weidema, 1998).*

Indicator Score	1	2	3	4	5
Indicators which are independent of the study in which the data are applied:					
Reliability of source	Verified data based on measurements	Verified data partly based on assumptions or non-verified data based on measurements	Non-verified data partly based on assumptions	Qualified estimate (e.g. by industrial expert)	Non-qualified estimate or unknown origin
Completeness	Representative data from a sufficient sample of sites over an adequate period to even out normal fluctuations	Representative data from a smaller number of sites but for adequate periods	Representative data from an adequate number of sites but from shorter periods	Representative data but from a smaller number of sites and shorter periods or incomplete data from an adequate number of sites and periods	Representativeness unknown or incomplete data from a smaller number of sites and/or from shorter periods
Indicators relating to the technological and natural production conditions under which the data are valid, and therefore dependent on the data quality goals for the study in which the data are applied:					
Temporal correlation	Less than 3 years of difference to year of study	Less than 6 years of difference	Less than 10 years of difference	Less than 15 years of difference	Age of data unknown or more than 15 years of difference
Geographical correlation	Data from area under study	Average data from larger area in which the area under study is included	Data from area with similar production conditions	Data from area with slightly similar production conditions	Data from unknown area or area with very different production conditions
Further technological correlation	Data from enterprises, processes and materials under study	Data from processes and material under study but from different enterprises	Data from processes and materials under study but from different technology	Data on related processes or materials but from same technology	Unknown technology or data on related processes or materials, but from different technology

Pedigree matrix by Bo P. Weidema (1998)

11.2 Data Collection Form

1 COMMISSIONER INFORMATION

Contact information:

2 GENERAL INFORMATION

2.1 Contact information

Company		**Facility**	
Contact person		Contact person	
Address		Address	
Country		Country	
Direct phone		Direct phone	
Email address		Email address	

2.2 Time period for data

From: YYYY-MM-DD To: YYYY-MM-DD

2.3 Type of product and production process

Type of product (pre-defined)

Short desc of producti process

2.4 Delivered goods

Description	Quantity	Unit	
Total delivered from facility Delivered to SKF			

3 INPUTS

3.1 Raw materials and components used for [Product related volumes]

Description	Quantity	Unit	Weight	Supplier(s)	Location	Comment

3.2 Auxiliary, e.g. process fluids etc. [Factory totals]

Description	Quantity	Unit	Weight	Supplier(s)	Location	Comment

3.3 Water [Factory totals]

Description	Quantity	Unit	Comment	Supplier(s)	Comment

3.4 Energy use - purchased energy [Factory totals]

Type	Quantity	Unit	Comment	Supplier(s)	Comment
Electricity District Heating Steam Natural gas Fuel oil Liquid Petroleum Gas Coal Diesel Gasoline					

4 TRANSPORTS

4.1 Outbound transports [Factory totals]

Description of goods	Distance (km)	Weight (total for data	Unit	Means of transport

5 OUTPUTS

5.1 By-products [Factory totals]

Description	Quantity	Unit	Comment	User/Rece	Comment
Waste to incineration Metal to recycling Carton to recycling					

5.2 Waste to landfill [Factory totals]

Description	Quantity	Unit	Comment	Receiver	Comment

5.3 Known emissions to air [Factory totals]

Description	Quantity	Unit	Comment (origin etc.)

5.4 Known emissions to water [Factory totals]

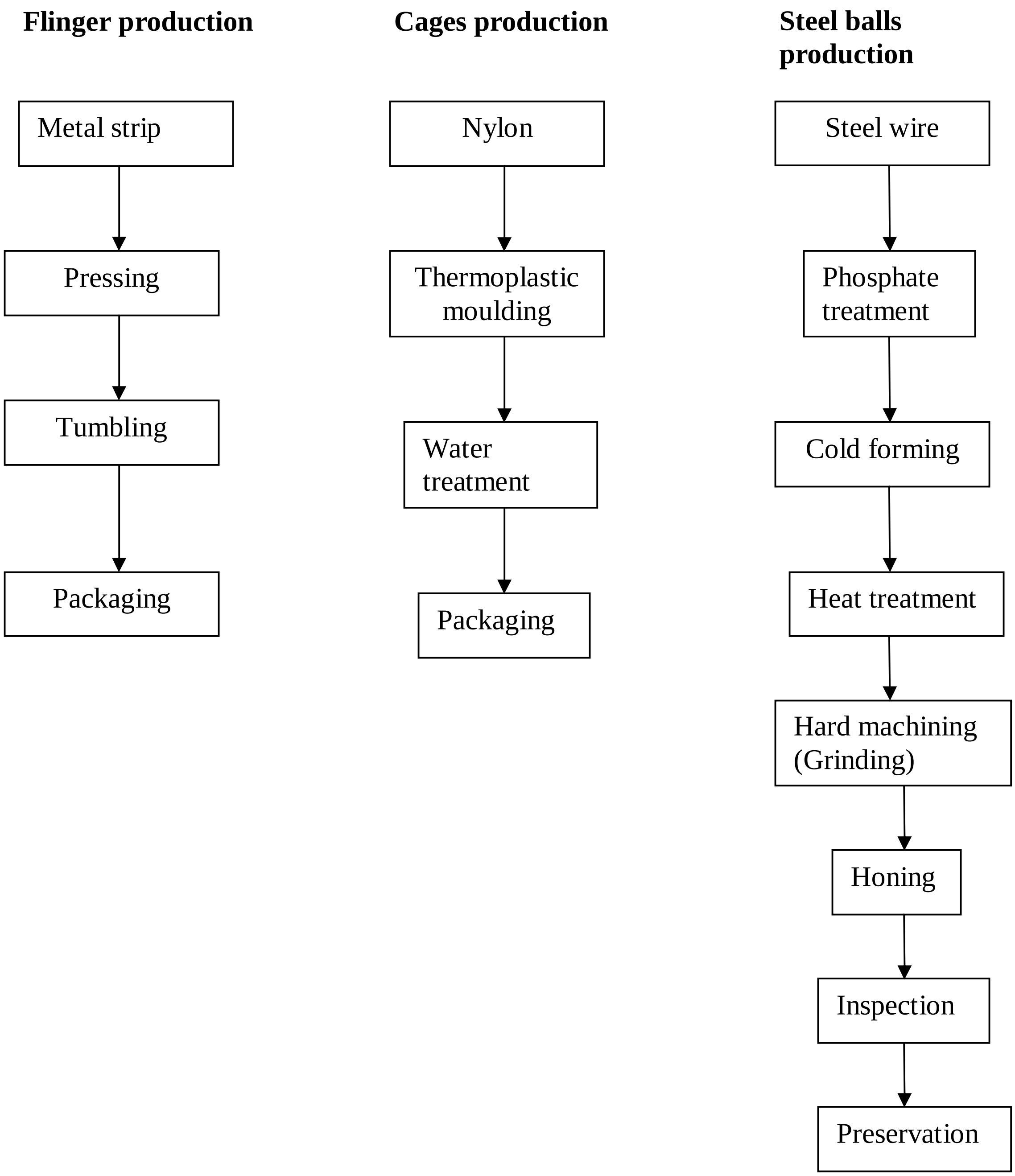
Description	Quantity	Unit	Comment (origin etc.)

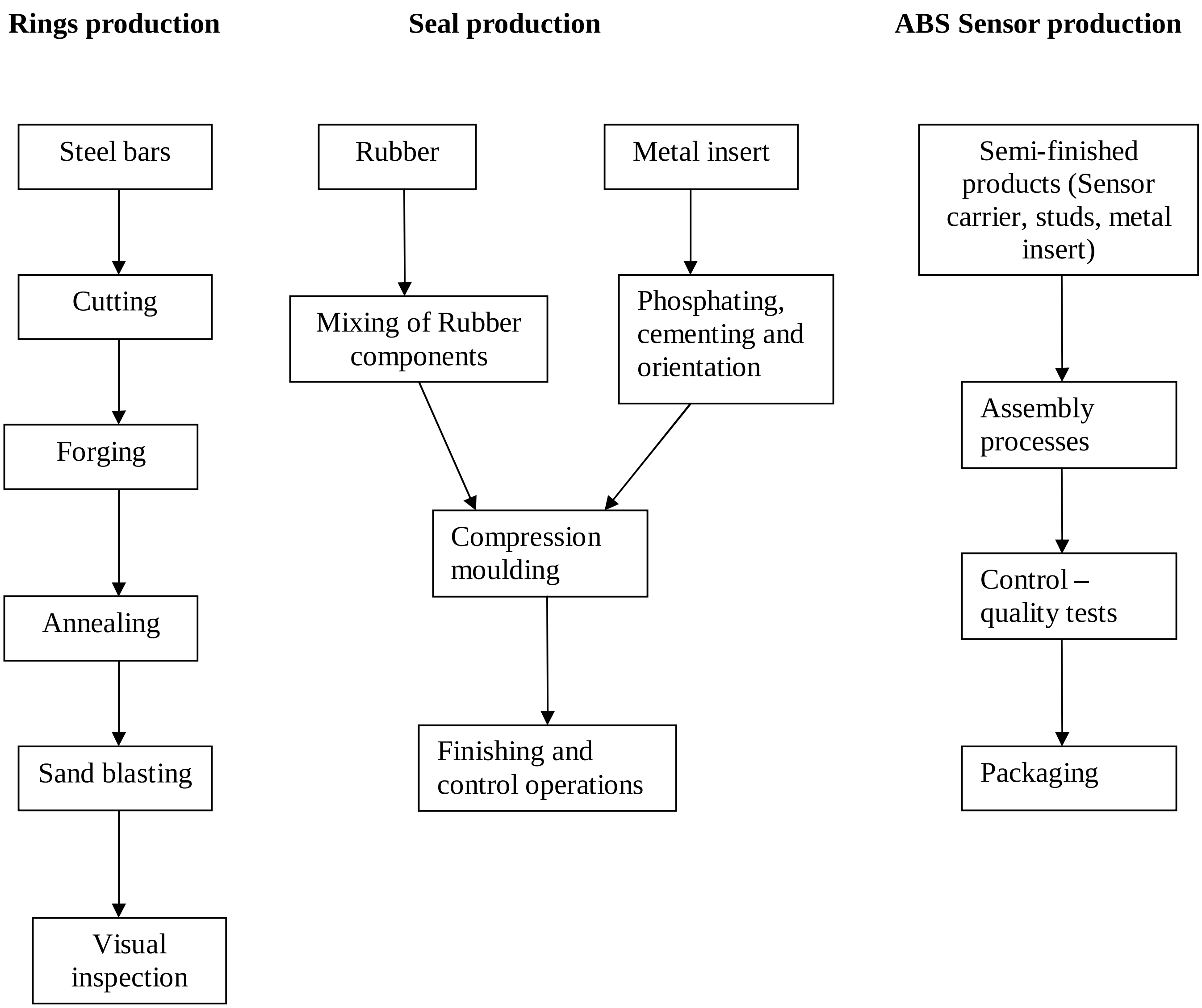
5.5 Hazardous waste handled by licence-holding company [Factory totals]

Description	Quantity	Unit	Comment (origin etc.)	Receiver	Comment

6 REMARKS/COMMENTS

11.3 Production processes of First Tier suppliers




Rings production
Seal production
ABS Sensor production
Steel bars
Cutting
Forging
Annealing
Sand blasting
Visual inspection
Rubber
Metal insert
Mixing of Rubber components
Phosphating, cementing and orientation
Compression moulding
Finishing and control operations
Semi-finished products (Sensor carrier, studs, metal insert)
Assembly processes
Control – quality tests
Packaging

11.4 Research of LCI Databases

In the following table, available LCI data by various databases are shown. This information does not comprise the complete datasets included in these databases but only the ones that could be useful for the present study.

Database	LCI data included
SPINE	• Electricity mixes of 1998 • Land (rail, trucks) – sea transports • Heat generation from waste (Swedish data) • Landfill disposal • Waste treatment (Swedish data) • Bearings – rings production processes (grinding, turning, polish) • Lubricant production (Swedish data) • Steel products data
Eco-Invent	• Updated electricity mixes (domestic production + imports) for EU, Japan (2007) • Heat and electricity from waste incineration • Transportation data • Specified emissions (for high or low populated areas etc.) • Resources extraction • Waste management data • Data quality matrix (based on the Weidema pedigree matrix)
International Energy Agency (IEA)	• National electricity mixes • Consumption of coal, oil, natural gas and renewables • Emission data (for CO_2 mainly)
International Iron and Steel Institute (IISI)	• National data for steel products and processes • Monthly or annual steel production • National steel imports and exports • Amount of steel scrap generated • Emissions related to steel production

Database	LCI data included
Bousteaud	• Data for each country • Fuel production statistics (production, delivery, use) ➢ Coal data ➢ Coke data ➢ Oil products data (diesel, gasoline, grease, kerosene, lubricants) ➢ Electricity data (from different sources e.g. coal, gas, nuclear, hydro etc.) distribution – imports – use ➢ Biomass data • Waste production – delivery& waste treatment data (incineration, landfill, recycle) • Transport (rail, road, sea, air) data • Data for heat generation from different sources (waste, coal, oil, biomass etc.) • Data for Collection & delivery of in – house scrap
European Reference Life Cycle Data System (ELCD)	• Energy carriers ➢ Oil, coal, gas, lignite: average European data ➢ Heat generation from CHP plants (average European data) ➢ Electricity mix for the European continent ▪ Emission factors from power plants ▪ Modelling of power mix ▪ Inputs-outputs (emissions, raw materials, etc.) • Materials ➢ Metals: steel processes, global and European data (1997 – 2002) • Transport: road, rail, sea, air (global-average data 2005)
Plastics Europe	• Variety of polymer materials (e.g. Nylon or PVC products) • Inventory data for each material: ➢ Energy and fuels ➢ Raw materials ➢ Emissions to air and water ➢ Solid waste • LCI data for fuels (e.g. crude oil, natural gas, gasoline) and electricity coming from co-generation
BUWAL	• Packaging materials (e.g. plastic, paper, glass, aluminium etc.) • Energy • Transport • Waste treatment

11.5 Inventory analysis

11.5.1 Site-specific data model

General information

GaBi flows and processes used for the energy, fuel, auxiliary materials (oils) and transport data

The GaBi flows and processes used in the SKF Bearing Production and First Tier supplier GaBi plans are:

Data	GaBi flow	GaBi process
Electricity	Power [Electric power]	Power grid mix *
Natural gas	Natural gas [Natural gas products]	Natural gas mix *
Lubricating oil	Lubricating oil [Operating materials]	EU-15: Lubricants at refinery
Transports (Usually truck)	"Cargo": for the product delivered "Diesel": Fuel input flow	Truck type: Cargo & distance related EU-15: Diesel at refinery (for fuel input)

* The power grid and natural gas mix GaBi processes correspond to the country where the SKF facility and its suppliers are located. For confidentiality issues are not revealed.

GaBi transport processes used for the First Tier Suppliers

Component	GaBi Transport process
Flinger	***GLO: Truck 7,5 t - 12 t total cap. / 5 t payload / Euro 3
Seal	GLO: Truck-trailer > 34 - 40 t total cap./ 27 t payload /
Rings	GLO: Truck-trailer 28 - 34 t total cap. / 22 t payload / Euro 4
Steel balls **	-
ABS Sensor	GLO: Truck 14 - 20 t total cap. / 11,4 t payload / Euro 3 (local)
Cages	GLO: Truck-trailer > 34 - 40 t total cap./ 27 t payload /
Studs	GLO: Truck 20 - 26 t total cap. / 17,3 t payload / Euro 3 (local)
Grease	GLO: Truck 28 - 32 t total cap. / 22 t payload / Euro 3

** Steel balls production data included the transport processes
*** The abbreviation GLO in GaBi means Global (geographical boundary)

IMPORTANT NOTICE:
In the following sections the blue line in the tables is used to separate the input and output flows of each model.

SKF bearing production plan

<u>GaBi flows and processes (or plans) used for the "SKF Bearing Production" plan</u>

Inputs & Outputs	**GaBi flow ***	**GaBi process (or plan)**
Flinger	Flinger (new flow created) **	Flinger production **plan**
Seal	Seal (new flow created) **	Seal production **plan**
Cage	Cage (new flow created) **	Cages production **plan**
Rings	Ring (new flow created) **	Rings production **plan**
Steel ball	Steel ball (new flow created) **	Steel balls production **plan**
ABS Sensor	ABS Sensor (new flow created) **	ABS Sensor production **plan**
Stud	Steel part [Metal parts]	Stud (GaBi data) **plan**
Grease	Lubricating oil [Operating materials]	Grease (GaBi data) **plan**
Process water	Process water [Operating materials]	-
District heating	Thermal energy (MJ) [Thermal energy]	-
SKF bearing	SKF bearing [Flows]	***SKF Bearing production (new process created)
Steel scrap	Steel scrap [Waste for recovery]	-
Oils used	Oil sludge [Hazardous waste for recovery]	-
Paper & Carton waste	Paper (unspecified)	-
Waste to landfill	Waste in landfill (inert material, sanitary and residual material landfill)	-

* Only the valuable material flows are connected with their respective GaBi unit processes.
** For the specific supplied components from the First Tier suppliers, new flows were necessary to create.

Flinger production plan

<u>GaBi flows and processes (or plans) used for the “Flinger Production" plan</u>

Inputs and outputs	**GaBi flow**	**GaBi process**
Metal insert	Stainless steel (cold rolled) [Metals]	* DE: Stainless steel (cold rolled)
Oils	Lubricating oil [Operating materials]	EU-15: Lubricants at refinery
Process water	Process water [Operating materials]	-
Flinger	Flinger (new flow created)	Flinger production (new process created)
Metal to recycle	Steel scrap (waste for recovery)	* CH: Steel (ECCS) mix
Packaging Waste	Waste solid	-
Emulsion waste	Sludge (from processing)	-

**** Abbreviations of GaBi:*** DE is for Germany and CH is for Switzerland

Seal production

Flows not taken into account *

Flow	Type
Emissions to air	Alkalinity
Emissions to water	PO4
	NH4
	CL
Hazardous waste	Exhaust solvents (MEK)
	Phosphating water
	Mud Phosphating

* Reasons of their exclusion from the model are given in the Inventory Analysis chapter

GaBi flows and processes used for the “seal production” plan

Flow	GaBi flow	GaBi process
Metal Insert/flinger	Flinger	Flinger/metal insert TIER 2 **plan**
Springs	Steel part (processed)	DE:steel cast part alloyed
Rubber	Styrene butadiene rubber	DE:Styrene butadiene rubber
MEK	Solvent [Operating materials]	-
Traditional cement	Cement (average) [Minerals]	-
Water based cement	Cement (minerals)	-
Water used as solvent	Water for industrial use	-
Phosphating products	Phosphating products (new flow created)	-
Hydraulic oil	Hydraulic oil	EU-15 lubricant at refinery **process**
Process water	Process water [Operating materials]	-
Seal	Seal (new flow created)	Seal production (new process created)
Metal to recycling	Steel scrap	-
Carton to recycling	Waste paper [Waste for recovery]	-
Nylon packages	Nylon 6 (PA 6) [Waste for recovery]	-
Waste sent to landfill (raw rubber)	Waste (solid) [Waste for disposal]	-
Phosphates	Phosphate	-
Hydrochloric acid	Hydrogen chloride	-
Hydrofluoric acid	Hydrogen fluoride	-
Sulfphuric acid	Sulphuric acid	-
Powders/dusts	Dust (unspecified)	-

Rings production

GaBi flows and processes used

In the rings production plan:

Flow	GaBi flow	GaBi process
Steel bar	Steel bars 60 mm (hot rolled)	"Steel bars 60 mm (hot rolled)" **plan**
Hydraulic oil	Hydraulic oil	"EU 15 lubricant at refinery"
Process water	Process water [Operating materials]	-
Ring	Ring (new flow created)	Rings production (new process created)
Metal to recycling	steel scrap	-
Sludge	Sludge (from processing)	-
Exhaust dust	Exhaust [Waste for recovery]	-
Aluminum emissions	Aluminum [Particles to air]	-
Iron emissions	Iron [Heavy metals to air]	-

In the Steel bar 60 mm production plan *:

Flow	GaBi flow	GaBi process
Steel billet input	Steel billet (150 mm)	DE:Steel billet PE
Total oils	Lubricating oil	EU-15 lubricants at refinery
Power	Power [Electric power]	Local power grid mix
Hydrochloric acid	Hydrochloric acid (100%)	DE: Hydrochloric acid mix (100%)
Light fuel oil	Light fuel oil [Crude oil products]	EU-15: Fuel oil light at refinery
LPG	Refinery gas [Crude oil products]	EU-15: Refinery gas at refinery PE
Steel bar	steel bars 60 mm (hot rolled) [new flow created]	SE:Steel bars 60 mm (hot rolled) production [new process created]

* Only the valuable material flows are shown in this table

Cages production

Flows not taken into account (Reasoning explained in the inventory analysis)

Flow	Type
Auxiliary materials	Cleaning fluid
	Solvent filters & solvent mixtures
Emissions to air	Dusts
	VOC

GaBi flows and processes used

Flows	GaBi Flow	GaBi process
Raw plastic	Polymer material [Plastics] *	RER: Polymer material compound *
Moulds washing fluid	Surfactants (tensides)	-
Total oils used	Lubricating oil	EU-15: Lubricants at refinery
Process water	Process water [Operating materials]	-
Rail transport	-	GLO: Rail transport cargo - average **process** EU-15: Power grid mix (process for power supply)
Diesel	Diesel [Crude oil products]	EU-15 diesel at refinery
Cage	Cage (new flow created)	Cage production (new process created)
Plastics to recycling	Plastic (unspecified) [Waste for recovery]	-
Waste to incineration	Waste (solid) [Waste for disposal]	-
Metal to recycling	steel scrap	-
Carton to recycling	Waste paper [Waste for recovery]	-
Domestic waste (landfill)	Waste in landfill	-
Emulsion oil (haz. Waste)	used oil [Hazardous waste for recovery]	-
Mould washing fluids (haz.waste)	Liquid hazardous waste	-
Oil hazardous waste	unspecified oil waste [Hazardous waste]	-

* For confidentiality issues, the exact type of GaBi flow and process for raw plastic is not shown.

ABS Sensor production

GaBi flows and processes used for the ABS Sensor production plan

Flows	GaBi flow	GaBi process (or plan)
Flinger	Flinger	Flinger TIER 2 **plan**
Micro coils	Micro-coil (new flow created)	Micro coil & compressed mold (Sensor Carrier) **plan**
Silicon	Silicon [Inorganic intermediate products]	-
Resin	Epoxy resin [Plastics]	RER:Epoxy resin [Plastics]
ABS Sensor	ABS Sensor (new flow created)	-
Carton waste	Cardboard [Consumer waste]	-
Copper waste	Copper scrap [Waste for recovery]	-
Plastic waste	Plastic (unspecified) [Waste for recovery]	-
Metal waste	Steel scrap	-
Electronics waste	Waste for disposal (unspecified)	-

GaBi flows and processes used in Micro-coils and compressed mold (Sensor Carrier) plan

Flows	GaBi flow*	GaBi process*
Micro-coils & compressed molds	Micro coil & compressed mold (new flow created)	Micro coil & compressed mold production (new process created)
Plastic	Plastic part (unspecified)	DE: Plastic injection moulding part
Inputs for injection moulding	Power [Electric power] Polymer material [Plastics]	Related power grid mix ** RER: Polymer material
Sea transport	Cargo (plastic part) Fuel oil	Bulk commodity carrier (average) / ocean **type of ship** Fuel oil heavy at refinery **process for fuel**
Copper	Copper [Metals]	DE: Copper mix
Wire	Wire [Metal parts]	DE: Wire production (new process created)
Brass	Brass (CuZn20) [Metals]	DE: Brass PE
Iron Parts	Iron fraction [Metals]	-

* For confidentiality issues, the exact type of GaBi flow and process for the polymer, copper and power grid processes is not shown.
**RER abbreviation is for European data.

Steel balls production

GaBi flows and processes used for the steel balls production plan

Flows	GaBi flows	GaBi process
Steel input	Steel wire [Metals]	Steel wire production (new plan created)
Coal power	Power [Electric power] *	Hard coal power plant BUWAL
Oil power	Power [Electric power]	Fuel oil power plant BUWAL
N.gas power	Power [Electric power]	Natural gas power plant BUWAL
Nuclear power	Power [Electric power]	Nuclear power plant BUWAL
Hydro power	Power [Electric power]	Hydro power plant BUWAL
Steel ball	Steel ball(new flow created)	Steel ball production (new process created)
Steel scrap	Steel scrap	-
Slugs & ash	Slag [Waste for recovery]	-
Mineral waste	Mineral waste [Consumer waste]	-
CO2 emissions	Carbon dioxide [Inorganic emissions to air]	-
Oxygen	Biological oxygen demand (BOD) [Analytical measures to fresh water]	-
C2H4	Ethene (ethylene) [Group NMVOC to air]	-
NMVOC	NMVOC (unspecified) [Group NMVOC to air]	-
Metals	Metals (unspecified) [Particles to air]	-

* As power input in the steel balls production is the total power input from each power plant.

For the “Steel wire production” plan the only flows that change are:

- ➢ Steel input flow is Steel scrap
- ➢ New process for the steel wire output flow has been created
- ➢ Not any steel scrap data

11.5.2 GaBi data model

<u>GaBi processes used for each plan</u>

GaBi plan	GaBi processes used
ABS Sensor	ABS Sensor production (new process created) DE: Plastic injection moulding part (unspecific) RER: Nylon 6.6 GF30 compound (PA 6.6 GF30) DE: Power grid mix
Flinger	Steel sheet stamping and bending (5% loss) EU-25: Power grid mix DE: Steel cold rolled GLO: Compressed air 7 bar (high power consumption) EU-15: Lubricants at refinery
Cage	DE: Plastic injection moulding part (unspecific) RER: Nylon 6.6 granulate (PA 6.6) DE: Power grid mix
Seal	Seal production (new process created) DE: Styrene-butadiene rubber mix (SBR) Metal insert production (same processes as for flinger)
Steel ball	Steel ball production (new process created) DE: Steel wire (St) GLO: Truck 12-14 t total cap. / 9,3 t payload / Euro 3 EU-15: Diesel at refinery
Ring	Rings production (GaBi model) Steel bars 60 mm (hot rolled) Ekdahl (same plan as in the other model)