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Environmental impacts of shoe consumption

Combining product flow analysis with an LCA model for Sweden

Master's thesis in Industrial Ecology

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ABSTRACT

In today's society, the increasing consumption and its impact on the environment is a relevant issue. The global market situation and varying environmental standards makes it even more complicated. Therefore, a focus on the life cycle of products including material flows in the society is necessary to improve environmental work and reduce environmental impacts.

In this thesis, the shoe consumption in Sweden and its environmental impacts was analyzed between 2000 and 2010 with a model approaching life cycle assessment, product flow analysis and material flow analysis. The consumption was defined as the net inflow of shoes into Sweden during one year, no life time was considered. The shoes were categorized according to the CN system used for trade and statistics, which generated six shoe groups involving waterproof, rubber & plastic, leather, textile, others and shoe parts. Four impact categories involving acidification, eutrophication, global warming and POCP were included.

According to this study, the shoe consumption in Sweden increased by 20% during 2000 and 2010. In 2010, the total consumption was dominated by rubber & plastic shoes, 36%, leather shoes, 24%, and textile shoes, 22%. Most shoes consumed in Sweden are imported from Asia, while an increase in Asian import from 56% to 63% can be seen during 2000 and 2010. The shoes contributing most to the environmental impact of the Swedish shoe consumption in 2010 were leather shoes, up to 50%, rubber & plastic shoes, up to 26% and textile shoes, up to 17%. For the included impact categories, one pair of leather shoes show up to 3 times higher impact compared to an average shoe.

The results show that material production corresponds to the highest impact with 80% of the total life cycle. The most contributing materials per kilogram included leather, wool, nylon, aluminium, synthetic rubber, PET plastic, PU plastic and viscose. For the Swedish shoe consumption, the environmental impact of leather was dominating for all impact categories followed by synthetic rubber, natural rubber, cotton, wool and various plastics. The impact changes according to the net inflow, but is also affected by conditions in import countries and material content in shoes. Natural textile and wood materials are preferable compared to leather, rubber and synthetic fibers with regard to environmental impact. Thus, an increase in consumption of some shoe groups such as leather shoes might then generate higher impact than others.

Key words: Shoe consumption, LCA, MFA, product flow analysis, Sweden

Preface

In this thesis, the Swedish shoe consumption has been studied with an LCA model approach based on the net inflow of shoes. The study was performed between January and May 2015 at IVL Swedish Environmental Research Institute and the Department of Energy and Environment, Environmental Systems Analysis, Chalmers University of Technology.

The project has been professionally supervised by Tomas Rydberg and Jenny Lexén at IVL and Assistant Professor Birgit Brunklaus at Chalmers University of Technology. The guidance provided by examiner Anna Nyström Claesson during the working process was highly appreciated, as well as the assistance from Associate Professor Henrikke Baumann when it came to LCA issues. Additionally, special thanks to Jonatan Wranne and Elisabet Hallberg at IVL for valuable support regarding the modelling.

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Marie Gottfridsson and Yuqing Zhang

Abbreviations

AP: Acidification potential

CO2: Carbon dioxide

EP: Eutrophication potential

EVA: Ethylene-vinyl acetate

GWP: Global Warming Potential

LCA: Life Cycle Assessment

LCI: Life Cycle Inventory

LCIA: Life Cycle Inventory Analysis

MD: Phylon

PET: Polyethylene terephthalate

POCP: Photochemical Ozone Creation Potential

PP: Polypropylene

PU: Polyurethane

PVC: Polyvinyl chloride

TPE: Thermoplastic elastomers

TPR: Thermal plastic rubber

VOC: Volatile Organic Compounds

Contents

1 Introduction

In a society where the population is increasing a high demand for resources and goods is putting a pressure on the environment. Additionally, since the growing economies worldwide result in higher consumption, the main sustainability issue to use resources without threatening the safety and well-being of future generations and the environment has become important (European Environment Agency 2012).

According to Baumann and Tillman (2004), it would require high effort to make the already established and evolving situation with the consumption sustainable. Therefore, environmental tools developed to assess the environmental impact related to products have emerged and can be used for such purposes (Horne et al. 2009). Since the early appearances around 1970, life cycle assessment has been a popular method for analyzing product systems with desired boundaries, for example from production to waste management (Baumann & Tillman 2004). This method can advantageously be combined with other tools to evaluate flows associated with the products, such as material and product flow analysis (Oguchi et al. 2008).

One example of a relevant product affected by this kind of consumption is footwear, which at the same time works as a suitable study object for an LCA approach. In the recent years, the potential hazardous content in shoes has been addressed as a problem in the shoe industry (Staikos et al. 2006). The trend of moving the production of goods to less developed countries with poor working conditions, health issues and lack of proper environmental legislation raises concern not only among customers, but also governments and the industry in general (Aronsson 2014).

A higher income and better financial prospects does not only result in negative impacts. When basic needs are fulfilled and less restraint on the economy allows it, people tend to care more about the environment and green choices (Kan 2010). General efforts towards being more environmentally friendly have started to affect the industry and generated a pressure on stakeholders in the shoe industry (Staikos et al. 2006). One method to create a greener business could be to use LCA approaches for analyzing impacts of the overall shoe consumption, since studying product and material flows assigned to the products could aid in making improvements in the environmental work of the shoe industry.

1.1 Purpose

The aim of the master thesis is to assess the environmental impact from the consumption of shoes in Sweden based on the net inflow. The methodologies used in the study are product flow analysis and material flow analysis to describe the flows of shoes in the Swedish society and life cycle assessment to assess the environmental impact of these flows.

The outcome can be relevant for the shoe industry when it comes to evaluating impact of shoes or as a foundation for further studies. In addition, if the impact of different kinds of shoes were accessible for customers, this kind of study could also help to make more environmental friendly choices.

1.1.1 Research questions

In order to reach the goals, research questions were formulated to support the aim and assist in the working process. These questions worked as a foundation for the modelling and interpretation of results.

- Describe the shoe consumption in Sweden for the years 2000 to 2010
    - How large is the yearly net inflow of shoes to Sweden, in total and distributed over different types of shoes?
    - What are the trends in shoe consumption between 2000 and 2010?
- Which materials are used in shoes on the Swedish market?
    - Describe the material composition of each type of shoes
- What is the overall environmental impact of shoe consumption?
    - What kinds of shoes and materials contribute the most to the overall environmental impact?
    - How do trends in shoe consumption affect the environmental impact, for example changed quantities of different types of shoes?
- Suggest improvements with regard to factors such as materials used in shoes to reduce the environmental impact of shoe consumption.
    - What can be done at a consumer, retailer and policy making level?

1.1.2 Study Limitations

The focus of the study is on the net inflow of shoes to Sweden during one year, hence the life time and use is not included. It is therefore assumed that all shoes entering Sweden are sent to waste treatment during the same year. This means the same amount that comes in is thrown away, or every new shoe is replacing another of the same kind. Also, consumption outside of the determined time frame of 2000-2010 will not be considered. The study is only using an LCA and MFA approach which means it cannot be fully compared to standards of the two tools. Packaging material related to shoe consumption is not included.

2 Background

To understand the situation of the shoe consumption in Sweden, insight into the history and market situation as well as consumer behavior is necessary. Additionally, knowledge regarding the life cycle of shoes and how they are manufactured must be gained to evaluate its environmental impact. This chapter serves as a background to the Swedish shoe industry and footwear in general.

2.1 The Swedish shoe market

The shoe industry can be traced back to the 19th century, where shoe manufacturing evolved from simple trading of hand-made goods to large scale factories with constantly developing technologies (Albers et al. 2008). At that time, shoes were produced in Sweden and the domestic industry started to grow in the early 20th century (Lönnqvist & Rolander 2008).

Along with the industrialization, new possibilities with an international shoe market and access to a wider range of customers also followed (Albers et al. 2008). After 1950, when the import of goods became less restricted, shoes from Italy became popular and factories started to move to other countries in Europe and Asia (Lönnqvist & Rolander 2008). While the import of less expensive shoes increased, many Swedish shoe factories could not remain profitable and closed down (Lönnqvist & Rolander 2008). The trend of importing shoes from Asia has continued and these days, shoes from especially China are dominating the Swedish market followed by a small share originating from Southern Europe (Lönnqvist & Rolander 2008). Despite the market situation, a limited selection of footwear such as boots, clogs and working shoes is still produced and exported from Sweden by some companies (Dahlberg 2010).

The sales of footwear have increased the latest years (Engvall 2009). As stated by Eleby et al. (2011), the future prospects for the Swedish shoe market are positive and it is claimed that the positive development will probably proceed.

2.1.1 Stakeholders

According to Eleby et al. (2011), Sweden is counted as one of the wealthiest countries in the world with over 9 million inhabitants. Since the focus lies on equality there are no major problems related to poverty (Eleby et al. 2011). When it comes to concerns about the environment, Swedish inhabitants are in general interested in making a difference as consumers (Eleby et al. 2011).

Living in a country located in the northern part of the world, Swedish shoe consumers are exposed to a cold and varied climate which requires different kinds of footwear depending on the season (Eleby et al. 2011). This will influence the shoe companies, which in turn must provide different options to the customers (Staikos et al. 2006).

Apart from the consumers, relevant stakeholders for the shoe industry in Sweden contain retailers in form of shoe stores including online shops, suppliers producing and distributing the shoes to the stores and a few remaining domestic shoe producers (Eleby et al. 2011).

As described by Swedish Chambers (2011, p. 6), shoe consumers in Sweden are "fashion oriented and brand-conscious", which results in following and easily accepting new trends. The consumer behavior has changed the consumption patterns, since shoes no longer need to be worn out to be discarded and replaced (Engvall 2009). Instead, shoes are often bought according to changing trends (Engvall 2009). Due to the increased and varying demand from customers, the shoe industry must adapt their production to stay relevant in the business (Staikos et al. 2006). Still, consumers are always limited by the assortment which is offered by the retailers (Staikos et al. 2006).

2.1.2 Work towards sustainability

As compared to the textile industry, there has been no major focus on work towards environmental sustainability in the shoe business until recently (Lönnqvist & Rolander 2008). According to Staikos et al. (2006), some efforts towards more environmentally friendly shoe production have been made by the industry. However, considering the increasing consumption of shoes worldwide, more action is required (Staikos et al. 2006).

So far when large fashion companies have had their business publicly examined with regard to environmental issues, customers have tended to care more about what they buy and companies have taken action for better conditions (Engvall 2009). Previous studies regarding how shoe companies deal with chemical content in shoes and social aspects have been performed which show a general lack of knowledge about suppliers and their working conditions (Engvall 2009). Therefore, as stated by Engvall (2009), shoe companies must take action, gain knowledge and affect their suppliers with solid environmental demands. It has been found that improvements can be made when large buyers threaten to cancel orders or change suppliers due to unsatisfactory social and environmental conditions of the suppliers (Lönnqvist & Rolander 2008).

One way to guarantee sustainability of products is to use environmental labels which involves the whole life cycle, such as the EU Ecolabel (Aronsson 2014). According to Aronsson (2014), there are currently only a few environmentally labeled shoe models sold in Sweden. However, the complexity of the situation regarding unknown subcontractors and general lack of knowledge regarding the life cycle of the shoes in question might make a labeling process more difficult (Lönnqvist & Rolander 2008). In some cases, environmentally conscious choices have been made in form of Eco labeled materials for production of textile shoes (Aronsson 2014).

Since the problems related to shoe production and suppliers are difficult to solve, cooperation between companies in the shoe industry and environmental organizations might facilitate the sustainability work (Lönnqvist & Rolander 2008). One example of such collaborations is The Swedish Shoe Initiative, which has been started by Swedish shoe companies to work towards more sustainable shoe production (Aronsson 2014). According to Aronsson (2014), it is meant to develop a tool for measuring the degree of sustainability of materials used for different shoes.

2.2 Shoes from a life cycle perspective

The production is only a part of the whole supply chain of shoe companies. As defined by Albers et al. (2008, p.7), supply chains involve “a network of suppliers, distributors and consumers and includes the transport that occurs in the group”. Increased production will affect every stage in the chain, as well as the related environmental impacts (Albers et al. 2008).

According to Lönnqvist and Rolander (2008), globalization of the shoe industry has resulted in a supply chain in which processes might be spread all over the world. That means a shoe bought in Sweden might have been designed in one country and produced in another while all materials have been imported from a third (Lönnqvist & Rolander 2008). Therefore, since the life cycle of shoes will affect the environment on both a local, national and global scale, it is necessary to understand the processes involved and the origin of the components used in the production (Albers et al. 2008). This section will describe the life cycle of shoes based on the Swedish market and consumption.

2.2.1 Shoe production and its environmental impact

Even though the environmental work has resulted in increased efficiency regarding energy and material use along with less use of harmful substances, the raised consumption of shoes is counteracting the improvements (Staikos et al. 2006). So far, the environmental focus has been set on reducing the chemicals used in shoes and preventing emissions from the production phase and more recently, the waste generated from use of shoes has been acknowledged as a significant problem (Staikos et al. 2006). This means to not only consider waste from raw material extraction and shoe production, but also final waste in form of used shoes. By thoroughly assessing their supply chains, shoe companies can detect environmental concerns and use environmental management strategies to make improvements (Albers et al. 2008).

Design and purchasing of shoes

Shoes are often complex products with many materials and parts involved (Ingre-Khans et al. 2010). According to NilsonGroup (2012), the design process involves choice of materials, product design and which suppliers to use for the production. This means there is a chance to influence the impact of the final product (NilsonGroup 2012). However, the share of shoes designed by shoe companies themselves may vary since it is possible to order already finished products from their suppliers as well (NilsonGroup 2012).

Energy and resources

According to Milà et al. (1998), the electricity used in different processes will affect the total environmental impact and depends on the country in question. By placing the production in areas where renewable energy sources are used for electricity, the production would generate less emissions compared to alternate countries using non-renewable energy in form of fossil fuels (Milà et al. 1998). The same concept also applies to resource use (Milà et al. 1998).

Production of materials

Some shoe companies have their own production facilities for shoe materials, such as leather tanneries, where they can control the environmental standards to a greater extent (Engvall 2009). If the leather comes from unknown suppliers it might have been transferred through several tanneries during the production process (Engvall 2009). Again, since the supply chain is often unclear to the shoe companies, it is difficult to evaluate the origin of materials used in shoes (Engvall 2009). Shoes imported from Asia often contain leather produced in Asian countries such as China, India and Pakistan (Engvall 2009).

The production of materials generate waste, such as leftovers from leather production, which might be treated differently depending on the country and principles of factories (Milà et al. 1998). In some countries, landfill might be dominating whereas in others incineration is more common (Staikos et al. 2006). Some countries with lack of proper waste management strategies might have production facilities which release waste straight into water ecosystems without any treatment (Aronsson 2014).

Shoe manufacturing

The production of shoes involves many different steps. In the process, shoe parts are often produced separately to be assembled together in a later production stage (Lönnqvist & Rolander 2008). When the materials and shoe parts have been ordered, the manufacturing involves processes such as cutting, sewing and lasting (NilsonGroup 2012). Finally, the shoes will be packed and prepared for transport to retailers (NilsonGroup 2012).

As previously mentioned, the dominating part of shoes sold in Sweden is produced in Asian countries (Statistics Sweden 2015). These countries often have a lack of environmental legislation and even if some regulations exist they are seldom complied (Lönnqvist & Rolander 2008). This has become a problem since many chemicals and adhesives used in shoe production may have toxic effects on humans and the environment (Milà et al. 1998).

In shoe manufacturing, the waste treatment follows the same principles as for material production since it depends on factories and systems of the area in question (Staikos et al. 2006). The environmental conditions in shoe factories are often examined by inspectors sent by the shoe companies, which might evaluate the treatment of wastewater as well as use of chemicals and resources (Engvall 2009).

Transportation

Since the shoes consumed in Sweden mostly are produced in other countries, transportation is necessary. As described by NilsonGroup (2012), shoes produced in Asia are first delivered by boat to a Swedish port and then transported by truck to a central storage. For NilsonGroup, the storage is located in Varberg and the ports in question are Gothenburg and Halmstad (NilsonGroup 2012). The extensive import, transportation and long distances mean that the choice of transport is important for the amount of emissions released and resulting environmental impact (NilsonGroup 2012).

Distribution, selling and use of shoes

The globalization of the shoe industry also results in long chains with different suppliers (Engvall 2009). According to Engvall (2009), a shoe company might be in contact with one supplier or agent which in turn may have many subcontractors. Additionally, a shoe retailer often has many suppliers since they have different assortment and specializations (NilsonGroup 2012). When the shoes have arrived from the suppliers they might be sold in stores or ordered online (NilsonGroup 2012). In some cases, shoes are also repaired and reused depending on the quality and materials (NilsonGroup 2012).

End-of-life treatment

According to Staikos et al. (2006), most shoes are landfilled after their use. However, most shoes are assumed to be incinerated in Sweden due to the current treatment of municipal solid waste (Lavoro et al. 2008). The current waste management system has a very low landfill percentage and even though recycling is common, it is not adapted to recycling of shoes (Lavoro et al. 2008).

3 Method

This section describes the methods used throughout the working process. In general, to analyze the shoe consumption in Sweden a flow analysis of the product and its related materials was performed followed by a life cycle assessment approach. Since consumption can be defined and interpreted in many different ways, one main issue was to determine how to set an appropriate definition for this study. Due to suggested methods and guidelines in the project description provided by IVL, the net inflow of shoes was used as a measure of the consumption. This means that the shoes imported to Sweden and not exported to other countries are seen as consumed.

$$Net\ inflow\ of\ shoes = Import\ of\ shoes\ to\ Sweden - Export\ of\ shoes\ from\ Sweden$$

Since no data was available for domestic production of shoes in Sweden, and the found information that the amount of shoes produced in Sweden is small compared to the imported amount, the domestic production was excluded.

3.1 Initial research

To prepare for the assessments and modeling an initial research process had to be performed. This process included information gathering, data collection and learning how to use relevant tools for the study, such as templates for handling data and the modeling software GaBi.

3.1.1 Literature study

The initial phase of the study included a literature review where chosen literature was used to get a deeper understanding of the shoe industry and production processes. Since the study is based on collected information and data it is important that it is relevant and reliable. Therefore, all references were evaluated before use. The evaluation was mainly based on the CARS system described by Harris (1997), where CARS stands for credibility, accuracy, reasonableness and support. Literature and scientific publications were searched through databases provided by Chalmers Library while considering age, content, authors and citations. When it was necessary, company websites and reports were also used.

Old LCA studies were provided by IVL and also found online where similar results could be used for comparison of data and relevant processes. Some reports contained information about shoe manufacturing and the leather industry, while others could work as guidelines how to carry out an LCA.

3.1.2 Study visit

To get a better understanding of the processes involved in leather manufacturing, a study visit to Elmo Leather in Svenljunga outside of Gothenburg was organized after the literature study and data collection had been initiated. It included a guided tour in the factory where every step in the production chain was described and also an explanation of the environmental issues related to leather production in general.

3.2 Categorization of shoes

Since the shoe industry involves many different shoe models and materials a method for grouping them had to be developed early in the study. The desired criteria included the necessary connection to the shoe industry and also a division according to shoe type and material content.

An already existing system for categorizing shoes and other goods in Europe and also Sweden is the Combined Nomenclature (CN) which is divided into different levels of detail and used for declaration and statistical purposes, such as trade of goods (European Commission 2015b). A higher level includes more categories and a more detailed description of the product and its material content (European Commission 2015b). The goods are divided into different chapters and footwear is represented by chapter 64. Since the CN system is used by the shoe industry and that the available import and export data at Statistics Sweden (2015) is presented according to the CN categories, it was suitable to use it as a basis for the categorization of shoes.

The criteria stating that the shoes needed to be divided according to their material content was also fulfilled by using the CN system, since brief material descriptions are available for CN level 2 up to level 8 (European Commission 2015b). The CN 4 level was determined as the most suitable level, whereas higher and more detailed levels were used to clarify the materials used in the shoes included in the different categories. The CN division is illustrated in Figure 1, where the six CN 4 categories involve in general waterproof shoes, rubber & plastic, leather, textile, other shoes and shoe parts (European Commission 2015b). A detailed description of the six CN 4 categories can be found in Appendix A.

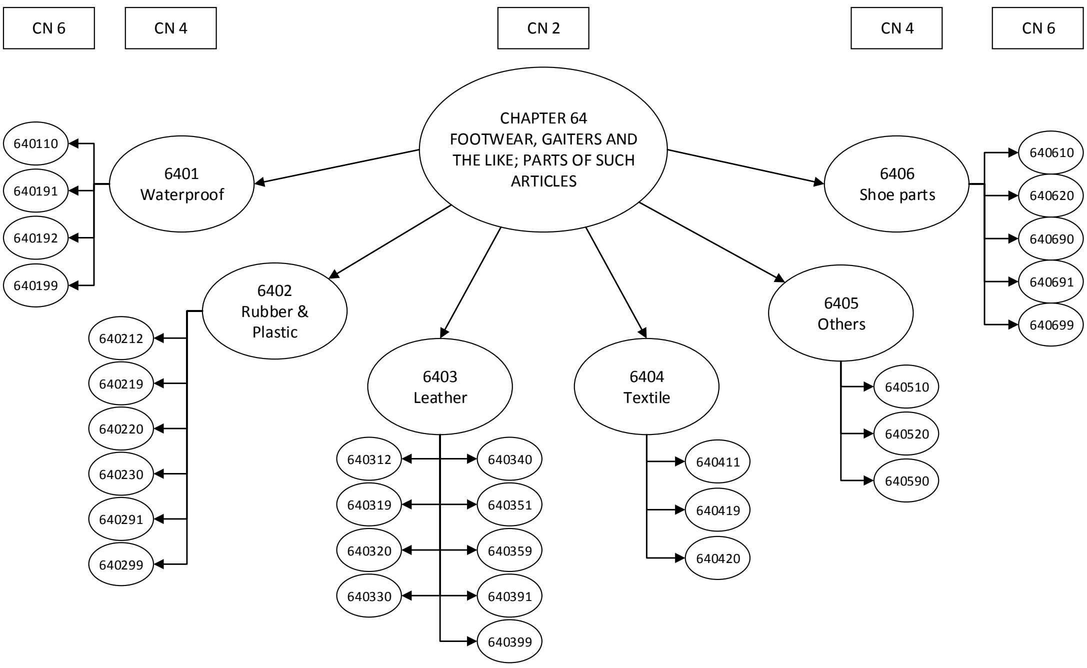


Figure 1 – Overview of the CN categories relevant for shoes and their subcategories with increasing level of detail.

3.2.1 Determination of materials in shoes

As described by Staikos et al. (2006), there is a wide range of different materials and chemicals used in the footwear industry. The material properties are important for the life time of shoes and also what impact they will cause on the environment during its life cycle (Staikos et al. 2006). Therefore, determining the materials used in shoes and understanding their characteristics is important in this kind of study.

Due to lack of specific material content declarations in the CN categories, materials used for the six different groups had to be determined in more detail. The final shoe materials to be used in the model were mainly decided according to a material list provided by the Swedish Shoe Environmental Initiative, SSEI. The list was divided into different shoe parts and stated the materials included in each part.

The main material groups included rubber, plastic, leather, textiles and metals in which more specific materials were listed. The rubber group included both natural and synthetic rubbers. Leather was dominated by primarily bovine but not excluding others in form of pig, goat and sheep. Hence, since the other leather origins only covered a small share of the total use, bovine leather was focused on in this study. The main textile materials were determined to be cotton, nylon, polyester and viscose. The chosen metals were iron, copper, zinc, brass and aluminum. Plastics identified were polyurethane (PU), ethylene vinyl acetate (EVA), MD, thermoplastics (TPR), polyvinyl chloride (PVC), polyethylene (PE) and polyethylene terephthalate (PET). Other materials in form of wood, cork, PU leather and fleece were also included. A detailed material list can be found in Appendix A.

3.3 MFA and LCA model

With regard to the limitations of the study, an approach combining the methods material flow analysis and life cycle assessment was seen as suitable for a model of the shoe consumption in Sweden. The results from the flow analysis were inserted into GaBi, a modelling software which can calculate environmental impacts of the included processes (Thinkstep 2015b). This section briefly describes the LCA and MFA methodologies while focusing on their application in this study.

3.3.1 Approach to material and product flow analysis

According to Brunner & Rechberger (2004), a traditional material flow analysis for a certain material shows the relevant stocks and flows within a determined system. The method involves balance calculations of inflows and outflows of included processes which will show eventual accumulation or depletion of material stocks (Brunner & Rechberger 2004). Therefore, MFA works as a useful basis for calculation of environmental impacts related to a system (Brunner & Rechberger 2004). In this study, a simplified MFA was performed where flows of materials used in shoes were determined. Since the life time of shoes was not considered, stocks of materials were left out.

As in this case, if a product is to be analyzed, a so-called product flow analysis can be used in the same way as an MFA (Oguchi et al. 2008). According to Oguchi et al. (2008), the inflows and outflows may be determined by import, export and overall use of shoes in the society. A study of relevant flows of a product will include all material flows associated with it (Oguchi et al. 2008).

Data collection for the material and product flow analysis

For determination of the flows, data regarding Swedish import and export of shoes was required for the different shoe categories. Suitable data for this purpose was found in the Statistics Sweden database (Statistics Sweden 2015).

Both the flows of shoes and materials were presented by weight. To be able to analyze one standard pair of shoes in every category a manual shoe weighing was performed which included relevant footwear of an average size of 39-40. Hence, an average weight of a pair of shoes could be determined. Weight percentages of material content in the average shoe for every category were then assumed by using literature, previous studies and examination of real shoes.

3.3.2 LCA methodology

As stated by Horne et al. (2009), life cycle assessment can be used for comparing environmental impacts related to different products and answer the question which of them has the lowest impact. This means an LCA approach was suitable for comparing impacts of different shoes. To be considered as a full LCA, the work must fulfill defined ISO 14040 standards regarding content and methodology including critical review which was not the case for this study (Horne et al. 2009).

Since the thesis was of an LCA character, the general steps included in the method were used to obtain desired results. As illustrated in Figure 2, the process was initiated by setting the framework in a goal and scope section, where the goal equals to the purpose of the study and the scope includes several choices required for the modelling (Baumann & Tillman 2004). Data collection, documentation, calculations and modelling was included in the “Life Cycle Inventory” (LCI), while the Life Cycle Impact Analysis (LCIA) was used to transform the inventory data into environmental impacts (Baumann & Tillman 2004). Finally, analysis methods developed to present, interpret and test the LCIA results were chosen with regard to the purpose of the study.

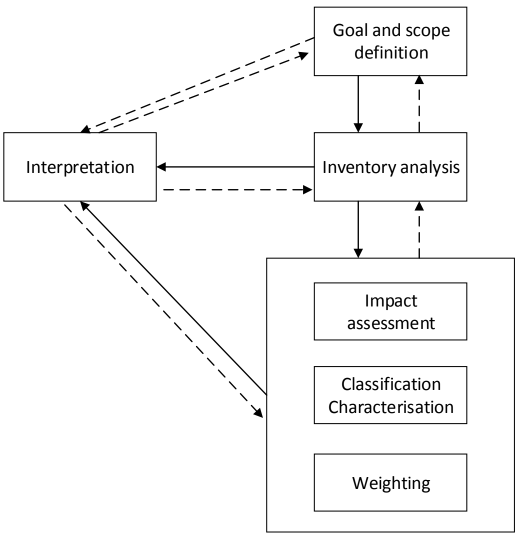


Figure 2 – An illustrated overview of the steps included in the LCA method as explained by Baumann and Tillman (2004, p. 20).

Type of LCA

Different types of LCA include accounting and change-oriented, where the primary is retrospective, comparative and used to assess the environmental impact related to a product (Baumann & Tillman 2004). Due to the goals of the study, an accounting LCA was suitable.

Functional unit

When a product system is to be analyzed a quantitative functional unit is required which must be related to the function of the system (Baumann & Tillman 2004). In this study, the functional unit was chosen as the total weight in kilograms of shoes consumed in Sweden in one year. Also, an additional functional unit in form of one typical pair of shoes for every chosen category was chosen to make the outcome of the study useful and understandable from a consumer perspective.

System boundaries

To define the boundaries of an LCA study, one must look upon temporal, spatial and system aspects since the product in question might be related to several others (Baumann & Tillman 2004). As defined by the project description, a time frame of 11 years between 2000 and 2010 was set with the motivation that eventual trends could be observed and relevant data for the period would probably exist. According to the functional unit, the study would also focus on one year at a time. Since the study object was set to Sweden, only consumption of shoes within the country was included. However, import of shoes from other countries required assessment of production and transportation data related to the relevant sources.

As described by Baumann and Tillman (2004), the choice of what processes should be included in the system depends on the life cycle and the desired outcome of the LCA. The beginning of the process, called “cradle”, involves raw material extraction and production, whereas “graves” includes end points in form of waste management (Lehtinen et al. 2011). Since the impact of the whole product system was desired, a so-called “cradle to grave” boundary was set for this study.

Impact categories

An important part of the scope involves defining what environmental impacts to include in the study, i.e. choosing relevant impact categories (Baumann & Tillman 2004). Some criteria to consider while choosing are how relevant the impact categories are for the study and the level of independence compared to each other (Baumann & Tillman 2004). According to Baumann and Tillman (2004, p. 129), there are three main groups called “resource use, human health and ecological consequences”, where each includes several categories of environmental impact. Among the available areas, standard impact categories related to ecological consequences in form of acidification, eutrophication, global warming potential (GWP), and photochemical ozone creation potential (POCP) were chosen to be included in the study. Details regarding the categories can be observed in Table 1.

Global warming potential involves emissions of greenhouse gases which contribute to climate change (Baumann & Tillman 2004). The scale is global since these pollutants tend to be long-lived and spread in the atmosphere, where they absorb heat radiation and cause a warmer climate on earth (Garrett & Collins 2009). Therefore, impacts from emissions contributing to global warming are complicated since ecosystems are dependent of the climate (Baumann & Tillman 2004).

Acidification involves emissions of substances which can be harmful to soils, water and ecosystems in general (Garrett & Collins 2009). The relevant pollutants in this category have a tendency to release acidic H+ ions, which means the acidification potential is determined by the pollutants' ability to form these ions (Baumann & Tillman 2004). While emitted, acidifying pollutants spread in the atmosphere where they may dissolve and cause acid rain (Baumann & Tillman 2004).

Eutrophication involves substances which affect the productivity of organisms and consumption of oxygen due to increased levels of nutrients in ecosystems (Baumann & Tillman 2004). Phosphorous and nitrogen act as nutrients for both terrestrial and aquatic plants, where increased growth in the latter case may result in more decomposition and dead zones (Baumann & Tillman 2004). These substances can be emitted to air or ground systems, which means this category operates both on a local and global scale (Garrett & Collins 2009).

Photochemical ozone creation potential involves emissions contributing to creation of a group of particles which can be harmful to living organisms and vegetation, in this case mainly ground level ozone (Garrett & Collins 2009). Resulting from chemical reactions in combination with sunlight, these pollutants are related to the smog phenomenon which is known to cause damage to health and plants (Baumann & Tillman 2004).

Table 1 – Overview of impact categories chosen for this study, descriptions according to Garrett & Collins (2009).

Impact Category	Acidification	Eutrophication	Global Warming Potential (GWP)	Photochemical ozone creation potential (POCP)
Unit	kg SO_2 equivalents / kg emissions	kg PO_4 equivalents / kg emission	kg CO_2 equivalents / kg emission	kg ethylene equivalents / kg emission
Pollutants	SO_2, NO_x, HCl, NH_3	N & P substances	CO_2, CH4, CFC, N_2O	Secondary pollutants (mainly ozone) formed from NO_x and VOC

Initial flowchart

For the modelling, an initial flow chart was constructed which included the flows and processes involved in the life cycle of shoes. The flow chart can be seen in Figure 3.

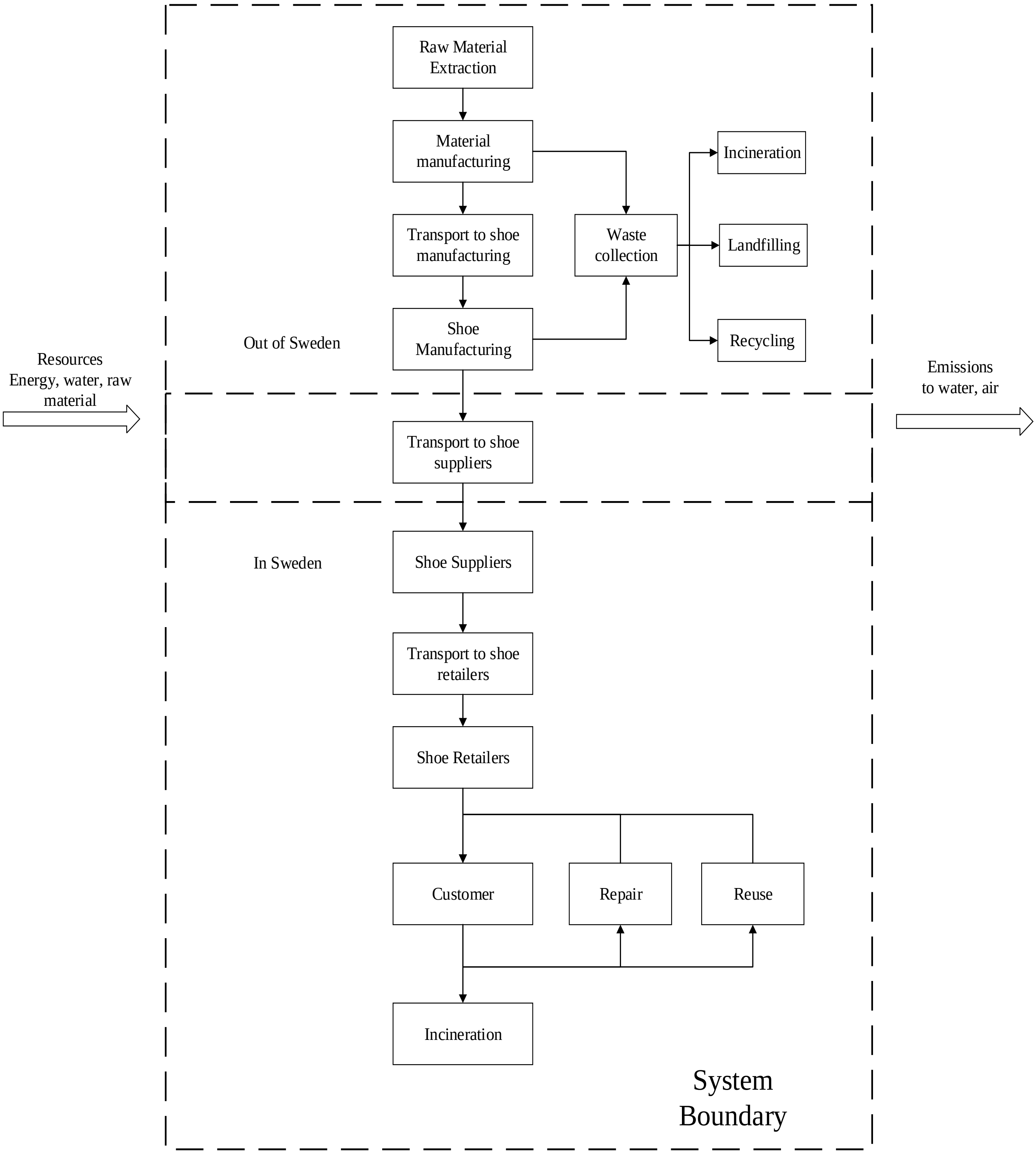


Figure 3 – An initial flowchart for the life cycle of shoes which includes all activities within the system boundaries.

Allocation

Allocation of impacts is necessary if some processes are used in several systems, for example if a production process generates more than one product (Baumann & Tillman 2004). The total impact must then be divided upon the different products. In this thesis, the allocation was determined by using literature. A mass allocation was used for cattle production with regard to its finished products in form of meat and raw hide, where raw hides corresponded to 3% of the total impact (Tuomisto et al. 2015). Also, in the case for waste management where processes generate heat and electricity, a system expansion approach included an assumed district heating system which could use the produced energy. The allocation problems are described further in Appendix A.

Life cycle inventory analysis

According to Baumann and Tillman (2004, p. 97), the aim of the life cycle inventory (LCI) is to "construct a flow model of a technical system" and involves creating a detailed flowchart, data collection, documentation and calculations of so-called "environmental loads" caused by activities and materials. The final flowchart was developed from the initial flow model with support from literature.

When the processes and materials involved in footwear manufacturing had been determined, the GaBi database was searched where data for some processes was found. Data for remaining processes had to be collected elsewhere. A suitable database for this was Ecoinvent, Swiss Centre for Life Cycle Inventories, from which data could be downloaded and imported into GaBi. According to Ecoinvent (2015), the database provides relevant and credible data with high quality for Life Cycle Inventories. The association also states that the Centre is the leading LCI data provider in the world (Ecoinvent, 2015).

Process data for leather production had to be collected and compiled in detail for the inventory due to limitations in available databases. For this purpose, valuable sources of information were already performed LCA studies since they often provided useful data. The data collected for leather was validated by comparing several data sources.

The calculation part of the life cycle inventory was performed by creating a model for the whole system with its relevant flows in GaBi. According to Baumann and Tillman (2004), more extensive life cycle assessments can preferably be executed with developed software tools. Even though the calculation procedures and methods within the GaBi software were unknown, the automatic modeling system was preferred in this study.

Life cycle impact assessment

As described by Baumann and Tillman (2004), the environmental loads calculated in the inventory must be translated into the more understandable and comparable impact categories which have been decided in the scope. Thus, in life cycle impact assessment, the results are prepared to show what consequences activities within the system cause on the environment. Since GaBi generates LCIA results through balance calculations, data for chosen impact categories could then be extracted from the model (Thinkstep 2015b). A data quality analysis aimed for testing the results was performed during the analysis.

3.3.3 Assumptions

Due to the nature of the study, limited availability of data and a limited time frame, it was necessary to make assumptions while creating the model and handling the data for the inventory. As far as possible, assumptions regarding material content in shoes, transport distances and allocation were made supported by references. Otherwise, suggestions from professionals were also considered. All assumptions can be found in Appendix A and C.

3.4 Method for analysis of results

The analysis was performed by using LCA methods and adapted to solve the research questions, which means it partly focused on environmental impacts related to trends in shoe consumption and materials used in shoes. Another purpose with the analysis was to check the data and assumptions used in the modelling.

3.4.1 Analysis of consumption trends

The consumption based on net inflow was assessed by studying changes in consumption patterns during the certain time period 2000-2010. The different shoe categories could then be compared according to annual net inflow and eventual trends were analyzed.

3.4.2 Interpretation and testing of LCA results

Regarding analysis in life cycle assessments, Baumann and Tillman (2004, p. 175) states that “the process of assessing results in order to draw conclusions is called interpretation in LCA terminology”. Diagrams are not only useful for presenting impact results, but also for analysis and evaluation of the model and assumptions (Baumann & Tillman 2004). Depending on the purpose, the results can be presented in different ways (Horne et al. 2009). As previously mentioned, an analysis of data quality can be used for interpretation of results. In this case, focus lies on “the significance, uncertainty and sensitivity of the LCIA results” (Baumann & Tillman, 2004, p. 143).

According to Baumann & Tillman (2004), a sensitivity analysis is used to examine data which has high impact on the results by changing the used numbers. To evaluate the assumptions made in the study, this type of analysis was performed at the end where the choice of testing parameters was based on the results. The analysis of data was performed both by using a data uncertainty check in which data sources were evaluated and a completeness check which evaluated data gaps and assumptions made in the modelling.

4 Results

This section will present findings from the trend analysis of consumption based on net inflow as well as results from the LCA. The LCA results are presented in the chosen impact categories both for the total weight and per pair of shoes. Finally, identified sources of environmental impact and impact of materials used in shoes will be shown. When possible, the results were also cross checked with other studies. The cross check and other controls of included data are presented in Appendix C.

4.1 Shoe consumption in Sweden from 2000 - 2010

According to compiled import and export data from Statistics Sweden, the shoe consumption based on net inflow in Sweden has increased overall between 2000 and 2010 with a sudden decrease in 2009. A peak in 2007 happened due to an increase in net inflow for group 6402, while the lowest value can be observed in year 2001, see Figure 4.

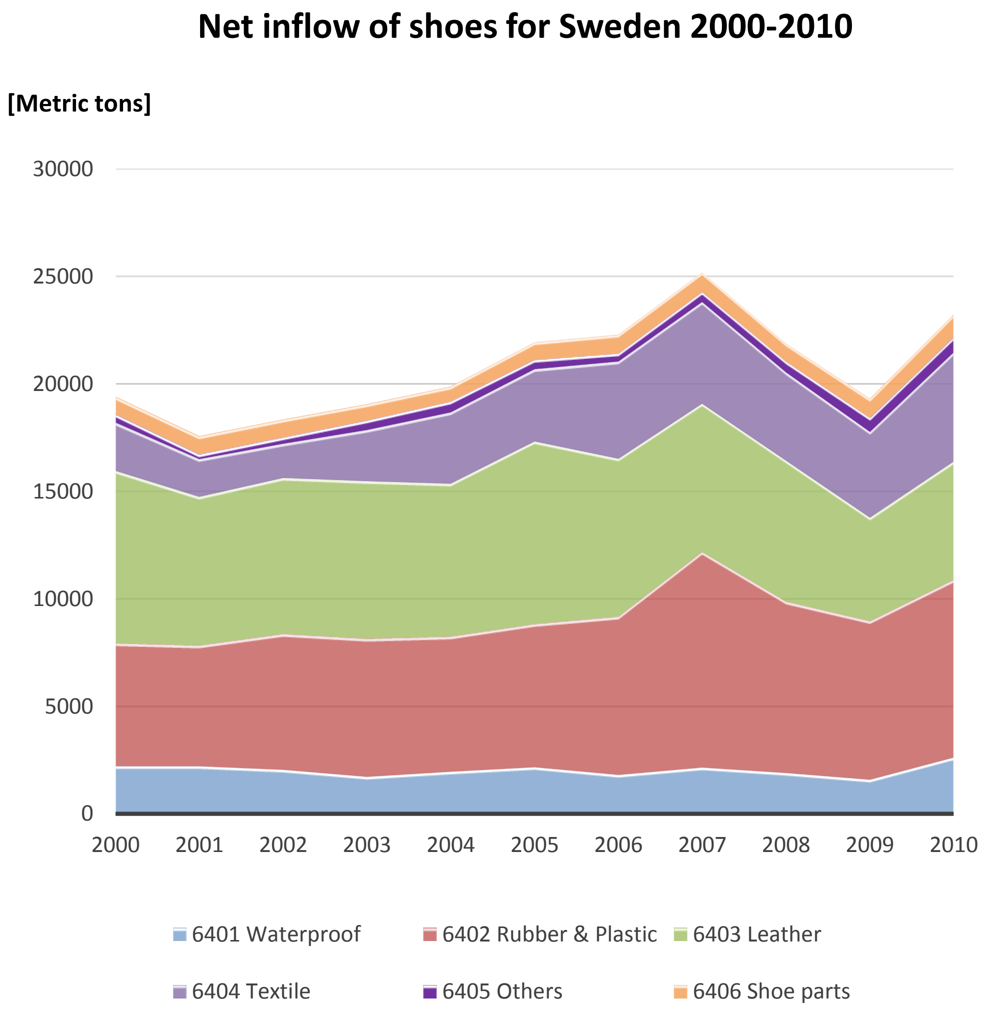


Figure 4 - Annual shoe consumption based on net inflow in metric tons with the share for every CN category, where net inflow is equal to import minus export.

The dominating shoe categories are CN 6403, leather footwear, and CN 6402, rubber and plastic shoes, where the latter has been the most consumed shoe category according to weight since 2006.

The third most consumed shoe group, CN 6404 involving textile shoes, has almost doubled from 12% to 22% of the total since 2000 which can be observed in Figure 5. CN 6401, the category including waterproof footwear, has a lower but steady consumption around 11% of the total during the whole period. The least consumed categories include other footwear, CN 6405, and shoe parts, CN 6406, which can be seen in Figure 5 below.

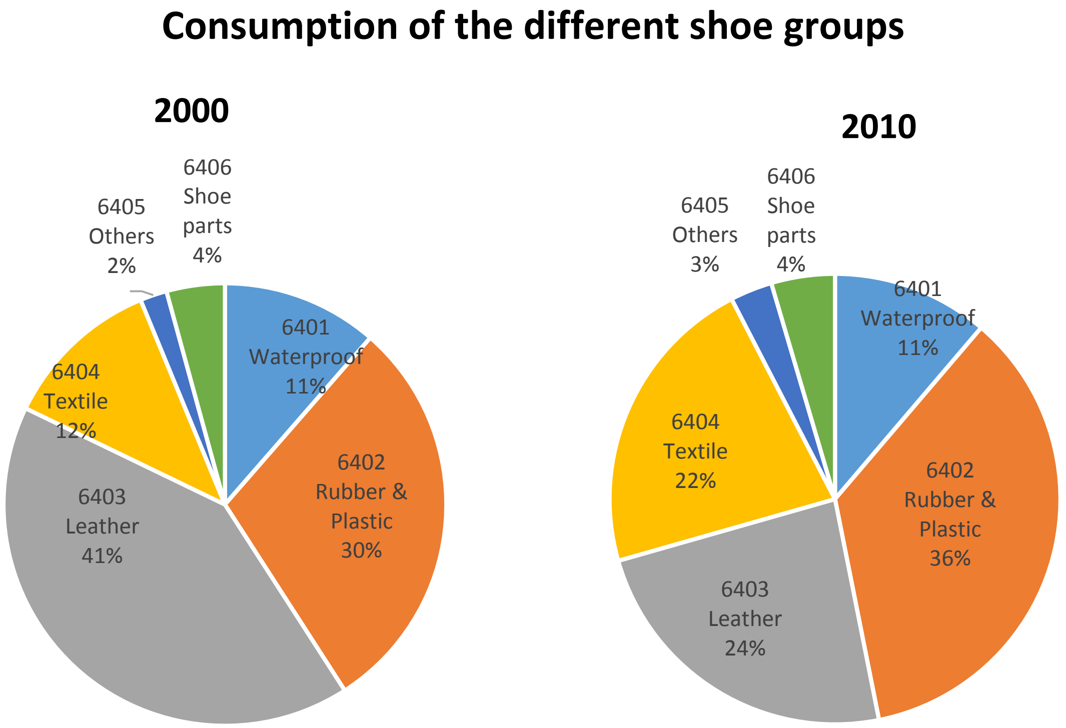


Figure 5 - The consumption of shoe groups 2000 & 2010

4.1.1 Origins of the shoe import

The areas which most shoes were imported from were Asia and Europe, which can be seen in Figure 6. The results show an increasing import from Asia, whereas the import from Europe has decreased during the studied time span of 11 years. Import from other continents is small in comparison.

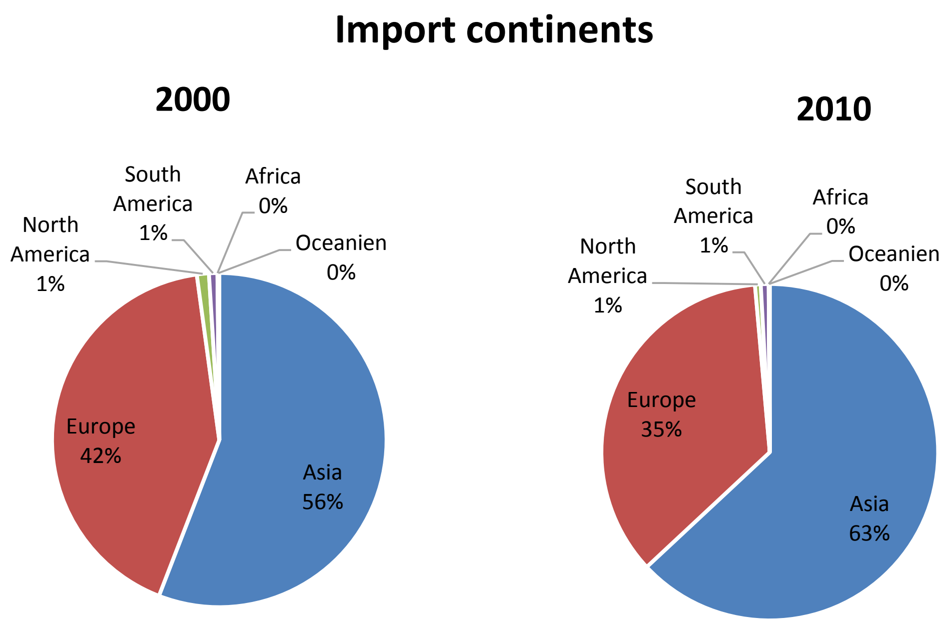


Figure 6 – Import continents for Swedish shoe consumption for 2000 and 2010.

By compiling statistics regarding import continents, it can also be seen that the amount of shoes imported from Asia and Europe varied for the different CN shoe groups. Due to small contributions from other continents, only Asia and Europe were included. The highest difference can be seen for group CN 6402 rubber & plastic, where 80 % of the imported shoes come from Asia, see Figure 7.

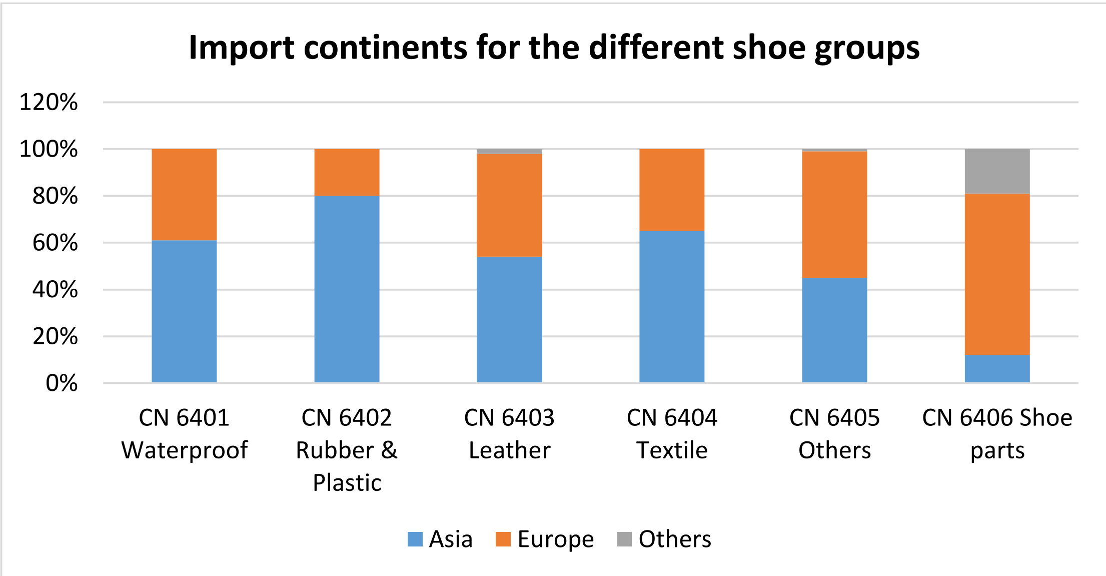


Figure 7 - Import continents for the different shoe groups according to data from Statistics Sweden (2015)

4.2 Impact of materials used in shoes

Seven main groups of materials used in shoes in form of plastic, rubber, leather, synthetic, textiles, wood and metal were included in this study. The material impacts were studied at the more detailed level which included 25 different materials. The focus was set on material weight and type of material, where material data was taken from GaBi and Ecoinvent.

4.2.1 Materials used in shoe production

This section briefly describes the material groups which were found to be relevant in shoe production during the initial research.

Rubber

The rubber category involves several different types, including natural and synthetic (Albers et al. 2008). The raw material, latex, is extracted from trees and can be treated with chemicals before use (Albers et al. 2008). According to Albers et al. (2008), another way to get rubber is to synthesize it artificially by using polymerization.

Mostly used in shoe soles and for different kind of boots, rubber is suitable since it is a lasting and often waterproof material (European Commission 2013). However, rubber production generates emissions to air in form of VOC and CO_2 which also contribute to the environmental impact from shoes (Albers et al. 2008). Another issue regarding rubber is the replacement of natural forests and agricultural land with plantations for latex production (Liu et al. 2006). As described by Liu et al. (2006), conversation of ecosystems might result negative changes such as loss of biodiversity. In general, using crops and plantations for large scale economic production can be seen as problematic due to the scarcity of land on earth (Liu et al. 2006).

Plastics

Common materials in shoes are different kinds of plastics. The main components in the production of the polymeric material are non-renewable fossil resources, which in turn results in release of VOC emissions to air (Albers et al. 2008). In addition, adhesives used in shoe manufacturing can also be produced from this kind of resource (Albers et al. 2008). Many types of synthetic polymers exist, such as polyester and polyethylene (Nkwachukwu et al. 2013).

Some plastics have been treated for special purposes, where different thermoplastics which are moldable by heating take up around 80% of the total plastic production (Nkwachukwu et al. 2013). Additionally, synthetic materials used in shoes are often made from different plastics, such as synthetic leather (Albers et al. 2008).

At its end of life stage, incineration of plastics might generate hazardous emissions of dioxins and furans (Nkwachukwu et al. 2013). Additionally, the fact that most plastics cannot be degraded biologically makes the waste challenging to handle which means recycling is preferable, though sometimes difficult (Nkwachukwu et al. 2013).

Textiles

In shoes, textiles can be used for lining and upper parts. Among the textiles used, cotton is an old and well-known material which is cultivated and made into yarn (Albers et al. 2008). If not cultivated organically, this kind of crop is often associated with large scale use of pesticides and water (Bevilacqua et al. 2014). This means natural water ecosystems and organisms might be affected negatively by cotton production (Bevilacqua et al. 2014).

According to Albers et al. (2008), cotton blends might also exist in form of cotton thread mixed with nylon, a synthetic fiber made from non-renewable resources which is related to impacts in form of emissions and use of toxic chemicals. Another example of a synthetic fiber made from non-renewable resources is polyester, based on PET (Albers et al. 2008). As described by Albers (2008), it is common to extract fibers from plastics such as PET, PU and PVC for shoe production.

Another textile material used in shoes is wool, which is obtained from sheep production along with a series of steps such as shearing, carding and combing (Barber & Pellow 2006). Wool production results in impacts from not only animal farming, but also transportation, waste and resource use (Barber & Pellow 2006).

Leather

Since the raw material used in leather production is animal hides, animal production and slaughtering initiates the life cycle of leather (Cleaner Production Institute 2009). Transportation of animals and hides is also required in this phase (Tärnsjö Garveri 2012).

As described by Tärnsjö Garveri (2012), the leather production is divided in four steps where each has different sub processes. The first main process, beam house processing, involves cleaning and washing of raw hides (Cleaner Production Institute 2009). After the initial treatment, a tanning process is used to remove proteins and turn the hides into stable leather (Tärnsjö Garveri 2012). The color and softness is generated in a post-tanning step, after which a finishing process gives the leather its final surface properties (Tärnsjö Garveri 2012).

The whole leather production process generates waste water containing chemicals and biological material as well as solid waste such as contaminated sludge (Prevodnik 2009). According to Aronsson (2008), examples of hazardous chemicals in untreated waste water from tanneries are pesticides, strong acids and chromium. The dominating use of chromium in the tanning process is one major issue associated with leather since it is a toxic and carcinogenic substance harmful to living organisms (Tärnsjö Garveri 2012). Even though vegetable tanning has become an option to conventional chromium tanning it only covers a very small share of the produced leather due to lower quality together with more expensive and time consuming production (Lönnqvist & Rolander 2008).

Despite the issues regarding water and toxicity, leather can be seen as a renewable alternative to materials made from fossil resources if raw hides are classified as a by-product from the meat and milk industry (IndustriAll 2012). Leather produced as a by-product is an example of a sustainability demand from shoe companies (NilsonGroup 2012).

Metals

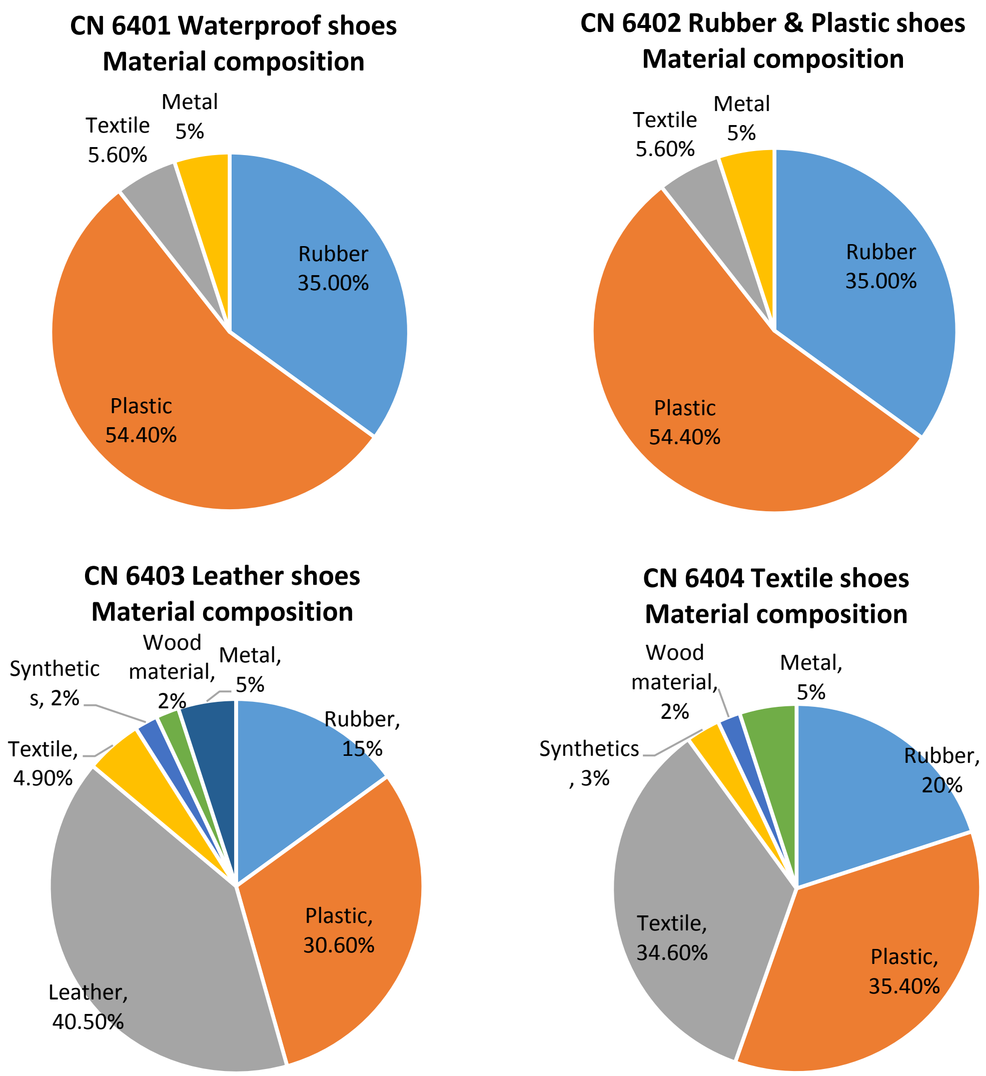
In general, metals are non-renewable resources extracted from metal ores (Norgate et al. 2007). The production process depends on the metal in question, since the ore might include several metals which must be separated before further processing steps (Norgate et al. 2007). According to Norgate et al. (2007), the extraction methods usually result in not only emissions to air, land and water, but also a remaining mixture of toxic metals and chemicals. Therefore, it is suitable to use the high recyclability of metals to avoid the environmental impacts caused during the production phase (Norgate et al. 2007).

Wood and cork

Natural, renewable materials in form of wood and cork can be used in shoe production, for example in soles and heels (Albers et al. 2008). Cork is extracted from cork oak trees by removing the bark, while the type of trees used for wood may vary (Albers et al. 2008).

4.2.2 Material composition of shoes

The partly assumed percentages of materials in shoes can be observed in Figure 8, while more detailed material assumptions are included in Appendix B. All shoe groups have different material compositions.



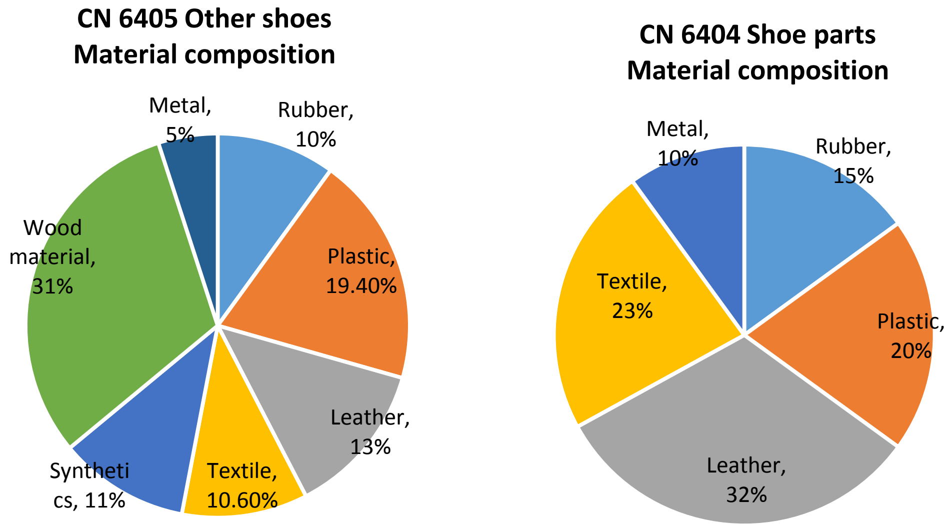


Figure 8 – Material compositions of shoe groups

4.2.3 Environmental impacts of different materials in shoes

To evaluate every material included in the study, impacts were calculated for one kilogram for each material and impact category. Four impact categories in form of Acidification Potential, Eutrophication Potential, Global Warming Potential and photochemical ozone creation potential have been evaluated in the impact assessment of both materials and shoes. In general, leather shows high impact in all impact categories. In this case, data from year 2010 was used. Due to similar result patterns for all impact categories, only global warming potential and eutrophication will be presented in this section while the rest can be found in Appendix B.

Global warming potential

As seen in Figure 9, leather has the highest global warming potential per kilogram followed by aluminium and nylon.

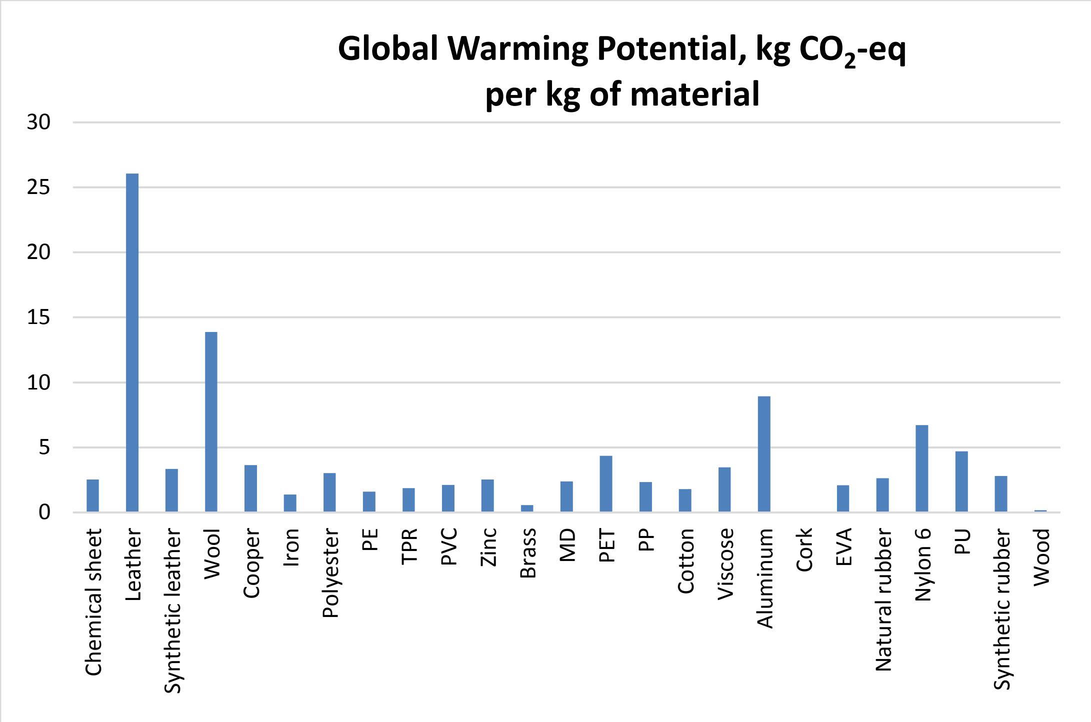


Figure 9 - Global Warming Potential for 1 kg of every included material based on data for 2010.

Eutrophication potential

Also in case of eutrophication potential, leather is the dominating material. The textiles show almost equal contribution. Otherwise, PU plastic and synthetic rubber also shows some eutrophication potential. See Figure 10.

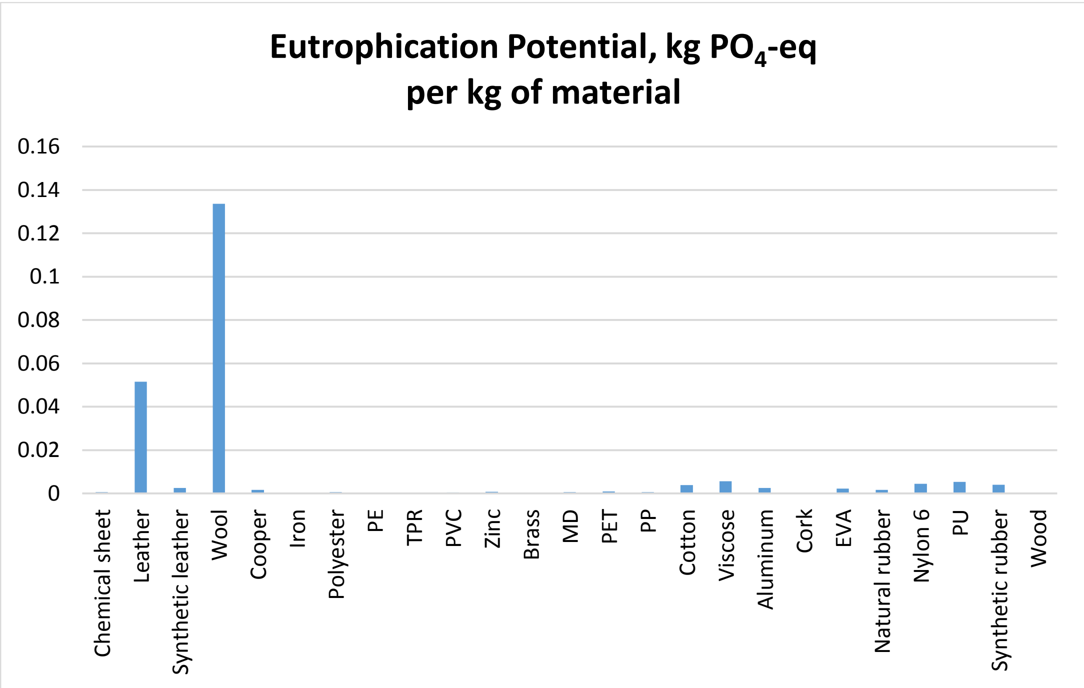


Figure 10 - Eutrophication potential for 1 kg of every included material based on data for 2010.

4.2.4 The most contributing materials to the environmental impact

The materials which contribute most to the environmental impact of Swedish shoe consumption were determined based on data for year 2010. To consider the amounts of materials used for shoes consumed in Sweden, materials percentages according to weight in shoes were assumed and can be found in Appendix B. The values were then used in the model. This section will include results for global warming potential and eutrophication, while the rest of the impact categories can be found in Appendix B.

Global warming potential

For the global warming potential category, leather, natural rubber and synthetic rubber are the three materials showing highest values. See Figure 11.

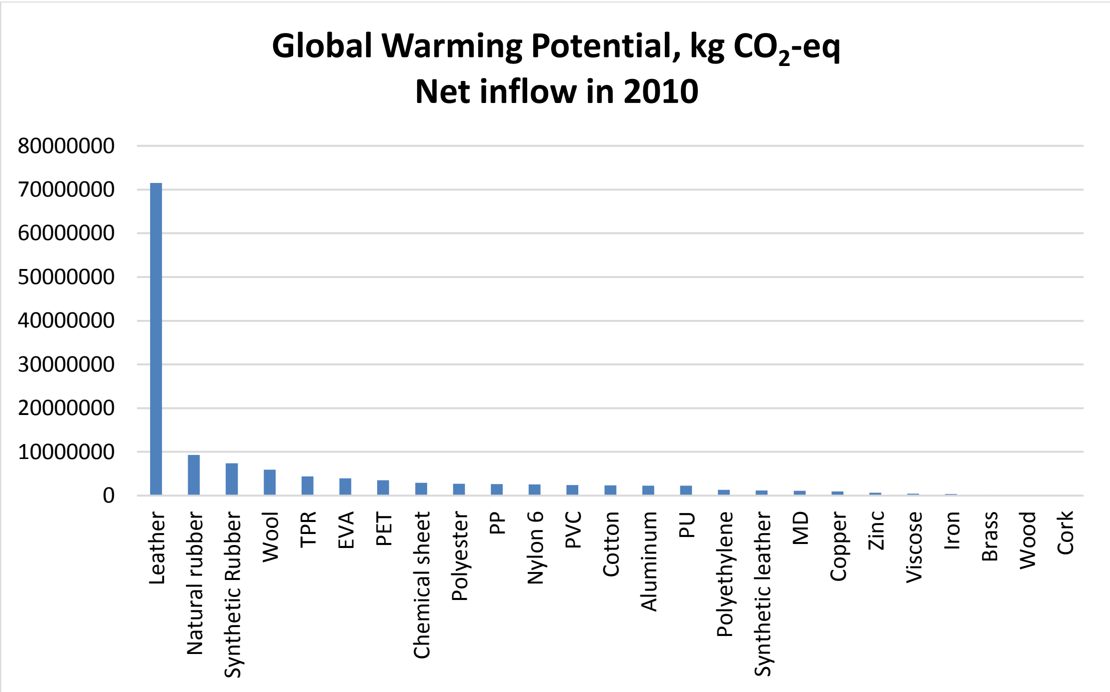


Figure 11 - Materials in shoes which have the highest global warming potential, data from shoe consumption in 2010

Eutrophication potential

Also for the case of eutrophication potential, the three materials which show the highest values are leather, wool, synthetic rubber and natural rubber. See Figure 12.

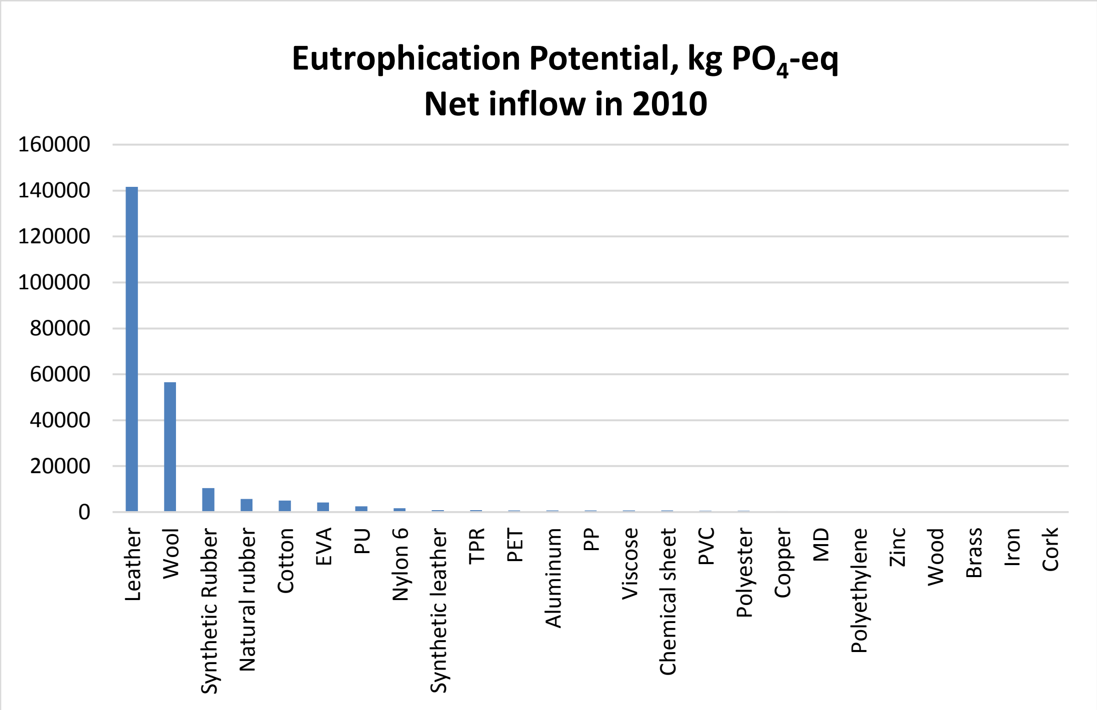


Figure 12 - Materials in shoes which have the highest eutrophication potential, data from shoe consumption in 2010

4.3 Environmental impacts of Swedish shoe consumption

The results from the model regarding impacts from shoe consumption in Sweden based on net inflow will be presented in this section, where the impact will be shown both as a trend and for the latest year in the study period (2010).

4.3.1 Trends of total impact from Swedish shoe consumption

For all impact categories, the highest peak can be seen in year 2007 and the lowest in year 2001. The total trends of impact are consistently following net inflow trend which can be seen in Figure 4 as well as Figure 13 to Figure 14. To increase the readability, only the graphs including global warming potential and eutrophication are included, see Appendix B for the other impact categories.

The two dominating shoe groups are in general leather shoes and rubber & plastic shoes. Textile shoes are the third main contributing group. Waterproof shoes have a consistent level of impact during the 11 years. Other shoes and shoe parts only correspond to a small percentage of the total impact.

Impacts from different shoe groups changed a lot due to variations in net inflow. The impact from leather shoes decreased while an increase can be observed for textile and rubber & plastic shoes.

Global warming potential

The difference between the two most contributing groups for GWP is not as big as for other impact categories, which can be seen in Figure 13 below. Even here, leather shoes and rubber & plastic contribute most.

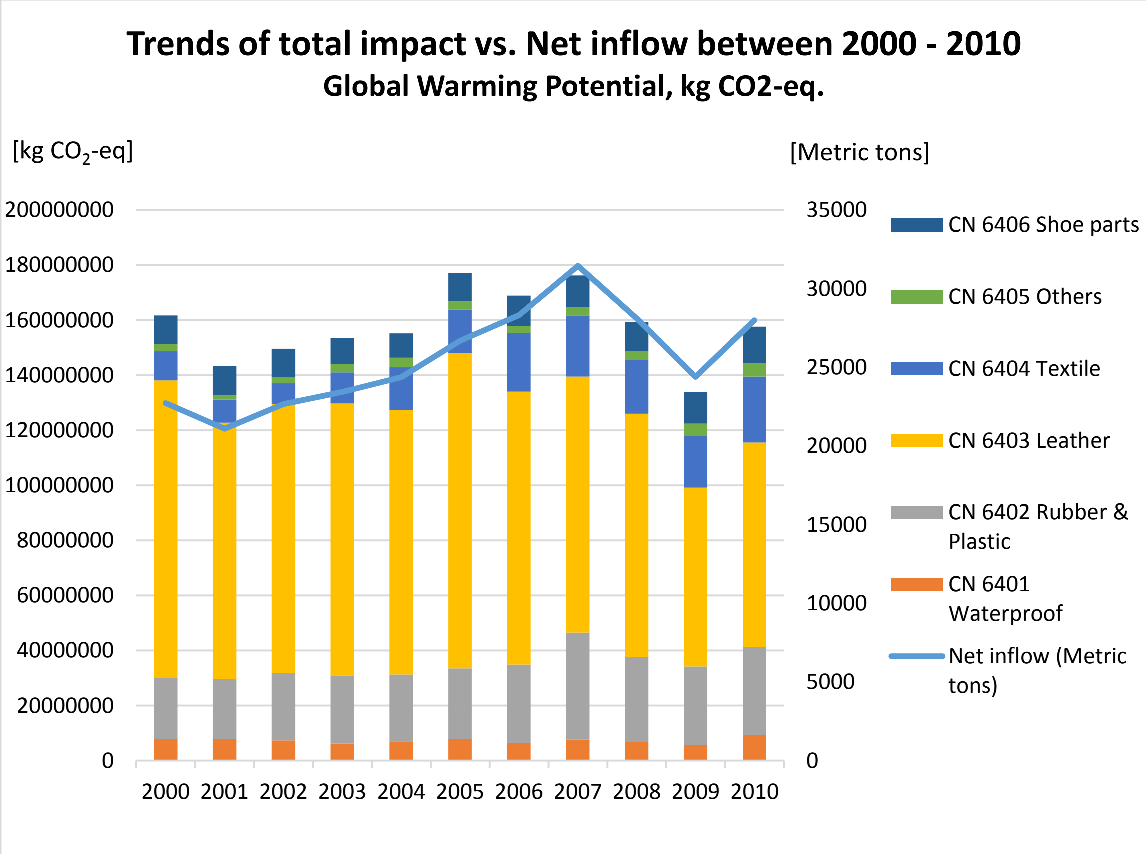


Figure 13 –Global Warming Potential for each CN category from year 2000 to 2010, the line for total net inflow shows the consumption trend during these years.

Eutrophication potential

Also in the case of eutrophication in Figure 14, leather shoes correspond to the highest level of contribution followed by rubber & plastic.

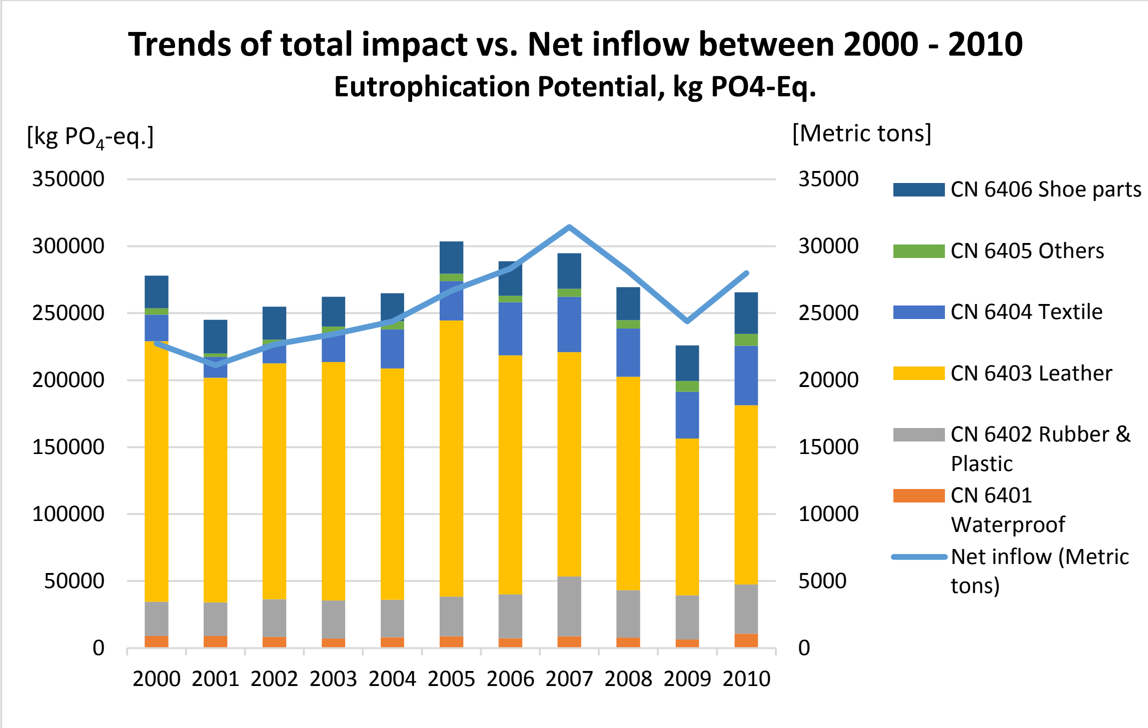


Figure 14 - Eutrophication potential of each CN category from year 2000 to 2010, the line for total net inflow shows the consumption trend during these years.

4.3.2 Environmental impact of shoe groups measured by net inflow

The total impact of shoes from year 2010 was determined for every impact category as well as the impact for every shoe category. The normalized results can be seen in Figure 15. Compared to the total impact, leather shoes and rubber & plastic contribute most. The absolute impact values for every shoe group and impact category are presented more in detail in Appendix C.

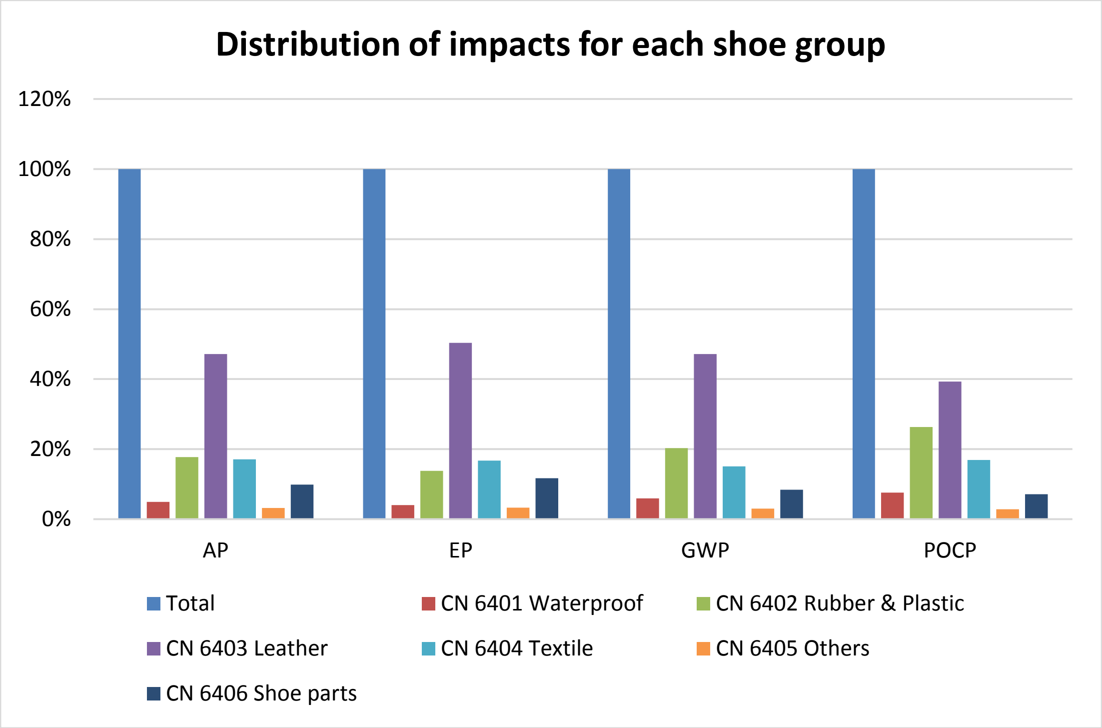


Figure 15 – Distribution of the total impact for the different impact categories, the total impact is set to 100%. AP is acidification potential, EP is eutrophication potential, GWP is global warming potential and POCP is photochemical ozone creation potential.

The total impact can also be divided upon the continents which shoes are imported from. Figure 16 shows a higher contribution from Asian shoe production. Due to similar results for all impact categories, only the diagram for global warming potential is presented.

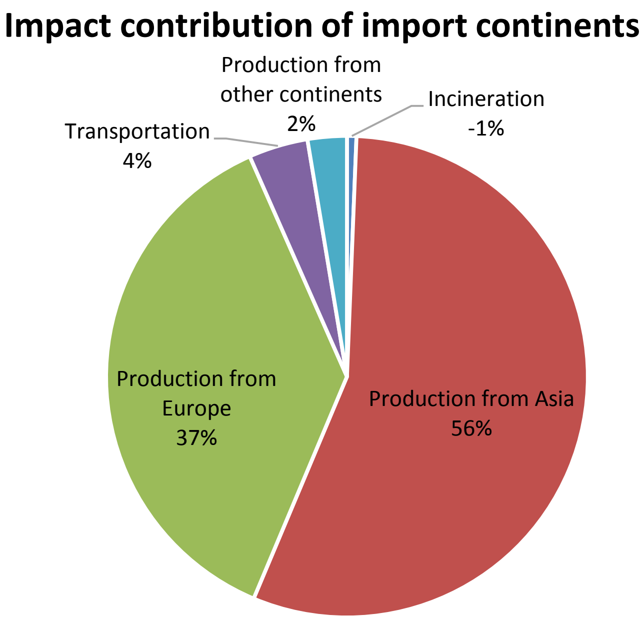


Figure 16 – The total impact divided with regard to the contribution from each import continent, shown for the total consumption of shoes in 2010 and global warming potential.

4.3.3 Environmental impact measured for one pair of shoes

From the results regarding impacts from one pair of shoes in different categories, leather shows a high value compared to one average pair based on shoes in all shoe groups. See Figure 17.

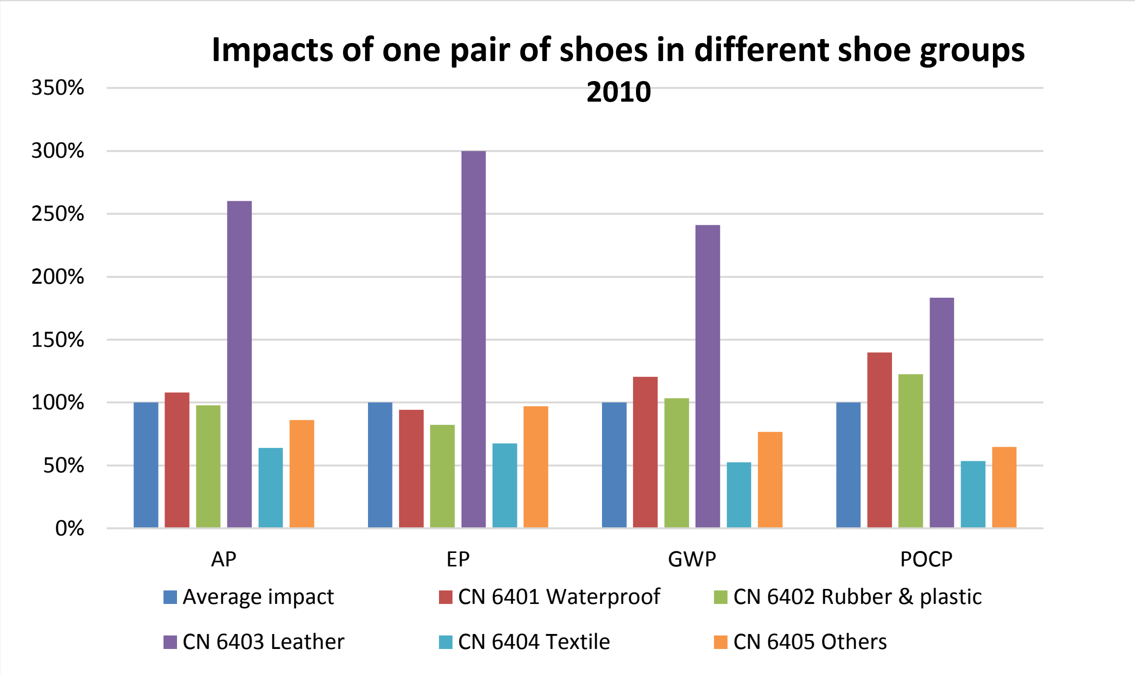


Figure 17 – Comparison of impacts for one pair of shoes from every group where impacts of an overall average shoe is set to 100%.

With regard to the customer perspective, the impact was calculated according to one average pair of shoes in every category based on data from year 2010. Shoe weights were assumed to be 1.5 kg/pair for waterproof shoes, 1.2 kg/pair for rubber and plastic shoes, 0.8 kg/pair for leather shoes and 0.5 kg/pair for textile shoes and other shoes. Shoe parts were not included. The study for determination of average shoe weights can be found in Appendix A and impact categories other than GWP can be found in Appendix B.

Global warming potential

An average pair of leather shoes shows the highest value for global warming potential followed by waterproof footwear and rubber & plastic shoes, see Figure 18.

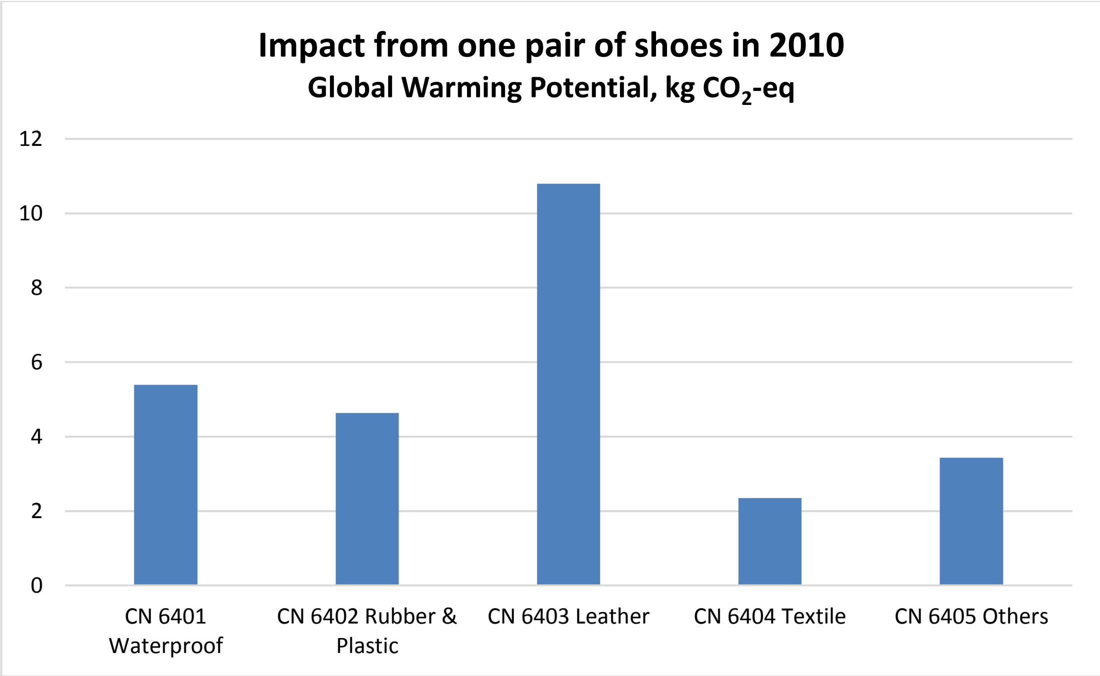


Figure 18 - Global Warming Potential for one pair of shoes in every CN category.

Eutrophication potential

A pair of leather shoes (CN 6403) show higher eutrophication potential followed by waterproof shoes and other shoes which can be seen in Figure 19.

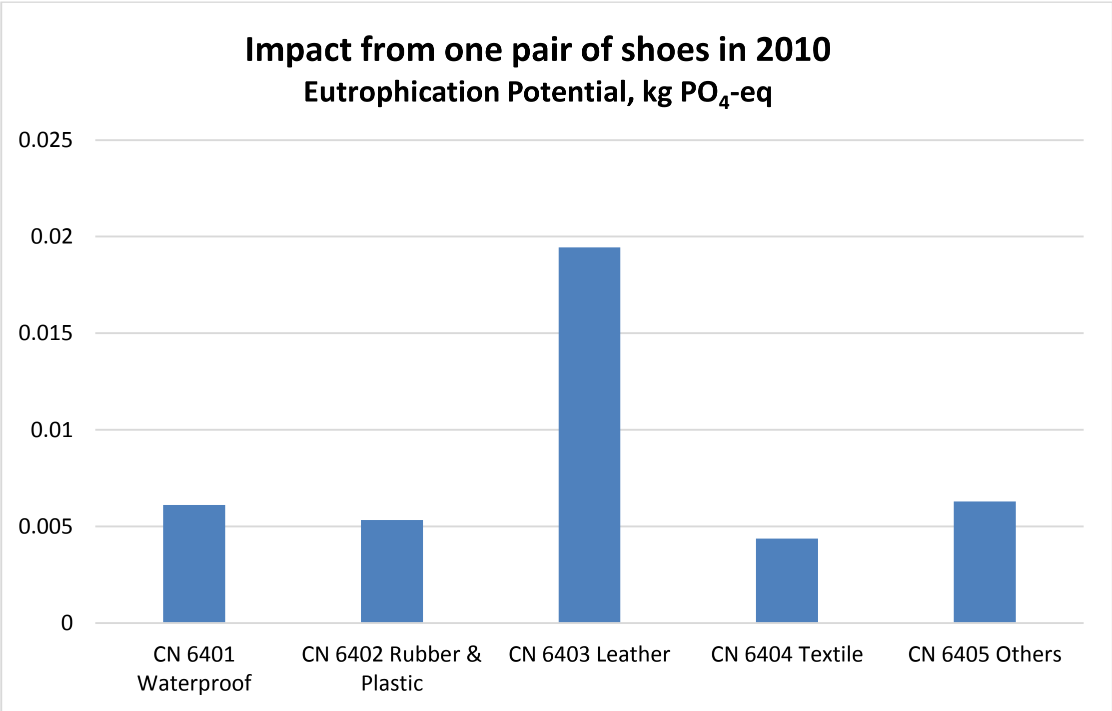


Figure 19 - Eutrophication Potential for one pair of shoes in every CN category.

4.3.4 Environmental impact from life cycle stages of shoes

This section shows impact sources for the total shoe net inflow in year 2010. It includes four chosen aspects related to the shoe life cycle in form of material production, shoe production, transportation and waste management in Sweden. Shoe materials include all upstream processes of material manufacturing with data from GaBi and Ecoinvent. The results in Figure 20 show that material production has high impact compared to other impact sources in the life cycle of shoes.

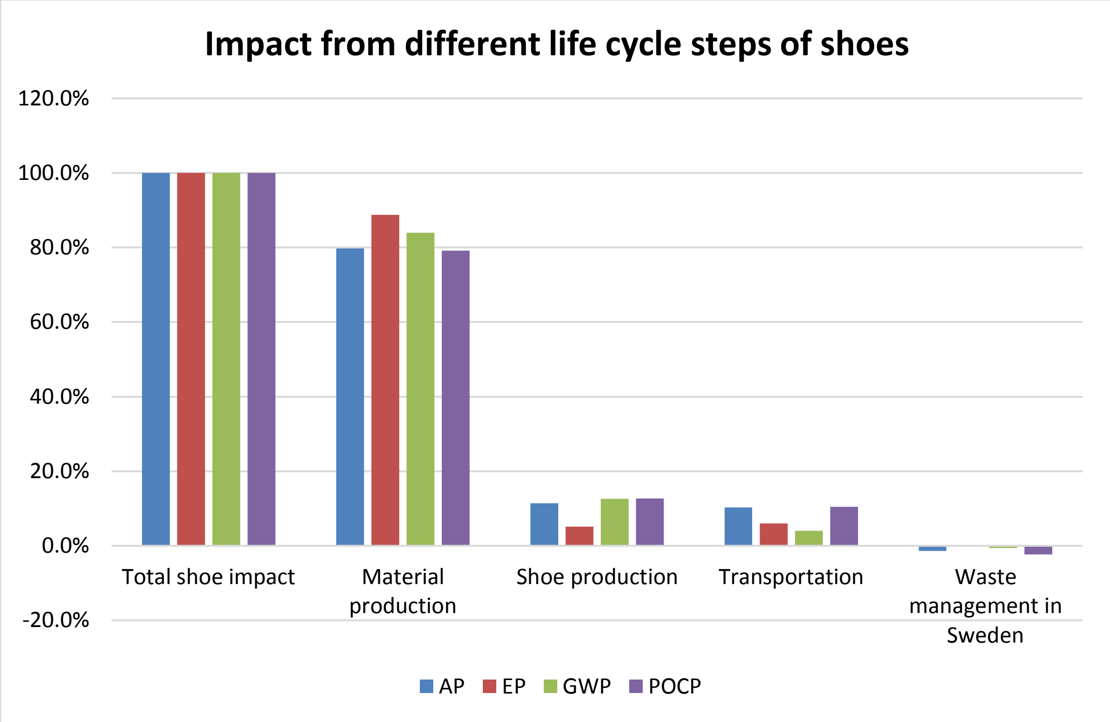


Figure 20 – Environmental impact contribution for different life cycle steps in shoe consumption where all impact categories are related to the total impact which is set to 100%.

5 Analysis

The analysis involves different parts. First, the results will be interpreted according to the research questions as well as the theoretical background regarding shoe consumption in Sweden. Secondly, the LCA related sensitivity analysis is presented while the analysis of data is included in Appendix C.

5.1 Interpretation of results according to research questions

In general, observations of the results regarding impacts from life cycle stages of shoes show that the material production corresponds to a significant part of the total. Shoe production and transportation has relatively low impact, while the waste management processes in Sweden reduce the impact with a small percentage.

The model considered import countries and continents, which showed that a high amount of the imported shoes comes from Asia. A lower amount of shoes was imported from Europe, while the shoe production in Sweden can be seen as nearly non-existent in comparison. Since production processes and electricity mixes in Asia tend to generate higher environmental impact due to extensive use of non-renewable resources, the import from Asia is one major contributing factor to the total impact of shoe consumption in Sweden. Even though the contribution from transportation is low, the distance between Asian countries and Sweden cannot be completely disregarded.

5.1.1 Analysis of net inflow of shoes and impact trends

Observations from the results regarding net inflow include an increase of rubber & plastic shoes during the studied years. Leather shoes followed the opposite pattern and decreased instead. Even though the variations indicate popularity of shoe groups, it could be worth to consider that the reporting of shoes in the different groups can be wrong and therefore misleading. Additionally, different subgroups might have been put together or removed which could have affected the data.

A peak for rubber & plastic shoes caused an overall increase of the total net inflow in 2007, which may be due to a sudden change in fashion trends. For example, a certain type of shoe in that group may have been introduced on the market and grown in popularity. Textile shoes have shown an increasing trend during the years, while the net inflows of the rest of the groups have been low and nearly constant. This could be explained by a general lower demand for waterproof shoes and working shoes which may only be bought out of necessity, as compared to other groups more sensitive to trends. In these cases, the possibility of error in the statistics must also be considered.

The increasing net inflow is matching the theory regarding a growing shoe industry, despite a reduction in 2009. The overall decrease in 2009 generated the lowest consumption based on net inflow during the studied time period. This type of total decrease might have been a result of a situation with less sales and a weaker economy, such as a financial crisis in the society.

5.1.2 Analysis of materials and shoes with regard to impact

The shoe groups contributing most to the total environmental impact of the shoe consumption in Sweden are leather and rubber & plastic, which also contribute to the highest shares of the total inflow. By studying and comparing the trend graphs, it can be observed that the total impact of each CN category is largely influenced by the net inflow of shoes. However, material content in shoes also affects the environmental impact and the results show that the type and amount of material are essential factors.

According to the results of impact per kilogram of material, leather has an extremely high value compared to other materials. As described in the background, leather production is an extensive process which has many activities resulting in different emissions. Another material based on animal farming which shows high impact is wool, but with regard to weight of the material and general material content in shoes, leather seems to be more relevant as impact source from the shoe consumption.

Other materials showing high impact per kilogram were natural rubber or latex, synthetic rubber, nylon, viscose, aluminium, PET and PU. Extraction and production of aluminium seems to cause more impact than other metals. Additionally, in terms of textiles, synthetic fibers show higher impact values per kilogram compared to natural materials. This follows the material descriptions, which stated that materials based on non-renewable resources as well as mining of metals have high environmental impacts.

Material impacts from the total shoe consumption

The materials with highest impact from the shoe consumption in Sweden corresponded to leather, natural rubber or latex, synthetic rubber and EVA. These materials showed high impact per kilogram, but it could also be connected to the material percentage in shoes as well as the consumed amount of shoes in which the materials are involved.

As seen from a customer perspective, to buy one pair of leather shoes has the highest impact compared to other shoe types. Apart from leather footwear, purchasing one pair of shoes included in the waterproof category would also generate high impact. This may be due to included materials and the fact that the average shoe weight in that category is high. Rubber & plastic shoes also show high impact per pair. Even in this case, the high impact should be due to the assumed average shoe weight and material content.

The results regarding material impact show that changes in consumption of some shoe groups will result in higher environmental impact than others, for example an increased use of leather shoes will be worse for the environment than an increase of textile shoes. Changed quantities of certain shoe types might then affect the environmental impact more than others.

5.2 Sensitivity analysis

The sensitivity analysis was performed with regard to shoe weight and electricity consumption, which had considerable impact according to the results. Also, since leather contributed most to the impact and involved assumptions, the sensitivity to changes in allocation, chemical input and waste management was analyzed and is presented in appendix C.

5.2.1 Shoe weights – Three scenarios

Since the impact of shoe pairs seems to be largely influenced by shoe weight and due to the large variation of shoe weights in the CN groups, three scenarios with low, normal and high values were created for a sensitivity analysis. For the normal base case, average shoe weights used in this study were used for the different categories. The light and heavy cases were determined by considering other shoes in the shoe weighing process, see Appendix A. The assumptions of shoe weights for the sensitivity analysis have been listed in Table 2.

Table 2 - Alternative shoe weights included in the sensitivity analysis for one pair of shoes in every category

	CN 6401 Waterproof	CN 6402 Rubber & Plastic	CN 6403 Leather	CN 6404 Textile	CN 6405 Others
Base case (kg)	1.5	1.2	0.8	0.5	0.5
Light case (kg)	1	0.5	0.3	0.3	0.3
Heavy case (kg)	2	2	1.2	1	1

5.2.2 Sensitivity regarding shoe weights

In this section, the impact results for the light case, heavy case and base case are presented according to the chosen impact categories. The results show that the impact per pair of shoes depends on shoe weight, which means the assumed weights largely affect the results in this study. It is also indicated that choosing lighter shoes instead of heavier shoes can reduce the environmental impact by half. This might be explained by the fact that the weight of shoes relates to raw material consumption, transportation and waste treatment, which means less resource use and emissions for lighter shoes.

Global warming potential

The results for GWP and eutrophication from the three scenarios can be seen in Figure 21 and Figure 22, the rest of the impact categories can be found in Appendix C.

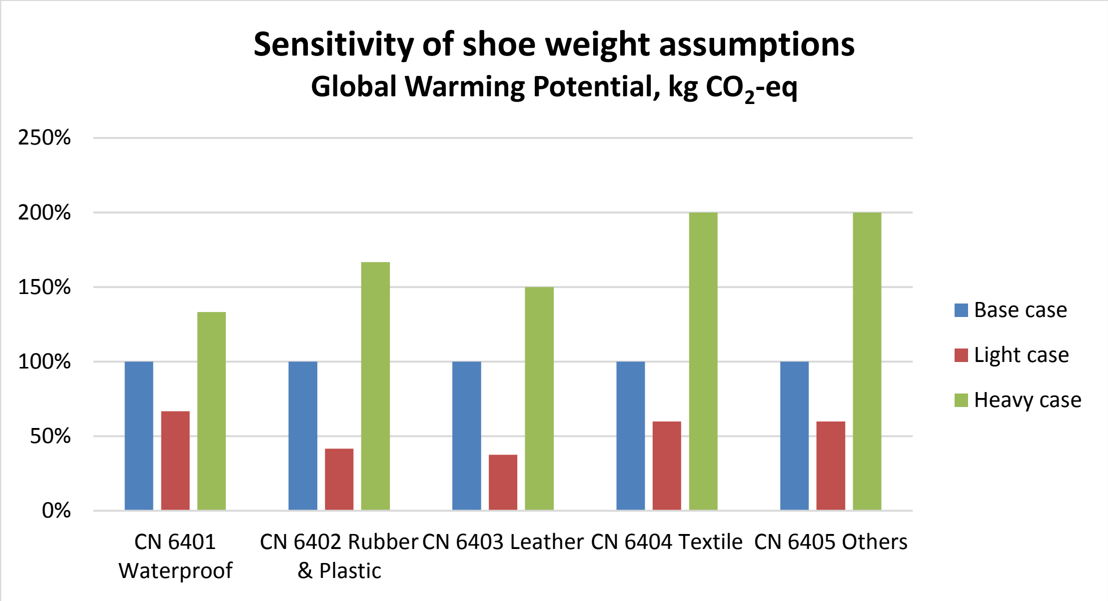


Figure 21 - Results from sensitivity analysis of shoe weight with three scenarios, the picture shows global warming potential for one pair of shoes in every group.

Eutrophication potential

With regard to eutrophication potential, it is clear that assumptions of heavier shoes will contribute more to the environmental impact, see Figure 22.

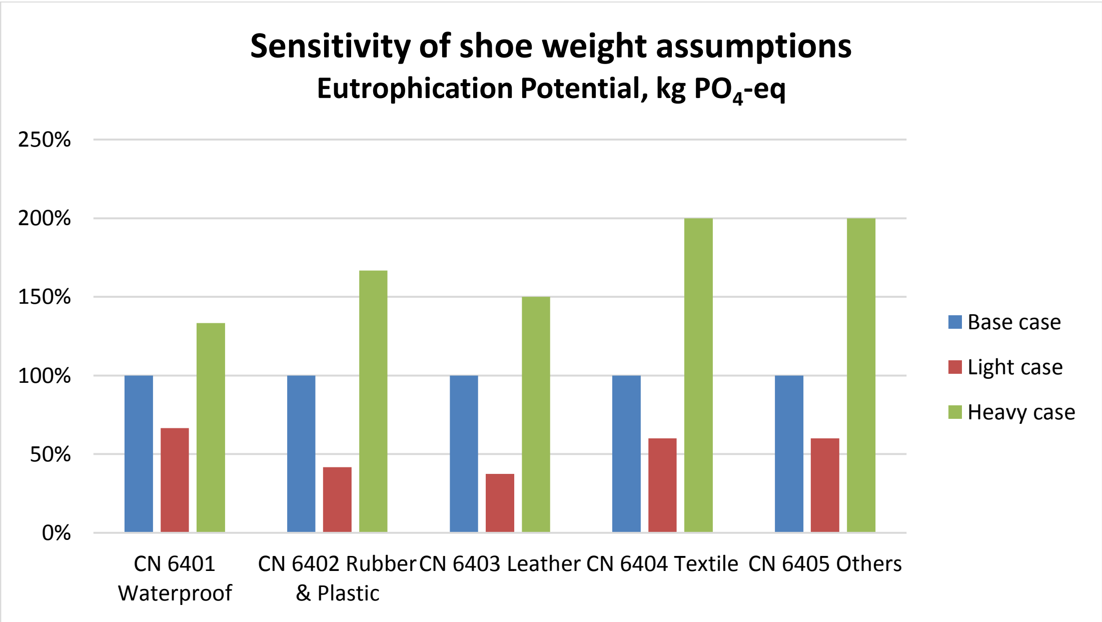


Figure 22 - Results from sensitivity analysis of shoe weight with three scenarios, the picture shows eutrophication potential for one pair of shoes in every group.

5.2.3 Sensitivity regarding energy use for shoes

Three different electricity mixes were used to check the sensitivity regarding electricity use in shoe production. The present case used two different electricity mixes, where the production from Europe had a European electricity mix and Asian production had a Chinese electricity mix. The heavy case was created by changing all electricity used for the total production to a Chinese mix, mainly based on non-renewable resources. The light case was chosen as a Swedish electricity mix based on more renewable energy sources. Chosen energy mixes are presented more in detail in Appendix B. The difference in impact from the three electricity scenarios is shown in Figure 23 below.

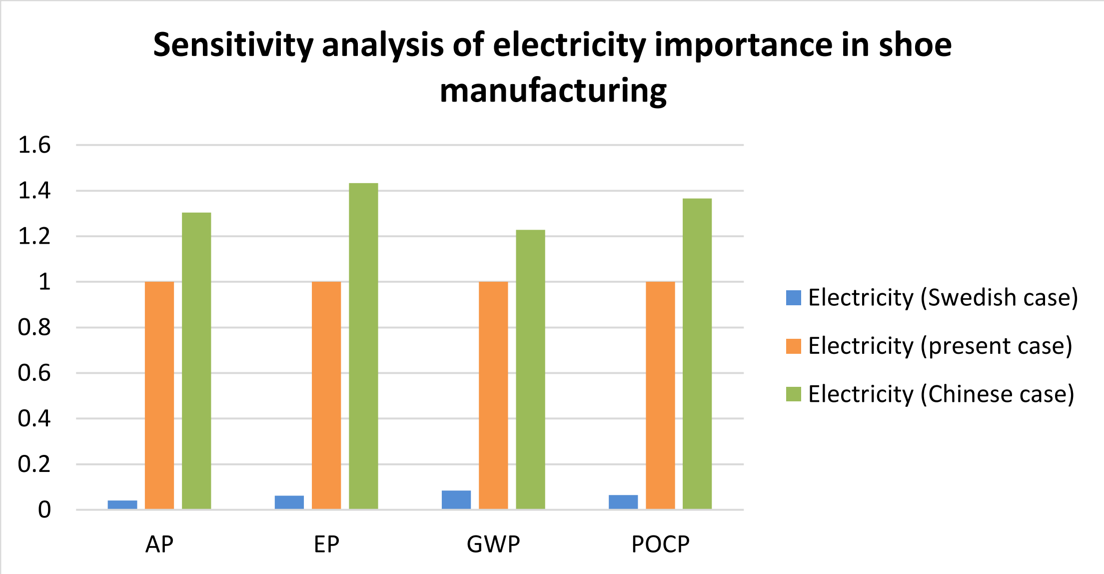


Figure 23 – Results from sensitivity analysis regarding electricity mix used for shoe production. The included electricity grid mixes are Chinese, Swedish and present (combined Chinese and European). The results of the present case have been set to 100% in each impact category. Abbreviations: AP (Acidification Potential), EP (Eutrophication Potential), GWP (Global Warming Potential) and POCP (Photochemical Ozone Creation Potential).

The results show that the chosen impact categories have different sensitivity to change of electricity mix. The Swedish case generates only 4%-6% of the impact of the present case, while the Chinese case resulted in higher impact than the present. The big reduction in the Swedish case shows that energy from renewable resources can largely reduce the total impact from electricity, which also influences the total impact of the shoe life cycle.

6 Discussion

Due to the limited time frame of the study, choices and limitations had to be made which affected the outcome. The data collection for the life cycle inventory was a time consuming process and important for the model and the results. This section will discuss choices, methods and the model.

Definition of shoe consumption

In this study, two of the main questions were how to set boundaries for the model and define the shoe consumption. Since the project description aimed towards using statistics to analyze the consumption, the net inflow was used and the life time of shoes was not considered. If the model would have included the life length of shoes, the results might have been different due to varying quality and durability of materials. Also, shoes may be stored at home or in warehouses which would result in a varying stock in the flow analysis. This means not all imported shoes would go to waste treatment every year and hence the environmental impacts related to those processes would be less. Due to the exclusion of life time and stocks of shoes in the society, recommendations regarding which shoe types are most environmentally friendly based on the results from this study should be seen as guidelines.

Categorization of shoes

Another important choice was the division of shoes into groups, where the CN system at level 4 was chosen as a basis for categorization. Six different groups represented shoes involving four main materials in form of rubber, plastic, leather and textiles, while one group included a mix of different materials. It can be argued that this type of categorization might not be sufficient from a sustainability perspective, since the groups are large and general. Shoes might also be reported in wrong category. A more detailed CN level might have been better to use, but since the descriptions are vague it would be difficult to determine the type of shoes and materials that are involved.

Even though a completely different categorization might have been possible and more appropriate for this kind of study, the available statistics were reported according to CN categories which suited the focus on net inflow. Also, if this kind of categorization is known by the shoe industry, the results can be useful from that perspective. However, the categorization does not affect the impacts from the total consumption based on net inflow.

The LCA and MFA model

Even though the LCA and MFA model used in the study did not include all required elements to fulfill ISO standards, it generated relevant results and seemed to be well adapted to the goal. The temporal boundary was set to one year, while data from ten years were used for the trend analysis. The chosen time span 2000 to 2010 involved recent data which made it suitable for a contemporary trend analysis.

The use phase was not included in the model, which means no impacts from suppliers, retailers and consumers are shown in the results. However, it can be assumed that the impacts from electricity use and transportation related to the use phase would be small compared to for example material production.

The large scope of the study required an LCA software since it would have been too much to handle with manual calculation methods. Even though the calculation processes and algorithms used by GaBi were unknown, the uncertainty level of this matter was considered low due to the extensive use of the software and its credibility.

Data collection and assumptions

Since the results in this kind of study are heavily dependent on actual data collected for the model, data sources, eventual data gaps and assumptions affect the outcome. Most of the material data was found in Ecoinvent and GaBi, while the leather data was collected separately from other sources. As stated in the data analysis, using different data sources might affect the results. The lack of availability of detailed data regarding leather production made the process difficult and time consuming, which means more reliable and complete results may be generated if more time could be spent on data collection and review.

The data analysis and cross checking with other studies of shoes showed that the results in this study were in the correct interval. Even though the shoe types involved in those studies were not the same, the numbers could be used as guidance for reasonableness. Since factors may vary between this study and others, the basis for comparison might not be optimal.

Some results were presented for one year, where the final year of the time span was chosen (2010). These results might have been different if an average for the whole period had been used instead.

According to the descriptions of CN categories, a group might contain everything from heavy ski boots to sandals, which means large differences both in weight and material content. Hence, the determination of an average shoe in every category generated a very general result which would change if another shoe type was used.

According to the results, one of the largest impact sources of shoe consumption was material use. The materials used in shoes were assumed according to shoe weighing and general approximations, which also affected the results. As seen in the study, different materials generate different impact, hence the chosen percentages of material content in shoes were important. Additionally, all possible materials used in shoes are not covered by this study. Shoes are complex products and some material groups such as plastics can include many variants with different chemical compositions. The materials used in shoes could therefore be studied further.

Choice of impact categories

Only four impact categories were included in this study, where all of them represent ecological consequences. Even though the categories are relevant and can be seen as sufficient for analyzing the environmental impact, it may be useful to expand the impact assessment and include categories for resource use and human health. Some materials might for example show higher impact in other categories due to extensive resource use in production or use of a high amount of toxic substances which cause health problems.

7 Conclusions

This study has analyzed the impacts of Swedish shoe consumption based on net inflow by using approaches towards product flow analysis, material flow analysis and life cycle assessment. The results show an increasing consumption trend which was dominated by rubber & plastic shoes, 36%, leather shoes, 24%, and textile shoes, 22% in 2010. During the time span between 2000 and 2010, consumption of rubber & plastic and textile shoes has increased by 6% while the net inflow of leather shoes has decreased by 17%. The consumption of textile shoes increased by 10%, whereas waterproof footwear showed a constant consumption of 11%. In total, the shoe consumption in Sweden increased by 20% during 2000 and 2010.

The categorization of shoes was made according to CN categories where the CN 4 level was chosen. The six categories of CN 4 involved waterproof footwear, rubber & plastic shoes, leather shoes, textile shoes, other shoes and shoe parts. This system is used for statistics and trade purposes and therefore involves the shoe industry. The statistics showed a high import of shoes from Asian countries to Sweden, which also increased from 56% in 2000 to 63% in 2010. This contributed to the total environmental impact for all included impact categories involving acidification, eutrophication, global warming and POCP due to transportation distances, energy sources and waste management used in Asia.

The materials used in shoes can be divided into main groups in form of rubber, plastic, textiles, leather, metal and wood materials. Every group involves more specific materials which contribute to the environmental impact of shoes, some of them more than others. As found in this study, the most contributing materials per kilogram included leather, wool, nylon, aluminium, synthetic rubber, PET plastic, PU plastic and viscose. This can be explained by high impacts of animal production, mining and use of non-renewable resources. The materials with lowest environmental impact were natural materials such as wood and cork. Similar results can be found in other reports.

With regard to materials causing highest impact in the Swedish shoe consumption, leather was dominating for all impact categories followed by synthetic rubber, natural rubber, cotton, wool and various plastics. Some variations in the order of most contributing materials existed for different impact categories. Among the included life cycle stages of shoes, the results showed that the material production corresponds to the highest impact with 80% of the total. The total impact trends also follow the trend of total consumption or net inflow.

Leather, the most contributing material to the environmental impact, was analyzed more in detail to see what factors affected. Impacts from raw hides due to animal production and allocation, electricity use and chemicals used in the leather manufacturing were found to be critical in this case.

The shoes contributing most to the environmental impact of the Swedish shoe consumption in 2010 were leather shoes, rubber & plastic shoes and textile shoes, which also corresponded to the highest net inflow. Leather shoes had a share between 40% and 50% of the total impact for the different impact categories. Rubber & plastic accounted for 14% up to 26% of the total impact, whereas textile shoes had a share of 15% to 17%.

If considering impact per pair of shoes in 2010, leather shoes dominated again followed by rubber & plastic and waterproof shoes when compared to the determined average shoe. For the included impact categories, leather shoes show up to 3 times higher impact compared to the average shoe. In general, these results were affected by material used in shoes, the weight percentage of different materials and the total weight of shoes. Changed quantities of certain shoe groups might then affect the total impact more than others. This also means that the assumptions regarding weight percentages for different shoes affect the results, as well as the fact that an average shoe is used in every category.

To summarize, the impacts of shoes can be affected by type and amount of material used in production as well as the total consumption. Also, the country of production matters due to different levels of environmental work and legislation. The results show that natural textile and wood materials are preferable compared to leather, rubber and synthetic fibers with regard to environmental impact. However, factors related to the use phase in form of quality, life time of shoes and stocks in the society were not considered in this study. If included, these aspects may also affect the total impact.

8 Recommendations

Due to the increased consumption trends today, it is important to consider environmental impacts from products used worldwide. As compared to textile goods, environmental impacts of shoes have not been evaluated to the same extent which makes it a relevant matter to focus on.

Even though the study excluded relevant aspects in form of life time and stocks of shoes, some types of shoes show higher environmental impact than others. Since this is mainly due to the materials used in the production, it would be preferable to choose certain materials above others from a sustainability point of view. The results show lower impact for textile shoes and natural textile and wood materials which might be an alternative to traditional shoes made of leather, rubber or plastic. This type of choices can be made both on a consumer and producer level, since the material type and weight can be considered already in the design phase.

Changing fashion trends towards shoe groups containing materials which cause high impact should be avoided if possible, which means the role of consumers and retailers becomes even more important. Due to the global situation of the shoe industry, shoe companies could also evaluate their supply chains, consider the situation in the countries shoes are imported from and improve their environmental work. At a policy making level, it could be of interest to develop a recycling system for shoes to reduce the amount of new materials produced or using eco labels to a greater extent. In general, it would require cooperation between the shoe industry and policy makers.

Less consumption would generate lower environmental impact in total. Therefore, a positive action towards more environmentally friendly shoe consumption would be to reduce the amount of shoes bought every year. To buy shoes of better quality and repair as well as reuse them can be seen as a preferable option if possible. However, more studies are required to see how much this kind of efforts actually would affect the total impact.

This study is one of the first with the aim to analyze environmental impacts related to shoe consumption on a national level, which means the method could be developed and more process data should be collected. Further studies could involve adding more materials to generate a better model and use as many impact categories as possible to generate an improved representation of the actual shoe industry and environmental impacts.

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Appendix A – Inventory data and additional information

A.1 Detailed description of CN Categories

As described in section 3.2, the categorization of shoes was made according to the CN categories. These categories were interpreted for the determination of material content in shoes. A description of the categories and shoes included can be found in Table 3.

Table 3 – Description of CN categories and examples of shoes included in every category (U.S. Customs 2012).

CN Category	Description	Examples of shoes included
6401	Waterproof footwear in rubber or plastic in which the construction is molded or cemented	Rubber or plastic boots, high or low, may contain metal toecap
6402	Dominated by shoes containing uppers and outsoles of rubber or plastic	Ski-boots, snowboard boots, sports footwear, plastic sandals or pumps, working shoes with or without metal toecap
6403	Shoes with uppers of leather, outsoles of leather, rubber or plastic dominating.	Ski-boots, sports footwear, sandals, leather shoes with wooden soles, working shoes which may include metal toecap, boots, leather shoes.
6404	Shoes with mostly textile uppers, outsoles of leather, rubber or plastic.	Textile shoes, sports footwear
6405	Other shoes which are not included in 6401-6404	Wooden shoes, shoes made from natural materials and animal fur
6406	Shoe parts	-

A.2 Description of shoe parts

Even though there are many different models produced, the general division and also the names of shoe parts is universal in the shoe industry (European Commission 2015a). This section briefly describes different shoe parts.

Upper

Considered to be a main part of a shoe, the upper is attached above the sole and covers the top and side of the shoe (U.S. Customs 2012). For some plastic and rubber shoes, such as rubber boots, a single piece of material can be used for almost the whole shoe and in this situation there is no clear line between the upper and the sole (U.S. Customs 2012). The uppers do not include accessories such as buckles, eyelets or any reinforcements (European Commission 2015a).

Lining

According to Stimpert (2015), the lining of shoes is the material attached to the inside of uppers, where it touches the top and side of feet as well as the back of the heel. The main function of lining is to make the shoe more comfortable by covering eventual seams on the inside, reduce humidity and support the foot (Stimpert 2015).

Insole

Insole, or inner sole, is the material touching the bottom of the feet (European Commission 2015a). Usually, it is added on the midsole of the shoes and might be fixed or removable (European Commission 2015b). The materials used may vary, even though textiles and leather are common for this purpose (European Commission 2013).

Midsole

According to Bumgardner (2015), the midsole corresponds to a middle layer of a sole which lies between the insole and the outsole. The material used depends on the purpose of the shoe (Bumgardner 2015). Some shoes may not have any midsole at all, while this type of sole is commonly used in running shoes for cushioning and support (Bumgardner 2015).

Outsole

The outsole corresponds to the bottom part of a shoe which touches the ground while being used (European Commission 2015a). Outsoles do not include any attachments such as heels, spikes or nails (European Commission 2015a).

Lamination

To increase the stability and performance of textiles, lamination can be added as coating (Singha 2012). As described by Singha (2012), the content and chemicals used in manufacturing depends on the purpose of the textile. In shoes, lamination is often a pre-made or extruded film which is attached onto the included materials to increase the function (Singha 2012).

Back and toecap

For normal shoes, back and toecaps or “stiffeners” are used for reinforcement purposes and often made of plastic (European Commission 2015a). Some other variants exist, since working shoes might need extra support and protection in form of rubber or metal (Oliver Footwear 2011). However, these might or might not be counted into this category.

Metal parts

Different metals can be used as accessories in shoes, such as in zippers and buckles (European Commission 2015a). It might also be incorporated into shoes with specific purposes, such as increasing the strength in hiking shoes or serve as protection in working footwear (Oliver Footwear 2011).

A.3 Assumptions and data for the modelling

This section lists additional data collected in the life cycle inventory. General data used can be seen in Table 4. Energy required to produce one pair of shoes was determined to be 3.24 MJ (Muñoz 2013). Data collected for the leather production can be found in Table 5.

Table 4 – Additional shoe data and assumptions for the life cycle inventory (Muñoz 2013).

Energy use per pair	3.24 MJ
Water use per pair	0.036 L
Incineration Sweden	100%
Reuse rate	2%
Repair rate	3%

Table 5 – Data collected for the leather production process (Tärnsjö Garveri 2012; Elmo Sweden 2013)

Input	Amount	Unit
Ammonia	0.00617	Kg
Ammonium bicarbonate	0.000585	Kg
Calcium hydroxide	0.2	Kg
Chloride dioxide	0.008258	Kg
Chromium sulphate	0.12713	Kg
Citric acid	0.0715	Kg
Electricity	120	MJ
Ethylene oxide	0.06013	Kg
Fatty acid	0.247115	Kg
Formic acid	0.050631	Kg
Isopropyl	0.00133	Kg
Lime slurry	0.012	Kg
Methyl methacrylate (MMA)	0.035252	Kg
Methylene di-isocyanate	0.009869	Kg
Polyurethane flexible foam	0.136	Kg

Propylene glycol	0.002521	Kg
Raw hides	0.75	Kg
Soda (sodium carbonate)	0.017375	Kg
Sodium chloride (rock salt)	0.35745	Kg
Sodium formate	0.1	Kg
Sodium sulphite	0.00158	Kg
Water	180	Kg

A.3.1 Import countries

In the life cycle inventory process, import countries were determined for transportation distances as well as electricity and water consumption purposes. The import contribution based on country can be observed in Figure 24, where China, Vietnam, Italy and Germany are dominating. China covers around one third of the total shoe import while Vietnam covers 13%. In Europe, Italy is the most dominating country with 5% of the total import followed by Germany and Norway which both cover 4%.

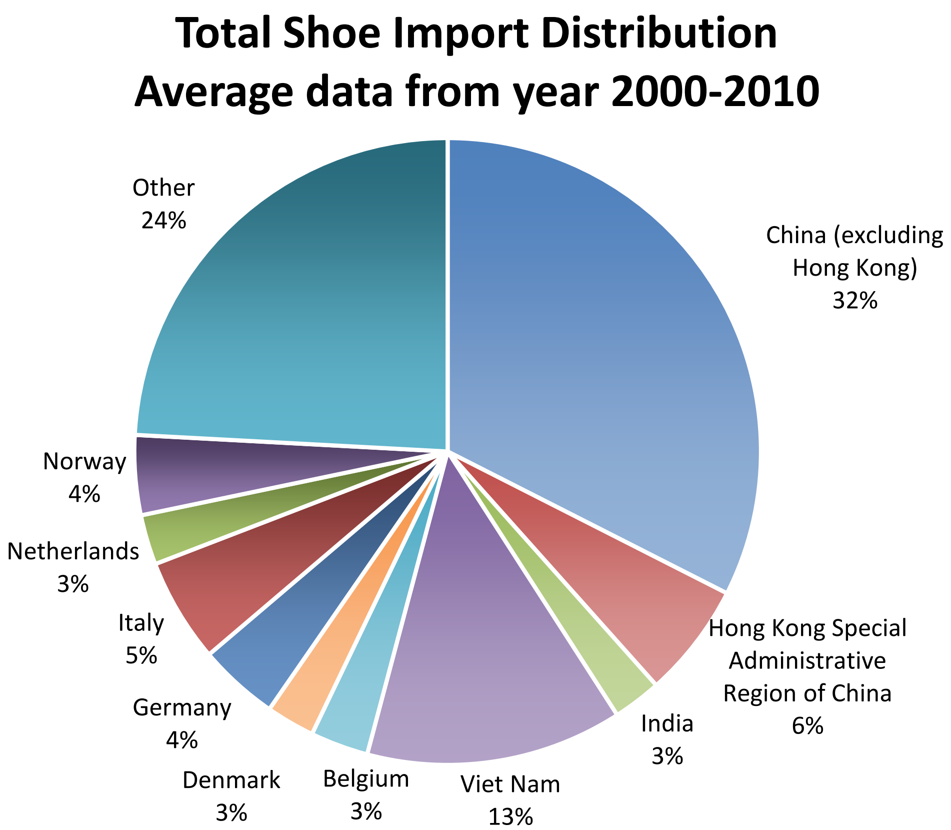

Figure 24 – Shoe import distribution based on average data from year 2000 to 2010 according to country.

A.3.2 Transportation modes and distances

The transportation distances used in the model were determined by calculating the average distance between the import countries and Sweden, see Table 6. Data for transportation processes was taken from GaBi.

Table 6 – Determination of transportation distances from shoe production facilities to Sweden based on import countries (SeaRates 2015).

Continent	From	To	Type	Distance (km)	Average (km)
Asia	China (Shanghai)	Sweden (Gothenburg)	Ship	20223	18000
	Vietnam (Ba Ngol)	Sweden (Gothenburg)	Ship	17994	
	India (Ahmedabad)	Sweden (Gothenburg)	Ship	13628	
Europe	Belgium (Antwerpen)	Sweden (Gothenburg)	Ship	1121	2000
	Italy (Acitrezza)	Sweden (Gothenburg)	Ship	5965	
	Italy (Acitrezza)	Sweden (Gothenburg)	Truck/Train	2217	
	Spain	Sweden (Gothenburg)	Truck/Train	2829	
	Slovenia	Sweden (Gothenburg)	Truck/Train	1718	
	Germany	Sweden (Gothenburg)	Truck/Train	1031	

Asia to Sweden

Regarding transport from factory to port, a journey of 50 kilometer with a diesel truck-trailer was assumed. For the transportation from Asia to Sweden, it was assumed that two different ships and fuels are used. The two cases corresponded to 5000 kilometer transport with a ship using light fuel oil and 13000 kilometer transport with a container ship using heavy fuel oil (Lloyd's Register Marine 2013).

Europe to Sweden

For the European import, the total transportation distance was assumed to be 2000 kilometers. In this case, two different trains fueled by electricity (1400 km) or diesel (600 km) were used in the model. Due to the simplified model, no sea transportation was included in the European case due to the short distance compared to the case for Asia.

Transport within Sweden

The transport within Sweden from the port to suppliers was assumed to be 200 kilometers equally divided upon a diesel based and an electricity based train.

A.3.3 Allocation

In this study, allocation was made for wool production, leather production and waste management. In case of wool, a dataset for greasy, unprepared wool was extracted from Ecoinvent. According to Barber and Pellow (2006), 55% of the greasy wool mass results in finished wool. An economic allocation of 90% based on weight was shown for wool, while 10% corresponded to grease (Barber & Pellow 2006). The dataset was adapted to finished wool according to the assumptions above and inserted into the model.

Cattle production may generate meat, milk and raw hides for leather production. Hence, the impacts from animal farming must be allocated according to the products. The allocation was determined to be 3% to raw hides, which means 3% of the total impacts for breeding of one cow were added to leather production (Tuomisto et al. 2015). This value is presented as an economic allocation by Tuomisto et al. (2015), where a higher percentage of 7% is set as a mass fraction. This difference served as a basis for sensitivity analysis regarding assumptions for leather which can be found in Appendix C.

Since waste management procedures such as landfill and incineration may generate electricity and heat, this output must be considered in the modelling. In this study, a system expansion was used to handle the problem.

A.3.4 Electricity mixes

In this study, two types of electricity grid mix were chosen. A Chinese electricity mix named CN: electricity grid mix was used for all shoes produced in Asia, while a European grid mix called EU-27: electricity grid mix was used for shoes produced in European countries. The data was taken from the GaBi database, which states that it is valid until 2016 (Thinkstep 2015a).

The energy sources which the electricity is generated from are shown in Figure 25 to Figure 27 with pictures extracted from the Gabi database.

As seen in Figure 25, the electricity mix in China is mainly based on hard coal which covers more than 78%. Hydro power is the second biggest source which covers 15%. Compared to the Chinese grid mix, EU-27 has nuclear, natural gas and waste as main sources which can be seen in Figure 26. The Swedish electricity mix shown in Figure 27 was used to indicate future trends where renewable energy serves as the main source.

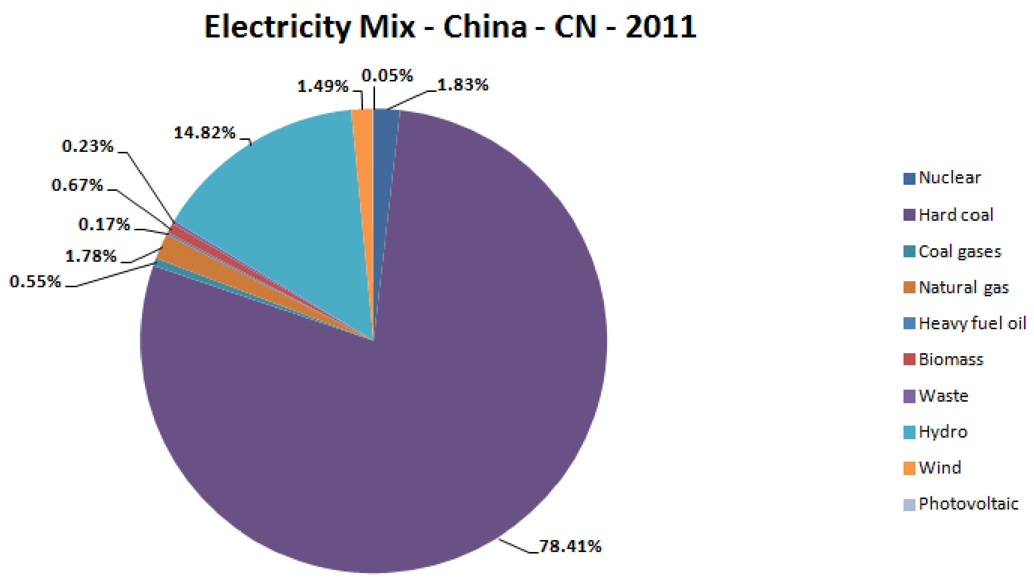

Figure 25 - Energy source where electricity generated from in the nation of China (Thinkstep 2015a)

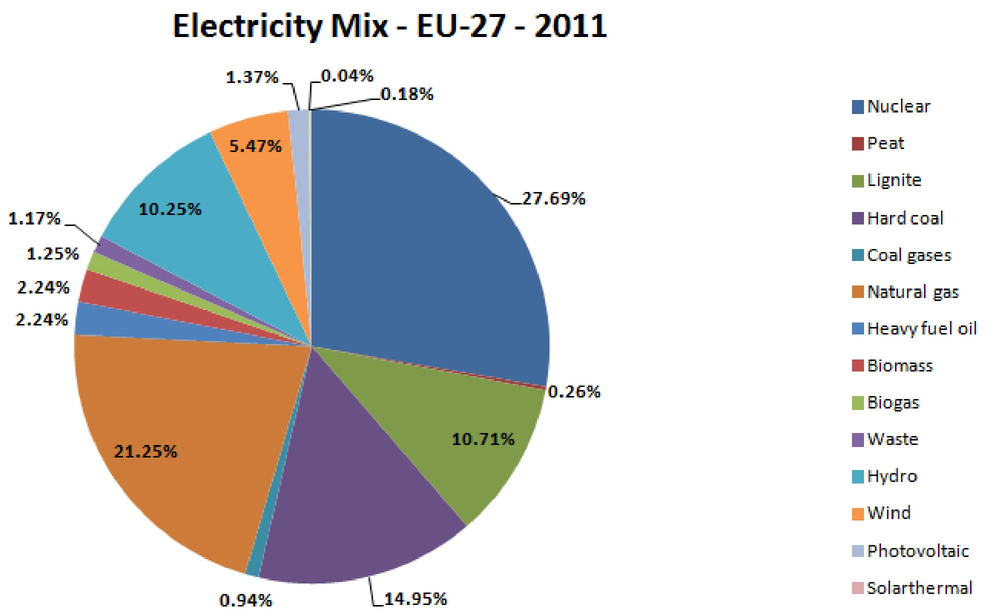

Figure 26 - Energy source where electricity generated from in EU-27 (Thinkstep 2015a)

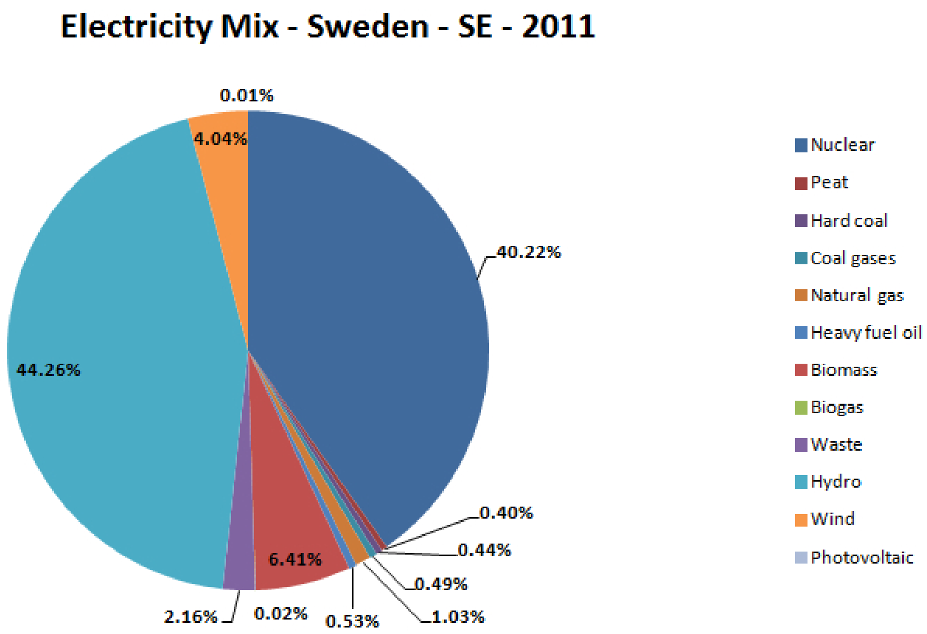

Figure 27 - Energy source where electricity generated from in the nation of Sweden (Thinkstep 2015a)

A.3.5 Waste management

The waste management for production and material waste in Europe and Asia was determined by using literature and assumptions. Figure 28 shows the share of recycling, landfill and incineration in Europe which was used as a basis for the assumptions regarding Europe (Lavoro et al. 2008). The waste management in Asia was assumed according to the general situation where landfill is dominating and almost no recycling exists. All assumptions regarding waste management are shown in Appendix C.

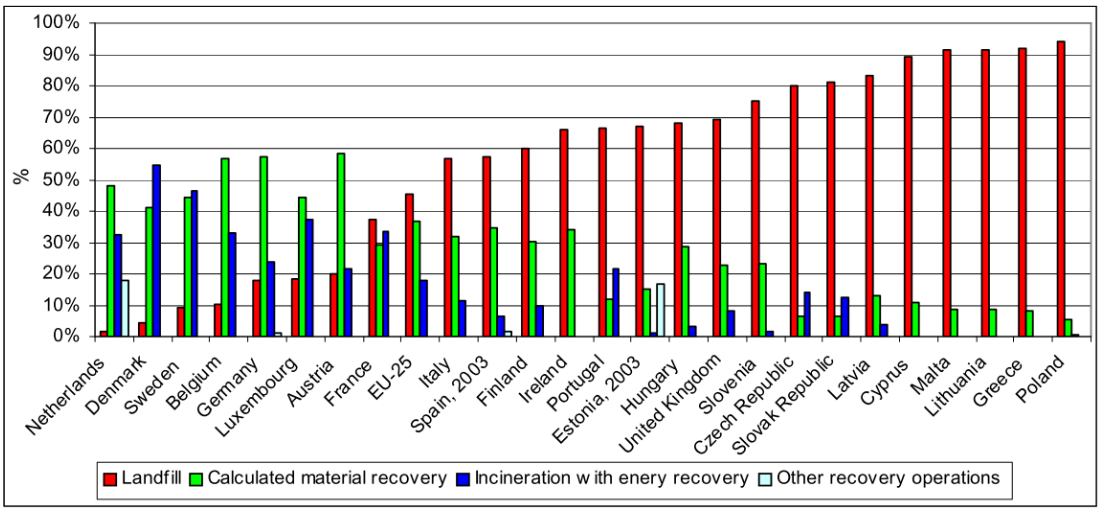

Figure 28 – Waste management for European countries divided into landfill, incineration and recycling (Lavoro et al. 2008)

A.4 Weights of shoe pairs in different groups

Some typical shoes in every CN category were weighed for analysis of the impact for one standard pair of shoes. As far as possible, the subgroups were studied to find one pair for each of them. The assumed average was not a pure average, but rather a value which seemed to represent the group as a whole. Results from the shoe weighing can be found in Table 7.

Table 7 – Results from the shoe weighing which resulted in one average determined weight for one standard pair in every shoe group.

Shoe pairs are of sizes 39-40		
CN 6401 - Waterproof footwear (Rubber and plastic, made from one template)		
Sub group (CN6)	**Description:**	**Weight [g]**
640192	High rubber boots	1500
640192	Rubber boots, medium height	1760
640199	Black rubber boots/jodhpurs, low cut	928
Missing categories: 640110, 640191		
Assumed average		1500
CN 6402 - Rubber and plastic footwear (Not waterproof)		
Sub group (CN6)	**Description:**	**Weight [g]**
640291	High heels covering the ankle, black	644
640299	Plastic flat shoe, rubber sole, white	328
640299	Plastic sandals, pink	232
640299	Flat shoes, yellow, plastic only	360
Missing categories: 640212, 640219, 640220, 640230		3000
Assumed average		1200
CN 6403 - Leather footwear (Leather and synthetic leather)		
Sub group (CN6)	**Description:**	**Weight [g]**
640319	White leather/synthetic sports shoes	604
640330	White sandal with wood sole, leather straps	292
640330	Sandal with wood sole, leather straps	476
640391	Leather boots, medium height	1108
640391	Suede boots with laces	776
640391	Suede shoes with laces, higher heels	924
640391	Leather boots with metal buckles, medium height	1040
640399	White sandals, leather uppers, rubber sole	396
640399	Low leather shoes with laces	740

Missing categories: 640312, 640320, 640340, 640351, 640359		
Assumed average		800
CN 6404 - Textile footwear (Uppers of textile material)		
Sub group (CN6)	**Description:**	**Weight [g]**
640411	Sports shoes, textile details, rubber soles	664
640419	Sandals with rib straps, rubber/plastic soles	340
640419	Sandals with textile straps, rubber soles	540
640419	Low red textile shoes with rubber soles	680
Missing categories: 640420		
Assumed average		500
CN 6405 - Other footwear (Uppers of textile material)		
Sub group (CN6)	**Description:**	**Weight [g]**
640510	Heels covering the ankle, leather uppers and wooden platform	892
640510	White pumps, leather upper, wooden heels	364
Missing categories: 640520, 640590,		
Assumed average		500

A.5 Flowchart for the CN shoe categories

A flowchart was constructed for the life cycle of shoes during the life cycle inventory process which can be seen in Figure 29. The steps involved are same for all shoe groups, while the material inputs in production of different shoe parts are varying. The flowchart indicates the material groups used for the shoe parts while specific material content can be found in Table 8 to 13.

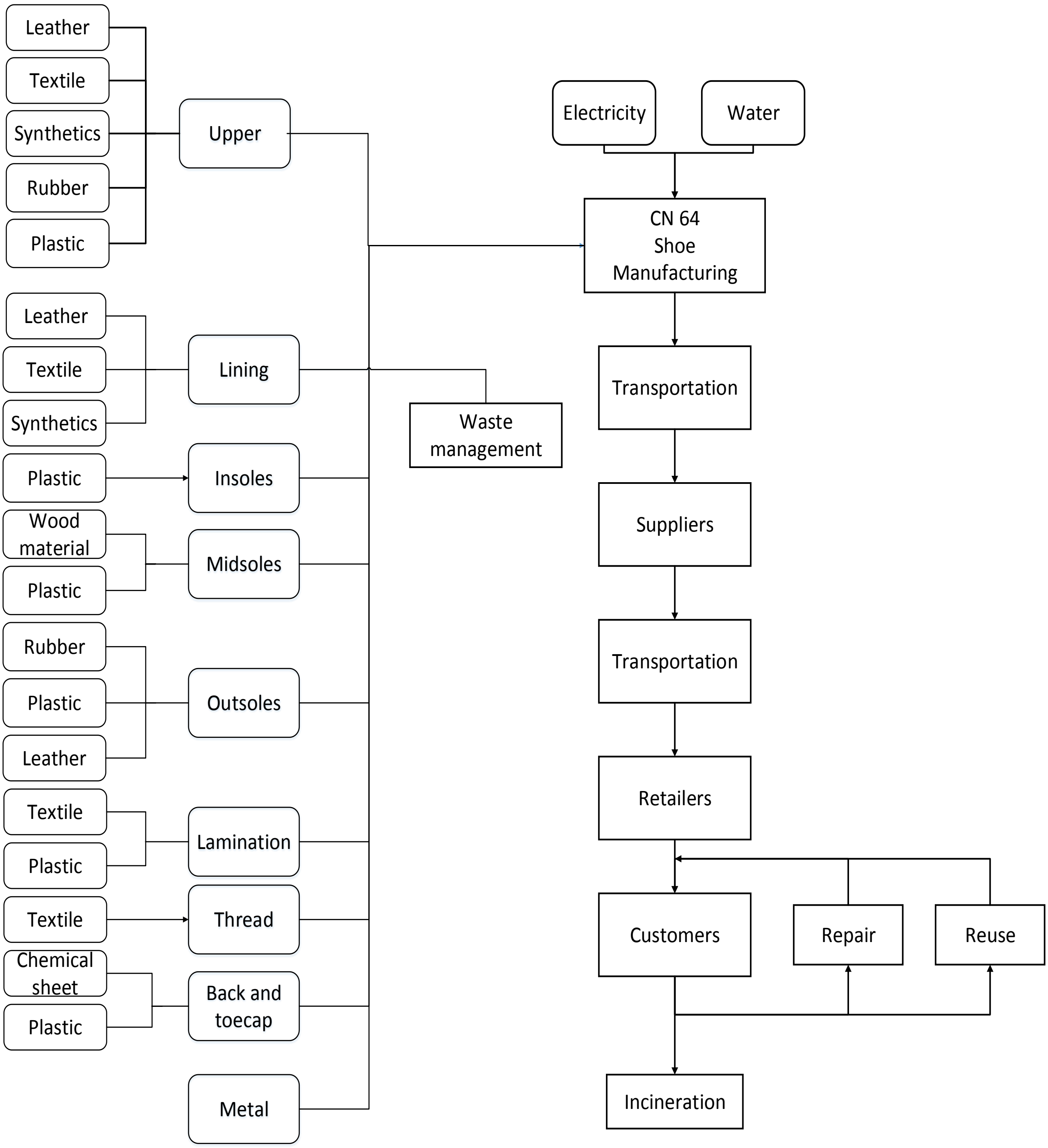

Figure 29 – Flowchart with material inputs for the CN 64 chapter which is general for all CN 4 groups.

A.6 Assumed materials in different shoe parts

A general list of materials which might appear in different shoe parts was made for the modelling, see Table 8 to Table 13. The final decisions were made based on literature and a material list provided by SSEI.

Table 8 – The final list of materials in shoe parts for group 6401 waterproof footwear.

CN 6401	Material Group	Specific material	Weight (%)
Upper	Rubber	Natural Rubber	10.0%
		Synthetic Rubber	10.0%
	Plastic	PVC	10.0%
		Polyethylene (PE)	7.0%
		PET	7.0%
	Total		**44.0%**
Lining	Textile	Polyester	1.0%
		Nylon	1.0%
		Wool	1.0%
		Cotton	1.0%
	Total		**4.0%**
Insole	Plastic	EVA	0.5%
		PU	0.5%
		MD	1.0%
	Total		**2.0%**
Midsole	Plastic	EVA	1.0%
		PU	1.0%
		MD	1.0%
	Total		**3.0%**
Outsole	Rubber	Natural Rubber	10.0%
		Synthetic Rubber	5.0%
	Plastic	EVA	5.0%
		TPR	10.0%
	Total		**30.0%**
Lamination	Plastic	PU	0.3%
		EVA	0.3%
	Textile	Polyester	0.4%
	Total		**1.0%**
Thread	Textile	Cotton	0.5%
		Nylon	0.5%
	Total		**1.0%**
Back and toecap	Plastic	Chemical sheet	5.0%
		Thermal plastic (Polypropylene, PP)	5.0%
	Total		**10.0%**
Metal		Iron	1.0%
		Zinc	1.0%
		Copper	1.0%
		Aluminum	1.0%
		Brass	1.0%
	Total		**5.0%**

Table 9 – The final list of materials in shoe parts for group 6402 rubber & plastic footwear.

CN 6402	Material Group	Specific material	Weight (%)
Upper	Rubber	Natural Rubber	10.0%
		Synthetic Rubber	10.0%
	Plastic	PVC	10.0%
		Polyethylene	7.0%
		PET	7.0%
	Total		**44.0%**
Lining	Textile	Polyester	1.0%
		Nylon	1.0%
		Wool	1.0%
		Cotton	1.0%
	Total		**4.0%**
Insole	Plastic	EVA	0.5%
		PU	0.5%
		MD	1.0%
	Total		**2.0%**
Midsole	Plastic	EVA	1.0%
		PU	1.0%
		MD	1.0%
	Total		**3.0%**
Outsole	Rubber	Natural Rubber	10.0%
		Synthetic Rubber	5.0%
	Plastic	EVA	5.0%
		TPR	10.0%
	Total		**30.0%**
Lamination	Plastic	PU	0.3%
		EVA	0.3%
	Textile	Polyester	0.4%
	Total		**1.0%**
Thread	Textile	Cotton	0.5%
		Nylon	0.5%
	Total		**1.0%**
Back and toecap	Plastic	Chemical sheet	5.0%
		Thermal plastic	5.0%
	Total		**10.0%**
Metal		Iron	1.0%
		Zinc	1.0%
		Copper	1.0%
		Aluminum	1.0%
		Brass	1.0%
	Total		**5.0%**

Table 10 – The final list of materials in shoe parts for group 6403 leather footwear.

CN 6403	Material Group	Specific material	Weight (%)
Upper	Leather	Bovine	35.0%
	Total		**35.0%**
Lining	Textile	Polyester	1.0%
		Nylon	0.5%
		Wool	0.5%
		Cotton	1.5%
	Leather	Bovine	2.5%
	Synthetics	Synthetic leather	2.0%
	Total		**8.0%**
Insole	Plastic	EVA	0.5%
		PU	0.5%
		MD	1.0%
	Total		**2.0%**
Midsole	Plastic	EVA	1.0%
		PU	1.0%
		MD	1.0%
	Wood material	Wood	1.0%
		Cork	1.0%
	Total		**5.0%**
Outsole	Rubber	Natural Rubber	10.0%
		Synthetic Rubber	5.0%
	Plastic	EVA	5.0%
		TPR	10.0%
	Leather	Bovine	3.0%
	Total		**33.0%**
Lamination	Plastic	PU	0.3%
		EVA	0.3%
	Textile	Polyester	0.4%
	Total		**1.0%**
Thread	Textile	Cotton	0.5%
		Nylon	0.5%
	Total		**1.0%**
Back and toecap	Plastic	Chemical sheet	5.0%
		PP	5.0%
	Total		**10.0%**
Metal		Iron	1.0%
		Zinc	1.0%
		Copper	1.0%
		Aluminum	1.0%
		Brass	1.0%
	Total		**5.0%**

Table 11 – The final list of materials in shoe parts for group 6404 textile footwear.

CN 6404	Material Group	Specific material	Weight (%)
Upper	Textile	Cotton	15.0%
		Polyester	10.0%
		Wool	3.0%
		Viscose	2.0%
	Total		**30.0%**
Lining	Textile	Polyester	0.5%
		Nylon	0.5%
		Wool	0.5%
		Cotton	1.5%
	Synthetics	Synthetic leather	3.0%
	Total		**6.0%**
Insole	Plastic	EVA	0.5%
		PU	0.5%
		MD	1.0%
	Total		**2.0%**
Midsole	Plastic	EVA	1.0%
		PU	1.0%
		MD	1.0%
	Wood material	Wood	1.0%
		Cork	1.0%
	Total		**5.0%**
Outsole	Rubber	Natural Rubber	10.0%
		Synthetic Rubber	10.0%
	Plastic	EVA	10.0%
		TPR	10.0%
	Total		**40.0%**
Lamination	Plastic	PU	0.3%
		EVA	0.3%
	Textile	Polyester	0.4%
	Total		**1.0%**
Thread	Textile	Cotton	0.5%
		Nylon	0.5%
	Total		**1.0%**
Back and toecap	Plastic	Chemical sheet	5.0%
		Thermal plastic	5.0%
	Total		**10.0%**
Metal		Iron	1.0%
		Zinc	1.0%
		Copper	1.0%
		Aluminium	1.0%
		Brass	1.0%
	Total		**5.0%**

Table 12 – The final list of materials in shoe parts for group 6405 other footwear.

CN 6405	Material Group	Specific material	Weight (%)
Upper	Leather	Bovine	10.0%
	Textile	Cotton	3.0%
		Polyester	2.0%
		Wool	2.0%
		Viscose	1.0%
	Synthetics	Synthetic leather	10.0%
	Total		**28.0%**
Lining	Leather	Bovine	1.0%
	Synthetics	PU	1.0%
	Textile	Polyester	0.2%
		Nylon	0.2%
		Wool	0.2%
		Cotton	0.4%
	Total		**3.0%**
Insole	Plastic	EVA	0.5%
		PU	0.5%
		MD	1.0%
	Total		**2.0%**
Midsole	Plastic	EVA	0.5%
		PU	0.5%
		MD	1.0%
	Wood material	Wood	0.8%
		Cork	0.2%
	Total		**3.0%**
Outsole	Rubber	Natural Rubber	5.0%
		Synthetic Rubber	5.0%
	Plastic	EVA	5.0%
		TPR	5.0%
	Leather	Bovine	2.0%
	Wood material	Wood	25.0%
		Cork	5.0%
	Total		**52.0%**
Lamination	Plastic	PU	0.3%
		EVA	0.3%
	Textile	Polyester	0.4%
	Total		**1.0%**
Thread	Textile	Cotton	0.5%
		Nylon	0.5%
	Total		**1.0%**
Back and toecap	Plastic	Chemical sheet	3.0%
		Thermal plastic	2.0%
	Total		**5.0%**
Metal		Iron	1.0%
		Zinc	1.0%
		Copper	1.0%
		Aluminum	1.0%
		Brass	1.0%
	Total		**5.0%**

Table 13 – The final list of materials in shoe parts for group 6406 shoe parts.

CN 6406	Material Group	Specific material	Weight (%)
Upper and Lining	Leather	Bovine	20.0%
	Plastic	PE	5.0%
	Textile	Nylon	5.0%
		Cotton	5.0%
		Wool	5.0%
	Total		**40.0%**
Soles	Rubber	Natural Rubber	10.0%
		Synthetic Rubber	5.0%
	Plastic	EVA	5.0%
		TPR	5.0%
		PU	5.0%
	Leather	Bovine	10.0%
	Total		**40.0%**
Thread	Textile	Cotton	1.0%
		Nylon	1.0%
	Total		**2.0%**
Metal		Iron	2.0%
		Zinc	2.0%
		Copper	2.0%
		Aluminum	2.0%
		Brass	2.0%
	Total		**10.0%**
Gaiters, leggings and similar articles	Textile	Cotton	2.0%
		Nylon	2.0%
		Wool	2.0%
	Leather	Bovine	2.0%
	Total		**8.0%**

Appendix B – Results

This appendix includes figures and tables not included in the results section. The results are analyzed and discussed in the analysis section.

B.1 Trends of total impact from shoe consumption

The total impacts of Swedish shoe consumption as well as impacts for different shoe categories were illustrated together with the net inflow for a trend comparison. All years between 2000 and 2010 were included.

Acidification potential

As observed in Figure 30, leather shoes contribute most to acidification followed by rubber & plastic. The impact trends roughly follow the trends in net inflow.

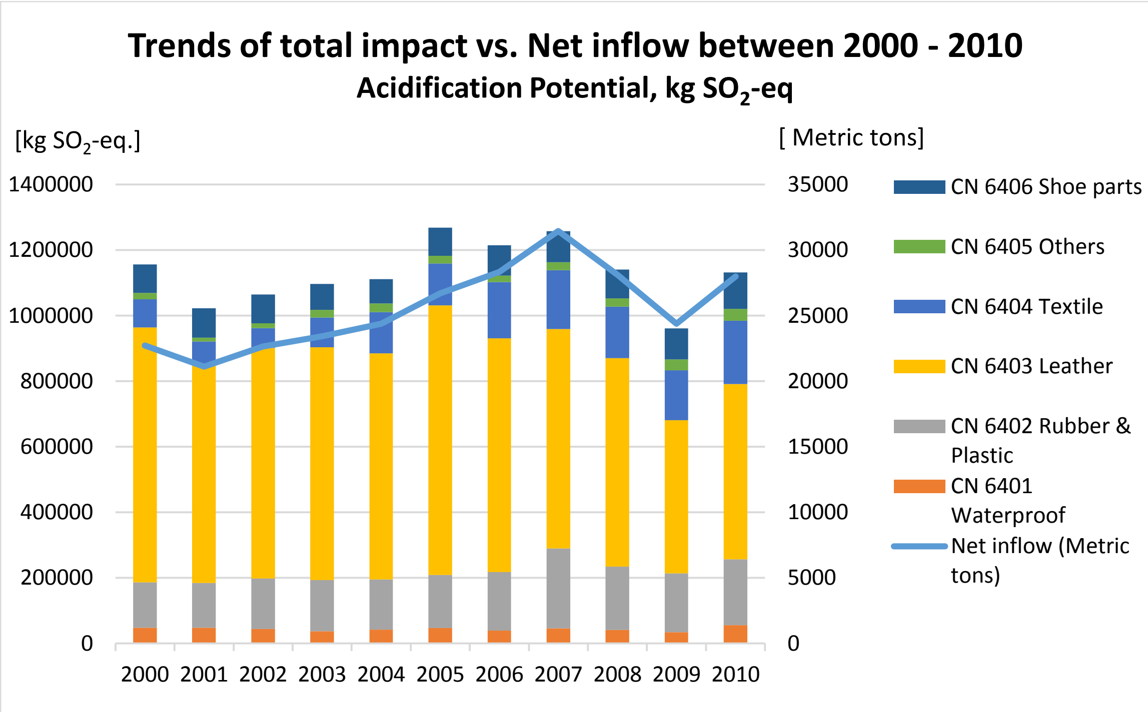

Figure 30 - Acidification Potential for each CN category from year 2000 to 2010, the line for total net inflow shows the consumption trend during these years.

Photochemical ozone creation potential

For POCP, leather shoes and rubber & plastic are dominating which can be seen in Figure 31 below. Even here, it can be seen that the trends of impact and net inflow are related to each other.

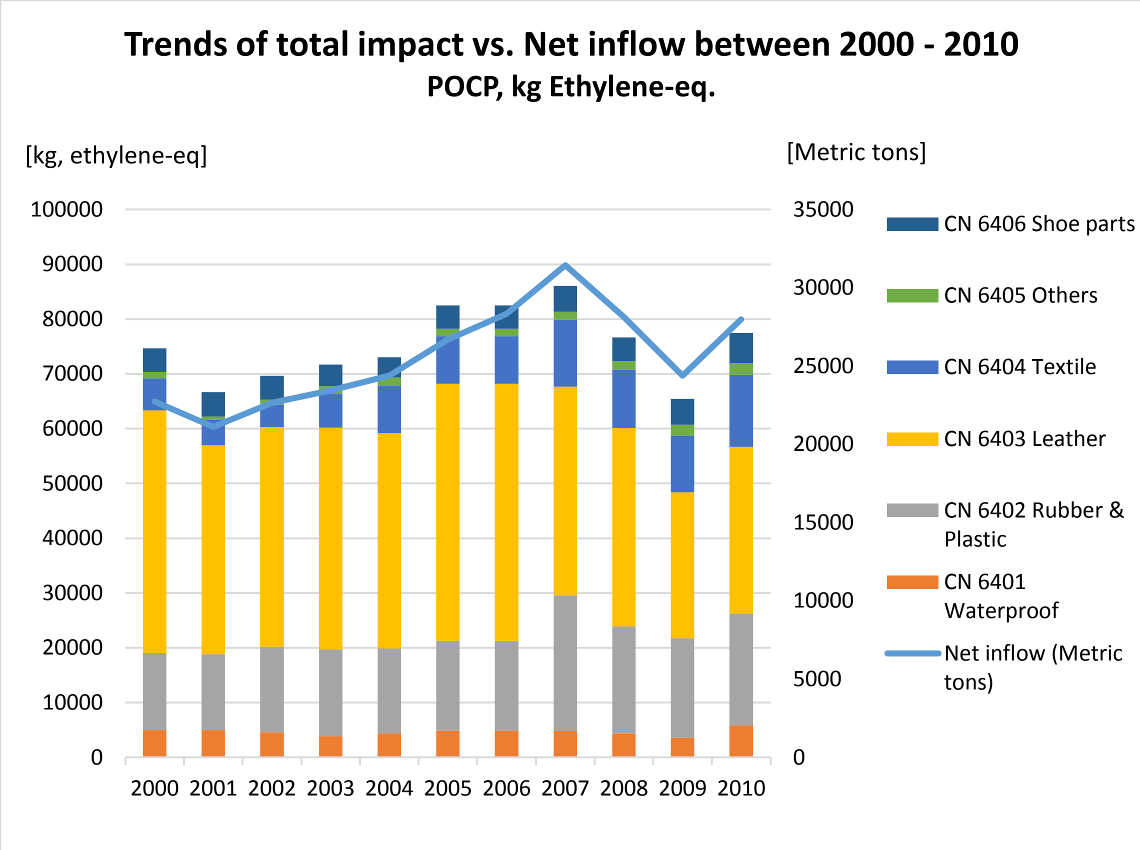

Figure 31 - Photochemical Ozone Creation Potential of each CN category from year 2000 to 2010, the line for total net inflow shows the consumption trend during these years.

B.2 Environmental impact of each shoe group measured by net inflow

In general, it can be found that rubber & plastic (CN 6402), leather and textile shoes (CN 6403) and textile shoes (CN 6404) are the three most contributing groups to the total impact of shoe consumption. It is clear that the impact mainly resulted from shoe production. Impact from transportation showed a high value for rubber & plastic (CN 6402).

Acidification potential

In terms of acidification, rubber & plastic shoes (CN 6402), leather shoes (CN 6403) and textile shoes (CN 6404) are the three groups with highest impact. For leather shoes, impact from production in Europe shares a higher percentage than other groups. The final waste treatment in form of incineration generated a negative value, which indicates an impact reduction. See Figure 32 below.

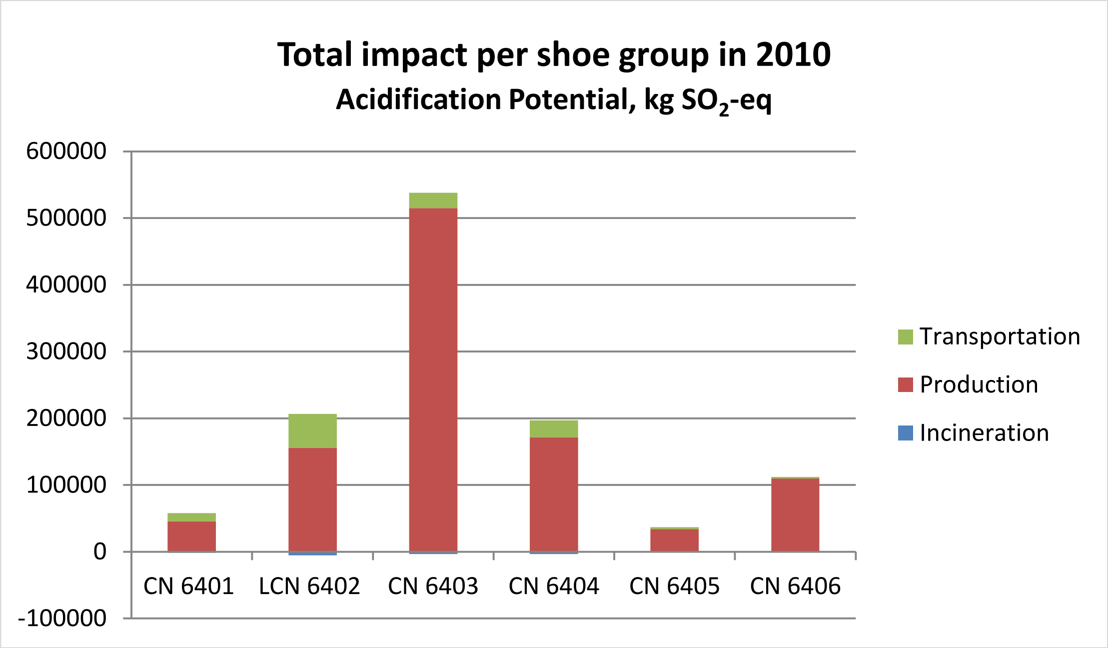

Figure 32 - Acidification potential of every group measured for year 2010, divided into production, transportation and incineration

Photochemical ozone creation potential

Also for POCP, rubber & plastic shoes (CN 6402) is dominating which can be observed in Figure 33 below.

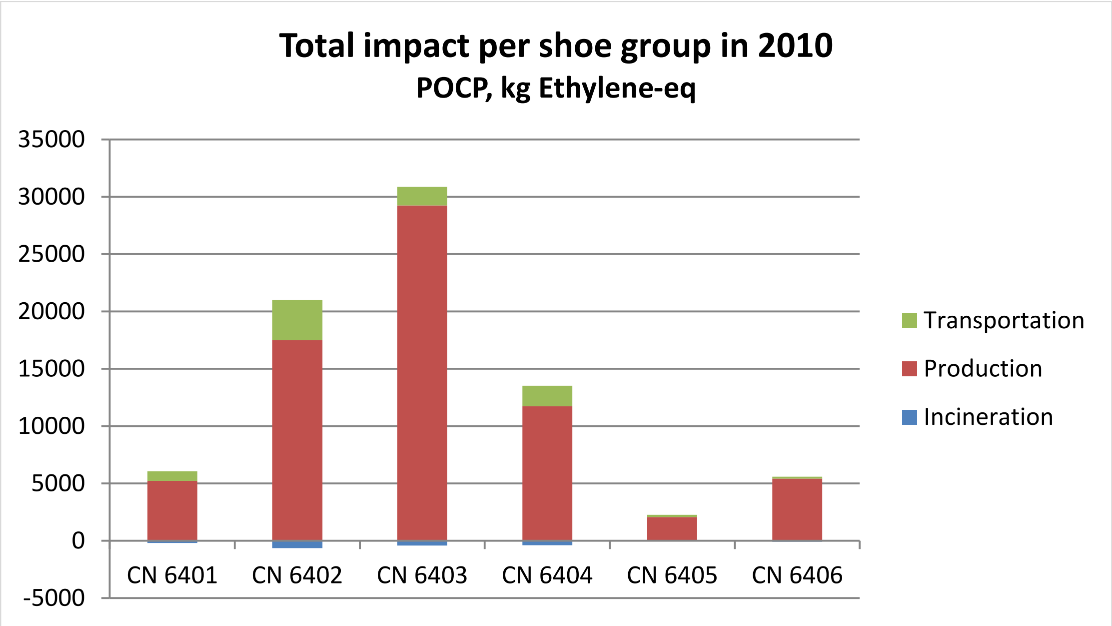

Figure 33 - Photochemical Ozone Creation Potential of every group measured for year 2010, divided into production, transportation and incineration

Global warming potential

Rubber & plastic shoes (CN 6402) have the highest impact in terms of global warming potential, where Asian production contributes to more than half of the total impact. See Figure 34 below.

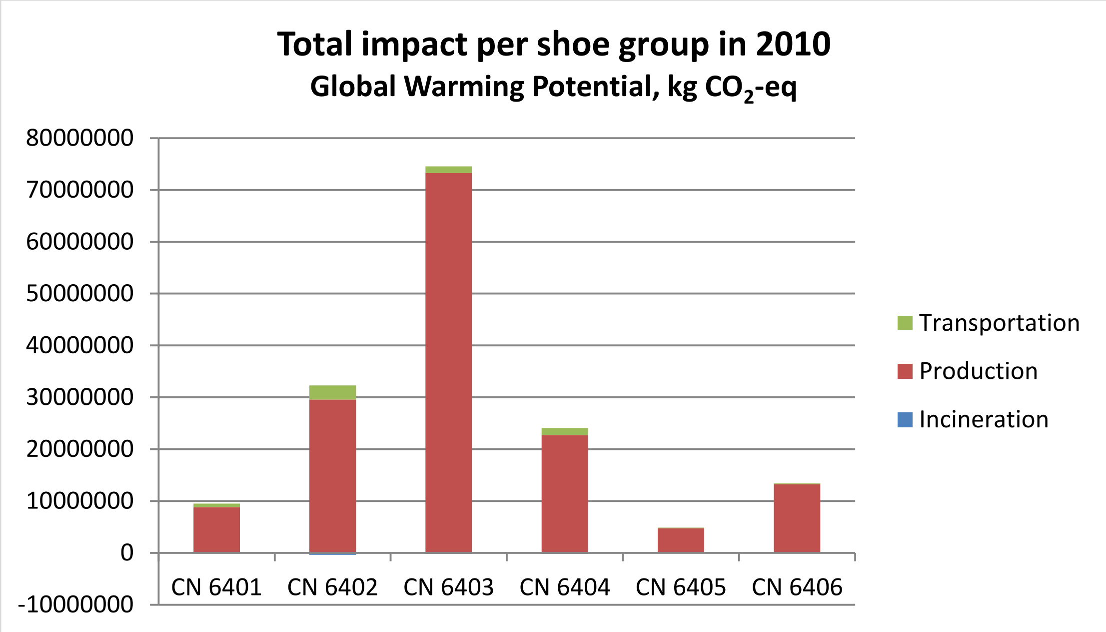

Figure 34 - Global Warming Potential of every group measured for year 2010, divided into production, transportation and incineration

Eutrophication potential

As observed in Figure 35, leather shoes (CN 6403) have the highest impact in case of eutrophication. Again, rubber and plastic shoes (CN 6402) have the highest impact contribution for transportation.

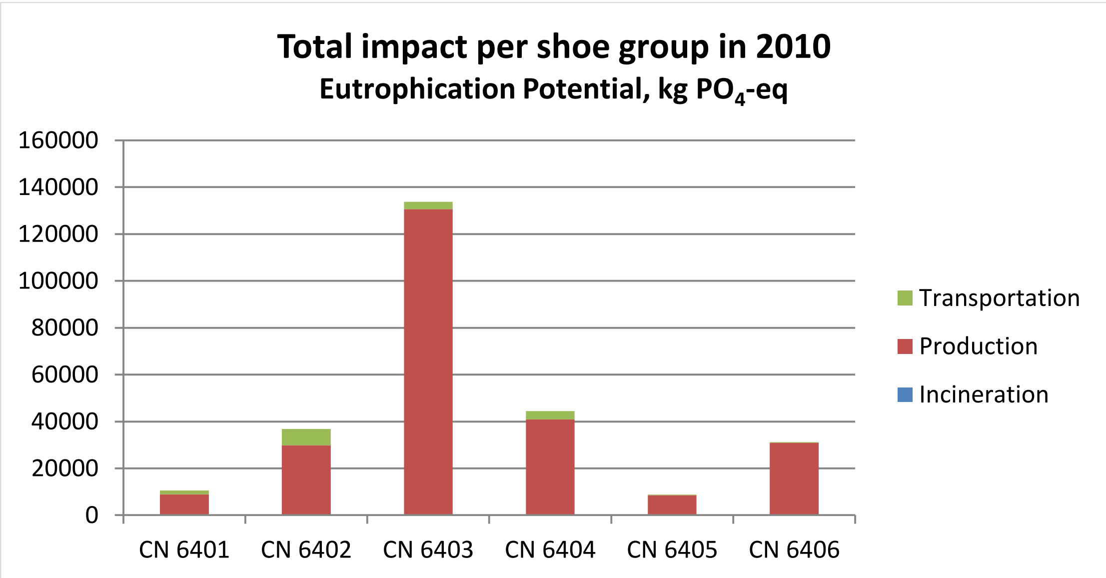

Figure 35 - Eutrophication potential of every group measured for year 2010, divided into production, transportation and incineration

B.3 Environmental impact of each shoe category measured per pair of shoes

This section shows the rest of the diagrams including impacts for one pair of shoes in the different shoe groups.

Acidification potential

According to the results, leather shoes show higher acidification potential compared to other groups which can be seen in Figure 36.

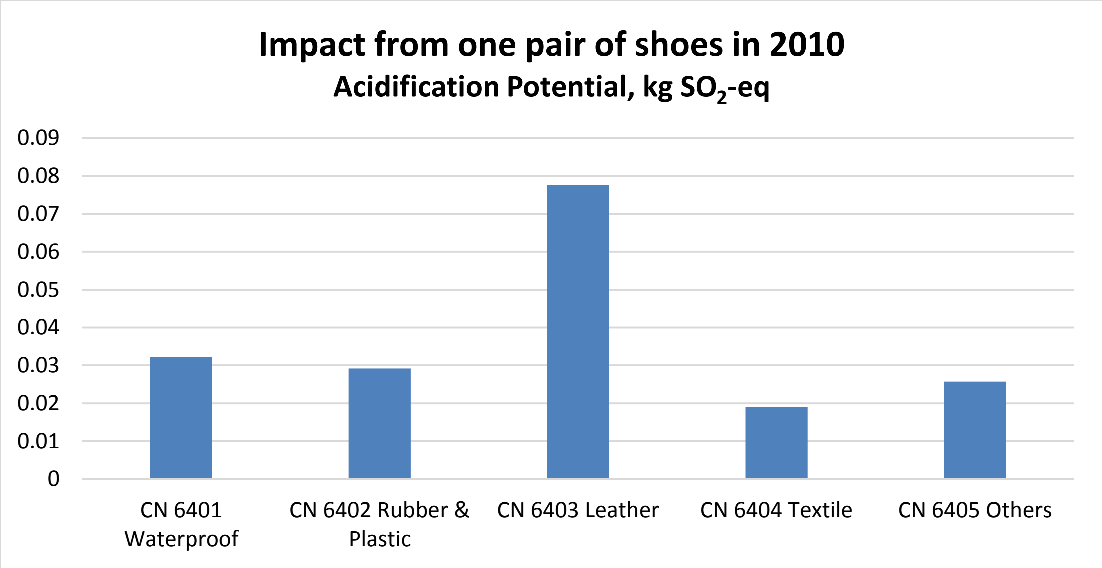

Figure 36 - Acidification Potential for one pair of shoes in every CN category.

Photochemical ozone creation potential

The first three shoe groups, leather, waterproof and rubber & plastic, show higher impact values for an average pair of shoes compared to the rest in case of POCP. See Figure 37.

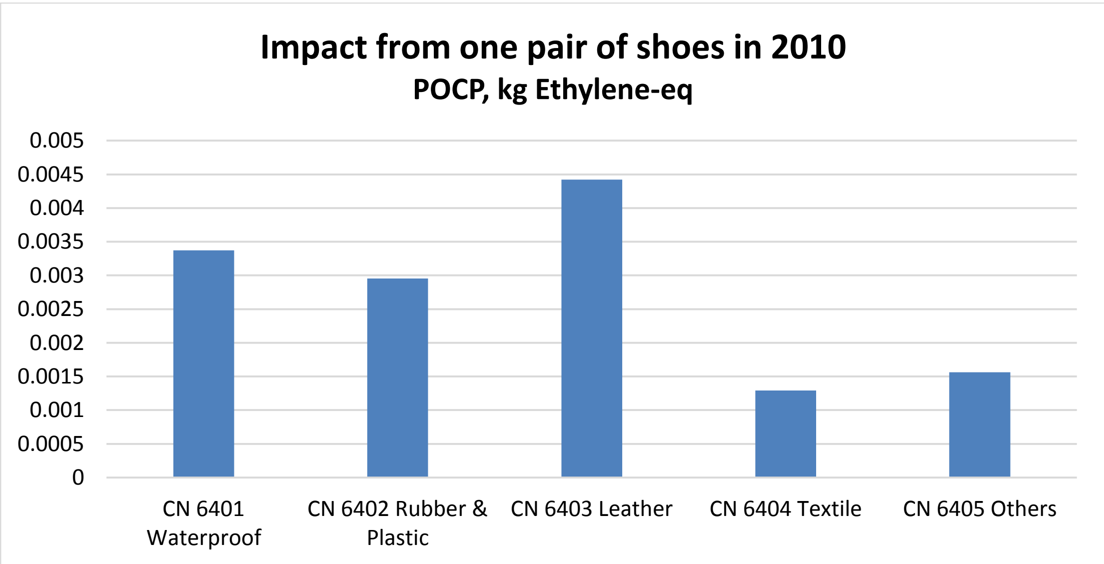

Figure 37 - Photochemical Ozone Creation Potential for one pair of shoes in every CN category.

B.4 Total amount of shoe pairs consumed per person in Sweden

As a complement to the study, the total amount of shoe pairs consumed per person in Sweden in 2000 and 2010 was determined based on the net inflow. The results show that the total amount of shoe pairs per person has increased during this time period, which can be seen in Table 14.

Table 14 - Amount of shoe pairs consumed per person in Sweden according to results from this study for years 2000 and 2010, the values for the Swedish population are 8.4 and 9.4 million (Statistics Sweden 2011)

	CN 6401 Waterproof	CN 6402 Rubber & Plastic	CN 6403 Leather	CN 6404 Textile	CN 6405 Others	Total amount of pairs per person
2000	0.16	0.53	1.12	0.50	0.085	2.42
2010	0.18	0.73	0.73	1.076	0.14	2.87

B.5 Detailed material assumptions for different shoe groups

Table 15 includes the assumptions of detailed materials in the shoe groups.

Table 15 – The materials included in different shoe groups and the assumed material percentage of total shoe weight.

Material	**CN 6401**	**CN 6402**	**CN 6403**	**CN 6404**	**CN 6405**	**CN 6406**
Natural Rubber	20.0%	20.0%	10.0%	10.0%	5.0%	10.0%
Synthetic Rubber	15.0%	15.0%	5.0%	10.0%	5.0%	5.0%
Leather (Cow)	/	/	38.9%	/	13.0%	32.0%
PVC	10.0%	10.0%	/	/	/	/
Polyethylene	7.0%	7.0%	/	/	/	/
PET	7.0%	7.0%	/	/	/	/
Polyester	1.4%	1.4%	2.7%	12.4%	2.6%	5.0%
Nylon	1.5%	1.5%	2.0%	1.0%	0.7%	8.0%
Cotton	2.5%	2.5%	2.5%	20.0%	8.3%	15.0%
EVA	6.8%	6.8%	6.8%	11.8%	6.3%	5.0%
PU	1.8%	1.8%	3.1%	3.3%	8.0%	5.0%
MD	2.0%	2.0%	2.0%	2.0%	2.0%	/
TPR	10.0%	10.0%	10.0%	10.0%	5.0%	5.0%
Chemical sheet	5.0%	5.0%	5.0%	5.0%	3.0%	/
PP	5.0%	5.0%	5.0%	5.0%	2.0%	/
Iron	1.0%	1.0%	1.0%	1.0%	1.0%	2.0%
Zinc	1.0%	1.0%	1.0%	1.0%	1.0%	2.0%
Copper	1.0%	1.0%	1.0%	1.0%	1.0%	2.0%
Aluminum	1.0%	1.0%	1.0%	1.0%	1.0%	2.0%
Brass	1.0%	1.0%	1.0%	1.0%	1.0%	2.0%
Wood	/	/	1.0%	1.0%	25.8%	/
Cork	/	/	1.0%	1.0%	5.2%	/
Viscose	/	/	/	2.0%	1.0%	/
Synthetic leather	/	/	/	/	2.0%	/

B.6 Environmental impacts of different materials in shoes

This section shows the rest of the diagrams related to materials which contribute most to the environmental impact in general.

Acidification potential

As seen in Figure 38, the material with highest acidification potential is leather. The metal which is contributing most is aluminium. Among the textiles, viscose and cotton are dominating.

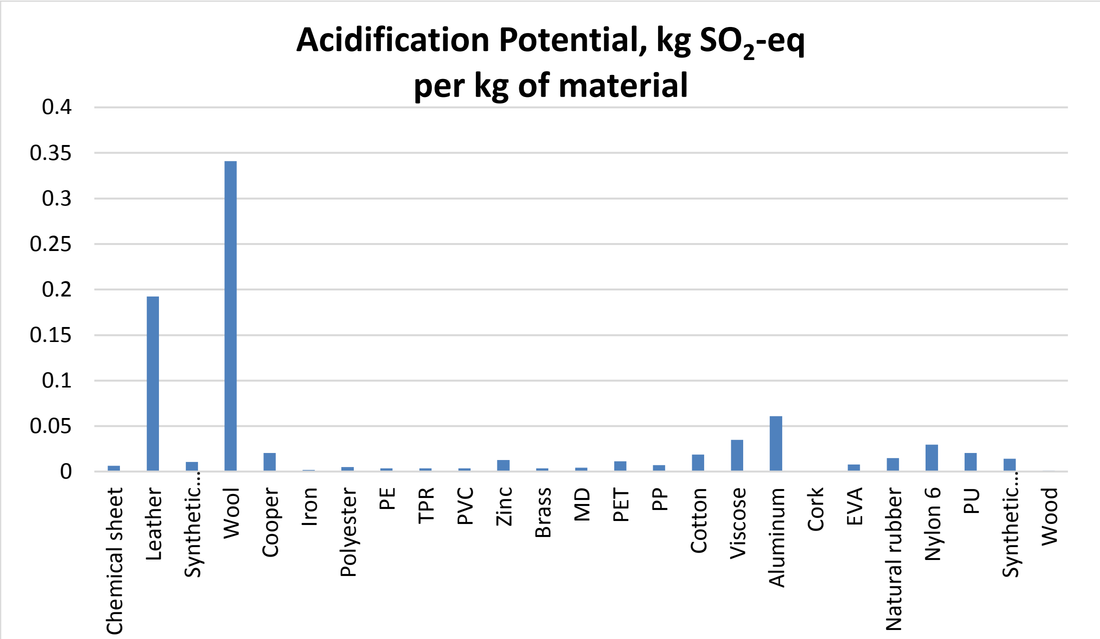

Figure 38 - Acidification potential for 1 kg of every included material based on data for 2010.

Photochemical ozone creation potential

In case of POCP, leather shows the highest value followed by nylon and aluminium. See Figure 39.

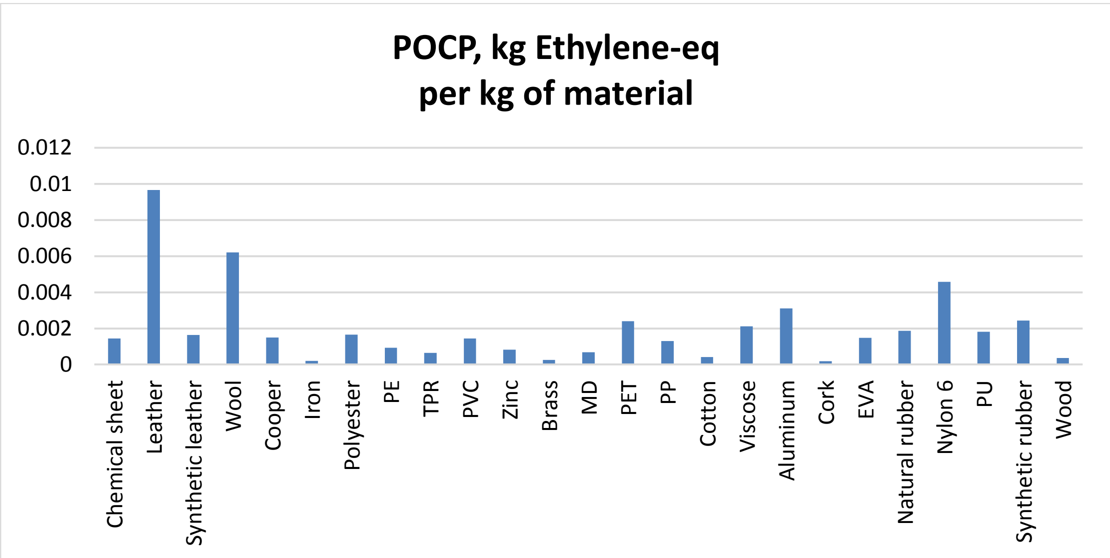

Figure 39 - Photochemical Warming Potential for 1 kg of every included material based on data for 2010.

B.7 Most contributing materials to the environmental impact

This section shows the rest of the diagrams related to materials used in Swedish shoe consumption which contribute most to the environmental impact due to amount and type.

Acidification potential

For the acidification potential, it is shown that leather, latex and synthetic rubber are the most contributing materials. See Figure 40.

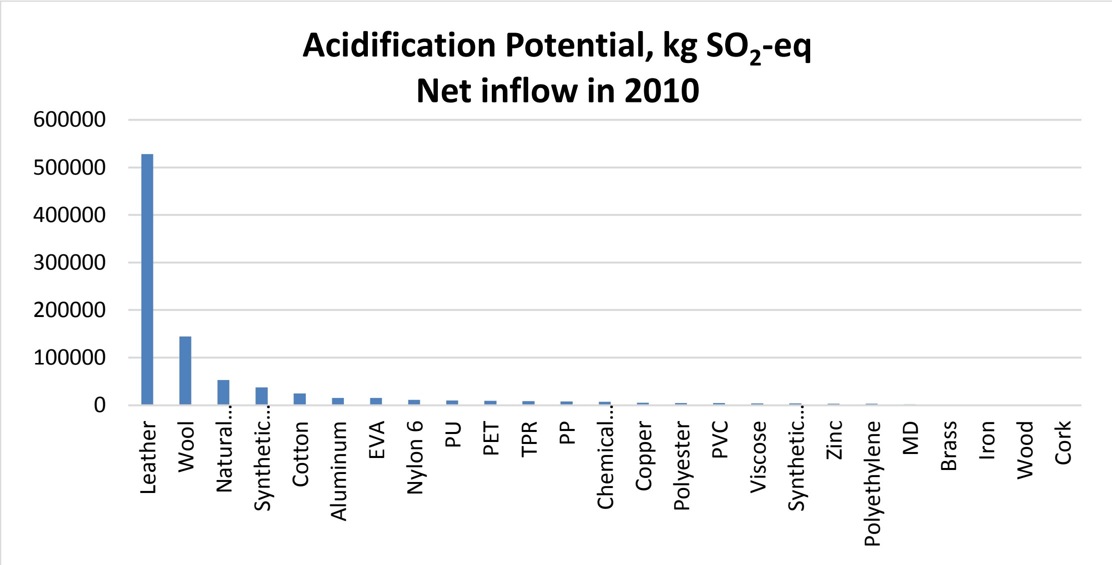

Figure 40 – Materials in shoes which have the highest acidification potential, data from shoe consumption in 2010

Photochemical ozone creation potential

For POCP, latex or natural rubber as well as synthetic rubber shows the highest values followed by leather. See Figure 41.

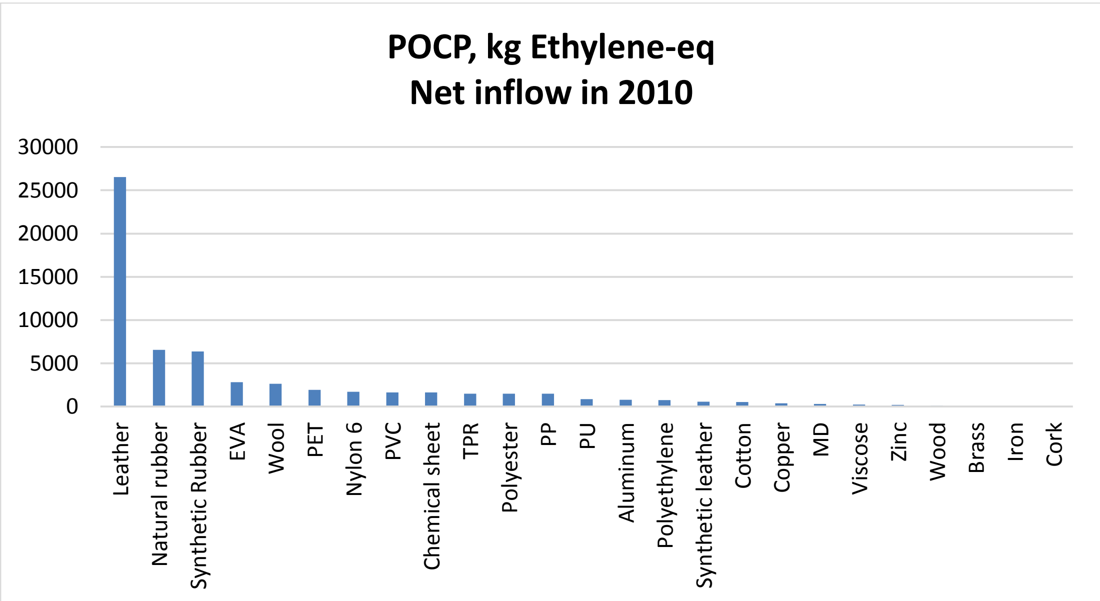

Figure 41 - Materials in shoes which have the highest photochemical ozone creation potential, data from shoe consumption in 2010

Appendix C – Analysis and checking of data

Two different LCA methods for checking of data were used in this study. First, a data uncertainty check was performed which evaluated data sources. Secondly, a completeness check was made to analyze eventual data gaps in the inventory. The results from the analysis are presented in this section together with comments and brief discussions.

C.1 Data uncertainty check

In this study, data for materials, energy generation, waste management and other aspects came from different data sources. According to Baumann & Tillman (2004), inconsistent data used for LCI may increase the uncertainty of the results. Table 16 lists all data related processes and the data source. Conclusions were drawn according to the chosen data.

Table 16 - List from the uncertainty check of data used in the study.

Processes	Data related	Data sources	Conclusion
Raw material	PET PVC Chemical sheet TPE PE PP PU Aluminum Polyethylene Cotton Synthetic leather Copper MD Zinc Brass Iron	Gabi Professional DB	Consistent choice of data source
	Latex Synthetic Rubber Wool EVA Nylon 6 Viscose Wood	Ecoinvent V3.1 2014 (Cut-off system model)	Consistent choice of data source

	Cork		
	Leather	Literature data Gabi Professional DB Ecoinvent V3.1 2014 (Cut-off system model)	Different data sources and lack some data information
Energy generation	CN: Electricity grid mix EU-27: Electricity grid mix	Gabi Professional DB	Consistent choice of data source
Water resource	EU-27: Tap water	Gabi Professional DB	Consistent choice of data source
Waste management	EU-27: Landfill of municipal solid waste EU-27: Waste incineration of municipal solid waste (MSW) ELCD/CEWEP	Gabi Professional DB	Consistent choice of data source
Transportation	Transportation from Asia to Sweden Transportation from Europe to Sweden Transportation from Supplier to Retailer	SeaRates distance calculators Google maps	Different data sources

From the data uncertainty check, it can be found that the data come from different sources which may lead to uncertainties in the conclusions. However, data sources such as GaBi, Ecoinvent and other references in form of scientific reports can be seen as reliable.

Data regarding materials mainly came from Gabi and Ecoinvent except leather which was compiled from literature, Gabi and Ecoinvent. Data for some chemicals used in leather production was missing due to insufficient data sources. For transportation, distances were calculated by the SeaRates Online calculator and Google maps. Average values were taken for the final distances which may affect results regarding impacts from transportation, however small effects. The effects of data and assumptions can be seen in the completeness check in next section.

C.2 Completeness check

A completeness check for data used in the research was carried out to check if the data gaps and assumptions could influence the results and conclusions. The data gaps and assumptions are listed in Table 17.

Table 17 - Completeness check of data gaps and assumptions

Data gap	Assumption	Effect on total results	May affect conclusions?
Domestic shoe production	No domestic production in Sweden	Around 3% decrease in net inflow and impact categories	No
Material weight percentage	Different CN shoe groups have different shoe material weight percentage, set according to literature and analysis of shoes	Amount of material in shoes and hence the impact depends on assumptions only. Heavier shoes cause more impact, as well as more material.	Yes
Shoe weight	Shoe weights were determined by manual weighing of some types of shoes in every group, all types were not included. Average shoe weights were determined.	Will affect the impact results for shoe pairs in different groups	Yes
Energy source	CN: Electricity grid mix (Chinese) for shoes imported from Asia countries EU-27: Electricity grid mix (European average) for shoes imported from European countries	Large differences can be observed for the impact categories due to chosen energy source	Yes
Water source	EU-27: Tap water (European average) both for shoes imported from Asia and Europe	Very small decrease in total impact	No
Electricity used for shoe production	3.24 MJ/Pair according to literature review, average electricity consumption data	Low effect	No
Water used for shoe production	0.036 L/Pair according to literature review	Average water consumption data	No
Waste management in Asia	Landfill rate is 80% and incineration rate is 20%, general waste management situation in Asia	A different incineration rate would have small effects	No

Waste management in Europe	Landfill 60%, incineration 14% and recycling 26%, based on average data of the European waste management situation. The countries have different waste management percentage.	The waste management in general has low effect on total results	No
Waste management of shoes in Sweden	100% incineration, impact from eventual landfill excluded (Mostly incineration in Sweden)	No impact from landfill, impact from landfill of waste very low compared to other impact sources.	No
Raw material waste	5% of total raw material input to waste treatment	Small effects on total results due to low impact from waste management.	No
Leather	Use bovine leather for the whole leather production	Small effect since bovine dominates the leather market, impact from other animal sources would be very small.	No
Allocation for leather	3% of total impact from cattle production allocated to raw hides	The impact from cattle production is very high, if leather would be seen as a by-product with 0% allocation, the impact from leather would be much lower. Leather is the dominating material.	Yes
Transportation from Asian countries to Sweden	Distance from Asian countries to Sweden: 18000 km Distance from European countries to Sweden: 2000 km Distance from suppliers to retailers: 300 km	Average distances. Small effects on impact from transportation	No

The table shows that some data gaps may influence the results and conclusions. The most significant assumptions are shoe material weight, electricity and shoe weights.

In terms of shoe materials, only the most common materials are included in the study. Due to the wide range of material weights in shoes, the assumptions were made according to average data. The references used in this study are not sufficient to get exact data for material percentage in shoes.

Electricity mixes are different in different countries. Considering the complexity of the system to model, using Chinese electricity grid mix and EU-27 might not be representative.

C.3 Cross check of results

To analyze the correctness and fairness of numbers in the results, a cross check with other studies was performed.

Cross check of material impact

To analyze the results for material impacts, other studies which involved determination of environmental impact per kilogram of material was desired. According to a study regarding environmental impact of shoes by Albers et al. (2008), leather was also determined to be the material which caused highest impact per kilogram. For global warming potential, the study showed an order of impact in form of nylon, rubber, PU, EVA, PET, cotton and other natural materials (Albers et al. 2008). Although the included materials slightly differ, it is overall similar to the resulting impact order in this study which proved to be leather, wool, aluminium, nylon, PU, PET, polyester, rubber, EVA and finally the natural materials wood and cork. Also, the conclusion regarding the findings that natural materials generate less environmental impact than synthetic materials appears in both studies (Albers et al. 2008).

Cross check of environmental impact of shoes

The results for the three different impact categories acidification potential, eutrophication potential and global warming potential could also be compared with the study by Albers et al. (2008). Even though the shoe types included were not completely the same, the results from the other study could be used as a guideline for fairness. The comparison and conclusions can be seen in Table 18.

Table 18 – Comparison of results from this study and Albers et al. (2008) regarding environmental impact of different types of shoes

Impact Category	Values from this study	Values from Albers et al. (2008)	Unit	Conclusion
AP	0.019 - 0.077	0.0092 - 0.0695	kg SO_2-Equiv.	OK, same intervals
EP	0.004 - 0.019	0.0015 - 0.0179	kg PO_4-Equiv.	OK, same intervals
GWP	2.35 - 10.79	1.672 - 7.51	kg CO_2-Equiv.	OK, slightly higher

Cross check of shoe consumption per person

The shoe consumption per person in Sweden was calculated by using a value for the Swedish population in 2010 of 9415570, as stated by Statistics Sweden (2011). According to this study, the total amount of shoe pairs consumed per person in 2010 was 2.9 to 6.03 which can be seen in Table 20. Other references present values around 4.6 shoe pairs per person in 2010, which is in the same size as in this study (Apiccaps 2011). Muñoz (2013) includes values for different European countries with a range from 3.3 to 6.8. The amount of shoe pairs consumed in Sweden found in this study depends on the shoe weight assumptions, which was discussed in the sensitivity analysis.

Table 19 - Amount of shoe pairs consumed per person in Sweden according to results from this study for year 2000, the value for the Swedish population is 8.9 million (Statistics Sweden 2011)

2000	CN 6401 Waterproof	CN 6402 Rubber & Plastic	CN 6403 Leather	CN 6404 Textile	CN 6405 Others	Total amount of pairs
Present case	0.16	0.53	1.12	0.50	0.085	2.42
Light case	0.24	1.28	3.00	0.84	0.14	5.53
Heavy case	0.12	0.32	0.75	0.25	0.042	1.49

Table 20 – Amount of shoe pairs consumed per person in Sweden according to results from this study for year 2010, the value for the Swedish population is 9.4 million (Statistics Sweden 2011)

2010	CN 6401 Waterproof	CN 6402 Rubber & Plastic	CN 6403 Leather	CN 6404 Textile	CN 6405 Others	Total amount of pairs
Present case	0.18	0.73	0.73	1.076	0.14	2.87
Light case	0.27	1.75	1.94	1.79	0.24	6.028
Heavy case	0.13	0.43	0.48	0.53	0.074	1.68

Cross check of leather impact results

Due to the high contribution to the total environmental impact from leather, a cross check of the results regarding environmental impact from leather and leather shoes was made. As seen in Table 21, the results vary for the studies involved. Values found in this study are in between values of other studies. It is difficult to draw any conclusions from this case, since there might be different data used and also different allocation methods.

Table 21 – Comparison of results regarding environmental impact (CO_2-emissions) from leather and leather shoes

	This study	Muñoz (2013)	Albers et al. (2008)	Carlsson-Kanyama & Räty (2007)
kg CO_2 per kg of leather	25	0,12	55	-
kg CO_2 per pair of leather shoes	11	3,2	7,51	15

Cross check of impacts from different types of shoes

The values for CO_2-emissions of different types of shoes found in this study were also compared to other studies. Based on the comparison in Table 22, the results were determined to be similar and therefore relevant. A report by Carlsson-Kanyama & Räty (2007) presented CO_2-emissions for different consumer goods, such as different types of shoes. The results were presented according to an economic basis in form of kg CO_2-emissions per SEK, which means the impacts had to be recalculated (Carlsson-Kanyama & Räty 2007). The shoes were determined to cost 218 SEK each, a suggested price for rubber boots stated in the same report. Also, values from other textile shoes were added from a footprint study involving three different models of sports shoes (NIKE Inc 2014). The textile shoe from Albers et al. (2008) is completely made from natural and recycled materials, which makes the value lower than this study.

Table 22 – Comparison of results regarding environmental impact (CO_2-emissions) from different types of shoes

	Waterproof footwear (Rubber boots) [kg CO_2 per pair]	Textile shoes (Sports shoes) [kg CO_2 per pair]	Leather shoes (Leather boots) [kg CO_2 per pair]
This study	5,39	2,35	11
Carlsson-Kanyama & Räty (2007)	5,23	3,71	6,54
NIKE Inc (2014)	-	10,8 - 13,8	-
Albers et al. (2008)	-	1,68	7,51

C.4 Results from the sensitivity analysis

Even for the rest of the impact categories, assumptions of shoe weights show relevance, especially for heavier weights. Acidification potential and POCP can be seen in Figure 42 and Figure 43.

Acidification potential

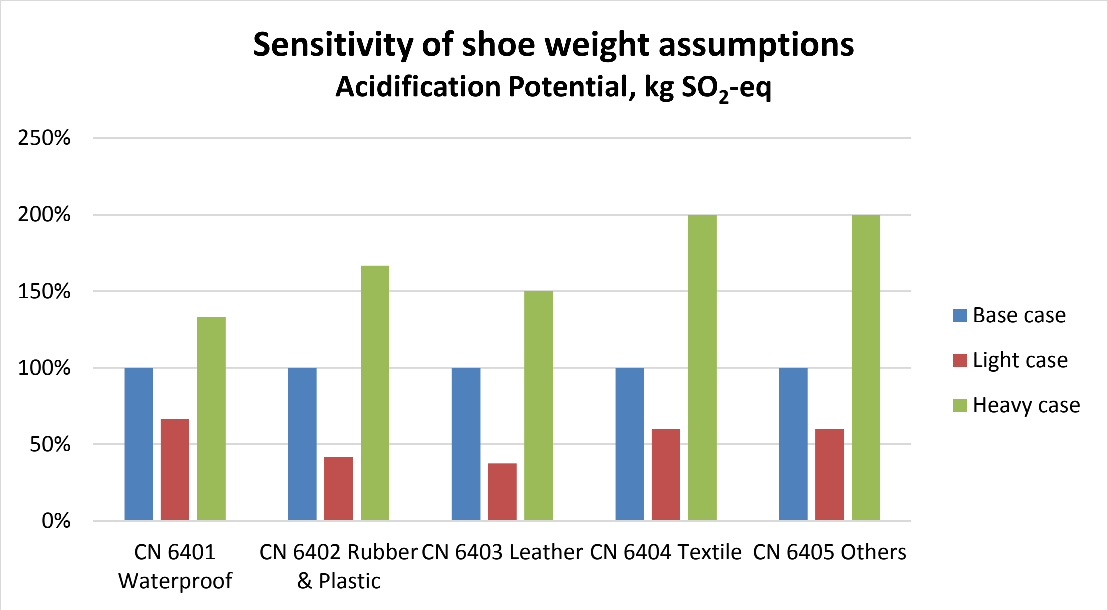

Figure 42 – Results from sensitivity analysis of shoe weight with three scenarios, the picture shows acidification potential for one pair of shoes in every group.

Photochemical ozone creation potential

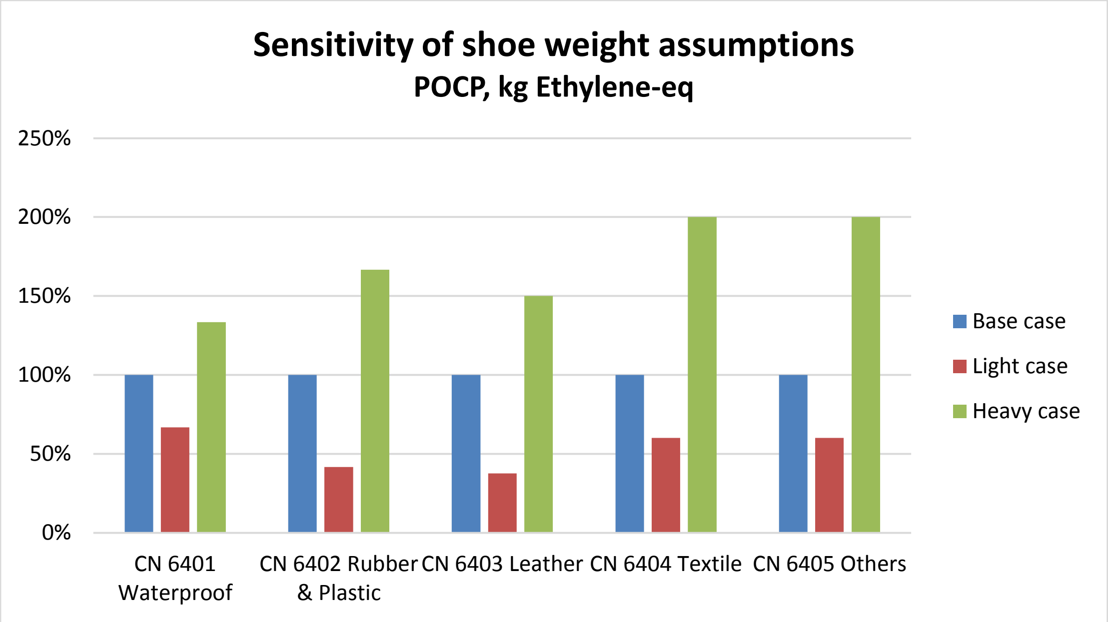

Figure 43 - Results from sensitivity analysis of shoe weight with three scenarios, the picture shows photochemical ozone creation potential for one pair of shoes in every group.

C.4.1 Sensitivity analysis of leather data and assumptions

To check which factors contribute most to the environmental impact in the leather production process, a comparison of different aspects was performed and can be seen in Figure 44. Chemicals and raw hides showed most contribution which made it relevant to perform a sensitivity analysis regarding chemical input and how much impact is allocated to raw hides.

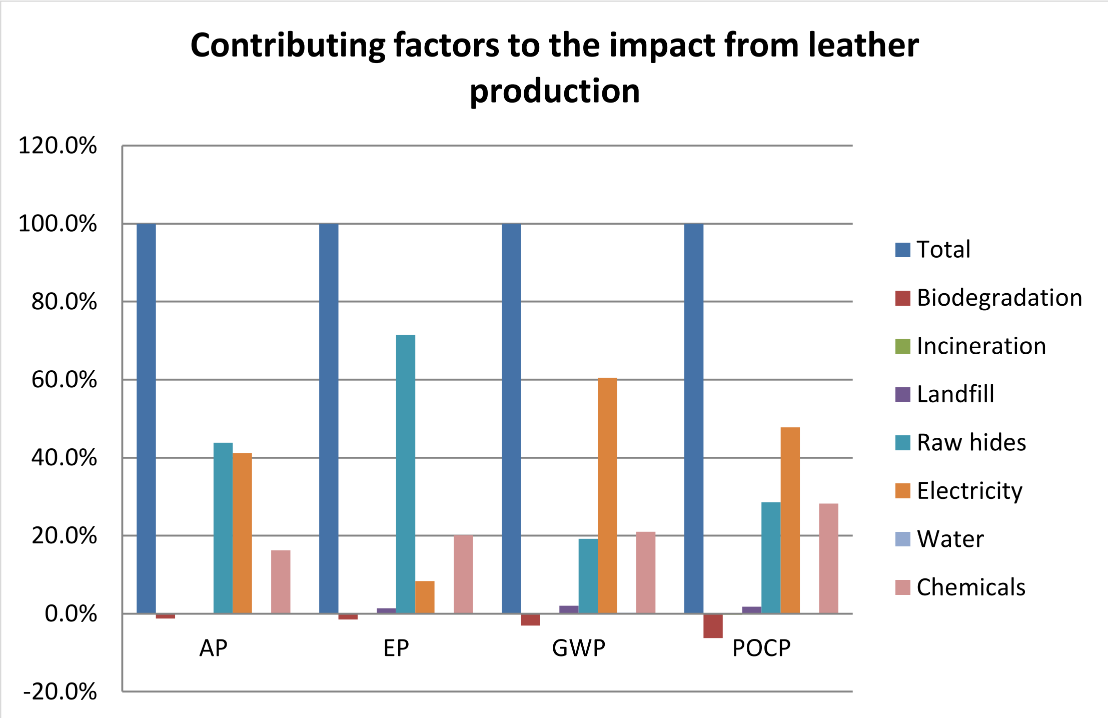

Figure 44 – Analysis of factors contributing to the impact of leather production which involved assumptions, the total impact is set to 100%.

The allocation of impacts from breeding of one cow was set to 3% for raw hides, which is low compared to other recommended values. Two other scenarios were set to 8% and 0%, where the latter case indicates that all environmental impact from animal production is included and raw hides are seen as a by-product. The results in Figure 45 indicate that the allocation will affect the final impact and is therefore important to consider

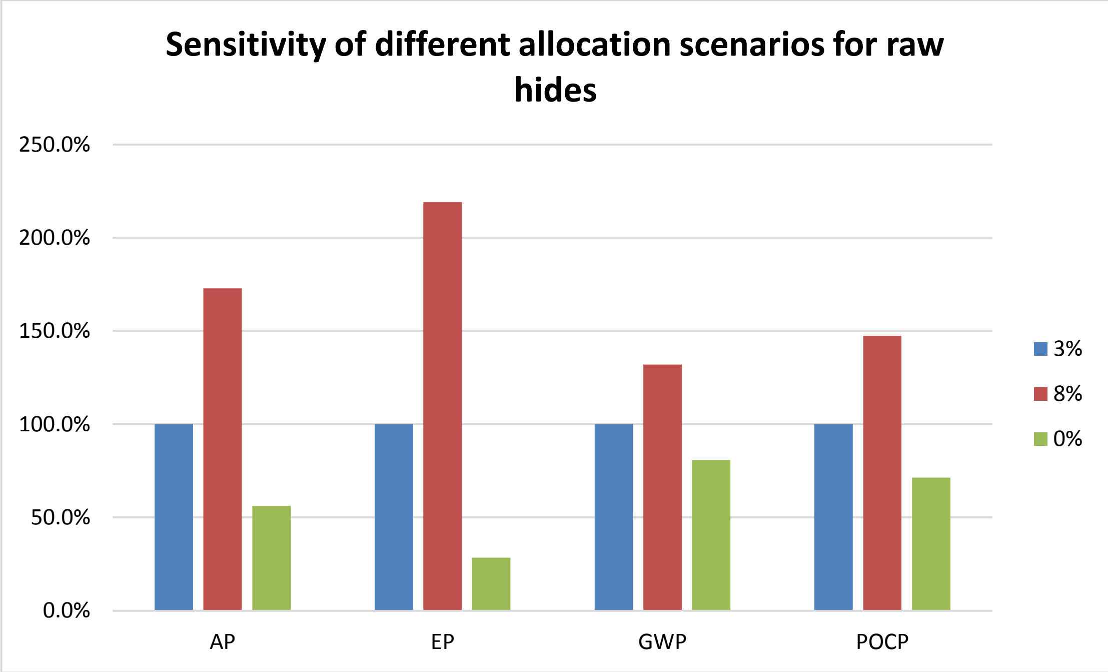

Figure 45 – Three different allocation scenarios for raw hides, where the case of 3% used in this study is set to 100%.

Data for chemicals used in leather production is difficult to achieve and some data gaps exist in this study. The sensitivity regarding chemical input in Figure 46 show that the amount of chemicals used in the process matter, which means the impact from leather should be higher if more data regarding chemicals was added.

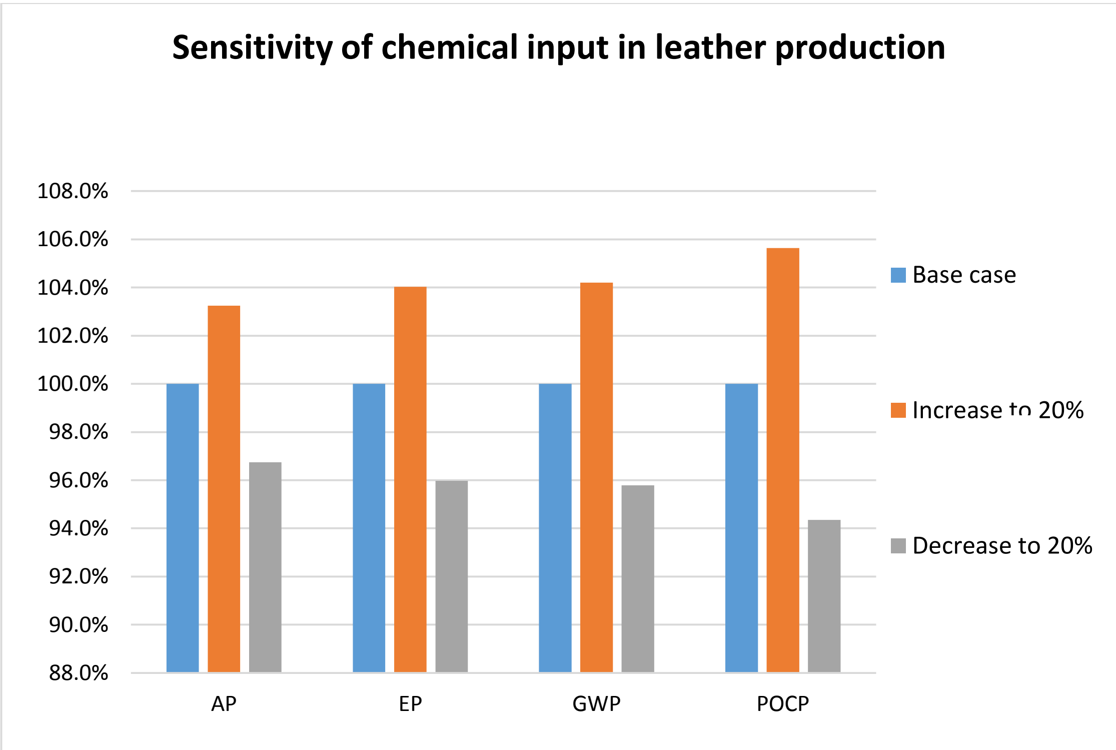

Figure 46 – Sensitivity analysis of chemical input in leather production based on a 20% increase and decrease of the input level used in this study which is set to 100%.

Depending on where the leather production is taking place, the conditions are different. Three waste management scenarios were therefore set based on Swedish, Asian and European methods which can be seen in Figure 47. In general, assumptions regarding where the leather is produced might affect the results even though waste treatment corresponds to a small percentage of the total impact.

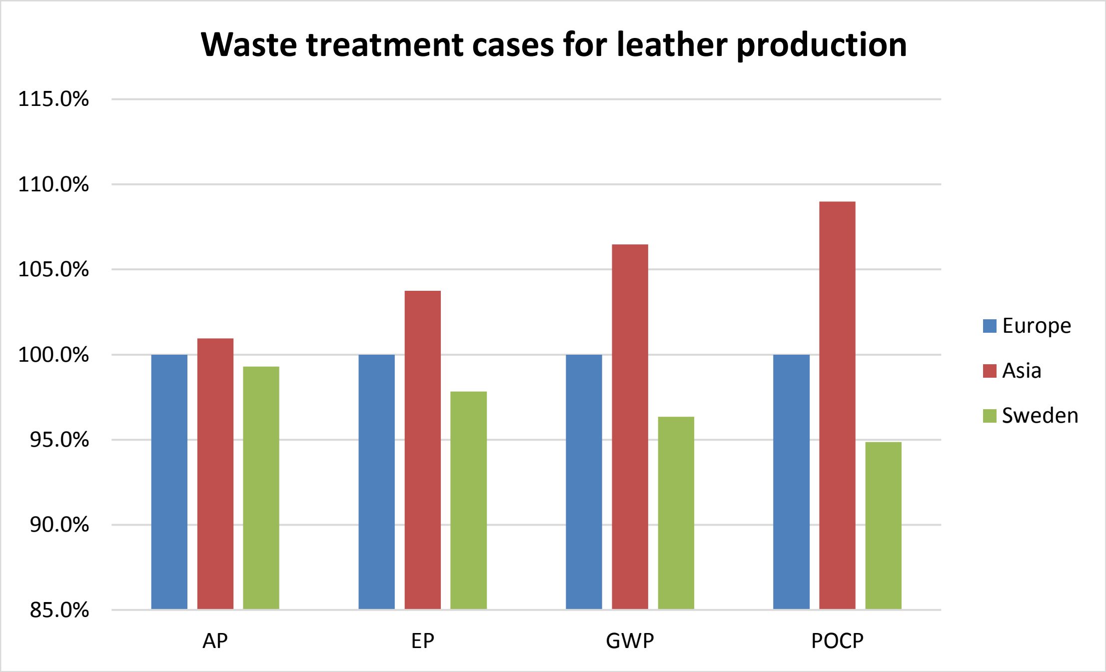

Figure 47 – Three different scenarios of waste management based of Swedish, Asian and European methods where the European case is set to 100%.

C.4.2 Best case scenario for shoes

A best case scenario analysis was performed to see how the total impact changed if optimal parameters were used instead of the present case in this study. The present base case involved data from year 2010. Assumptions for the best case scenario are based on the sensitivity analysis and listed below.

- Low consumption – Lowest net inflow in year 2001
- Greener electricity - Swedish electricity grid mix for the whole shoe production
- Lighter shoes – Lower weight for shoes
- Better waste management of leather – Use Swedish standard of treatment

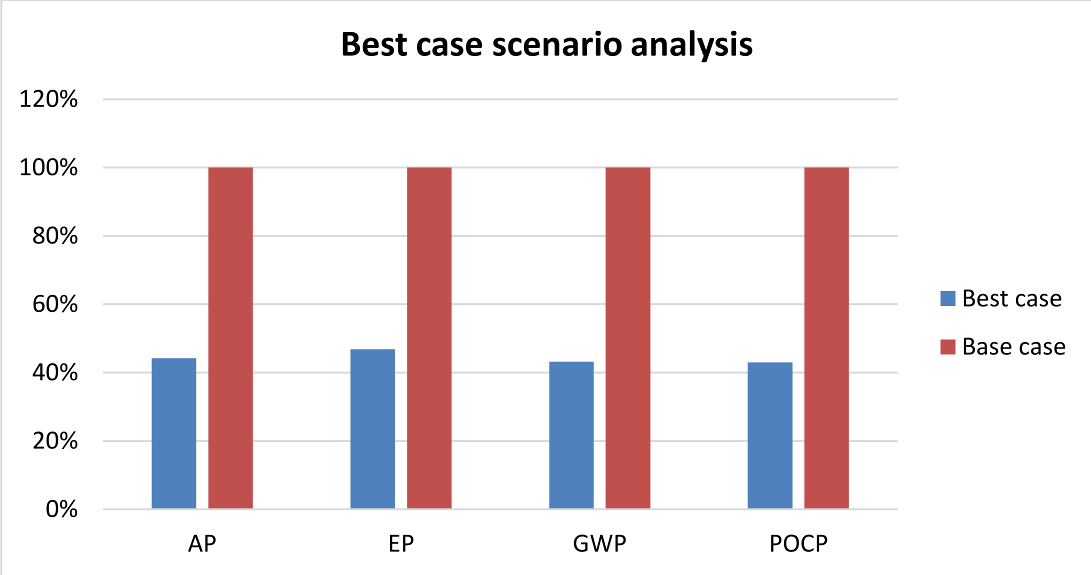

Figure 48 - Sensitivity analysis using best case assumptions for shoe manufacturing. The results from the base case have been set to 100% in each impact category. Abbreviations: AP (Acidification Potential), EP (Eutrophication Potential), GWP (Global Warming Potential) and POCP (Photochemical Ozone Creation Potential).

The results in Figure 48 show that combining factors such as lighter shoes and a more environmentally friendly electricity mix might reduce at least 50% of the total impact.