The Importance of Buildings' Environmental Impact in Life Cycle Assessment

--A case study of SKF's spherical roller bearing 24024

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Abstract

Life cycle assessment (LCA) is an important and comprehensive method for analysis of the environmental impact of products and services throughout their whole life cycle from extraction of raw material through production and use to disposal. However, the environmental impacts from buildings related to the products are generally excluded when performing LCAs on products. Existing LCAs dealing with buildings normally consider the building as a product, when they in fact in most cases are background systems to other products.

Building-related environmental issues have recently become increasingly important. Buildings are accountable for approximately 40% of society's total environmental impact. At the same time are technologies and systems for maintaining and constructing them environmentally well existing. Buildings have large potential for environmental improvements. One of the reasons for the poor performance of buildings is the lack of customer demand of such buildings.

The aim of this study is to investigate the importance of buildings' environmental impact in products' life cycle and to develop a tentative method to include buildings' environmental impact into products' LCAs. The intended application of this study is to increase companies' awareness that it is important to request and buy/build environmentally friendly buildings.

A case study of SKF's spherical roller bearing (SRB) 24024 has been performed. Buildings' environmental impacts associated with SRB24024 are compared with the results of production processes' environmental impact from the study "Life cycle assessment on SKF's spherical roller bearing" conducted in 2001 by Chalmers University of Technology, Sweden, to measure importance of buildings' environmental impact in the life cycle of SRB 24024.

The results of this report indicate that buildings have caused up to more than 25% of SRB 24024's total environmental impact within its life cycle. The results also show that buildings are the largest emitter of certain dominated pollutants comparing to each component of a bearing. Therefore, it is justifiable to say that it is necessary to include buildings' environmental impact into products' LCAs.

An experimental method to include buildings' environmental impact into products' Life cycle assessment is presented and discussed in this study. Also, this study implies that SKF has an opportunity to improve their environmental performance by making progress in the environmental performance of their buildings, especially improvements on energy consumption.

Acknowledgements

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Yunfeng Li, May 2006

Table of contents

1 Introduction

This chapter describes an introduction of the study including three different dimension backgrounds and purpose of the study.

1.1 Environmental impacts of buildings

In recent years, building-related environmental issues have become increasingly important. Buildings are accountable for approximately 40% of society's total environmental impact (IPCC 2001). At the same time are technologies and systems for maintaining and constructing them environmentally well existing. As consequence of this, some governments have introduced new policy instruments, such as the European Community's directive on the energy performance of buildings, in order to reduce the negative impact from the activities of building sector (European Parliament 2002). Buildings have large potential for environmental improvements. One of the reasons for the poor performance of buildings is the lack of customer demand of such buildings (Landman 1999; Nässén 2005).

Building and construction have both large economic footprint and impressive ecological footprint. This sector accounts for around one-tenth of the world's GDP, at least 7% of world employment, half of all resource use, up to 40% of energy consumption, 30% of raw materials consumption, 25% of timber harvest, 35% of the world's CO_2 emissions, 16% of fresh water withdrawal and 50% of ozone-depletion (Roodman and Lenssen 1995; UNEP 2003a).

Building-associated environmental issues are also important for companies. There are already more than 88 000 companies in the world that have been certified to the ISO 14001 environmental management system (EMS) (ISO 2005). As a part of the EMS, companies have an explicit requirement to consider the environmental performance of their purchases and suppliers, including buildings and building materials (Hendrickson and Horvath 2000).

1.2 Life Cycle Assessment (LCA)

Life cycle assessment (LCA) is an important and comprehensive method for analysis of the environmental impact of products and services. It is a multi-disciplinary tool which models technical system, social system and natural system at the same time. The conventional LCA evaluates environmental impacts throughout the life cycle of a product, from extraction of raw material through production and use to disposal.

LCA could be applied for identification of improvement possibilities, decision making, choice of environmental performance indicators, market claims and learning (Baumann and Tillman 2004).

The procedure of performing an LCA involves three main phases: goal and scope definition, inventory analysis and impact assessment. The framework of an LCA study is shown in figure 1 below.

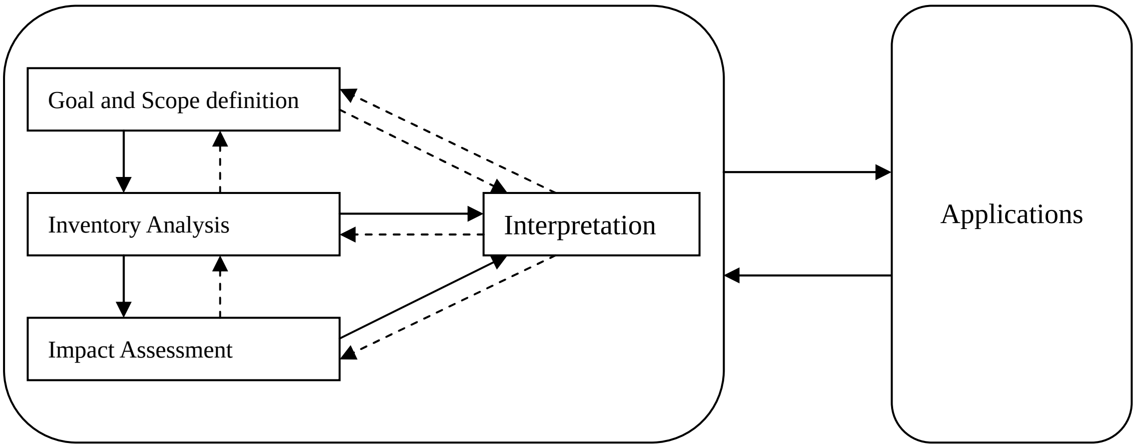

Figure 1: The framework of LCA (Baumann and Tillman 2004).

LCA is an ambitious method that evaluates environmental impact from the whole industrial system involved in the production, use and waste management of a product or service. Ideally, a LCA study should include all parts within a product's lifecycle as complete as possible. However, it is rare that personnel and production of capital goods, i.e. buildings, machinery, vehicles etc, is included in conventional LCAs, because of feasibility (more data to collect) or uncertainty (whether the environmental impact of certain parts of the life cycle is negligible compared to the rest of the life cycle) (Baumann and Tillman 2004). More research and development on these areas are needed to be done to make these issues clearer.

1.3 LCA of buildings

Many academic studies and articles have been presented to assess the environmental effects related to buildings and construction. There are several methods and tools that are applied to the assessment of buildings' impact, such as life cycle assessment (LCA), environmental impact assessment (Scheuer, Keoleian et al.), embodied-energy analysis, and material flow analysis (MFA). Within these methods, the life cycle assessment (LCA) is considered as the most appropriate one for environmental impact assessment of buildings and construction (Kohler and Moffatt 2003).

However, existing LCAs dealing with buildings generally consider the building as a product, when they in fact in most cases are background systems to other products. The environmental impacts from buildings related to the products are excluded when performing LCAs on products. Interestingly, many presented LCAs of buildings have indicated that the operation phase (heat and electricity) accounts for a major part of the impact in all assessed categories (Adalberth, Almgren et al. 2001; Finnveden and Palm 2002; Junnila 2004; Scheuer, Keoleian et al. 2003; Suzuki and Oka 1999). The procedure of producing products in a building belongs to the use phase of the building. Thereby, it is necessary to consider buildings environmental impact when performing LCAs for products. From a market perspective, a way to create a stronger demand for environmental friendly buildings from customers could be to include the environmental impact from buildings in clear relation to all other sources of environmental impacts in the product's life cycle.

Taking all these situations and questions discussed above into consideration, we perform this study to ascertain if it is necessary to include buildings' environmental impact into a product's environmental life cycle assessment.

1.4 Purpose

The purpose of this project is to investigate the importance of buildings' contribution to environmental impact in products' lifecycle and to develop a tentative method to calculate and include the buildings' environmental impacts into product's Life Cycle Assessment (LCA).

2 Methodology

This chapter describes the methodology of the study. Methods of data collection as well as approach of weighting importance of buildings' environmental impact in products' life cycle are presented.

2.1 Research method

The case study method with embedded quasi-LCA analysis has been chosen to apply to the research. In general, case study is the preferred strategy when "how" or "why" questions are posed and when the investigator has little control over events and desires to understand complex social phenomenon (Yin and Campbell 2003). The suitability of case study was supported by the fact that environmental issues within product's life cycle is complex and the transparency of relative importance of buildings' environmental impact in product's life cycle is not clearly evident. Case study was selected also because the study *compares* environmental impacts from building with environmental impacts from production processes within the same system boundary. In addition, the potential application of the study – gaining in-depth knowledge of the case and supporting decision making – was also the reason why case study was opted for.

A conventional life cycle assessment of a product takes into consideration of environmental impact of production process throughout the life cycle of the product. In this study we will add environmental impact from buildings to the assessment. All buildings associated with each phase in the life cycle of the product are investigated. The life cycle model including buildings is illustrated in figure 2.

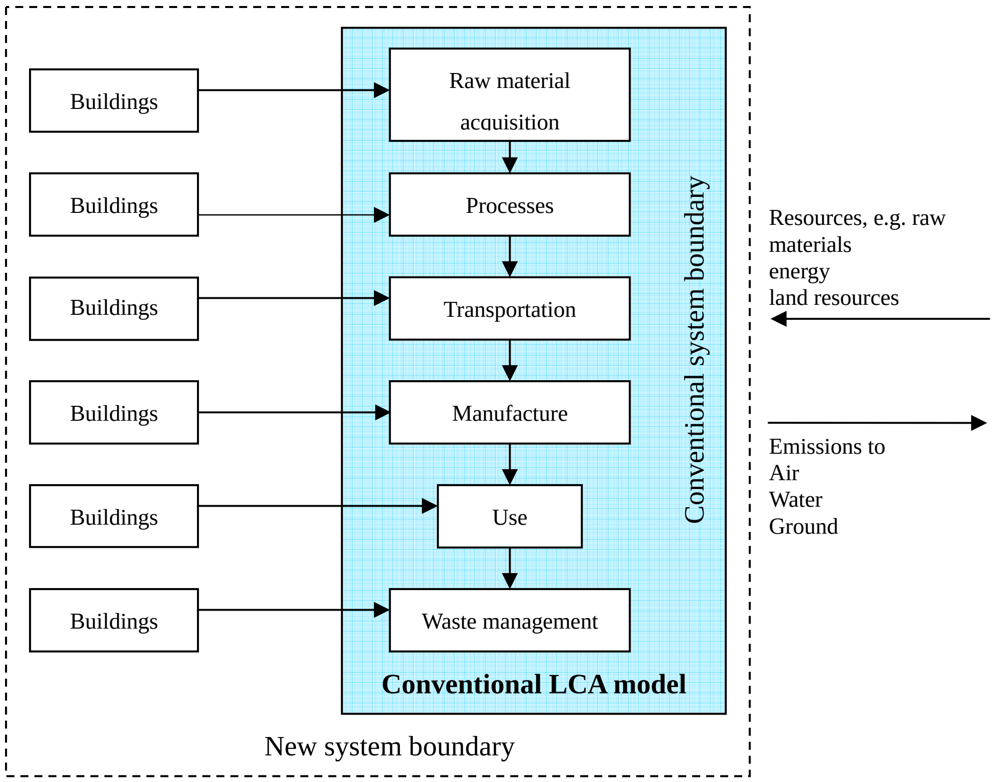

Figure 2: *The life cycle model including buildings.*

2.2 Selection of case

Based on the purpose and attribute of this study, there are some factors which conduct selection of investigated product. First, the production process of the considered product should not be too complex to achieve in limited time of the study. Second, the geographical boundary of the production should not be too wide to collect data. Third, there is a complete LCA study of the product to be ready for using as base study. Taking account of these three factors, I have determined to choose one of SKF's spherical roller bearing as the studied product. The finished LCA study of the product, "Life Cycle Assessment on SKF's Spherical Roller Bearing" (Ekdahl 2001), is referred as the base study.

2.2 Method of data collection

Interview with responsible persons is the main approach of data collection. Discussion on site with interviewee has been performed as much as possible. This data search strategy has been proved to be the most successful one to collect data (Baumann and Tillman 2004).

However, the personal interview is not always available, some because of the time limit of the study and some due to the distance between the parties is very large. Therefore, phone interview, mail, fax, email or a combination of above had also been used during the data collection. These methods are more time-consumed than face-to-face interview, but they have given good results as well though not immediately.

Literatures, reports from LCAs and similar project, and online databases have been accessed as data sources in the data collection.

No matter how thorough the investigator, there will always be some data gaps. Estimation and assumption from technical experts or model calculations have been used to fill these gaps.

2.3 Measuring buildings

The measurement of importance of buildings' environmental impacts in products' life cycle includes two steps: environmental impact assessment of buildings and comparison of the environmental load between production processes and buildings. Activities performed in these two stages will be described below.

2.3.1 Environmental impact assessment of buildings

In this study, a quasi-LCA method is used to assess the environmental impact of buildings. The three main phases of the analysis named scope definition, inventory analysis and impact assessment are described as following.

2.3.1.1 Scope definition

In the scope definition phase, all the choices that are necessary to model the investigated system and to evaluate buildings' environmental impact are made. The crucial elements which are needed to be defined comprise functional unit, system boundary, allocation method and choice of impact category.

Functional unit corresponds to a reference flow to which all other flows of the system are related. It also describes the function, benefit and performance of the product. It is important to note that it is essential the functional unit is the same as the based LCA study to simplify the comparison between production processes and buildings within the life cycle of the studied product.

System boundaries need to be specified in several dimensions (Baumann and Tillman 2004):

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

To be consistent with the base study and make the comparison in a reasonably fair way, the system boundary is defined to be identical to the one used in the base study.

However, there is a particular boundary issue associated with buildings need to be defined. Due to building-related environmental impact comes from the whole life cycle of buildings from construction through use, maintenance to demolition, it is necessary to make decision of the phases you want to investigate.

Allocation needs to be applied to those situations where the building has multiple functions and where several production processes are carried out in the same building, if the environmental load is to be expressed in relation to only one of the products. The recommended order of preference between allocation methods is described as following:

1 Whenever possible allocation should be avoided by identifying buildings exclusively related to the studied product

2 Where allocation cannot be avoided the environmental loads should be partitioned between different products or buildings' various functions. Partitioning should reflect *underlying physical relationships* between products and buildings. The resulting allocation will not necessarily be in proportion to any simple measurement such as the mass or molar flow of the co-products.

3 Where physical relationships alone cannot be established or used, allocation may be based on the other relationships between products, such as economic valued of products.

One should always be aware of that the differences in result might get from using different basis for the allocation method.

Choice of impact categories is also one of the important steps because the concept *environmental impact* implies a number of different things. The ISO standard gives headlines for impact categories: resource use, ecological consequences and human health (ISO 14040 1997). However, it is recommended that the impact categories are defined in terms of more operational way , like global warming, acidification, eutrophication etc. (Baumann and Tillman 2004). In addition, it is also important to keep the impact categories as same as in the base study.

2.3.1.2 Inventory analysis

Having defined the principles of system boundaries and other pivotal requirements for modeling the studied system, the second step, inventory analysis is ready to progress. Activities of inventory analysis include:

1. Construction of the supply chain of the product according to the system boundaries defined in the scope definition.

2. Identification of buildings under consideration.

3. Data collection of all identified buildings in the product system followed by documentation of collected data.

4. Calculation of the environmental loads of the system in relation of the functional unit.

Supply chain has been used here instead of a flowchart which is conventional in LCA study. A *supply chain* consists of all stages involved, directly or indirectly, in fulfilling a customer request. The supply chain not only includes the manufacturer and suppliers, but also transporters, warehouses, retailers, and customers themselves (Chopra and Meindl 2001). The reason why supply chain is congruent is that it is more helpful to identify buildings. Conventional LCA flowcharts focus on modeling detailed production activities and flows between them within the defined system. What we investigate in this study is one type of capital goods – buildings. *Capital goods* refer to real products that are used in the production of other products but are not incorporated into the new product that is derived from the production of the older product (Wikipedia 2006). Therefore, detailed information of production processes is not necessary. The important issue is where the product and components are produced. The choice of supply chain is also supported by the fact that the activities indirectly related to production, such as management of product, support services etc are not included in conventional LCA flowcharts. While in this study, we concentrate on investigating environmental impact of buildings which are involved in the whole organizational system of a certain product. Consequently, the general framework of flows of materials and products is more suitable. It is worth to mention that the supply chain used in this study is subject to the defined system boundary, and thereby maybe not a complete supply chain.

Identification of buildings is the second step of inventory analysis. The entities of the supply chain consist of manufactures, material suppliers, distributors and service providers. Each entity normally represents a corporation/firm. Hence, the identification of buildings can be disassembled to each firm. Buildings both directly and indirectly related to the studied product in each company are investigated in this study. They mainly could be sorted and assigned to three groups: production group, administration group and support service group. See table 1.

Table 1 Types of buildings considered in firms in this study.

Buildings	Sub-department
Administration group	
Office	Administration
	HRM
	Marketing
	Logistic
	IT
	R & D
	Auditoriums
	Purchase & sales
	Security department
Shops	Retailer
	Exhibition halls
Production group	
Factories	Operational place
	Change rooms
	Factory-integrated office
Waste treatment plants	Waste water treatment plant
	Recycling station
Workshops	
Warehouses	
Support group	
Laboratory	
Leisure Place	
Restaurants	
Energy center	
Parking place	
Dormitory	
Temporary Buildings	Remote areas
	Additional offices

Data collection is one of the most time-consuming stages. Environmental relevant data of buildings, i.e. material and energy flows and emissions, is collected and analyzed. In addition, products information and data used to support allocation need to be collected as well, such as economic valued of products and physical relationships between flows.

2.3.1.3 Impact assessment

The aim of impact assessment is to describe the environmental consequences of the environmental loads quantified in the inventory analysis and to make the results more readable, comprehensible and easier to communicate. The two core sub-phases of impact assessment are classification, characterization.

Classification aims at sorting and assigning the inventory result parameters into the various impact categories. Certain substance could contribute to more than one impact category. For instance, NO_x is assigned to both acidification and eutrophication.

Characterization is a quantitative step. The environmental loads are calculated per category using equivalency factors which reflect the common denominator of pollutants of the corresponding category. The characterization methods are in principle based on the physico-chemical mechanisms which indicate the cause-effect chain in the natural systems. Therefore, the characterization is objective.

2.3.2 Comparison of environmental impact

By comparing environmental impact from buildings with the impact of production process in the based LCA study, we can measure the relative importance of buildings' environmental in products' life cycle.

3 Aim of the study

In this chapter, the aim and the intended application of the study are defined. In addition, the intended audiences of the study are stated as well.

3.1 Aim

The aim of the study is to weight the relative importance of buildings' environmental impact in products' life cycle. The intended application of the study is to increase the awareness of companies that it is important to request and buy/build environmentally friendly buildings.

The purpose is further to develop a tentative method to include buildings' environmental impact into products' LCAs.

3.2 Intended audiences

The intended audience of the study is mainly decision makers and employees who work at environmental issues at SKF. It is critically reviewed by the supervisors at Chalmers and SKF as well as by the examiner at department of Environmental System Analysis at Chalmers University of Technology.

4 Case study: SKF's Spherical Roller Bearing

In this chapter SKF, Spherical Roller Bearings and the base study are described.

4.1 SKF

Established by a Swedish engineer Mr. Sven Wingquist in 1907, SKF Group is the leading global supplier of products, customer solutions, and services in the business of rolling bearings and seals today. The SKF Group has 150 companies with 38748 employees and 105 production sites all over the world. The head office is located in Göteborg, Sweden (SKF 2005a).

SKF focused intensively on quality, technical development and marketing from the very beginning. The various divisions have been approved for quality certification in accordance with either ISO 9000 or QS 9000. Meanwhile, the group also pays special attention to sustainability issues and commits itself to reduce environmental impact from its production. It has a global ISO 14000 environmental certification and was included in the Dow Jones Sustainability Indexes for the fifth year running. The Dow Jones Analysis placed the SKF Group first in the Environmental Dimension of its sector. SKF has run energy reduction programs at all units for some years (SKF 2005b). A concrete target for reduction of carbon dioxide emission was introduced in 2005: decreasing emissions by 5% per year - irrespective of the volume (SKF 2005c).

4.2 Spherical Roller Bearing

Spherical roller bearings (SRB) are inherently self-aligning heavy-load carriable, see figure 3. They have five different components: outer ring, inner ring, rollers, cages and guide rings. One spherical roller bearing has two rows of rollers with a common sphered raceway in the outer ring and two inner ring raceways inclined at an angle to the bearing axis, and the rollers are embedded in cages and separated by a guide ring which is centered on the inner ring to guide rollers, see figure 4 (SKF 2005a). They are self-aligning and consequently insensitive to misalignment of the shaft relative to the housing and to shaft deflection or bending. In applications the bearing is fit into a bearing housing.

Figure 3: *Spherical roller bearing. The bearing in the figure is not a SRB24024 but a spherical roller bearing with fewer rollers. The appearance is nevertheless very similar (Ekdahl 2001; SKF 2005a).*

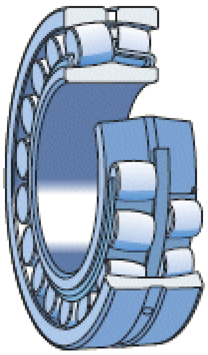

Figure 4: *Section plane of a spherical roller bearing (SKF 2005a).*

SKF's bearings are widely used in different branches of industry from vehicles manufacturers to household appliances maker (SKF 2004). For example, SKF's spherical roller bearings are used for continuous casting at the Avesta-Sheffield plant which is located in Degerfors, Sweden. There are 1100 bearings of different types used in a caster including two spherical roller bearings 24024 are installed in gear drives. It also includes two split spherical roller bearings which are directly under the cast steel and thereby exposed to extreme conditions, especially heat. All bearings are changed every 1,5-3 years (Ekdahl 2001).

4.3 Base study: LCA of SRB 24024

The bearing investigated in this study is one medium size spherical roller bearing, SRB 24024. Life cycle assessment of this specific bearing has been conducted in 2001 by Chalmers University of Technology titled “Life Cycle Assessment on SKF’s Spherical Roller Bearing”. This report will be used as based material for this study. SRB 24024 has the following properties (Ekdahl 2001):

Components: outer ring, inner ring, guide ring, 2 cages and 52 rollers
Outer diameter: 180 mm
Inner diameter: 120 mm
Width: 60 mm
Weight: 5.40 kg

5 Scope definition

In this chapter the scope of the case study is defined. The system boundary, functional unit and choice of environmental impact categories are defined and explained.

5.1 Functional unit

Conventionally, the functional unit used to assess environmental impact of buildings is per square meters. However, the functional unit of this study is *one spherical roller bearing of type 24024 ready for sale*, in order to be consistent with the based LCA study and to simplify the comparison.

5.2 System boundary

According to the principles of system boundaries definition described in chapter 2, boundaries related in this study are defined.

5.2.1 Boundaries in relation to natural system

A building's life cycle is normally considered starting from manufacturing of construction materials, through construction, use, maintenance and ending with demolition. A building's life is very complex, it consumes a lot of materials either trace back to the nature or stay in the techno-sphere, emits plenty of pollutants and generates much waste within each phase.

Nevertheless, the study only considers emissions to air and water and residues stayed at the techno-sphere from energy consumption during operational phase.

5.2.2 Time boundaries

Most of the site-specific data are based on production and consumption in the year 2005, except for data from the steel company SSAB is based on 1999 measurement. But there are no dramatic changes of the steel production processes and of the buildings' operational system; therefore the data is also suitable for using.

The database of Swedish energy mix (electricity and heat) is taken from the CIT Ekologik database in order to make the comparison with the corresponding LCA study in a fair way.

5.2.3 Geographical boundaries

Most of corporations involved in the supply network are located in Sweden except for the manufacturer of inner ring, which is located in Poland and manufacturer of outer ring, which is located in France.

5.2.4 Boundaries within technical system

Environmental impact of a building comes from the whole life cycle phases, i.e. from manufacturing of building materials through construction, operation and maintenance to demolition. It is necessary to decide which phases need to be considered.

There are many scientific studies researched in buildings' environmental impact by applying LCA. They happen to have the same view that the operational phase accounts for the major part of environmental impact. Researches on commercial buildings indicate that use phase shares 80-90% of total impact within 50-year service life (Scheuer, Keoleian et al. 2003; Suzuki and Oka 1999). Investigation of residential buildings shows the same picture, operational phase contributes 70-90% across all assessed impact categories (Adalberth, Almgren et al. 2001; Junnila and Saari 1998; Ochoa, Hendrickson et al. 2002).

Based on these researches and in order to simplify the data collection, I decided to just focus on environmental impact during the use phase of buildings in this study.

Activities which cause environmental impact could be divided into three service group: heating service, electricity service and other services (water use, wastewater generation, courtyard care/landscaping and office waste generation). In this study, data is only collected for heating service and electricity service rather than other services because of the low availability of these types of data and limited time of the project.

Allocation method used in this study is mainly based on weight. Allocation according to internal distribution keys and economic value are also applied to some factories. Comparison of different allocation methods, i.e. based on products number, will be discussed in chapter 9.

5.3 Choice of environmental impact categories

In order to compare the environmental impacts between buildings and production process, the environmental impact categories assessed in this study are the same as the base LCA study of spherical roller bearing 24024 (Ekdahl 2001):

- Acidification
- Eutrophication
- Global warming (100years)
- Ecotoxicity, aquatic
- Human toxicity, air
- Human toxicity, water
- Photochemical oxidant creation (0-4days high NO_x)
- Resource depletion

6 Inventory Analysis

In this chapter the supply chain of the studied bearing is constructed, the entities involved in the whole supply chain are briefly described, the method of identification of buildings is presented and the inventory data is collected and calculated.

6.1 Supply chain

The studied objects in this study are all buildings either directly or indirectly related to the studied product. Therefore, detailed information of production process is not necessary. Instead, description of organizational system of the investigated product is more useful to identify buildings; such information is firms which are involved in the entire business network of the product and organization of each firm. Supply chain exactly meets these requirements. A supply chain consists of manufactures, material suppliers, distributors, service providers and material flows. By constructing the supply chain of the studied product, we are able to identify all entities involved in the business network of the product.

The supply chain of the spherical roller bearing 24024 is shown in figure 5 below. However, subjected to the system boundary defined for the specific product in this study, the supply chain of the spherical roller bearing 24024 is not complete. It has been cut off at the point where the bearing is assembled and ready for sale. Therefore, the customers and end use part are not modeled.

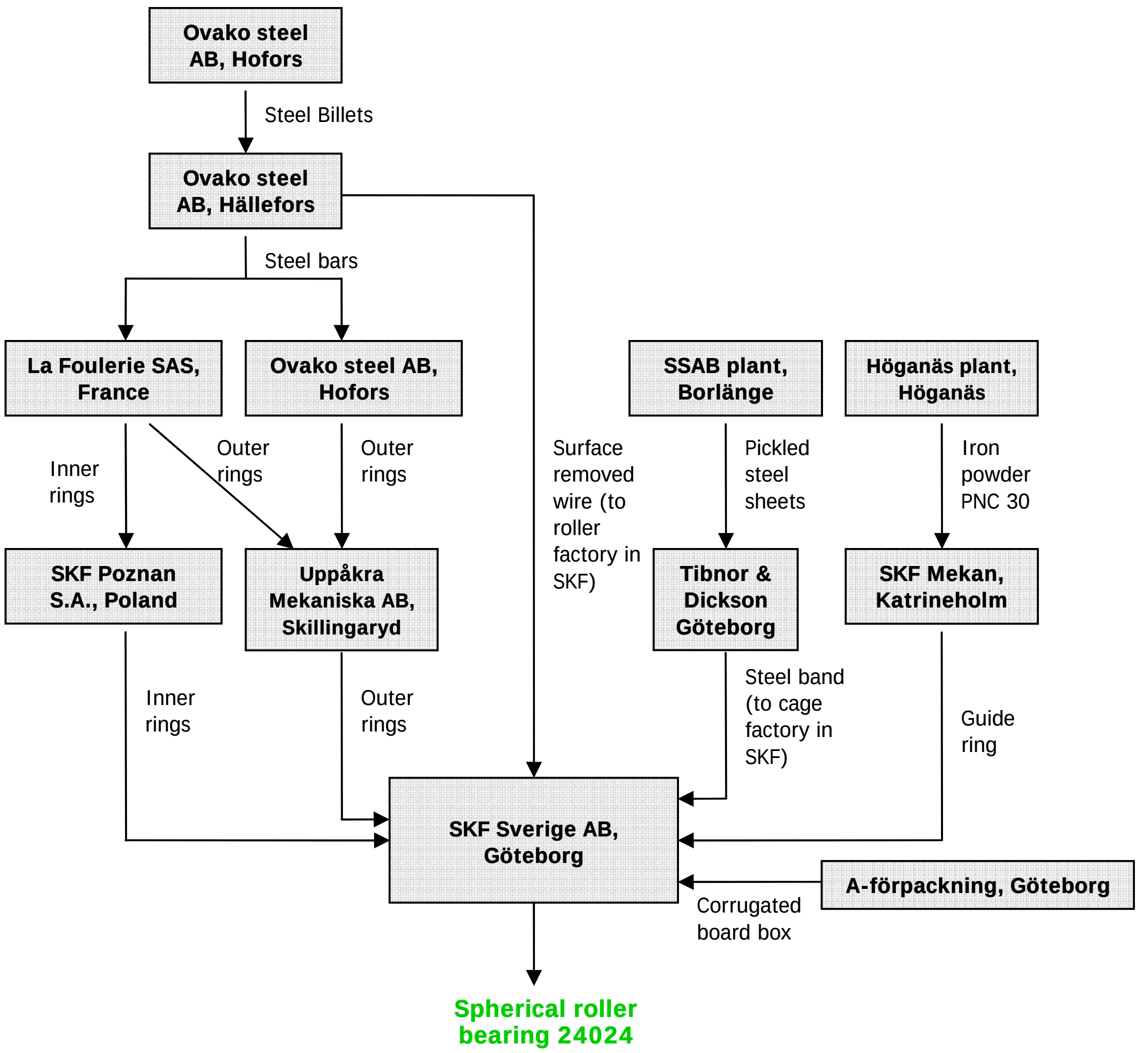

Figure 5: *Supply chain of spherical roller bearing 24024.*

6.2 Entities

The bearing contains five types of components: an inner and an outer ring, rollers, a guide ring and two cages. It is packed in a corrugated board box after the assembly. In the following, a brief introduction of activities in entities within the network of the SRB 24024 is given.

6.2.1 OVAKO Steel AB

OVAKO Steel AB is a leading European long special steel products company with headquarter in Stockholm, Sweden. It is owned by three companies Rautaruukki, SKF and Wärtsilä (OVAKO 2006).

There are two production sites of OVAKO Steel AB involved in the entire network of SRB24024. The raw material of outer and inner rings as well as rollers is steel which is produced from scraps at OVAKO Steel in Hofors, Sweden. In Hofors, scraps are processed to produce square billets with dimension 150 mm which is used to make rollers and rings for SRB 24024.

The square billets are transported to OVAKO Steel in Hällefors to make steel bars with the dimension 70 mm and surface removed wire with dimension 14.50 mm. Then the steel bars are distributed to OVAKO Steel in Hofors and La Foulerie in France to produce rings. The surface removed wire is coiled and transported to SKF in Göteborg to produce rollers.

In OVAKO Steel in Hofors, the outer ring is produced in the ring mills. The outer rings are sent to Uppåkra Mekaniska AB while the inner rings are sent to SKF Poznan S.A. to be turned before being delivered to SKF in Göteborg.

6.2.2 La Foulerie SAS

La Foulerie SAS used to be part of SKF Group until it was sold to an Italian steel company Formas SpA in 1st Jan, 2005 (SKF 2005a). It is located at Carignan, France. Some parts of outer ring and inner ring of SRB24024 are produced by La Foulerie in 2005. The outer rings are sent to Uppåkra Mekaniska AB to do turning before being delivered to SKF in Göteborg.

6.2.3 Uppåkra Mekaniska AB

Uppåkra Mekaniska AB is a leading subcontractor within cutting machining in Sweden and located at Skillingaryd in southern part of Sweden. Uppåkra does turning for outer rings before sending them to SKF in Göteborg.

6.2.4 SKF Poznan S.A.

SKF Poznan S.A. is SKF’s production site in Poland and is owned by SKF. It produces inner rings of SRB24024 and does turning of inner rings from La Foulerie SAS before sending to SKF in Göteborg.

6.2.5 SSAB Tunnplåts

SSAB Tunnplåts is one of the subsidiaries of Swedish Steel AB (SSAB) which is a leading producer of high-strength steel sheet and steel plate with group office in Stockholm in Sweden. SSAB Tunnplåts is located in Borlänge and is the biggest steel sheet manufacturer in Scandinavia (SSAB 2006). It is the raw material supplier of cages for SRB24024. Pickled steel sheets are the raw materials of cages, but the steel sheet is not directly transported to SKF in Göteborg. They are delivered to Dickson Plåt Service Center AB to produce steel band which is then transported to SKF.

6.2.6 Dickson and Tibnor

Dickson Plåt Service Center AB is located in Göteborg and responsible for producing steel band from steel sheets in this study. The steel band is formed in Dickson and transported to SKF to produce cages.

Tibnor is also one of the subsidiaries of SSAB and is located in Göteborg too. It takes care of trade issues between SSAB Tunnplåts and Dickson Plåt Service Center AB.

6.2.7 Höganäs AB

Höganäs AB is the world's largest producer of metal and iron powders and locates at Höganäs in Sweden. It is the raw material suppliers of guide rings for SRB24024. The iron powder is produced in Höganäs AB and sold to SKF Mekan AB to produce guide rings for bearings.

6.2.8 SKF Mekan AB

SKF Mekan AB is located at Katrineholm in Sweden and is in charge of guide rings production. It is a part of SKF group. Guide ring is produced in SKF Mekan and directly transported to SKF in Göteborg for assembly.

6.2.9 A-förpackning

A-förpackning is the distributor of corrugated board box for packaging SRB24024. The box is produced in a company in Malmö which is not included in this study since poor availability of data collection.

6.2.10 SKF Sverige AB

Information of SKF is available in chapter 3. The rollers and cages are produced in SKF in Göteborg. Both outer and inner rings are heat treated in SKF before they go to assembly.

6.3 Identification of buildings

Identification of buildings is a very important step since it directly affects the data completeness of the study. In order to identify buildings related to the studied product accurately, great knowledge of each firm's organization as well as materials/products flow is needed. Site visiting to each company is the best way to handle this issue. However, due to limited time of this study, it has only been done for SKF Sverige AB, SKF Mekan AB, Tibnor and OVAKO Steel in Hofors. For other companies, identification of buildings is done by interviewing and discussing with key persons through phone and via email.

The method used to identify buildings in the case study is as following:

1. Identify studied product in each individual corporation

2. Acquire materials flow associated to the studied product in each firm

3. Identify buildings in three different groups according to the list in table 1

6.4 Inventory results

Data of energy consumption of buildings was collected by interviewing key persons in each company. Site specific data of electricity and heat consumption of every individual building was collected as much as possible in each firm. For those buildings where detail information of energy consumption is not available, estimation from experts was applied.

Having collected the energy use from buildings and the product/materials information in each firm, the electricity and heat consumption of buildings was allocated and related to the functional unit, *one bearing ready-for-sale.* The allocation was based on weight. The allocated results of energy use were shown in the following table. From the table, we can find out that SKF is the biggest consumer of energy. It consumes 58% of electricity and 82% of heat in the entire system.

Table 2 Average energy consumption of buildings in companies for one bearing.

		Energy consumption		Energy resource
	Unit	**Electricity**	**Heat**	
SKF	**kWh**	4.87E+00	9.71E+00	Swedish average
SKF Mekan	**kWh**	6.90E-02	3.78E-02	Swedish average
Ovako steel, Hofors	**kWh**	6.53E-01	9.41E-01	Swedish average
Ovako steel, Hällefors	**kWh**	6.53E-01	-	Swedish average
SSAB	**kWh**	1.15E-02	1.52E-03	Swedish average
Tibnor & Dickson	**kWh**	5.45E-03	1.17E-02	Swedish average
Höganäs	**kWh**	N/A	N/A	Swedish average
Uppåkra	**kWh**	1.05E-01	-	Swedish average
A-förpackning	**kWh**	6.64E-03	7.11E-04	Swedish average
SKF Poznan S.A., Poland	**kWh**	9.23E-01	7.18E-02	Ele (Polish average) Heat (Coal)
La foulerie, France	**kWh**	1.03E+00	1.02E+00	Ele (French average) Heat (Natural gas)
Total	**kWh**	**8.32E+00**	**1.18E+01**	

After the allocation of energy use to the studied product was finished, the inventory results from use of electricity and heat were calculated. In order to make the comparison between this study and the base LCA study of SRB24024 in a fair way, the databases of electricity production and district heating production are the same as the base study.

In case of Swedish companies, the calculation was based on the same database from CIT Ekologik as in the base study (CIT Ekologik 1998a, 1998b).

For the two foreign companies, SKF Poznan S.A. and La Foulerie SAS, the inventory results from electricity use were calculated based on the database from the literature ‘The Hitch Hike’s Guide to LCA’ (Baumann and Tillman 2004a). The electricity mix in France and Poland was based on 1998 level. The district heating used by SKF Poznan S.A. was assumed to be produced from coal fired combined heat and power (CHP) plant, while natural gas is the primary fuel of the CHP plant who supplies heat to La Foulerie SAS. The inventory results from heat use were calculated based on the SPINE@CPM LCI database (CPM 1997a, 1997b).

The inventory data set with selected parameters is shown in the following table 3. The complete data sets could be found in appendices.

Table 3 Emissions to air from energy use of buildings for one bearing.

Substances	**Environment**	**Quantity**	**Unit**
CO_2	Air	2.80E+00	kg
CO	Air	1.04E-02	kg
NOx	Air	5.89E-03	kg
NMVOC[1]	Air	2.17E-03	kg
SO_2	Air	7.69E-03	kg
CH_4	Air	6.05E-03	kg
Particulates	Air	2.28E-03	kg

[1] NMVOC stands for non-methane volatile organic compounds.

7 Impact Assessment

In this chapter the inventory results are classified, characterized and aggregated into different impact categories.

7.1 Classification and characterization

The classification and characterization have been performed in one step. The impact categories presented in the tables below are those with at least one contributing substance. As mentioned before, some substances could contribute to more than one environmental impact category.

The characterization indicators used in this study is according to the "Index list May 2000" provided by CIT Ekologik (Ekdahl 2001), for purpose of being in harmony with the compared LCA study and simplifying the comparison.

7.1.1 Acidification

Emission of substances which contribute to acidification have been characterized and added as SO_2 equivalents. Both emissions to air and water are included. The results are shown in the following table.

Table 4 Acidification (max) (CIT Ekologik, Index list May 2000)

Category Indicator	Substances	Environment	Factor	Quantity	Result	Unit
Acidification potentials	SO_2	Air	1.00E+00	7.69E-03	7.69E-03	kg
	HCl	Air	8.80E-01	1.55E-04	1.36E-04	kg
	NO_x	Air	7.00E-01	5.89E-03	4.12E-03	kg
	NH_3	Air	1.88E+00	5.29E-06	9.94E-06	kg
	NH_3	Water	1.88E+00	1.56E-09	2.93E-09	kg
Total, kg SO_2 equivalents					**1.20E-02**	**kg**

Emission of SO_2 to air is the largest contributor to the acidification. The main source of SO_2 is production of district heating used by Swedish companies.

The second biggest contribution substance is NO_x. The main emitter of NO_x is also the production of district heating, Swedish average.

Therefore, the production of district heating obviously dominates the acidification in this study. While in the base LCA study of the investigated bearing, it is the production of rollers which is responsible for the largest part of this impact category, because of more use of district heating than other components (Ekdahl 2001).

7.1.2 Ecotoxicity, aquatic

Ecotoxicity in aquatic environment is expressed in cubic meter of polluted water and only emissions to water are considered.

Table 5 Ecotoxicity, aquatic (CIT Ekologik, Index list May 2000)

Category Indicators	Substances	Environment	Factor	Quantity	Result	Unit
Ecotoxicity aquatic potentials	As	Water	2.00E+06	1.25E-08	2.50E-02	m3
	Cd	Water	2.00E+09	7.01E-09	1.40E+01	m3
	Cr^{3+}	Water	1.00E+07	9.29E-08	9.29E-01	m3
	Cu	Water	2.00E+07	3.06E-08	6.12E-01	m3
	Ni	Water	3.30E+06	4.82E-08	1.59E-01	m3
	Oil	Water	5.00E+05	1.34E-04	6.68E+01	m3
	Pb	Water	2.00E+07	4.86E-08	9.71E-01	m3
	Zn	Water	3.80E+06	1.37E-07	5.21E-01	m3
Total, m3 polluted water					**8.40E+01**	**m3**

The substance giving the biggest contribution to this impact category is oil. The production of district heating for Swedish companies is the largest emitter of oil to water.

Cadmium (Cd) is the second main contributor to aquatic ecotoxicity. Although the amount of emission of Cd is very low, the indicator of Cd to this impact category is the highest in this characterization method. The main source for Cd is again the production of district heating supplied to Swedish companies.

Evidently, it is the production of district heating again which gives the largest rise to aquatic ecotoxicity. On the compared LCA study side, the main sources of substances contributing to this category are the production of energy wares with the production of liquefied petroleum gas (LPG) as the primary dominator (Ekdahl 2001).

7.1.3 Eutrophication (max)

Substances which cause eutrophication could be released to either water or to air. Eutrophication is expressed in kg NO_x equivalents.

Table 6 Eutrophication (max) (CIT Ekologik, Index list May 2000)

Category Indicators	Substances	Environment	Factor	Quantity	Result	Unit
Eutrophication potentials	PO_4^{3-}	Water	7.69E+00	5.99E-05	4.60E-04	kg
	NO_x	Air	1.00E+00	5.89E-03	5.89E-03	kg
	NH_3	Air	2.69E+00	5.29E-06	1.42E-05	kg
	NH_3	Water	2.69E+00	1.56E-09	4.19E-09	kg
	Total N	Water	3.23E+00	3.87E-05	1.25E-04	kg
	COD	Water	1.69E-01	2.37E-05	4.00E-06	kg
	BOD	Water	1.69E-01	5.70E-07	9.64E-08	kg
Total, kg NOx equivalents					**6.49E-03**	**kg**

Emissions of NO_x to air, principally originated from production of district heating in Sweden, are the main contributor to this impact category.

Followed NO_x, the emission of PO_4^{3-} to water is the second most important substance which causes eutrophication. However, contribution of PO_4^{3-} to this category is much less than NO_x's. The dominated source for emission of PO_4^{3-} is production of electricity for the two foreign companies, La Foulerie SAS and SKF Poznan S.A.

Not surprisingly, the production of district heating contributes most to this impact category once again in this study. Relatively, in the compared LCA study, the eutrophication was distributed among the components and different activities, and there is no distinct dominator (Ekdahl 2001).

7.1.4 Global warming (100 years)

Global warming potential with a time perspective of one hundred years is expressed in kg CO_2 equivalents in this study.

Table 7 Global warming (100 years) (CIT Ekologik, Index list May 2000)

Category Indicator	Substances	Environment	Factor	Quantity	Result	Unit
Global warming potentials	BOD	Water	1.38E+00	5.70E-07	7.87E-07	kg
	COD	Water	1.38E+00	2.37E-05	3.26E-05	kg
	CH_4	Air	2.10E+01	6.05E-03	1.27E-01	kg
	CH	Air	1.10E+01	4.14E-05	4.56E-04	kg
	CO_2	Air	1.00E+00	2.80E+00	2.80E+00	kg
	N_2O	Air	3.10E+02	1.45E-05	4.49E-03	kg
	CO	Air	3.00E+00	1.04E-02	3.13E-02	kg
	NOx	Air	7.00E+00	5.89E-03	4.12E-02	kg
	PAH	Air	1.10E+01	1.60E-08	1.75E-07	kg
	Propene	Air	1.10E+01	1.91E-06	2.10E-05	kg
Total, kg CO_2 equivalents					**3.00E+00**	**kg**

Regarding to this impact category, the emission of carbon dioxide (CO_2) is obviously shown to be the biggest dominator. Both productions of electricity and district heating are important source for emission of CO_2. Each of them approximately accounts for 50% of total CO_2 release.

The second important contributor of global warming potential is emission of methane (CH_4). Production of electricity used by La Foulerie and SKF Poznan S.A. is the main source CH_4 emission. However, the contribution of CH_4 to this impact category is still much less than effect of CO_2.

The production of electricity and the production of district heating have approximately the same contribution to this impact category in this study. Similar to it, electricity as well as district heating used in the process chain of rings had the largest contribution to global warming in the finished LCA study of the bearing (Ekdahl 2001).

7.1.5 Human toxicity

Human toxicity is expressed in kg contaminated bodyweight and presented both for emissions to air and water in this study.

7.1.5.1 Air

Table 8 Human toxicity, Air (CIT Ekologik, Index list May 2000)

Category Indicator	Substances	Environment	Factor	Quantity	Result	Unit
Human toxicity potentials, Air	As	Air	4.70E+03	1.83E-07	8.58E-04	kg
	Cd	Air	5.80E+02	6.51E-08	3.77E-05	kg
	CO	Air	1.20E-02	1.04E-02	1.25E-04	kg
	Cr^{3+}	Air	6.70E+00	1.27E-06	8.52E-06	kg
	Cu	Air	2.40E-01	1.04E-06	2.49E-07	kg
	Dioxin	Air	3.30E+06	4.82E-13	1.59E-06	kg
	Hg	Air	1.20E+02	1.21E-07	1.45E-05	kg
	Ni	Air	4.70E+02	1.73E-06	8.13E-04	kg
	NOx	Air	7.80E-01	5.89E-03	4.59E-03	kg
	PAH	Air	1.70E+01	1.60E-08	2.71E-07	kg
	Pb	Air	1.60E+02	9.44E-07	1.51E-04	kg
	SO_2	Air	1.20E+00	7.69E-03	9.23E-03	kg
	Toulene	Air	3.90E-02	1.05E-06	4.10E-08	kg
	V	Air	1.20E+02	1.02E-06	1.23E-04	kg
	Zn	Air	3.30E-02	1.21E-06	3.98E-08	kg
Total, kg contaminated bodyweight					**1.60E-02**	**kg**

Emission of SO_2 is the largest contributor of this impact category. The investigated two activities, production of electricity and district heating, account for 57% and 43% of the emission individually.

The second important dominator of human toxicity air is release of NO_x. The main source of NO_x emission is the production of district heating in Sweden.

7.1.5.2 Water

Table 9 Human toxicity, Water (CIT Ekologik, Index list May 2000)

Category Indicator	**Substances**	**Environment**	**Factor**	**Quantity**	**Result**	**Unit**
Human toxicity potentials, Water	As	Water	1.40E+00	1.25E-08	1.75E-08	kg
	Cd	Water	2.90E+00	7.01E-09	2.03E-08	kg
	Cr^{3+}	Water	5.70E-01	9.29E-08	5.29E-08	kg
	Cu	Water	2.00E-02	3.06E-08	6.12E-10	kg
	Ni	Water	5.70E-02	4.82E-08	2.75E-09	kg
	Oil	Water	9.20E-04	1.34E-04	1.23E-07	kg
	Pb	Water	7.90E-01	4.86E-08	3.84E-08	kg
	Sn	Water	1.40E-03	8.28E-06	1.16E-08	kg
	Zn	Water	2.90E-03	1.37E-07	3.98E-10	kg
Total, kg contaminated bodyweight					**2.67E-07**	**kg**

The drainage of oil into water environment is the biggest contributor of human toxicity water. It accounts for approximately 50% of the total impact. The main cause of this release is the production of district heating consumed by Swedish companies. The second largest contributor of this impact category is emission of Cr^{3+}. Again, the production of district heating is the main emitter of this substance.

7.1.5.3 Discussion

It is easy to address that the production of district heating accounts for the largest contribution to human toxicity in both air and water environment in this study. Comparatively, the transportation by electric trains and the production of district heating used in the process chain of rollers dominate the human toxicity (air); while the consumption of LPG within the process chain of rings has the largest influence on human toxicity (water) in the compared LCA study (Ekdahl 2001).

7.1.6 Photochemical oxidant creation (0-4 days, high NO_x)

The photochemical oxidant formation potential is expressed in kg ethane equivalents.

Table 10 Photochemical oxidant creation (0-4 days, high NOx) (CIT Ekologik, Index List May 2000)

Category Indicator	Substances	Environment	Factor	Quantity	Result	Unit
Photochemical oxidant creation potentials	Aromatics	Air	7.61E-01	4.35E-07	3.31E-07	kg
	Benzene	Air	4.02E-01	3.02E-06	1.22E-06	kg
	CH_4	Air	7.00E-03	6.05E-03	4.24E-05	kg
	CO	Air	3.20E-02	1.04E-02	3.33E-04	kg
	Ethene	Air	1.00E+00	1.01E-05	1.01E-05	kg
	Formaldehyde	Air	3.79E-01	6.36E-07	2.41E-07	kg
	HC	Air	3.37E-01	2.13E-05	7.19E-06	kg
	NMVOC	Air	4.16E-01	2.17E-03	9.01E-04	kg
	Pentane	Air	3.00E-01	3.34E-06	1.00E-06	kg
	Propene	Air	1.06E+00	4.20E-06	4.45E-06	kg
	Toulene	Air	5.65E-01	1.05E-06	5.94E-07	kg
	VOC	Air	3.77E-01	4.39E-05	1.65E-05	kg
Total, kg ethene equivalent					**1.32E-03**	**kg**

Emissions of NMVOC and CO are two biggest contributor of photochemical oxidant creation. The main source of them is production of district heating.

On the other hand, the activities primarily dominating this impact category in the base study were the consumption of energy and the release of carbon monoxide from the heat treatment (Ekdahl 2001).

7.1.7 Resource depletion (Reserve based)

Reserve-based resource depletion is defined as the part of an identified resource that meets minimum physical and chemical criteria to current mining and production practices. Only resources, whose depletion is judged to become, or still be, a problem within the next one hundred years are considered in the characterization method (Ekdahl 2001; Lindfors 1995).

Table 11 Resource depletion (Reserve based) (CIT Ekologik, Index list May 2000)

Category Indicator	Substances	Environment	Factor	Quantity	Result	Unit
Resource depletion potential, reserve based	Copper ore (0.35% Cu)	Resource	1.03E-14	6.83E-05	7.04E-19	kg
	Crude oil	Resource	8.09E-15	2.44E-01	1.97E-15	kg
	Hard coal	Resource	7.00E-16	8.71E-01	6.10E-16	kg
	Iron ore	Resource	4.35E-15	2.29E-04	9.94E-19	kg
	Natural gas	Resource	9.15E-15	1.65E-01	1.51E-15	kg
	Peat	Resource	7.00E-16	1.55E-01	1.08E-16	kg
	Uranium ore	Resource	5.96E-10	1.27E-04	7.57E-14	kg
Total, kg reservebase-1					**7.99E-14**	**kg**

Uranium (U) ore is the substance which dominates the resource depletion category. Uranium ore is mainly used to refine uranium which is then consumed as primary energy resource to produce electricity in nuclear power plant.

Crude oil which is the second largest contributor of this impact category is used to produce both electricity and district heating. The production of district heating is the primary consumer of crude oil in this study.

Natural gas has the third largest influence on this impact category. It is mainly used to produce district heating in this study. La Foulerie SAS is the biggest consumer of natural gas since heat consumed in the firm is produced only from natural gas.

It is easily seeing that the production of electricity is responsible for the largest contribution to this impact category in this study. While in the base study, the consumptions of steel and energy (electricity and natural gas) affect resource depletion most (Ekdahl 2001).

7.2 Discussion

From the above analysis, we can obviously find out that the production of district heating dominates most of the impact categories in this study. The most important pollution substances are CO, CO_2, SO_2, CH_4, NO_x and NMVOC to air and oil to water environment.

The site-specific data is only collected for the energy consumption of buildings in the operational phase in this study. If we consider other activities during the use phase and include other phases of buildings, the environmental impacts will be larger than what has been shown here.

The environmental impacts are assessed according to the index list from CIT Ekologik which is identical to the base study. Some emitted substances have not been included in the index list, see table 12. Therefore, it gives reason to believe that the environmental impacts will be higher than what is expressed here if the assessment of emissions is more complete.

Table 12 Substances not included in the index list of characterization method.

Direction	FlowType	Substance	Unit	Environment	Total
Input	Non-elementary	Biomass	kg	Technosphere	5.77E-01
Input	Resource	Bentonite	kg	Ground	3.21E-05
Input	Resource	Lead in ore	kg	Ground	8.23E-07
Input	Non-elementary	Lime	kg	Technosphere	8.71E-03
Input	Non-elementary	Sulphuric acid	kg	Technosphere	5.18E-04
Output	Emission	Co	kg	Air	3.27E-07
Output	Emission	Cs-134	kBq	Air	6.67E-06
Output	Emission	Kr-85	kBq	Air	8.61E+02
Output	Emission	Particles	kg	Air	2.28E-03
Output	Emission	Radioactive	kBq	Air	1.27E+07
Output	Emission	Rn-222	kBq	Air	1.64E+03
Output	Emission	Sr-90	kBq	Air	9.19E-06
Output	Emission	Sb	kg	Air	1.47E-07
Output	Emission	Se	kg	Air	1.16E-07
Output	Emission	U-238	kBq	Air	1.06E-04
Output	Emission	Dissolved solids	kg	Water	1.44E-04
Output	Emission	Radioactive	kBq	Water	1.19E+05
Output	Emission	Cs-134	kBq	Water	1.18E-03
Output	Emission	Sr-90	kBq	Water	1.11E-03
Output	Emission	Sr	kg	Water	5.24E-07
Output	Emission	Suspended solids	kg	Water	1.71E-06
Output	Emission	U-238	kBq	Water	3.97E-04
Output	Non-elementary waste	Hazardous	kg	Technosphere	2.29E-02
Output	Non-elementary waste	Highly radioactive	kg	Technosphere	1.71E-04
Output	Non-elementary waste	Medium and low radioactive waste	m3	Technosphere	4.76E-08
Output	Non-elementary waste	Waste in deposit	kg	Technosphere	2.32E-01

8 Analysis

In this chapter, the environmental impacts from buildings and from production process are compared and some further analyses are performed.

8.1 Comparison between buildings and production processes

The main purpose of this study is to investigate the importance of buildings' environmental impact within products' life cycle by applying a case study. This has been done by comparing results from this study with corresponding results in the base LCA study, "Life cycle assessment on SKF's spherical roller bearing". The comparison has been performed in several dimensions.

8.1.1 Energy consumption

The electricity and heat consumption in buildings and in production processes are compared and shown in the following table 13. The results are expressed in buildings' percentage of value of buildings and processes in total.

Table 13 Energy consumption in buildings and production processes for one bearing.

		Energy consumption	
	Unit	**Electricity**	**Heat**
Buildings	kWh	8.32E+00	1.18E+01
Production processes(Ekdahl 2001)	kWh	3.90E+01	1.28E+01
Buildings proportion	%	17.58	48.02

The results in the above table show that buildings consumed electricity shares 18% of total value of electricity use in buildings and processes while buildings' consumption of heat possesses 48% of total heat utilization within the life cycle of the spherical roller bearing 24024.

Relatively, energy consumption was the most important source of environmental impact in Ekdahl. The energy carriers include electricity, heavy fuel oil and district heating which is the dominator of most environmental impact categories in production processes (Ekdahl 2001).

Consequently, it can be expected that buildings' environmental impact will be comparable with the environmental loads from production processes within the life cycle of the investigated product.

8.1.2 Environmental impacts

Environmental loads expressed with different impact categories describe the environmental consequence in a more readable way. Consequently, it is easier and clearer to find out the importance of buildings' environmental impact in products' life cycle by comparing different impact categories between buildings and processes. The distribution of environmental loads over buildings and production processes within the life cycle of the studied product is shown in figure 6.

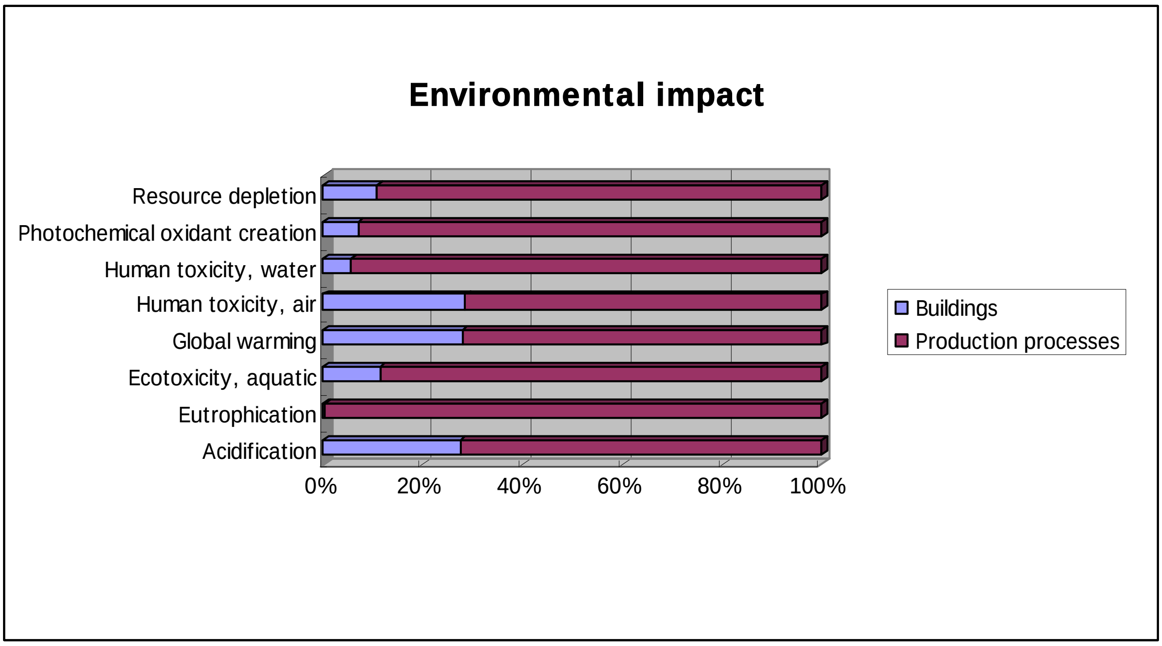

Figure 6: *Distribution of environmental impacts over buildings and production processes for producing one bearing.*

In perspectives of acidification, global warming and human toxicity (air), buildings' contribution to them are comparable to production processes' within the life cycle of the studied product.

In addition, the compared LCA study included the production of district heating used to heat the roller factory in SKF in Göteborg and this activity was identified to be the main contributor to acidification (Ekdahl 2001). Thinking over this situation, it will give buildings higher proportion in acidification than what is indicating in figure 6.

In case of aquatic ecotoxicity, photochemical oxidant creation, human toxicity (water) and resource depletion, buildings have much less contribution in these impact categories than production processes.

Regarding to eutrophication, buildings contribution to it is neglectable comparing to the influence from production processes.

As mentioned before in section 7.2, see table 12, the inventory data of buildings as well as the impact assessment of emissions are not complete. They will give higher values to all impact categories related to buildings in this study if all of them are more complete. Moreover, it is reasonable to believe that certain parts of the energy consumption (e.g. district heating) in some factories were included in the based LCA study. They will lower the environmental impact from production processes if they were withdrew.

It is justifiable to say that buildings have considerable importance on environmental impact, even though not as great as the production processes, within the life cycle of the studied product.

8.1.3 Important parameters

"Although the overall results are the main objective in comparison, it is often interesting to analyze the results in a more detailed way. Instead of looking at the results at the level of the whole life cycle, it is possible to also look "inside" the life cycle. The analytical purpose of this is to identify for which activities in the life cycle improvements are most needed"(Baumann and Tillman 2004).

In the referenced LCA study, a dominance analysis was performed to identify which component/activities give greatest rise to certain important/dominant pollutants. In this study, the same pollutants released from operation of buildings are added and compared with emissions from production processes firstly. The dominance analysis is re-performed within the new system simultaneously encompassing buildings and production processes. Values of emissions related to components of a bearing are originally cited from the report "Life cycle assessment on SKF's spherical roller bearing" (Ekdahl 2001).

8.1.3.1 Distributions of selected emissions

Emissions of selected substances which dominate different environmental impacts categories in both the referenced study and this study are investigated. The distribution of these major pollutants over buildings and production processes within the life cycle of SRB24024 is shown in figure 7. The real values of emissions for producing one bearing are shown in appendix VI.

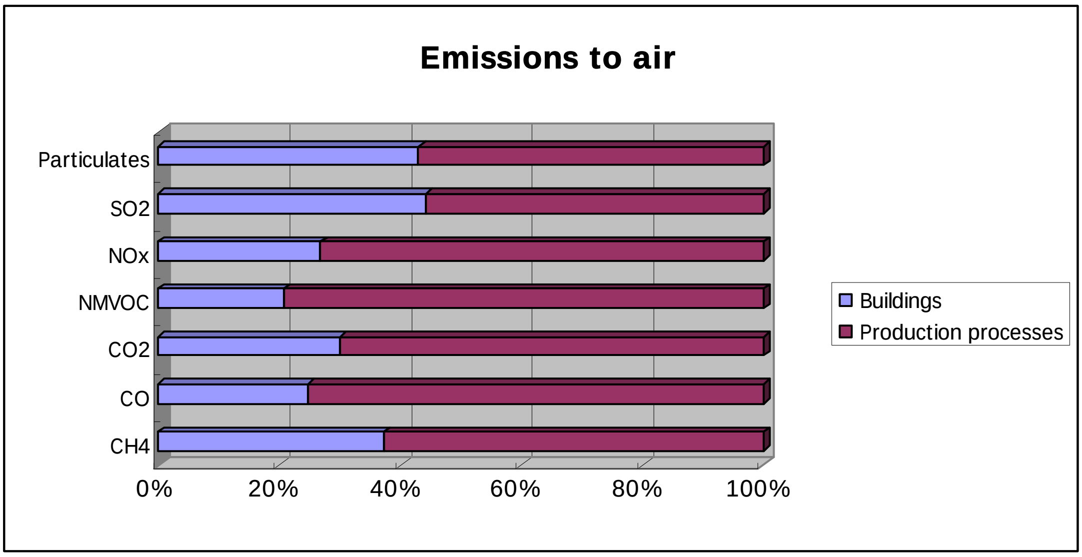

Figure 7: *Distributions of selected substance emitted to air over buildings and production processes for producing one bearing.*

Buildings and the production processes have roughly the same contributions to emissions of sulphur dioxide (SO_2) and particulates. Whereas in the cases of CO, NO_x, CO_2 and CH_4, buildings account for 30%-40% of total emissions of these pollutants. At last, approximately 20% of NMVOC emission is conduced by buildings operation.

Consequently, from the angle of dominating pollutants, it is absolutely necessary to include buildings' environmental impact into the life cycle assessment of the spherical roller bearing 24024. Besides, it is important to remember that the inventory data of buildings in this study is not completed.

8.1.3.2 CH_4

Emissions of methane (CH_4) contribute to global warming and photochemical oxidant creation.

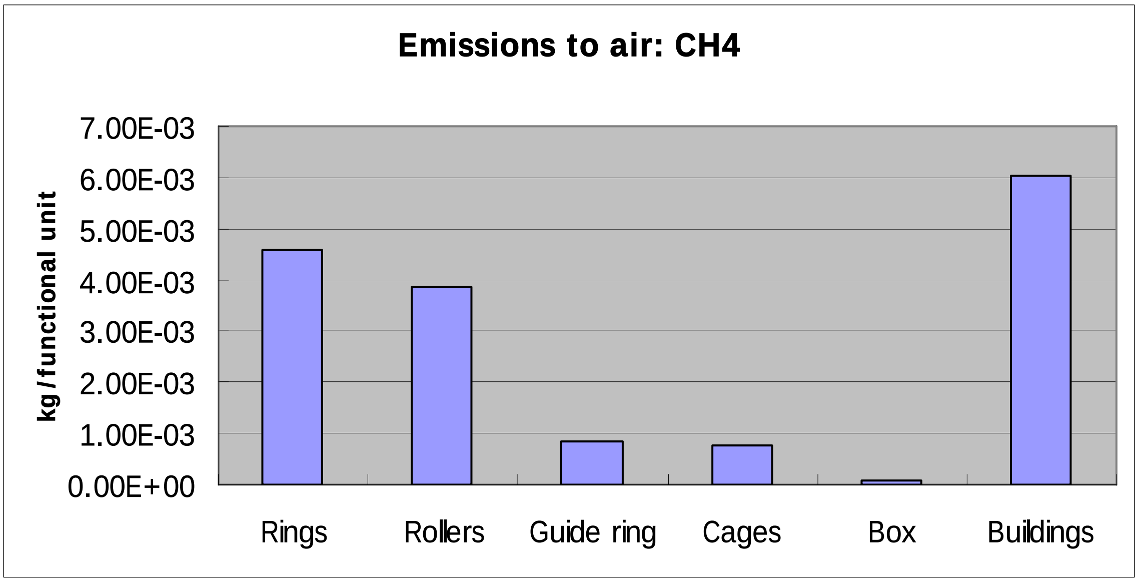

Figure 8: *Emission of methane (CH4) to air contributes to global warming and photochemical oxidant creation. The diagram presents a comparison of the emission from buildings and components.*

Evidently, buildings contribute most to the emission of methane to air comparing to other components of the bearing. Within the operation of buildings, consumption of electricity causes the largest emissions of methane.

8.1.3.3 CO

Emissions of carbon monoxide (CO) contribute to global warming, human toxicity and photochemical oxidant creation.

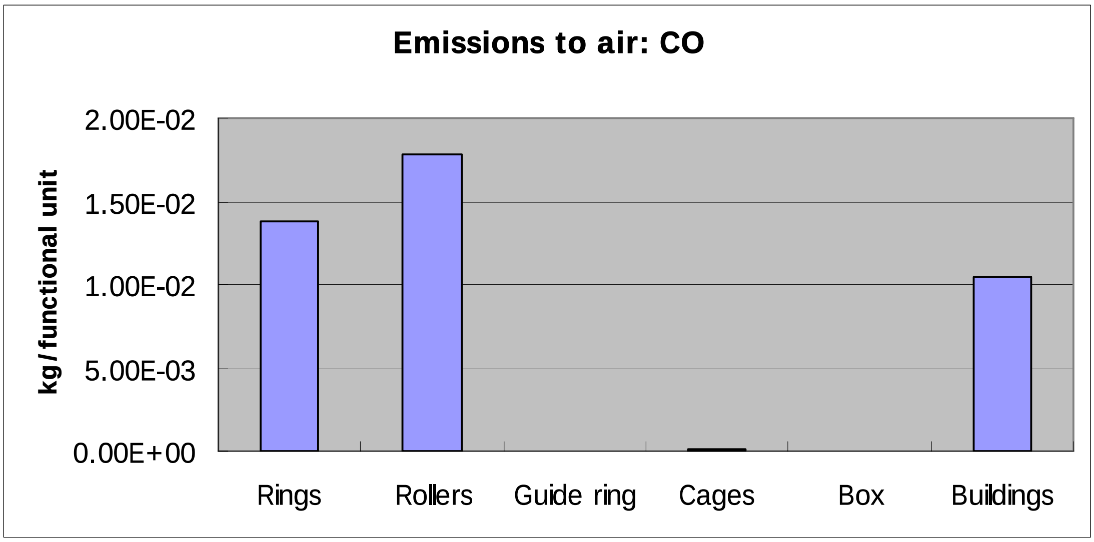

Figure 9: *Emission of carbon monoxide (CO) to air contributes to global warming, human toxicity and photochemical oxidant creation. The diagram presents a comparison of the emission from buildings and components.*

Buildings are the third largest contributor of the emissions of CO to air after production of rollers and rings. Production of district heating dominates the CO emissions from buildings.

8.1.3.4 CO_2

Emissions of carbon dioxide (CO_2) contribute to global warming.

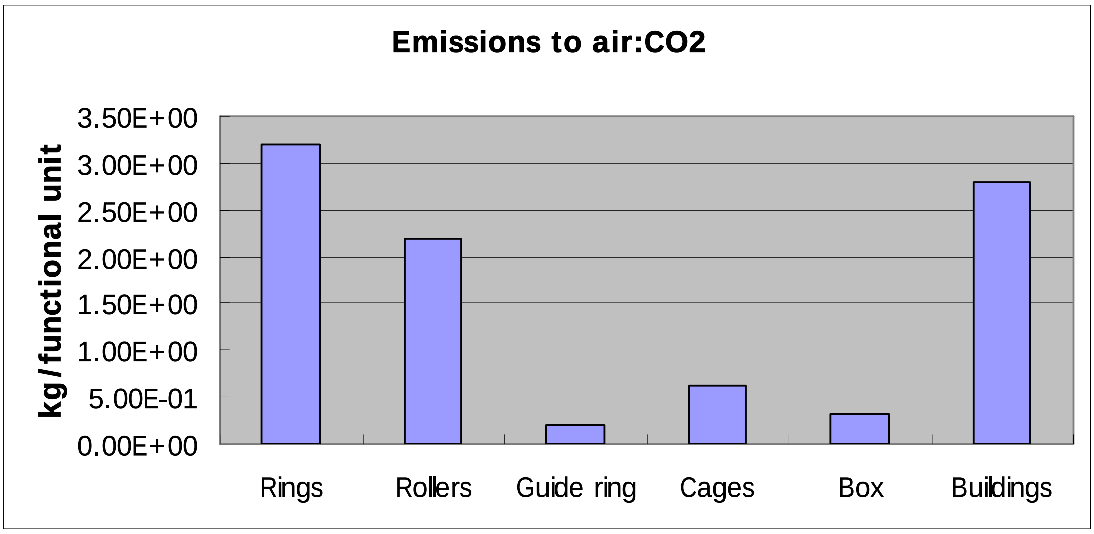

Figure 10: *Emission of carbon dioxide (CO_2) to air contributes to global warming. The diagram presents a comparison of the emission from buildings and components.*

Buildings are the second largest part responsible for CO_2 emissions in the whole life cycle of SRB 24024. Productions of both electricity and district heating for buildings are main source of CO_2 release.

8.1.3.5 NMVOC

Emissions of non-methane volatile organic compounds (NMVOC) to air contribute to the photochemical oxidant creation.

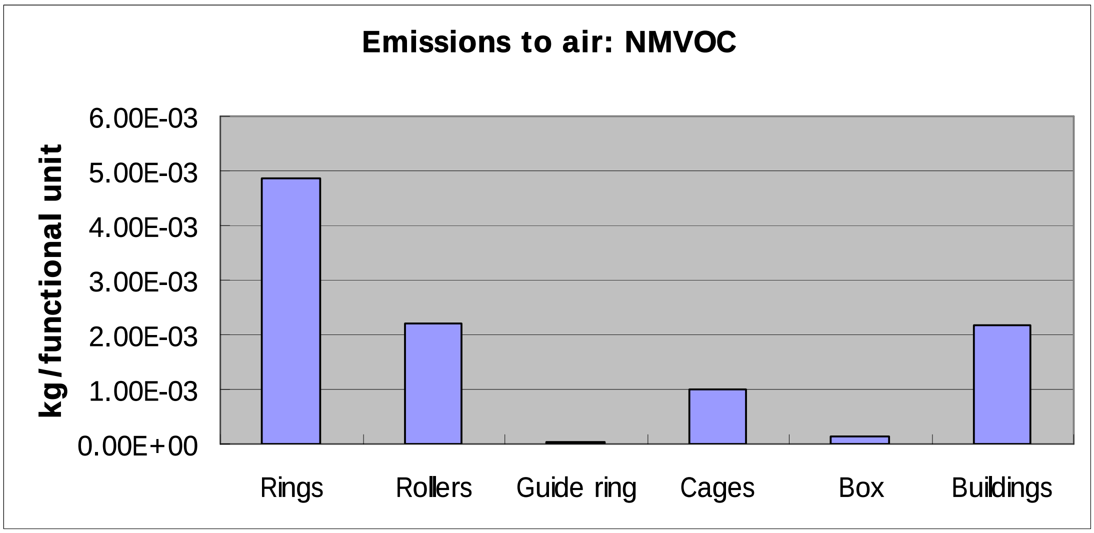

Figure 11: *Emission of non-methane volatile organic compounds (NMVOC) to air contributes to photochemical oxidant creation. The diagram presents a comparison of the emission from buildings and components.*

Followed production of rings and roller, buildings are the third biggest contributor of NMVOC emission to air. Within the operation of buildings, most of NMVOC originates from production of district heating.

8.1.3.6 NOx

Emissions of NO_x to air contribute to acidification, eutrophication, global warming and human toxicity.

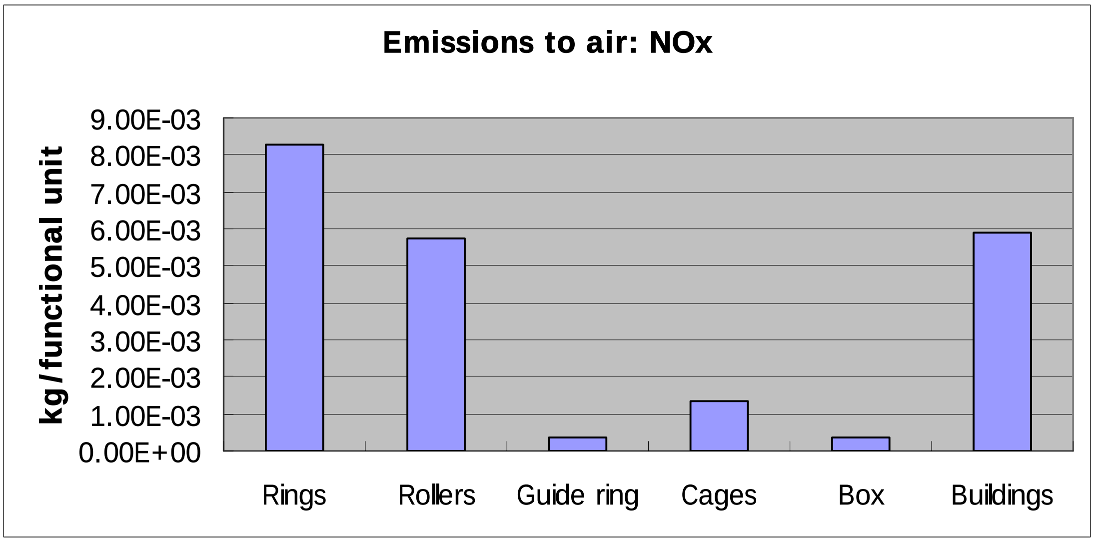

Figure 12: *Emission of NO_x to air contributes to acidification, eutrophication, global warming and human toxicity. The diagram presents a comparison of the emission from buildings and components.*

Buildings are the second dominator of NO_x emissions to air. Production of district heating contributes most to NO_x emissions within buildings' operation in this study.

8.1.3.7 SO_2

Emissions of sulphur dioxide contribute to acidification and human toxicity.

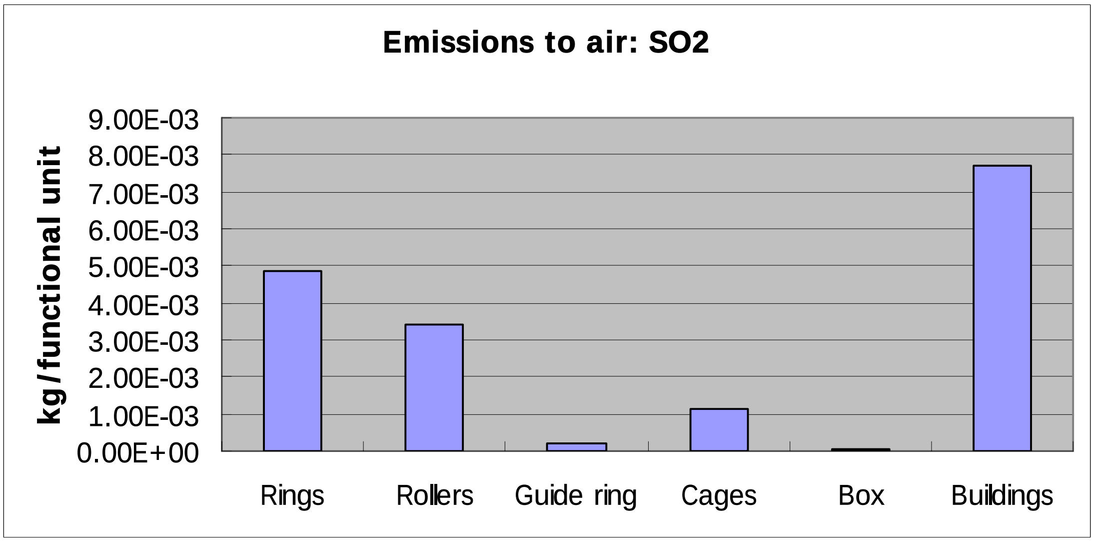

Figure 13: *Emission of sulphur dioxide to air contributes to acidification and human toxicity. The diagram presents a comparison of the emission from buildings and components.*

Buildings have the highest emissions of sulphur dioxide (SO_2) to air comparing to each single component manufacturing and again the production of district heating is responsible for the largest emissions.

8.1.3.8 Particulates

Emissions of particulates cause long-term hazardous effect to human health and consequently increase mortality (Ostro, Chestnut et al. 1999).

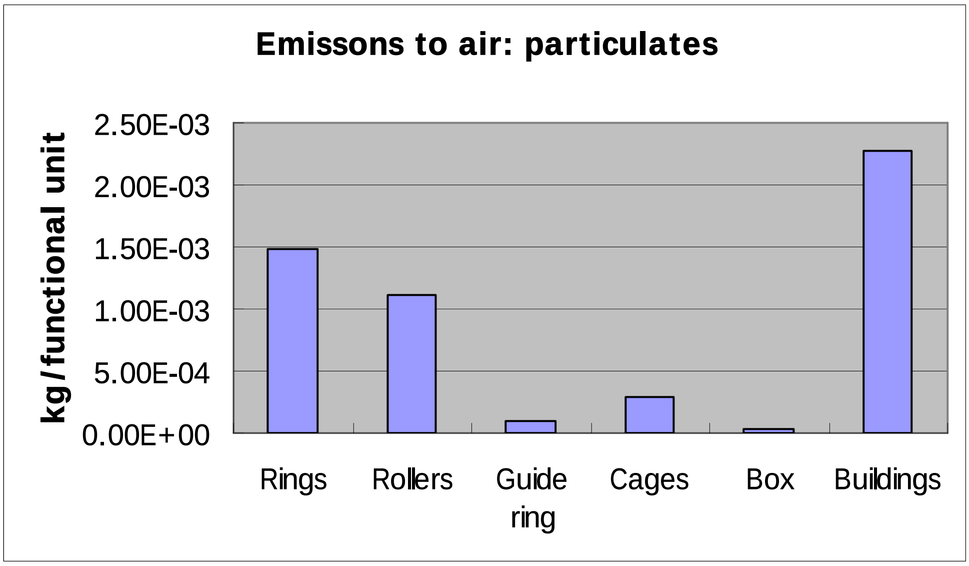

Figure 14: *Emission of particulates to air cause hazardous effect to human health. The diagram presents a comparison of the emission from buildings and components.*

Buildings are the biggest emitters of particulates. The productions of electricity and district heating have fifty-fifty contribution to particulates emissions in this study, while they originate mostly from the production of district heating in the base study.

8.1.3.9 Discussion

From the above analysis of important parameters and comparison among different components and buildings, we could find out that the production of rings and the operation of buildings are two most significant parts responsible for emissions of these selected parameters, see table 14.

Table 14 Dominators of emissions of selected pollutants.

	First dominator	**Second dominator**
CH_4	Buildings operation	Rings production
CO	Rollers production	Rings production
CO_2	Rings production	Buildings operation
NMVOC	Rings production	Buildings operation
NO_x	Rings production	Buildings operation
SO_2	Buildings operation	Rings production
Particulates	Buildings operation	Rings production

Standing on this point, we leastwise could get the following understatement: it is important and necessary to take buildings into consideration if the life cycle assessment of the investigated bearing aims at identifying for which activities improvements are most needed.

On the other hand, the results also imply that: if SKF wants to improve the environmental performance related to bearings, it will be good to consider improvements on buildings operation, because SKF's buildings account for 58% of electricity consumption in all buildings and 82% of total heat consumption in this study.

8.2 Dominance analysis

A dominance analysis is performed in this study to identify which type of buildings has the greatest (dominant) environmental impact. Buildings involved in this study are grouped into two clusters: factory buildings and non-factory buildings. Since only energy consumption during the operational phase of buildings investigated in this study, comparison of energy use in the two groups, to large extent, reflects the relative weight of environmental impact. Consequently, to simply the analysis, contrast between factory buildings and non-factory buildings is based on energy consumption, see figure 15.

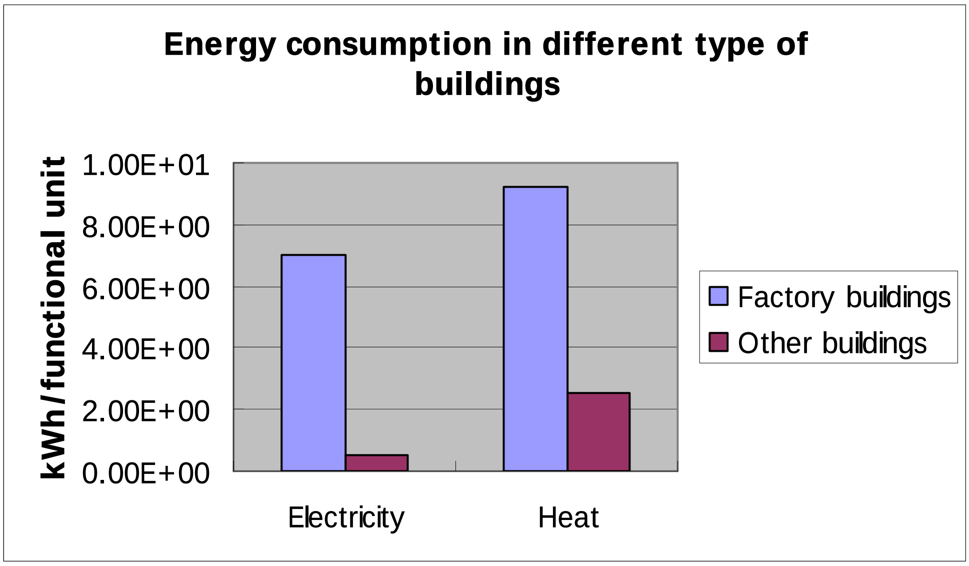

Figure 15: *Comparison of energy consumption between different types of building for producing one bearing.*

It is very apparent that factory buildings occupy most part of energy consumption. The reason is that they are often much higher than non-factory buildings and thereby need big ventilation systems and other facilities.

8.3 Decision maker analysis

"The basis for decision maker analysis is identification of the different companies and organizations that carry out the different activities in the technical system. The potential application of this analysis is for the commissioner of the study to identify the extent to which environmental impact is under his/her control" (Baumann and Tillman 2004).

The decision maker analysis in this study is made for SKF Sverige AB in Göteborg. The SKF Group is a large corporation. In addition to bearing manufactures, producers of some bearing components and certain raw material suppliers are also part of it. However, other raw material producers, transportation companies, distribution enterprises and packaging producers are not part of SKF Group. The degree of influence that SKF has over them varies and depends on how tightly they are bound to SKF through collaboration and/or supplier contracts. Companies involved in the supply chain of the spherical roller bearing (SRB) 24024 are sorted into three groups according to different levels of influence: SKF Sverige AB, other SKF companies of which SKF is the owner or a shareholder and non-SKF companies. Energy consumption of buildings in each group for producing one bearing is shown in figure 16.

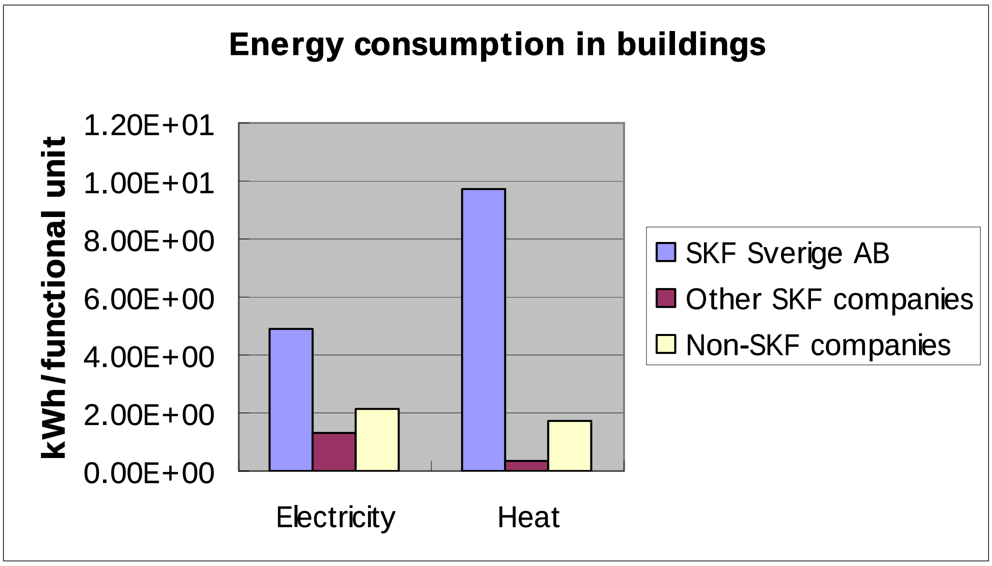

Figure 16: *Decision maker analysis of energy consumption of buildings for one spherical roller bearing.*

It is easy to notice that SKF Sverige AB overwhelms other two groups in both perspectives of electricity and heat consumptions. The reason is it constitutes the largest part of activities within the processes chain of the spherical roller bearing which in turns means more buildings are required to perform these activities. The overwhelmingness is also supported by the fact that the identification of buildings in SKF Sverige AB is the most completed in this study.

Based on this, the decision makers need to put effort on reducing energy consumption in SKF Sverige AB and to influence the choice of energy suppliers of SKF Sverige AB to abate the environmental impacts from buildings operation.

As deeper analysis, distribution of selected emissions over the three groups is studies as well, see figure 17.

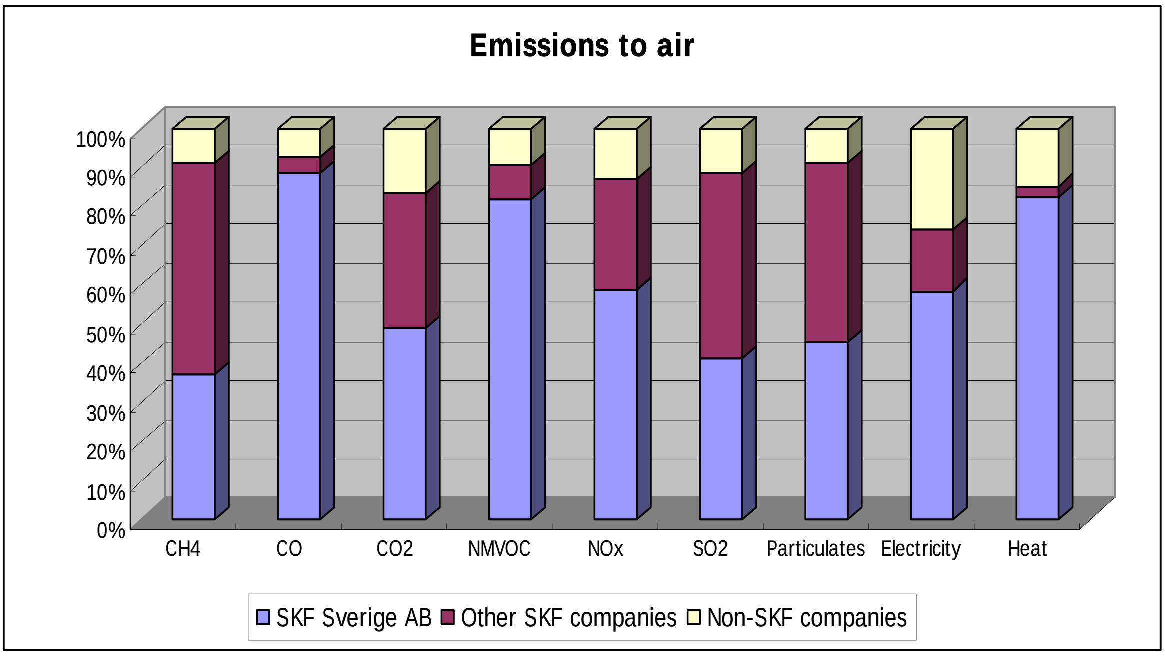

Figure 17: *Decision maker analyses of selected inventory results for one spherical roller bearing.*

The diagram detailedly shows whom the decision maker needs to influence most if he/she targets at abating emissions of a specific substance from buildings operation. Taking carbon dioxide (CO_2) and NO_x for instance, the decision maker needs to influence the choice of energy supplier of SKF Sverige AB and other SKF companies which represent most part of CO_2 and NO_x release. To reduce the emissions of carbon monoxide (CO) and NMVOC, the decision maker needs to target at cutting down energy consumption of buildings in SKF Sverige AB most. In case of CH_4, SO_2 and particulates, the decision maker should influence other SKF companies most to diminish emissions of them, especially SKF Poznan S.A., Poland which uses electricity and heat generated from coal.

8.4 Sensitivity analysis

"Sensitivity analysis is a procedure to determine the sensitivity of the outcomes of an alternative to changes in its parameters" (Principia Cybernetica Web 2006). Sensitivity analysis can be done by systematically changing the input parameters. If a small change in a parameter results in relatively large changes in the outcomes, the outcomes are said to be sensitive to that parameter.

In this study, a sensitivity analysis is carried out by assuming electricity in the entire system is generated from the marginal source of electricity in Europe: coal power plants. Environmental impacts from operation of buildings are calculated and compared. The results expressed in marginal value relative to average value for each individual impact category, see figure 20.

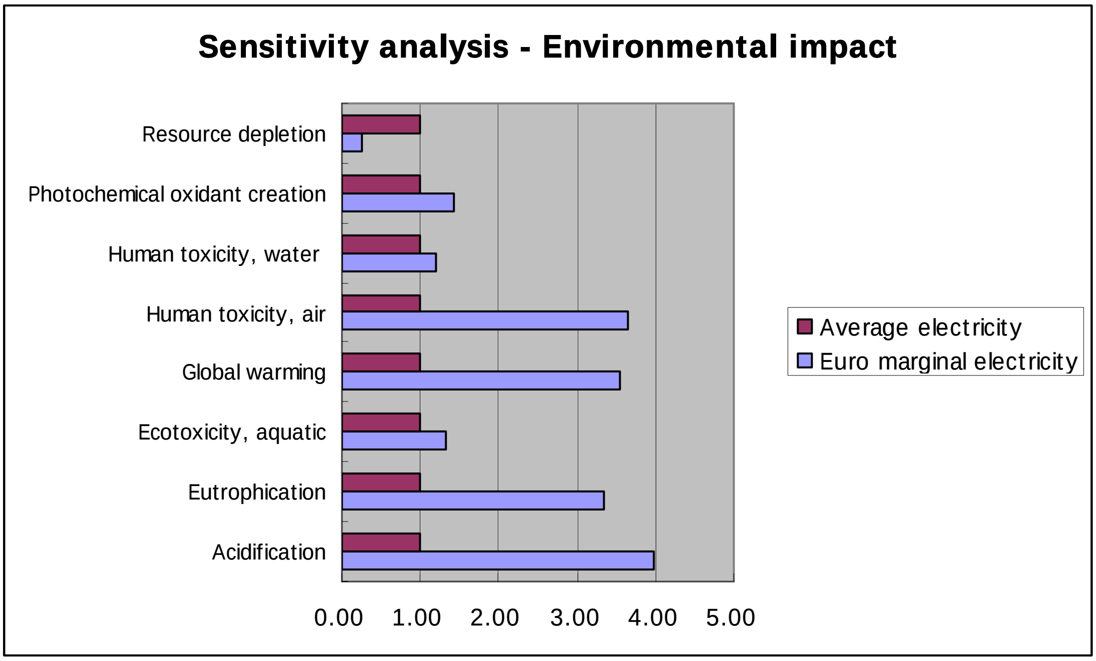

Figure 18: *Sensitivity analysis of environmental impacts with assumption of electricity used in the entire system is European marginal level.*

It is conspicuous that the outcomes are very sensitive to the choice of electricity data. The environmental impacts, except resource depletion, rise dramatically when the data of European marginal electricity is applied. The reason why resource depletion declines is consumption of uranium, the dominator of this impact category, decreases a lot in coal power plants.

8.5 Comparison of different allocation methods

The allocation method applied in this study is based on weight in order to be identical to the base study. But one may argue if the weight-based allocation is the most proper one or not since many alternative allocation methods are applicable. Therefore, three different allocation methods are investigated and the results they give are compared in this section. The three different allocation methods are allocation according to weight, allocation according to added value and allocation according to numbers of product. Due to the information about weight, added value and number of product/materials is not fully complete for all companies involved in this study, the comparison of different allocation methods is only performed for buildings in SKF Sverige AB in Göteborg, Sweden. The inventory results calculated based on the three different allocation methods for operation of buildings in SKF Sverige AB, are compared and expressed in relative to allocation based on weight, see table 15.

Table 15 Comparison of different allocation methods applied in SKF Sverige AB.

Allocation method	Relative to weight based
Weight-based	100%
Added-value-based	246%
Number-based	208%

It is clear to see that the results between the three allocation methods differ significantly. The allocation according to weight of product by far gives the lowest values. The results from the allocation based on added value are 2.46 times higher while the allocation based on numbers of product gives values that are 2.08 times higher.

These figures show why the choice of allocation method is so vital in inventory analysis and impact assessment. All of the allocation methods investigated here are highly uncertain. It is difficult to say if the allocation based on weight which is used in this study is the best approach or if other methods are more suitable. Further investigation on them is needed to identify what method is most proper.

9 Discussion

In this chapter, methodological issues such as choice of allocation methods, data collection strategies are discussed, and possibility of generalization of the study in SKF is deliberated as well.

9.1 Methodological issues

One of the main purposes of the study is to develop a tentative method to include buildings' environmental impact into products Life Cycle Assessment. Many methodological issues associated to this study are indefinitely proper and need to be reconsidered when one does a similar research. I will discuss the two most important issues here: choice of allocation method and data collection strategies.

9.1.1 Choice of allocation method

As mentioned before, the choice of allocation method is very crucial in life cycle inventory and impact assessment. In the following, I will discuss and give some suggestions about the choice of allocation method when including buildings' environmental impact into products' LCAs.

Most buildings in industry are normally multifunctional. However, there might be a few buildings which are exclusively used for one product. Ideally, the allocation should be avoided by identifying those buildings which are uniquely associated to the studied product.

In those buildings where different products are produced or several activities related to different products are performed, the allocation is not able to be avoided. The allocation method needs to be selected.

It might be the most proper way to deal with the allocation problems associated with buildings to allocate based on areas/space related to the studied product. Buildings as background system provide areas where products could be produced and spaces where other supportive activities could be performed. Buildings also provide services (e.g. light, heat and proper indoor climate) to creating suitable environment in the specific area/space where manufacturing of products and supportive activities are performed. Depending on the size of the area/space required to finish a product, the demand of these services are determined. At the same time, the environmental impacts from utilizing these services are ascertained too. In this sense, the information of area/space essentially reflects the underlying physical relationships between products and buildings' functions. Therefore, allocation according to area/space is worth to be considered as the most suitable approach. However, this method is also believed to be very complicate and time-consuming. It is often difficult to accurately measure the area/space belonged to one specific product for all investigated buildings, especially offices. The feasibility of this allocation method needs to be investigated more to make final decision.

Besides allocation based on area/space, other alternative methods are also considerable. One of them is to allocate based on added value of products. It intuitively sounds reasonable that if a product stands for a large portion of the company's profit it might be considered as accounting for an equally large part of the company's environmental load. However, there are numerous parameters which influence the final added value of the product. For example, large-scale production implies effectiveness in the processes and will lower the cost of materials which in turn higher the added value of the product. Meanwhile, the way how the decision maker measures the sales value of the product also influences the final added value of the product. Normally, regular subsidies and taxes on activities are part of the price which the decision maker really gets, or expects to get. If this is the situation, the added value of the product is higher than what it actually is created in processes. Therefore, a correction for social payments may be needed when the allocation is based on added value. Many other factors will also affect the final added value. But I will not further investigate them here. Hence, the allocation method according to added value of products is highly uncertain and need to be considered carefully if one wants to apply it.

Allocation based on any simple physical measurements such as number of products or molar flow of co-products is usually not recommended. Taking number for instance, this method might be considered suitable for cases where the product range is not too wide since it will address the same environmental load to each one of the products. Nevertheless, other parameters will still influence the environmental impact of the product. One of these parameters is time needed to produce products. For example, in a fixed time period, the company may only produce one studied product (A) while another product (B) is finished by multi-numbers. On the other hand, it is reasonable that the services supplied by the building where theses production processes are performed should be equally allocated to product A and product B in this fixed time period, if the production environment is identical in the building. In this sense, allocation according to numbers of produced products will lower environmental load contributed by the studied product (A). Consequently, allocation based on numbers of products is highly uncertain. For this method to be reliable and fair, a good knowledge is needed, not only for the studied product but also for the other products and the way they are produced.

Several other allocation methods such as proportion according to operational time of products or size of products are applicable to the allocation problems of buildings' environmental load. These methods will not be further investigated in this study. It is reasonable to believe that all of the allocation methods are to some extent uncertain and each of them has its own pro and con.

I would also recommend here to consider applying different allocation methods to different buildings. For factory buildings, allocation according to area/space may be preferred since it reflects the underlying relationship between products and buildings' functions very well and it is easier to divide and measure the area of the production channel for each product. For administrative buildings, allocation according to economic values of products might be more suitable. The reason is the higher one product stands for the companies turnover the more effort/labor will be put on it. The amount of effort/labor determines the requirement of buildings/rooms to perform the administrative activities. The reason why allocation according area/space is not chosen for this type of buildings is the difficulty of dividing and measuring the area associated to one specific product in administrative buildings.

9.1.2 Data collection strategies

Data collection is a vital methodological issue for all scientific researches. Life cycle assessment is an ambitious tool which evaluates environmental impact from the whole industrial system involved in the production, use and waste management of a product or service. In this study, the environmental impacts from buildings related to the studied product within the life cycle of it are calculated and added. Hence, data need to be collected for the same system as the conventional LCA of the investigated product. Since the involved industrial system spans very widely in way of geography and industrial technologies, the data collection is flexural and time consuming. For this reason, a deliberate planning for data collection is necessary to gather required information effectively. I will discuss data collection strategies applied to the specific research subject: including buildings' environmental impact into products' LCAs in this chapter.

First of all, think through what data is needed to be collected and make a general data collection sheet listing all data categories. Environmentally relevant information about buildings should undoubtedly be included in the categories, such as energy consumption, waste generation, materials utilization etc. It is important to remember that products' information associated to each building is also necessary to be included since it will be used to allocate environmental load to the studied product. In addition, depending on goals of different studies, other information of buildings such as area of buildings (m^2) and owner of them may be required as well.

Secondly, consider which type of data is needed for each category. One typical instance is the choice of data about energy consumption in buildings: average value or total value. For example, data of energy consumption in an office building is normally expressed in kWh per m^2 for the whole building. Alternatively, the total figure of energy use in the building is also available. Hence, there are two approaches to allocate energy consumption to the investigated product. One is to collect the average data then multiply it with areas associated to the studied product. The other one is to simply collect the total consumption figure then proportion it to the studied product. I recommend collecting the average data if the measurement of product-related areas is not difficult to perform, because this method reflects the function of buildings better.

Thirdly, it is very significant to make decision about source of data. No one can be an expert on all the different technical fields represented in a life cycle. Therefore, accessing to other relevant data sources is necessary. This could be achieved by interviewing, browsing (e.g. in shops), phoning, searching library or World Wide Web, citing literatures (e.g. companies environmental report) and experiment etc. "Interviewing data supplier was proved to be the most successful way through which data was accessed" (Baumann and Tillman 2004). This method is also proved to be the most efficient way to gain data in this study, especially when the difference of professional background between interviewer and interviewee is great. Therefore, it is recommended that site interview should be performed as much as possible to improve accuracy and quality of data. Communications by email or phone or combination of them are very helpful on data collection and the data quality is also good by these ways. Nevertheless, they are more time-consuming than interview and detailed description and explanation are compulsory. However, they are still good data searching strategies and worth to consider.

Fourthly, before approaching data suppliers, it is necessary to inform yourself on a general level about the technologies and organization of each data supplier which you want to interview. This will help you communicate with expert and increase the effectiveness of the interviews. It is also necessary to mention that it will be better to initiatively have a strategy for handling confidentiality issues and proprietary information before you start interviewing.

Finally, I will present some practical suggestions on data collection, especially on personal communication, based on my experience from this study. The most vital issue concerning personal communication for data collection is to contact the right person. In order to gather required information effectively, different contacts need to be communicated for various data. For example, in this study, energy consumption in buildings was collected by interviewing energy system managers in real estate departments while information about products was gained from production managers and staffs in sales departments in companies. To get right contacts in a company for specific information, the practitioner may inquire his/her coordinator in the corporation and ask for his/her help to reach the right person. Once you have got the right contact, you need to fully prepare the first meeting with him/her. The reasons are not only because this meeting is the first opportunity you can express your study and the contact will get the first impression of the study, but more importantly because it might be the only chance for you and the contact understand the study identically, especially when the distance between the two parties is great. Therefore, think through questions, such as what information you expect from him/her, how you will explain your study to him/her and if you need him/her to guide you a site visit or not etc, before approaching the interviewee. It is very important to remember that explaining your study from a perspective which is closely related to the contact's professional field. Sometimes, instead of interpreting the integral study, it is better to focus on describing certain specific parts which are crucial for the contact to know to assist you to collect data. This strategy not only helps the contact understand the study easily and knows exactly what data you expect from him/her, but also highly improve the data collection efficiency. In addition, keeping continuous connection with contacts by phone or email regularly is also very significant. It helps avoid and correct possible misunderstanding between you and the contacts. At the same time, this makes you know where the study is and helps you keep the entire project under control.

There are still many other methodological issues to which the attention needs to be paid, such as selection of energy data, methods of environmental impact assessment and so on. They will not be investigated in this study.

9.2 Generalization of the study in SKF

For further research, the possibility to generalize this study in the whole SKF is discussed here. To analyze in what parts an industry can abate its environmental load, we may divide the industry's environmental impact into unit processes. The unit processes are the smallest components upon which an industry is built, and consist of a number of production processes and support processes. The production processes produce products while the support processes support production. The advantage of dividing environmental impact into unit processes is that we can obtain a well-defined structure of the industry and thereby facilitate the comparative analysis between different unit processes. Buildings with space heating and lighting are examples of support processes, and manufacturing and assembling are examples of production processes.

In the SKF case, we may define all buildings as support process unit and define different production processes units according to the size of bearings or based on different activities to produce bearings. An example of lists of unit processes in SKF is presented in table 16.

Table 16 List of different unit processes in SKF.

Support processes	All buildings	All buildings
Production processes	**Sorting based on different activities**	**Sorting based on the size of bearing**
	Roller production unit	Large size bearing unit
	Cage production unit	Medium size bearing unit
	Guide ring production unit	Other products unit
	Bearing assembly unit	
	Other production unit	

By evaluating and comparing environmental impacts in each unit process, it is possible to identify in what parts SKF needs to improve most to reduce its environmental impact.

However, there might be other ways to define different unit processes which is more suitable for SKF. Solid knowledge about SKF is necessary to deal with this issue and choose the best approach.

10 Conclusion

This chapter presents the importance of buildings' environmental impacts in products' life cycle and suggestions for SKF's environmental performance related to spherical roller bearings are given.

10.1 Importance of buildings' environmental impact in products life cycle

The main purpose of the study is to investigate importance of buildings' environmental impact in products' life cycle. This has been done by applying the case study of one of SKF's spherical roller bearings: SRB 24024. The results from comparison of environmental impacts between production processes and buildings within the life cycle of SRB 24024 indicate that buildings cause up to more than 25% of certain environmental impacts within the life cycle of the studied product, see table 17. Therefore, it can be concluded that including buildings' environmental impact into products' life cycle assessment is important and necessary.

Table 17 Comparison of environmental impact between buildings and production processes for producing one bearing.

Category indicator	Unit	Environmental impact of buildings	Environmental impact of processes (Ekdahl 2001)	Buildings ratio (%)[2]	Buildings proportion (%)[3]
Acidification	kg SO_2 equivalents	1.20E-02	3.16E-02	37.9	27.5
Eutrophication	kg NO_x equivalents	6.49E-03	1.59E+00	0.4	0.4
Ecotoxicity, aquatic	m^3 polluted water	8.40E+01	6.50E+02	12.9	11.4
Global warming	kg CO_2 equivalents	3.00E+00	7.84E+00	38.3	27.7
Human toxicity, air	kg contaminated bodyweight	1.60E-02	4.03E-02	39.6	28.4
Human toxicity, water	kg contaminated bodyweight	2.67E-07	4.52E-06	5.9	5.6
Photochemical oxidant creation	kg ethene equivalents	1.32E-03	1.76E-02	7.5	7.0
Resource depletion	kg reserveaase-1	7.99E-14	7.04E-13	11.3	10.2

Though buildings do not play as important role as the production processes do in causing environmental consequence within the life cycle of SRB 24024, their contribution to certain assessed environmental impact categories especially to global warming, acidification and human toxicity (air) is great and fully comparable to processes' donation. At the same time, buildings' effect on aquatic ecotoxicity and

[2] Results shown in this column are buildings' ratio relative to value of corresponding impact category in production processes.
[3] Results shown in this column are buildings proportion of value of buildings and processes in total.

resource depletion is also not neglectable. It is also important to remember that building' environmental impacts presented in table 17 are evaluated based on incomplete inventory data which lower the results. Therefore, if the inventory data of buildings could be more complete, it will further ascertain the belief that it is important and necessary to include buildings' environmental impact when performing LCAs of products.

From another perspective, the results from comparison of emissions of main pollutants (e.g. CO, CO_2, CH_4, SO_2, NMVOC and particulates) between production processes and buildings show that the operation of buildings is the most important individual emitter of these substances relative to other process units for components of a bearing, see table 14. This implies that it is worthy to consider including buildings into life cycle assessment of a product if the LCA study aims at identification of improvement potential of companies environmental performance. Sometimes, it is easier to reduce environmental load by improving operation of buildings than by innovating production processes. For example, Trygg and Karlsson pointed out that the potential for electricity reduction was higher for the support processes (e.g. space heating, ventilation and lighting) than for the production processes in their research about how Swedish industries can reduce their electricity use to adapt to a deregulated European electricity market by investigating eleven industries in Sweden (Trygg and Karlsson 2005). Standing on this point of view, it is important to include buildings' environmental impact into products' LCAs.

10.2 Suggestions on SKF's environmental performance

The results of the case study show that buildings' environmental impact is comparable to the environmental load from production processes, which means that the buildings' impact is not neglectable. It implies that SKF needs to consider not only improvements on production processes, but also improvements on buildings in order to make progress in their environmental performance.

Looking through the dominant activities of environmental impact related to the investigated spherical roller bearing 24024 in this study and in the base study, we could easily find out that the energy consumption dominates the environmental impact and is the activity where improvements are most needed to achieve better environmental performance in SKF. Some suggestions on reduction of energy use are given below.

- Reducing energy use when no production is taking place
- Making energy use more efficient
- Using green energy, like electricity from renewable energy sources

Installing advanced energy control systems is very helpful to reduce energy use when no production is taking place. Automatically controlled production processes by computers have been widely utilized in SKF. Whether there is any further potential or not to reduce energy use in this way needs to be investigated more. However, the potential of reducing energy use in operation of factory buildings is also available. For example, light and space heating should be turned off when the production is stopped, share energy services between different production channels by designing and positioning illumination and heat devices as efficient as possible.

There are many ways to make energy use more efficient. First, recycling surplus heat from production processes is a very good strategy for SKF to use energy efficiently. The production of heat is the largest contributor of environmental impact in life cycle of SRB 24024 in both this study and the base study. Reduction of heat consumption is required to abate negative environmental consequence in SKF. Currently, only heat generated from the heat treatment facility in the bearing factory is recycled and reused (SKF 2005b). Recycling more surplus heat from production processes is a good strategy to reduce heat consumption in SKF. Second, replacing energy-consuming machines with energy-saving ones and innovation of existing production channels are of course considerable choices. Finally, changes of human behaviors will also improve the effectiveness of energy use. Light and space heating should be turned off wherever it is not necessary and shut down computers or keep them in energy save model as much as possible, etc.

Selecting energy suppliers who provide green energy will also be beneficial for SKF’s environmental work. With the rapid expansion of green electricity market throughout the world and the deregulation of the European electricity market, SKF may gradually switch its electricity to more environmentally friendly electricity. However, which type of green electricity is most environmentally suitable and beneficial for SKF is not definite now. Further studies on this subject are needed to give final decision on it.

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Appendix

I Production of Electricity, Swedish average (large industries)

(CIT Ekologik 1998a)

Direction	FlowType	Substance	Unit	Environment	Sub total (Swedish companies)
Input	Non-elementary	Lime	kg	Technosphere	8.71E-03
Input	Non-elementary	Oxygen	kg	Technosphere	3.62E-03
Input	Non-elementary	Sulphuric acid	kg	Technosphere	5.18E-04
Input	Resource	Bentonite	kg	Ground	3.21E-05
Input	Resource	Biomass	kg	Ground	6.45E-02
Input	Resource	Copper in ore	kg	Ground	6.83E-05
Input	Resource	Crude oil	kg	Ground	6.98E-02
Input	Resource	Hard coal	kg	Ground	6.82E-01
Input	Resource	Hydro power	MJ	Ground	1.13E+01
Input	Resource	Iron in ore	kg	Ground	2.29E-04
Input	Resource	Lead in ore	kg	Ground	8.23E-07
Input	Resource	Lignite	kg	Ground	8.50E-03
Input	Resource	Natural gas	kg	Ground	1.60E-02
Input	Resource	Uranium in ore	kg	Ground	1.09E-04
Input	Resource	Wind power	MJ	Ground	2.41E-02
Output	Emission	CO	kg	Air	3.12E-04
Output	Emission	CO_2	kg	Air	1.29E+00
Output	Emission	Methane	kg	Air	3.92E-03
Output	Emission	N_2O	kg	Air	9.86E-06
Output	Emission	NH_3	kg	Air	5.29E-06
Output	Emission	NOx	kg	Air	2.13E-03
Output	Emission	PAH	kg	Air	1.60E-08
Output	Emission	Particles	kg	Air	1.20E-03
Output	Emission	Rn-222	kBq	Air	1.57E+03
Output	Emission	SO_2	kg	Air	4.35E-03
Output	Emission	VOC	kg	Air	8.99E-05
Output	Emission	COD	kg	Water	5.20E-06
Output	Emission	Dissolved solids	kg	Water	3.28E-05
Output	Emission	N total	kg	Water	1.11E-05
Output	Emission	NH_3	kg	Water	1.56E-09
Output	Emission	Oil	kg	Water	1.94E-05
Output	Non-elementary waste	Demolition	kg	Technosphere	2.16E-04
Output	Non-elementary waste	Highly radioactive	kg	Technosphere	1.41E-04
Output	Non-elementary waste	Other	kg	Technosphere	3.42E-01

II Production of electricity, French and Polish average

(Baumann and Tillman 2004)

Direction	Flow type	Environment	Substances	Unit	SubTotal (La Foulerie+SKF Poland)
Input	Natural resource	**Ground**	Copper in ore	kg	2.20E-05
			Crude oil	kg	1.97E-02
			Lignite	kg	8.05E-03
			Limestone	kg	8.40E-03
			Natural gas	Nm3	1.37E-02
			Hard coal	kg	6.26E-01
			Uranium in ore	kg	2.28E-05
			Water	kg	4.64E+01
			Wood	kg	6.23E-03
	Emission	**Air**	Cd	kg	8.80E-09
			CH_4	kg	3.51E-03
			CO	kg	2.32E-04
			CO_2	kg	1.00E+00
			Cs-134	kBq	6.67E-06
			Hg	kg	1.11E-07
			Kr-85	kBq	8.61E+02
			N_2O	kg	9.40E-06
			NH_3	kg	5.28E-06
			NMVOC	kg	2.14E-04
			NO_x	kg	1.68E-03
			PAH	kg	1.59E-08
			Particles	kg	1.13E-03
			Pb	kg	2.49E-07
			Rn-222	kBq	1.25E+03
			SO_2	kg	4.05E-03
			Sr-90	kBq	9.19E-06
			U-238	kBq	1.06E-04
	Emission	**Water**	COD	kg	5.19E-06
			Cs-134	kBq	1.18E-03
			Total-N	kg	7.72E-06
			Oil	kg	1.94E-05
			PO_4^{3-}	kg	5.99E-05
			Sr-90	kBq	1.11E-03
			U-238	kBq	3.97E-04
	Residue	**Technosphere**	Highly radioactive waste	m3	3.89E-09
			Medium and low radioactive waste	m3	4.76E-08
			Waste in deposit	kg	2.32E-01

III Electricity mix

a) Electricity mix of French and Polish average (Baumann and Tillman 2004; IEA 2005b)

Primary resource	Share %	
	France[4]	Poland[5]
Coal	7.01	91.05
Lignite	0.35	0
Oil	2.30	1.57
Natural gas	0.98	1.55
Nuclear	76.54	0.00
Waste	0.46	0.18
Hydro	12.24	2.10
Other, e.g. wind	0.13	0.08
Biomass	0	0.29
Import	0	3.18
Total	100.00	100.00

b) Electricity mix of Swedish average (large industries) (CIT Ekologik 1998a)

Primary resource	Share %
	Sweden[6]
Nuclear power	46.55
Hydro power	46.80
Coal condensed power	1.55
Oil condensed power	2.70
Combined heat and power, natural gas	0.50
Combined heat and power, renewable fuels	1.70
Wind power	0.10
Gas-turbine	0.10
Total	100.00

[4] The mix of electricity production in France is based on 1998 level when the deregulation of European electricity market had not been launched until 2002. Therefore there is no imported electricity.
[5] The mix of electricity consumption in Poland is based on 2003 level.
[6] The mix of electricity production in Sweden is based on 1995 level.

IV Production of district heating, Swedish average

(CIT Ekologik 1998b)

Direction	FlowType	Substance	Unit	Environment	Sub total (swedish companies)
Input	Non-elementary	Biomass	kg	Technosphere	5.13E-01
Input	Non-elementary	Heat	MJ	Technosphere	1.12E+01
Input	Non-elementary	Peat	kg	Technosphere	1.55E-01
Input	Resource	Crude oil	kg	Ground	1.74E-01
Input	Resource	Hard coal	kg	Ground	1.90E-01
Input	Resource	Hydro power	MJ	Ground	2.37E+00
Input	Resource	Lignite	kg	Ground	3.58E-03
Input	Resource	Natural gas	kg	Ground	6.40E-02
Input	Resource	Uranium in ore	kg	Ground	1.83E-05
Output	Emission	Acetylene	kg	Air	1.72E-06
Output	Emission	Alkanes	kg	Air	6.28E-06
Output	Emission	Alkenes	kg	Air	1.91E-06
Output	Emission	Aromates (C9-C10)	kg	Air	4.35E-07
Output	Emission	As	kg	Air	1.83E-07
Output	Emission	Benzene	kg	Air	3.02E-06
Output	Emission	Butane	kg	Air	1.95E-06
Output	Emission	Cd	kg	Air	5.63E-08
Output	Emission	CO	kg	Air	1.01E-02
Output	Emission	Co	kg	Air	3.27E-07
Output	Emission	CO_2	kg	Air	1.27E+00
Output	Emission	Cr^{3+}	kg	Air	1.27E-06
Output	Emission	Cu	kg	Air	1.04E-06
Output	Emission	Dioxin	kg	Air	4.82E-13
Output	Emission	Ethane	kg	Air	4.97E-06
Output	Emission	Ethene	kg	Air	1.01E-05
Output	Emission	Formaldehyde	kg	Air	6.36E-07
Output	Emission	HCl	kg	Air	1.55E-04
Output	Emission	Hg	kg	Air	9.48E-09
Output	Emission	Methane	kg	Air	2.13E-03
Output	Emission	N_2O	kg	Air	4.62E-06
Output	Emission	Ni	kg	Air	1.73E-06
Output	Emission	NMVOC	kg	Air	1.94E-03
Output	Emission	NMVOC, diesel engines	kg	Air	6.78E-06
Output	Emission	NMVOC, natural gas combustion	kg	Air	4.74E-06
Output	Emission	NMVOC, petrol engines	kg	Air	9.83E-16
Output	Emission	NMVOC, power plants	kg	Air	2.78E-06
Output	Emission	NOx	kg	Air	3.44E-03
Output	Emission	Particles	kg	Air	1.09E-03
Output	Emission	Pb	kg	Air	8.32E-07
Output	Emission	Pentane	kg	Air	3.34E-06
Output	Emission	Propane	kg	Air	4.20E-06
Output	Emission	Propene	kg	Air	1.91E-06

Output	Emission	Radioactive	kBq	Air	1.27E+07
Output	Emission	Rn-222	kBq	Air	6.70E+01
Output	Emission	Sb	kg	Air	1.47E-07
Output	Emission	Se	kg	Air	1.16E-07
Output	Emission	SO_2	kg	Air	3.24E-03
Output	Emission	Toluene	kg	Air	1.05E-06
Output	Emission	V	kg	Air	1.02E-06
Output	Emission	VOC	kg	Air	4.01E-05
Output	Emission	VOC, coal combustion	kg	Air	1.55E-07
Output	Emission	VOC, diesel engines	kg	Air	3.64E-06
Output	Emission	VOC, natural gas combustion	kg	Air	1.03E-14
Output	Emission	Xylene	kg	Air	3.06E-07
Output	Emission	Zn	kg	Air	1.21E-06
Output	Emission	As	kg	Water	1.25E-08
Output	Emission	BOD	kg	Water	5.70E-07
Output	Emission	Cd	kg	Water	7.01E-09
Output	Emission	COD	kg	Water	1.85E-05
Output	Emission	Cr^{3+}	kg	Water	9.29E-08
Output	Emission	Cu	kg	Water	3.06E-08
Output	Emission	Dissolved solids	kg	Water	1.11E-04
Output	Emission	N total	kg	Water	2.76E-05
Output	Emission	Ni	kg	Water	4.82E-08
Output	Emission	Oil	kg	Water	1.14E-04
Output	Emission	Pb	kg	Water	4.86E-08
Output	Emission	Radioactive	kBq	Water	1.19E+05
Output	Emission	Sn	kg	Water	8.28E-06
Output	Emission	SO_4^{2-}	kg	Water	2.05E-04
Output	Emission	Sr	kg	Water	5.24E-07
Output	Emission	Suspended solids	kg	Water	1.71E-06
Output	Emission	Zn	kg	Water	1.37E-07
Output	Non-elementary waste	Ashes	kg	Technosphere	7.71E-03
Output	Non-elementary waste	Bulky	kg	Technosphere	5.66E-02
Output	Non-elementary waste	Hazardous	kg	Technosphere	2.29E-02
Output	Non-elementary waste	Highly radioactive	kg	Technosphere	3.00E-05
Output	Non-elementary waste	Industrial	kg	Technosphere	1.66E-01
Output	Non-elementary waste	Slags & ashes (energy production)	kg	Technosphere	3.06E-04

V Emissions of selected pollutants from buildings and production processes

	Unit	Production processes	Buildings
CH_4	kg	1.01E-02	6.05E-03
CO	kg	3.17E-02	1.04E-02
CO_2	kg	6.53E+00	2.80E+00
NMVOC	kg	8.25E-03	2.17E-03
NO_x	kg	1.60E-02	5.89E-03
SO_2	kg	9.68E-03	7.69E-03
Particulates	kg	3.01E-03	2.28E-03

VI Number of buildings investigated

	Factory buildings	Non-factory buildings	Total
SKF Sverige AB	3	14	17
Other SKF companies	4	7	11
Non-SKF companies	9	22	31
Total	16	43	59

VII Production of electricity, European marginal (Coal)

(Baumann and Tillman 2004)

Flow type	Environment	Substances	Indicators	Unit	Quantity (per bearing)
Secondary resource	***Technosphere***	Electricity	Per TJ		8.32E+00
Natural resource	***Ground***	Copper in ore	4.28E+00	kg	1.28E-04
		Crude oil	2.58E+03	kg	7.73E-02
		Lignite	1.95E+03	kg	5.84E-02
		Limestone	2.21E+03	kg	6.62E-02
		Natural gas	1.90E+03	Nm3	5.69E-02
		Hard coal	1.83E+05	kg	5.48E+00
		Uranium in ore	1.33E-01	kg	3.98E-06
		Water	1.07E+07	kg	3.21E+02
		Wood	1.32E+03	kg	3.95E-02
Emission	***Air***	Cd	1.79E-03	kg	5.36E-08
		CH_4	1.00E+03	kg	3.01E-02
		CO	5.66E+01	kg	1.70E-03
		CO_2	2.76E+05	kg	8.26E+00
		Cs-134	3.88E-02	kBq	1.16E-06
		Hg	3.25E-02	kg	9.74E-07
		Kr-85	5.03E+06	kBq	1.51E+02
		N_2O	1.79E+00	kg	5.36E-05
		NH_3	1.50E+00	kg	4.48E-05
		NMVOC	3.39E+01	kg	1.02E-03
		NOx	4.52E+02	kg	1.35E-02
		PAH	3.52E-03	kg	1.05E-07
		Particles	3.22E+02	kg	9.63E-03
		Pb	6.59E-02	kg	1.97E-06
		Rn-222	7.30E+06	kBq	2.19E+02
		SO_2	1.06E+03	kg	3.18E-02
		Sr-90	5.36E-02	kBq	1.61E-06
		U-238	1.22E+01	kBq	3.65E-04
Emission	***Water***	COD	1.18E+00	kg	3.54E-05
		Cs-134	6.89E+00	kBq	2.06E-04
		Total-N	7.14E-01	kg	2.14E-05
		Oil	2.55E+00	kg	7.64E-05
		PO_4	1.75E+01	kg	5.24E-04
		Sr-90	6.49E+00	kBq	1.94E-04
		U-238	2.57E+01	kBq	7.70E-04
Residue	***Technosphere***	Highly radioactive waste	2.27E-05	m3	6.80E-10
		Medium and low radioactive waste	2.78E-04	m3	8.33E-09
		Waste in deposit	6.58E+04	kg	1.97E+00