Analysis of potential environmental improvements concerning transports of water-borne lacquer to Swedwood International

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Examensarbete 2006
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Dokumenttitel och undertitel

Analys av möjliga miljöförbättringar gällande transporter av vattenburna lacker till Swedwood International

Sammandrag

Denna studie är en miljösystemanalys av transporter av vattenburna lacker, levererade från olika lackproducenter till ett flertal möbelfabriker tillhörande Swedwood International, huvudsakligen i Östeuropa. Syftet är att identifiera och beräkna den uppkomna miljöpåverkan, och utifrån resultaten ge förslag på förbättringsåtgärder.

Möjligheten att reducera vatteninnehållet i de vattenburna lackerna har analyserats, och tillsammans med en kartläggning av dagens transportsträckor och -kvantiteter har tre möjliga scenarier beräknats för varje medverkande fabrik. För vart scenario har en blandningsprocess av vattenburna lacker adderats, för att möjliggöra jämförelser. Scenario nr 1 representerar dagsläget, med extern lackblandning följd av transport av färdigblandad vattenburen lack, nr 2 innebär intern lackblandning i Swedwood-fabrik, till följd av transport av vattenreducerade lacker, och i nr 3 transporteras vattenreducerade lacker till lackblandning externt, varpå transport av färdigblandad lack följer. För att enkelt kunna beräkna olika parametrars inverkan på resultatet utifrån varje enskild användares önskemål har en modell skapats, i vilken även placering av lackblandningsställe kan varieras.

Studiens undersökta miljöpåverkanskategorier är växthuseffekt, övergödning, försurning och bildning av fotokemiska oxidanter. Utöver detta har energianvändningen studerats. I möjligaste mån har livscykelanalysmetodik och -principer enligt ISO 14040-43 följts.

Resultaten visar att produktionen av de vattenburna lackerna bidrar mest till den totala miljöpåverkan, och genom att primärt fokusera på förbättringar inom detta område får övriga förbättringsåtgärder större genomslag. I synnerhet elproduktionsbetingelserna påverkar miljön, vilket visar att det spelar stor roll vilken typ av el som används. Utförd känslighetsanalys visar att lastbilens motortyp samt andelen vatten som kan tas bort från lackerna före transport till stor del påverkar emissionerna orsakade av transporter.

Ur ett Swedwood-perspektiv är det viktigt att fokusera på transportsträckor i kombination med vattenreduktion från lacker; ju större del av sträckan man kan transportera lacken vattenreducerad, desto större miljömässiga förbättringar kan uppnås. Att uppföra ett eller flera externa lackblandningsställen kan vara en god idé i de fall transportsträckorna är långa, men då skall understrykas det faktum att lackproducenter i dagsläget ansvarar för nödvändig kvalitetssäkring, samt att kunskap, erfarenhet och monetära medel – icke utredda i denna studie – skulle krävas för en dylik optimeringssatsning

Nyckelord

Miljösystemanalys, livscykelanalys, transporter, vattenburna lacker

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Abstract

This study is an environmental system analysis concerning the transport of water-borne lacquers from different lacquer suppliers to Swedwood furniture industries situated mainly in Eastern Europe. The aim of the study is to identify and calculate for environmental impacts to suggest possible improvement areas based on the achieved results.

The possibilities of reducing water-content from the water-borne lacquers have been analysed and, together with a mapping of the present transportation distances and delivered lacquer quantities, three possible cases for each participating industry have been calculated for. In order to make comparisons, a mixing process of water-borne lacquers has been added each case. The first case represents the present situation, where the external production of water-borne lacquer is followed by the transportation of the ready-mixed lacquers. The second case shows the transportation of water-reduced lacquers followed by the internal mixing of lacquers within a Swedwood factory. In the third case, water-reduced lacquers are transported to a central mixing site in between the supplier and the Swedwood factory, where a mixing process follows before further transportation of already mixed lacquers. In order to facilitate the calculations of the impacts caused by different parameters, a model has been created, in which locations of the central mixing site also can be varied.

The investigated environmental impact categories are global warming potential, eutrophication potential, acidification potential and photochemical oxidant creation potential. Energy use has also been studied. The ambition has been to follow the method and principles of life cycle assessment in the standard protocol ISO 14040-43.

The results show that the production of water-borne lacquers contributes the most to the total environmental impact. By focusing on improvements in this field in a first step, subsequent improvement in other areas as a second step will have a greater effect. The type of electricity production varies a lot, showing that electricity production parameters are highly significant for the environmental impacts. The sensitivity analysis shows that the type of truck engine and the share of water reduced from the lacquer to a high degree affect the total emission load caused by transportation.

Through a Swedwood perspective it is of great importance to focus on the transport distances in combination with the reduction of water from the lacquer; the greater the part of a distance you can transport the lacquer reduced from water, the higher the environmental impact improvements you achieve. To build one or a few central mixing sites might be a good idea in the cases where transport distances are long, but then, following facts are of great importance to remember: today the lacquer producers vouch for the required quality, and to achieve the desired optimisations both knowledge, experience and funding would be needed.

Keywords

Environmental assessment, life cycle assessment, transports, water-borne lacquers

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Preface

This master thesis finishes my degree in Environmental Engineering at The Faculty of Engineering (LTH), Lund University, and it has been made on behalf of Swedwood International in cooperation with the Department of Technology and Society at LTH. I would like to thank my supervisors; associate professor Pål Börjesson (LTH) and Victoria Olsson (Swedwood), for all help with my project. I would also like to express gratitude to those who have helped me with data and information for my calculations. And, most of all, I would like to thank the always supporting and accurately proofreading secretary Susanne Söderlund.

Lund, 2007-01-10
Kristin Alnemo

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1 Introduction

1.1 Background

This master thesis is performed in cooperation with Swedwood International, with the head office located in Ängelholm, Sweden. Swedwood is owned by IKEA, and it is an industrial group of companies consisting of 35 production units in nine countries. The primary function of Swedwood is to manufacture and distribute wood-based furniture, with IKEA as the main customer.

IKEA's code of conduct, "The IKEA Way on Purchasing Home Furnishing Products" (IWAY), demands that all products must be manufactured in a responsible way. Because of that, IKEA requires its suppliers to reduce the environmental impacts continuously. Among those, an important focus area is the environmental impact caused by transports, and in particular emissions to air. This study focuses on the transports of water-borne lacquers between suppliers and Swedwood factories all over Europe, but it also takes into consideration the emissions caused by lacquer production. The investigated factories are situated in Hungary, Poland, Romania, Slovakia and Sweden.

The transports, mainly performed by trucks but sometimes by ship, contribute in different ways to the environmental impacts. The results and suggestions that arise from this study can be used as a basis for decision-making, perhaps leading to further improvements within the area of environmental impacts caused by transports of water-borne lacquers.

1.2 Aims and objectives

The aim of this study is to estimate environmental impact and to identify possible improvement areas within the transport of water-borne lacquers, using a life cycle approach. The objective is to point out where the highest impact areas are, and to propose measures of what can be done to lower them.

The study is divided into two parts, aiming at a comparison, after which the objective can be reached and the results can make basis for future decision-making. In the first part, transport distances between suppliers and Swedwood factories over Northern and Eastern Europe are mapped, and quantities of water-borne lacquers, frequencies of transports and status of transport vehicles are investigated. From these results, environmental impacts are calculated. The second part estimates the potential improvements and reduced environmental impact by transports of lacquers, where water to a percentage wise share has been eliminated, added with a later mixing procedure of lacquers and water. This mixing procedure can be situated either close to each Swedwood factory, or somewhere central between several factories.

2. The study in general

This master thesis project is an environmental assessment, which follows and evaluates environmental impact caused by transports and a mixing procedure of water-borne lacquers. The study is carried out through a perspective of life cycle assessment, LCA, but because of delimitations, it does not completely follow the standard protocol of LCA (ISO 14040-14043).

Life cycle inventory (LCI) data have been collected from various types of sources: environmental reports, communication with workers at Swedwood's factories all over Europe and other experts on the transport and lacquer markets, and existing LCA reports.

In order to simplify all calculations, an Excel model has been built, in which variables easily can be changed, followed by result presentations. The results are presented per functional unit (FU), and, in *Chapter 9*, the results are also presented per factory and per year.

2.1 Functional Unit

According to the ISO standard, a correctly made LCA must include a functional unit, chosen to describe the function of the system and, when two or more systems are investigated, be comparable and equivalent. A comparison between different types of transport vehicles is always risky, and furthermore between two production systems like this, the results can be widely spread. In addition, it is important to be aware of the fact that the environmental impact varies depending on local environmental conditions. As the aim of this study is to map and compare the different scenarios, there has to be a common denominator, a functional unit (FU). The functional unit in this study is "1 kg water-borne lacquer ready to be used".

2.2 System boundaries

A company's strategic choice of transport could be based on various aspects, e.g. economic criteria, regional politics, work market, environment and energy criteria and time related aspects.[1] This report, however, presumes that the transport alternatives already have been selected, and on that basis focuses on an optimisation of the present situation. The study only focuses on the environmental part, and this optimisation gives results in terms of minimizing the environmental impact.

The tool being used is Life Cycle Assessment (LCA), which helps identify where in the life of a product, service or process the biggest potential environmental impact takes place. Thus, no complete LCA can be made in this study, because it would be a very large, complex and demanding system to analyse. For example, results of the total environmental impact from transports can be divided into infrastructure and traffic, both of which in turn can be divided into steps like production, operation and maintenance and winding-up.[2] All components contributing to the transport shall, through a pure system perspective of LCA, be included in the system and therefore be analysed from the cradle to the grave. Nevertheless, by following the main principles of the ISO standard this study can identify key parameters.

One should observe that the energy consumption and emissions to air that occur during the application of the lacquers, and which are of great importance from a life cycle perspective, are not reported with this choice of functional unit.

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[1] Uppenberg, et.al, 2003, p.11
[2] ibid, p.19

In this report, three cases have been identified and investigated, all including the mixing process of water-borne lacquers and transports *(Figure 1)*. None of the cases includes production of raw material for the production of lacquers, or handling of waste products from the mixing procedure. In a later sensitivity analysis *(Chapter 7)*, variables estimated to affect the results are changed and evaluated. In *Chapter 9*, a Swedwood perspective is used, considering the potential environmental impact caused Swedwood activities only. This so affects Case I that the mixing process of water-borne lacquers at the supplier is excluded.

2.3 Delimitations

No geographical delimitations concerning air emissions have been made in this study; all emissions are included and treated equally, regardless of where they are emitted. However, after having taken electricity production into consideration, the differences due to electricity production circumstances are included, which means that for example figures for electricity vary depending on country.

No emissions to water are calculated, because of the assumption that they are of minor importance for this study. Only emission to air and energy demand are included.

Emissions of particles is an environmental impact category which should be presented in a life cycle analysis, but, when in this master thesis calculating the environmental impact, emissions of particles are not included. In contrast, there is a qualitative discussion concerning emissions of particles.

When transporting water-borne lacquers, there are plastic containers, usually 20, 200 or 1000 litre, protecting the contents. These are washed and recycled between usages[3], but none of these activities is included in this study.

2.4 Data

All data concerning quantities of lacquers and delivery frequencies are collected via personal communication with key actors at the different factories of Swedwood International. Note that the definition of metric ton is used when calculating with tons. Transport data is taken from NTM[4] and transport distances are estimated by Map24[5]. Data for the mixing process of water-borne lacquers has been received by an existing LCA report of paint[6] together with personal communication with actors on the Swedish market of paint and lacquer production[7].

2.5 Data quality

Inventory data for lacquer and paint, except for the production of stain, is taken from 2002 and later. Data for the production of stain is based on an LCA report written in 1999[8]. This report uses Swedish industrial mean values, and these factories have highly developed technologies.

[3] Heide, 2006
[4] NTM, 2006
[5] Map24, 2006
[6] Axelsson, et al, 1999
[7] Gustavsson & Skoog, 2006
[8] Axelsson, et al, 1999

Diesel quality data and data for emissions from different diesel engines are from 2006. Concerning differences in energy efficiency between long distance traffic transports, regional traffic transports, urban traffic transports and transports by ship, LCI data are based on reports from 1994 and 1997. Those are the same figures as used by NTM.

All personal communication is performed in the spring and summer of 2006.

2.6 Allocations

In this study, no allocations are made. Allocation made in the LCA report of paint is based on weight of the main product.

2.7 General assumptions

Lacquers considered in this study are water-borne and used in Swedwood's manufacturing processes. Depending on field of application, they comprise different makes and different quantities and are purchased from different suppliers. When calculating, the lacquers have been treated equally, independently of existing differences between chemical compositions etc. Common to them is that they have been produced at a paint and lacquer manufacture's, and from there been transported long distances, all over Northern and Eastern Europe. Mapping of these transports provides a general view, which makes it possible to compare with transports of only lacquer with a certain share of water reduced. These transports though, have to be followed by a mixing industry, either neighbouring each Swedwood factory or situated centrally between the factories. There are numerous ways to calculate and many different results can be achieved. In order to present clear and useful results, there must be limitations made. Because of that, three cases have been identified and used as bases for the calculations. These cases are listed below; see *Appendix C* for details and calculations, and *Figure 1* for case illustration. In *Chapter 9,* these cases are further developed and analysed, through a Swedwood perspective.

Case I

This first case is a present case analysis, where figures are based on existing conditions. These are presented in *Appendix A*. Today, suppliers produce paints and lacquers internally, which are then assumed to be transported the shortest possible way directly to Swedwood factories. Quantities of lacquers and transport distances are investigated through communication with key actors at the different Swedwood factories, and the transport vehicles are assumed to be the same for all transports. In a sensitivity analysis *(Chapter 7)*, the various vehicle characteristics are changed and analysed.

Case II

In the second case, only lacquers with a certain weight-share of water eliminated are transported from suppliers to Swedwood factories, where an internal mixing process follows. The water elimination of the lacquers is based on information from lacquer experts and later analysed in a sensitivity analysis *(Chapter 7)*. The transport distances and transport vehicles are assumed to be the same as in Case I. In addition, the suppliers of the lacquer concentrates are assumed to be the same as the suppliers of water-borne lacquers in the first case, even though this is not always the case.

Case III

The third case involves two different transport parts: the first one is transport of water-reduced lacquers from supplier to central mixing site, where they undergo a mixing process, and the second one is transport of ready-to-use water-borne lacquers from this central mixing site to Swedwood factory. The reduced weights of water in lacquers are assumed to be the same as in Case II, as are the suppliers of the same. None of the transport distances are known and therefore the central mixing site is assumed to be placed in between the supplier and the Swedwood factory, later to be varied in a sensitivity analysis *(Chapter 7)*.

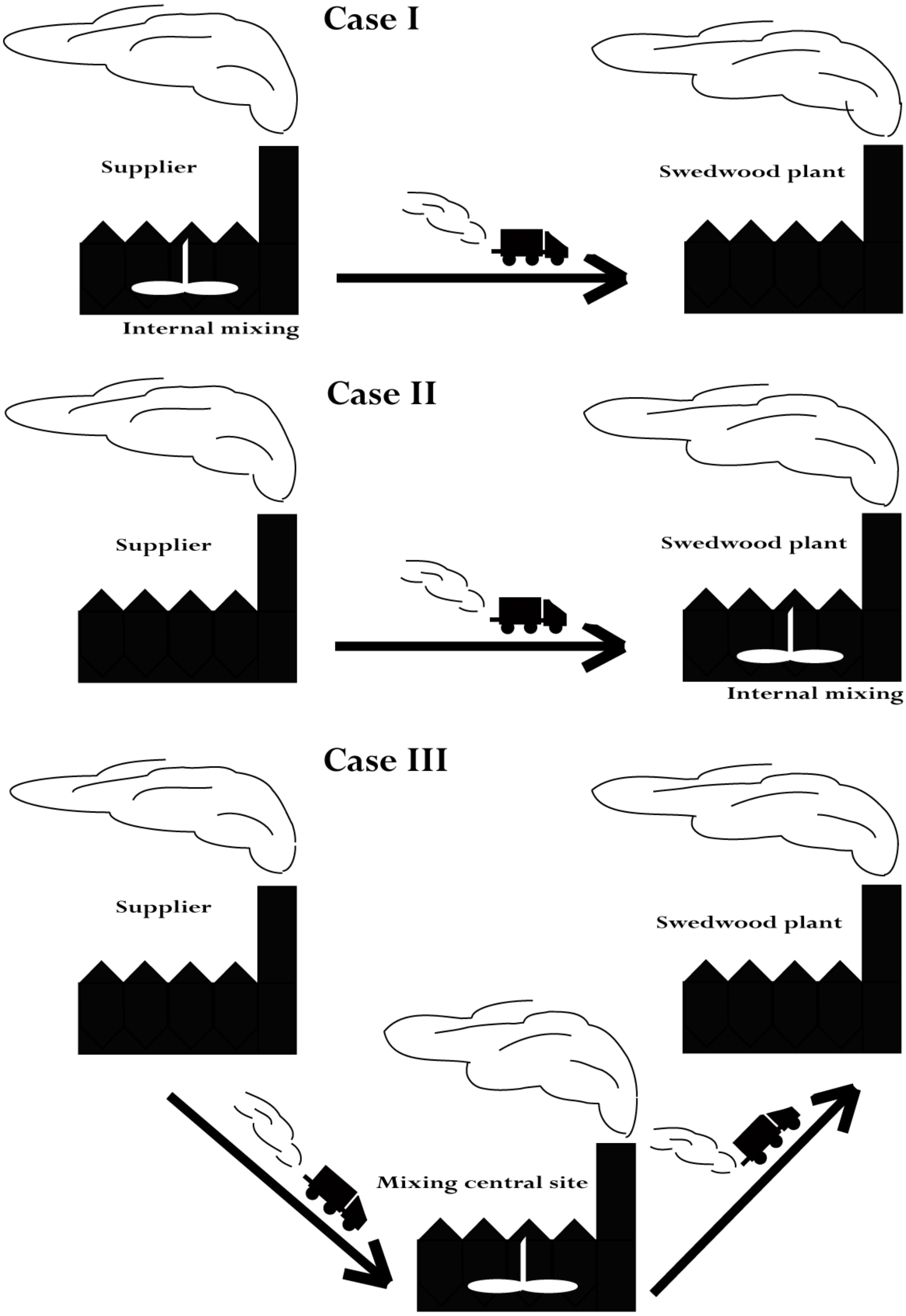

Figure 1. Illustration showing the three cases used; Case I, Case II and Case III

2.7.1 Assumptions for lacquers

During the work on this report, the information gathered has indicated that the mixing procedure means not simply to mix water-reduced lacquer with water. Required for satisfying results are certain techniques, machines and knowledge[9]. This implies that the mixing process in fact is more complicated than just adding water to lacquer powder, and therefore more easily compares to the production of water-borne lacquer. In order not to risk underestimates of the impact of the lacquer mixing process, the following important assumption is made:

The mixing process of water-borne lacquer is assumed to be equal with the production of water-borne lacquer, in terms of emissions to air and energy use.

An existing LCA report regarding paint, based on industrial mean values, has served as a basis for inventory data collection concerning lacquers. However, the LCA report does not, due to lack of data, involve water-borne lacquers. The product investigated there instead is water-borne stain, with a water content of approximately 86 %[10]. In order to be able to carry out this study, another important assumption has been made:

The production of water-borne lacquers is assumed to be equal with the production of water-borne stain, in terms of emissions to air and energy use.

These two assumptions together lead to the following assumption, equally important to this study:

The mixing process of water-borne lacquer is assumed to be equal with the production of water-borne stain, in terms of emissions to air and energy use.

According to the above line of reasoning, the LCA report concerning paint provides LCI data for the mixing process of water-borne lacquer.

In the discussed LCA-report above, the inventory results are calculated for the whole production chain, including the production of raw material. These figures are excluded when focusing on the mixing process.

2.7.2 Assumptions for transports

There are numerous ways of transporting products and several variables affect the result, e.g. type and size of truck, fuel consumption and fuel quality. These variables are listed below, together with the present case assumption. In order to easily calculate the emissions caused by transports, an Excel model has been constructed, based on data from NTM[11] and Tillman[12] *(Appendix C)*. In this study, the main variable to change is transport distance, but the model also makes it possible to investigate the impact caused by other variables. NTM data are provided via an internal Internet site, demanding login password. Via personal communication, a time limited password has been obtained and used[13].

When calculating for environmental impact caused by transports, the actual route taken by the cargo is hard to know, because of the shipment often being integrated in a larger transport

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[9] Nydensten, 2006
[10] Axelsson, et al, 1999
[11] NTM, 2006, p2
[12] Tillman, 1994
[13] Swahn, 2006

chain, including unloading and reloading. The distances are therefore assumed to be those displayed by the Internet based tool for calculation of transport deliveries: Map24[14].

Vehicle type

According to the producers, some deliveries occur with relatively small quantities, approximately 5-20 tons per delivery, to Swedwood factories.[15] These transports probably are not delivering to only one site at the time; these are most likely shared transports together with other deliveries along a predefined way.[16] Regardless of this, the type and size of vehicle is not varied. Instead the impact caused by the load factor is investigated in a later sensitivity analysis *(Chapter 7)*.The vehicle type is assumed to be a truck with maximum load of 26 tons[17].

A unique means of transportation is that by ship. In order to optimise the ship both economically and environmentally, each ship is constructed for its special task. This causes difficulties when calculating; energy use and emissions cannot simply be taken from a pre-defined table, each ship must be analysed individually.[18] In this study this is not possible, due to both lack of time and data. For transports when a ship is needed, the vessel is assumed a medium-sized ship with a maximum freight capacity of 2000-8000 dwt.[19]

Engine and fuel type

The European Union has stated standardisations, regulating emissions from engines. When focusing on engines of heavy-duty trucks, the emission standards are identified as Euro.[20]

In 1991, an environmental classification system for diesel fuels was implemented, and each class was given a certain tax level[21]. The classification of diesel is called *Miljöklass* (Mk).

In order to get traffic promotion and licenses for the truck, transporters in Eastern Europe must use at least Euro 3 engines, and fuel of the environmental classification Mk 1[22]. Therefore, these variables are kept constant while calculating the three different cases[23]. However, in order to investigate their environmental impact, they are later changed in a sensitivity analysis *(Chapter 7)*.

Both engines and fuel type are further discussed in *Chapter 4*.

Transport distances

Details regarding delivery distances are collected from key actors at the Swedwood factories, providing information regarding which lacquer suppliers are being used. From these figures, Map24[24] has mapped out the probable routes; see *Table 1* for chosen parameters. For all transports, the regional driving distances – those between urban areas and motorways – are assumed to be 15 km. For the transports that include ship transport the urban traffic distances

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[14] Map 24, 2006
[15] Barczak, Käll, Lezniak, Bazela, Haramiova, Banovcan, Nord & Lujanski, 2006
[16] Nilsson N, 2006
[17] Ibid
[18] Lundgren, 2000
[19] deadweight tons; 2000-8000 dwt corresponds to approximately 30-130 heavy duty trucks (Rydh C-J, 2002)
[20] Europeiska gemenskapernas kommission, 2005
[21] SPI, 2006
[22] Nilsson, 2006
[23] SPI, 2006
[24] Map 24, 2006

are assumed to be 10 km, due to the different driving conditions when arriving at and driving out of a harbour area. In the calculation model it is possible to define long distance traffic, regional traffic, traffic in urban areas, and shipping distances.

Table 1. Parameters chosen for route calculation, here marked in bold[25]

Type of route	Fastest		**Shortest**	
Motorway-use	More	**Normal**	Less	Avoid
Ferry-use	More	**Normal**	Less	Avoid
Average speed settings [km/h]	Motorway	Primary route	Local road	Ferry
	100	**80**	**40**	**30**

Load factor

There are difficulties regarding load factor assumptions, since the load factor decreases along the delivery route and it is not known to where the other deliveries go and where along the route the Swedwood factory is situated. Hence, it is assumed that the load factor on an average is 70 %, independently of the actual lacquer quantity delivered. The load factor's impact on the results is investigated in *Chapter 7*.

Fuel consumption

In the basic case, the average fuel consumption for trucks is set at 3,5 litres per 10 km. This is based on NTM's default values, which in turn are based on type of vehicle. These figures are changed in the sensitivity analysis *(Chapter 7)*.

Sulphur in fuel

In the same way as above, NTM provides default values concerning the content of sulphur in fuel (2 ppm), which are used in base case of this study. Important to remember is that these figures can vary a lot, especially when dealing with ship transport calculations.[26] The figures vary based on fuel quality, which means that changes in the classification of diesel result in changes in sulphur emission. In *Chapter 7*, these changes are carried out.

2.8 Environmental impact categories

The results are presented in terms of energy demand, global warming potential (GWP), acidification potential (AP), eutrophication potential (EP) and photochemical oxidant creation potential (POCP). Characterisation indicators are taken from Rydh, et al (2002)[27] and are presented in *Appendix B.* The environmental impact categories are presented in *Table 2* below.

Table 2 Included environmental impact categories and their equivalence factors

Environmental impact category	Shortening	Equivalence factor and unit
Global warming potential	GWP	[g CO_2-equivalents/g]
Eutrophication potential	EP	[g PO_4^{3-}-equivalents/g]
Acidification potential	AP	[g SO_2-equivalents/g]
Photochemical oxidation creation potential	POCP	[C_2H_2-equivalents/g]

[25] Map 24, 2006
[26] NTM, 2006
[27] Rydh, et al, 2002

2.8.1 Global warming potential, GWP

During the last 150 years, the global climate has changed. The word climate can be defined as the long-term average pattern of weather, which is the combination of temperature, humidity, precipitation, wind, cloudiness and other atmospheric conditions at a specific time and place. The global climate changes might be caused by greenhouse gases, e.g. carbon dioxide (CO_2), hydrocarbons (HC), methane (CH_4) and water vapour.[28] There are both natural and anthropogenic greenhouse gases, all affecting the climate in different ways. Carbon dioxide has attracted the main attention, since the concentration of this compound has increased drastically after the industrial revolution.[29]

Global warming, also known as the greenhouse effect, is a global mechanism, critical for maintaining the surface temperature of the earth. Most researchers agree that increasing concentrations of greenhouse gases in the atmosphere, of which many are caused by human activity, can affect this mechanism in a way that increases the global temperature, leading to climate changes in terms of more extreme weather conditions, higher sea levels, etc. The greenhouse gases let the short-wave solar radiation hit the earth, which becomes warm emitting long-wave heat radiation, which then in turn is absorbed by the greenhouse gases, increasing the temperature further.[30]

Combustion of fossil fuels is the dominating contributor to global warming, in Sweden as well as in the rest of the world. Contrary to the fact that the total emissions from road transports are decreasing, the emissions of greenhouse gases from the same sector are constantly increasing. This is due to the fact that the transport volumes are increasing at a constant rate, directly followed by emissions of greenhouse gases. Improvements in technology and fuel have lowered the total amount of emissions, but emission of greenhouse gases is still increasing. [31]

In this study, the global warming potential is calculated in a perspective of 100 years (GWP-100), which is an often used and recognized impact category.

2.8.2 Acidification potential, AP

Plants, animals and humans are all affected by the acidification process, which is caused by emissions from e.g. transports, energy plants, industries and agriculture. Sulphur dioxide (SO_2), nitrous oxides (NO_x) and ammonia (NH_3) are compounds contributing a lot to the acidification process, and for a long time emissions of those compounds have been one of the major environmental issues. Water vapour in the atmosphere is combined with hydrogen sulphide (H_2S) and nitrous oxide vapours released by burning fossil fuels, resulting in sulphuric and nitric acid rain with extremely low pH.[32] In Sweden, acidification is one of the great regional environmental problems, affecting both land and water.[33]

Nitrogen oxide and nitrogen dioxide are generally referred to as nitrous oxides. Nitrogen is one of the most essential nutrients for life, and natural leaching of different compounds of nitrogen to air and water has always occurred. However, various oxides of nitrogen act as

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[28] Smith & Smith, 1998, p.31
[29] Svensk Energi, 2005
[30] European Community, 2006
[31] Miljömålsportalen A, 2006
[32] Smith & Smith, 1998, p.523
[33] Miljömålsportalen B, 2006

catalysts for the formation of tropospheric ozone, contribute to acid precipitation, and damage human health. The major sources of nitrogen pollution are agriculture, industry and traffic.

In cases when the deposition of nitrogen has been very large, the soil in the forests has become nitrogen saturated. Under these circumstances, the forest vegetation cannot take up all the nitrogen, resulting in acidification of ground and water. Acid precipitation has its greatest impact on soils that are low in cations and poorly buffered.[34] Acidification releases metals and makes them available for uptake by plants, affecting the growth of the forests negatively and damaging sensitive animal and plant species[35].

Sulphur initially enters the atmosphere as hydrogen sulphide, which quickly combines with oxygen to form sulphur dioxide. This falls out with precipitation – acid rain – as weak sulphuric acid (H_2SO_4) or directly as dry deposition. Major sources from human activity are the burning of fossil fuels and acidic drainage from coal mines; amongst the emissions of sulphur, approximately 70 % has its origin from oil and coal combustion. Approximately 4 % of the sulphur dioxide emissions in Sweden are caused by the production of electricity.[36] Sulphur dioxide is an air pollution transported long distances with the winds; 90% of the sulphur dioxide deposition in Sweden comes from Central Europe and Great Britain. Sulphur also adds to the atmosphere through volcanic eruptions' releases of gases from decomposition.[37]

2.8.3 Eutrophication potential, EP

Eutrophication of waters is a nutrient enrichment caused by too high levels mainly of nitrogen and phosphor. These compounds are added to the environment via e.g. fall-out of nitrous oxides from traffic and power plants, and leakages of ammonia from agriculture and phosphorous from wastewater treatment plants, agriculture and industries. In marine environments, eutrophication is one of the most serious threats, contributing to the eutrophication. The process of eutrophication causes e.g. algal bloom, resulting in turbid water, decreasing quantities of seaweed, and, in the worst case, a lack of oxygen at the bottom of the sea. When there is no oxygen, no fish or other species can survive. If the algae causing the bloom are poisonous, both the animal and the human health are threatened.[38]

The largest part of nitrogen emissions comes from agriculture via its use of manure, and the atmospheric contribution mainly is caused by the energy sector. Precipitation today consists not only of nitrate but also of ammonium (NH_4^+); the first primarily caused by emissions of nitrous oxides from traffic and the second by ammonia from manure[39]. About 75-80 % of the nitrogen load in Sweden originates from other countries[40].

2.8.4 Photochemical oxidant creation potential, POCP

Ozone (O_3) is an ambivalent atmospheric gas; it works both shielding and damaging, depending on where it occurs. Between 10 and 40 km above the earth – in the stratosphere – ozone protects the planet from biologically harmful ultraviolet radiation, while close to the

[34] Naturvårdsverket A, 2006
[35] Statens Energimyndighet, 2004
[36] Svensk Energi, 2005
[37] Smith & Smith, 1998, p.353
[38] Miljömålsportalen C, 2006
[39] Naturvårdsverket A, 2006
[40] Miljömålsportalen C, 2006

ground – in the troposphere – the compound cuts visibility, irritates the eyes and the respiratory system, and injures or kills plants when occurring in too high concentrations. Tropospheric ozone is formed by the reaction of photochemical oxidants, such as nitrogen oxides and volatile hydrocarbons (HC), with oxygen gas (O_2), in the presence of sunlight.[41] Both nitrogen oxides and hydrocarbons are represented naturally in the lower part of the atmosphere, and so is the ozone. However, as these photochemical oxidants have increased, because of heavy emissions from the traffic and energy sectors, the tropospheric ozone levels now are too high. The photochemical oxidants travel with the winds all over the world, thereby constituting a global problem.[42]

2.8.5 Energy demand

All production of electricity as well as conversion and usage of energy affect the environment in different ways, directly or indirectly. There are fuel combustions followed by emissions to air, there is land use and changed living conditions for organisms because of building power plants, etc. Both the EU's and the world's energy provisions are dominated by fossil fuels, among which oil is the most important. In Sweden, emissions to air caused by electricity production are relatively low, because the production of electricity to 90% originates from nuclear power and hydropower, which have no combustion-related emissions.[43] In other countries, there are different electricity production situations. See *Appendix A* for differences between Swedish and European production of electricity.

A country's use of energy is based on economical and technological growth, electricity production prices and energy politics control mechanisms. In a short time perspective, there is a direct correlation between industry production volumes and energy use. On a longer view, industry energy use is affected by other variables, such as investments and changes in products. The transport sector's use of energy consists primarily of oil products. [44]

[41] Smith & Smith, 1998, p.347
[42] Miljömålsportalen D, 2006
[43] Svensk Energi, 2005
[44] Statens Energimyndighet, 2004

3 Lacquers – a general overview

The aim of this chapter is to provide a general and relevant description of the production of lacquer, to show the complexity of the same, and to clarify why the mixing process assumption has been made. The environmental impact caused by the process of mixing water-reduced lacquer with water is estimated to be the same as the one for the production of water-borne lacquer.

Lacquer is a transparent (without pigments) or coloured (with pigments) solution, natural or synthetic, usually supplied as an ornamental or protective coating, resistant to chemical and mechanical strain. Lacquers and paints consist to 95-100 % of a mixture of one or more binding agents, solvents and pigments. The rest is additives, often less than 1 %, added to affect one or more of the lacquer or paint's qualities positively[45], of which many are miscellaneous organic molecules. Depending on the field of application and the desired quality – e.g. hardness, durability, gloss or water resistance – the lacquer formula varies, and so does the procedure of mixing. Lacquer dries by solvent evaporation only, which causes the hard, durable finish.

3.1 Water-borne lacquers

An expression commonly used for lacquers with water as solvent is water-based lacquer. This is in fact misleading, since the base in all lacquers and paints is the binding agent.[46] Because of that – and to avoid misunderstandings – the more correct phrase water-borne lacquer is used throughout this study.

Water-borne lacquers are becoming increasingly frequent in e.g. the lacquering of furniture and floors, thereby replacing lacquers based on solvents in, and much effort has been put into the work of development from solvent-borne to water-borne lacquers. The main explanation is the environmental demand for lower emissions of organic solvents, but also the fact that water-borne lacquers are less toxic and less environmentally harmful, and have a better resistance to fire.[47] A water-borne lacquer contains little or no organic solvent. The binding agent is an organic compound, usually a polymer, with the task to combine the participating components. Different additives, e.g. drying agents, preservatives and antifoaming agents are added, to give the lacquer the required characteristics.[48]

3.1.1 Binding agents

The main component in paint and lacquer is the binding agent, which after the drying process forms the firm lacquer film causing the contact between foundation and surrounding[49]. The binding agent has to be a solid substance, which entails that its molecules have to be relatively large. The larger the molecules, the better the mechanical strength and chemical resistance. In addition, combinations of different binding agents are often used to achieve the desired qualities. In water-borne lacquers, the binding agent can be e.g. acrylic latex, which is common when lacquering wooden furniture.[50]

[45] NIFAB, 2002
[46] Ibid
[47] Nordsjö Färg A, 2006
[48] Alcro Färg, 2004
[49] NE.se, 2006
[50] NIFAB, 2002

3.1.2 Solvents

A solvent is per definition a liquid with the ability to solve the binding agent in a lacquer or paint, and which evaporates during the drying process[51]. Some solvents, however, so called reactive diluting agents, react chemically with the binding agent during the drying process, e.g. in ultraviolet-varnished lacquers.[52] A solvent is either organic, e.g. alcohols, esters and chlorinated hydrocarbons, or inorganic, which in the paint industry is water only. The solvent penetrates the binding agent's polymer molecules, making them less fixed and more movable. This is a slowly working process, due to the fact that the polymer molecules are large, but high temperature and stirring speeds up the process. A solvent's solving ability differs depending on which polymers the lacquer consists of, and therefore it is difficult to generalize as to the best solvent.

Solvents are often divided into groups depending on chemical composition, solubility parameters or volatility. The volatility of the solvent is a very important characteristic, especially when incorporated lacquers drying in a physical way, e.g. evaporation. Solvents evaporating quickly give short drying time and therefore reduce the risk of draining. On the other hand the wanted quality of the painted area might not be achieved.[53] In water-borne lacquer, the primary solvent is naturally water, working through the physical procedure of evaporation. But, other solvents are often added aswell.

The water quality varies geographically, depending on surroundings, affecting hardness of the water and ion content, which can cause precipitation of pigments. To avoid such occurrences, the water sometimes has to be distilled before use in the process.[54] Water as a solvent evaporates slowly, and the rate also depends on the relative humidity of the air[55].

3.1.3 Additives

To affect one or more of the qualities of the lacquer in a positive direction, additives are used. Additives are not a homogenous group, but they can be sorted after at what time in the process they are active: during the production, the storing, the application process or the drying process, or if they are active in the film. Many additives have surface-active features and are used as e.g. foam moderators and dispersants. Latex colours and many other water-borne products always consist of tensides, which are compounds with one hydrophilic and one hydrophobic part, forming particles of colloidal size (micelles) at a certain temperature *(Figure 2)*. One additive often used is a cold stabilisation agent, used in water-borne systems to increase the stability against freezing and heating. Biocides are other additives, common in water-borne products, which help the product resist attacks from bacteria and mould. Slip agents are used to reduce the surface's friction, thereby increasing the water rejection and the hardness of the surface. [56]

[51] TNC, 2006
[52] NIFAB, 2002
[53] Ibid
[54] Nydensten, 2006
[55] NIFAB, 2002
[56] Ibid

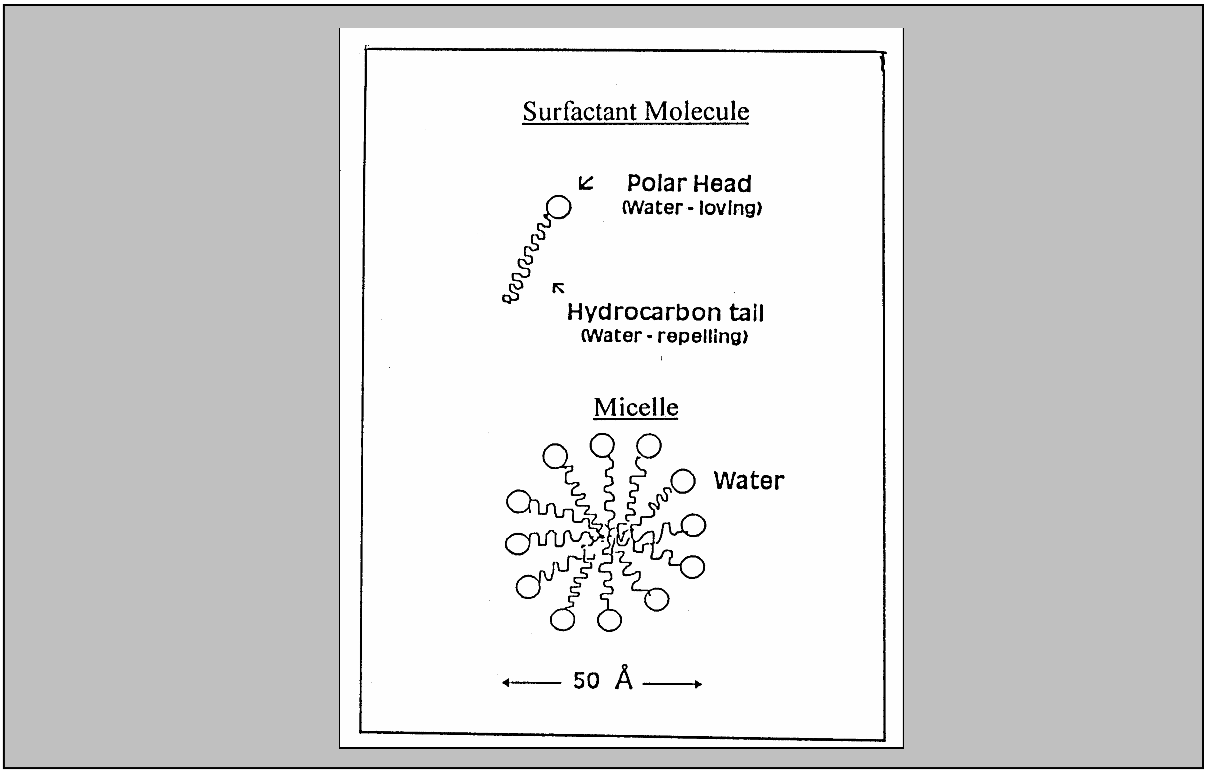

Figure 2. Illustration of a micelle, consisting of one hydrophobic part (non-polar hydrocarbon tail) and one hydrophilic part (polar head)[57]

3.1.4 Pigments

Pigments are small, insoluble particles, consisting of materials that selectively absorb certain wavelengths of light. Pigments can only absorb wavelengths coming directly from a light source; they can never create their own, like e.g. fluorescent substances.

3.2 Lacquer production

Production of paints and lacquers is mostly a question of material flow – raw materials and semi-manufactured products are transported between sites where a mixing process can take place. The first step when these products arrive at the factory is the weighing in process. Liquid raw materials however are normally pumped vial dial indicators. This is both easier and cheaper and gives less environmental problems than ordinary weighing in.[58]

The production of transparent lacquers is a relatively simple process, where a binding agent blends with a solvent and possible additives, then strains and drains. The only process that is complicated and relatively energy demanding is the one where pigments are to be added. This procedure is divided into three steps, overlapping each other. The first one presses out air and moisture from the pigment surface by adding a binding dispersion agent, the second one separates pigment particles and the third one stabilizes the product. This can be done in different ways, the simplest one being manufacturing in a dissolver. Another common technique is to put half of the ingredients together in one container and then mixing the final product afterwards in an additional one. This procedure of mixing afterwards is risky, due to the fact that the technique is sensitive: the binding agent might destroy the pigment solution, the solvent could withdraw adsorbed binding agents, the diluting process might proceed

[57] Goyal & Aswal, 2001
[58] NIFAB, 2002

excessively quickly resulting in flocculation, and so on. Before the paint or lacquer is drained it has to be sifted or filtrated, in order to remove dirt and unwanted particles. The filling process can be manual or automatic, depending on which volumes are to be drained.

3.2.1 Production of water-borne lacquer

The production of water-borne lacquer starts with a mixing process together with water, thickening agents and possible pigments. After that, binding agents and additives like foam moderators, additional thickening agents, tensides and biocides are added. At the end, the lacquers are poured into plastic or metallic cans, ready to be transported to a consignee.[59]

3.2.2 Drying process

When the lacquer dries, one of its characteristics is to leave a firm layer, which requires the binding agent to consist of large molecules. These molecules can either exist before the drying process (physical drying process), or develop through a chemical reaction during the process (chemical drying process). Regarding water-borne lacquers, the physical drying process occurs in a procedure when the solvent (in this case water) evaporates and the binding agent particles aggregate to one film, without being able to re-aggregate again. The process of film building is complicated, consisting of detailed steps of water evaporation along with packing without particle deformation, followed by shrinking of the film and deformation of the spherical particles, which in turn are followed by the diffusion by molecule parts into neighbouring particles *(Figure 3)*. [60]

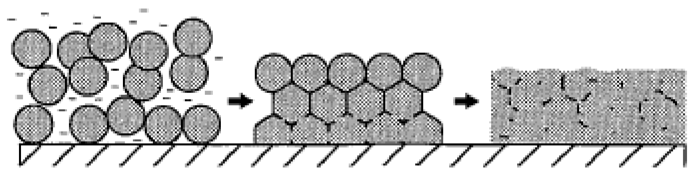

Figure 3. Film-forming in dispersion, e.g. water[61]

3.2.3 Required machines

The machines needed for the production of water-borne lacquers are various types of blenders, which work by different principles and because of that have features that fit different products. Most common, both for mixing in the beginning and at the end of the process, are dissolvers and turbine-, propeller- or anchor mixers. To achieve the best result, the design of the reactor tanks has to be adjusted to the mixer. Separate, closed mixers at the end of the process are expensive but good from an environmental point of view and also helps avoid fire accidents. If there are sufficient tanks, flexibility increases and residence time decreases.[62]

3.2.4 Water content

To be able to calculate the environmental impact caused by the transport of lacquers, it is crucial to know the water content of the lacquer. However, the water content varies, depending on how and where the lacquer is used. Principally, the water from the binding agent controls the total dry content[63]. The binding agent consists of 40-60 weight-percent of

[59] Ljungdahl, 2006
[60] NIFAB, 2002
[61] Ibid
[62] NIFAB, 2002
[63] Ljungdahl, 2006

water. Together with additives and crucial rinses in production, this results in complete products with a dry content of at least 35 volume-percent.[64] Of the remaining 60-65 %, about 99 % is binding agent[65], which implies that 30-40 % of the product is water. Of this water, roughly half can be taken away without harming the product, to be added later on in the process.[66] Therefore, for the basic cases, the weight reduction of lacquer, owing to the elimination of water, is assumed to be 20 %[67]. In a sensitivity analysis *(Chapter 7)*, different weight reduction figures have been calculated for.

3.3 Handling of waste

Because of limitations that have to be made, the handling of waste is not considered in the calculations part of this project. Nevertheless, as for all other manufacturing industries, waste in both solid and liquid forms arises from the mixing processes, constituting environmental risks if not handled properly. The handling of rest products is a large and important issue, and an area where improvements often can be made.

The production of paints and lacquers causes waste products, divided into hazardous waste or industrial waste, according to the Swedish waste statute[68]. These products have to be taken care of according to the regulations of each individual country.

3.3.1 Waste products caused by the production of lacquers

As written above, different types and quantities of waste arise, as a result of the production of paints and lacquers, requiring different waste handling processes. In Sweden, the differences between industrial and hazardous waste are as follows:

Industrial waste is waste that can be recycled, deposited on waste disposal sites or combusted in an ordinary waste treatment for household waste. Examples of industrial waste are empty packing, pallets, scrap metal, dry paints and lacquers, liquid rests of water-borne paints and lacquers, soft plastics, paper and corrugated cardboard.

Hazardous waste, e.g. rests of liquid paint, solvents, alkali waste, acids and waste oil[69] have to be sent away for destruction[70]. The person or industry handling hazardous waste and sending it away is responsible for the waste being taking care of by a licensed waste shipper, and for the waste treatment plant being a licensed caretaker of the waste. In addition, there are demands concerning journal writing regarding the quantities sent for destruction.

After usage of paint and lacquer, there are large quantities of tin cans and plastic containers left. If they are not treated as hazardous waste, both tin cans and plastic containers must be recycled. In Sweden, this means either leaving them at a recycling site or hiring an independent shipper to get them. Containers left for recycling are allowed to have minor amounts of paint or lacquers left.[71] Waste handling in procedures like this can cause problems in some countries, because of the sometimes incomplete waste handling infrastructures.

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[64] Ibid & Nydensten, 2006
[65] Ibid
[66] Ibid
[67] Nydensten, 2006
[68] SFS, 2001
[69] Nordsjö Färg B, 2003
[70] Repa, 2006
[71] Repa, 2006

The production of water-borne lacquers, or mixing of the same, generates polluted water from the manufacturing vessels, which has to be cleaned before discharge. [72] How the water treatment plant works depends on country and regulations, but common for all is that they cause quantities of silt, which consequently has to be taken care of.

3.4 Working environment

Connected to the production of paints and lacquers, there are health risks affecting the working environment. Except accidents, there are physical workloads, chemical health risks, and noise and vibration levels having that have an impact on the total working environment.[73] Certain measures must be taken in order to protect the workers and increase the safety of the place of work. Firstly, knowledge is important. Education at work regarding the handling of paints, lacquers, solvents, chemicals etc, the usage of safety equipment and outfits, and the managing of machines might prevent accidents. Solvents in production emit solvent steams, requiring ventilated spaces.

Different kinds of paints and lacquers affect the working environment differently. Material safety data sheets provide information regarding the chemicals involved, how to react when unintentional wastages or emissions occur, how to store the products, where the product must not be used or kept, compounds that should be used for putting out fires (water, carbon dioxide, carbonic acid, powder, foam etc), how to mark containers, how to take care of waste and what the expected effects and reactions on humans are.

[72] Alcro Färg, 2004
[73] Axelsson, et al, 1999

4 Transports – a general overview

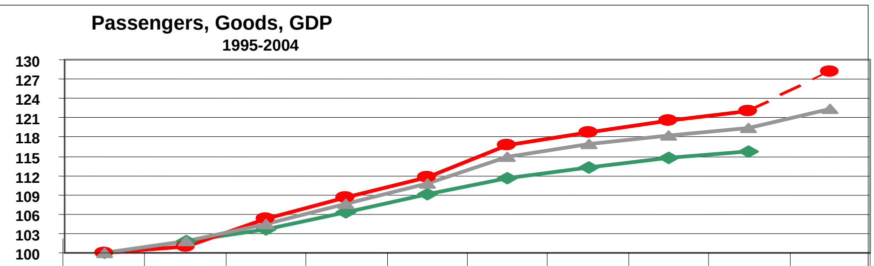
The objective of this chapter is to describe the existing transport situation in Europe. In addition, emissions from transports are cut down into constituent compounds, which are discussed from an environmental impact perspective.

4.1 Transports in Europe

The volumes of transports in Europe are increasing, almost at the same rate as the gross domestic product (GDP) *(Figure 4)*[74]. This is partly because of the fact that transports of goods are closely related to production volumes and therefore grow at the same rate.[75] The transports of goods between 1995 and 2004 have increased with approximately 2,8% per year.[76]

In OECD countries, the use of petroleum-based fuels in transports is 97 %.[77] In the countries of EU-25, emissions of CO_2 vary with the industrial structure and with the consumption of fossil fuels. The energy sector, responsible for more than ⅓ of the CO_2 emissions, is the largest source, but the growing transport sector follows closely, with a contribution of ¼ of the CO_2 emissions.[78]

In spite of these facts, the total pollution caused by road transport is decreasing. This is thanks to improvements in technology and fuel quality, which have been forced in order to be able to meet the European emission limits. However, these improvements have not been able to lower the emissions of greenhouse gases from road transports; they are still following the increasing transport volume rate. Since 1990, the total increase of greenhouse gases from transports has been 20%[79].



	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
Passengers (1) (pkm)	100	102	104	106	109	112	113	115	116	
Goods (2) (tkm)	100	101	105	109	112	117	119	121	122	128
GDP (at constant 1995 prices)	100	102	105	108	111	115	117	118	119	122

Figure 4. Increasing rates of passengers, goods and GDP in Europe[80]

4.2 Emissions caused by diesel vehicles

The composition of diesel exhaust is highly complex and varies depending on type of vehicle, engine and fuel, driving pattern, lubricating oil, fuel consumption and whether an emissions

[74] EEA, 2004, p. 8
[75] OECD, 2003, p.36
[76] European Commission, 2005, p. 106
[77] Åhman, et.al., 2005
[78] Vattenfall, 2006, p.48
[79] Naturvårdsverket B, p.4
[80] EEA, 2004, p. 8

control system is present or not. The diesel engine emissions consist of a wide range of organic and inorganic compounds, but they have been reduced significantly over the last 30 years, due to improvements in technology and fuel. Mainly, they consist of small particles (PM) (90 % are less than 1µm) and oxides of nitrogen, but smaller volumes of carbon monoxide (CO) and hydrocarbons also appear.[81]

Nowadays, all engines have to be approved according to European Union regulations. These state that emissions must not exceed certain levels; these emission standards for heavy trucks are communicated as different Euro-figures. *(Table A.5)*. The emissions of carbon monoxide, hydrocarbons, nitrous oxides and particles determine the environmental classification of the vehicle. Within the European Union, there are great differences between the national regulations.

A report from the European Commission[82] states that the purest diesel fuels of the then existing 15 EU states in the year of 2003 were sold in Germany and Sweden. The Swedish diesel is provided in three different environmental classes (Mk 1, Mk 2 and Mk 3). Today, Swedish diesel of Mk 3, with the lowest quality demands, equals the aims for the European Union diesel standard of 2009 (<500 ppm sulphur).[83] Diesel of Mk 2 (also named city diesel) consists of less than 50 ppm sulphur and Mk 1 of consists of less than 10 ppm sulphur, but also has a lesser share of aromatic hydrocarbons, resulting in lower sulphur dioxide, particle and hydrocarbon emission. In Sweden, diesel of Mk 1 is being used almost always and everywhere.[84] In *Table A.6*, data concerning the different environmental classes is presented.

4.3.1 Emissions of carbon dioxide (CO_2)

Today carbon dioxide is considered as a big threat to the environment. Each year emission levels increase with 1,8 %. The combustion of fossil fuels, such as coal and oil, creates emissions of carbon dioxide, with a risk of affecting earth temperature via the global warming potential. Carbon dioxide is the most important anthropogenic greenhouse gas, and the countries within the OECD emit almost half of the world's total carbon dioxide emissions.[85]

The quantity of carbon dioxide emitted is directly proportional to the quantity of fuel consumed; there can be differences in carbon dioxide emissions between different fuel types, but the type of engine is irrelevant in this case. The diesel engine has a high energy efficiency, about 45 %, and a 30 % lower fuel consumption than corresponding petrol engine, which results in lower usage of fuel and thereby lower emissions of carbon dioxide.[86] One litre of Mk 1 diesel contributes with 2540 gram carbon dioxide to the air, while the value for the older type of diesel, Mk 3, is 2660 gram.[87]

4.3.2 Emissions of sulphur oxides (SO_x)

The amount of sulphur oxides in emitted exhaust gases are directly proportional the amount of sulphur in the fuel[88]. Emissions of sulphur from shipping have earlier been underestimated,

[81] DieselNet A & SPI, 2006
[82] Europeiska gemenskapernas kommission, 2005
[83] ibid
[84] Sveriges Åkeriföretag, 2006
[85] Statens Energimyndighet, 2004
[86] Volvo, 2006
[87] Sveriges Åkeriföretag & NTM, 2006
[88] Sterner, 2003, p.241

but are now larger than the sum of all emissions on land. This is because of the fact that international sea transports, un-hindered, can use heavy, sulphur rich oils for fuel.[89]

Because of new technologies and changed fuel consumption patterns, sulphur dioxide emissions have declined; the use of Mk 1 diesel has reduced these emissions to an almost insignificant level; <0.01 g/l.[90]

4.3.3 Emissions of nitrous oxides (NO_x)

Diesel exhausts consist of relatively high concentrations of nitrogen oxides, and the emissions are highly affected by the combustion temperature.[91] Nitrogen emissions from diesel vehicles are 3-4 times more than from petrol vehicles, but they can be lowered by modification of fuel combustion[92]. Emissions of nitrogen oxides contribute both to the acidification potential and eutrophication potential.

4.3.4 Emissions of hydrocarbons (HC)

Since diesel is a fuel which has its origin in the hydrocarbon-rich raw oil, hydrocarbons make a participating share of the exhaust gases. However, they do not contribute with as high levels as those of nitrogen oxides. Many hydrocarbon compounds are judged to be carcinogenic.

Emissions of hydrocarbons depend on both engine and fuel,[93] and can be lowered by engines with a more effective combustion and the use of a catalyst for after-oxidation.[94]

4.3.5 Emissions of particles (PM)

Diesel exhausts consist of a complex mixture of small particles, with a core of coal, which have hundreds of chemicals adsorbed onto its surface, e.g. hydrocarbons and sulphuric acid. These particles affect human health in a serious way; the small particle size makes the particles readily permeable, allowing them to enter the lungs via breathing, and from there they reach the circulation of the blood, causing cardiovascular and bronchial diseases.[95] Many of the particles are furthermore known as or suspected mutagens and carcinogens.

The emissions of particles depend on both engine and fuel[96], and they can be lowered by more effective combustion, and less share and sulphur in the fuel[97]. Nevertheless, particle emissions are by diesel exhausts caused to only 20 %; the main contributor is the wear of brakes and tyres against the roads[98].

[89] Svensk Energi, 2005
[90] Sveriges Åkeriföretag & NTM, 2006
[91] Smith & Smith, 1998, p.349
[92] Volvo, 2006
[93] DieselNet B, 2006
[94] Volvo, 2006
[95] Vägverket, 2006
[96] ibid
[97] ibid
[98] Gustafsson, et al, 2005

5 Inventory results

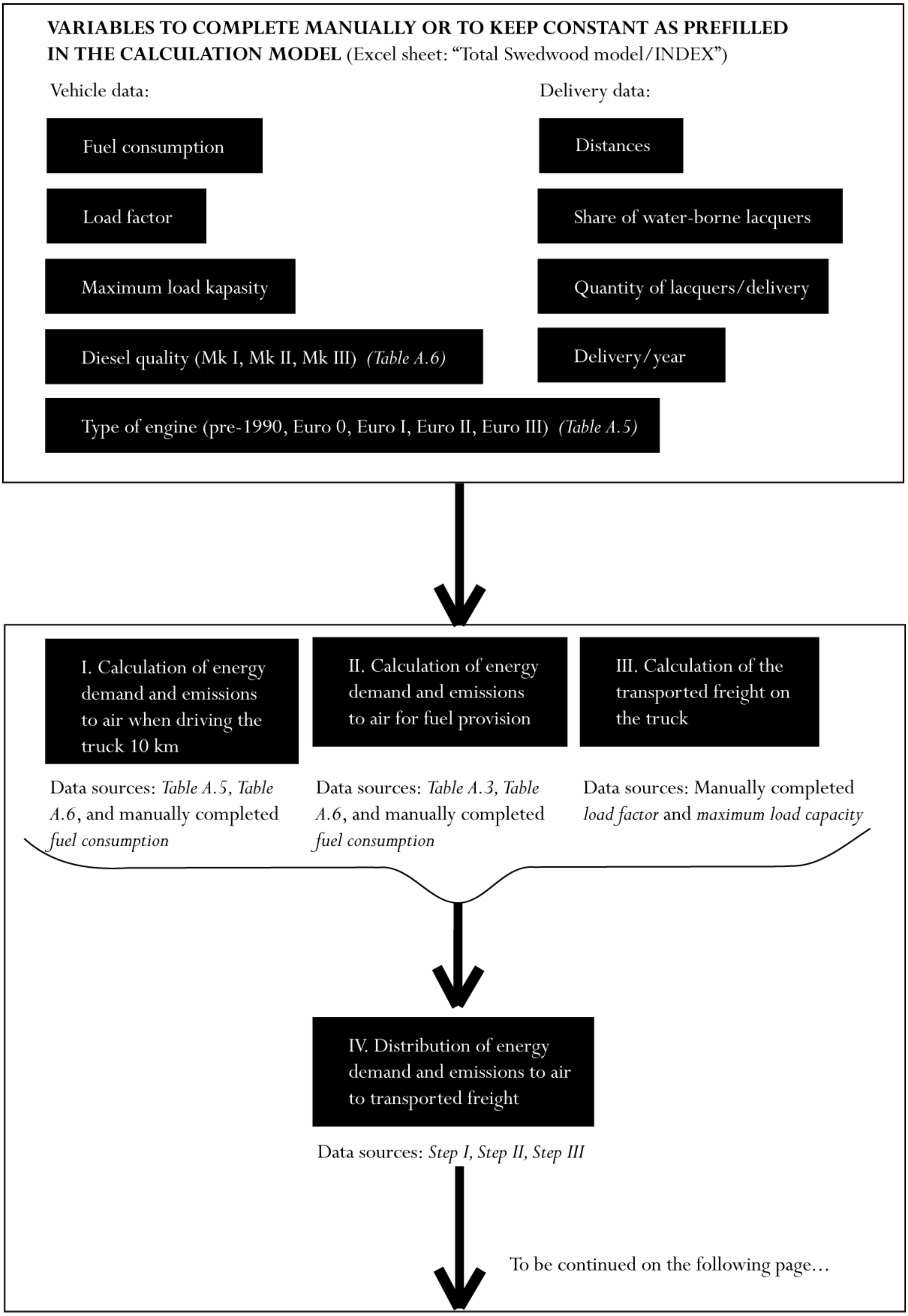
The first part of the study involves mapping of the present situation: transports of water-borne lacquers to the different Swedwood plants. Key actors from each plant have been contacted and in *Chapter 5.1,* inventory results based on the information provided by those actors are presented.

A calculation model has been developed, using the program and tool Microsoft Excel *(Total Swedwood model.xls),* in order to manage the large quantity of data and to easily calculate and to obtain relevant results for this study. The model, presented below *(Figure 5)*, is based on both generic and specific data, collected via literature and through personal communication, and renders the inventory results presented in this chapter.

The inventory results in these chapters are presented as emissions to air and energy demand per functional unit (1 kg water borne lacquer ready to use), and later, in *Chapter 9*, as emissions to air and energy demand per year. The tables referred to are found in *Appendix A*, and *Appendix B*. For further explanation of the calculation model, see *Appendix C.*

Today, water-borne lacquers and paints used in Swedwood manufacture are produced at different suppliers', located in different countries. In some cases, one supplier provides several Swedwood factories, and in other cases, the Swedwood factory gets its deliveries from more than one supplier; see *Table 4* for details. When an order from Swedwood arrives at the lacquer and paint supplier, the supplier hires a shipper, which packs the ordered products. Mostly, they use so called EU pallets, which have defined dimensions recognized and used all over Europe. The shipper gets orders from different suppliers to different receivers, and is in charge over the packaging and delivery route. [99]

[99] Andreasson, 2006


VARIABLES TO COMPLETE MANUALLY OR TO KEEP CONSTANT AS PREFILLED IN THE CALCULATION MODEL (Excel sheet: "Total Swedwood model/INDEX")
Vehicle data:
Fuel consumption
Load factor
Maximum load kapasity
Diesel quality (Mk I, Mk II, Mk III) (Table A.6)
Type of engine (pre-1990, Euro 0, Euro I, Euro II, Euro III) (Table A.5)
Delivery data:
Distances
Share of water-borne lacquers
Quantity of lacquers/delivery
Delivery/year
I. Calculation of energy demand and emissions to air when driving the truck 10 km
Data sources: Table A.5, Table A.6, and manually completed fuel consumption
II. Calculation of energy demand and emissions to air for fuel provision
Data sources: Table A.3, Table A.6, and manually completed fuel consumption
III. Calculation of the transported freight on the truck
Data sources: Manually completed load factor and maximum load capacity
IV. Distribution of energy demand and emissions to air to transported freight
Data sources: Step I, Step II, Step III
To be continued on the following page…

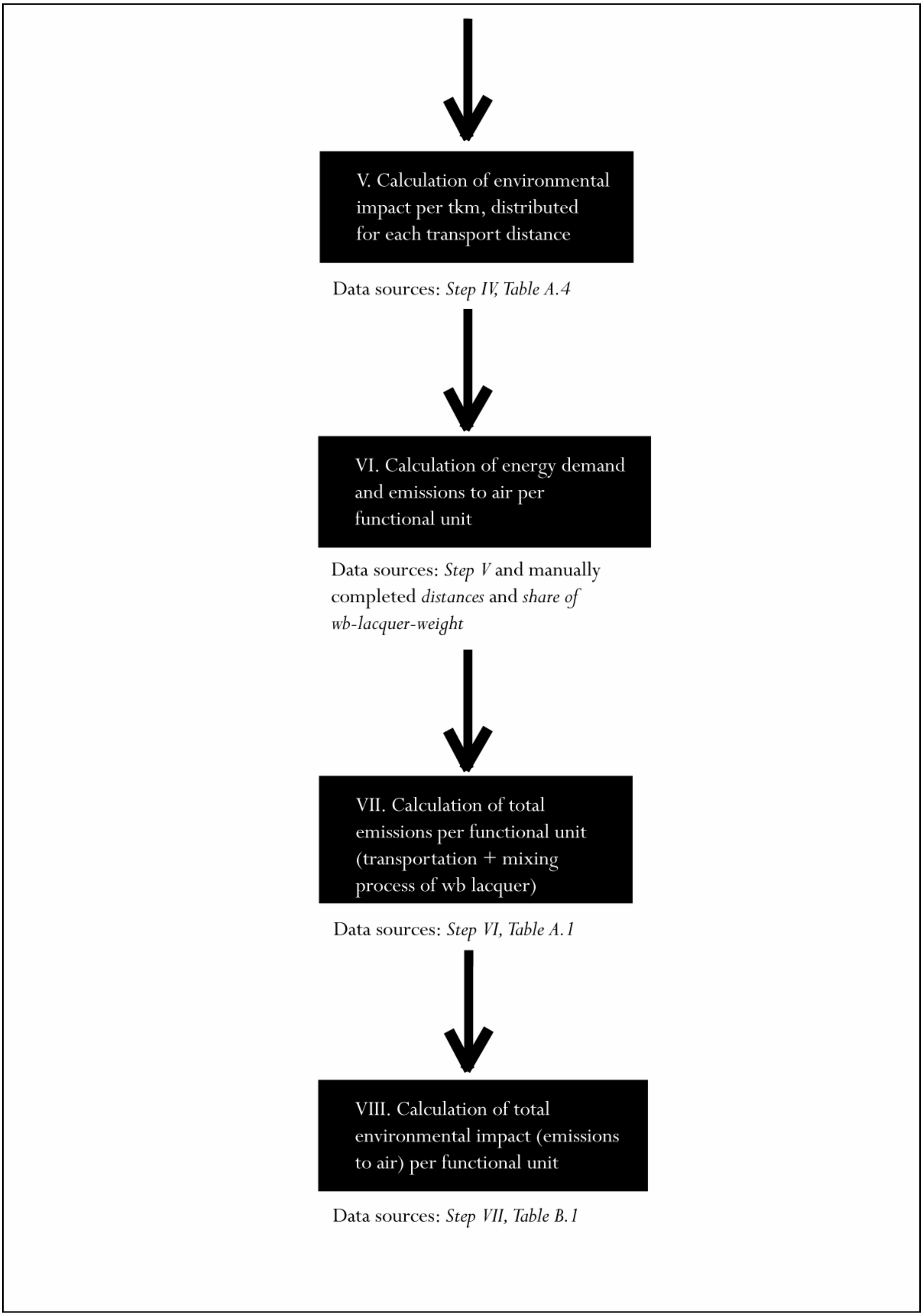


Figure 5. Calculation process for the Excel model ”Total Swedwood model.xls”, with references to tables, variables and calculation steps. The tables referred to are found in *Appendix A* and *Appendix B*

5.1 Swedwood plants

Data regarding transport of water-borne lacquers to Swedwood plants have been collected from each factory; key actors have answered questions concerning suppliers, amounts of lacquers, transportation means and delivery frequency. These data are put together in *Table 3* below. Distances are calculated using the Internet tool Map24[100].

Table 3 Details regarding all transports of water-borne lacquers to the Swedwood factories included

SWEDWOOD PLANT	Lacquer supplier(s)	Means of transport	Distance, one way [km]	Average quantity of lacquers [ton/delivery]	Delivery frequencies [delivery/year]	Average quantity of lacquers [ton/year]
Lubawa, Poland[101]	3H - Lacke, Hiddenhausen, Germany	Truck	895	12,5	72	900
	Akzo Nobel AB, Malmö, Sweden	Truck	778			
		Ship (Sweden-Poland)	49			
	Becker Acroma, Plewiska, Poland	Truck	297			
Älmhult, Sweden[102]	Akzo Nobel AB, Malmö, Sweden	Truck	138	0,75	104	78
Bräntorp, Sweden[103]	Becker Acroma, Bellö, Sweden	Truck	200	9	45	405
	Becker Acroma, Märsta, Sweden		450			
Goleniow, Poland[104]						
Konstantynow, Poland[105]	Becker Acroma Polska, Plewiska, Poland	Truck	459	6	52	312
Jasna, Slovakia[106]	Becker Acroma CZ, Velké Mezirici, Czechia	Truck	360	4	26	104
Malacky-2, Slovakia[107]	Silvi Nova Slovakia, Zloven, Slovakia	Truck	233	5,2	48	249,6
	Akzo Nobel AB, Malmö, Sweden	Ship (Sweden-Poland)	49			
		Truck	1064			
Spartan, Slovakia[108]	Hesse, Germany	Truck	1082	7	41	287
Tibro, Swedwood[109]	Akzo Nobel AB, Malmö, Sweden	Truck	361	8,5	52	442
Siret, Romania[110]	Becker Acroma, Bellö, Sweden	Ship (Sweden-Poland)	49	4	24	96

[100] Map 24, 2006
[101] Barczak, 2006
[102] Käll, 2006
[103] Nilsson, 2006
[104] No data has been provided from the Swedwood plant Goleniow (Poland)
[105] Lezniak, 2006
[106] Bazela, 2006
[107] Haramiova, 2006
[108] Banovcan, 2006
[109] Johansson, 2006
[110] Lujanski, 2006

		Truck	1999			
Sopron, Hungary[111]	Becker Acroma, Bellö, Sweden	Ship (Sweden-Poland)	49	7	26	182
		Truck	1423			
	Kneho, Horn-Bad Mainberg, Germany	Truck	973	6	26	156
Zbanszyn, Zbanszynek, Babimost, Poland[112]						

5.2 Transport

Based on the figures presented in *Appendix A,* inventory results for transport of 1 kg water-borne lacquers 1 km are given in *Table 4* and *Table 5*. They are presented as energy demand and emissions to air per functional unit and kilometer.

Table 4 Inventory results for base case; transport per functional unit and kilometer by truck

Truck, 26 ton max load, 70 % load capacity, Mk I, Euro III	Unit	Long distance traffic	Regional traffic	Urban traffic
Emissions to air				
CO_2	[mg/(FU*km)]	51,2	96,8	125
NO_x	[µg/(FU*km)]	330	620	800
HC	[µg/(FU*km)]	47	90	120
CH_4	[µg/(FU*km)]	1,4	26	3,3
CO	[µg/(FU*km)]	46	86	110
PM	[µg/(FU*km)]	5,7	11	14
SO_2	[µg/(FU*km)]	13	24	33
Energy demand	[J/(FU*km)]	720	1360	1750

Table 5 Inventory results for base case: transport per functional unit and kilometer by ship

Medium-sized ship	Unit	Ship
Emissions to air		
CO_2 (fossil)	[mg/(FU*km)]	13
NO_X	[µg/(FU*km)]	450
HC	[µg/(FU*km)]	11
CO	[µg/(FU*km)]	40
PM	[µg/(FU*km)]	20
SO_2	[µg/(FU*km)]	230
Energy demand (fossil)	[J/FU*km)]	180

5.3 Lacquers

Inventory data for the mixing process of lacquer comes from an LCA report concerning the production of water-borne stain, with a water content of 86 %, based on industry mean values *(Table 6)*[113]. The results from that study include components and processes from production of raw material to production of the water-borne stain, but only the figures concerning production of water-borne stain have been included in this study.

As discussed earlier in *Chapter 2*, the production of water-borne stain is assumed to be comparable with the production of water-borne lacquers, which, in order not to underestimate the results, is assumed to be equal to the mixing process of lacquer concentrates with water.

[111] Dravai, 2006
[112] No data has been provided from the Swedwood plant Zbanszynek (Poland)
[113] Axelsson, et al, 1999

The inventory results are presented below as energy demand and emission to air per functional unit.

In the above-mentioned LCA report, no details are provided as to which steps of the production process should be regarded as the main and minor contributors to the environmental impact. The report presents the results plainly as emissions and energy demand divided into the production of all participating raw materials (pigments, binding agents, etc) and the manufacture of the lacquers ready-to-use. [114] These data probably make a source of uncertainty, which thereby makes the results uncertain, when comparing environmental impacts caused by mixing process of water-borne lacquers with the ones caused by transports.

Table 6 Inventory results for production of 1kg water-borne stain (production of raw material excluded), here estimated to be equivalent the mixing of water-borne lacquers

I kg water-borne stain	Unit	
Emissions to air		
CO_2 (fossil)	[g/FU]	324
CO	[mg/FU]	44
CH_4	[mg/FU]	260
C_xH_y	[mg/FU]	100
$VOC_{solubles}$	[mg/FU]	100
NO_x	[mg/FU]	990
SO_x	[mg/FU]	180
PM	[mg/FU]	130
Energy use		1,7
Electricity	[MJ/FU]	0,13
Oil	[MJ/FU]	0,78
Natural gas	[MJ/FU]	0,78

[114] Axelsson, et al, 1999

6 Life cycle impact assessment

This chapter submits results of the analyses from the three cases investigated as described in *Chapter 2*. The results are presented and compared in tables and figures with reference to the four environmental impact categories used – GWP, EP, AP, POCP – and energy demand. These category outcomes are commented on in this chapter, and a sensitivity analysis for relevant variables is performed in *Chapter 7*. The characterisation indicators used for calculation are presented in *Appendix B.*

In this chapter, all effects are calculated per functional unit, which makes both quantities of lacquer transported and number of deliveries per year irrelevant. The only variables affecting the result are delivery distances (for both transport of already mixed water-borne lacquers and water-reduced lacquers), vehicle size, load factor, type of engine, and diesel quality. Lacquer and delivery quantities are important and interesting when mapped out and the deliveries compared to each participating Swedwood plant; this is calculated for in *Chapter 9*.

Figures in this chapter show the total impact of the mixing process of water-borne lacquers and the transportation of them. For each impact category, total effects for Case I are presented in one figure, divided into transport and mixing process. Impacts from the mixing process are constant, but by including them, one can observe their contributing share. In *Appendix D*, tables are presented showing the impacts of the Swedwood plants as a percentage. The tables *Table D.1-D.8* referred to in this chapter are all found in *Appendix D*. The first figure for each impact category is followed by a figure of comparison between the three investigated cases, also divided into transport and mixing process. This figure always illustrates the transport to the plant with the highest total environmental impact, Sopron, together with the mixing process of water-borne lacquer. For the same reason as above, the contributing mixing process share is presented. Finally, a figure showing impacts depending on means of transportation and traffic situation (long distance traffic, regional traffic and urban traffic respectively) is presented, divided into compounds affecting each environmental impact category.

6.1 Global Warming Potential (GWP)

Of all participating Swedwood plants, the dominating contributor to the global warming potential is Sopron, followed by Siret and Lubawa, due to the long delivery distances *(Figure 6)*. As shown in *Table D.1*, the transports to Sopron contribute with 30 % to the total Sopron GWP result (mixing process and transport). In contrast, the transports to Älmhult contribute with only 2 % to the Älmhult GWP result (mixing process and transport).

When taking a closer look at the three cases applied at the main contributor Sopron, the mixing process part proves to cause the highest impact in every case *(Figure 7)*. In addition, the closer to the Swedwood plant the central mixing site is situated, the less impact is caused by transportation. This is due to the weight reduction caused by elimination of water.

Figure 8 shows that driving in urban areas causes the highest impact on GWP per functional unit and kilometre. In the same figure, as well as in *Table D.2*, it is shown that emissions of CO_2 are the main contribution, with nearly 100 %, to the global warming potential.

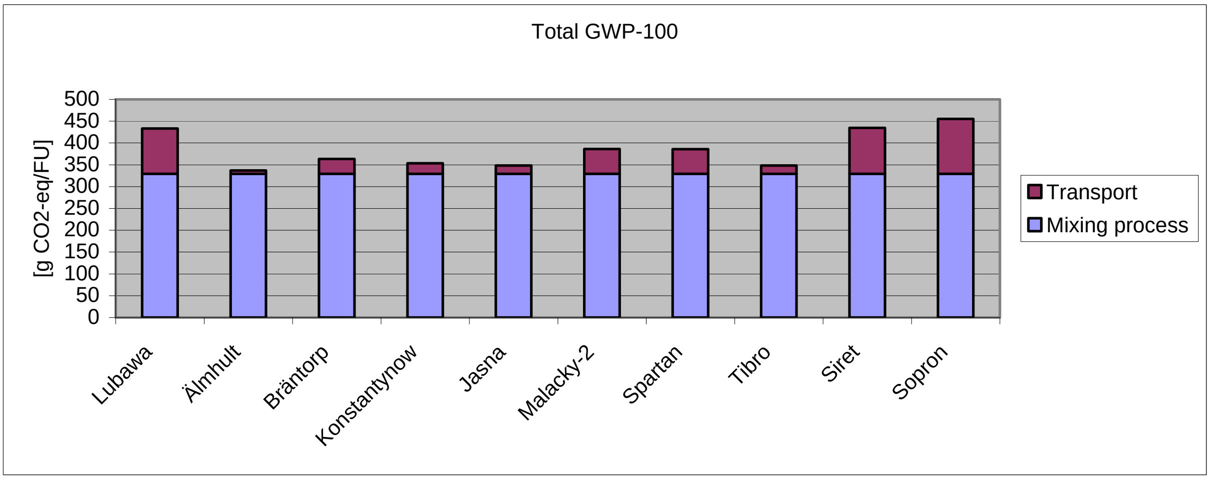


Figure 6. Total GWP caused by mixing of lacquers followed by transports to Swedwood plants (Case I)

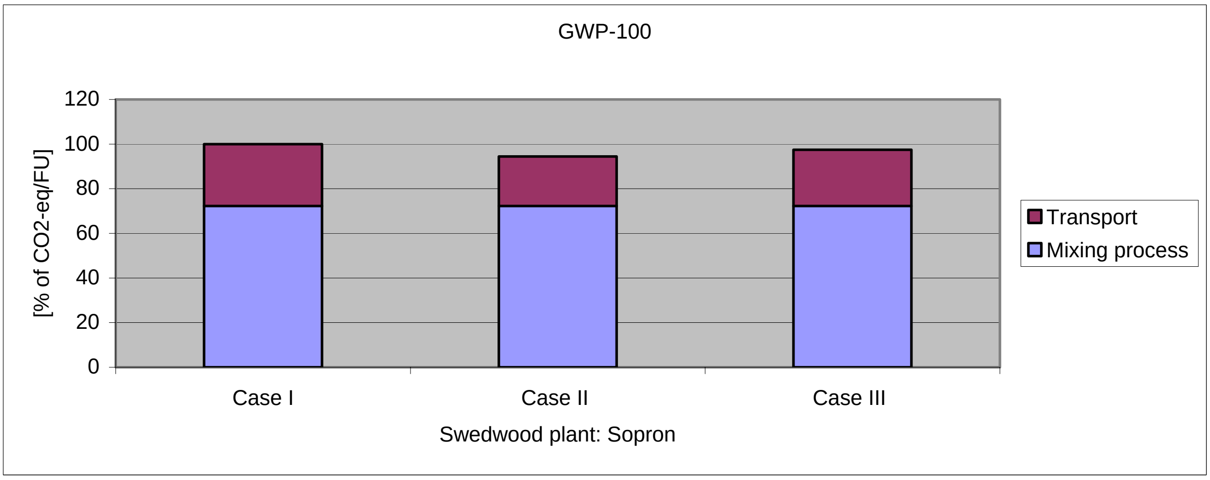


Figure 7. Impact (in %) on GWP caused by the three investigated cases; transport and mixing process

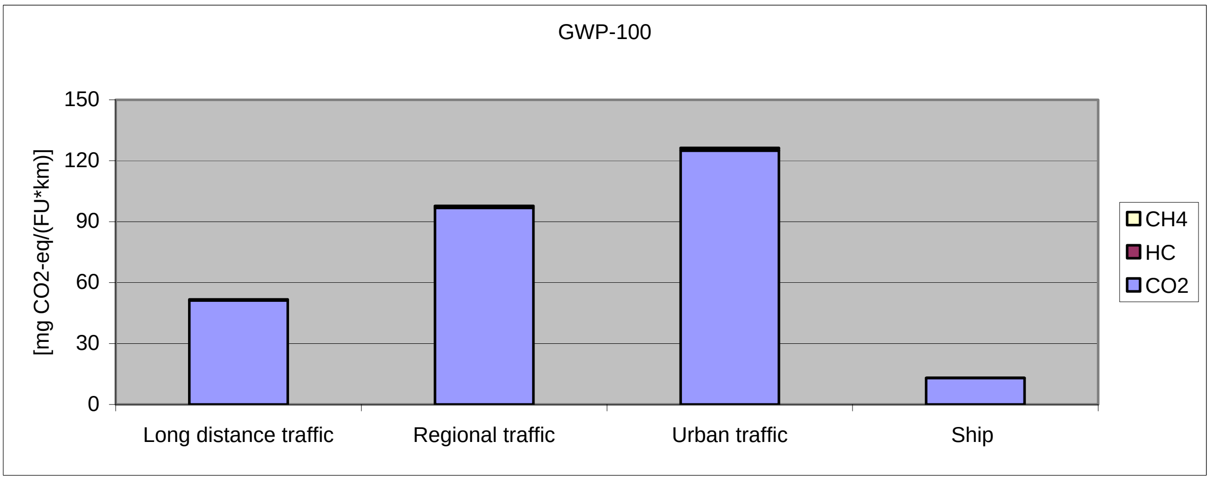


Figure 8. GWP per FU and km, depending on means of transportation and traffic situation, divided into affecting compounds

6.2 Acidification Potential (AP)

As seen in *Figure 9*, Sopron, followed by Siret and Lubawa, is the Swedwood plant whose deliveries affect the acidification potential the most per functional unit and kilometre. The least impact on AP is caused by Älmhult. These results are due to the long distances only. The transport to Sopron contributes with 20 % of the total Sopron AP impact (mixing process and transport included), while the transport to Älmhult only represents 1 % of the total Älmhult AP impact (*Table D.3)*.

Figure 10 shows the differences between the three cases; when the mixed water-borne lacquers are transported long distances, as a result of the central mixing site location, the impact figures on AP are slightly higher.

The two compounds affecting AP is NO_x and SO_2, and as seen in *Figure 11* and *Table D.4*, the NO_x emissions from transports contribute mostly. Transportation by ship gives higher emissions of SO_2 than transportation by truck but still, the NO_x emissions dominate.

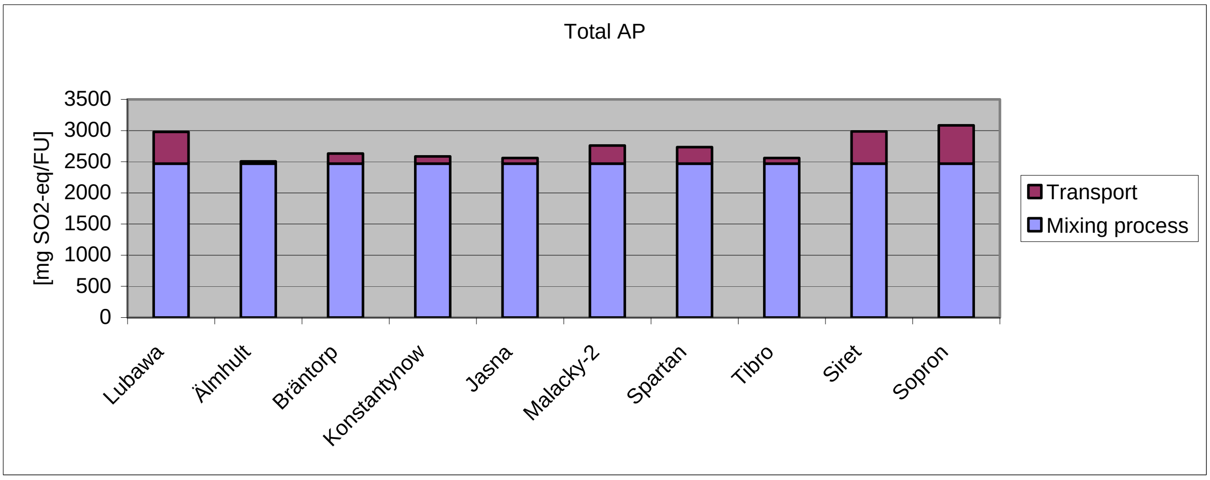


Figure 9. Total AP caused by mixing of lacquers followed by transports to Swedwood plants (Case I)

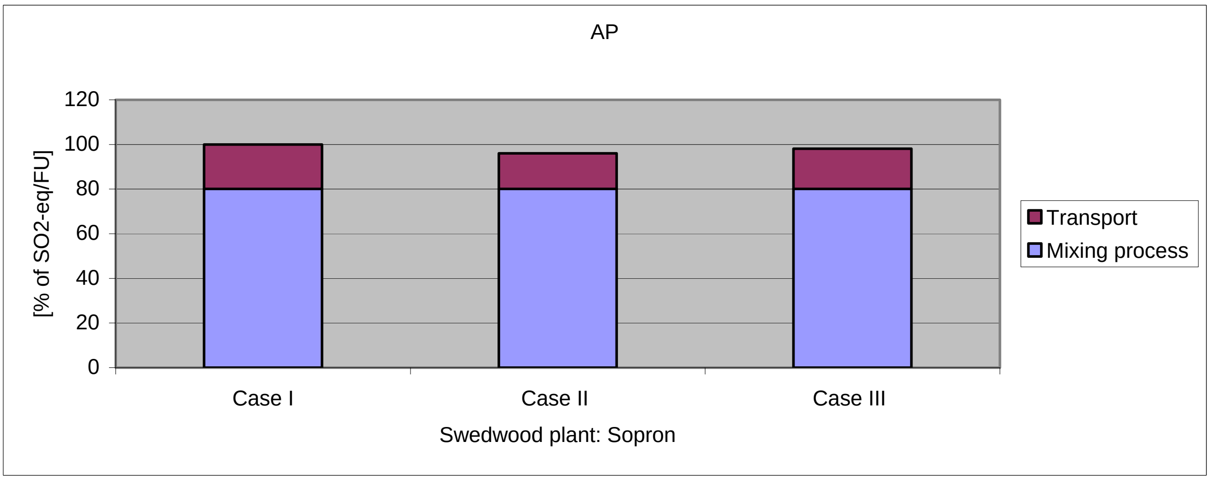


Figure 10. Impact (in %) on AP caused by the three investigated cases

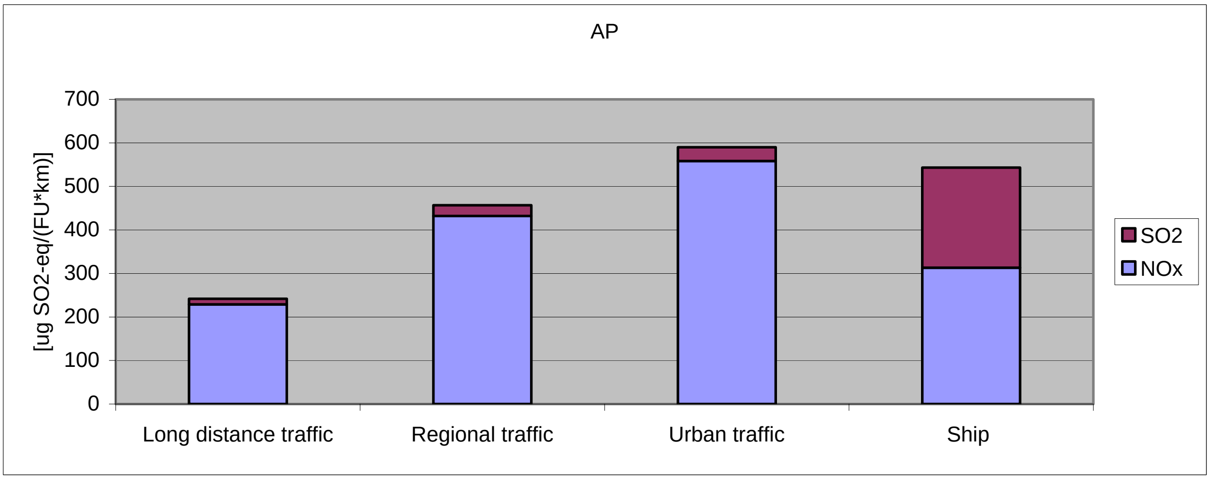


Figure 11. AP per FU and km, depending on means of transportation and traffic situation, divided into affecting compounds

6.3 Eutrophication Potential (EP)

The eutrophication potential impact is dominated by the mixing process of water-borne lacquer, but transports long distance affect almost as much. This is shown in *Table D.5* and in *Figure 12*, where the most affecting Swedwood plants in order of magnitude are proved to be Sopron, Siret and Lubawa. In contrast, Älmhult contributes the least to EP. Also, as seen in *Table D.5*, the transport to Sopron contributes with 45 % of the Sopron EP impacts (mixing process and transport), while the corresponding figure for Älmhult is 5 %.

Figure 13 shows the three investigated cases, of which Case I, due to transports of the already mixed lacquers, emits the most EP affecting compounds, followed by Case III and Case II.

NO_x compounds are the only compounds that affect EP. The NO_x emissions from truck traffic depend on the traffic situation, where driving in urban areas gives the highest emissions per functional unit and kilometre *(Figure 14)*. Transport by ship emits NO_x, though, as seen in *Figure 14* affecting EP less than trucks driving in both urban traffic and in regional distance traffic.

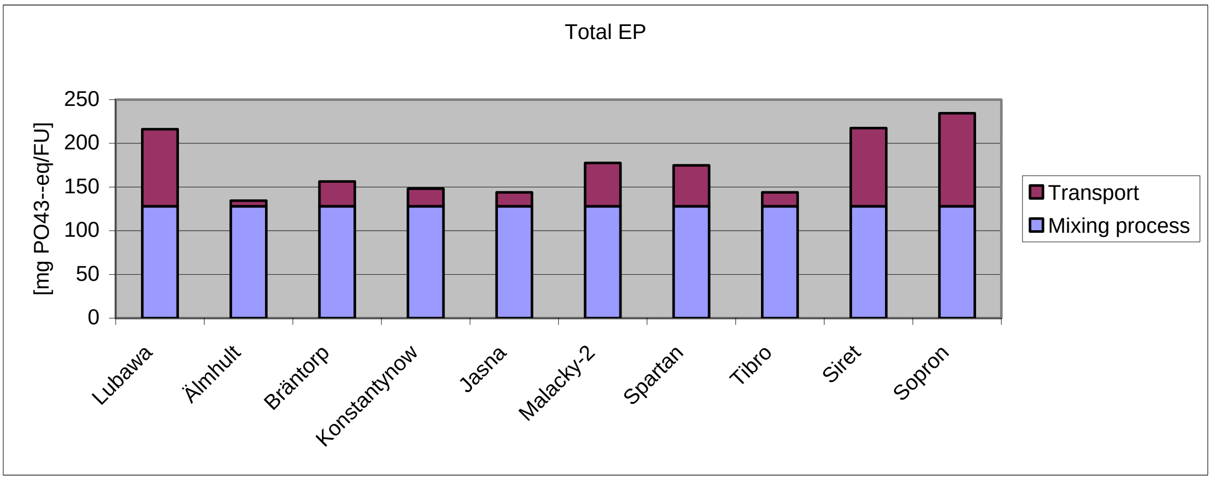


Figure 12. Total EP caused by mixing of lacquers followed by transports to Swedwood plants (Case I)

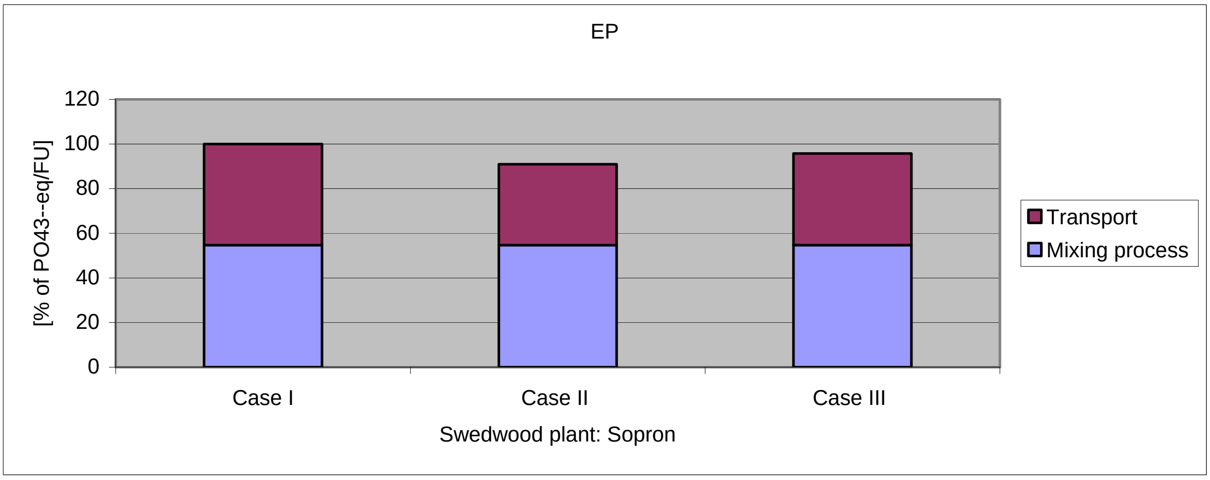


Figure 13. Impact (in %) on EP caused by the three investigated cases

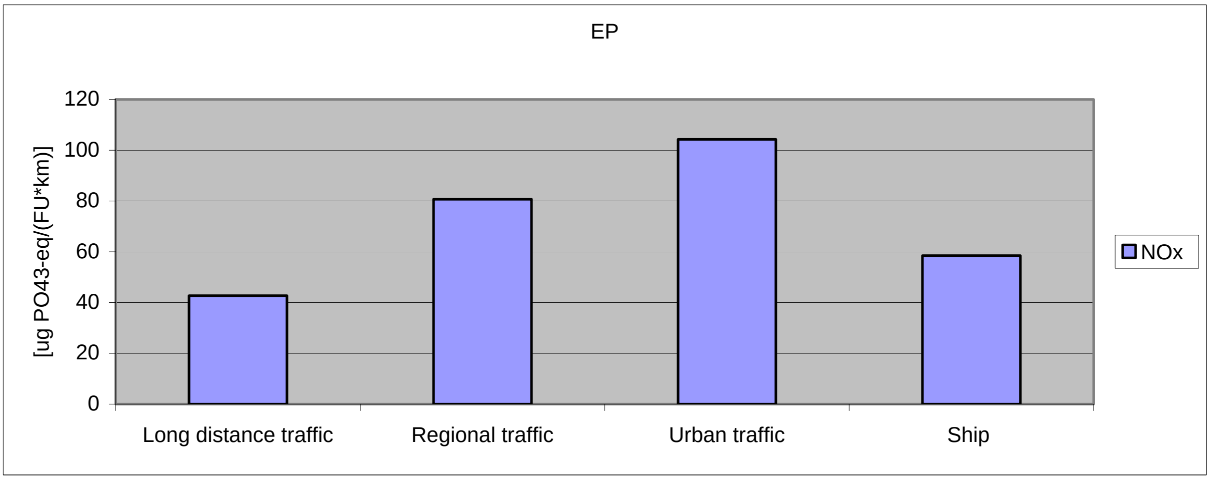


Figure 14. EP per FU and km, depending on means of transportation and traffic situation, divided into affecting compounds (in this case only one NO_x)

6.4 Photochemical Oxidant Creation Process (POCP)

Figure 15 shows that the dominating process affecting POCP is the mixing process of water-borne lacquers, and the Swedwood plants affecting POCP the most are the those with long-distance deliveries of these lacquers. *Table D.7* shows that the long transports to Sopron contribute with 20 % to the total Sopron POCP impact, while the corresponding figure for the short transports to Älmhult is 1 %.

When comparing the three investigated cases, *Figure 16* shows that the closer to the Swedwood plant the central mixing site is located, the less the POCP impact.

Carbon oxide, HC and CH_4 are the compounds affecting POCP in this study. Of these, as seen in *Figure 17* and *Table D.8*, HC is the dominating compound (93 %), followed by CO (7%). The emission of CH_4 when compared with the others is, very low and has an insignificant contribution to the POCP. As for all other environmental impact categories, driving in urban traffic affects the emissions the most.

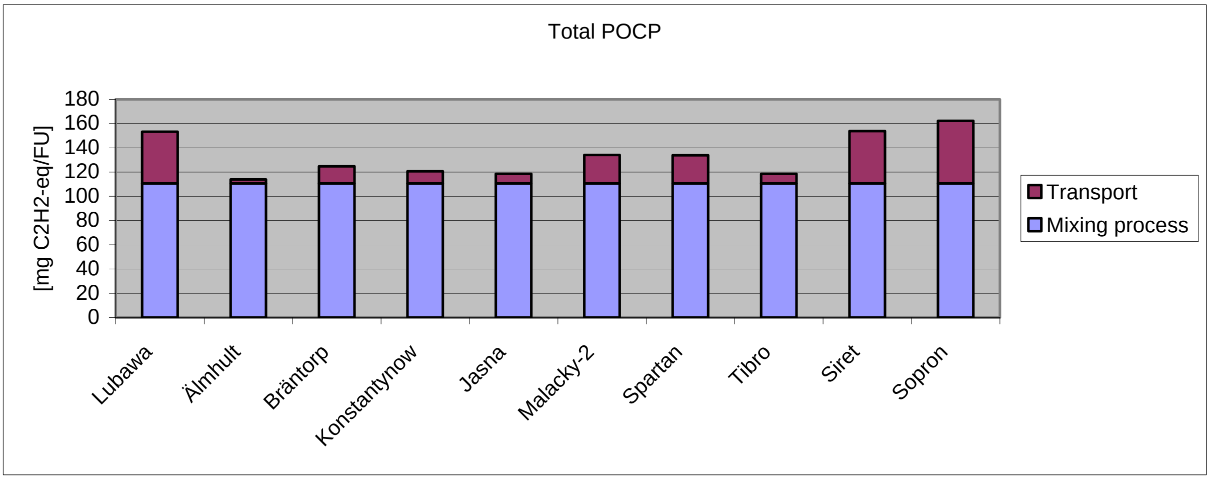


Figure 15. Total POCP caused by mixing of lacquers followed by transports to Swedwood plants (Case I)

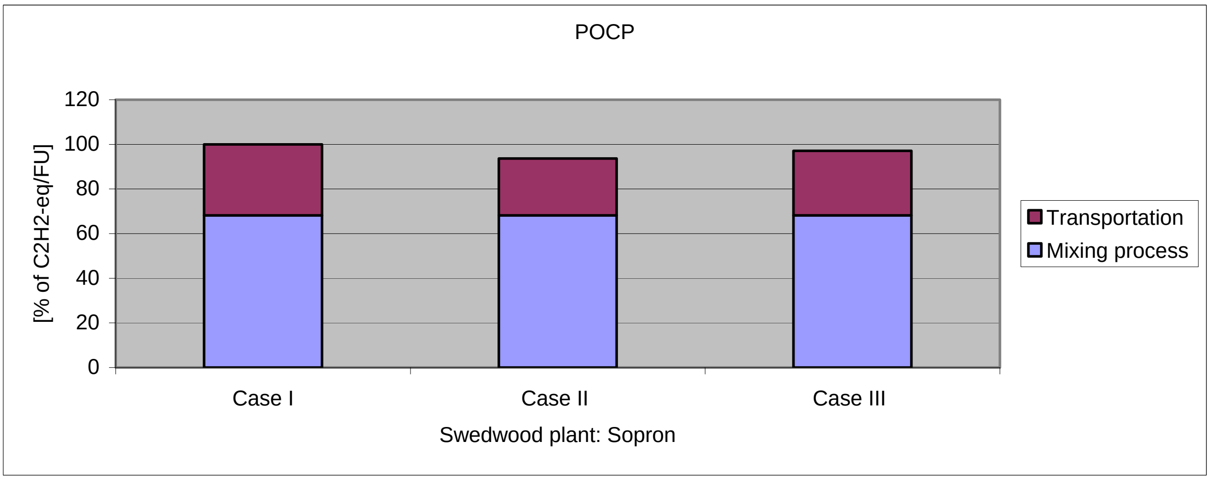


Figure 16. Impact (in %) on GWP caused by the three investigated cases

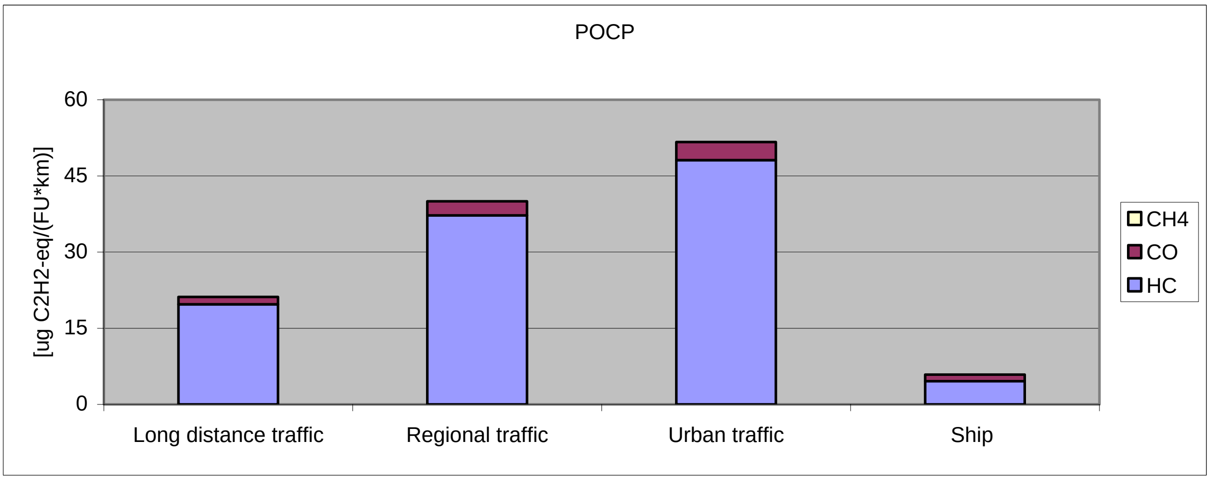


Figure 17. POCP per FU and km, depending on means of transportation and traffic situation, divided into affecting compounds

6.5 Energy Demand

When focusing on energy demand, there are many ways to present the results. In *Figures 18-20* below, the energy demand is presented as MJ/FU. Since all participating Swedwood plants are situated in Europe, European average values of electricity production are used as base for calculation. In *Chapter 7*, these figures are investigated and compared to Swedish average electricity-production data and data for the corresponding coal condensing plant.

As seen in *Figure 18* and *Table D.9*, the mixing process of water-borne lacquers dominates the total energy demand. They also show that the rate of energy demand concerning transports follows the transport distance.

Case I gives the highest results, while case II gives the lowest *(Figure 19)*, just as for the environmental impact categories investigated above.

Energy demand depends on traffic situation *(Figure 20)*; truck driving in urban areas demands more energy than long-distance truck driving, and transport by ship demands even less energy.

About 8 % of the energy used in the production of water-borne lacquers is electricity. Other energy sources contribute to 92 % of the total energy used for mixing process. The term other energy means usage of energy from fossil fuels (e.g. oil, natural gas, petrol, and diesel).

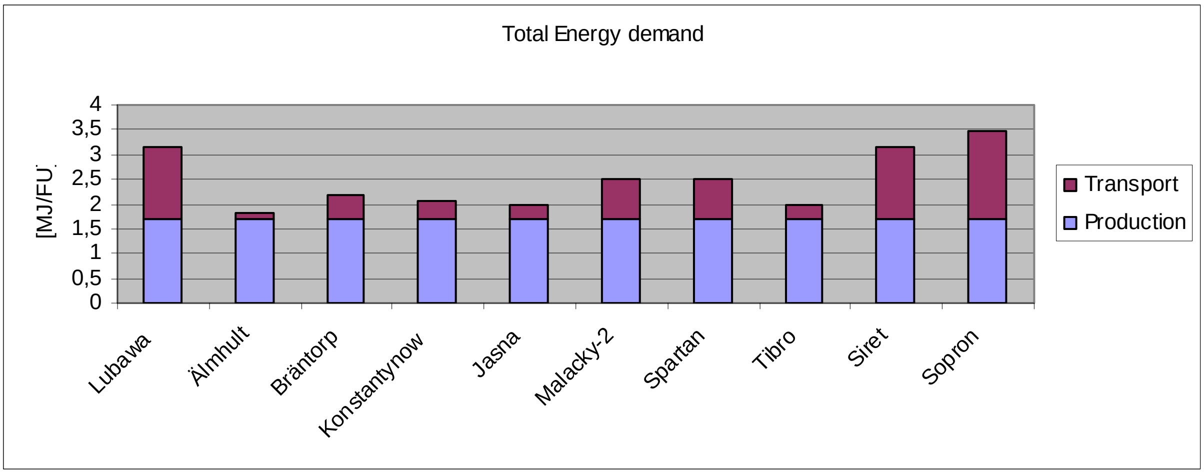


Figure 18. Total Energy demand caused by mixing of lacquers followed by transports to Swedwood plants (Case I)

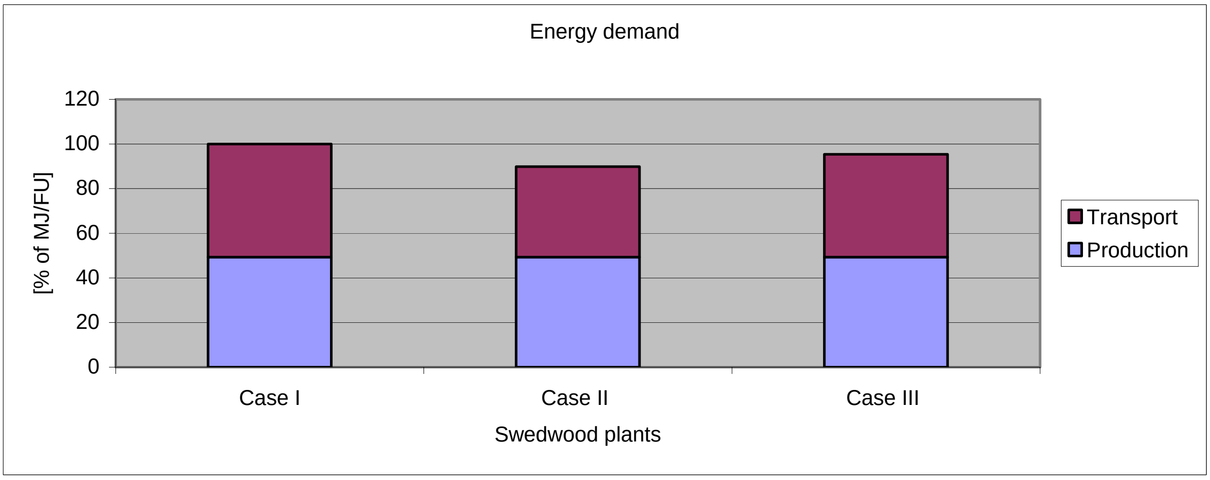


Figure 19. Impact (in %) on Energy demand caused by the three investigated cases

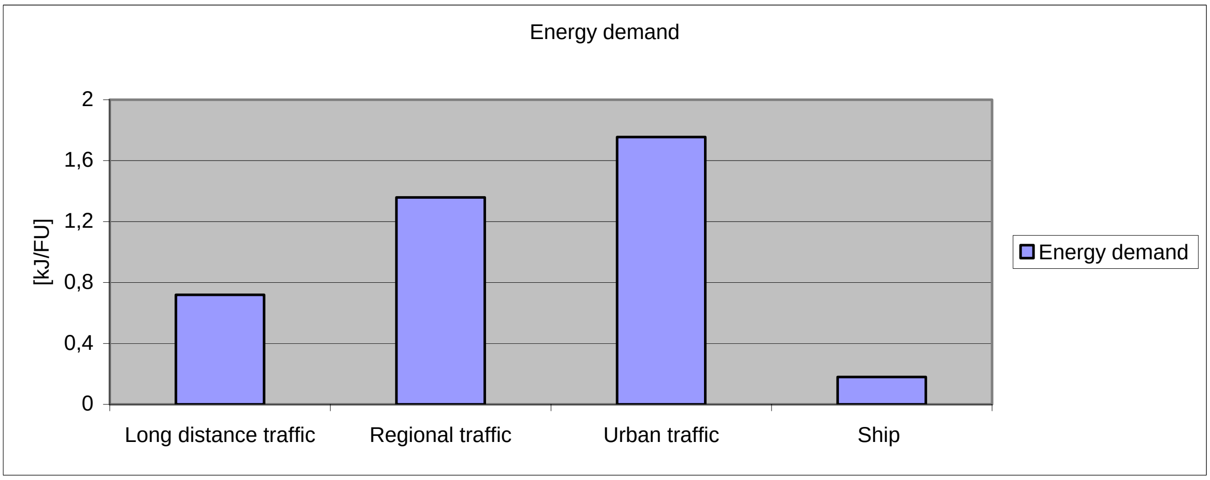


Figure 20. Energy demand depending on means of transport and traffic situation, per km

7 Sensitivity analysis

In most cases, a certain few parameters have a large impact on the result. An optimising of some of the affecting parameters is probably positive, but though they affect the outcome, such efforts can cause a sub-optimisation. The method "Sensitivity analysis" used in this chapter analyses the impact caused by variation of one key parameter at the time, keeping the other parameters constant and unchanged. Parameters estimated to affect the results are tested and evaluated, one at a time, resulting in figures presented for each parameter. As in *Chapter 6*, the presented figures – if nothing else is mentioned – illustrates the transport to the plant with the highest total environmental impact, Sopron. In *Appendix E*, tables referred to are presented.

7.1 Case I

In the basic assumptions made in this study, the mixing process of water-borne lacquers was included when calculating for Case I, as for the two other cases. This assumption had to be made, in order to make a proper comparison, following the LCA standard, between the cases. However, when looking at this from an exclusively Swedwood point-of-view, the mixing process of water-borne lacquers in the first case should not be added to the environmental impact contribution caused by Swedwood activities. In order to see how this affects the results, an analysis is being performed, where Case I excludes this mixing process. The results are presented below *(Figures 21-24)* as emissions caused by the two Swedwood plants affecting the environment the most and the least (Sopron and Älmhult); the other plants lie in between. In *Table E.1*, the calculated values for the two Swedwood plants are presented.

Figure 21. Total GWP-100 caused by Swedwood activities (mixing process and transport), when excluding the mixing process of water-borne lacquers in Case I

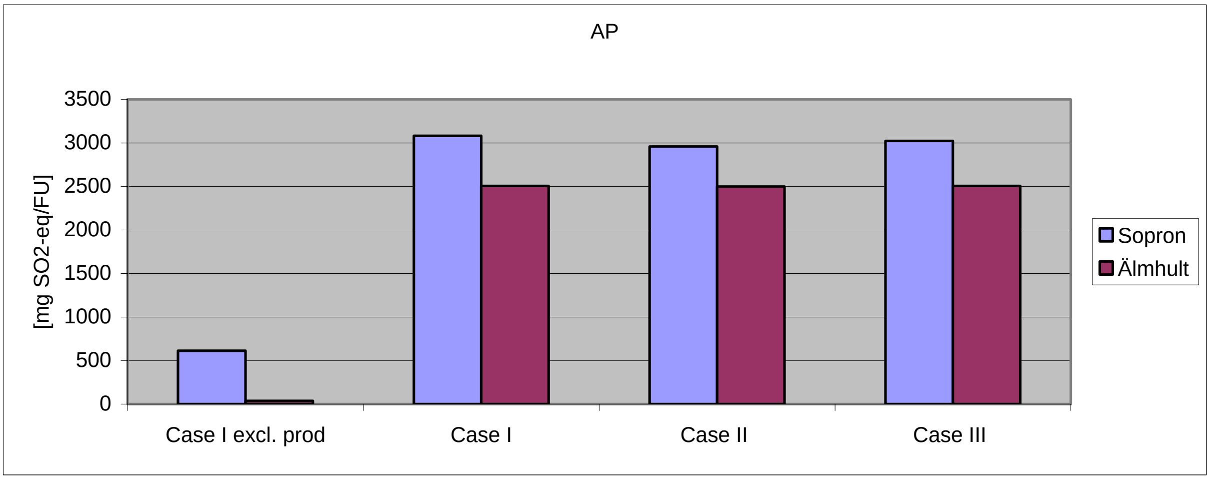


Figure 22. Total AP caused by Swedwood activities (mixing process and transport), excluding the mixing process of water-borne lacquers in Case I

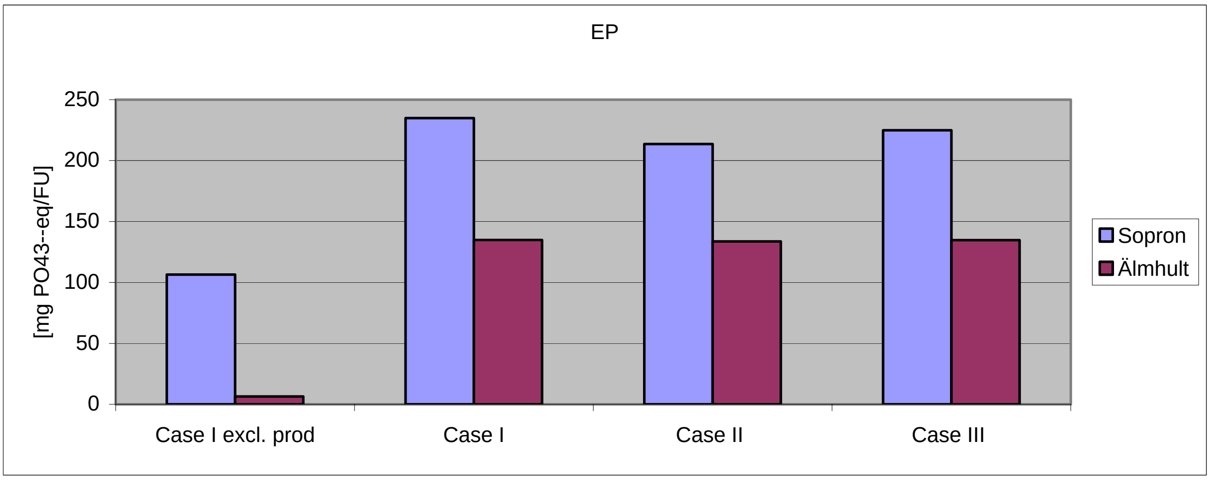


Figure 23. Total EP caused by Swedwood activities (mixing process and transport), excluding the mixing process of water-borne lacquers in Case I

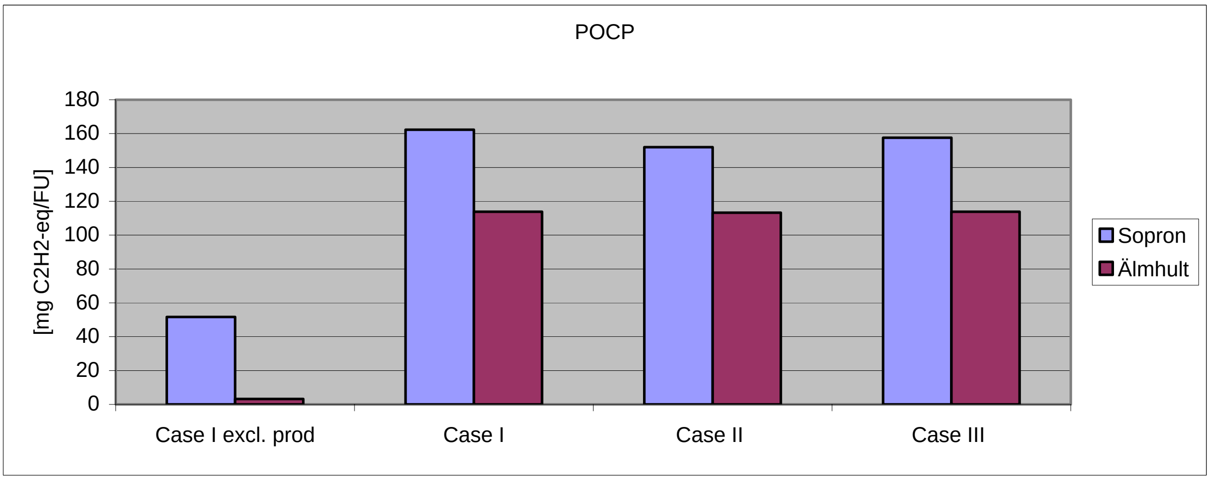


Figure 24. Total POCP caused by Swedwood activities (mixing process and transport), excluding the mixing process of water-borne lacquers in Case I

7.2 Transport distances

As seen in *Chapter 6*, the environmental impacts caused by transports, when calculating per functional unit and kilometre, are mainly due to the transport distances. The closer to the Swedwood plant the central mixing site is located, the less are the impacts on the environment. This has been tested in a sensitivity analysis, where the long-distance transport parameters have been changed as in *Table E.2*.

The alternative in the middle (X = 50 km, Y = 50 km) corresponds to Case III, where the central mixing site is located in between the supplier and the Swedwood plant. The parameter X is the distance from the supplier to the central mixing site, with transports of lacquers with a 20 % weight-reduction due to water elimination. Y is the distance from the central mixing site to the Swedwood plant, with a weight reduction of 0 %; the lacquers are already mixed and ready-to-use. *Figure 26* proves the above made assumption to be correct, and in *Table E.2,* it is shown that all emissions follow the same linear rate as that presented in *Figure 26.*

However, as seen in *Figure 25*, the transport distance has a minor impact on the total environmental impact (mixing process and transport). This is due to the great impact caused by the mixing process. But, *Figure 26* shows that when focusing on the transport distance and excluding the mixing process, a central mixing site location five times closer to the Swedwood plant than in Case III gives an environmental impact reduction of almost 15 percent, while a corresponding, central mixing site location five times further away than in Case III, causes a 15 percent environmental impact increase. Assuming that the impact caused by the mixing process could be lowered, the change in transport distances would make a more significant difference than the one shown in *Figure 25*.

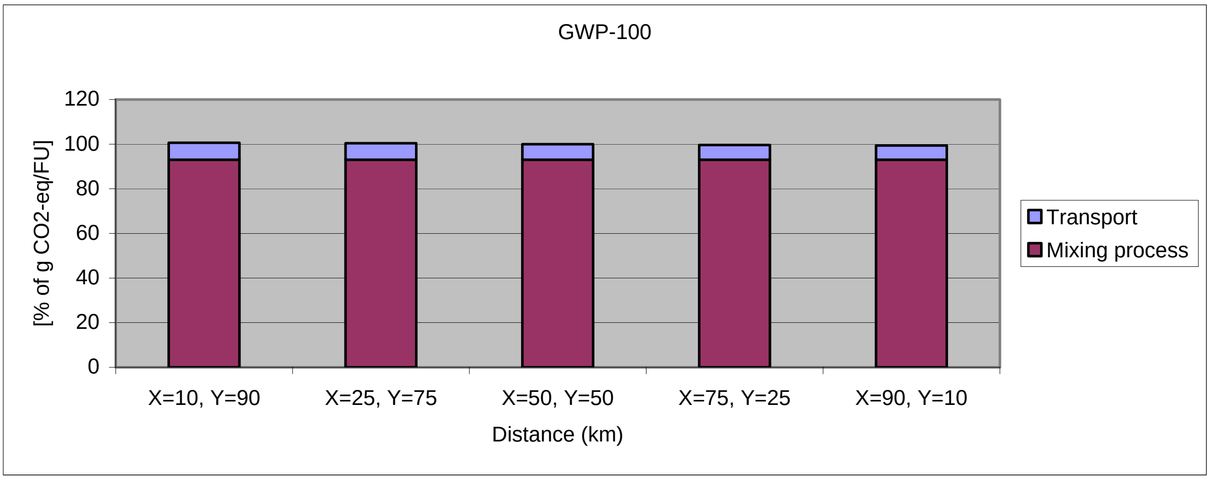


Figure 25. Total (mixing process and transport) emissions to air (percentage of GWP) when changing the long distances (in km)

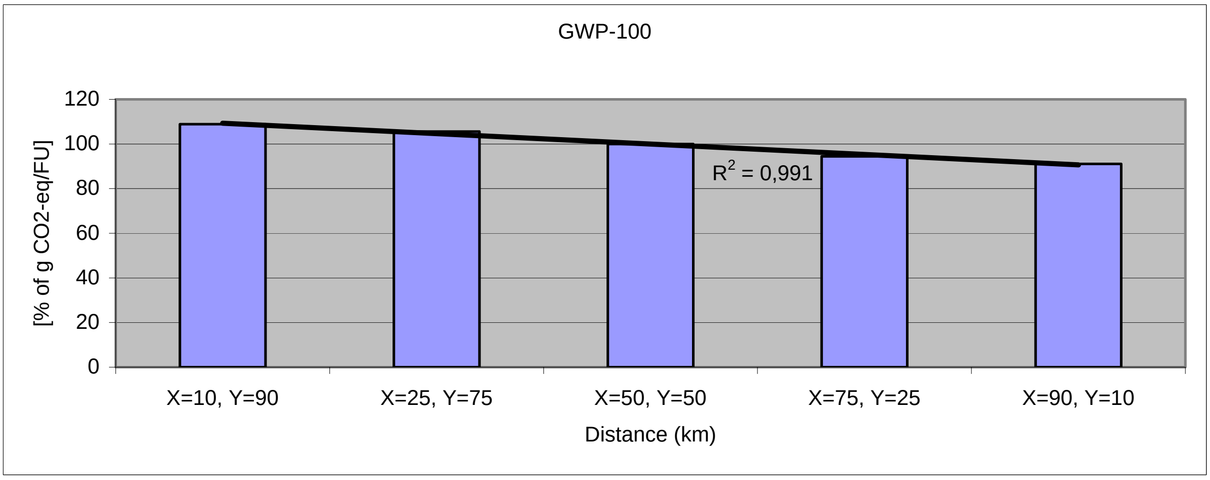


Figure 26. Emissions to air (percentage of GWP) when changing the long distances, excluding mixing process (in km)

7.3 Load factor

A difficult parameter to estimate is the truck load factor, which has been discussed in *Chapter 2*. In the base cases, the load factor has been 70 %, and altering this figure affects the environmental impact categories as presented in *Table E.3* and in *Figures 27-28* below.

As seen in *Figure 27*, illustrating the transport to Sopron and a mixing process, no significant differences in total environmental impact occur when changing the load factor. This is due to the large impact from the mixing process. Nevertheless, when increasing the load factor from 70 % to 85 %, and just focusing on the transports, an environmental impact decrease of almost 20 percent can be achieved *(Figure 28)*.

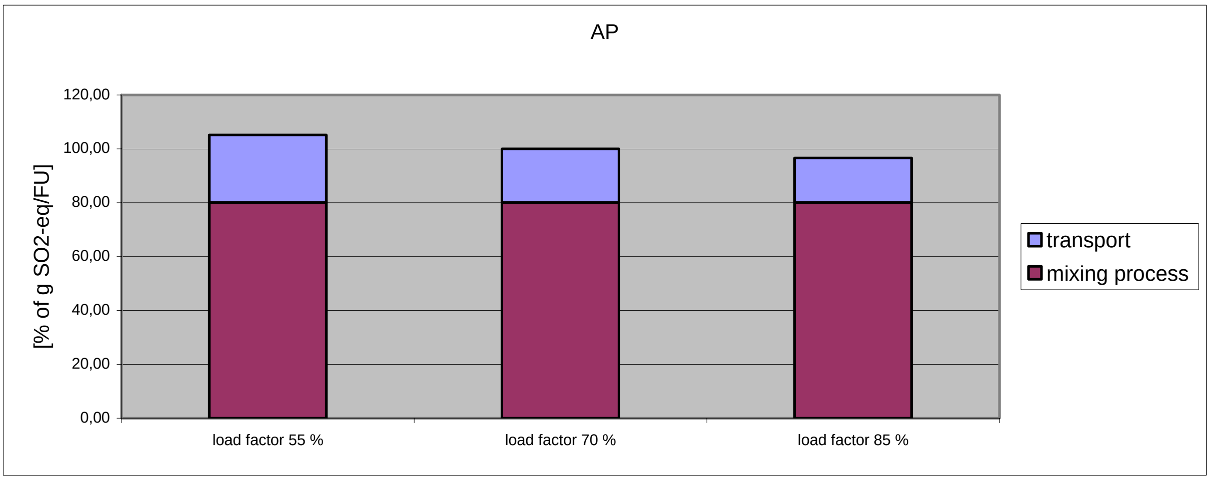


Figure 27. Total (mixing process and transport to Sopron) emissions to air (percentage of AP) when changing the truck load factor

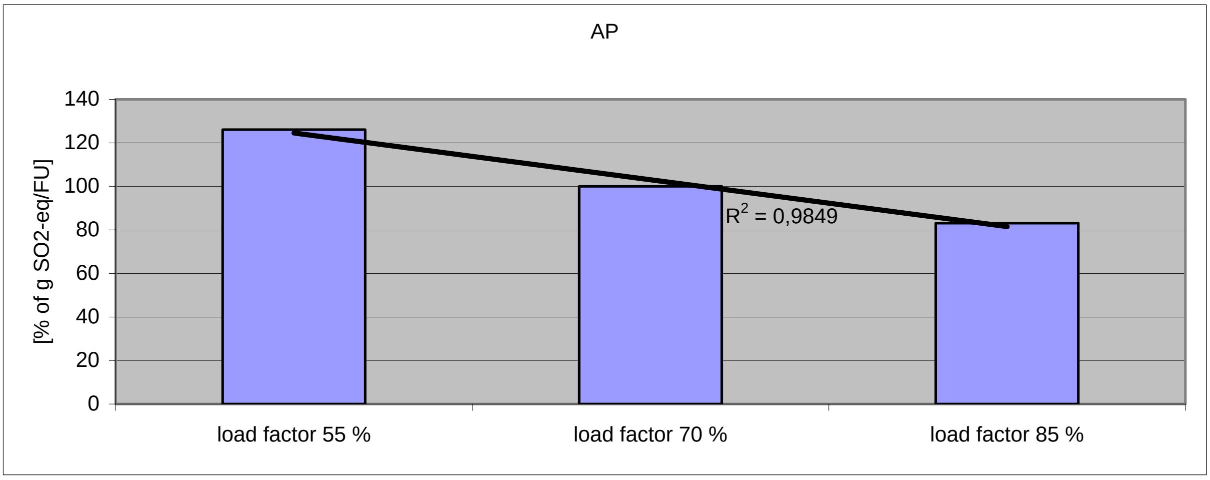


Figure 28. Emissions to air (percentage of AP) when changing the truck load factor

7.4 Fuel consumption

The truck fuel consumption is also a parameter estimated to affect the environmental impact outcomes. There are differences between e.g. engine efficiencies, driving patterns, and truck technologies, all resulting in variations in fuel consumptions.

Figure 29 shows that the environmental impact change caused by changes of fuel consumption is minor when focusing on the total impact caused by mixing process and transport. This is due to the great impact brought about from the mixing process.

As shown in *Table E.4* and in *Figure 30*, the correlation between fuel consumption and emission to air affecting the environmental impact categories is linear. If decreasing the fuel consumption with 0,5 litres per 10 km (based on 3,5 litres per 10 km) and concentrating on only transport, almost 20 % less environmentally impacting emissions are emitted.

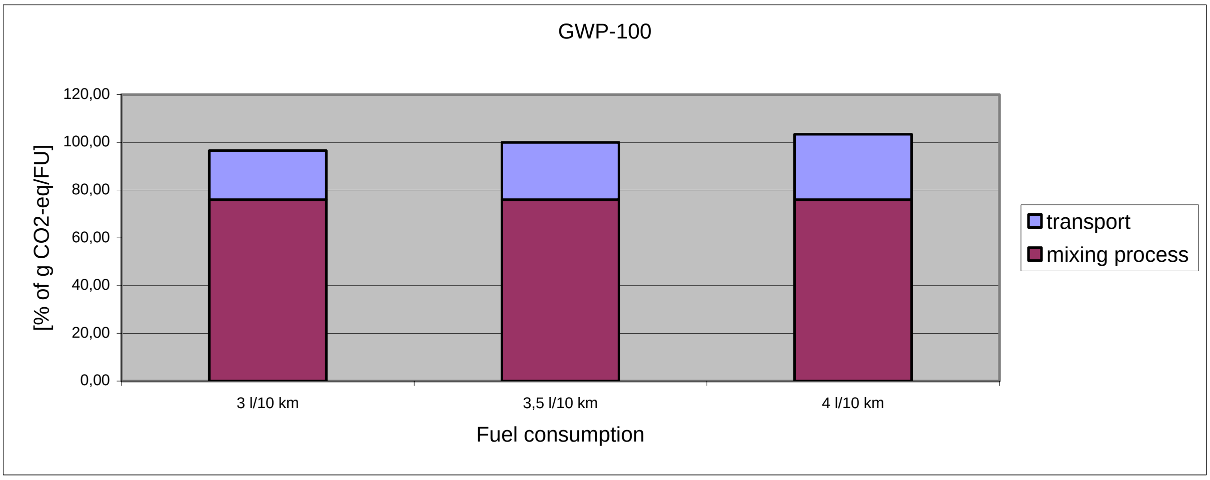


Figure 29. Total (mixing process and transport to Sopron) emissions to air (percentage of GWP) when changing the truck fuel consumption

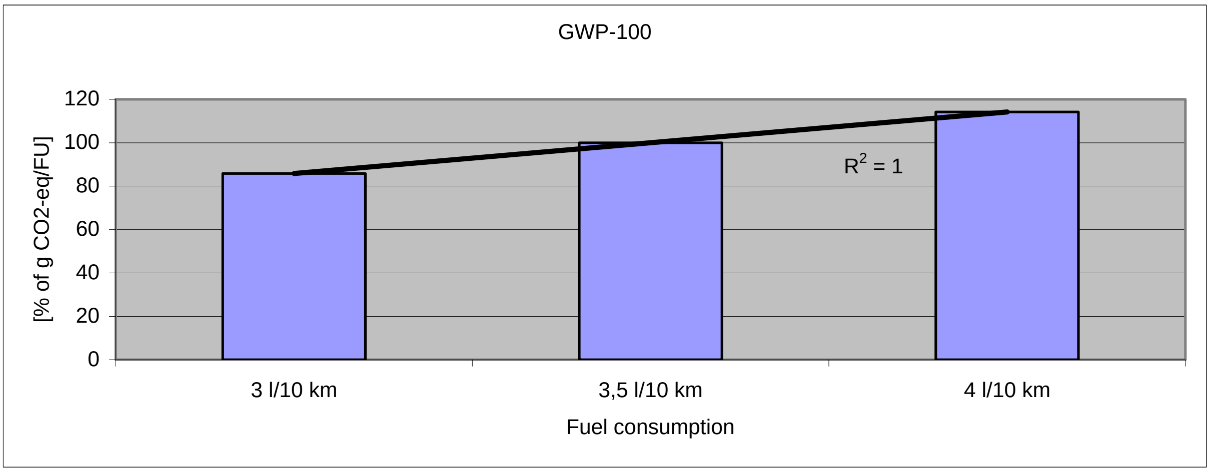


Figure 30. Emissions to air (percentage of GWP) when changing the truck fuel consumption

7.5 Type of engine

During the last 30 years, much has happened on the truck engine area; new technologies have been developed and improved, and so have the engines. As mentioned earlier, in *Chapter 2*, the assumed type of engine used in trucks distributing goods all over Europe is the one with the Euro 3-classification. However, there might be exceptions, and therefore a sensitivity analysis considering the type of truck engine is performed.

Table E.5 presents data, on which the following figures *(Figures 31-34)* are based. The same table shows how low the impact from transport is when comparing emissions per kilometre. The various environmental impact categories in *Figures 31-34* are shown to be differently affected depending on the type of engine. For example, AP depends on emissions of both SO_2 and NO_x, while EP is only affected by NO_x emissions. However, since the emission of SO_2 is to do mainly with diesel quality, the SO_2 emissions are constant regardless type of engine.

As seen in the *Figures 31-34* below, there are great differences between the older engines and the newer ones. All environmental impact categories are affected, except GWP *(Figure 31)*, since the emissions of CO_2 mainly depends on the fuel consumption. *Figures 32-34* show that technology improvements have been made, affecting the outcomes in a positive way. N.B. *Figures 31-34* are calculated for the mixing process together with transport of lacquer to the Sopron plant, in order to see the outcomes caused by changes in type of engine.

As earlier explained emissions of particles are not included in this study, though being a negative effect caused by transports. N.B. Modern engines have particle filters, resulting in less emissions of particles.

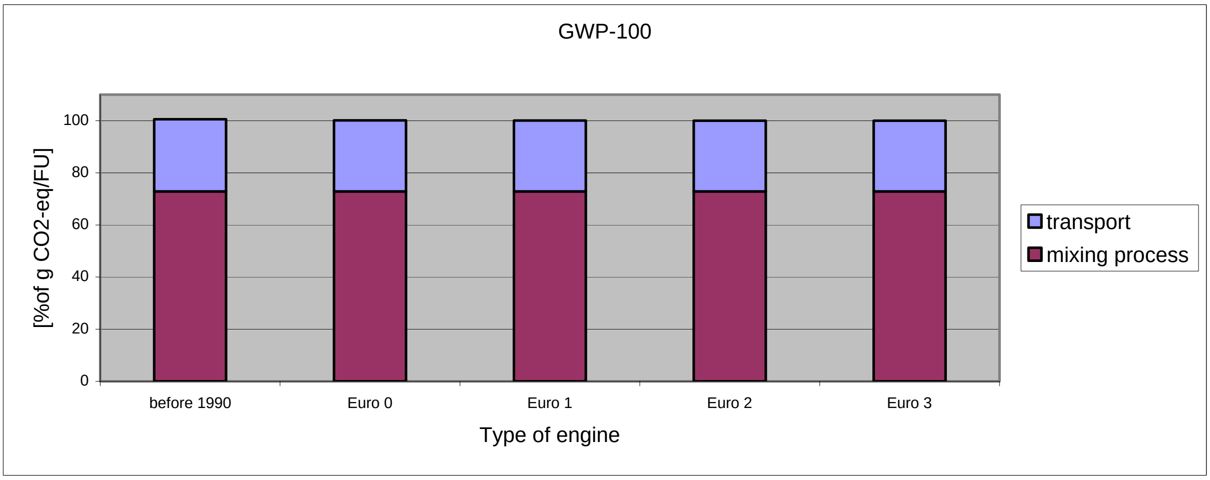


Figure 31. Total (mixing process and transport to Sopron) emissions to air (percentage GWP) when changing the truck type of engine

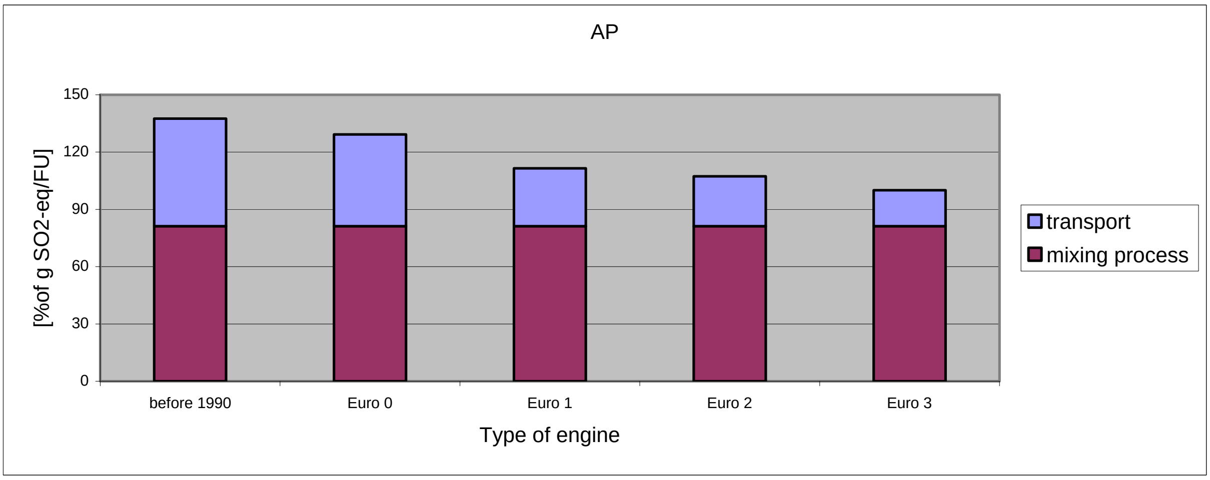


Figure 32. Total (mixing process and transport to Sopron) emissions to air (percentage of AP) when changing the truck type of engine

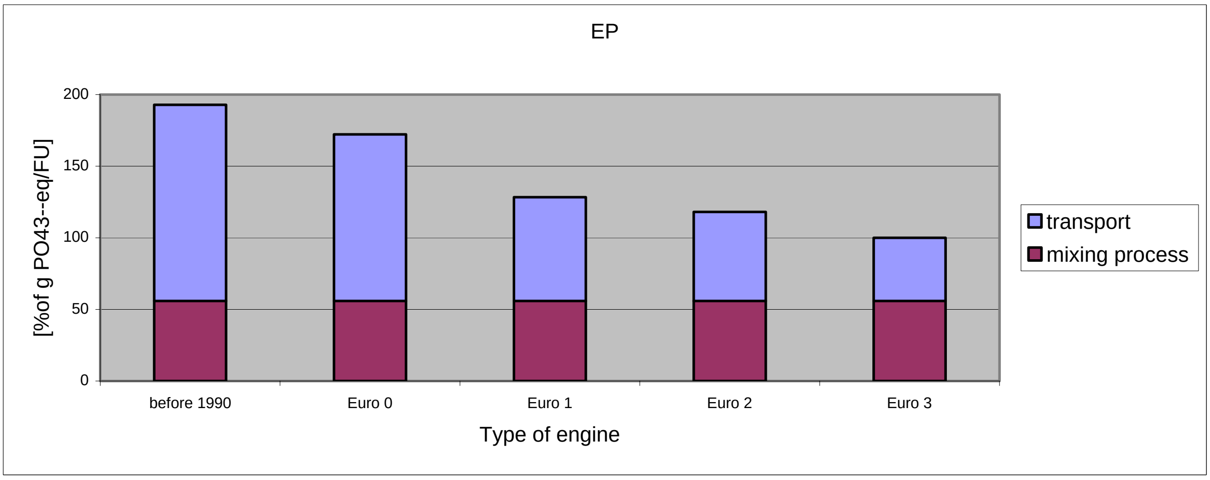


Figure 33. Total (mixing process and transport to Sopron) emissions to air (percentage of EP) when changing the truck type of engine

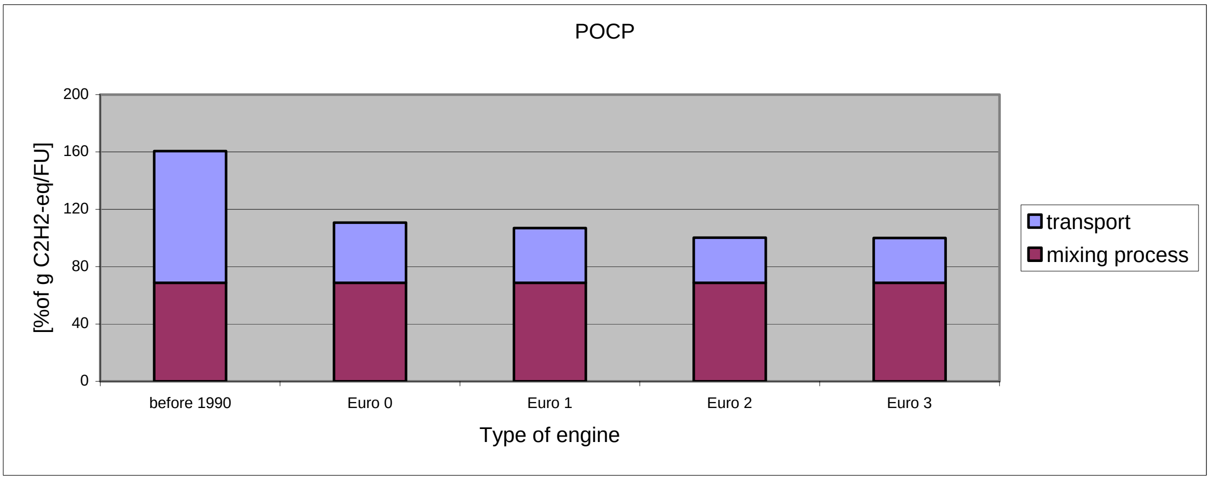


Figure 34. Total (mixing process and transport to Sopron) emissions to air (percentage of POCP) when changing the truck type of engine

7.6 Diesel quality

The only compounds affecting the environmental impact results owing to diesel quality are CO_2, SO_2 and particles. As discussed in *Chapter 2*, CO_2 affects the global warming potential and SO_2 the acidification potential. Emissions of particles are in this study only discussed in terms of quality, not quantity.

As seen in *Table E.6* and in *Figure 35* below, there are minor differences between the three classes of diesel quality: only a 1 percent difference between Mk I and Mk III when excluding the mixing process, proving that this parameter is of less importance for the outcome.

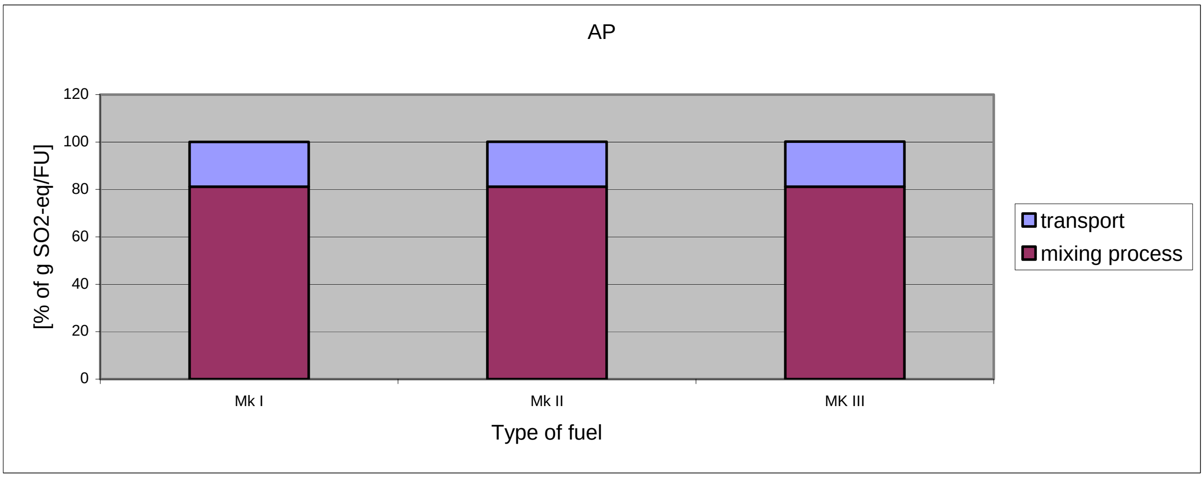


Figure 35. Emissions to air (percentage of AP) when changing the diesel quality

7.7 Water weight reduction

As discussed in *Chapter 3*, 20 % is the estimated share of water weight to remove, before transport and a later mixing process (where the water is added). Changes in weight reduction affect the result as in *Figures 36-39*, when including the mixing process. In order to compare with the mixing process, transports to Sopron are calculated for each environmental impact category.

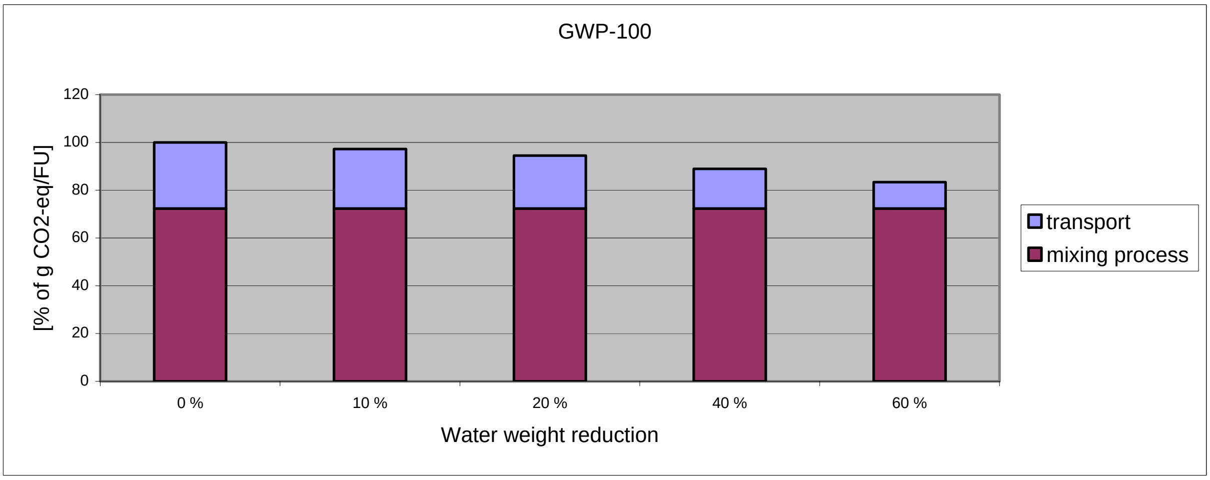


Figure 36. Total (mixing process and transport to Sopron) emissions to air (percentage of GWP) when changing the lacquer weight reduction

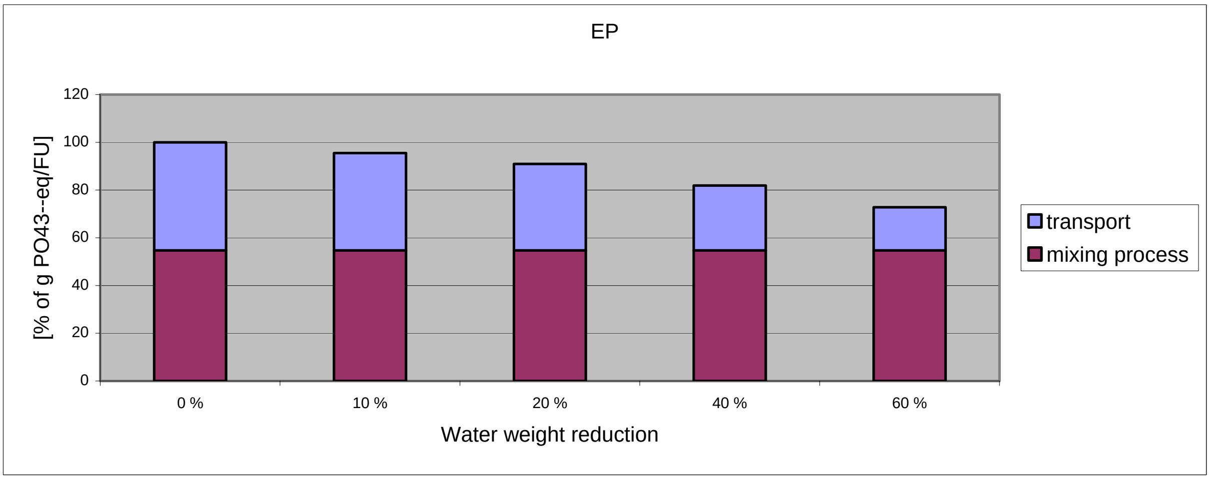


Figure 37. Total (mixing process and transport to Sopron) emissions to air (percentage of EP) when changing the lacquer weight reduction

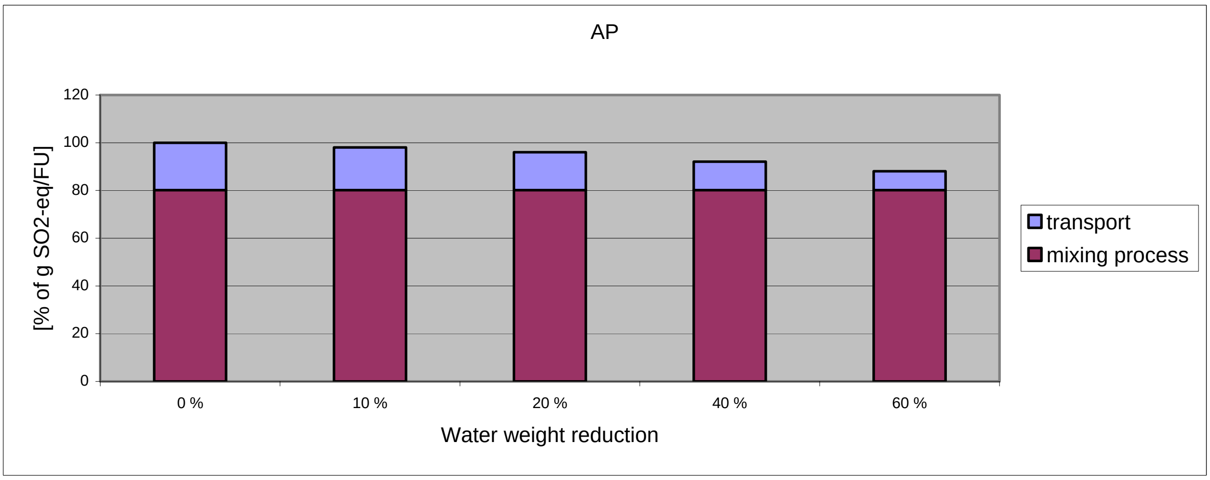


Figure 38. Total (mixing process and transport to Sopron) emissions to air (percentage of AP) when changing the lacquer weight reduction

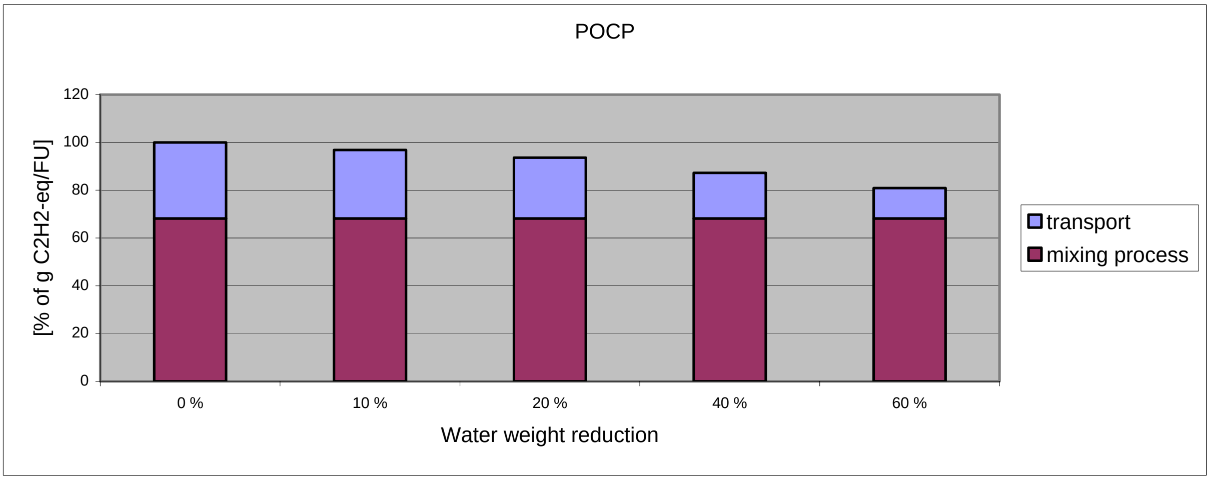


Figure 39. Total (mixing process and transport to Sopron) emissions to air (percentage of POCP) when changing the lacquer weight reduction

7.8 Electricity production

As written in *Chapter 2* and as seen in *Table A.2*, the type of electricity production differs between countries. When focusing on natural resources used for electricity production, compared to Swedish industrial mean values, the production of European average electricity emits 10 times more CO_2, 30 times more CO, 20 times more NO_x, 75 times more SO_2 and 20 times more CH_4 *(Table A.2)*. The corresponding figures for pure coal-based production in condensing plant, when using Swedish average electricity as a base, are emission of 20 times more CO_2, 10 times more CO, 30 times more NO_x, 30 times more SO_2 and 60 times more CH_4

These differing results between Swedish and European electricity figures are due to the dominating usage of coal in Europe, resulting in high emissions to air, affecting all environmental impact categories. In the base case of this study, figures for European average electricity production have been used, when calculating emissions caused by electricity production. The resulting environmental impact of these figures is investigated below and presented, compared to the impact caused by corresponding Swedish average electricity production figures and figures concerning coal condensing plant. *Table E.8* and *Figures 41-44* show each contributing effect on the environmental impact categories caused by electricity production for energy use for the mixing process of water-borne lacquers, when changing electricity production. In *Figure 40*, GWP-emissions are presented, comparing the three investigated cases in respect of electricity production situation. Note that about 8 % of the energy used in the production of water-borne lacquers is electricity, and that following figures focus only on emissions caused by electricity production. Other energy sources contribute, as written in *Chapter 6.5*, to 92 % of the total energy used for the mixing process. When transport to Sopron is the object for comparison, the relative environmental impact caused by electricity production is low. Consequently, when comparing electricity production with shorter distances, the relative impact gets higher. For all three electricity production cases production of Swedish electricity emits the lowest environmentally affecting emissions, all categories. N.B. This is a theoretical comparison; Swedish average electricity cannot be used practically at the Sopron factory.

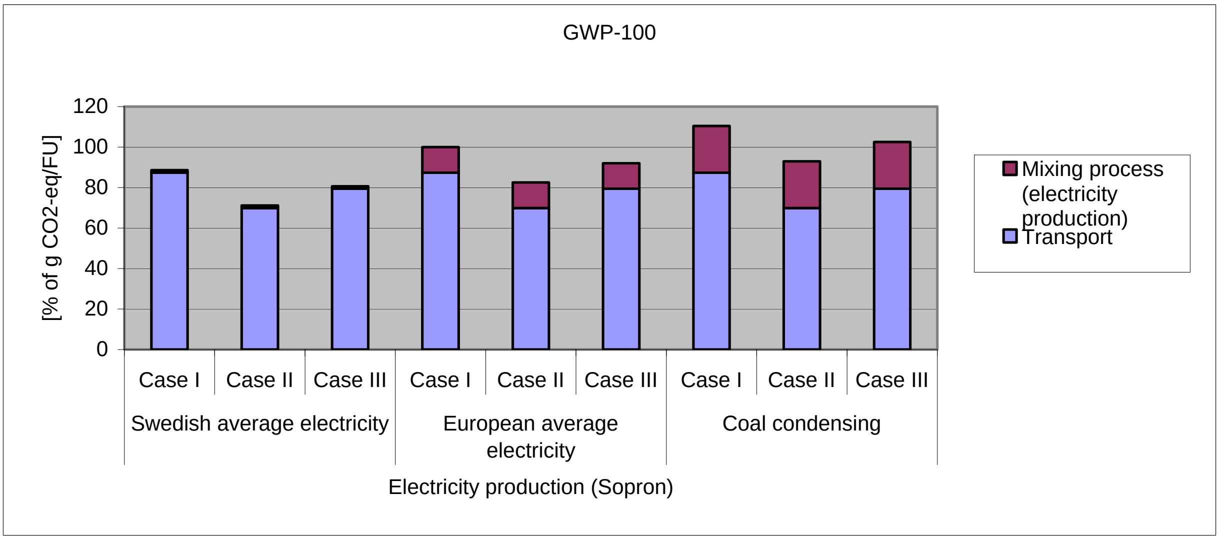


Figure 40. Emissions to air (percentage of GWP) when comparing electricity production for mixing process with transports to Sopron for all three cases and for three different types of electricity production

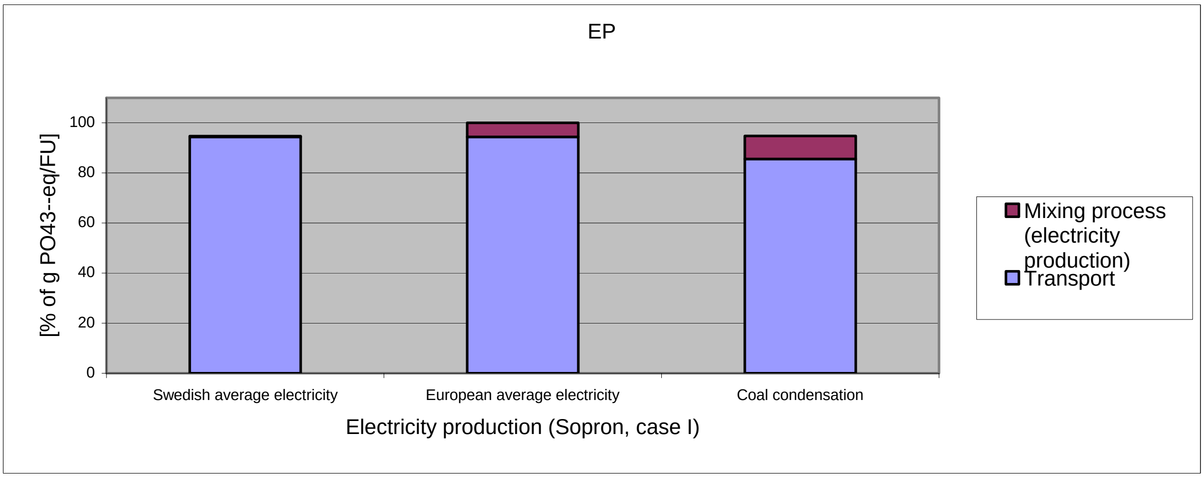


Figure 41. Emissions to air (percentage of EP) when comparing electricity production for mixing process with transports to Sopron for Case I and for three different types of electricity production

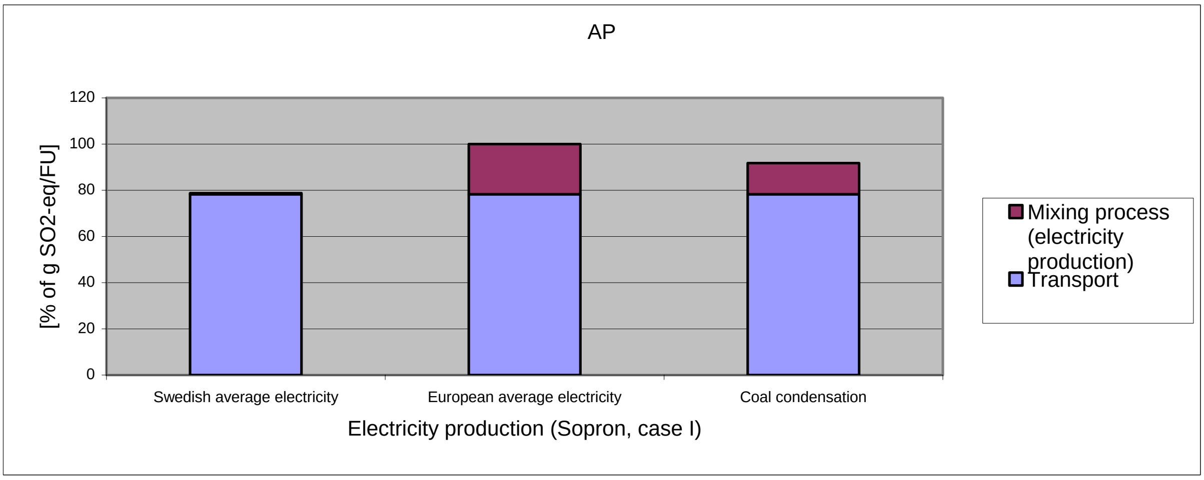


Figure 42. Emissions to air (percentage of AP) when comparing electricity production for mixing process with transports to Sopron for Case I and for three different types of electricity production

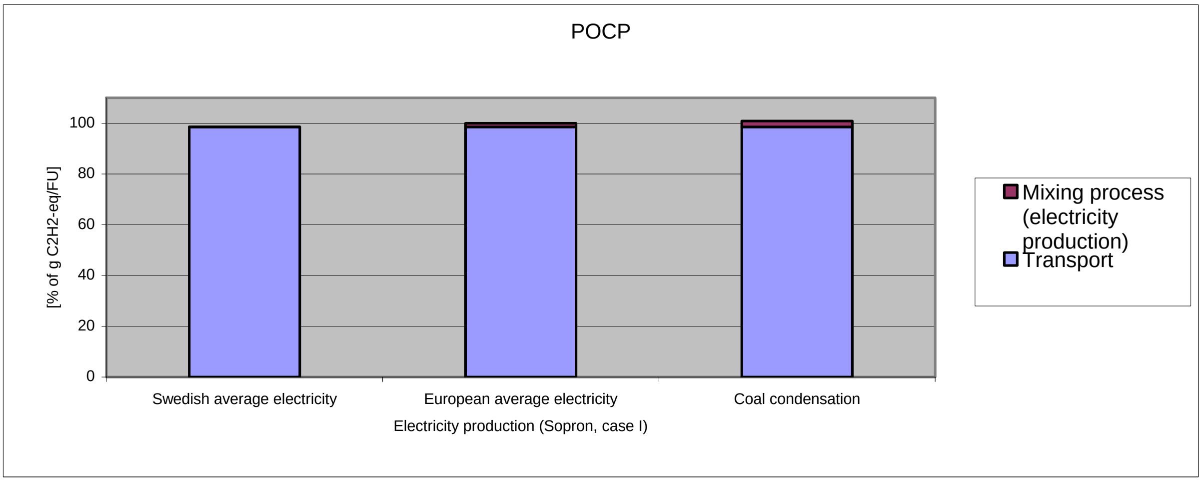


Figure 43. Emissions to air (percentage of POCP) when comparing electricity production for mixing process with transports to Sopron for Case I and for three different types of electricity production

8 Conclusions and discussion

As written in *Chapter 1,* the aim of this master thesis is to "estimate environmental impacts and to identify possible improvement areas". The first part of that aim has been conducted both via the life cycle analysis and via the sensitivity analysis, and is discussed further in this chapter. The second part of the aim is investigated in *Chapter 9*, where the analysis is focused on a Swedwood perspective. This chapter deals with questions like which parameters should be focused on when discussing from an environmental point of view and what has to be investigated further before making any decisions.

Which of the parameters investigated in this study give the highest environmental impacts?
Many participating parameters affect the outcomes, and, amongst them, the dominating parameter is the *mixing process of water-borne lacquers*. In all investigated cases and for all environmental impact categories, the impact caused by the mixing process is the highest. Note that it is important to take into consideration the mixing process assumptions made at the beginning of this study; the assumptions are probably overestimations, resulting in different outcomes than in reality. As the environmental impact for the mixing of water-borne lacquer for all cases and impact categories is more than twice as high as the corresponding figures for transports to Sopron (the plant having the longest deliveries), the mixing process is probably the major contributor, regardless of potential overestimations. If it becomes possible to lower the emissions caused by the mixing process, the relative share of all other estimated parameters will rise, resulting in more total environmental improvements to be made via transport and delivery optimisations.

The second parameter affecting the outcomes significantly is *type of engine*. Comparisons between older types of engines and newer ones, using engines with higher Euro-classification, show that the latter give lower quantities of environmentally impacting emissions. Particularly EP is affected, as a result of the lowered NO_x emissions, which also are reflected in the AP results. This shows how important it is to make sure that the shippers use approved engines according to high Euro-standards. In addition to that, emissions of particles are lowered if using newer engines instead of older.

Water weight reduction is the third environmental impact dominating parameter; the differences according to changes caused by water weight reduction are significant. If obtaining a higher reduction possibility of water from the lacquer – without affecting the lacquer quality – before transporting to mixing site, central or internal, environmental impact decreases for each impact category. There is only a certain share of water to remove, and this process of water reduction must, in order to not harm the end-product, follow an optimised process chain, in which components are to be added in a certain sequence.

Changes in *fuel consumption* lead to changes in environmental impact; the more fuel demanding the truck is, the larger the quantities of emissions released. Driving patterns, though not investigated in this master thesis, affect this parameter, and improvements can therefore be made by increased knowledge of, and education in, responsible driving. In addition, technical improvements can be made, as fuel consumption also depends on the quality of engine. Because of the high rate of emissions caused by the mixing process, fuel consumption gives no significant contribution to the total environmental impact (mixing process and transport). However, as stated above, if impacts caused by the mixing process can be lowered, fuel-consuming patterns will become increasingly important and serve as cases for improvements.

Changes in *load factor* also affect the total outcome, but scarcely when taking the mixing process into calculation. When attention is paid exclusively to the transports, results show that emissions to air are lowered proportionally to the increase of load factor. If a decrease in environmental impact from the mixing process could be realised, the load factor would contribute more to the total environmental impact. This shows that it is an improvement area; when optimising the deliveries both according to goods packing and route planning, the load factor can be held higher and as a result cause lower emissions. This is an issue for the shipper, since neither the supplier nor the receiver (Swedwood plant) is in charge over the logistical delivery details. Nevertheless, influence caused by combined efforts and pressures from interest groups can affect the shipper, resulting in optimisations.

The different *transport distances* cause impacts on the environment. The closer to the Swedwood plant or central mixing site the supplier is located, the lower the emissions caused by transports. However, when comparing the emissions due to different delivery distances with the emissions caused by mixing process, the first-mentioned are significantly lower. If it is possible to reduce the mixing process impacts, the share of transport distance impact increases, making the distance parameter more important. Improvements can be made by looking over the deliveries; are there suppliers located closer than those used presently? Transports by ship are difficult to calculate, but in this study, those distances are relatively short, not making significant impacts on the total outcomes.

The *diesel quality* will have almost an insignificant effect on the total emission results, regardless of calculations with or without mixing process. Consequently, improvement within this area should not be the highest priority.

Energy use is not equal wherever the Swedwood plant is located, or wherever the prospected central mixing site is to be built. The use of energy depends on political decisions like energy costs, and differently developed energy demanding technologies. Production of electricity and heat fuels also differs significantly depending on plant location. Therefore, the outcomes of *energy demand* vary, depending on geographical location and energy market in respective country. GWP is the environmental impact getting significantly affected by energy use. There are great differences between the production of Swedish average electricity and European average electricity, which shows that great improvements within this area can be made by using electricity produced using renewable energy sources instead of fossil fuels.

A combination of all investigated parameters – short distances, high load factor, low fuel consumption, etc – would lower the environmental impacts even more.

Changes in the first case

When applying a Swedwood perspective, the mixing process of water-borne lacquers is not to be included in Case I. This process should instead be charged to the environmental impact of the supplier. This is another way to calculate for the environmental impact caused by Swedwood activities, and it is interesting to analyse the outcomes, even though the method is not correct to use when speaking in terms of life cycle analysis.

When excluding the mixing process of water-borne lacquer from Case I, there is a large decrease in environmental impact for each impact category. The difference between Case I and the two other cases becomes significant, independent of which transport distance to Swedwood plant being calculated for. This is logical, since the mixing process of water-borne lacquers is the main contributor to the total environmental impact, regardless of transport distances and all other parameters, and there is no possibility for any of the other two cases to have a lower total of emissions when calculating like this. When discussing in these terms, and excluding the mixing process, the situation of today is the most preferable: transports of already mixed water-borne lacquers directly from the supplier. In that case, focus should be laid on improvements within the area of transports; e.g. driving patterns, transport distances and load factors.

Possible sources of error and further improvement areas

The figures concerning suppliers´ location and quality of lacquers and deliveries, which are used in all the calculations of this study, are based totally on communications with Swedwood actors. They might have given pieces of information not comparable with another; while some might have included total deliveries of different types of paints and lacquers, others might have included only deliveries of water-borne lacquers. This has not been investigated, and could affect the results.

Two of the Swedwood factories meant to participate have not answered the questions serving as base for calculations, and therefore have been eliminated from the study. Further investigations could focus on including them.

This study uses lacquer inventory data based on the production of water-borne stain. There are no details provided concerning this production. If analysing where within the area improvements are to be made, further investigations are required.

Waste handling is an area of future improvements, in many cases depending on the country in which the prospective mixing site is to be built; national laws and regulations must be followed. Besides the handling of solid and liquid hazardous and industrial waste, documentation is important; by knowing quantities, environmental improvements can be made.

In addition, it is important to be aware of the fact that the environmental impact varies depending on local environmental conditions. Though many emissions are global and transported long distances before fall-out, some of them directly affect the local environment when emitted. These different environmental conditions have not been taken into consideration.

The constructed calculation model used in this study can be further developed. At present it serves as a tool when receiving inventory data; it can easily deliver various types of results depending on different variable inputs. Nevertheless, focus has not yet been laid on user-friendliness, which can be improved. The model can also be expanded, including areas that in this study not have been investigated. If in the future working with this model, it is important to keep the included figures updated.

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9 Suggestions

This chapter focuses on the Swedwood perspective and discusses differences in the environmental impact of transport distances, water-borne lacquer quantities and quantities of delivery respectively. If building mixing sites; should there be many or a few, internal or central and which are the advantages and the disadvantages?

A comparison between the participating Swedwood plants contributing the most and the least to the environmental impacts

When focusing on emissions and energy demand per functional unit, the results show that the Sopron plant in Hungary is the main contributor, due to its long delivery distances from the supplier's. But, when taking lacquer quantities per delivery together with delivery quantities per year into calculation, the dominating contributor is instead the Lubawa factory, located in Poland. This is due to the highest average quantity of lacquer transported per year.

In both cases above, the Älmhult plant in Sweden is the one having the least environmental impact, because of short, intra-national transport distances and in spite of minor quantities of lacquers per delivery. Nevertheless, note that no Swedwood plant has so high delivery frequencies as Älmhult. This is an area of optimisation; Lubawa and the other plants having high impacts due to the high quantities of lacquers and deliveries could reduce its impacts by following Älmhult, except for delivery frequencies. The Älmhult plant in turn should try to co-ordinate its orders, in order to lower the delivery frequencies and thereby the emissions.

The conclusion is that transport distances and quantities of lacquers and deliveries together affect the total results, and can be optimised by looking over the suppliers' locations - perhaps changing to supplier closer by - and by looking over orders. In many cases there are large quantities of different kinds of lacquers ordered; it is possible that the same lacquer could be used for many different applications, and there should not have to be as many small orders as there are now. An investigation of lacquers used would probably enable orders of fewer different lacquers, and thereby decrease the delivery frequencies.

A comparison between three different cases

Today -when lacquers are manufactured by lacquer producers and then transported, ready-to-use, to a Swedwood plant- the environmental impact is higher for every impact category than what would be if water was to be eliminated from the lacquers before transports. Both transport distances and the transport of ready-to-use lacquers affect the total results. As already written, transport distances should be investigated and optimised, to enable lower impact results. But, this study's results show that the weight share of water eliminated from the lacquer, more than transport distance, affects the results. Efforts should be put into investigating how much water that can be eliminated without harming the end product.

Prospective building of a mixing site?

This study shows that there seems to be no reason to build up one central mixing site for each Swedwood plant. Nevertheless, the longer the transport distances, the higher the environmental impact caused by transports. The Swedwood plant having the longest lacquer transport distances (Sopron) is to 20-45 % affecting the environmental impact categories via transports. For the Sopron plant and maybe the closest following Swedwood plants, one joint central mixing site would be an idea. Advantages and disadvantages are identified and put together below:

Advantages:

- Effectiveness and specialisations concerning the mixing process (machines, technologies etc.)
- Improvements in both environmental, economical and health and safety areas could be achieved.
- Based on requirements from Swedwood plants this central mixing site could draw up large orders, optimise the delivery frequencies and provide the participating Swedwood plants with ordered lacquers and paints.
- An effective central mixing plant would lower the emissions from the mixing process, due to spin-off effects when specialising, as well as the emissions from the optimised delivery transports.
- Another positive effect would be the improved control regarding both total ordered quantities and deliveries, making further improvements easier to process.
- Direct possibilities to affect the shippers' choice of delivery route and packing routines can also affect on changes like this.

Disadvantages

- At the present situation, with orders of ready-to-use water-borne lacquers, the suppliers vouch for the quality of the products; what is not of satisfaction (manufacture defects etc.) can be returned and put in a claim for. If this process instead is handled within the Swedwood group, these production guarantees would no longer exist.
- There are both environmental and economical risks involved concerning stockholding of chemicals like lacquers and paints. Risk analyses have to been made, in order to avoid accidents leading to environmental damaging.
- When building industrial plants, there can be start-up difficulties, leading to prospectively higher emissions.

Whether building a central mixing site or an internal one, focus should be laid on improvements concerning energy use and electricity production. Usage of energy is today depending on factors like energy costs, developed technologies etc., according to in which country the plant is situated, and in many cases the environmental aspects are not as high prioritised as cost effectiveness. In addition to that, production conditions of electricity differ a lot, depending on geographical location of the plant. Improvements can be made by using electricity produced in a less environmentally impacting way, if that is possible. That depends on how the energy market works in respective country.

10 References

Written publications
Axelsson U., Jarnhammar A., Widell K-O., Jernberg P., Jansson G., Zachrisson M. & Holmer O., 1999, *Livscykelanalys av färg*, Stockholm, IVL Svenska Miljöinstitutet AB Rapport B 1338A

Goyal P.S & Aswal V.K, 2001, *Micellar structure and inter-micelle interactions in micellar solutions: Results of small angle neutron scattering studies,* Mumbai, India, Inter-University Consortium for Department of Atomic Energy Facilities, Mumbai Centre, R5-Shed, Bhabha Atomic Research Centre,

Gustafsson M., Blomqvist G., Dahl A., Gudmundsson A., Ljungman A., Lindbom J., Rudell B. & Swietlicki E., 2005, *Inandningsbara partiklar från interaktion mellan däck, vägbana och friktionsmaterial, slutrapport av WearTox-projektet*, Linköping, VTI-rapport 520, ISSN 0347-6030

Lundgren Karin, 2000, *Mått för transport –på lokal nivå*, Göteborg, KM Miljöteknik AB, Vägverket publikation 2001:8

NIFAB/Nordiska Ingenjörsbyrån för Färg AB, 2002, *Diplomkurs Färger & Lacker*

Rydh C-J., Lindahl M., Tingström J., 2002, *Livscykelanalys – en metod för miljöbedömning av produkter och tjänster,* Lund, Studentlitteratur, ISBN 91-44-02447-9

SFS, *Avfallsförordning (2001:1063)*, 2001, Miljö- och samhällsbyggnadsdepartementet

Smith R. L., Smith T.M., *Elements of Ecology – 4th edition,* 1998, Menlo Park, USA, The Benjamin/Cummings Publishing Company Inc, ISBN 0-321-01518-5

Statens energimyndighet, *Energiläget 2004,* 2004, Energimyndighetens förlag, Multitryck i Eskilstuna AB

Sterner O, *Förgiftningar och miljöhot,* 2003, Lund, Studentlitteratur, ISBN 91-4402242-5

Tillman A-M., 1994, *Godstransporter i livscykelanalys; Schablonvärden för energianvändning och emissioner*, Göteborg, CTH Teknisk miljöplanering

Uppenberg S., Almemark M., Brandel M., Lindfors L-G., Marcus H-O., Stripple H., Wachtmeister A., Zetterberg M., 2001, *Miljöfaktabok för bränslen, Del 1. Huvudrapport*, Stockholm, IVL Svenska Miljöinstitutet AB Rapport B 1334A-2

Uppenberg S., Almemark M., Brandel M., Lindfors L-G., Marcus H-O., Stripple H., Wachtmeister A., Zetterberg M., 2001, *Miljöfaktabok för bränslen, Del 2. Bakgrundsinformation och teknisk bilaga*, Stockholm, IVL Svenska Miljöinstitutet AB Rapport B 1334B-2

Uppenberg S., Stripple H., Ribbenhed M., 2003, *Miljödeklarerad infrastruktur – Metodutveckling för miljöbedömning av infrastruktursystem*, Stockholm, IVL Svenska Miljöinstitutet AB Rapport B 1526

Åhman M., Modig G., Nilsson L. J., 2005, *Transport fuels for the future – the long-term options and a possible development path*, Risø International Energy Conference: Technologies for sustainable energy development in the long term., Denmark, Roskilde, 23-25 May.

Electronic publications

Alcro Färg, http://www.pro.alcro.se
- *Alcro-Beckers miljöredovisning*,
http://www.pro.alcro.se/miljoinfo/Miljoredovisning_2004.pdf [2006-07-12]

DieselNet – Diesel Emissions Online, http://www.dieselnet.com
- A) *Diesel Exhaust: A Critical Analysis of Emissions, Exposure, and Health Effects,* http://www.dieselnet.com/papers/9710nauss.html [2006-08-23]
- B) *Emission standards: Europe; Heavy-Duty Diesel Truck and Bus Engines,* http://www.dieselnet.com/standards/eu/hd.php [2006-08-23]

EEA – European Environment Agency http://www.eea.europa.eu
- *Ten key transport and environment issues for policy-makers*, EEA Report No 3/2004 http://reports.eea.europa.eu/technical_report_2004_3/en [2006-08-19]

European Commission, http://ec.europa.eu
- *Energy and transport in figures 2005, Directorate – General for Energy and Transport*, http://ec.europa.eu/dgs/energy_transport/index_en.html [2006-08-17]
- *Europa – Environment – The Sixth Environment Action Programme of the European Community 2002-2012 – Executive Summary*, http://ec.europa.eu/environment/newprg/pdf/6eap_xsum_sv.pdf / [2006-08-19]

Europeiska Gemenskapernas Kommission, http://eur-lex.europa.eu [2006-08-20]
- Rapport från EU-Kommissionen, *Kvaliteten på bensin och diesel som används för vägtransporter i Europeiska Unionen*, KOM, 2005, 69 slutlig, http://eur-lex.europa.eu/LexUriServ/site/sv/com/2006/com2006_0186sv01.pdf

Map24 –Kartor och vägbeskrivning – karta över Sverige, Europa och USA, http://www.map24.se [2006-04-26]

Miljömålsportalen, http://www.miljomal.nu [2006-06-29]
- A) *Om miljömålen – Begränsad klimatpåverkan* http://miljomal.nu/om_miljomalen/miljomalen/mal1.php
- B) *Om miljömålen – Bara naturlig försurning,* http://miljomal.nu/om_miljomalen/miljomalen/mal3.php
- C) *Om miljömålen – Ingen övergödning* http://miljomal.nu/om_miljomalen/miljomalen/mal7.php
- D) *Ozon i luft,* http://miljomal.nu/Pub/Indikator.php?MmID=2&InkID=Ozo-27-NV&LocType=CC&LocID=SE

Nationalencyklopedin http://www.ne.se/jsp/search/article.jsp?i_art_id=236170, searched phrase: *lack* [2006-06-26]

Naturvårdsverkets webbplats, http://www.naturvardsverket.se [2006-06-29]
- A) Naturvårdsverket, *Övergödning av mark och vatten,* http://www.naturvardsverket.se/index.php3?main=/dokument/fororen/overgod/eutro.html
- B) *Miljömålen – miljömålen på köpet, de Facto 2006,* http://www.naturvardsverket.se/bokhandeln/pdf/620-1250-9.pdf

Nordsjö färg, http://nordsjo.se [2006-07-20]
- A) *Miljöredovisning Segeanläggningen 2006, Akzo Nobel,* http://www.nordsjo.se/docs/Miljobroschyr_Svensk.pdf [2006-07-20]
- B) *Avfallshantering*, 2003,, http://www.nordsjo.se/pdf/avfallshantering.pdf [2006-09-28]

NTM – Nätverket för transporter och miljön, http://www.ntm.a.se [2006-04-28]
- *Underlagsdata lastbil*, password required

OECD – Organisation for Economic Co-operation and Development [2006-08-22]
- *Analysis of the links between transport and economic growth,* 2003, Working party on National Environmental Police, Working Group on Transport, http://www.oecd.org/dataoecd/29/37/31661238.pdf

REPA – Register för producentansvar, http://www.repa.se [2006-09-08]

SPI – Svenska Petroleum Institutet, http://www.spi.se/[2006-07-13]

Svensk Energi, www.svenskenergi.se [2006-08-07]
- *Elåret 2005,* http://www.svenskenergi.se/energifakta/elaret_05/elaret_2005.pdf

Sveriges Åkeriföretag, http://www.akeriekonomi.se [2006-08-19]

TNC - Sveriges nationella centrum för terminologi och fackspråk, http://www.tnc.se [2006-07-21]

Vattenfall Europe, www.vattenfall.de [2006-07-08]
- *Curbing Climate Change – An outline of a framework leading to a low carbon emitting society,* 2006, http://www.vattenfall.de/www/vf_com/vf_com/Gemeinsame_Inhalte/DOCUMENT/360168vatt/386246envi/2005-CurbingClimateChange.pdf

Volvo på väg, http://www.volvopavag.com [2006-08-23]

Vägverket, http://www.vv.se [2006-09-08]

Personal communication

Andreasson Barbro, Warehouse/Distribution Manager, Akzo Nobel Industrial Coatings AB, Malmö, +46 40 355387, barbro.andreasson@mma.akzonobel.com [2006-07-25 – 2006-07-28]

Banovcan Marian, Purchaser, Swedwood Slovakia, Spartan, [2006-02-13 – 2006-02-28]

Barczak Jacek, Jacek.Barczak@swedwood-lubawa.com.pl [2006-02-14 – 2006-02-21]

Bazela Dusan, Dusan.Bazela@swedwood.sk [2006-02-13]

Dravai Ruben, purchasing leader, Swedwood Sopron Butor Kft, ruben.dravai@swedwood.hu [2006-02-21]

Gustafsson Erik, Business Support Purchase/EHS, Ängelholm, erik.gustafsson@swedwood.com

Gustavsson Magnus, Laboratory engineer, Application Development & Support, Perstorp Specialty Chemicals AB, +46 435 386 53, Magnus.Gustavsson@perstorp.com [2006-07-07 – 2006-07-19]

Haramiova Jana, Purchaser Swedwood Slovakia, s.r.o. OZ Malacky II. - Nabytok jana.haramiova@swedwood.sk [2006-0-07 – 2006-03-17]

Heide Flemming, sales responsible Swedwood and Slovakia, Becker Acroma, +4524401064, fhe@BeckerAcroma.com [2006-07-12]

Johansson Arja, Purchaser, Tibro Kontorsmöbler AB, arja.johansson@swedwood.com [2006-02-13 – 2006-02-22]*Käll Sven*, Swedwood AB, sven.kall@swedwood.se [2006-02-14 – 2006-02-27]

Lezniak Roman, Purchase Department, Swedwood Poland, Konstantynow, roman.lezniak@swedwood.com [2006-02-13-2006-02-21]

Ljungdahl Åsa, Research & Development, Alcro-Beckers AB, +46-8-775 63 14, asa.ljungdahl@alcro-beckers.com [2006-07-07]

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LCI data; lacquers

As discussed in *Chapter 2*, the mixing process of water-borne lacquers is assumed to cause as much environmental impact as the production of water-borne lacquers, which is assumed to be equal to that of water-borne stain. The following figures *(Table A.1)*[1] are based on industrial mean values and are used when calculating the environmental impact in all cases *(Chapter 6)*. Observe that *Table A.1* shows figures regarding both the production of raw material and the production of water-borne stain. This is compensated for when calculating; only production of water-borne stain is included.

Table A. 1 LCI data for the production of 1 kg water-borne stain (production of raw material included)*

I kg water-borne stain	Unit	
Emissions to air		
CO_2 (fossil)	[g/FU]	498
CO	[g/FU]	0,2
CH_4	[g/FU]	0,4
N_2O	[g/FU]	0
C_xH_y	[g/FU]	0,6
VOC	[g/FU]	0
$VOC_{solubles}$	[g/FU]	0,6
NO_x	[g/FU]	1,9
SO_x	[g/FU]	3,3
SO_4	[g/FU]	<0,001
PM	[g/FU]	0,2
Metals	[g/FU]	<0,001
Energy use		
Electricity	[MJ/FU]	0,2

*only emissions to air and energy use are presented here

LCI data; electricity production

Data from *Table A.2* are used when calculating for energy demand in *Chapter 6*, and later in *Chapter 9*, when comparing different production conditions for Swedwood plants.

Table A. 2 LCI data for production of electricity from the cradle to the grave[2]

Inflow	Unit	Swedish average electricity*	European average electricity**	Coal condensation***
Natural resources				
Biomass	[mg/MJ]	2660		
Coal	[mg/MJ]		45000	158000
Raw oil	[mg/MJ]	10400	8000	2730
Natural gas	[mg/MJ]	230	5600	153
Uranium	[mg/MJ]	3,9	3,3	
Emissions to air				
CO_2	[g/MJ]	13	132	231
CO	[mg/MJ]	3,6	105	32
NO_x	[mg/MJ]	21	373	614
SO_2	[mg/MJ]	14	1050	385
CH_4	[mg/MJ]	19	38	1200

* The Swedish average electricity is based on approximately 49% water power, 46% nuclear power, 5% energy heat power

** The European average electricity is based on data from UCPTE (Union for the Coordination of Production and Transmission of Electricity); which is a cooperation of energy producers in Europe. Participating countries are Austria, Belgium, France, Germany, Greece, Holland, Italy, Luxembourg, Portugal, Spain, Switzerland and Yugoslavia

***Modern coal condensation technology in Germany

[1] Axelsson, et al, 1999
[2] Rydh, et al 2002

LCI data; transport

When calculating environmental impact caused by transport, following tables are used *(Table A.3-Table A.6)*. For calculation explanations, see *Appendix C – Calculation Model*.

Table A. 3 Environmental impact caused by production and distribution of 1 MJ fuel[3]*

	Unit	Production & distribution
Energy consumption, tot	[MJ/MJ]	0,06
Emissions to air	[mg/MJ]	
NO_x	[mg/MJ]	31
SO_x	[mg/MJ]	19
CO	[mg/MJ]	2
CO_2	[mg/MJ]	3500
CH_4	[mg/MJ]	2
HC	[mg/MJ]	33
PM	[mg/MJ]	1

*only emissions to air and production & distribution are presented here

Table A. 4 Emissions to air and energy demand per tonkm caused by truck and ship transports[4]

	Unit	Truck [long distance traffic]	Truck [regional traffic]	Truck [urban traffic]	Ship
Energy demand	[MJ/(ton*km)]	0,9	1,7	2,2	0,18
SO_2	[mg/(ton*km)]	85	160	210	230
NO_x	[mg/(ton*km)]	810	1530	1980	450
CO	[mg/(ton*km)]	310	580	750	40
CO_2	[g/(ton*km)]	66	125	161	13
HC	[mg/(ton*km)]	80	150	200	11
PM	[mg/(ton*km)]	90	170	220	20

Table A. 5 Emissions from diesel engines of different classifications[5]

	Unit	Before 1990	Euro 0	Euro 1	Euro 2	Euro 3
NO_x	[g/l]	52	44	27	23	16
HC	[g/l]	6	2,1	1,8	1,3	1,3
PM	[g/l]	3	1	0,5	0,35	0,26
CO	[g/l]	8	3,7	3,4	2,5	2,3

Table A. 6 Fuel data for diesel of Mk I, Mk II and Mk III[6]

Qualities of diesel fuels	Unit	Mk I	Mk II	Mk III
Energy content	[kWh/l]	9,8	9,8	9,95
Density	[g/l]	815	815	840
Emissions of CO_2	[g/l]	2540	2560	2660
Sulphur -maximum	[mg/kg]	10	50	50
Sulphur -average	[mg/kg]	2	2	2

LCI data; base case transports

Based on the delivery and lacquer quantity information given by key actors at the different Swedwood plants, transport vehicles used in the base case of the study are trucks with 26 tons

[3] Uppenberg, et al, 2001& NTM, 2006
[4] Tillman, et al, 1994
[5] NTM, 2006
[6] Ibid

maximum loading capacity and medium-sized ships. The weight-share of water-borne lacquer in shipments is based on information from Nydensten (2006)[7]. In *Table A.7* and *Table A.8* below, data collected and calculated from NTM and Tillman et. al (1994) for those vehicles are presented.

Depending on the usage of vehicles, and the load and transport distance, energy demand and emission to air varies from case to case. Due to this, an Excel model has been built, in which variables can be changed manually resulting in automatically presented tables and diagrams. In *Appendix C – Calculation model*, the model is presented and explained.

Table A. 7 Inventory results for base case; transport per functional unit and kilometer by truck (different traffic situations)

Truck	Unit			
Max load	[ton]	26		
Fuel consumption	[l/10 km]	3,5		
Load capacity	[%]	70		
Energy content	[kWh/l]	9,77		
Density	[kg/m^3]	815		
Share of wb-weight in shipment	[%]	100		
Truck	**Unit**	**Long distance traffic**	**Regional traffic**	**Urban traffic**
Emissions to air				
CO_2	[µg/(FU*km)]	51 220	96 750	125 000
NO_x	[µg/(FU*km)]	330	620	800
HC	[µg/(FU*km)]	47	90	120
CH_4	[µg/(FU*km)]	1,4	26	3,3
CO	[µg/(FU*km)]	46	86	110
PM	[µg/(FU*km)]	5,7	11	14
SO_2	[µg/(FU*km)]	13	24	33
Energy demand	[J/(FU*km)]	720	1360	1750

Table A. 8 Inventory results for base case: transport per functional unit and kilometer by ship[8]

Medium-sized ship	Unit	Ship
Emissions to air		
CO_2 (fossil)	[µg/(FU*km)]	13 000
NO_X	[µg/(FU*km)]	450
HC	[µg/(FU*km)]	11
CO	[µg/(FU*km)]	40
PM	[µg/(FU*km)]	20
SO_2	[µg/(FU*km)]	230
Energy demand (fossil)	[J/FU*km)]	180

[7] Nydensten, 2006
[8] Tillman, et al, 1994

References

Axelsson U., Jarnhammar A., Widell K-O., Jernberg P., Jansson G., Zachrisson M. & Holmer O., 1999, *Livscykelanalys av färg*, Stockholm, IVL Svenska Miljöinstitutet AB Rapport B 1338A

Rydh C-J., Lindahl M., Tingström J., 2002, *Livscykelanalys – en metod för miljöbedömning av produkter och tjänster*, Lund, Studentlitteratur, ISBN 91-44-02447-9

Tillman A-M., 1994, *Godstransporter i livscykelanalys; Schablonvärden för energianvändning och emissioner*, Göteborg, CTH Teknisk miljöplanering

Uppenberg S., Almemark M., Brandel M., Lindfors L-G., Marcus H-O., Stripple H., Wachtmeister A., Zetterberg M., 2001, *Miljöfaktabok för bränslen, Del 2. Bakgrundsinformation och teknisk bilaga*, Stockholm, IVL Svenska Miljöinstitutet AB Rapport B 1334B-2

Underlagsdata lastbil, s.2, NTM, kräver lösenord, jag har tillfälligt
Nydensten Jan-Eric, Swedwood Älmhult [2006-06-21]

Characterisation indicators

Data in *Table B.1* are used when calculating the total environmental impact caused by the four environmental impact categories (GWP, EP, AP and POCP) used, and when calculating each chemical compound's share to environmental impact category respectively. Emissions to water are not calculated for, and therefore indicators regarding them are eliminated from the table.

Table B. 1 Characterisation indicators[1]

	GWP-100 [g CO_2-eq/g]	**EP** [g PO_4^{3-}-eq/g]	**AP** [g SO_2-eq/g]	**POCP** [g C_2H_2-eq/g]
Emissions to air				
SO_x			1	
NO_X	7*	0,13	0,696	
NH_3		0,35	1,88	
CO_2	1			
CO	3*			0,032
CH_4	21			0,007
C_2H_2				1
$CHCl_3$	5		0,803	0,004
CFC ("hard")	2,73			
CFC ("soft")	0,62			
HC	11			0,416
C_xH_y[2]				0,398
VOC[3]				0,416

* NO_x and CO contribute indirectly to a potential green house effect, and for that reason are not included in the environmental impact calculations and results.

References

Rydh C.J., Lindahl M. & Tingström J., 2002, *Livscykelanalys – en metod för miljöbedömning av produkter och tjänster*, Studentlitteratur, Lund

Axelsson U., Jarnhammar A., Widell K-O., Jernberg P., Jansson G., Zachrisson M. & Holmer O., 1999, *Livscykelanalys av färg*, Stockholm, IVL Svenska Miljöinstitutet AB Rapport B 1338A

[1] Rydh, et al., 2002
[2] Axelsson, et al., 1999
[3] Ibid

The calculation model

In order to be able to calculate emissions caused by the different transportation cases, an Excel model has been built based on data from NTM[1] and Tillman[2]. The model follows the same procedure as NTM's Internet tool NTM Calc when calculating, and the outcomes have been controlled and compared, showing that this model works. By using this model, the result can be presented instantly, both in tables and in diagrams, without having to copy tables from the NTM Calc. This model facilitates the analysis made during this master thesis, because of the many cases, factories and parameters being analysed.

Calculation description

In *Table C.1*, all parameters that the user itself can change are presented. The empty squares can be filled in with values either based on NTM's data, or by own assumptions. The calculation process *(Table C.2)* uses values introduced in *Tables A.3-A.6* in *Appendix A* and *Table B.1* in *Appendix B.* In *Table C.2*, the steps from S*tep I* to *Step VI* concern the transportation, and in *Step VII*, the mixing process of water-borne lacquers is added, resulting in a total environmental impact calculation in *Step VIII*.

Table C. 1 Environmental impact sheet – used in the Excel model

i. Transportation from supplier to mixing central	**Unit**		**Truck [long distance traffic]**	**Truck [regional traffic]**	**Truck [urban traffic]**	**Ship**
Distance X	[km]					
Lacquer concentration	[%]					

ii. Transportation from mixing central to Swedwood factory			**Truck [long distance traffic]**	**Truck [regional traffic]**	**Truck [urban traffic]**	**Ship**
Distance Y	[km]					
Lacquer concentration	[%]					

If X=0; the supplier provides water-borne lacquers (present conditions) [Case I]
If Y=0; the mixing central is located at or nearby the Swedwood factory [Case II]
If 0<X<(X+Y); the mixing central is located somewhere between the supplier and the Swedwood factory [Case III]

iii. Vehicle data	**Unit**	
Maximum load capacity	[ton]	
Load factor	[%]	
Fuel consumption	[l/10km]	

Following figures depend on type of engine (Euro) and diesel quality (Mk); see *Table A.5* and *Table A.6*

iv. Diesel quality	**Unit**	
Density	[kg/m3]	
Energy content	[kWh/l]	
Emissions of CO2	[g/l]	
Sulphur -average	[kg/kg]	
v. Diesel engine emission	**Unit**	
NOx	[g/l]	
HC	[g/l]	
PM	[g/l]	
CO	[g/l]	

[1] NTM, 2006
[2] Tillman, et al, 1994

Table C. 2 The calculation process of the developed Excel model, calculating the total environmental impact caused by transport and mixing process of water-borne lacquers

Step	Explanation	Calculation	Unit
I	Calculation of environmental performance (energy demand and emissions to air) when driving the truck 10 km	*Emissions to air:* Table A.5 [g/l]*fuel consumption [l/10km] *Emissions to air (CO2):* Table A.6 [g/l]*fuel consumption [l/10km] *Emissions to air (SO2):* Table A.6 [g/l]* fuel consumption [l/10km]*Table A.6 [kg/kg]*64/32 [(g/mol)/(g/mol)] *Energy demand:* Table A.6 [kWh/l]l*fuel consumption [l/10km]	[g/10km] [kWh/10km]
II	Calculation of environmental performance for fuel provision	*Emissions to air:* Table A.6 [kWh/l]*fuel consumption [l/10km] *Table A.3 [g/MJ]*3,6 [MJ/kWh] *Energy demand:* Table A.6 [kWh/l]*fuel consumption [l/10km] *Table A.3 [MJ/MJ]	[g/10km] [kWh/10km]
III	Calculation of transported freight by truck	Load factor [%]*0,01[$\%^{-1}$]*maximum load capacity [ton]	[ton]
IV	Distribution of the environmental performances (Step I & Step II) to transported freight (Step III)	*Emissions to air:* (Step I+Step II)/Step III [(g/10km)/ton)]*0,1 [10 km/km] *Energy demand:* (Step I+Step II)/Step III [(kWh/10km)/ton)]*0,1 [10 km/km]	[g/tkm] [kWh/tkm]
V	Calculation of environmental impact per tkm, distributed for each transportation distance. Using Table A.4 as base and factors for multiplication. The figures for ship remain unchanged.	*Emissions to air:* Step IV [g/tkm]*Table A.4 [(g/tkm)/(g/tkm)] *Energy demand:* Step IV [kWh/tkm]*Table A.4 [(kWh/tkm)/(kWh/tkm)] *3,6 [MJ/kWh]	[g/tkm] [MJ/tkm]
VI	Calculation of emissions per functional unit	*Emissions to air: (*Distance X [km]*Step V [g/tkm]*0,001 [ton/FU]*Share of wb-lacquer-weight [%]*0,01 [$\%^{-1}$])+(Distance Y [km]*Step V [g/tkm]*0,001 [ton/FU]) *Energy demand:* (Distance [km]*Step V [MJ/tkm]*0,001 [ton/FU]* Share of wb-lacquer-weight [%]*0,01 [$\%^{-1}$])+(Distance Y [km]*Step V [MJ/tkm]*0,001 [ton/FU])	[g/FU] [MJ/FU]
VII	Calculation of total emissions per functional unit (transportation + mixing process of w-b lacquer)	*Emission to air:* Step VI [g/FU]+Table A.1 [g/FU] *Energy demand:* Step VI [g/FU]+Table A.1 [g/FU]	[g/FU] [MJ/FU]
VIII	Calculation of total environmental impact per functional unit	*Emissions to air:* Step VII [g/FU]*Table B.1 [g X-eq/g]	[g X-eq/FU]

References
NTM – Nätverket för transporter och miljön, http://www.ntm.a.se [2006-04-28]
- *Underlagsdata lastbil*, password required

Tillman A-M., 1994, *Godstransporter i livscykelanalys; Schablonvärden för energianvändning och emissioner*, Göteborg, CTH Teknisk miljöplanering

Environmental impact tables

The following tables show the different types of environmental impact as a percentage for the Swedwood plants analysed in *Chapter 6*. The figures are calculated with *Table 3* in *Chapter 5* as a basis, following the calculation model presented in *Appendix C*.

Global warming Potential (GWP)

Table D. 1 GWP emissions per FU and Swedwood plant and transport share as a percentage of total emission

Emissions/FU	Unit	Production	Transports	Unit	Transport impact of total emissions
Sopron	[g CO_2-eq/FU]	329	126	[%]	28
Siret	[g CO_2-eq/FU]	329	106	[%]	24
Lubawa	[g CO_2-eq/FU]	329	104	[%]	24
Malacky-2	[g CO_2-eq/FU]	329	57	[%]	15
Spartan	[g CO_2-eq/FU]	329	57	[%]	15
Bräntorp	[g CO_2-eq/FU]	329	34	[%]	9
Konstantynow	[g CO_2-eq/FU]	329	24	[%]	7
Tibro	[g CO_2-eq/FU]	329	19	[%]	6
Jasna	[g CO_2-eq/FU]	329	19	[%]	6
Älmhult	[g CO_2-eq/FU]	329	8	[%]	2

Table D. 2 Emissions affecting GWP, as a percentage

Emissions	Unit	Long distance traffic	Regional traffic	Urban traffic	Ship
CO_2	[%]	98,9	98,9	98,9	99,1
HC	[%]	1,0	1,0	1,0	0,9
CH_4	[%]	0,1	0,1	0,1	0
Total	[%]	100	100	100	100

Acidfication Potential (AP)

Table D. 3 AP emissions per FU and Swedwood plant and transport share as a percentage of total emission

Emissions/FU	Unit	Production	Transports	Unit	Transport impact of total emissions
Sopron	[mg CO_2-eq/FU]	2470	610	[%]	20
Siret	[mg CO_2-eq/FU]	2470	520	[%]	17
Lubawa	[mg CO_2-eq/FU]	2470	510	[%]	17
Malacky-2	[mg CO_2-eq/FU]	2470	290	[%]	11
Spartan	[mg CO_2-eq/FU]	2470	260	[%]	10
Bräntorp	[mg CO_2-eq/FU]	2470	160	[%]	6
Konstantynow	[mg CO_2-eq/FU]	2470	110	[%]	4
Tibro	[mg CO_2-eq/FU]	2470	90	[%]	4
Jasna	[mg CO_2-eq/FU]	2470	90	[%]	4
Älmhult	[mg CO_2-eq/FU]	2470	40	[%]	1

Table D. 4 Emissions affecting AP, as a percentage

Emissions	Unit	Long distance traffic	Regional traffic	Urban traffic	Ship
NO_x	[%]	94,6	94,6	94,6	57,7
SO_2	[%]	5,4	5,4	5,4	42,3
Total	[%]	100	100	100	100

Eutrophication Potential (EP)

Table D. 5 EP emissions per FU and Swedwood plant and transport share as a percentage of total emission

Emissions/FU	Unit	Production	Transports	Unit	Transport impact of total emissions
Sopron	[mg CO_2-eq/FU]	128	110	[%]	45
Siret	[mg CO_2-eq/FU]	128	90	[%]	41
Lubawa	[mg CO_2-eq/FU]	128	90	[%]	41
Malacky-2	[mg CO_2-eq/FU]	128	50	[%]	28
Spartan	[mg CO_2-eq/FU]	128	50	[%]	27
Bräntorp	[mg CO_2-eq/FU]	128	30	[%]	18
Konstantynow	[mg CO_2-eq/FU]	128	20	[%]	14
Tibro	[mg CO_2-eq/FU]	128	20	[%]	11
Jasna	[mg CO_2-eq/FU]	128	20	[%]	11
Älmhult	[mg CO_2-eq/FU]	128	10	[%]	5

Table D. 6 Table D.6 Emissions affecting EP, as a percentage

Emissions	Unit	Long distance traffic	Regional traffic	Urban traffic	Ship
NO_x	[%]	100	100	100	100
Total	[%]	100	100	100	100

Photochemical Oxidation Creation Potential (POCP)

Table D. 7 POCP emissions per FU and Swedwood plant and transport share as a percentage of total emission

Emissions/FU	Unit	Production	Transports	Unit	Transport impact of total emissions
Sopron	[g CO_2-eq/FU]	111	50	[%]	20
Siret	[g CO_2-eq/FU]	111	40	[%]	17
Lubawa	[g CO_2-eq/FU]	111	40	[%]	17
Malacky-2	[g CO_2-eq/FU]	111	20	[%]	11
Spartan	[g CO_2-eq/FU]	111	20	[%]	10
Bräntorp	[g CO_2-eq/FU]	111	10	[%]	6
Konstantynow	[g CO_2-eq/FU]	111	10	[%]	4
Tibro	[g CO_2-eq/FU]	111	10	[%]	4
Jasna	[g CO_2-eq/FU]	111	10	[%]	4
Älmhult	[g CO_2-eq/FU]	111	1	[%]	1

Table D. 8 Emissions affecting POCP, as a percentage

Emissions	Unit	Long distance traffic	Regional traffic	Urban traffic	Ship
CO2	[%]	93,1	93,1	93,1	
HC	[%]	6,9	6,9	6,9	
CH4	[%]	0,0	0,0	0,0	
Total	[%]	100	100	100	

Energy Demand

Table D. 9 Energy demand per FU and Swedwood plant and transport share as a percentage of total emission

Emissions/FU	Unit	Production	Transports	Unit	Transport impact of total emissions
Sopron	[MJ/FU]	1,7	1,75	[%]	51
Siret	[MJ/FU]	1,7	1,47	[%]	46
Lubawa	[MJ/FU]	1,7	1,45	[%]	46
Malacky-2	[MJ/FU]	1,7	0,79	[%]	32
Spartan	[MJ/FU]	1,7	0,79	[%]	32
Bräntorp	[MJ/FU]	1,7	0,48	[%]	22
Konstantynow	[MJ/FU]	1,7	0,34	[%]	17
Tibro	[MJ/FU]	1,7	0,27	[%]	14
Jasna	[MJ/FU]	1,7	0,27	[%]	14
Älmhult	[MJ/FU]	1,7	0,11	[%]	6

Sensitivity analysis calculation

The following tables are used in *Chapter 7*, when analysing the different parameters' impacts on the result. Each investigated parameter in the sensitivity analysis has its own table. *Table E.1* is further analysed in *Chapter 9*, where a Swedwood perspective is used. The calculation process follows the calculation model in *Appendix C*, and the data are the same as used in the calculations in *Chapter 6*. In *Tables E.2-E.4* and in *Tables E.6-E.7*, emissions to air caused by the mixing process are excluded, in order to illustrate how the results as a percentage changes when varying the transport parameters. In *Table E.5*, figures for total emissions (mixing process and transport) are presented.

Case I

Table E.1 Calculation of the three cases for Sopron and Älmhult, and Case I with the production of water-borne lacquers excluded

GWP-100	Unit	Case I excl. prod	Case I	Case II	Case III
Sopron					
Production	[g CO_2-eq/FU]	0	329	329	329
Transport	[g CO_2-eq/FU]	126	126	101	115
Total	[g CO_2-eq/FU]	126	455	430	444
Älmhult					
Production	[g CO_2-eq/FU]	0	329	329	329
Transport	[g CO_2-eq/FU]	7,8	8	6	8
Total	[g CO_2-eq/FU]	7,8	337	335	337

EP	Unit	Case I excl. prod	Case I	Case II	Case III
Sopron					
Production	[mg PO_4^{3-}-eq/FU]	0	128	128	128
Transport	[mg PO_4^{3-}-eq/FU]	106	106	85	96
Total	[mg PO_4^{3-}-eq/FU]	106	235	214	225
Älmhult					
Production	[mg PO_4^{3-}-eq/FU]	0	128	128	128
Transport	[mg PO_4^{3-}-eq/FU]	6	6	5	6
Total	[mg PO_4^{3-}-eq/FU]	6	135	134	135

AP	Unit	Case I excl. prod	Case I	Case II	Case III
Sopron					
Production	[mg SO_2-eq/FU]	0	2470	2470	2470
Transport	[mg SO_2-eq/FU]	613	610	490	550
Total	[mg SO_2-eq/FU]	613	3100	3000	3000
Älmhult					
Production	[mg SO_2-eq/FU]	0	2470	2470	2470
Transport	[mg SO_2-eq/FU]	37	40	30	40
Total	[mg SO_2-eq/FU]	37	2500	2500	2500

POCP	Unit	Case I excl. prod	Case I	Case II	Case III
Sopron					
Production	[mg C_2H_2-eq/FU]	0	111	111	111
Transport	[mg C_2H_2-eq/FU]	52	52	41	47
Total	[mg C_2H_2-eq/FU]	52	162	152	158
Älmhult					
Production	[mg C_2H_2-eq/FU]	0	111	111	111
Transport	[mg C_2H_2-eq/FU]	3	3	2,2	2,2
Total	[mg C_2H_2-eq/FU]	3	114	113	114

Transport distances

Table E.2 Emissions to air when changing the long distance transport parameters, emissions caused by mixing process excluded

Emissions to air	Unit	X=10 km, Y=90 km	X=25 km, Y=75 km	X=50 km, Y=50 km	X=75 km, Y=25 km	X=90 km, Y=10 km
GWP-100	[mg CO_2-eq/FU]	27000	26200	24800	23500	22600
Total	[%]	109	106	100	94	91
EP	[mg PO_4^{3-}-eq/FU]	22,3	21,6	20,5	19,3	18,7
Total	[%]	109	106	100	94	91
AP	[mg SO_2-eq/FU]	126	122	116	110	106
Total	[%]	109	106	100	94	91
POCP	[mg C_2H_2-eq/FU]	11,1	10,7	10,1	9,6	9,3
Total	[%]	109	106	100	94	91

Load factor

Table E.3 Emissions to air when changing the truck load factor, emissions caused by mixing process excluded

Emissions to air	Unit	Load factor 55 %	Load factor 70 %	Load factor 85 %
GWP-100	[g CO_2-eq/FU]	160	126	104
Total	[%]	127	100	82
EP	[mg PO_4^{3-}-eq/FU]	135	106	88
Total	[%]	127	100	82
AP	[mg SO_2-eq/FU]	772	613	509
Total	[%]	127	100	82
POCP	[mg C_2H_2-eq/FU]	66	52	43
Total	[%]	127	100	82

Fuel consumption

Table E.4 Emissions to air when changing the truck fuel consumption, emissions caused by mixing process excluded

Emissions to air	Unit	Fuel consumption 3 l/10 km	Fuel consumption 3,5 l/10 km	Fuel consumption 4 l/10 km
GWP-100	[g CO_2-eq/FU]	89	104	119
Total	[%]	86	100	114
EP	[mg PO_4^{3-}-eq/FU]	76	88	100
Total	[%]	86	100	114
AP	[mg SO_2-eq/FU]	441	510	579
Total	[%]	86	100	114
POCP	[mg C_2H_2-eq/FU]	37	43	49
Total	[%]	86	100	114

Type of engine

Table E.5 Emissions to air, long distance traffic, Mk I, when changing the truck engine

Emissions to air	Unit	before 1990	Euro 0	Euro 1	Euro 2	Euro 3
GWP-100						
mixing process	[mg CO_2-eq/FU]	329000	329000	329000	329000	329000
	[%]	99,98	99,98	99,98	99,98	99,98
transport	[mg CO_2-eq/(FU*km)]	50	50	50	50	50
	[%]	0,02	0,02	0,02	0,02	0,02
EP						
mixing process	[ug PO_4^{3-}eq/FU]	130000	130000	130000	130000	130000
	[%]	99,97	99,97	99,97	99,97	99,97
transport	[ug PO_4^{3-}-eq/(FU*km)]	138	113	70	60	43
	[%]	0,10	0,09	0,05	0,05	0,03
AP						
mixing process	[ug SO_2-eq/FU]	2470000	2470000	2470000	2470000	2470000
	[%]	99,99	99,99	99,99	99,99	99,99
transport	[ug SO_2-eq/(FU*km)]	724	617	389	335	242
	[%]	0,03	0,02	0,02	0,01	0,01
POCP						
mixing process	[ug C_2H_2-eq/FU]	110000	110000	110000	110000	110000
	[%]	99,98	99,98	99,98	99,98	99,98
transport	[ug C_2H_2-eq/(FU*km)]	62	28	26	21	21
	[%]	0,06	0,03	0,02	0,02	0,02

Type of fuel

Table E.6 Emissions to air when changing the diesel quality[1]

Emissions to air	Unit	Mk I	Mk II	Mk III
GWP-100				
mixing process	[g CO_2-eq/FU]	329	329	329
	[%]	72,8	72,8	72,8
transport	[g CO_2-eq/(FU*km)]	123	124	50
	[%]	27,2	27,2	28,4
EP				
mixing process	[mg PO_4^{3-}eq/FU]	128	128	128
	[%]	55,9	55,9	55,9
transport	[mg PO_4^{3-}-eq/(FU*km)]	101	101	101
	[%]	44,1	44,1	44,1
AP				
mixing process	[mg SO_2-eq/FU]	2470	2470	2470
	[%]	81,2	81,2	81,2
transport	[mg SO_2-eq/(FU*km)]	574	577	578
	[%]	18,9	19,0	19,0
POCP				
mixing process	[mg C_2H_2-eq/FU]	110	110	110
	[%]	68,8	68,8	68,8
transport	[mg C_2H_2-eq/(FU*km)]	50	50	50
	[%]	31,2	31,2	31,2

[1] N.B. The maximum sulphur figures are used, instead of the average figures.

Water weight reduction

Table E.7 Emissions to air when changing the weight reduction of water, emissions caused by mixing process excluded

Emissions to air	Unit	Weight reduction 0 %	Weight reduction 10 %	Weight reduction 20 %	Weight reduction 40 %	Weight reduction 60 %
GWP-100						
transport	[g CO_2-eq/FU]	126	114	101	76	50
	[%]	27,7	24,9	22,2	16,6	11,1
mixing process	[g CO_2-eq/FU]	329	329	329	329	329
	[%]	72,3	72,3	72,3	72,3	72,3
EP						
transport	[mg PO_4^{3-} eq/FU]	106	95	85	64	43
	[%]	45,3	40, 8	36,3	27,2	18,1
mixing process	[mg PO_4^{3-} eq/FU]	128	128	128	128	128
	[%]	54,7	54,7	54,7	54,7	54,7
AP						
transport	[mg SO_2-eq/FU]	613	551	490	368	245
	[%]	19,9	17,9	15,9	11,9	7,9
mixing process	[mg SO_2-eq/FU]	2470	2470	2470	2470	2470
	[%]	80,1	80,1	80,1	80,1	80,1
POCP						
transport	[g C_2H_2-eq/FU]	51,6	46,4	41,3	31,0	20,7
	[%]	31,86	28,6	25,4	19,1	12,7
mixing process	[g C_2H_2-eq/FU]	111	111	111	111	111
	[%]	68,2	68,2	68,2	68,2	68,2

Electricity production

Table E.8 Emissions to air caused by electricity production, when changing geographical electricity production conditions, emissions caused by transport excluded

Emissions to air	Unit	Swedish average electricity	European average electricity	Coal condensation
GWP	[g CO_2-eq/FU]	1,7	18	33
EP	[ug PO_4^{3-}eq/FU]	350	6300	10400
AP	[mg SO_2-eq/FU]	3,7	170	106
POCP	[ug C_2H_2-eq/FU]	32	780	1200

Swedwood perspective; tables and figures

The data in *Table F.1* below are based on data collected from the Swedwood key actors *(Chapter 5, Table 3)* and are used when investigating each plant through a Swedwood perspective in *Chapter 9*. The figures below *(Figures F.1-F4)* present the data from *Table F.1* in an illustrative way: emissions from environmental impact categories per year.

Table F 1 Emissions per year for each participating Swedwood plant, only transport

Emissions per year	GWP-100 [ton CO_2-eq]	EP [kg PO_4^{3-}-eq]	AP [kg SO_2-eq]	POCP [kg C_2H_2-eq]
Lubawa	93,7	79,4	459	38,3
Sopron	42,6	36,0	207	17,5
Spartan	16,3	13,4	76,0	6,7
Malacky-2	14,3	12,3	72,5	5,8
Bräntorp	13,9	11,5	64,9	5,7
Siret	10,1	8,6	49,6	4,1
Tibro	8,6	7,1	40,0	3,5
Konstantynow	7,6	6,3	35,6	3,1
Jasna	2,0	1,7	9,4	0,8
Älmhult	0,6	0,5	2,9	0,3

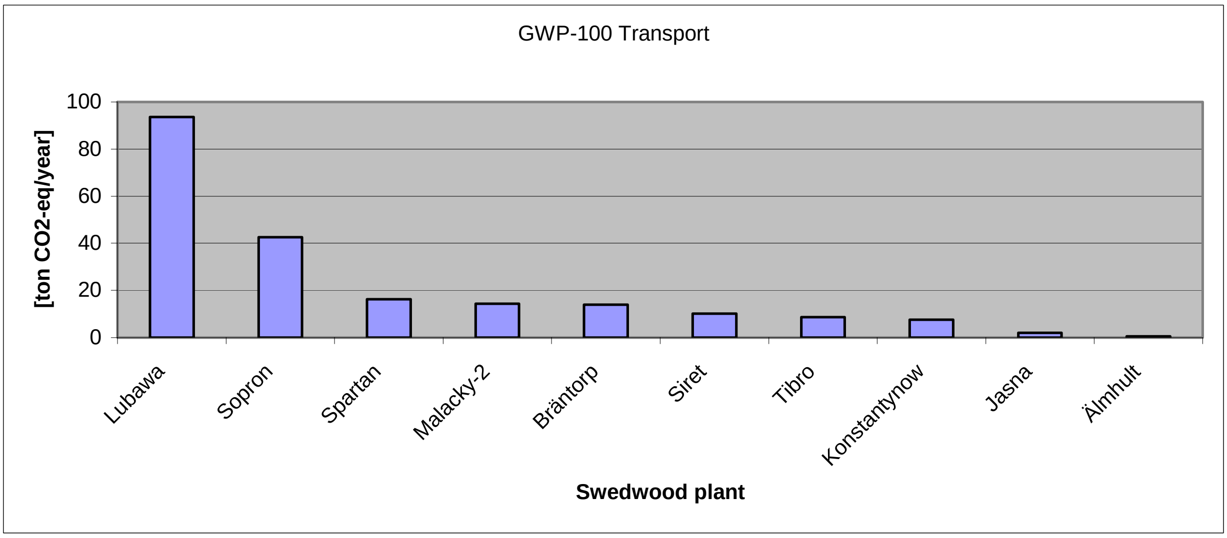

Figure F.1 GWP per year for each participating Swedwood plant, only transports

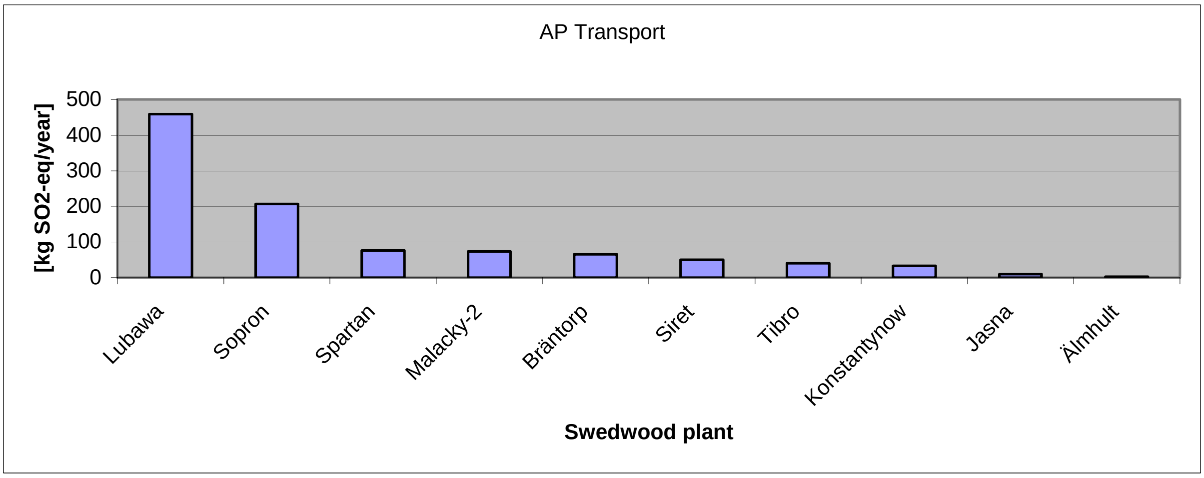

Figure F.2 AP per year for each participating Swedwood plant, only transports

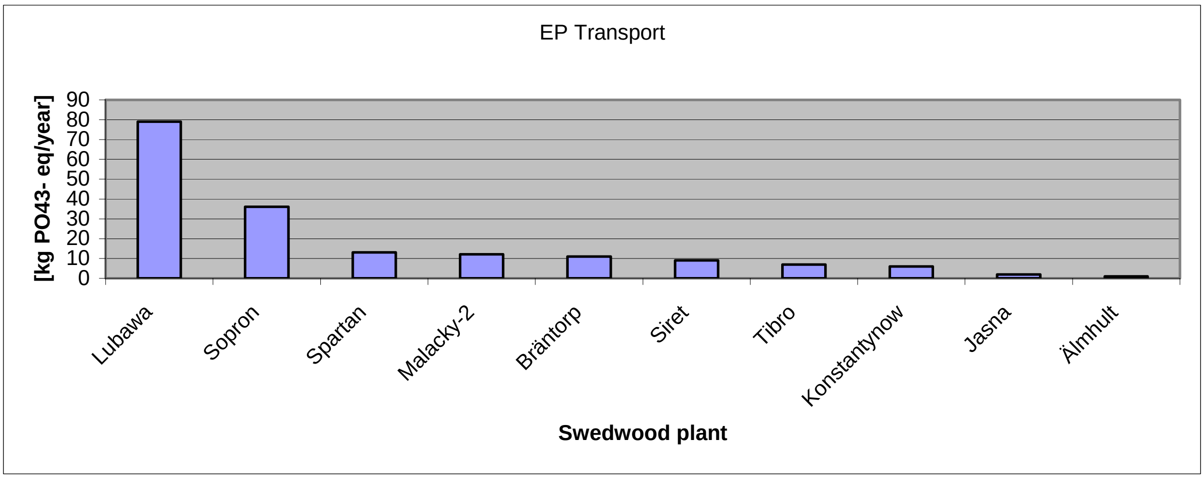

Figure F.3 EP per year for each participating Swedwood plant, only transports

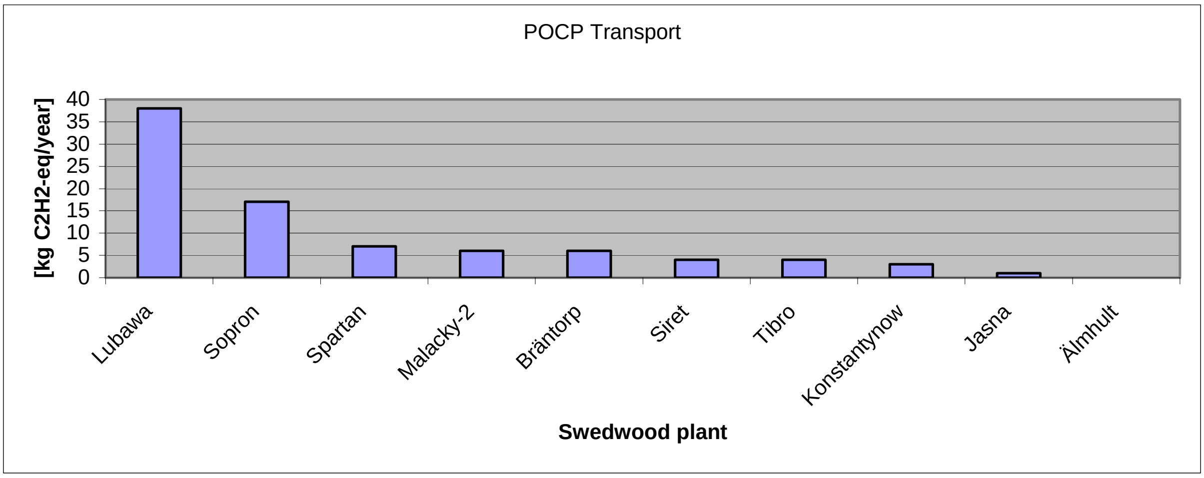

Figure F.4 POCP per year for each participating Swedwood plant, only transports

References:
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