LCA for the plain bearing GE30, manufactured from steel tubes

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Abstract

This life cycle assessment has been carried out as a master thesis on behalf of the Technical development unit at SKF Nova. The study is a stand-alone LCA for the plain bearing GE30.

The main purpose is to identify the activities, during the life cycle of the bearings that contribute to most negative environmental impacts.

The LCA was carried out for the plain bearing GE30, manufactured at SKF Gleitlager in Püttlingen, Germany. Included in the studied systems were production of raw materials, production of steel tubes, transportation, manufacturing of the plain bearings and recycling of the used bearings.

The functional unit chosen was 1000 kg of finished plain bearings GE30.

To assess the potential environmental impacts, characterisation and weighting was used. The impact categories included in the study were abiotic resource depletion, global warming, acidification, eutrophication, ozone depletion, photochemical oxidant creation and human toxicity. The three weighting methods used were EPS (Environmental Priority Strategies), ET (Environmental Themes) and EDIP (Environmental Design of Industrial Products).

Both characterisation and weighting showed that the main contribution to the total environmental impact occurred during the production of the steel tubes at Ovako Steel AB in Hofors.

Sammanfattning

Denna livscykelanalys är utförd som magisteruppsats, på uppdrag av teknisk utveckling på SKF Nova. Den studerade produkten är glidlagret GE30.

Huvudsyftet är att identifiera de aktiviteter, som under glidlagernas livscykel, står för störst negativ miljöpåverkan.

Glidlagret GE30 tillverkas av SKF Gleitlager i Püttlingen i Tyskland. Inkluderat i det studerade systemet var produktion av råmaterial, tillverkning av stålrör, transporter, tillverkning av glidlager och återvinning av använda lager.

Den funktionella enheten valdes till 1000 kg glidlager GE30.

Karakterisering och viktning var de två metoder som användes för att bedöma den potentiella miljöpåverkan. De effektkategorier som inkluderades i analysen var resursutnyttjande, växthuseffekten, försurning, övergödning, ozonnedbrytning, bildande av fotokemisk smog och hälsoeffekter på människor. De tre viktningsmetoder som användes var EPS (Environmental Priority Strategies), ET (Environmental Themes) and EDIP (Environmental Design of Industrial Products).

Både karakterisering och viktning visade att tillverkningen av stålrör på Ovako Steel AB i Hofors stod för störst del av den totala miljöpåverkan.

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1 Introduction

The Technical Development Centre at SKF Nova in Sweden is among other things working with product development of plain bearings. One of their projects is run together with SKF Gleitlager in Püttlingen, Germany. The task of the project has been to describe the production process in terms of environmental performance as well as the product quality. In order to investigate the environmental performances of the production process an LCA on one of their main products is carried out. The product chosen is the plain bearing type GE30, which is the most sold of all SKF Gleitlager plain bearing types. This particular plain bearing is used for several applications. The biggest customer is Caterpillar and one application is to reduce friction for shovels in their construction machines.[1]

This thesis is carried out in order to calculate the environmental impacts for the plain bearing type GE30. The bearing is manufactured from steel tubes produced by Ovako Steel in Hofors. The environmental impacts will be studied in a life cycle perspective for the specific plain bearing family GE30 and the methodology used will be life cycle assessment (LCA). Throughout the work the thesis will follow the International Standard ISO 14040:1997, *Environmental management - Life cycle assessment - Principles and framework*. The main purpose of this thesis is to find out which activities during the life cycle of the GE30, which contribute to most negative environmental impacts. The study is a cradle to gate LCA. Excluded processes from this study are transports from SKF Gleitlager to dealers and customers as well as the use of the plain bearings. Regarding recycling the used plain bearings are assumed to be recycled in closed loop. However, the treatment of steel in the recycling process is excluded simply because it is not contributing to almost any negative environmental impacts.

The first step in this LCA is to describe all environmentally relevant flows, in and out of a defined system, for the life cycle of the plain bearing GE30. Then these flows will be quantified in the inventory and the collected data will be categorised into different impact categories. The potential environmental impacts which the GE30 life cycle contributes to for these categories will be measured. Furthermore the quantified data will be assessed with three different weighting methods. The three methods used are Environmental Priority Strategies (EPS) [2, 3], Environmental Themes (ET) [3] and Environmental Design of Industrial Products (EDIP) [3].

2 General principles of life cycle assessment

LCA is a technique for assessing the environmental aspects and potential impacts associated with a product or a function. It can for example be a comparison between alternative life cycles with the same function or a comparison between different processes within one life cycle.

When carrying out an LCA study, the LCA framework as it is defined in the European Standard ISO 14040 is a good starting point. The phases are described in Figure 2.1 below.

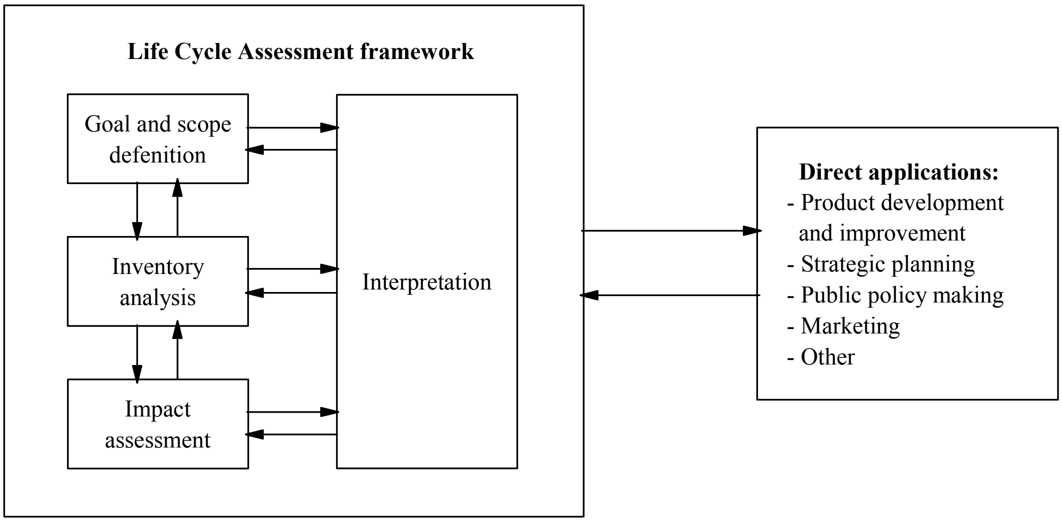

Figure 2.1) LCA framework as it is defined in the European Standard ISO 14040.

2.1 Goal and scope definition

In the goal and scope definition the purposes and the extension of the study are stated. When carrying out an LCA study, methodology choices are very important because different methodology choices give different results. Therefor the commissioner and the practitioner should come up with a goal and scope definition resulting in an LCA, which gives answers to the right questions [4].

2.1.1 Goal of the study

The ISO standard states that the goal definition should include the intended application of the study, the intended audience and the reason for carrying out the study [5].

It is important to describe the purposes from the beginning. However, these purposes can be redefined during the study and additional purposes that may evolve during the project can be added. To make it easier to reach the goal when doing the study, interpreting of the goal into more specific purposes is to prefer. An easy way to state the purposes is to formulate them as questions, e.g. [4]:

- Where are the improvement possibilities in the life cycle of the studied product or service?

- Which processes in the life cycle of this product contributes most to negative environmental impacts?
- What would be the environmental consequences of changing these processes?

2.1.2 Scope of the study

In the scope of the study it is stated how much of the life cycle of the studied product will be included in the LCA. Furthermore, system boundaries, where cut offs will be made and general assumptions and allocations also should be stated.

2.1.1.1 Functions and functional unit

The functional unit is the unit to which all data in the inventory will be related. For the life cycle of a product the functional unit can be defined as for example a number of products or a certain mass. The functional unit corresponds to a function that describes the product application. A clear statement on the specification of the functions of the product shall be made.

For a stand-alone LCA study, the definition of the functional unit is seldom critical. But when it comes to for example a comparative LCA study, the functional unit must represent the function of the compared alternatives in a reasonably fair way. Furthermore, the compared alternatives might have different performances and different life times. That often makes it more complicated and the definition of the functional unit is then very important.

2.1.1.2 System boundaries

The ISO standard (ISO 14040, 1997) states that ideally the system boundaries should be set so that all flows are inflows and outflows from and to the environment without human transformation. However, this is very time consuming and often almost impossible to obtain. Therefor the ISO standard (ISO 14041, 1998) has criteria for how to proceed on inclusion or exclusion of flows (cut-off criteria). The main content in the cut-off criteria is that relevant flows should be included in the study. Hence, flows that can be considered irrelevant for the result can be excluded.

The system boundaries need to be specified in several dimensions [4]:

- Boundaries in relation to natural systems.
- Geographical boundaries.
- Time boundaries.
- Boundaries within the technical system.

2.1.1.3 Impacts on the environment - choice of impact categories

About the choice of impact categories the ISO standard only states that use of resources, ecological consequences and human health should be considered, but an LCA study often takes this further. To be able to draw any conclusions about the environmental impacts, these have to be divided into more operative impact categories. An example of a list of impact categories can be seen in Table 2.1.

Table 2.1) List of impact categories from Nordic Guidelines on Life-Cycle Assessment, 1995.

Impact category
1. Resources - Energy and materials
2. Resources - Water
3. Resources - Land (including wetlands)
4. Human health - Toxicological impacts (excluding work environment)
5. Human health - Non-toxicological impacts (excluding work environment)
6. Human health impacts in work environment
7. Global warming
8. Depletion of stratospheric ozone
9. Acidification
10. Eutrophication
11. Photo-oxidant formation
12. Ecotoxicological impacts
13. Habitat alterations and impacts on biological diversity
14. Inflows which are not traced back to the system boundary between the technical system and nature
15. Outflows which are not traced back to the system boundary between the technical system and nature

2.1.1.4 Data quality requirements

When carrying out an LCA study it is necessary to consider what type of data that is required to collect during the inventory. In LCA literature, one can find many different definitions of data quality. However the terms *reliability, accessibility and relevance* are in this literature frequently discussed [6].

2.1.1.5 Allocations

In a lot of situations several products share the same process. In such cases the environmental load has to be partitioned between the different products and this is the allocation procedure.

Decisions of allocation procedures might be difficult to take in this early stage, but has to be considered. The reason is that the choice of allocation method can affect the result a lot.

2.1.1.6 Assumptions and limitations

According to the ISO standard (ISO 14040, 1997), assumptions should be considered and stated in the goal and scope definition. In practice that counts for major assumptions that is possible to anticipate in the early stages of the study. When it comes to limitations these should also be stated this early. The limitations can either be those who are results of choices made in the scope definition or results of problems during the carrying out of the study, e.g. failure to collect data.

2.2 Inventory analysis

In the inventory analysis all environmentally relevant flows, for the system decided upon in the goal and scope definition, will be described and quantified. The result of the analysis is a flow model that can be described as an incomplete mass and energy balance over the system. The first step is the construction of a flow chart, where after follows data collection and calculation procedures.

2.2.1 Construction of flow chart

A good way of surveying the life cycle activities of the product system studied, is to construct a flow chart. Maybe a general flow chart already has been constructed, in the goal and scope definition, according to the system boundaries decided upon. In the inventory analysis this flow chart is expanded and made more detailed, in order to describe all activities in the system and the flows between them. This is a process that follows the work with data collection. As more and more information is found out about the system, the flow chart is more and more expanded.

2.2.2 Data collection

This phase during an LCA is a very time consuming process. Very often it is not a matter of data collection as much as searching for data. For some activities in the life cycle it might be almost impossible to get the right data and assumptions and limitations might be unavoidable. Nevertheless, the data collection is a highly critical process, since this is the base for calculating the magnitude of environmental impacts caused by the studied life cycle. Lack of data for some relevant activities might affect the final result considerably.

2.2.2.1 What type of data should be collected?

For every process in the studied life cycle numerical data for input and output should be collected. That includes for example inputs of energy and raw materials, inputs and outputs of products and outputs in terms of emissions to air, water and land. Furthermore, data for fuel consumption and emissions during included transports need to be collected. When allocation procedures are necessary for a process, data that will be used as a basis for the allocation need to be collected. Such data could for example be weight, manufacturing cost or market price for products involved in the studied process.

To describe the numerical data, qualitative data need to be collected. Quality data can for example be:

- Descriptions of how processes works
- Information about whether emissions were measured, calculated or estimated
- Information about who carried out the measurements, calculations or estimations
- What year the data collaborates to
- If the data is specific for the studied processes or general data form another data source

It is very important to collect this kind of information, since it makes it possible to interpret and compare the numerical data. If good quality data is collected for a process it will be easier to understand what the data stands for.

2.2.2.2 Data sources

There are several data sources for collection of data and as no LCA practitioner can be expert in all processes included in the LCA, other people need to be asked. Good data sources can for example be people that are experts on the specific processes involved. In that case personal contacts need to be taken and communication between the practitioner and the data source is very important.

But there are many other data sources, e.g. data bases for energy production and transports, branch organisations, waste management companies and technical models.

2.2.2.3 Planning for data collection

When asking data suppliers for information about a process it is important to be well prepared. To get the data suppliers attention the practitioner need to know how the processes works in order to ask the right questions and to understand the answers. It is also important to think about for which processes site-specific data are necessary and for which general data can be used. If the data supplier asks about confidentiality issues or the opportunity to read the LCA, the practitioner should have strategies for handling such questions.

2.2.2.4 Validation of data

According to ISO 14041 (1997) collected data must be validated, which means that the data should be checked to judge if data are reasonable or not. This can be done by for example:

- Mass balances
- Follow ups, e.g. communication with people at a studied plant
- Scientific properties; e.g. combustion of fossil fuel gives a specific output mass of coal.

2.2.3 Calculation procedures

When the data is collected and the system boundaries are set the next step in the LCA study is calculation procedures. The calculations are preferably carried out in the following steps [4]:

1. Normalise data for all activities included in the LCA, which means that within an activity, all inputs and outputs must be related to the functional output (or input) of that activity.
2. Calculate the flows linking the activities in the flow chart, using the flow representing the functional unit as a reference.
3. Calculate the flows passing the system boundary, again related to the flow representing the functional unit.
4. Sum up the resource use and all emissions for the entire system.
5. Document the calculations.

2.2.4 Allocations

The ISO standard (ISO 14041, 1998) gives the following order of preference for allocation methods:

a) Whenever possible allocation should be avoided by:

1. Increased level of detail of the model
2. System expansion

b) Where allocation can not be avoided, the environmental loads should be partitioned between the system’s different products or functions in a way which reflects the underlying physical relationship between them.

c) Where physical relationship alone cannot be established or used as the basis for allocation, the inputs should be allocated between the products and functions in a way that reflects other relationships between them.

2.3 Life cycle impact assessment

In the inventory analysis the environmental loads of all activities included in the system are quantified. The life cycle impact assessment is carried out to describe the environmental impacts of these environmental loads. In order to do that the loads are divided into environmental impact categories, e.g. ozone depletion, global warming and toxicological impacts on human health. These impacts are examples of sub categories of the three general categories of environmental impacts that need to be studied in an LCA, resource use, human health and ecological consequences.

2.3.1 The different phases of LCIA

The life cycle impact assessment can be divided into several sub-phases. According the ISO standard two of these sub-phases are mandatory and that is classification and characterisation. The other sub-phases are optional.

2.3.1.1 Impact category definition

In this sub-phase the impact categories which will be included in the study are defined. The relevant environmental impacts decided upon in the goal and scope definition are here divided into more specified impact categories. When the LCA practitioner decide upon which impact categories will be considered the factors *completeness, practicality and independence should be considered* (Nord, 1995).

When reading about LCA one comes across a lot of different suggestions on complete sets of impact categories. An example of such a list from "Nordic Guidelines on LCA" can be seen in table 2.1 (section 2.1.2.3).

2.3.1.2 Classification

In this phase the LCI result parameters are sorted and put in the right impact category. The best way to find out to which impact category the different parameters correspond is to study published lists, where various substances together with their equivalency factors are listed per impact category. It is important to be very careful when you do such a thing. Some environmental loads correspond to more than one impact category and therefor have to be listed in all affected categories. However, this double assignment is only done for impacts that are independent of each other. Double assignment in a case of dependent impacts will lead to double counting.

2.3.1.3 Characterisation

This is mainly a quantitative step. The size of potential environmental impacts are calculated per category , with the use of equivalency factors defined in the modelling of cause effect chains. If for example the studied impact category is acidification, all acidifying emissions (SO_x, NO_x, HCl, etc.) in the LCI calculations are added up on basis of their equivalency factors. The sum is an indication of the size of the potential acidification impact.

2.3.1.4 Normalisation

Here the characterisation results are related to the actual or the predicted magnitude for each impact category. The aim is to gain better understanding of the magnitude of environmental impacts caused by the studied system. The question can for example be:

- Is the acidification impacts caused by the studied product large in relation to total acidification impacts in the country where the product is produced and used?
- Is the energy consumption caused by the studied product large in relation to total energy use in the area where the product is produced and used?

This relation is not so meaningful when the comparison is made between the impact per functional unit and the total impact in the region. It is more meaningful when the comparison is made between the total impact of the use of all produced products and the total impact in the region.

2.3.1.5 Weighting

Weighing can be defined as the qualitative or quantitative procedure where the relative importance of different environmental impacts are weighted against each other. The relative weight of the different impact categories are expressed by their weighting factors.

The methods for generating weighting factors are predominantly based on social sciences. Methods for generating weighting factors are based on principles of several kinds [4]:

- Monetarisation. With this approach, our values concerning the environment are described as costs of various environmental damages or as prices on various environmental goods. Economic valuation methodologies are concerned with how values are described for goods for which there is no market (and therefor no price). A ”price” can be derived from individuals’ willingness to pay (i.e. they are asked how much they are willing to pay to for example avoid extinction of a species) or be revealed by their behaviour (e.g. the difference in price of similar houses close and far away from an airport reveals the cost of noise).
- Authorised targets. The difference between current levels of pollution and targeted levels can be used to derive weighting factors. Target levels can be formulated by national authorities as well as by companies. This approach could be said to be based on a ”distance-to-target” thinking.
- Authoritative panels. Panels can for example consist of scientific experts, government representative, decision makers in a company and residents in an area.
- Proxies. With a proxy approach, one or a few parameters are stated to be indicative for the total environmental impact. Examples of proxy parameters are ”energy consumption” and ”weight”.
- Technology abatements. The possibility of reducing environmental loads by using different technological abatement methods, (e.g. filters, etc.) can be used to set weighting factors. This approach could be said to be based on ”distance-to-technically feasible target” thinking.

Since there are ethical and ideological values involved in the weighting element in LCIA, there will never be a consensus on these values. Many engineers have therefor an awkward relationship to weighing, and use of weighing factors often lead to discussions about whether they are ”scientifically correct” or not, whether the values are representative or not, etc. The awkwardness also relates to the discussion on what is objective and what is subjective.

2.3.1.6 Data quality analysis

Additional techniques and information may be needed to better understand the significance, uncertainty and sensitivity of the LCA results in order to identify (ISO 14042, 1998):

- The most polluting activities in the life cycle.
- The most crucial inventory data, i.e. the data describing the activities in the life cycle for which slight changes in the value change the ranking between compared alternatives.
- The most crucial impact assessment data describing impact categories for which slight changes in their value change the ranking between compared alternatives.

2.3.2 Ready-made LCIA methods

A number of ready-made LCIA methods exist and the practical advantage with these are that the environmental information for various pollutants and resources are aggregated to a single number, an index. The indices for the various pollutants and resource indicate their relative environmental harm. In other words, all environmental problems are ”measured” with a single measuring scale (rod) with such an LCIA method. The total environmental impact of a system can thereby be obtained by multiplying all environmental loads of the system by their corresponding indices and summing them up, like in the equation below. In principle, by chance, the result could very well be ”42”.

Total environmental impact $=\Sigma_i \; load_i \bullet index_i$,
where i = environmental impact category, e.g. acidification, global warming, etc.

In LCA literature, many LCIA methods are described in principle, but lists with indices for various substances have been developed only for a smaller number of them. The LCIA methods with such indices uses different means, i.e. weighing principles, to obtain the indices. Determining the relative harm of different environmental impacts is a value-bound procedure, and their different weighting principles therefore reflects different social values and preferences.

3 Definition of goal and scope for this study

3.1 Goal of the study

The reason for carrying out this LCA is to describe the environmental performances of the SKF plain bearing GE30. The main purpose is to find out which activities during the lifetime of the GE30, that contribute to most negative environmental impacts. GE30 is chosen because there already is some life cycle inventory data available for this bearing type and because it is the most sold bearing at SKF Gleitlager.

The study was commissioned by the Technical Development Centre at SKF Nova and they are also the intended audience. The intended application is to increase the knowledge of the potential environmental impacts that can be associated with the life cycle of SKF plain bearings.

3.2 Scope of the study

There are two major production phases involved in the manufacturing of the plain bearing GE30. The phases are production of steel tubes from steel scrap at Ovako Steel in Hofors and production of the plain bearing from the tubes at SKF Gleitlager in Püttlingen. Transports included in the manufacturing of the GE30 will also be considered as well as recycling. Regarding the GE30 in use this will not be considered. Plain bearings are produced in order to reduce friction and save energy. The positive environmental impacts of the use of plain bearings is likely to exceed the potential negative environmental impacts. This is the reason for exclusion of the use of the GE30.

3.2.1 System boundaries

The system boundaries decided upon for this LCA can be seen in figure 3.1.

In figure 3.1 the flows from the biosphere are flows, which are traced all the way back to the extraction of the raw material from the nature. All flows to the biosphere are flows, which are followed all the way to the nature and the environmental impacts of these flows are considered.

In the beginning of this LCA study, all flows where cut off at the gates of the included production plants. To decide which flows were going to be traced back to the cradle, the ready-made life cycle impact method EPS was used. By analysing the EPS weighting factors for the substances that were included in the two product systems, choices for system expansions could be made. The material flows that have been traced back to the cradle can be seen within the biosphere in figure 3.1.

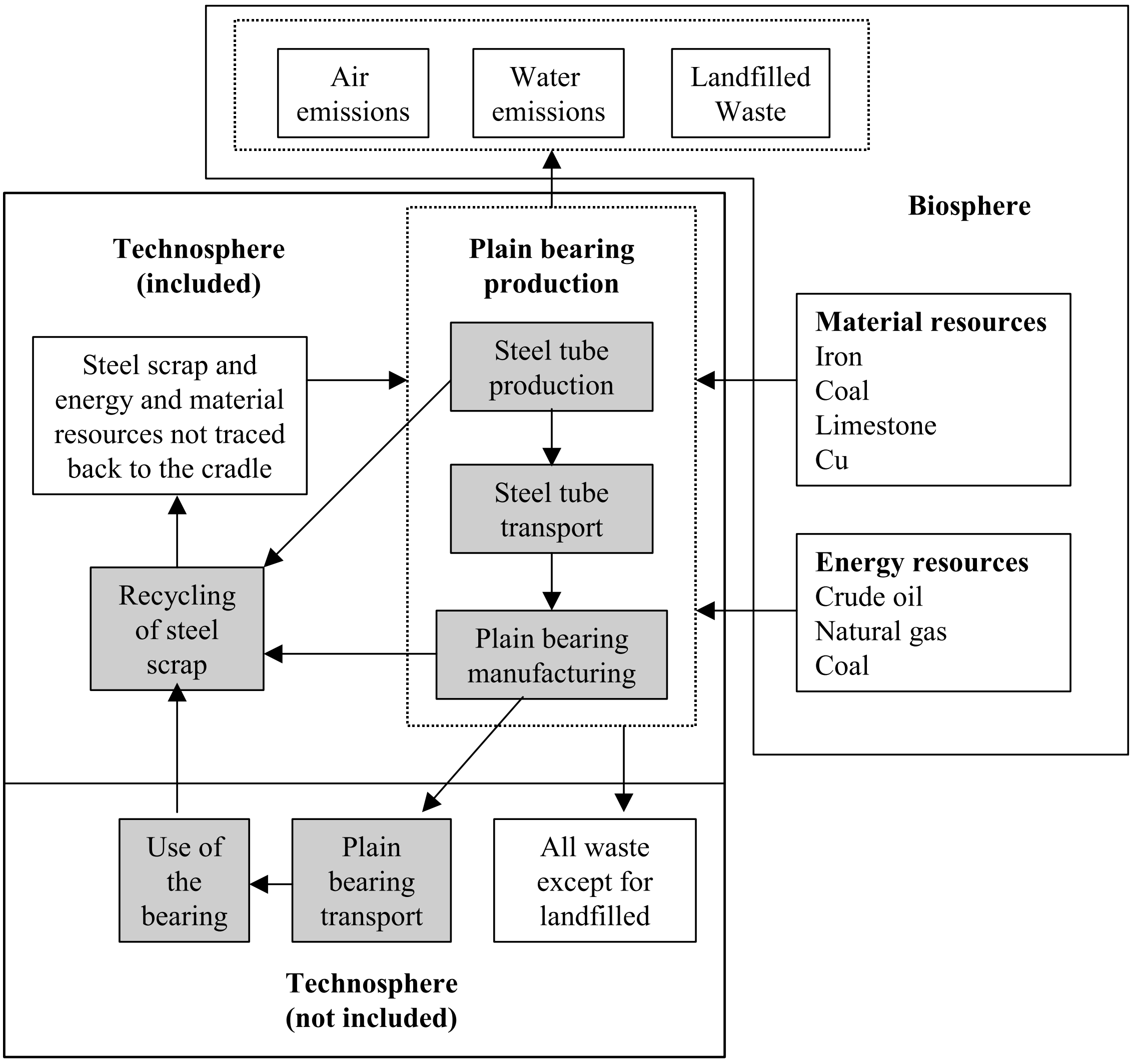

Figure 3.1) System boundaries. The grey boxes are activities and the white boxes are material flows.

3.2.2 Functions and functional unit

The functional unit in this LCA study is 1000 kg of the plain bearing GE30 and all data will be related to this unit.

3.2.3 Limitations and assumptions

When carrying out an LCA it is very difficult to follow all flows into a system from the cradle and all outflows from a system to the grave. It is even harder to quantify all these flows. In this LCA the inflows and outflows, which have been studied from the cradle and to the grave, can be seen as boxes within the biosphere in figure 3.1. All other flows stay in the technosphere.

The steel tubes at Ovako Steel are produced from steel scrap and used plain bearings can therefore be used for production of new steel tubes. The assumption is that this is the case here and the bearings are then recycled with closed loop. Hence, the plain bearings are recycled to the steel tube producer Ovako Steel. No transports for recycling are considered.

At SKF Gleitlager in Püttlingen, six different types of the plain bearing GE30 are manufactured. However, only the three most frequently sold types of GE30:s are considered in this study (the grey fields in table 3.1). Two of the other three types are produced from tubes of stainless steel. Since the manufacturing process for stainless steel differs from the process for SKF3 steel, these two types are excluded from this study. The outer ring for one of the GE30 types is manufactured from a ring instead of from a tube. It is also produced in a CNC machine, instead as the other GE30:s in a multi-spindle turning machine. Therefor this type is also excluded from the LCA study. The total number of plain bearings of type GE30 manufactured the studied year, 1998, was 273 000. The total number included in the study is 219 000 pieces. [7]

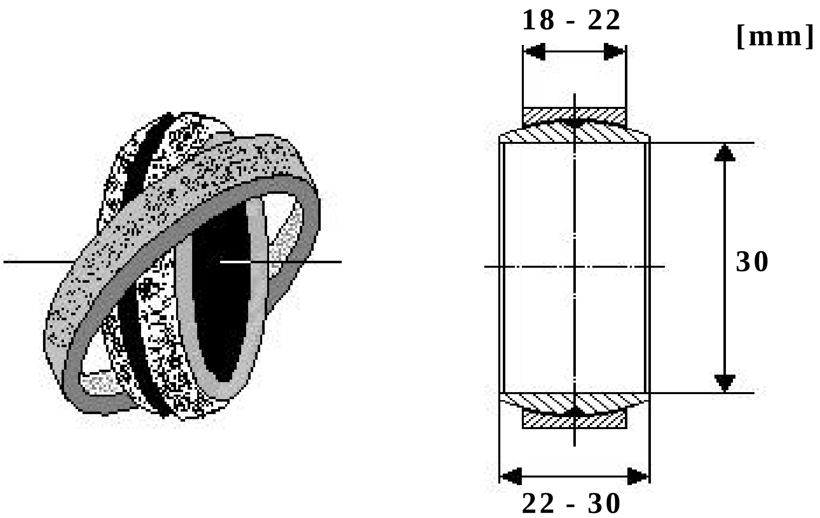

Figure 3.2) The plain bearing type GE30. The inner diameter for the three studied bearing types is the same, but the width and outer diameter differs.

A typical GE30 can be seen in figure 3.2. Hence, as can be seen in the picture, the figure 30 after GE refer to the inner diameter of the bearing. The outer diameter and the width of both inner and outer ring differ depending on bearing type. However, as can be seen in table 3.1, the mass of the bearing types included in this LCA differs very little regardless of different measures.

Table 3.1) Different types of plain bearings in the GE30 family 1998. The grey fields are included in this LCA study.

Type of plain bearing	**Mass/plain bearing (kg)**	**Pieces/year (1998)**	**Possible to manufacture from SKF3 steel tubes**
GE30 ES	0,16	131 000	Yes
GE30 ES-2RS	0,16	69 000	Yes
GEH30 ES-2RS	0,35	12 000	Yes
GEM30 ES-2RS	0,17	19 000	Yes
GE30 C	0,16	37 000	No
GE30 TGR	0,16	5 000	No
Total		**273 000**	

3.2.4 Types of impacts being considered

A list of impact categories decided upon for this LCA can be seen in table 3.2. See section 5.1 for reasons for exclusion of some impact categories.

Table 3.2) List of impact categories from Nordic Guidelines on Life-Cycle Assessment, 1995.

Impact category
1. Resources - Energy and materials
4. Human health - Toxicological impacts (excluding work environment)
7. Global warming
8. Depletion of stratospheric ozone
9. Acidification
10. Eutrophication
11. Photo-oxidant formation
12. Ecotoxicological impacts
14. Inflows which are not traced back to the system boundary between the technical system and nature
15. Outflows which are not traced back to the system boundary between the technical system and nature

3.2.5 Allocations

Three different allocation methods have been used for different processes involved in this LCA. The obvious choice of allocation method for the processes involved in the steel tube production at Ovako Steel was weight. The allocation procedures for the manufacturing of the plain bearings in Püttlingen were more complicated. The oil consumption in the turning process for the GE30 manufacturing in Püttlingen, was allocated with process time. The reason is that the oil flow is continuos during the turning and therefor only depending on the process time. All the general data for the Püttlingen site, for example electricity and heat consumption, was allocated with company turn over.

3.2.6 Data quality

Data for this thesis has been obtained from different sources. At Ovako Steel in Hofors and SKF Gleitlager in Püttlingen site specific data has been collected by interviews with production site managers, from annual environmental reports and from specific emission measurements. The data was collected between September 1999 and March 2000 and all data is therefor from 1998 and 1999.

Regarding LCI data for acquisition and production of energy wear and raw material as well as for transports this data has been obtain from the Spine database. The data origins from 1996 – 1999.

All data for this thesis has been documented in the Spine format according the standards at CPM, Chalmers University of Technology.

4 Life cycle inventory analysis for the plain bearing GE30 produced at SKF Gleitlager in Germany

The LCI analysis for the bearing is divided into four sections from gate to gate:

- Steel tube production at Ovako Steel AB in Hofors, Sweden.
- Manufacturing of the plain bearing GE30 at SKF Gleitlager in Püttlingen, Germany.
- Transports of steel tubes from Hofors to Püttlingen.
- Recycling of the plain bearing GE30.

Under the section *Recycling of the plain bearing GE30*, the consumption of virgin iron ore is also discussed.

For the manufacturing of the plain bearing GE30 during 1998, steel tubes with outer diameters of 41,55 and 47,75 mm were used. The wall thicknesses of the tubes were 6,74 and 4,34 mm respectively. From now on in the report, these are referred to as 41,55 and 47,75. The tubes where previously bought from WRG in Germany and SKF Gleitlager just recently switched over to Dalmine and Ovako Steel as suppliers. [7]

4.1 Steel tube production at Ovako Steel in Hofors

At Ovako the tubes are manufactured from steel scrap in a multi step process. These two specific tubes go through four major processes before they are delivered to Püttlingen:

- Production of steel ingots from steel scrap.
- Rolling of ingots into billets.
- Hot rolling of billets into tubes.
- Cold working of the tubes into customised steel tubes.

All these processes consist of several minor steps, which are all considered in this study. In figure 4.1 the process chain for production of the two studied steel tubes can be seen. Life cycle inventory data and allocation procedures for these processes are presented in appendices A and B.

4.1.1 Production of steel ingots at the Steel Mill

Iron scrap and slag formers are loaded into an electric arc furnace that has a charging weight of 110 tons. Three graphite electrodes are put into the furnace and when the scrap starts to melt limestone, anthracite (hard coal) and aluminium are added. The limestone is added as slag former, the coal as slag former and alloy and the aluminium for oxygen reduction. Into the furnace there is also a constant flow of oxygen. Then the steel is refined and alloyed in a ladle furnace, where it is also degassed. The steel is then teemed uphill into ingot modules. Each heat is teemed into 24 ingots. The modules are removed and the ingots are heated in a soaking pit furnace to the proper rolling temperature. [8, 9]

4.1.2 Rolling of ingots into billets at the Rolling Mill

In the pit furnace the ingots are heated to the proper rolling temperature and then the forming of ingots into billets is started in rolling stand 1. Then the surface defects are removed in the oxygen-scarfing machine. The billet rolling is continued in rolling stands 2 and 3 and then the billets are placed on a cooling bed. After rolling stand 2 and 3, some billets are delivered to customers. The other billets are sand blasted, inspected and surface defects, if any, are removed by grinding. These billets are delivered to either external customers or to the hot rolling mill at Ovako. The different billet dimensions produced at the rolling mill are 150 mm square and 120, 90 or 80 mm round. For the manufacturing of the two tubes studied in this thesis, billets of dimension 80 round are used. [10, 11]

4.1.3 Production of hot rolled tubes at Tube Mill 5

In a rotary furnace the billets are heated to rolling temperature, about 1 200°C. The centre is marked in one of the end surfaces of the billet, the billet is forced over a plug and the hole is pierced. The wall thickness of the tube is decided by rolling over a mandrel in the Assel mill. In the reducing mill, the outer diameter of the tube is determined. The next step is the calibrating and straightening mill, where the dimensions of the tube are finely adjusted. After that the tube is placed on a cooling bed. The hot rolled tubes are then directly transported to the customer or passed on for further processing. In this case the tubes are passed on for cold working at Ovako. The diameters of the tubes that are passed on for cold working are 70,7 x 47,5 mm. [12, 13]

4.1.4 Production of cold rolled tubes

At Ovako Steel two different cold working methods are used and they are cold rolling and cold drawing. The two tubes for this thesis are both cold rolled. The tubes of dimension 70,7 x 47,5 mm are processed by cold rolling as can be seen at right in figure 4.1. First the tubes are cold rolled and then passed on for grinding or peeling, depending on the customers demand. After that they are controlled for cracks with ultra sound, cut and delivered. [14, 15]

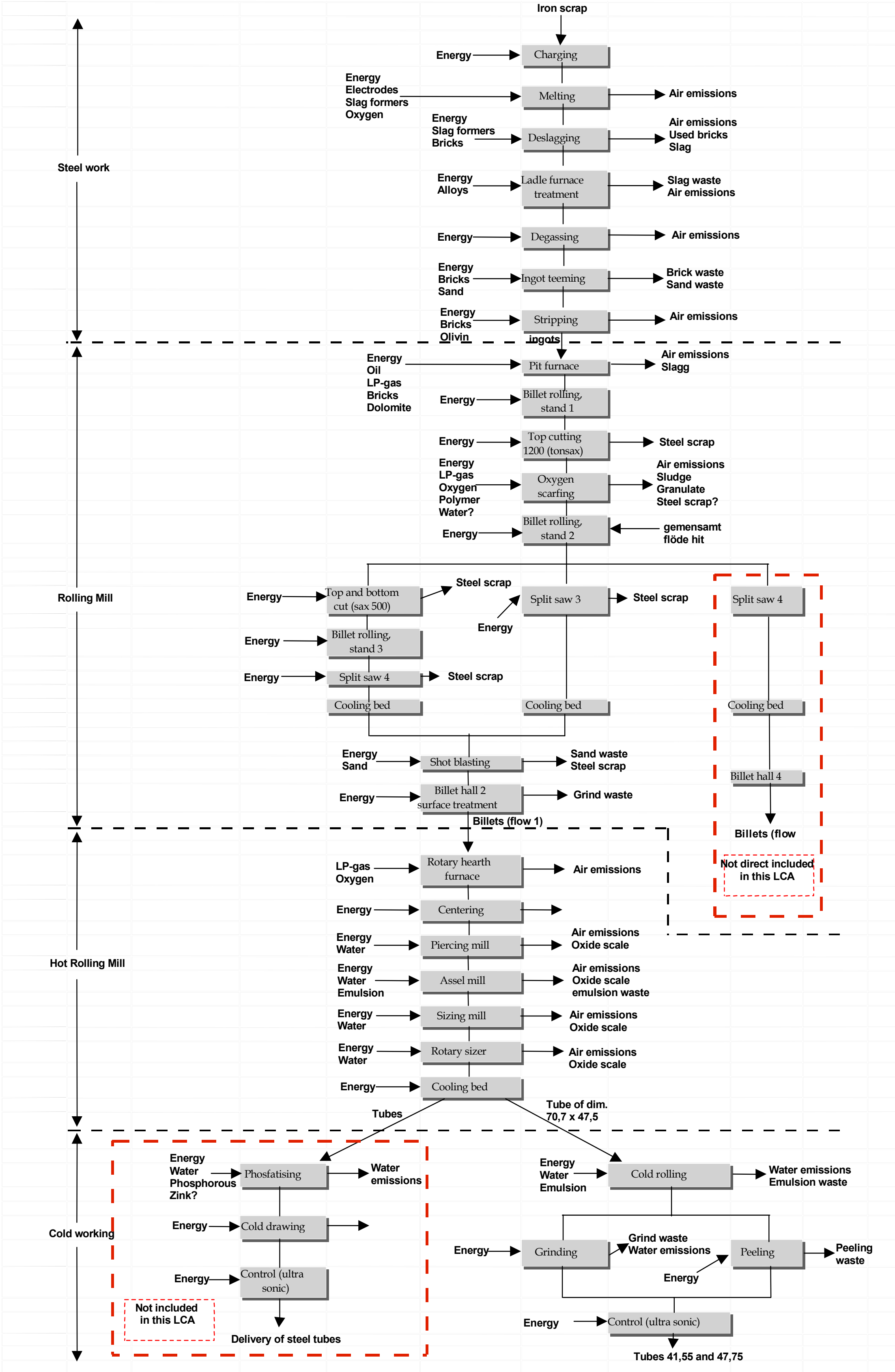

Figure 4.1) Flow chart for production of the studied steel tubes at Ovako Steel.

4.2 Transports of steel tubes from Hofors to Püttlingen

The steel tubes are transported by heavy truck and ferry from Hofors to Püttlingen [7] and the fuel is diesel. The total distances for the transports are:

- Heavy truck transports 1480 km (Hofors - Trelleborg + Travemünde - Püttlingen) [19, 20]
- Ferry transports 240 km (Trelleborg - Travemünde) [19, 20]

The LCI data for the transports of 1958 kg steel tubes can be seen in table C.1, appendix C. The reason for the weight 1958 kg is that 1958 kg tubes are required to manufacture 1000 kg plain bearings GE30.

4.3 Manufacturing of the plain bearing GE30 at SKF Gleitlager in Germany

4.3.1 Plant properties

At SKF Gleitlager plain bearings, bushings and rod ends are manufactured. The plain bearings stand for about 75% of the company turnover. The plain bearing manufacturing is separated from the production of bushings and rod ends in the plant. However, the process water and emulsions are treated in the same systems [7]. Therefor some allocations have been necessary to make.

4.3.2 Assumptions and limitations

The steel tubes they use for the production of GE30 1998 where as said before delivered by WRG. But as they are no longer the supplier, the data for steel tube production in this report is obtained from the new supplier, Ovako Steel. Therefor assumptions have been necessary to make. The dimension of the tubes from Ovako is not exactly the same as for the tubes from WRG. The steel tube input weight for manufacturing of one GE30 is about one percent less for the Ovako tubes than for the WRG tubes. This results in about one percent less steel loss and a little shorter manufacturing time for manufacturing of the GE30 from the Ovako tube. Since this will affect the total result very little, the assumption is that the steel loss and the manufacturing time is the same for the Ovako tubes as for the WRG tubes.

4.3.3 Process steps for GE30 production

The entire process chain with inputs and outputs for the processes included in the production of GE30, can be seen in figure 4.3 [16, 17]. An output of 1000 kg GE30 requires an input of 1958 kg steel tubes. Life cycle inventory data and allocation procedures for manufacturing of 1000 kg GE30 are presented in appendix D.

4.3.3.1 Turning

In the turning process a lot of neat cutting oil (ECOCUT 3032 LE) is applied on the tube surfaces continuously. Not all of the oil is collected properly, some of it ends up on the plant floor. The plant floor is therefor once a week filled with wood chips, which

4.3.3.1 Turning

In the turning process a lot of neat cutting oil (ECOCUT 3032 LE) is applied on the tube surfaces continuously. Not all of the oil is collected properly, some of it ends up on the plant floor. The plant floor is therefor once a week filled with wood chips, which absorb the cutting oil The wood chips are collected and sent to a district heating plant for combustion. The collected cutting oil goes together with the turning chips to an oil separator, figure 4.2.

In the oil separator the turning chips are separated from the cutting oil in three different mechanical filters. The cutting oil is used again for turning and the turning chips are recycled by a steel scrap recycling company. [7]

Some of the oil also follows the exhaust gases into the fan system. In the fan system the off gases first are cleaned with condensing and then with an electrostatic filter.

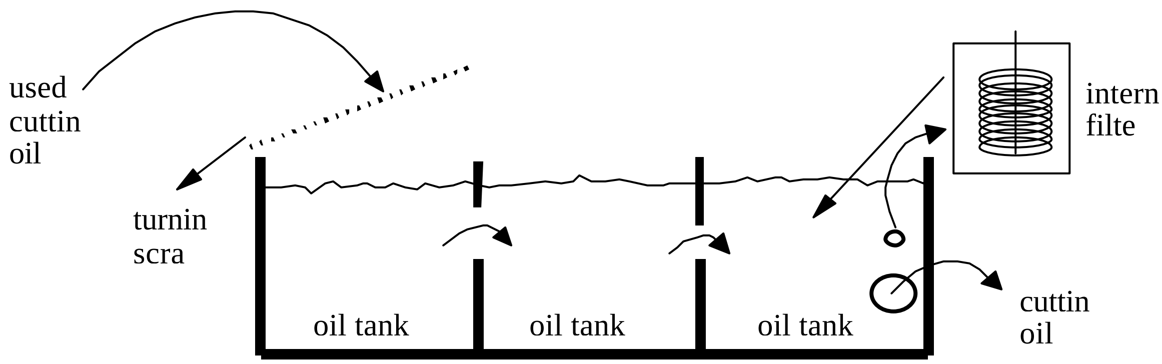

Figure 4.2) Oil separator for turning scrap and drilling chips.

4.3.3.2 Drilling of two lubrication holes and deepering

The next step in the production process is drilling and deepering. The reason for the drilling is that two lubrication holes are needed in the GE30 for bearing maintenance during the use. The bearings are lubricated during its use to reduce friction between the bearing surfaces and to extend the bearing lifetime. The deepening of the surface of the inner ring is for keeping the lubrication oil between the outer and inner ring. The drilling chips are collected and transported to the steel briquetting industry together with the turning chips and the grinding sludge. During the drilling a coolant (ECOCOOL SCIP) is added for the process. After separation from the drilling chips, the coolant is recycled and used again. This activity is not quantified for the study.

4.3.3.3 Washing

After drilling the rings pass on to the washing, water and chemicals are added into the washing tank. The outputs of this box are, as can be seen in figure 4.3, mist extraction, water emissions and oil waste. The water goes to the distillation plant and after the plant the concentrate will be waste oil and the distillate will mostly be water, which is used in the surface treatment (phosphating). The oil waste goes to oil separation and is then used again.

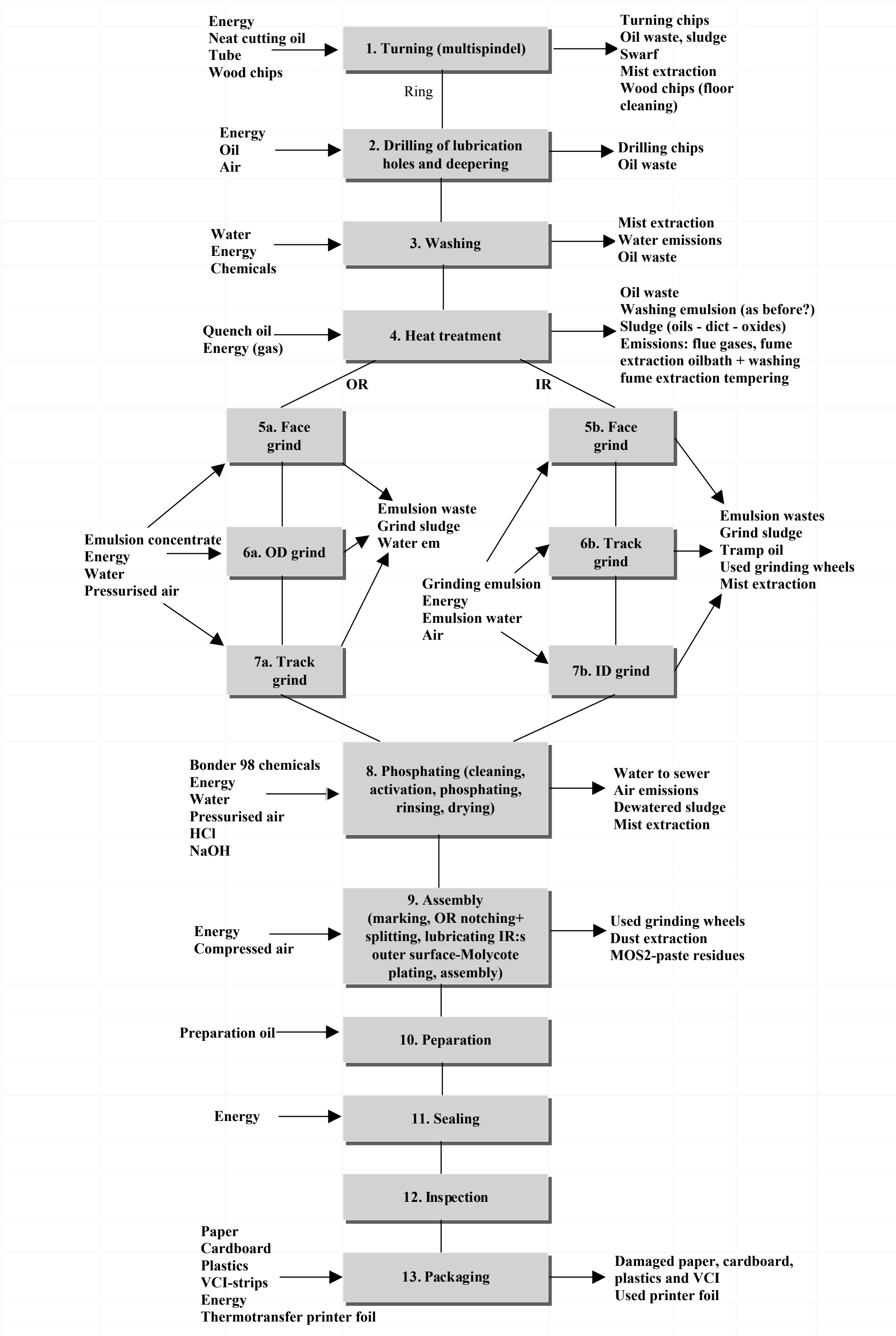

Figure 4.3) Flow chart for manufacturing of the plain bearing GE30 at SKF Gleitlager in Püttlingen. An output of 1000 kg GE30 from process 13 requires an input of 1958 kg steel tubes into process 1.

4.3.3.4 Heat treatment

Box 4 in figure 4.3 shows inputs and outputs for the heat treatment The process steps that are included in the heat treatment can be seen in figure 4.4. In the first step the rings are heated up to about 180ºC by combustion of natural gas. Then the rings are put in an oil bath for cooling; that is the hardening. The temperature of the quench oil (Isorapid 277 E) in the bath has to be held at about 70 ºC continuously. Therefor the oil bath is connected to an oil tank with thermostat and cooling system and the quench oil is then circulated between the bath and the tank. At the bottom of the oil tank sludge is formed, which is removed two times a year. The sludge is transported to a power plant for combustion.

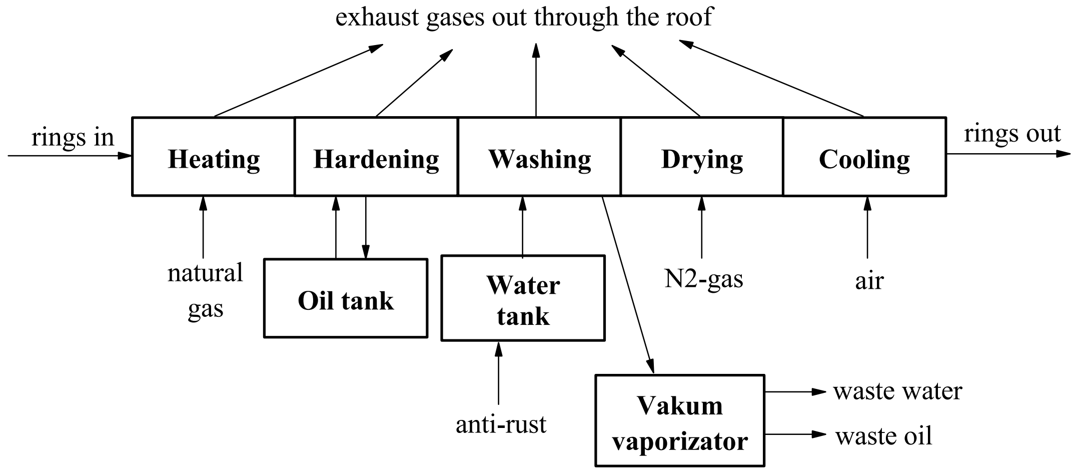

Figure 4.4) Process schedule for heat treatment of rings for plain bearings.

To remove the quench oil from the rings they are washed with water. But in order to prevent the rings from corrosion an anticorrit (P3-neutracare ®400) has to be added to the washing water. The used washing water goes to a vacuum vaporizator where the water is separated from the oil. For description of how the vacuum vaporizator works and where the wastewater and waste oil go see "Cleaning systems and recycling". After the washing the rings are dried with Nitrogen gas at a temperature of 140-150 ºC, before they are cooled down with air. At all five process steps the exhaust gases are led out through the roof without any cleaning. [7]

4.3.3.5 Grinding

The processes 5 to 7 all concerns different types of grinding and they are from an environmental point of view of input and output types basically the same process. Grinding stones are used together with a coolant, consistent of 95% water and 5% of the mineral oil Ecocool 1700 S. The grinding waste is dewatered in a press and then the grinding sludge is transported to the metal briquetting industry together with the turning and drilling waste. The water is transported to the central water tank.

4.3.3.6 Manganese phosphating

In order for the plain bearings to maintain the same properties until they are put in use their surfaces have to be protected. Therefor they are manganese phosphated in a multiple process, where a lot of chemicals are involved and therefor the environmental load is clearly significant. The process gives air and water emissions as well as waste sludge and wastewater.

4.3.3.7 Assembly

The next step is the assembly, where the outer ring is split and the inner ring is pressed into the outer. Then some of the bearings are Molycote plated at the outer rings inner surface and others are applied with rubbing in oil. This activity is not quantified for the study.

4.3.3.8 Packaging

The last step is the packaging and the packaging procedures for the GE30 are as follows:

- 50% in single pack (54x24x54 mm).
- 35% in cassettes with 60 bearings in each (269x182x84 mm).
- 15% in bulks with 10 parts in each (115x115x52 mm).

The single packaged bearings are first put in a plastic bag and then in a paper box. The bearing type and brand is printed on the box with thermotransfer printer foil. The cassettes are recycled and the bulks are plastics. This means that the packaging of each plain bearing in average requires half of a single pack box and 1,5% of a bulk. After packaging all plain bearings are sent to Schweinfurt and then straight to customers or to Brussels, where they keep stocks of bearings. This activity is not quantified for the study because it is considered to be of very little environmental significance to the result. [7]

4.3.4 Process water

The used process water that is not recycled is collected in a process water tank. When the water tank is filled an authorised company measure the content of certain substances in the water. They control that the content of the substances are under the limits of the German government water law. If the content is under the limits the water is sent to the communal wastewater treatment plant in the same industrial area (about 200 m) and if not, cleaning procedures have to be carried out. However that has never happened. The measured substances are Cr, Cu Ni, pH-value and moody. For SKF Gleitlager the critical substance is Chromium, but so far they have never exceeded the limit. [18]

4.4 Recycling of the plain bearing GE30

The plain bearing is as said before assumed to be recycled in closed loop, which means that the bearings are recycled and returned to the steel mill. Also recycled steel scrap from production of steel tubes and manufacturing of plain bearings are assumed to be recycled in closed loop. The amount of virgin iron consumed is assumed to be the same as all non recycled steel losses in the life cycle, which is 385 kg.

4.4.1 Allocation procedures for consumption of virgin iron during manufacturing of the conventional plain bearing

The steel tubes are produced exclusively from steel scrap. However, the amount of steel scrap on the market is not infinite. An increased consumption of steel scrap for steel tube production would probably mean that someone else has to use virgin iron instead. The problem is whether the steel scrap should be accounted as resource, taken from the biosphere, or as material input from the technosphere. The following allocations have been made for the iron consumption in the steel tube production:

- The steel flow in the life cycle of the plain bearing GE30 is somewhat considered as a closed circle. This means that the plain bearing, after use, is returned to Hofors for steel tube production. That also counts for the recyclable steel scrap during the steel tube production (e.g. end cut) and the plain bearing manufacturing (e.g. losses in turning). This flow is considered as material flow within the technosphere. All other steel losses during the life cycle are considered as a loss of steel from the scrap market. Therefor these losses are accounted for as consumption of virgin iron. The environmental load associated with extraction of iron ore and production of virgin iron will be included.

- Mass flow of steel in the GE30 life cycle:
  - 1530,5 kg steel scrap required for production of 1000 kg cold rolled steel tubes.
  - 387 kg recycled (back to the furnace).
  - The loss is therefor 143,5 kg from the steel tube production.
  - 1958 kg steel tubes required for production of 1000 kg GE30.
  - 854 kg recycled (from the turning process).
  - The loss from the GE30 manufacturing is therefor 104 kg.
  - 1,958*1530,5=2997 kg steel scrap required for production of 1000 kg GE30.
  - The relative loss from steel tube production: 143,5*1,958=281 kg.
  - 1000 kg GE30 back to steel production after use.
  - This results in a total loss of 104+281kg=385 kg steel or 12,85 % of the total amount of steel scrap required for the production of 1000 kg GE30.

- These 385 kg will be accounted as virgin iron in the GE30 life cycle.

That means 1530,5*0,1285=196,5 kg virgin iron and 1334 kg scrap for production of 1000 kg steel tubes.

5 Life cycle impact assessment for the plain bearing GE30, manufactured from steel tubes

In the impact assessment for this LCA study the phases classification, characterisation, weighting and data quality analysis has been included. The weighting has been carried out with three different ready-made weighting methods.

EPS - Environmental Priority Strategies (version EPS 2000)
EPS is an LCIA method based on willingness to pay. The impact unit for the weighting is one Environmental Load Unit (ELU), which corresponds to one ECU. The method was developed by *Steen and Ryding*, 1992. [2, 3]

ET - Environmental Themes (version ET 1999)
ET is instead of willingness to pay based on political goals in Sweden and Holland. The method used in this thesis is the Swedish version. The method is measured in Environmental Theme impact points (ET imp. pts). [3]

EDIP - Environmental Design of Industrial Products (version EDIP 1997)
The EDIP method is also based on political goals, but in Denmark. The impact unit for EDIP is Potential Effects (PE). [3]

The LCI data for the impact assessment can be seen in appendix. The following tables have been used:

- Table B.1 in appendix B. These data has been multiplied by a factor 1,958 because manufacturing of 1000 kg plain bearings requires 1958 kg steel tubes.
- Table C.1 in appendix C.
- Table E.2 in appendix E.

Also included in the LCI data for the impact assessment is electricity consumption. Environmental relevant inputs and outputs for extraction of energy carriers, production of energy carriers and electricity production have been added to the tables in appendix. For the steel tube production Swedish average electricity has been used and for plain bearing manufacturing German average has been used. The data has been obtained from the Spine database at Technical Environmental Planning at Chalmers University of Technology.

5.1 Classification

The impact categories decided upon for this thesis can be seen in table 5.1.

Table 5.1) List of impact categories from Nordic Guidelines on Life-Cycle Assessment, 1995.

Impact category
1. Resources - Energy and materials
4. Human health - Toxicological impacts (excluding work environment)
7. Global warming
8. Depletion of stratospheric ozone
9. Acidification
10. Eutrophication
11. Photochemical oxidant formation
12. Ecotoxicological impacts
14. Inflows which are not traced back to the system boundary between the technical system and nature
15. Outflows which are not traced back to the system boundary between the technical system and nature

The list is the same as the list in table 2.1 (section 2.1.2.3) except for categories 2, 3, 5, 6, 13, which have been excluded. Reasons for exclusion of these categories:

2). Resources – Water	No water stress in Sweden or Germany [21].
3). Resources – Land	No use of land.
5). Human health (non-toxicological impacts)	Only Human health (toxicological impacts) are included in this thesis.
6). Human health (impacts in working environment)	Only Human health (toxicological impacts) are included in this thesis.
13). Habitat alteration and impacts on biological diversity	Decided not to be relevant.

5.2 Characterisation

In this phase the potential contribution of inputs and outputs to the impact categories decided upon in the classification will be assessed. Not all of the impact categories are quantified and the reasons for that is:

- Inflows (cut-offs) The environmentally relevant inflows are all included in the characterisation. They are not all traced back to the cradle, but the once that are considered relevant are considered as resources from the technical system.

- Outflows (cut-offs) All air and direct water emissions are considered. Indirect water emissions that goes to the communal water cleaning system have not been quantified. This water is not considered to be of any relevance of the total environmental impact. Outflows which have been cut off and that can be of importance concerns different kinds of wastes. The only impact considered and quantified for waste is landfilled waste.

- Ozone depletion No contribution to depletion of stratospheric ozone by either of the two compared plain bearings.

5.2.1 Acidification

Table 5.2) Acidification potential. Characterisation factors from CML Guide [22].

Acidification (max)	**Substance**	**Environment**	**Quantity**	**Factor**	**Result**	**Unit**
	HCl	Air	1,90E-02	8,77E-01	1,67E-02	kg
Category indicator:	HF	Air	2,60E-02	1,60E+00	4,16E-02	kg
Acidification potential	NH_3	Air	4,60E-04	1,88E+00	8,65E-04	kg
	NO_x	Air	1,65E+01	6,96E-01	1,15E+01	kg
Unit:	SO_2	Air	4,50E+00	1,00E+00	4,50E+00	kg
kg SO_2-equivalents	SO_x	Air	1,60E-01	1,00E+00	1,60E-01	kg
	HNO_3	Water	1,40E-05	7,32E-01	1,02E-05	kg
	NH_3	Water	3,10E-05	1,88E+00	5,83E-05	kg
	NH_4NO_3	Water	1,00E-03	7,00E-01	7,00E-04	kg
	SO_2	Water	3,00E-02	1,00E+00	3,00E-02	kg
	SO_4^{2-}	Water	1,40E-04	6,53E-01	9,14E-05	kg
Total kg SO_2-equivalents					**1,62E+01**	**kg**

NO_x, SO_2 and SO_x are the main contributors to acidification potential. Together they stand for over 99 % of the total acidification potential.

Substance	***Emission source***
NO_x (total 16,5 kg)	10,6 kg from electricity production in Germany. 1,7 kg from truck transports, Hofors to Püttlingen. 2,4 kg steel tube production at Ovako in Hofors 1,2 kg plain bearing manufacturing in Püttlingen.
SO_x (total 0,16 kg)	All from steel tube production at Ovako in Hofors
SO_2 (total 4,5 kg)	3 kg from electricity production in Germany 1,3 kg from steel tube production at Ovako in Hofors

5.2.2 Ecotoxicity, aquatic

Table 5.3) Ecotoxicity aquatic potential. Characterisation factors from CML Guide [22].

Ecotoxicity, aquatic	**Substance**	**Environment**	**Quantity**	**Factor**	**Result**	**Unit**
	Oil	Water	7,46E+00	5,00E+01	3,73E+02	m^3
Category indicator:	Phenol	Water	6,79E-02	5,90E+03	4,00E+02	m^3
Ecotoxicity aquatic	As	Water	9,60E-04	2,00E+02	1,92E-01	m^3
potential	Cd	Water	7,40E-03	2,00E+05	1,48E+03	m^3
	Cr	Water	2,50E-02	1,00E+03	2,50E+01	m^3
Unit:	Cu	Water	5,30E-02	2,00E+03	1,06E+02	m^3
m^3 polluted water	Ni	Water	6,50E-02	3,30E+02	2,15E+01	m^3
	Pb	Water	2,10E-01	2,00E+03	4,20E+02	m^3
	Zn	Water	5,30E-02	3,80E+02	2,01E+01	m^3
Total, m^3 polluted water					**2,85E+03**	**m^3**

Cadmium (Cd) is the substance with the largest contribution to aquatic ecotoxicity potential, about half of the total. The emissions comes from the pickling process of hot rolled steel tubes, 7 mg, and from production of iron and extraction of iron ore, 0,4 mg. These two activities are also the sources for oil, phenol and lead emissions to water. The recipient for the substances released from the pickling process is Hoån.

5.2.3 Eutrophication

Table 5.4) Eutrophication potential. Characterisation factors from CML Guide [22] except BOD [23] and COD [23]

Eutrophication (max)	Substance	Environment	Quantity	Factor	Result	Unit
	NH_3	Air	4,60E-04	2,69E+00	1,24E-03	kg
Category indicator:	NO_x	Air	1,65E+01	1,00E+00	1,65E+01	kg
Eutrophication potential	BOD	Water	5,60E-02	1,69E-01	9,46E-03	kg
	COD	Water	1,50E-01	1,69E-01	2,54E-02	kg
Unit:	HNO_3	Water	1,40E-05	7,69E-01	1,08E-05	kg
kg NO_x-equivalents	NH_3	Water	3,10E-05	2,69E+00	8,34E-05	kg
	NH_4NO_3	Water	1,00E-03	7,69E-01	7,69E-04	kg
	Tot-N	Water	2,60E-02	3,23E+00	8,40E-02	kg
	Tot-P	Water	1,90E-04	2,35E+01	4,47E-03	kg
Total kg NO_x –equivalents					**1,66E+01**	**kg**

NO_x is by far the main contributor to potential eutrophication. Alone it stand for over 99% of the total eutrophication potential.

Emission source: see acidification section 5.2.1

5.2.4 Global Warming

Table 5.5) Global warming potential. Characterisation factors from IPPC [24].

Global Warming (100 years)	Substance	Environment	Quantity	Factor	Result	Unit
	CH_4	Air	1,30E+00	2,10E+01	2,73E+01	kg
Category indicator:	CO	Air	7,30E+00	3,00E+00	2,19E+01	kg
Global warming potential	CO_2	Air	6,22E+03	1,00E+00	6,22E+03	kg
	HC	Air	2,45E+00	1,10E+01	2,70E+01	kg
Unit:	N_2O	Air	4,40E-03	3,10E+02	1,36E+00	kg
kg CO_2-equivalents	NO_x	Air	1,65E+01	7,00E+00	1,16E+02	kg
	PAH	Air	3,00E-04	1,10E+01	3,30E-03	kg
	BOD	Water	5,60E-03	2,29E+00	1,28E-02	kg
	COD	Water	1,50E-01	2,29E+00	3,44E-01	kg
Total kg CO_2-equivalents					**6,41E+03**	**kg**

CO_2 is the dominating substance in this impact category with about 97% of the total global warming potential.

Emission source

3 650 kg	Electricity production in Germany
1 230 kg	Plain bearing manufacturing in Germany
1 120 kg	Steel tube production at Ovako in Hofors

5.2.5 Human toxicity

5.2.5.1 Air

Table 5.6) Human toxicity potential, Air. Characterisation factors from CML Guide [22].

Human toxicity, Air	Substance	Environment	Quantity	Factor	Result	Unit
	CO	Air	7,32E-06	1,20E-02	8,79E-08	kg
Category indicator:	F-	Air	1,50E-09	4,80E-01	7,20E-10	kg
Human toxicity potential,	HF	Air	2,60E-08	4,80E-01	1,25E-08	kg
Air	NO_x	Air	1,65E-05	7,80E-01	1,29E-05	kg
	SO_2	Air	4,49E-06	1,20E+00	5,39E-06	kg
Unit:	SO_x	Air	1,60E-07	1,20E+00	1,92E-07	kg
kg contaminated	Dioxines	Air	7,00E-12	3,30E+06	2,31E-05	kg
bodyweight	PAH	Air	2,90E-10	1,70E+01	4,93E-09	kg
	As	Air	6,70E-11	4,70E+03	3,15E-07	kg
	Cd	Air	4,90E-12	5,80E+02	2,84E-09	kg
	Co	Air	3,10E-12	2,40E+01	7,44E-11	kg
	Cr	Air	1,70E-10	6,70E+00	1,14E-09	kg
	Cu	Air	7,70E-11	2,40E-01	1,85E-11	kg
	Fe	Air	6,70E-08	4,20E-02	2,81E-09	kg
	Hg	Air	5,90E-11	1,20E+02	7,08E-09	kg
	Mn	Air	1,20E-11	1,20E+02	1,44E-09	kg
	Ni	Air	9,60E-11	4,70E+02	4,51E-08	kg
	Pb	Air	2,30E-10	1,60E+02	3,68E-08	kg
	V	Air	1,80E-10	1,20E+02	2,16E-08	kg
	Zn	Air	1,70E-09	3,30E-02	5,61E-11	kg
	SO_2	Water	3,00E-08	1,20E+00	3,60E-08	kg
Total, kg contaminated bodyweight					**4,22E-05**	**kg**

Dioxin and NO_x emissions are the two substances with the largest contribution for this category.

Emission source:
NO_x see section 5.2.1
Dioxin All from the production of steel billets at the Ovako steel mill in Hofors.

5.2.5.2 Water

Table 5.7) Human toxicity potential,Water. Characterisation factors from CML Guide [22].

Human toxicity, Water	Substance	Environment	Quantity	Factor	Result	Unit
	F-	Water	5,90E-03	4,10E-02	2,42E-04	kg
Category indicator:	HNO_3	Water	1,40E-05	7,80E-04	1,09E-08	kg
Human toxicity potential,	Oil	Water	7,46E-03	9,20E-04	6,86E-06	kg
Water	Phenol	Water	6,79E-05	4,80E-02	3,26E-06	kg
	Tot-CN	Water	1,30E-04	5,70E-02	7,41E-06	kg
Unit:	Tot-P	Water	1,90E-04	4,10E-05	7,79E-09	kg
kg contaminated	As	Water	9,60E-07	1,40E+00	1,34E-06	kg
bodyweight	Cd	Water	7,40E-06	2,90E+00	2,15E-05	kg
	Cr	Water	2,50E-05	5,70E-01	1,43E-05	kg
	Co	Water	1,50E-06	2,00E+00	3,00E-06	kg
	Cu	Water	5,30E-05	2,00E-02	1,06E-06	kg
	Fe	Water	2,70E-03	3,60E-03	9,72E-06	kg
	Ni	Water	6,50E-05	5,70E-02	3,71E-06	kg
	Pb	Water	2,10E-04	7,90E-01	1,66E-04	kg
	Zn	Water	5,30E-05	2,90E-03	1,54E-07	kg
Total, kg contaminated bodyweight					**4,80E-04**	**kg**

Fluoride ions (F-), Lead (Pb) and Cadmium (Cd) are the substances with the highest contribution to this category.

Substance	*Emission source:*
Cadmium	All from steel tube production; 6,4 mg from pickling at Ovako and 0,7 mg from production and extraction of raw materials.
Fluoride	All from steel tube production; all from production and extraction of raw materials.
Lead	All from steel tube production; 190 mg from pickling at Ovako and 22 mg from production and extraction of raw materials.

5.2.6 Photochemical oxidant creation

Table 5.8) Photochemical oxidant creation potential. Characterisation factors from CML Guide [22] except CO [25].

Photochemical oxidant creation (0-4 days high NO_x)	Substance	Environment	Quantity	Factor	Result	Unit
Category indicator:	CH_4	Air	1,31E+00	7,00E-03	9,17E-03	kg
POCP	CO	Air	7,32E+00	3,20E-02	2,34E-01	kg
Unit:	HC	Air	2,45E+00	4,16E-01	1,02E+00	kg
kg ethene-equivalents	VOC	Air	2,30E-01	3,77E-01	8,67E-02	kg
Total, kg ethene equivalents					**1,35E+00**	**kg**

The substance with the highest contribution for potential photochemical oxidant creation is HC.

Emission source: 2,18 kg from electricity production in Germany.

5.2.7 Resource depletion (Reserve-based)

The reserve base is defined as that part of an identified resource that meets minimum physical and chemical criteria related to current mining and production practices. In that approach, the weighting factor is defined as the inverse of the reserve base [26]

Wij = 1 / Rij

Table 5.9) Resource depletion potential. Characterisation factors from CML Guide [22] except for bauxite [27] and iron [27].

Resource depletion (Reserve based)	Substance	Environment	Quantity	Factor	Result	Unit
	Coal	Resource	2,33E+03	7,00E-16	1,63E-12	kg
Category indicator:	Crude oil	Resource	1,94E+02	8,09E-15	1,57E-12	kg
Abiotic resource depletion	LP-gas	Resource	1,89E+02	9,15E-15	1,73E-12	kg
potential, reserve base	Natural gas	Resource	4,33E+02	9,15E-15	3,96E-12	kg
	Oil	Resource	1,53E+01	8,09E-15	1,24E-13	kg
	Uranium (as pure U)	Resource	3,50E-02	5,96E-10	2,09E-11	kg
Unit:						
kg reservebase-1	Bauxite	Resource	1,82E+01	1,19E-14	2,17E-13	kg
	Copper ore [0,35 % Cu]	Resource	7,80E+00	1,03E-14	8,03E-14	kg
	Cr	Resource	4,30E+01	1,68E-12	7,22E-11	kg
	Fe	Resource	3,10E+01	1,32E-14	4,09E-13	kg
	Iron ore	Resource	1,06E+03	4,35E-15	4,60E-12	kg
Total					**1,07E-10**	**kg**

Chromium (Cr) and Uranium are the substances that contributes most to this impact category. Together they stand for about 95% of the total resource depletion potential.

Substance	***Emission source:***
Cr	All from steel tube production
Uranium	1,25E-11 kg from electricity production in Germany.
	0,85E-11 kg from electricity production in Sweden.

5.2.8 Characterisation summary

In figure 5.1 the characterisation for all eight impact categories considered in this thesis can be seen divided between the activities steel tube production, steel transport and plain bearing manufacturing. The upper block of each impact category is with electricity production included. It is difficult to draw the conclusion that one activity contributes to more environmental impacts than another by studying the figure. Therefor it is interesting to see what processes within each activity that contributes to most potential environmental impacts.

For the plain bearing manufacturing almost all impact for all eight categories come from electricity production in Germany. The processes of most importance for steel tube production within each impact category can be seen in table 5.10. The environmental impacts from electricity production are included.

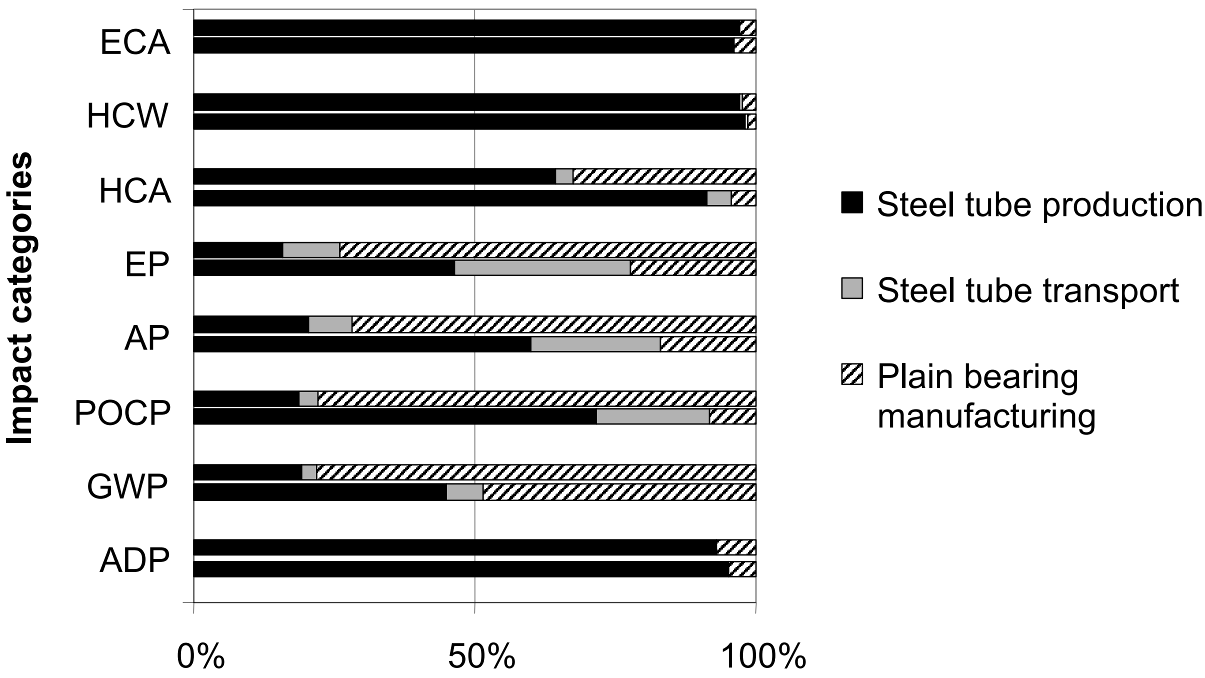

Figure 5.1) Characterisation for all eight impact categories considered in this thesis. The upper block of each impact category is with electricity production included.

Table 5.10) Processes for the steel tube production with major influence on each impact category, electricity production included.

Impact category	**Processes with major importance**
Ecotoxicity Aquatic potential	50% from pickling and 45% from acquisition of metal ore
Human toxicity potential Water	55% from acquisition of metal ore and 40% from pickling
Human toxicity potential Air	Almost all from dioxin emissions at the steel mill
Eutrophication Potential	30% from raw material production, 10% from electricity production, 18% each from steel mill and rolling mill, 15% from heat treatment and 10% from tube mill 5
Acidification Potential	55% from raw material production, 7% from electricity production, 14% from the rolling mill, 10% from the steel mill, 8% from heat treatment and 6% from tube mill 5
Photochemical Oxidant Creation Potential	Almost all from electricity production
Global Warming Potential	31% from raw material production, 14% from electricity production, 20% from the steel mill, 15% from tube mill 5 and 10% each from rolling mill and heat treatment
Abiotic resource Depletion Potential	Almost all from the use of Chromium as a resource

5.3 Weighing results

In the weighting inputs and outputs from the inventory have been weighed against each other depending on how much of the total environmental impact they contribute with. Hence, the substances that are considered to have the highest environmental impact have the highest weighing factors for each weighting method. To calculate the total environmental impact, these weighting factors are multiplied with the amount of the corresponding substance flow and then all products are summoned up [4]. Emission factors and resource consumption for electricity production are included in the weighting calculations.

5.3.1 EPS

In table 5.11 weighting results for the life cycle of 1000 kg plain bearings GE30 with the EPS method are presented. The substance that contributes to most environmental impact is the use of Chromium (68,1%) as a resource followed by CO_2 emissions (12,5%) and the use of natural gas as a resource (8,9%).

Table 5.11) Weighing results for manufacturing of 1000 kg plain bearings GE30. The relative contribution to the total environmental impact is also included.

Substance	kg/ton plain bearings	ELU/kg	ELU/ton plain bearings	% of total ELU
Coal (r)	2 330	0,05	117	2,2%
Crude oil (r)	193	0,5	97	1,8%
Natural gas (r)	433	1,1	476	8,9%
Cr (r)	43	85	3 650	68,1%
Fe (r)	31	0,961	30	0,6%
Iron ore (r)	1 060	0,2244	237	4,4%
CO_2	6 220	0,108	672	12,5%
NO_x	16,5	2,13	35	0,7%
PAH (a)	0,0003	64 300	19	0,3%
Total			**5 333**	**99,5%**

To see if resource use, emissions or waste gives the highest contribution to the total environmental load, the weighing results are divided into impact groups.

Table 5.12) Relative contribution to the total environmental impact for different impact groups for production of 1000 kg plain bearings GE30.

Impact Group	ELU/ton GE30	% of total ELU
Energy Resources	689	13%
Material Resources	3 920	73%
Air emissions	726	14%
Water emissions	≈0	<0,1%
Waste	≈0	<0,1%
Total	**5 333**	**100%**

When comparing the different impact groups the material consumption show to be the main contribution to the total environmental impact.

5.3.2 Environmental Themes

In table 5.13 weighting results for the life cycle of 1000 kg plain bearings GE30 with the Environmental Themes method are presented. The substance that contributes to most environmental impact is landfilled waste (55,8%) followed by NO_x emissions (15,8%) and dioxine emissions (9,2%).

Table 5.13) Weighing results for manufacturing of 1000 kg plain bearings GE30. The relative contribution to the total environmental impact is also included.

Substance	**g/ton plain bearings**	**ET impact points/g**	**ET imp pts/ton plain bearings**	**% of total ET imp pts**
Natural gas (r)	432 600	0,006354	2 750	0,2%
Cr (r)	43 000	1,167	50 170	4,0%
Iron ore (r)	1 058 000	0,003	3 200	0,3%
CO_2	6 221 000	0,016	99 700	7,9%
NO_x	16 530	11,98	198 000	15,8%
SO_2	4 494	10,84	48 700	3,9%
Dioxines	0,007	16 500 000	115 500	9,2%
Cd (aq)	0,0074	561 812	4 160	0,3%
Waste, landfilled	560 100	1,25	700 100	55,8%
Total			**1 222 000**	**97,3%**

To see if resource use, emissions or waste gives the highest contribution to the total environmental load, the weighing results are divided into impact groups.

Table 5.14) Relative contribution to the total environmental impact for different impact groups for production of 1000 kg plain bearings GE30.

Impact group	**ET impact pts/ton GE30**	**% of total ET impact pts**
Energy resources	2 750	0,2%
Material resources	53 400	4,4%
Air emissions	461 900	38%
Water emissions	4 160	0,3%
Waste	700 100	57%
Total	**1 222 000**	**100%**

Waste appear to be the main contributor to the total environmental impact.

5.3.3 EDIP

In table 5.15 weighting results for the life cycle of 1000 kg plain bearings GE30 with the EDIP method are presented. The substance that contributes to most environmental impact is the dioxine emissions (63,6%) followed by the use of coal (14,4%) and natural gas (13,8%) as resources.

Table 5.15) Weighing results for manufacturing of 1000 kg plain bearings GE30. The relative contribution to the total environmental impact is also included.

Substance	g/ton plain bearings	PE/g substance	PE/ton plain bearings	% of total PE
Coal (r)	2 332 000	0,00001	23	14,4%
Crude oil (r)	193 500	3,9E-05	7,5	4,6%
Natural gas (r)	432 600	5,2E-05	22	13,8%
Oil (r)	15 300	3,9E-05	0.60	0,4%
Fe (r)	31 000	8,5E-05	2.6	1,6%
CO_2	6 221 000	1,49E-07	0,93	0,6%
Dioxines	0,007	14 771	103	63,6%
Fe	67	0,00587	0.39	0,2%
Hg	0,059	6,405	0.38	0,2%
Total			**163**	**99,5%**

To see if resource use, emissions or waste gives the highest contribution to the total environmental load, the weighing results are divided into impact groups.

Table 5.16) Relative contribution to the total environmental impact for different impact groups for production of 1000 kg plain bearings GE30.

Impact group	PE/ton GE30	% of total PE
Energy resources	53	33%
Material resources	3,2	2%
Air emissions	105	65%
Water emissions	≈0	<0,1%
Waste	≈0	<0,1%
Total	**162**	**100%**

Air emissions give the main contribution to the total environmental impact for the plain bearing.

5.3.4 Summary of weighting results for all three methods

In figure 5.2 the weighting results have been divided into different activities for all three methods. Steel tube production contributes to most environmental impacts according all three weighting methods used, both with and without electricity emission factors.

In figure 5.3 the relative contribution to the total environmental impact for different impact groups with all three weighting methods can be seen. The main contributor to the environmental load for the EPS method is clearly material resources and mainly Chromium. For Environmental Themes the main contributor is waste (slag from the steel mill) and for EDIP air emissions (dioxin from the steel mill).

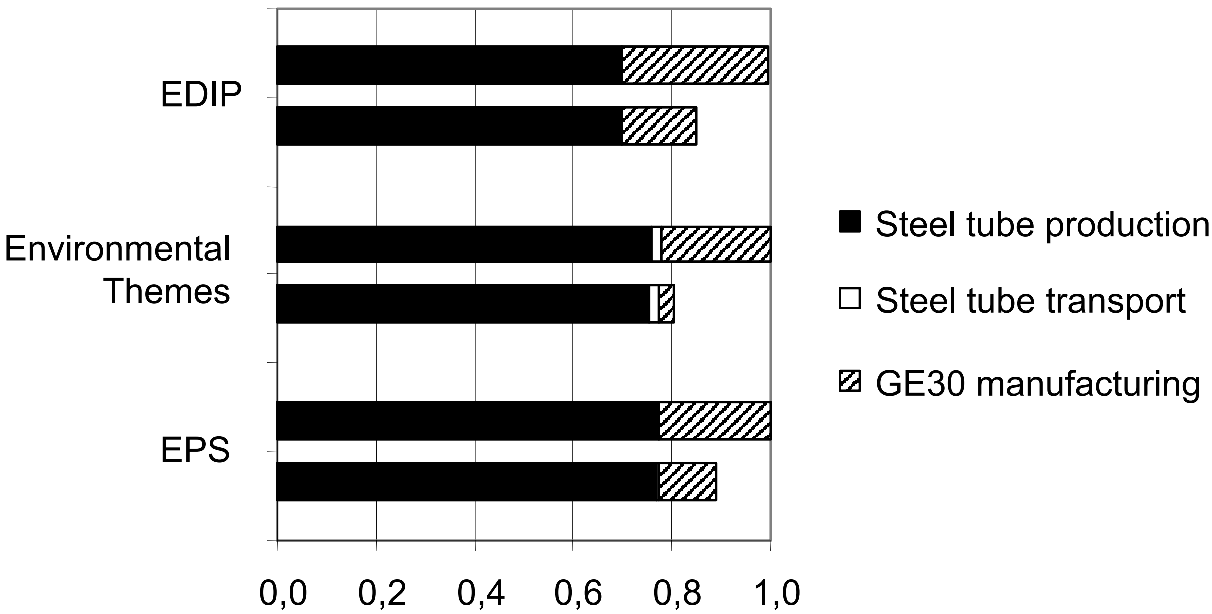

Figure 5.2) Weighting results for all three weighting methods, with and without electricity emission factors included.

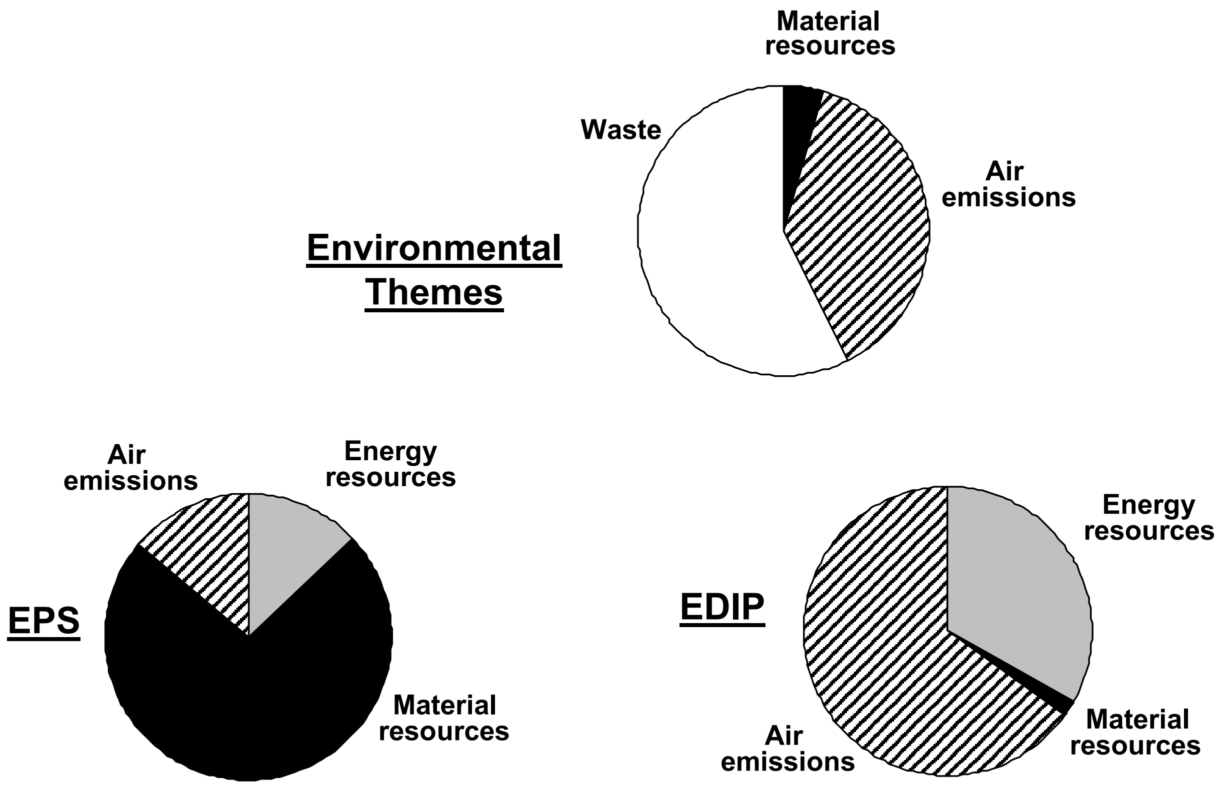

Figure 5.3) Relative contribution to the total environmental impact for different impact groups with all three weighting methods can be seen.

6 Life cycle inventory analysis for energy consumption

Impact assessments with weighting methods are normative because the basis for the methods are different, some methods focus more on resources and some on emissions [4]. In this section the raw data in the inventory, regarding energy consumption and air emissions, is compared for the different processes.

Table 6.1) The energy consumption in kWh for manufacturing of 1000 kg of the plain bearing GE30 from steel tubes. For the manufacturing process 1958 kg steel tubes is required. Therefore the data for tube production in table B.1 (appendix B) has been multiplied by 1,958.

Energy ware	**Tube prod. (1958 kg)**	**Tube trsp (1958 kg)**	**Plain Bearing man (1000 kg)**	**Total (1000 kg)**
Fuel oil	507	44	224	775
Natural gas	33	1	6 155	6 189
LP gas	2 410			2 410
District heating	323			323
Steam	582			582
Electricity	2 884		5 867	8 751
Total fossil fuel	2 950	45	6 379	9 374

In table 6.1 the energy consumption for the life cycle of 1000 kg GE30 is presented. The consumption of both electricity and fossil fuel is about twice as high for the GE30 manufacturing than for the steel tube production. The consumption of 44 kWh light fuel oil for steel tube transports comes from production of diesel.

Table 6.2) Air emissions in kg for manufacturing of 1000 kg of the plain bearing GE30 from steel tubes. For the manufacturing process 1958 kg steel tubes is required. Therefore the data for tube production in table B.1 (appendix B) has been multiplied by 1,958.

Substance	**Tube prod. (1958 kg)**	**Tube trsp (1958 kg)**	**Plain Bearing man (1000 kg)**	**Total (1000 kg)**
CO_2	1 096	149	1229	2474
CO	0,39	0,2	0,44	1,03
NO_x	2,35	1,7	1,2	5,25
SO_2	1,31	0,05	0,08	1,44

Table 6.3) Same as table 6.2 but with electricity emission factors included..

Substance	**Tube prod. (1958 kg)**	**Tube trsp (1958 kg)**	**Plain Bearing man (1000 kg)**	**Total (1000 kg)**
CO_2	1176	149	4 882	6200
CO	2,7	0,2	3,8	6,7
NO_x	2,5	1,7	12	16,2
SO_2	1,35	0,05	3,1	4,5

In table 6.2 the activity with the highest air emissions differs depending on the substance. However, with electricity emission factors included in table 6.3 the GE30 manufacturing contributes to much higher amount of air emissions.

7 Interpretation

In the characterisation, without electricity emission factors, steel tube production gives the highest environmental impact for almost all impact categories as can be seen in figure 5.1. The only potential impact which is higher for the plain bearing manufacturing is the global warming potential. However, the difference is very small.

With electricity emission factors included in the characterisation, the plain bearing manufacturing give the highest potential environmental impact for the categories eutrophication, acidification, photochemical oxidant creation and global warming. The categories with higher potential impact for steel tube production are resource depletion and the three categories regarding toxicity.

In table 5.10 it can be seen that acquisition of raw material and production of electricity are main contributors to potential environmental impacts for many categories. Hence, many of the potential environmental impacts are not direct but indirect connected to the production of plain bearings.

In figure 5.2 it can be seen that the steel tube production has a significantly higher impact on the environment for all three weighting methods. This is also the case when emissions and resource use for electricity production is included.

It may seem odd that with electricity emission factors included, the weighting methods show higher environmental impact for steel tube production when the characterisation does not seem to show the same result. The reason for this is that a few substances within each weighting method can be of major importance. This can be seen in tables 5.11, 5.13 and 5.15. One single substance for each weighting method is of great importance:

- EPS – Chromium as a resource is 68% of the total ELU
- Environmental Themes – Waste is 56% of the total ET impact points
- EDIP – Dioxin is 64% of the total PE

When looking at the energy consumption in table 6.1 it can be seen that the consumption is about twice as high for plain bearing production than for steel tube production. That holds for both fossil fuel and electricity consumption. Therefor it is not very strange that the emissions are higher as well. Especially when as much as 80% of the electricity in Germany is produced with fossil fuel.

8 Conclusions and recommendations

In the goal definition a main purpose was stated. However it is not very easy to draw any clear conclusions about which activities that give the highest environmental impacts. Instead it may be more interesting to study the total result and see what can be done to reduce the total environmental impact. Hence, where to put in the effort for best result. Therefore it is very interesting that the different impact groups in tables 5.12, 5.14 and 5.16 are of such major importance for the different weighting methods:

- EPS: Material Resources stand for 73% of the total ELU
- Environmental Themes: Waste stand for 57% of the total ET impact points
- EDIP: Air emissions stand for 65% of the total PE

How do we decide which method that is best to use when calculating the total environmental impact? Do we really have to know that? The bases for the methods are different so why not look at all three and see what processes to change if we want to decrease them all. Here follows a few proposals and recommendations for further studies:

1. For the EPS method the resource consumption of Chromium is the factor that affects the result most. To reduce this one has to study the recycling process. It may be possible to recycle Chromium alloyed steel scrap to produce new Chromium alloyed products.

2. For the Environmental Themes method landfilled waste is of major importance for the total result. Projects for using the waste as resources instead of dumping it is ongoing at Ovako Steel continuously. The slag waste from steel production can be used as fillings when building roads. The problem is that the slag contains a lot of metal oxides so it has to be shown that the leakage is acceptable.

3. The substance of greatest importance for the total environmental impact when using the EDIP method for weighting is dioxin emissions. Dioxin is a very toxic gas and not wanted either around humans or in the environment. The dioxin emissions, 3,6 mg, comes from the steel production in the steel mill at Ovako. It is recommended that all possibilities for reducing this emission are investigated and taken into consideration.

However, one has to be careful when conclusions about the result are made because there are a few problems regarding data quality. The study is a cradle to gate study and two activities that could be of importance for the result are excluded. One of them, transports from SKF Gleitlager to dealers and customers, would probably not affect the result much. But the use of the plain bearings could be of major importance for the result. In most applications the GE30 is lubricated with oil every now and then. If a lot of oil is used for the lubrication, this could affect the result a great deal.

Another problem could be that not all flows are traced back to the cradle or followed to the grave. This could of cause affect the result as well. The only input flows of magnitudes high enough to possibly affect the result are production of H_2SO_4 (30 kg) or N_2 (410 kg). Production of 30 kg H_2SO_4 only requires about 15 kg FeS_2 (pyrite), 7 kg

O_2 and heat. Pyrite is the most common sulphide mineral and is used for both sulphur and iron production. Compared to almost 1100 kg iron ore required for production of 1000 kg GE30, 15 kg of pyrite would make very little difference to the result. The production of N_2 would not affect the result either.

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Appendices

Flow charts, allocation procedures and LCI data

Appendix A

Flow chart, life cycle inventory data and allocation procedures for production of cold worked steel tubes at Ovako Steel AB in Hofors, Sweden. All data from 1998.

The processes included in the production of the studied tubes are:

- **Steel ingot production at the Steel Mill**
- **Steel billet production in the Hot Rolling Mill**
- **Production of hot rolled steel tubes at Tube Mill 5**
- **Pickling of hot rolled tubes**
- **Heat treatment of hot rolled tubes**
- **Cold rolling of steel tubes**

Production of steel ingots at the Steel Mill

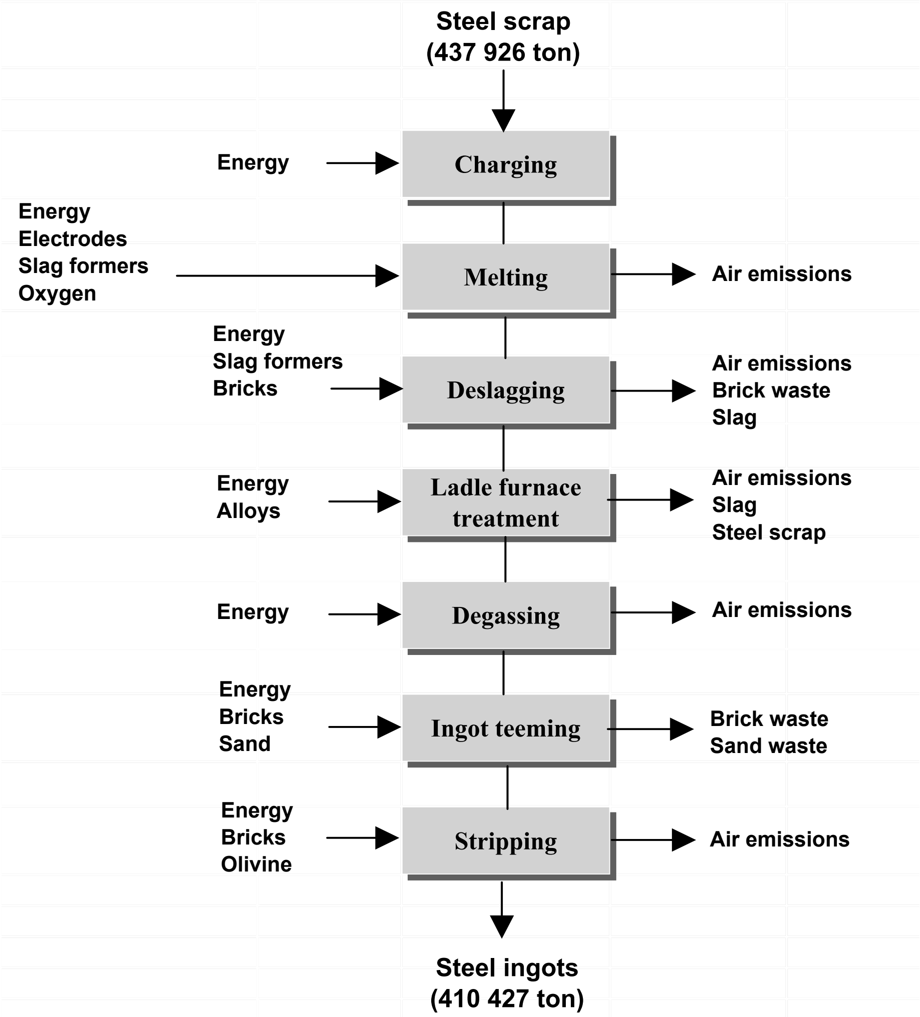

Figure A.1). Flow chart for the production of steel ingots at Ovako Steel. Some of the most important environmental inputs and outputs are represented.

Table A.1). Life cycle inventory data for the Steel Mill at Ovako Steel AB, as recived from Ola Stuffe at the Steel Mill. Some of the data is related to the production of 1000 kg steel ingots and others given as annual amounts (1998). The total weight of steel ingots produced 1998 was 410 427 kg.

Activity	Substance	Input quantity	Output quantity	Unit	Supplier	Ends up	Data type	Provider of information	Comments
Scrap yard	*Scrap*	383		kg/ton		ingot, scrap, slag	A	R. Wiklund	own scrap
	Thin plate with zn	77		kg/ton		ingot, scrap, slag	A	R. Wiklund	
	Fragmented scrap	117		kg/ton		ingot, scrap, slag	A	R. Wiklund	
	Grinding waste	10		kg/ton		ingot, scrap, slag	A	R. Wiklund	own waste
	Rusor	58		kg/ton		ingot, scrap, slag	A	R. Wiklund	
	Other scrap	422		kg/ton		ingot, scrap, slag	A	R. Wiklund	
	Scrap, total	1067		kg/ton					
Arc furnace	*Brick, furnace*	317		ton/yr	Misc		A	T. Lindmark	
	Brick, other	151		ton/yr	Misc	Deposited	A	T. Lindmark	
	Brick, other		151	ton/yr	Misc	Deposited	A	T. Lindmark	same amount out as in
	Magnesite	952		ton/yr	Misc	Deposited	A	T. Lindmark	
	Magnesite		952	ton/yr	Misc	Deposited	A	T. Lindmark	same amount out as in
	Natural sand	1 470		ton/yr	Misc	slag	A	T. Lindmark	
	Oxygen gas	12 500 406		m³/yr	AGA	slag, off gases	A	T. Lindmark	21°C
	Light fuel oil	291		m³/yr	Shell	off gases	A		
	Electricity	486		kWh/ton			A		
	NOx		148	g/ton		off gases	Measured	IMKAB	
	Dust/particles		18	kg/ton		Deposited	Measured	IMKAB	
	Dust/particles		0,0086	kg/ton		off gases	Measured	IMKAB	
	Carbon	0,17		kg/ton		slag, deposited	Measured	IMKAB	
	Slag, furnaces		98	kg/ton		deposited	Calculated	Asok	
	Al, bars	1		kg/ton		in the steel	A		
	Electrodes	3		kg/ton		slag, dust, off gases	A		
	Lime stone	34		kg/ton		slag, dust, off gases	A		
	Antracite	14		kg/ton		slag, dust, off gases	A		
Skänkugn-skänkar	*Brick, furnace*	1 177		ton/yr		back to supplier for recycling	A		
	Magnesite, taphole	116		ton/yr		deposited	A		
	Magnesite, taphole		116	ton/yr		deposited	A		same amount out as in
	Brick, other	18		ton/yr		back to supplier for recycling	A		
	Magnesite, other	421		ton/yr		deposited	A		
	Magnesite, other		421	ton/yr		deposited	A		same amount out as in
	Steam	41		kg/ton		water, off gases	A	Sölve Hagman	
	Dust/particles		0,25	kg/ton		deposited	Measured	IMKAB	
	Dust/particles		0,0021	kg/ton		off gases	Measured	IMKAB	
	Scrap		31,04	kg/ton		scrap yard	Measured		melted again
	Limestone	4		kg/ton		slag	Measured	R. Wiklund	
	Alumet		2	kg/ton		slag	Measured	R. Wiklund	
	Coal	5		kg/ton		in the steel	Measured	R. Wiklund	
	Al, wire	0,27		kg/ton		in the steel	Measured	R. Wiklund	
	Silicon 17 103	4,68		kg/ton		in the steel	Measured	R. Wiklund	
	Chromium 17 215	14,16		kg/ton		in the steel	Measured	R. Wiklund	
	Chromium 17 220	1,03		kg/ton		in the steel	Measured	R. Wiklund	
	Electricity	28		kWh/ton			A		
Gjuthall	*Kokills*	11		kg/ton		back to supplier for recycling	Measured		
	Dust/particles		0,0567	kg/ton		off gases	Measured		
Stripper/ beredning	*Dust/particles*		0,0887	kg/ton		off gases			
	Brick	1803		ton/yr		deposited	Unspecified	T. Lindmark	
	Brick		1803	ton/yr		deposited	Unspecified	T. Lindmark	same amount out as in
	Magnesite	56		ton/yr		deposited	Unspecified	T. Lindmark	
	Magnesite		56	ton/yr		deposited	Unspecified	T. Lindmark	same amount out as in
	Olivine	3310		ton/yr		deposited	Unspecified	T. Lindmark	
	Olivine		3310	ton/yr		deposited	Unspecified	T. Lindmark	same amount out as in
Övrigt	*Industrial water*	13 837 491		kbm/år		Hoån			
	Drinking water	45 266		kbm/år		Hoån			

A) Economical information, purchased quantity.

Allocation procedures for production of steel ingots:

- The total production of steel ingots 1998 was 410 427 ton. Since 1067 kg steel scrap is needed for production of 1000 kg steel ingot, 437 926 ton steel scrap was consumed.
- All steel ingots go through the same production channel.
- The environmental data (inputs and outputs) for the processes will be related to production of 1000 kg steel billets.
- For simplicity the specific alloys in the different steel types has not been taken into consideration. Instead, it was assumed that the alloys in the different steel types produced at Ovako Steel are shared equally between the steel types.
- Therefor, allocation procedures have been carried out exclusively according to weight.
- This means that the data, in table A.1, which is already related to the production of 1000 kg steel ingot, is simply transferred to table A.2.

Organizing the LCI data

To continue the calculations and link the environmental data with the data for the other processes involved, the activities are summarized and organized in different categories. These are resources, waste and emissions, as can be seen in table A.2. The data in table A.1 and A.2 are presented as raw data. This means that all material flows are cut off at the gates of the Ovako Steel factory in Hofors. Therefor no data concerning for example raw material acquisition, electricity production or sludge deposition is presented. Instead, this is considered later on in this LCA (see appendix B).

Table A.2). LCI data for production of 1000 kg steel ingots.

Substance	Input	Output	Unit	Environment	Comments
Resources					
Iron and steel scrap	1 067		kg	Technosphere	
Ingot mould (cast Iron)	11		kg	Technosphere	
Carbon, black	0,17		kg	Technosphere	
Aluminium	1,27		kg	Technosphere	1)
Carbon, graphite	3		kg	Technosphere	2)
Carbon, graphite	5		kg	Technosphere	
Limestone	38		kg	Technosphere	
Anthracite (hard coal)	14		kg	Technosphere	
Silicon (17 103)	4,68		kg	Technosphere	
Chromium (17 215 + 17 220)	15,19		kg	Technosphere	
Magnesite	3,76		kg	Technosphere	
Brick	8,44		kg	Technosphere	
Olivine	8,06		kg	Technosphere	
Natural sand	3,58		kg	Technosphere	
Oxygen gas	30,46		m^3	Technosphere	
Light fuel oil	0,59		kg	Technosphere	
Light fuel oil (carrier)	6,91		kWh	Technosphere	3)
Electricity	514		kWh	Technosphere	4)
Surface water	33,71		m^3	River (Hoån)	
Municipal water	0,11		m^3	Technosphere	
Solid waste					
Ingot mould		11	kg	Technosphere	
Steel scrap		31,04	kg	Technosphere	
Magnesite		3,76	kg	Technosphere	
Brick		5,53	kg	Technosphere	5)
Brick		2,91	kg	Technosphere	5)
Olivine		8,06	kg	Technosphere	
Slag		100	kg	Technosphere	
Dust/particles		18,25	kg	Technosphere	
Air emissions					
NOx		0,148	kg	Air	
Dust/Particles		0,156	kg	Air	
CO2		70	kg	Air	6)
SO2		2,37	g	Air	6)
Hg (gas)		20,6	mg	Air	6)
Dioxin		2,5	mg	Air	6)
Chlorinated phenols		12	mg	Air	6)
Chlorinated benzenes		44	mg	Air	6)
Water emissions					
Process water		33,8	m^3	River (Hoån)	

1) Bars and wires
2) Electrodes
3) Energy content in the combusted oil
4) no Emission Factors (no effects of the electricity production included)
5) Some of the brick is deposited and some recycled
6) Measured by the authorized company imkab (1998)

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Production of steel billets at the Hot Rolling Mill

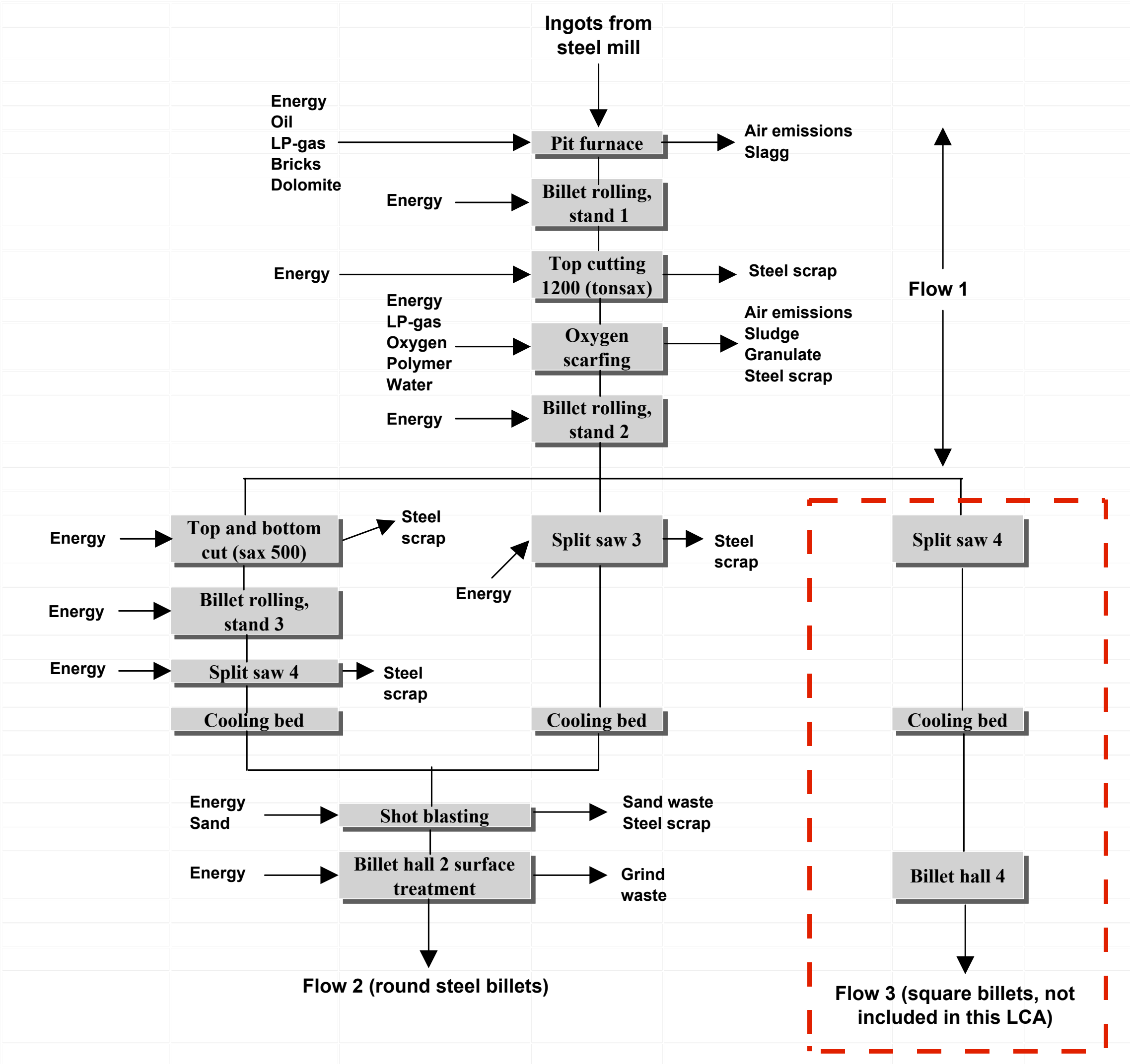

Figure A.2). Flow chart for the production of steel billets at Ovako Steel. Some of the most important environmental inputs and outputs of the included activities are represented. Regardless of what the different steel billets final dimensions are, they are all processed in the same way up to after rolling stand 2. Then the billets that will be processed to round billets go into flow 2 and the square ones into flow 3. Flow 3 is not included in this LCA.

Specification of the flows (1998)

- Total weight of steel ingots into flow 1 — 410 427 tons
- Total weight of billets out from flow 2 — 156 575 tons
- Total weight of billets for tubes out from flow 2 — 106 761 tons
- Total weight of billets out from flow 3 — 183 225 tons

Table A.3). Life cycle inventory data for the Rolling Mill at Ovako Steel AB (1998), as recived from Lars-Gunnar Larsson at the rolling mill.

Activity	Substance	Input quantity	Output quantity	Unit	Supplier	Ends up	Data type	Provider of information	Comments	Spec flow
Pit furnace	*Steel ingot*	410 427		ton						
	Brick	55		ton				T. Klaussen	1), 2)	
	Brick		55	ton		Recycled		T. Klaussen		
	Dolomite	10		ton				T. Klaussen	2)	
	Dolomite		10	ton		Deposited		T. Klaussen		
	Oil, EO3	198		m³		Rural air	Measured	T. Klaussen		
	Oil EO5	7 112		m³		Rural air	Measured	T. Klaussen		
	Oxygen gas	4 298 326		15° C m³	AGA	Rural air, slag	Measured	T. Klaussen		
	LPG, furnace 3	581		ton	Shell	Rural air	Measured	T. Klaussen		
	LPG, infra heater	62		ton	Shell	Rural air	Measured	T. Klaussen		2
	NOx		47	ton		Rural air	Estimated	H. Burtsoff		
	Dust/particles		8,6	kg		Rural air	Measured	H. Burtsoff		
	SO2		18	ton		Rural air	Calculated	H. Burtsoff		
	CO2		14 649	ton		Rural air	Calculated	H. Burtsoff		
	Slag, furnaces		860	ton		Deposited	Measured	T. Klaussen		
Oxygen scarfacing	*Granulate*		9 646	ton		Deposited	Measured	Stewen Persson		
	Sudge		3 079	ton		Deposited	Measured	Stewen Persson		
	Oxygen gas	5 124 013		15° C m³	AGA	Rural air, slag	Measured	T. Klaussen		
	LPG	454		ton	Shell	Rural air	Measured	T. Klaussen		
	NOx		13	ton		Rural air	Estimated	H. Burtsoff		
	Polymers	1 750		l		Technosphere		Stewen Persson		
									2)	
Billet hall 2	*Grinding dust*		116	ton		Deposited	Estimated	L-G Larsson		2
	Steel chips		374	ton		Scrap yard	Estimated	L-G Larsson		2
	Shot blasting dust		252	ton		Deposited	Estimated	L-G Larsson		2
Rolling mill	*Nitrogen gas*	2 030		15° C m³	AGA	Atmosphere		T. Klaussen		
	Grease	18 215	18 215	kg		Destruction		Per Hellberg	2)	
Hydraulic oil	*Hydraulic oil*	14128		l			Measured	Per Hellberg		
	Hydraulic oil		14128	l		Destruction	Measured	Per Hellberg		
	Hydraulic oil	11549		l			Measured	Per Hellberg		2
	Hydraulic oil		11549	l		Destruction	Measured	Per Hellberg		2
Press. air	*Pressurized air*	21 124 350	21 124 350	Nm³			Measured	C. Kvarnström		
Electricity	*Electricity*	19 300		MWh						
	Electricity	7 500		MWh						2
Scrap	*Bottom and top cut*					Scrap yard	Calculated	M. Thögersen		
	Other scrap					Scrap yard	Measured	S. Hasgörs		2
	Factory scrap		3 899	ton		Scrap yard				
Water	*Industrial water*	682 500	682 500	m³		River, Hoån				
	Drinking water	47 096	47 096	m³		River, Hoån	Measured	B. Kvarnström		

1) The suppliers are Fagersta Eldfasta, Bjuf och Höganäs

2) The data type is economical information, purchased amount

Allocation procedures for production of steel billets:

- All allocations have been made according to weight.
- The different steel billets produced at Ovako Steel are 80, 90, 120 mm round and 150 mm square.
- The manufacturing process is the same until after rolling stand 2, where all billets are 150 mm square.
- After that the billets go to partitioning or to further rolling procedures.
- The total output weight for flow 2 and 3 is 339 000 tons. Therefor flow 2 counts for 46,1% of flow 1.
- For the input and output data in flow 2 no difference has been made between the different dimensions of round billets.
- In other words it is assumed that the billets are processed equally regarding time, oil, etc.
- Only the weight of the billets has been used as basis for allocation.
- The total weight of round billets produced in flow 2 where 156 575 tons. Therefor these tubes count for all of the input and output data specific for flow 2 in table A.3.
- As an example these billets counts for 46,1 % of electricity in flow 1 and all of the electricity in flow 2 (data from table A.3):
- 0,461 x 19 300 MWh + 7 500 MWh = 16 397,3 MWh

Divided with the total weight of round billets (156 575 ton), that gives an electricity consumption of:
16 397,3 MWh / 156 575 ton = 0,1047 MWh/ton = 104,7 kWh/ton.

Organizing the LCI data
To continue the calculations and link the environmental data with the data for the other processes involved, the activities are summarized and organized in different categories. Table A.4.

Table A.4). LCI data for production of 1000 kg round steel billets of dimension 80 mm.

Substance	Input	Output	Unit	Environment	Comments
Resources					
Steel ingot	1 202		kg	Technosphere	
Brick	0,16		kg	Technosphere	
Dolomite	0,029		kg	Technosphere	
Light fuel oil	17,97		kg	Technosphere	1)
Light fuel oil	208,34		kWh	Technosphere	2)
Oxygen gas	27,73		15° C m³	Technosphere	
LPG	3,44		kg	Technosphere	1)
LPG	44,06		kWh	Technosphere	2)
Polymers	5,15		ml	Technosphere	
Nitrogen gas	0,006		15° C m³	Technosphere	
Grease	0,054		kg	Technosphere	
Hydraulic oil	115,34		ml	Technosphere	
Electricity	104,70		kWh	Technosphere	3)
Surface water	2,01		m³	River, Hoån	
Municipal water	0,14		m³	Ground water	
Solid waste					
Dolomite		0,03	kg	Technosphere	
Slag, furnace		2,53	kg	Technosphere	
Slag, oxygen scarfacing		28,39	kg	Technosphere	
Sludge		9,06	kg	Technosphere	
Dust		4,74	kg	Technosphere	
Grease		0,05	kg	Technosphere	
Hydraulic oil		115,00	ml	Technosphere	
Brick		0,16	kg	Technosphere	
Steel scrap		144,49	kg	Technosphere	4)
Air emissions					
NOx		0,177	kg	Air	
Dust/particles		25,31	mg	Air	
SO2		52,97	g	Air	
CO2		53,51	kg	Air	5)
Water emissions					
Waste water		2,150	m³	River, Hoån	

1) Consumption of energy resource
2) Energy content in the combusted oil (energy carrier)
3) Consumption; no Emission Factors (no effects of the electricity production included)
4) Losses in pit furnace, cutting, partitioning and other processes (back to scrap yard)
5) Combustion of Light fuel oil and LPG (2,4 kg CO2/kg oil and 3,02 kg CO2/kg LPG; source).

Production of hot rolled tubes at Tube Mill 5

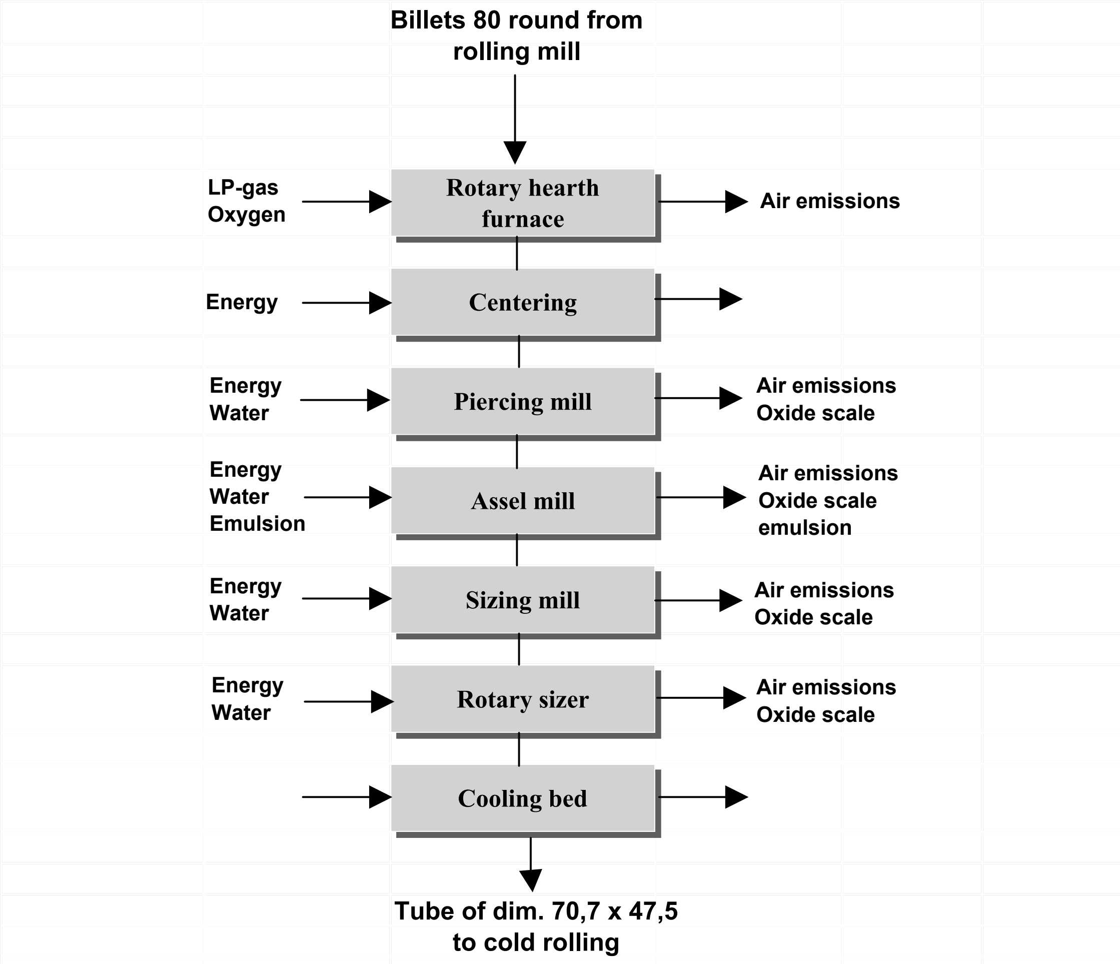

Figure A.3) Flow chart for the production of hot rolled steel tubes at Rolling Mill 5. Some of the most environmentally interesting inputs and outputs are represented.

Table A.5) LCI data for production of hot rolled steel tubes at Tube Mill 5, as presented from Cecilia Persson at the hot tube mill.

Activity	Substance	Input quantity	Output quantity	Unit	Ends up	Data type	Comments
Partitioning	*Steel tube*	50 160		ton			
	Steel tube		49 658	ton			
	Steel scrap		502	ton	Recycled		
Tube Mill	*Steel*	49 658		ton		Measured	
	El	15 305		MWh		Calculated	1)
	LPG	2 280		ton	Rural air	Measured	2)
	Pressuriezed air	7 417 400		m3	Rural air, slag	Calculated	1)
	District heating	1 706		MWh	Technosphere	Calculated	1)
	Drinking water	4 897		m3		Calculated	1)
	Industrial water	198 463		m3		Calculated	1)
	Hydraulic oil	11 510		l	Technosphere	Calculated	1)
	Emulsions	183		ton	Technosphere	Calculated	1)
	Emulsions		183	ton	Technosphere	Calculated	1)
	Oil		14	ton	Technosphere	Calculated	1)
	Scrap, factory		695	ton	Recycled	Calculated	3)
	Oxidic scale		1 065	ton	Deposited	Calculated	4)
	Scrap, end cut		1 291	ton	Recycled	Calculated	5)
	Steel		46 927	ton		Measured	
	CO2		3 453	ton	Rural air	Calculated	6)
	NOx		5,2	ton	Rural air	Calculated	7)
	CO		2,1	ton	Rural air	Calculated	8)
	Water		209 973	ton			

1) 40 % of the total data for hot rolling. Allocated on weight
2) Consumption of LPG in furnace 35 at Tube Mill 5
3) Factory scrap; 1,4 % of the steel in
4) Losses in furnace 38; 1,5 % of the steel in * 1,43 for the oxide Fe2O3
5) End cut; 2,6 % of the steel in
6) Calculated according 3,02 kg CO2 / m3 LPG, 91,74 MJ / m3 LPG and 46 MJ / kg LPG
7) Calculated according 50 mg NOx/MJ LPG combusted in furnace 38
8) Calculated according 20 mg CO/MJ LPG combusted in furnace 38

Allocation procedures:
All allocations according to weight. This means that the data in table A.5 has been divided with the steel tube output weight, 46 927 tons.

Table A.6) LCI data for production of 1000 kg hot rolled steel tubes.

Substance	Input	Output	Unit	Environment	Comments
Resources					
Steel bar	1 069		kg	Technosphere	
Electricity	326		kWh	Technosphere	1)
District heating	36,4		kWh	Technosphere	1)
LPG gas	48,6		kg	Technosphere	
LPG gas	621		kWh	Technosphere	2)
Emulsions	3,90		kg	Technosphere	
Hydraulic oil	0,245		l	Technosphere	
Surface water	4,23		m3	Hoån	
Municipal water	0,104		m3	Technosphere	
Waste					
Steel scrap		53,0	kg	Technosphere	3)
Slag, oxidic scale		22,7	kg	Technosphere	4)
Oil		0,30	kg	Technosphere	5)
Emulsions		3,90	kg	Technosphere	
Air emissions					
NOx		0,112	kg	Air	
CO2		73,6	kg	Air	
CO		0,045	kg	Air	
Water emissions					
Waste water		4,33	kg	Hoån	

1) Consumption; no Emission Factors (no effects of the electricity production included)
2) Energy content in the combusted LPG (energy carrier)
3) Back to the scrap yard
4) Deposited in the industrial deposit
5) To destruction company

Heat treatment of hot rolled steel tubes

Table A.7) LCI data for heat treatment of hot rolled steel tubes, as presented by Cecilia Persson at the tube mill.

Substance	Input quantity	Output quantity	Unit	Ends up	Data type	Comments
Steel	81 950		ton		Measured	
LPG	2 785		ton		Measured	1)
Metanol	150 000		l	Recycled	Estimated	2)
Nitrogen	2 784 739		m3		Measured	3)
Nitrogen		2 784 739	m3	Rural air	Estimated	4)
Oxidic scale		586	ton	Deposited	Calculated	5)
Steel		81 540	ton	Technosphere	Measured	
CO2		4 217	ton	Rural air	Calculated	6)
CO2		82,7	m3	Rural air	Estimated	7)
NOx		12,8	ton	Rural air	Estimated	8)

1) LPG consumption in furnace 5, 6, 9, 10, 11, 13 and 14
2) Estimated consumption in furnace 9, 10, 14 (protection gas)
3) Protection gas in furnace 9, 10, 14
4) Same amount out as in
5) 1,5 % of the steel in; calculated as Fe2O3
6) Calculated according 3,02 kg CO2/m3n LPG, 91,74 MJ/m3n LPG and 46 MJ/kg LPG
7) Estimated from protection gas in furnace 9,10 och 14
8) Estimated according 100 mg NOx / MJ LPG and 46 MJ/kg LPG

Allocation procedures:
Allocations made by weight.

Table A.8) LCI data for heat treatment of 1000 kg steel tubes.

Substance	Input	Output	Unit	Comments
Resources				
Steel tube	1 005,025		kg	
LPG gas	34,155		kg	
LPG gas	436,424		kWh	1)
Methanol	1,840		l	
Nitrogen	34,152		m3	
Waste				
Oxidic scale		7,186	kg	
Air emissions				
NOx		0,157	kg	
CO2		52,731	kg	
CO		0,063	kg	
Nitrogen		34,152	m3	

1) Energy content in the combusted LPG (energy carrier)

Pickling of hot rolled steel tubes

Table A.9) LCI data for the pickling, as presented by Cecilia Persson at the tube mill.

Substance	Input quantity	Output quantity	Unit	Ends up	Data type	Comments
Steel	88 124		ton		Not known	
Steam	10 460		ton		Not known	1)
Steam	3 758		MWh		Not known	2)
Electricity	1 836		MWh		Not known	
H2SO4	1 190		ton		Not known	
Lime	89		ton		Not known	3)
Water		8 569,00	m3	Technosphere	Not known	4)
Steel		88 124	ton	Technosphere	Not known	
Sludge		508	m3	Deposited	Not known	
Iron salt		760	ton		Not known	
H2SO4 aerosols		50	kg	Rural air	Not known	5)
Suspended solids		50	kg	River, Hoån	Not known	6)
N-total		200	kg	River, Hoån	Not known	6)
COD		150	kg	River, Hoån	Not known	6)
Cd		0,3	kg	River, Hoån	Not known	6)
Cu		0,2	kg	River, Hoån	Not known	6)
Ni		0,9	kg	River, Hoån	Not known	6)
Cr		0,3	kg	River, Hoån	Not known	6)
Pb		1,0	kg	River, Hoån	Not known	6)
Zn		0,5	kg	River, Hoån	Not known	6)

1) used for heating of the H2SO4 in the pickling process
2) energy content in the steam; no EF
3) used in the neutralisation
4) process water out from neutralisation
5) from Environmental report
6) from Environmental report (1/2 of the flow from neutralisation - the phosphating is accounted for the other half)

Allocation procedures:
About half of the emission flow from neutralisation, original comes from the pickling. The rest comes from the phosphating. The neutralisation emission data is collected from the Ovako Steel Environmental Report, 1998. Then all allocations have been made by weight.

Table A.10) LCI data for pickling of 1000 kg steel tubes.

Substance	Input	Output	Unit	Environment
Resources				
Steel	1 000,0		kg	Technosphere
H2SO4	13,50		kg	Technosphere
Steam	119		kg	Technosphere
Steam	43		kWh	Technosphere
Electricity	21		kWh	Technosphere
Lime	1,0		kg	Technosphere
Waste				
Sludge		5,76	dm3	Technosphere
Iron salt		8,62	kg	Technosphere
Air emissions				
H2SO4 aerosols		0,57	g	Air
Water emissions				
Process water		0,097	m3	Hoån
Suspended solids		0,57	g	Hoån
N-tot		2,3	g	Hoån
COD		1,7	g	Hoån
Cd		3,4	mg	Hoån
Cu		2,3	mg	Hoån
Ni		10,2	mg	Hoån
Cr		3,4	mg	Hoån
Pb		11,3	mg	Hoån
Zn		5,7	mg	Hoån

Production of cold rolled steel tubes

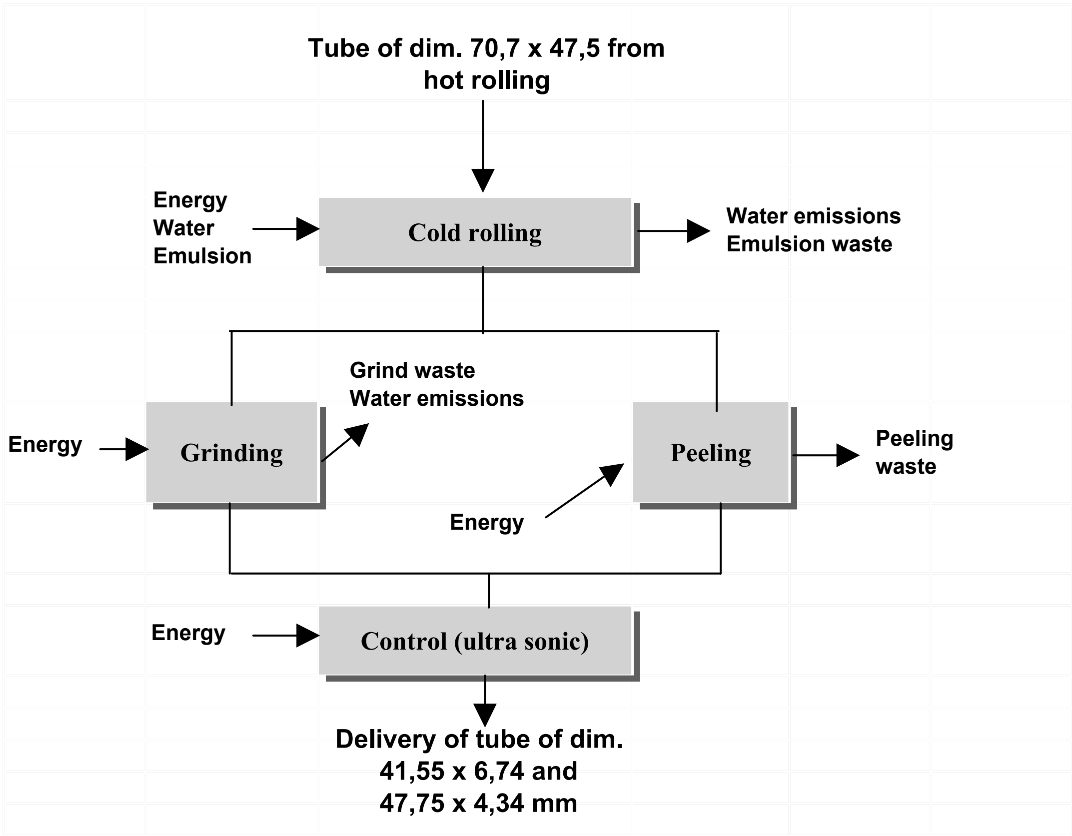

Figure A.4) Flow chart for cold rolling of steel tubes at the Cold Rolling Mill. Some of the most environmentally interesting inputs and outputs are represented..

Table A.11) LCI data for the cold rolling mill, as presented by Rickard Qvarfort at the cold rolling mill and from environmental report, Ovako 1998. In the column flow, CR means that cold rolling should be accounted for all the amount and CD the same for cold drawing. When noted with w, weight has been used as allocation method.

Activity	Substance	Input quantity	Output quantity	Unit	Ends up	Provider of information	Comments	Flow
General data for the cold working	*Steel tube*	20700		ton		Rickard Qvarfort		CR
	Steel tube	17700		ton		Rickard Qvarfort		CD
	Electricity	10 402		MWh		Rickard Qvarfort	1)	40/60
	Press. air	5 901 500		m3		Rickard Qvarfort	2)	w
	Steam	23 936		ton		Rickard Qvarfort	3)	w
	Steam	8 600		MWh		Rickard Qvarfort	4)	w
	Distr. heating	4 300		MWh		Rickard Qvarfort	3)	w
	Dringking w.	41		m3		Rickard Qvarfort		w
	Hydr. oil	29 946		l		Rickard Qvarfort		50/50
	Emulsion	0,8		l/ton		Rickard Qvarfort		CR
	Steel scrap		2 070	ton	Recycled	Rickard Qvarfort	5)	CR
	Steel scrap		1 859	ton	Recycled	Rickard Qvarfort	5)	CD
	Steel tube		18 630	ton		Rickard Qvarfort		CR
	Steel tube		15 842	ton		Rickard Qvarfort		CD
	Emulsions/oil water		693	ton	Technosphere	Rickard Qvarfort	6)	CR
	Mixed oils		36	ton	Technosphere	Rickard Qvarfort	7)	w
Phosphating	*Steam*	3 959		ton		Rickard Qvarfort	8)	CD
	Steam	1 420		MWh		Rickard Qvarfort	9)	CD
	H2SO4	not known						w
	H2SO4		84,0	mg	River, Hoån	Environmental report	10)	w
	Natriumstearat	8		ton		Rickard Qvarfort		CD
	Zinkphosphorous	25		m3		Rickard Qvarfort		CD
	Process water		4 200	m3	River, Hoån	Environmental report	11)	CD
	Phosphorous acid		4,2	mg	River, Hoån	Environmental report	12)	CD
	Susp mtrl		50	kg	River, Hoån	Environmental report	13)	CD
	N-total		200	kg	River, Hoån	Environmental report	13)	CD
	COD		150	kg	River, Hoån	Environmental report	13)	CD
	Cd		0,3	kg	River, Hoån	Environmental report	13)	CD
	Cu		0,2	kg	River, Hoån	Environmental report	13)	CD
	Ni		0,9	kg	River, Hoån	Environmental report	13)	CD
	Cr		0,3	kg	River, Hoån	Environmental report	13)	CD
	Pb		1,0	kg	River, Hoån	Environmental report	13)	CD
	Zn		0,5	kg	River, Hoån	Environmental report	13)	CD

1) 40 % accounted for CR and 60 % for CD
2) not environmentaly interesting
3) For plant heating; taken from HEAB (Hofors Energi AB)
4) Energy content in the steam for plant heating, energy carrier
5) Back to the scrap yard
6) Total collected volume for cold working, components included
7) Total for cold working (hydraulic oil, separated oil, components, etc.)
8) For the phosphating; taken from HEAB (Hofors Energi AB)
9) Energy content in the steam for phosphating, energy carrier
10) 0,02 mg/m3 process water (4200 m3). The limit value is 1 mg/m3
11) Water to neutralisation (about 1/2 of the load on the neutralisation plant)
12) 0,001 mg/m3 process water (4200 m3). The limit value is 1 mg/m3
13) 1/2 of the emissions from the neutralisation (the other half comes from pickling

Allocation procedures:
At the Ovako Steel Cold rolling mill, steel tubes can be produced either by cold rolling or cold drawing. The steel tubes in this LCA are produced by cold rolling. In the column Flow in table A.11, CR means that cold rolling should be accounted for all the amount. When noted with w, weight has been used as allocation method and for example 40/60 means 40 % for CR and 60 % for CD.

Table A.12) LCI data for production of 1000 kg cold rolled steel tubes.

Substance	Input	Output	Unit	Environment
Resources				
Steel tube	1 111,111		kg	Technosphere
Electricity	223,339		kWh	Technosphere
Steam	0,694		ton	Technosphere
Steam	249,275		kWh	Technosphere
District heating	124,638		kWh	Technosphere
Municipal water	1,183		l	Technosphere
Hydraulic oil	0,804		l	Technosphere
Emulsions	0,8		l	Technosphere
H2SO4				Technosphere
Solid waste				
Mixed oils		0,870	kg	Technosphere
Emulsions/oil water		37,198	kg	Technosphere
Steel scrap		111,111	kg	Technosphere
Air emissions				
Not known				
Water emissions				
H2SO4		2,43E-003	mg	Hoån

Total LCI data for production of cold rolled steel tubes which goes through the studied processes

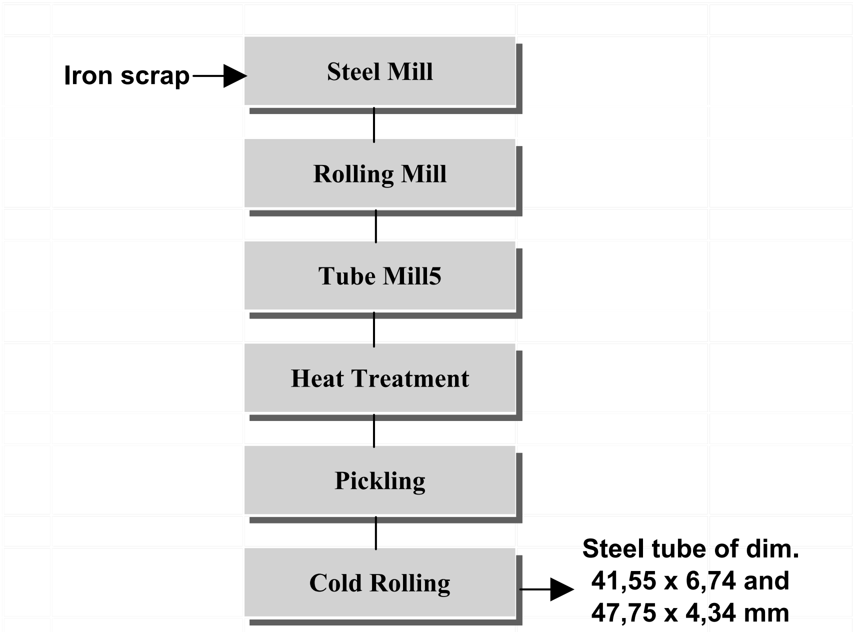

Figure A.5) The processes included in the LCA study for production of cold rolled steel tubes at Ovako Steel.

Factors for the LCI data in the involved processes
Since all data in the LCI tables for the involved processes are related to 1000 kg steel out from each process the data has to be multiplied with corresponding factors:

Steel Mill	1,4344
Rolling Mill	1,1936
Tube Mill 5	1,1167
Heat treatment	1,1111
Pickling	1,1111

The data for cold rolling (table A.12) is simply transferred directly to table A.13. For the other processes the factor is depending on the steel loss in the following processes. This means for example that all data for production of 1000 kg steel ingots (table A.2) has to be multiplied by 1,4344 to get the right data for production of 1000 kg of cold rolled steel tubes.

Table A.13) Total LCI data for production of 1000 kg cold rolled steel tubes.

Substance	Input	Output	Unit	Environment
Resources				
Iron and steel scrap	1 531		kg	Technosphere
Cast Iron	16		kg	Technosphere
Carbon, black	0,24		kg	Technosphere
Aluminum	2		kg	Technosphere
Carbon, graphite	4		kg	Technosphere
Carbon, graphite	7,2		kg	Technosphere
Limestone	56		kg	Technosphere
Anthracite (hard coal)	20		kg	Technosphere
Silicon (17 103)	6,7		kg	Technosphere
Chromium (17 215 + 17 220)	22		kg	Technosphere
Magnesite	5,4		kg	Technosphere
Brick	12		kg	Technosphere
Dolomite	0,035		kg	Technosphere
Olivine	12		kg	Technosphere
Natural sand	5,1		kg	Technosphere
Oxygen gas	77		15° C m^3	Technosphere
Nitrogen gas	37,953		15° C m^3	Technosphere
Methanol	2,044		l	Technosphere
H2SO4	15,004		kg	Technosphere
Hydraulic oil	1,22		l	Technosphere
Grease	0,064		kg	Technosphere
Emulsions	4,35		kg	Technosphere
Polymers	6,15		ml	Technosphere
Light fuel oil	22,29		kg	Technosphere
Light fuel oil (carrier)	258,58		kWh	Technosphere
LPG	96,31		kg	Technosphere
LPG	1 230,90		kWh	Technosphere
District heating	165,2		kWh	Technosphere
Electricity	1 473		kWh	Technosphere
Steam	826		kg	Technosphere
Steam	297		kWh	Technosphere
Surface water	55		m^3	River (Hoån)
Municipal water	0,44		m^3	Technosphere
Solid waste				
Ingot mould		15,8	kg	Technosphere
Steel scrap		387,3	kg	Technosphere
Magnesite		5,4	kg	Technosphere
Brick		8,1	kg	Technosphere
Brick		4,2	kg	Technosphere
Olivine		11,6	kg	Technosphere
Dolomite		0,04	kg	Technosphere
Slag		214	kg	Technosphere

Sludge		10,81	kg	Technosphere
Sludge		6,40	dm3	Technosphere
Grease		0,06	kg	Technosphere
Oil		1,20	kg	Technosphere
Emulsions		41,55	kg	Technosphere
Hydraulic oil		137,26	ml	Technosphere
Dust/particles		31,8	kg	Technosphere
Air emissions				
NOx		0,72	kg	Air
Dust/Particles		0,25	kg	Air
CO2		305,04	kg	Air
CO		0,120	kg	Air
SO2		66,62	g	Air
Hg (g)		29,5	mg	Air
Dioxin		3,6	mg	Air
Chlorinated phenols		17,2	mg	Air
Chlorinated benzenes		63,1	mg	Air
Nitrogen		38	m3	Air
Svavelsyradimma		0,63	g	Air
Water emissions				
Process water		51,2	m3	River (Hoån)
susp mtrl		0,63	g	River (Hoån)
H2SO4		2,43E-003	mg	River (Hoån)
N-tot		2,52	g	River (Hoån)
COD		1,89	g	River (Hoån)
Cd		3,78	mg	River (Hoån)
Cu		2,52	mg	River (Hoån)
Ni		11,35	mg	River (Hoån)
Cr		3,78	mg	River (Hoån)
Pb		12,61	mg	River (Hoån)
Zn		6,30	mg	River (Hoån)

Appendix B

Total tube data with included extraction of resources and production of raw material and allocation procedures for consumption of virgin iron.

In this appendix environmental data for extraction and production of some energy and raw material inputs have been included. Also emissions from the extraction and production phases are included.

Energy resources included:

- Coal
- Crude oil
- Natural gas

Raw material resources included:

- Aluminum
- Coal
- Limestone
- Iron
- Oil

The LCI data for extraction and production of the resources are obtained from the Spine database at Technical Environmental Planning, Chalmers University of Technology, Sweden.

Allocation procedures for consumption of virgin iron during manufacturing of the conventional plain bearing:

The steel tubes are produced exclusively from steel scrap. However, the amount of steel scrap on the market is not infinite. An increased consumption of steel scrap for steel tube production would probably mean that someone else has to use virgin iron instead. The problem is whether the steel scrap should be accounted as resource, taken from the biosphere, or as material input from the technosphere. The following allocations have been carried out for the iron consumption in the steel tube production:

- The steel flow in the life cycle of the plain bearing GE30 is somewhat considered as a closed circle. This means that the plain bearing, after use, is returned to Hofors for steel tube production. That also counts for the recyclable steel scrap during the steel tube production (e.g. end cut) and the plain bearing manufacturing (e.g. losses in turning). This flow is considered as material flow within the technosphere. All other steel losses during the life cycle are considered as a loss of steel on the scrap market. Therefor these losses are accounted for as consumption of virgin iron. The environmental load associated with extraction of iron ore and production of virgin iron will be included.
- Mass flow of steel in the GE30 life cycle:
    - o 1530,5 kg steel scrap required for production of 1000 kg cold rolled steel tubes.
    - o 387 kg recycled (back to the furnace).
    - o The loss is therefor 143,5 kg from the steel tube production.
    - o 1958 kg steel tubes required for production of 1000 kg GE30.
    - o 854 kg recycled (from the turning process).
    - o The loss from the GE30 manufacturing is therefor 104 kg.
    - o 1,958*1530,5=2997 kg steel scrap required for production of 1000 kg GE30.
    - o The relative loss from steel tube production: 143,5*1,958=281 kg.
    - o 1000 kg GE30 back to steel production after use.
    - o This results in a total loss of 104+281kg=385 kg steel or 12,85 % of the total amount of steel scrap required for the production of 1000 kg GE30.
- These 385 kg will be accounted as virgin iron in the GE30 life cycle.
- That means 1530,5*0,1285=196,5 kg virgin iron and 1334 kg scrap for production of 1000 kg steel tubes.

Table B.1) Total LCI data for production of 1000 kg cold rolled steel tubes, with production and extraction of resources included.

Substance	Input	Output	Unit	Environment
Resources				
Iron and steel scrap	1 334		kg	Technosphere
Virgin steel	197		kg	Biosphere
Iron ore	540		kg	Biosphere
Cast Iron	16		kg	Technosphere
Carbon, black	0,24		kg	Biosphere
Coal	145		kg	Biosphere
Aluminum	1,8		kg	Biosphere
Bauxite	9,0		kg	Biosphere
Carbon, graphite	4,3		kg	Biosphere
Carbon, graphite	7,2		kg	Biosphere
Limestone	81		kg	Biosphere
Anthracite (hard coal)	20		kg	Biosphere
Silicon (17 103)	6,7		kg	Technosphere
Chromium (17 215 + 17 220)	22		kg	Technosphere
Magnesite	5,4		kg	Technosphere
Brick	12		kg	Technosphere
Dolomite	0,035		kg	Technosphere
Olivine	12		kg	Technosphere
Natural sand	5,1		kg	Technosphere
Oxygen gas	0,11		kg	Technosphere
Nitrogen gas	48		kg	Technosphere
Methanol	1,6		kg	Technosphere
H2SO4	15		kg	Technosphere
Na2SO4	4,6		kg	Technosphere
NO3-N	12		kg	Technosphere
Peat	0,14		kg	Technosphere
Chalice	5,5E-004		kg	Technosphere
Emulsifier	3,6E-006		kg	Technosphere
Portland soda	0,21		kg	Technosphere
Solvey soda	0,20		kg	Technosphere
Hydraulic oil	1,0		kg	Technosphere
Grease	0,06		kg	Technosphere
Emulsions	4,4		kg	Technosphere
Polymers	0,005		kg	Technosphere
Light fuel oil	34		kg	Biosphere
Light fuel oil (carrier)	259		kWh	Biosphere
Natural gas	1,2		kg	Biosphere
Natural gas	17		kWh	Biosphere
LPG	96		kg	Biosphere
LPG	1 231		kWh	Biosphere
District heating	165		kWh	Technosphere
Electricity	1 473		kWh	Technosphere

Steam	826		kg	Technosphere
Steam	297		kWh	Technosphere
Surface water	55 000		kg	River (Hoån)
Municipal water	440		kg	Technosphere
Solid waste				
Ingot mould		16	kg	Technosphere
Steel scrap		387	kg	Technosphere
Magnesite waste		5,4	kg	Landfill
Olivine waste		12	kg	Landfill
Slag		214	kg	Landfill
Sludge		11	kg	Landfill
Oil waste		1,3	kg	Technosphere
Anhydrite waste		0,11	kg	Not known
Ashes		0,025	kg	Landfill
Brick scrap		12	kg	Landfill
Dust		32	kg	Landfill
Electrolysis bath		0,020	kg	Technosphere
Mineral waste		0,018	kg	Not known
Mixed waste		0,014	kg	Not known
Redmud		6,2E-006	kg	Not known
Stone		0,020	kg	Technosphere
Waste		252	kg	Not known
Industrial waste		0,010	kg	Not known
Hazardous waste		0,046	kg	Technosphere
Household waste		0,035	kg	Not known
Scrap		1,4	kg	Technosphere
Waste containing explosives		1,1E-006	kg	Not known
Other rest products		19	kg	Not known
Air emissions				
As		3,4E-005	kg	Air
Cd		2,5E-006	kg	Air
CH4		0,66	kg	Air
Cl2		7,7E-005	kg	Air
Chlorinated phenols		1,7E-005	kg	Air
Chlorinated benzenes		6,3E-005	kg	Air
Co		1,6E-006	kg	Air
CO		0,20	kg	Air
CO2		560	kg	Air
Cr		8,4E-005	kg	Air
Cu		4,0E-005	kg	Air
Dioxin		3,6E-006	kg	Air
F-tot		7,9E-004	kg	Air
Fe		3,4E-002	kg	Air
Fluoride		2,0E-007	kg	Air
Halon		2,2E-005	kg	Air

HC		8,9E-002	kg	Air
HCl		9,8E-003	kg	Air
HF		1,3E-002	kg	Air
Hg		3,0E-005	kg	Air
Mn		5,9E-006	kg	Air
N3		48	kg	Air
N2O		1,9E-003	kg	Air
NH3		2,4E-004	kg	Air
NH4		2,5E-009	kg	Air
NH4NO3		1,4E-004	kg	Air
Ni		4,9E-005	kg	Air
NOx		1,2E+000	kg	Air
PAH		1,5E-004	kg	Air
Particulates		0,69	kg	Air
Pb		1,2E-004	kg	Air
SO2		0,67	kg	Air
SOx		8,3E-002	kg	Air
Tar		5,6E-004	kg	Air
THC		2,1E-004	kg	Air
TOC		1,5E-004	kg	Air
V		9,2E-005	kg	Air
VOC		0,11	kg	Air
Zn		8,4E-004	kg	Air
Water emissions				
Al		1,4E-004	kg	Water
As		4,9E-007	kg	Water
BOD		2,9E-003	kg	Water
Cd		3,8E-006	kg	Water
Chloride		5,9E-005	kg	Water
Co		7,6E-007	kg	Water
COD		7,7E-002	kg	Water
Cr		1,3E-005	kg	Water
Cu		2,7E-005	kg	Water
Dissolved solids		6,1E-003	kg	Water
F-tot		3,0E-003	kg	Water
Fe		1,4E-003	kg	Water
Fluorides		2,6E-005	kg	Water
HNO3		7,0E-006	kg	Water
Inert chemicals		4,0E-004	kg	Water
Lignin		2,8E-007	kg	Water
Mn		7,0E-004	kg	Water
N-tot		1,1E-002	kg	Water
NaCl		2,2E-005	kg	Water
NH3		1,6E-005	kg	Water
NH4-N		1,8E-003	kg	Water
NH4NO3		5,1E-004	kg	Water

Ni		3,3E-005	kg	Water
NO3-N		1,1E-004	kg	Water
Oil		3,6E-003	kg	Water
P-tot		9,9E-005	kg	Water
Pb		1,1E-004	kg	Water
Phenol		3,4E-005	kg	Water
Salt waste		5,9E-009	kg	Water
SO2		1,5E-002	kg	Water
SO4		7,1E-005	kg	Water
Sr		1,4E-003	kg	Water
Susp solids		3,7E-003	kg	Water
Tot-CN		6,7E-005	kg	Water
Willow		2,5E-007	kg	Water
Zn		2,7E-005	kg	Water

Appendix C

Transports of 1958 kg steel tubes from Hofors to Püttlingen.

Distances:

Hofors to Püttlingen

• Hofors - Trelleborg	720 km	Heavy truck
• Trelleborg - Travemünde	240 km	Ferry
• Travemünde - Püttlingen	760 km	Heavy truck

The LCI data is obtained from the Spine database at Technical Environmental Planning, Chalmers University of Technology, Sweden. Environmental loads from diesel production and transports with heavy truck and ferry are included. The heavy truck transports are carried out with trucks with one trailer, long distance, Euro 0. Only one-way transports are considered because the trucks are assumed to be used for other transports from Püttlingen. The transport distances are collected from:

- *http://www.abo.fi/~oholm/distance/*; Road distances in the US and Europe including the Nordic countries.
- Shell Euro Atlas.

Table C.1) LCI data for the total transports (heavy truck and ferry) of 1958 kg steel tubes from Hofors to Püttlingen.

Substance	**Input**	**Output**	**Unit**	**Environment**
Resources				
Crude natural gas	87,7		g	Resource
Crude natural gas	1,25		kWh	
Crude oil	3 795		g	Resource
Crude oil	44		kWh	
Air emissions				
CH4		4,23	g	Air
CO		198	g	Air
CO2		149 253	g	Air
HC		100	g	Air
N2O		0,7	g	Air
NOx		1 693	g	Air
Particulate		34,9	g	Air
SO2		49,9	g	Air
Water emissions				
COD		0,177	g	Water
N-tot		0,029	g	Water
Oil		0,060	g	Water
Phenol		0,00086	g	Water

Appendix D

Flow chart, life cycle inventory data and allocation procedures for production of 1000 kg conventional plain bearings GE30 at SKF Gleitlager in Püttlingen, Germany.

In table D.2 extraction and production of light fuel oil and natural gas are included. The data is obtained from the Spine database.

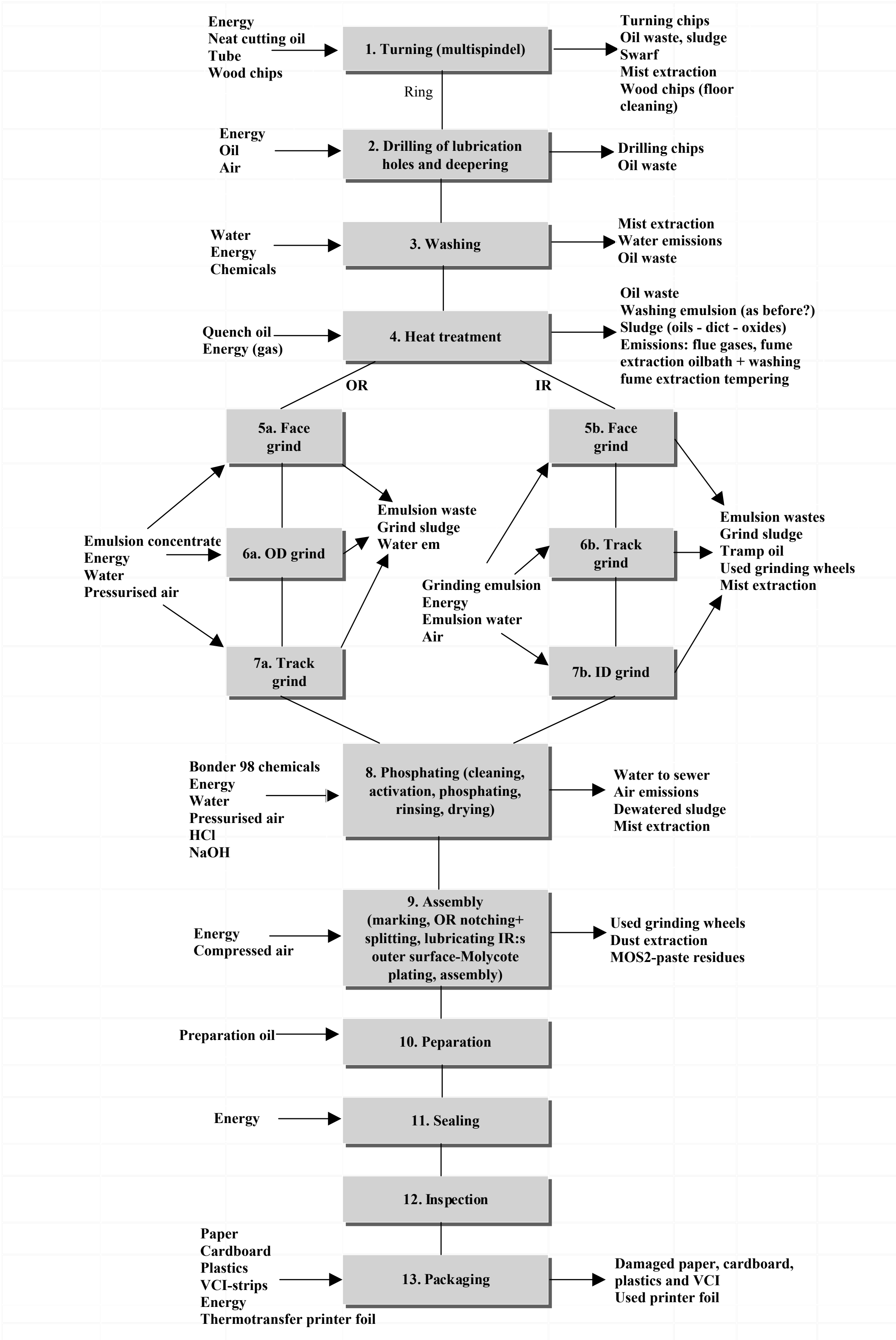

Figure D.1) Flow chart for production of the conventional plain bearing GE30.

Table D.1) LCI data for the plain bearing manufacturing as received from Peter Spengler at SKF Gleitlager GmbH in Püttlingen, Germany.

Activity	Substance	Input quantity	Output quantity	Unit	Environment	Comments
Energy for plant heating and electricity consumption	*Electricity*	5 823		MWh	Technosphere	1)
	Natural gas	432 092		m3	Technosphere	1)
	Light fuel oil	18 600		kg	Technosphere	1)
	CO2		900 183	kg	Air	2)
	SO2		78	kg	Air	2)
	CO		323	kg	Air	2)
	NOx		872	kg	Air	2)
Water for the entire plant	*Process water*	1 600		m3	Technosphere	1)
	Drinking water	3 483		m3	Technosphere	1)
	Waste water		4 125	m3	Technosphere	1)
	Waste water		958	m3	River	1)
Turning	*Cutting oil*	8600		kg	Technosphere	
	cutting oil		8600	kg	Technosphere	
	Wood chips	5 000		kg	Technosphere	
	Wood chips		5 000	kg	Technosphere	
	Turning chips		848 000	kg	Technosphere	
Washing	*Cleaner*	155		kg	Technosphere	
Heat treatment	*Quench oil*	6 563		kg	Technosphere	
	Quench oil		6 563	kg	Technosphere	
	Natural gas	161 248		m3	Technosphere	
	CO2		319 271	kg	Air	
	NOx		290	kg	Air	
	CO		116	kg	Air	
	N2	252 000		m3	Air	
	N2		252 000	m3	Air	
	Anticorit	558		kg	Technosphere	
Grinding	*Concentrate*	10 185		kg	Technosphere	
	Sludge		174 640	kg	Technosphere	
Phosphating	*Bonding salt*	12 000		kg	Technosphere	
	Sludge		10 700	kg	Technosphere	
Neutralization	*NaOH*	180		l	Technosphere	
	NaHSO3	240		l	Technosphere	
	HCl	60		l	Technosphere	
	H2SO4	800		l	Technosphere	
Assembly	*Running-in oil*	1 713		kg	Technosphere	
Packaging	*cardboard paper*	-			Technosphere	
	plastics	-			Technosphere	
Other waste products	*Machining emulsions*		32100	kg	Technosphere	1)
	Exhausting and filter mtrls		16500	kg	Technosphere	1)
	Non halogenetic machine oils		21 703	kg	Technosphere	1)
	Mixed oils		4290	kg	Technosphere	
	Machining sludge		6170	kg	Technosphere	
	Paper waste		28875	kg	Technosphere	1)
	Mixed steel scrap		46000	kg	Technosphere	
	Solid steel scrap		122000	kg	Technosphere	
	Micro chemicals		80	kg	Technosphere	
	Sodium nitrite		37,5	kg	Technosphere	1)
	Painting sludge		225	kg	Technosphere	1)

1) 75% of the amount for the entire factory

2) From combustion of natural gas and light fuel oil

Allocation procedures for production of the plain bearing GE30:

- The data in table D.1 that corresponds to energy and water consumption for the entire SKF plant is marked with comment 1. The data is representative for the production of plain bearings rod ends and bushings. For allocation of this data the turn over has been used as base. Production of all plain bearings stand for 75 % of the total turn over and therefor also 75 % of this data.

- The data in table D.1 that does not have any comment is data that only concerns the production of plain bearings. This data has been allocated by input weight of the steel tubes used for plain bearing production. 1998 the total input weight of tubes for plain bearing production was 1 943 182 kg. The total weight of tubes for production of GE30:s was 65 802 kg which corresponds to 3,39 %.

Table D.2) LCI data for production of 1000 kg of the plain bearing GE30.

Substance	Input	Output	Unit	Environment
Resources				
Steel tube	1 958		kg	Technosphere
Electricity	5 867		kWh	Technosphere
Natural gas	430		kg	Resource
Natural gas	6 155		kWh	Resource
Light fuel oil	18		kg	Resource
Light fuel oil	224		kWh	Resource
Process water	1 612		kg	Resource
Sanitärt water	3 509		kg	Resource
Cutting oil	8,7		kg	Technosphere
Wood chips	5,0		kg	Resource
Neutralreiniger	0,20		kg	Technosphere
Quench oil	6,6		kg	Technosphere
N2	317		kg	Technosphere
Anticorit	0,60		kg	Technosphere
Concentrate	10		kg	Technosphere
Bonding salt	12		kg	Technosphere
NaOH	181		ml	Technosphere
NaHSO3	242		ml	Technosphere
HCl	60		ml	Technosphere
H2SO4	806		ml	Technosphere
Running-in oil	1,7		kg	Technosphere
Solid waste				
Cutting oil		8,7	kg	Technosphere
Wood chips		5,0	kg	Technosphere
Turning chips		854	kg	Technosphere
Quench oil		6,6	kg	Technosphere
Grinding sludge		176	kg	Technosphere
Phosphating sludge		11	kg	Technosphere
Machining emulsions		32	kg	Technosphere
Exhausting and filter materials		17	kg	Technosphere
Non halogenetic machine oils		22	kg	Technosphere
Mixed oils		4,3	kg	Technosphere
Machining sludge		6,2	kg	Technosphere
Paper waste		29	kg	Technosphere
Mixed steel scrap		46	kg	Technosphere
Solid steel scrap		123	kg	Technosphere
Micro chemicals		0,08	kg	Technosphere
Sodium nitrite		0,038	kg	Technosphere
Painting sludge		0,23	kg	Technosphere
Hazardous waste		0,006	kg	Not known
Household waste		4,7E-003	kg	Not known
Industrial waste		1,3E-003	kg	Not known

Air emissions				
NOx		1,2	kg	Air
N2O		2,4E-005	kg	Air
CH4		1,5E-003	kg	Air
CO2		1 229	kg	Air
CO		0,44	kg	Air
SO2		0,079	kg	Air
Halon		2,8E-006	kg	Air
VOC		0,015	kg	Air
N2		317	kg	Air
Water emissions				
Oil spill		4,0E-004	kg	Sea

Appendix E

Life cycle inventory data for the total electricity needed to produce 1000 kg conventional plain bearings GE30.

The total electricity needed for the production of 1000 kg of GE30 is:

- **2 884 kWh** **Production of 1 958 kg steel tubes at Ovako Steel**
- **5 867 kWh** **Production of 1 000 kg GE 30 in Püttlingen**

The data for Swedish average electricity and all LCI data is obtained from the Spine data base at Technical Environmental Planning, Chalmers University of Technology, Sweden.

The data for German average electricity are as follows:

Coal	47%
Nat U	30%
Oil	9%
Natural gas	5%
Hydro power	4%
Renewable	1%
Others	4%

Only environmental loads from electricity production from coal, oil and uranium are included, for both Sweden and Germany.

Table E.1) LCI data for production of 2 884 kWh electricity in Sweden.

Substance	Input	Output	Unit	Environment
Resources				
Coal	0.95		kg	Other
Natural gas	0.12		kg	Other
Area	13		m2	Resource
Bauxite	0.19		g	Resource
Copper ore	2984		g	Resource
Fuel wood	75757		g	Resource
Iron ore	96		g	Resource
Lead ore	34		g	Resource
Uranium ore	1738		g	Resource
Wood	6.7		g	Resource
Ammonia	23		g	Technosphere
Bio fuel	1.00		g	Technosphere
H2SO4	233		g	Technosphere
Heavy oil	4.7		kg	Technosphere
NaOH	7.6		g	Technosphere
Nitric acid	11		g	Technosphere
Waste				
Building waste		96	g	Technosphere
Highly active rad ac waste		63	g	Technosphere
Low active rad ac waste		38 404	ug	Technosphere
Low active rad ac waste		1.7E-05	m3	Technosphere
Medium active rad ac waste		1.7E-05	m3	Technosphere
Other rest products		142 476	g	Technosphere
Air emissions				
CO		2 345	g	Air
CO2		79 614	g	Air
HC		11	g	Air
NOx		103	g	Air
Particles		18	g	Air
SO2		36	g	Air
Water emissions				
N-tot		3.6	g	

Table E.2) LCI data for production of 5 867 kWh electricity in Germany.

Substance	Input	Output	Unit	Environment
Resources				
Heavy oil	981		kWh	Other
Coal	11099		kWh	Other
Area	0.035		m2	Resource
Bauxite	175		mg	Resource
Copper ore	4177		g	Resource
Iron ore	70		g	Resource
Lead ore	13		g	Resource
Uranium ore			g	Resource
	9.5		g	Resource
Ammonia	31		g	Resource
	335			Technosphere
NaOH	8.6		g	Technosphere
Nitric acid	16		g	Technosphere
Waste				
Building waste		137	g	Technosphere
		91		Technosphere
Low active rad ac waste		55293	ug	
Low active rad ac waste			m3	Technosphere
Medium active rad ac waste			m3	Technosphere
Other rest products		40310	g	Technosphere
Air emissions				
CO			g	Air
CO2		3653125	g	Air
HC		2182	g	Air
NOx		10602	g	Air
Particles			g	Air
		3005	g	Air
Water emissions				
N-tot		0.66	g	Water