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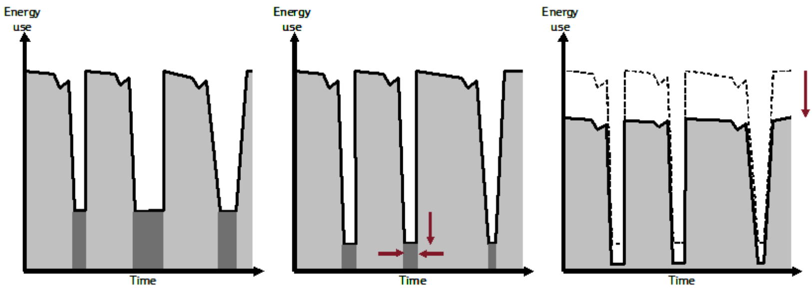

Environmentally assessing a Product-Service System

Bearings & maintenance in the pulping industry

Master of Science Thesis

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Cover: energy consumption in a typical pulp mill. The pits represent energy consumption during downtime, a common result of bearing failure. Bearing maintenance aims at reducing the width of these gaps, but also the grey areas in general. How is this connected to the environmental impact of the final pulp product? (Illustration by Mats M. Berglund, SKF)

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Preface

This report sums up roughly six months of intense work. It has been a long personal journey for me, and an experience out of the ordinary in my academic career. As I started to investigate the maintenance contract offered by SKF, I had no idea where I was going to end up in my research. Countless dead ends forced me to change direction and try new paths, think in new ways and kill my darlings. It surely taught me a lot on how to lead a project, how to communicate, the importance of honesty and clarity and finally the complexity of reality.

Many people have helped me on this journey, and I would like to thank my industrial supervisor Magnus Fors for an amazing flow of energy and ideas. Great thanks I owe also to the company SKF for providing the case scenario and the means to conduct this study, as well as to DMI for providing the necessary data. Also to all their employees around the world that I have come across during the work; Scott, John, Dennis, Lars, Tor, Matthew, Per, Hanna, Björn, Mats, Birger, Paul and Jonas and many more. All the people that helped, inspired and supported me at the department of Environmental Systems Analysis at Chalmers University in Gothenburg. I especially want to thank also my academic supervisor Henrikke Baumann for a sharp mind and sharp eyes as well as my secondary supervisor Steven Sarasini for support and inspiration.

Gothenburg, February 2013.

Nothing is as great as life.

Summary

Compelling evidence tells us we need to change consumption and production patterns to allow for ecosystems not to collapse in the near future. This is true also for industrial actors and the products they manufacture and sell to be incorporated in other systems, manufacturing other products. Not only must manufacturing processes be radically more effective, it seems also that there is a need to consume less material goods and focus more on the utility of products then the products per se. Product-Service Systems, PSS, are put forward as a tool with this aim. The study uses a case scenario where a bearing manufacturer and a pulp mill engage in a bearing maintenance contract, identified as being a PSS.

The study aims at assessing the effectiveness of that PSS. It is done in two steps; the first is a custom environmental assessment of the pulp over time for the duration of the maintenance contract so far. The second is a more in-depth, qualitative analysis of the contract structure, which is compared to literature findings on PSS that support environmental goals. The results render information on both the effectiveness of the PSS and some improvement potentials. Trends illustrate a worsening of environmental performance of the pulp production over time, but also some promising areas open for improvement. They could be addressed by internalizing the costs of products, setting explicit environmental goals and making cultural change efforts in the bearing manufacturer organisation.

Sammanfattning

Övertygande bevis talar för att det måste ske en radikal förändring i hur vi konsumerar och producerar varor i dagens samhälle, för att ekosystemen ska kunna hantera bördan. Inte minst är det viktigt i industriella sammanhang, där tillverkare framställer produkter som säljs till andra tillverkare som använder dem att framställa en tredje typ av produkt. Inte bara måste produktion bli effektivare, the måste till en förändring som gör att vi konsumerar mindre materiella produkter överlag, och fokuserar mer på nyttan av produkter än på den specifika produkten i fråga. Så kallade Produkt-Service System, PSS, har lyfts fram som en potentiell åtgärd för att råda bot på detta. Den här uppsatsen utgör en fallstudie där en tillverkare av kullager och en pappersmassatillverkare samarbetar kring ett underhållskontrakt för lagren i fråga. Detta kontrakt identifieras i studien som ett PSS.

Studien ämnar utvärdera effektiviteten i detta PSS. Det görs i två steg: inledningsvis genom en utvärdering av miljöpåverkan i tillverkning av pappersmassa och därefter genom en mer djupgående analys av kontraktet mot bakgrund av vad som sägs i akademisk litteratur om hur ett miljöeffektivt PSS ser ut. På så vis genereras resultat som berättar något om hur effektivt kontraktet är i praktiken, och hur det kan förbättras ytterligare. Resultaten visar en trend till ökande miljöpåverkan av pappersmassaproduktionen, men finner också hoppfulla förbättringsområden. Främst ligger de i att internalisera kostnaderna för lager i kontraktet, att sätta upp specifika miljöbaserade mål och att söka få till stånd en kulturell förändring i organisationen hos lagertillverkaren som stödjer ett arbete mot en kombination av produkter och service.

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1 Introduction

Recently, it has become clear that in order to create a sustainable society, interventions have to be more radical than just the re-designing of existing products. In fact, many schools of thought hold that for a sustainable society, we need to move towards a point where we are reliant on 10% of the resources that are consumed by industrialized countries today (per capita) (UNEP, 2002). Technological solutions are usually incremental in nature and tend to lead to even higher levels of pollution during the entire life cycle (Mont, 2000). If technological improvements make products cheaper, consumer spend the money earned on more products, thus potentially increase the environmental burden (Goedkoop, 1999).

Traditionally, economic systems have been the result of linear thinking. After the point of sale, the manufactures responsibility ends and the buyer becomes responsible for the utilization and disposal of goods, many times without knowing what resources are incorporated in the goods and how to efficiently utilize the goods during usage and disposal (Stahel, 1986). In life cycle studies, it is often concluded that the major impact occurs during the usage phase (see for example studies on housing (Ortiz, Castells, & Sonneman, 2008), on various products groups (Hanssen, 1998), on automobiles (Maclean & Lave, 1998) or on floor coverings (Jönsson, 1999)). Producers have had little incentive to focus on the end of life of products (i.e., after consumers have discarded them), because managing this has been the responsibility of government. In other words, factors such as the amount of waste generated by a product and the cost of recycling or disposing of it have not been included in the bottom line of companies that make the product (Fishbein, McGarry, & Dillon, 2000).

Even though efficiency measures might have decreased the relative pressure on the environment for each product manufactured, the rise in consumption has still increased the pressure on the environment in total measures (Naturvårdsverket, 2005). And as global consumption is forecast to continue in the future (WWF, 2012), there is a need to consume less material products, rather than continuously increasing the consumption of less damaging products. Simultaneously, traditional manufacturers are dependent on the sales volume of their products, as it is the key driver of profit. This creates an incentive to *increase* product turnover. Product manufacturers even have incentives to design goods with built-in obsolescence (Fishbein, McGarry, & Dillon, 2000) to keep sales volume increasing. It must also be acknowledged that merely increasing energy efficiency of production processes must not directly correlate with reduced environmental burdens, when this has external secondary effects. Such was the case in a study on passive housing, where results indicated a higher environmental load in some aspects when the house was disconnected from district hearing systems to rely more on electrical energy from grid. Even though total consumption was lower, some aspects of total impact did still increase (Brunklaus et al, 2010). Hence, there is a need to carefully assess each case of action to ensure environmental impact reduction. To increase manufacturer influence over its products and their life cycles, a systemic perspective and an integration of actor responsibility and activities is required (Baumann, Boons, & Bragd, 2002). The only answer to reduce the flow of material products is to create products and services that provide consumers with the same level of performance and that have a much more dematerialized life cycle and thus, a lower environmental burden (Mont, 2000).

It has been suggested that the approach of a Product-Service System (PSS) is capable of doing so. It is based on the idea that producers integrate with their customers, away from merely transferring products to agree upon a service with a specific performance. An example could be a maintenance contract to support a product sold, or a car pool where users pay for a service. Common in both examples is that the function or performance is more important that the product *per se*. PSS could potentially *decouple value creation from environmental impacts* through efficiency measures and the reduction of product material overturn.

For a manufacturer of bearings to be used in the pulping industry, what has been described above is highly relevant. To address higher societal demands on environmentally sound business, effective measures are highly sought for. The manufacturer activities impact the environment in two significant ways. The first is the contribution that the products can make in reducing the impact of the pulping industry and its products. Bearings functionality influence performance of a pulp mill, and has the potential to reduce energy consumption per unit of pulp produced. The second is the impact of the own manufacture, both the impact of each product and the total impact of production. As business grows, impact needs to decline.

This study departs from acknowledging that a PSS has a possible potential of helping a manufacturer reduce it's dependence on product overturn to generate profit, and that this same system can aid reducing the environmental impact of the products and the processes they function in. In total, this system can reduce the environmental impacts induced by both the manufacturer and its customers engaged in the Product-Service System.

1.1 Aims

The aim of this study is twofold; the first being to examine how bearing maintenance can influence environmental impact of pulp. The second part of the aim is to find a structured and logical way to assess the maintenance offer, on the basis of its potential of reducing the environmental impact, stemming from manufacture or use of the product. Conducting this assessment will then complete the aim.

1.2 Methodology

To support the aims, a case study concerning two actors is utilized. Data collection includes quantitative data from the pulp production process, and qualitative data through interviews from the bearing manufacturer to support the assessment of the PSS offer. The first part tracks process energy consumption over a time span of the four years preceding this study. Energy consumption is translated into environmental impacts inspired by the Impact Assessment part of the Life Cycle Analysis methodology. This translates environmental information to comprehensible information (Baumann & Tillman, 2004). The second part analyses the PSS offer through information on its fundamental structure and characteristics.

1.3 Report outline

This report starts off by describing the case study and its involved actors and relationship. It includes an in-depth description the maintenance contract and its aims, its elements and implementation. This is followed by a specific analysis of the contract in the case study; how it was set up and what determined its goals and targets, what people was involved and at what stages. It continues by setting the scope of the environmental assessment by describing the pulping production and how bearings are utilized in this process. The connection to energy consumption and environmental impacts is established and further delimitations to the assessment are presented. Following this information is the results of the assessment and how they can be interpreted. Thereafter, a point of theoretic reference is generated by some literature findings on environmental perspectives of Product-Service Systems. This literature study, the environmental assessment and the qualitative analysis of the contract in the case study, allows for an analysis of the environmental benefits and potential of utilizing maintenance contracts as a means of reducing the environmental impact of bearings in industrial use and of pulp production.

2 Case study

This section outlines the basis of the case study. The manufacturer, the customer and the fundamentals of the maintenance service are described in order to form an understanding of the layout of the study.

2.1 The manufacturer

SKF is a leading global supplier of bearings, seals, mechatronics, lubrication systems and services that include technical support, maintenance and reliability services, engineering consulting and training. Employee count reaches over 40.000 world wide and its customers are split into three business areas and 40 business segments of which pulp and paper industry is one. Bearings constitute the fundamental product and SKF is proud over its long traditions and great knowledge in industrial bearing manufacture and utilization.

2.2 The customer

Daishowa-Marubeni International Ltd. (DMI) is an integrated forest products company first established in western Canada in 1969 by Daishowa Paper Manufacturing Co. Ltd. and Marubeni Corporation of Japan. DMI is a producer of roughly 500,000 tons of pulp each year. The process is a chemical Kraft pulp, from which cardboard, fine papers, and various grades of printing papers, etc. is made. The mill is a modern facility, situated on the North American continent, with infrastructure to support exporting electrical energy to the local grid. Electrical energy supply in the region is primary coal fired (DMI, 2013).

2.3 General features of the IMS

This information has been gathered through interviews of key individuals at SKF; one Business Development Manger, two Senior Maintenance Consultants and one Maintenance Strategy Consultant as well as through studies of official material of the manufacturers official webpage unless in any other way stated.

2.3.1 Contract aims

The SKF Integrated Maintenance Solution (IMS) is intended to support existing maintenance in a pulp mill to decrease total costs of ownership and increase its availability and productivity. It was developed as a way for SKF to create a channel for their expert knowledge around rotating equipment, and to tie closer relationships to their customers. It was revealed over time that by engaging in customer service and maintenance on a broader level, a higher price could be charged for the bearings and it could provide a channel to secure sales of SKF bearings. Furthermore, customers were experiencing frequent bearing failures and due to that lost important time and resources. From another point of view, engagement on maintenance activities can provide a basis for sustained value generation. As bearing quality increase the lifetime of bearings, sales volume risks falling. SKF has experienced the need to find a balance to how long bearings should last, as not to loose sales volume. In theory it would be possible to create bearings that last almost forever with the right maintenance support. Increasing the level of integration with key customers through maintenance and service is a way to keep quality increases and value generation intact.

2.3.2 Contract fundamentals

The Integrated Maintenance Solution can either just be contracted for a part of an industry process, such as the rolls in a paper mill or be set up for the whole process (see Figure 1).

The manner in which this is decided is basically dependent upon the contractor and current knowledge, skills and perception of importance. The IMS is constructed to address the specific needs from the customer inside the box of knowledge of the involved actors. As an example, if this "box" excludes some specific important environmental aspects, so will the contract.

The service activities can include the redesign of troublesome equipment or implementation of new machinery or technical solutions. It also includes the supply of people on-site, spare parts, lubrication management services, technology upgrades, organizational change management and training to keep customer staff in line with best practices. It is (at least to some extent) performance-based. From the SKF webpage on IMS (SKF, 2006):

> *"We supply bearings, seals and lubricants and manage the maintenance of your machinery"*

and continued:

> *"Each agreement is different, customized to your specific business goals and needs and complementing your internal resources. All services are delivered under a monthly service fee, with a performance component if SKF exceeds the established objectives."*

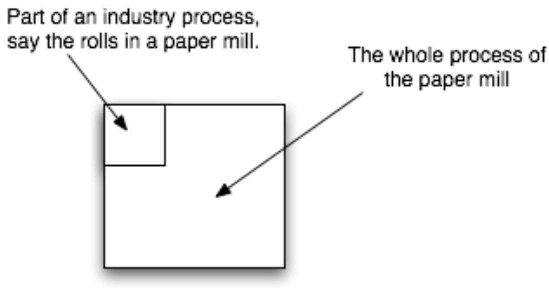

Figure 1: the scope of the Integrated Maintenance Solution within a customer's process.

2.3.3 Time perspectives

The IMS contracts are typically initiated by a pre-study where SKF examines the process structure, the maintenance organisation, the handling of data routines etc. at the customer site. This is to get an understanding of and mutually define the situation "as it is" and to find large structural strengths and weaknesses. A future "what should be"-vision is agreed upon and the gaps between current and future state are defined. When this is done, a value proposition is made to define what potential improvements SKF can offer and what types of activities this would include. A concept and a scope of the IMS activities are established, as well as costs, benefits and time frame for the contract. Again, from the SKF webpage on IMS (SKF, 2006):

> *"The typical term of an IMS agreement is three to five years, however, as your partner, we anticipate an on-going relationship. Generally, an IMS includes a defined cost structure and agreed-upon performance measures."*

If the proposition is accepted, some in depth measurements and studies can be made to determine process efficiency and stability. According to these measurements, and customer demands, certain KPIs are set up to support performance targets. The KPIs are set up as a combination of SKF knowledge of what process improvements that can be expected, and customer wants and needs. The scope of the contract is limited to concern and focus on achieving the targets set for the KPIs.

All of the activities support the reconstruction and reorganization of the customer's maintenance unit to perform better and create more reliable and efficient machinery and processes. An IMS contract usually alters many current ways and methods used, which requires organizational and cultural change management. This is a critical issue, and something that SKF value as absolutely necessary for an IMS to be successfully implemented and functioning. For SKF, approaching customers through maintenance activities is regarded to be crucial. One of the interviewees described the situation as:

> *"When sales people meet purchasing departments of a customer, they only speak numbers. Direct conflicts. Maintenance people, have a completely different approach being able to form a bond with the customer of mutually beneficial cooperation and long-term agreements. Numbers are not the importance here, it's the possibility to understanding customer needs that matters in the long term."*

This stresses the importance of integration and simultaneously the danger of focusing on sales volume and numbers too much. As such, this integration requires extended time and knowledge to be effective, as cooperation over time requires more than a single point transaction.

2.4 The IMS applied

Due to some start up issues between 2006 and 2007, 2008 and 2009 represent the first years of complete implementation of the maintenance contract. The initial wishes form the pulp mill included improving operations performance by increasing the availability of the equipment. A cultural change of the personnel within the facility was sought in order to facilitate such an improvement. The SKF initial assessment was made according to standard procedures of an IMS, which uncovered some maintenance procedures of the mill assets that had the potential of being improved. Those procedures included issues such as poor lubrication practices, poor condition monitoring processes and lack of technology to support the objectives. The contract was set up as to provide leadership in managing the reliability improvement efforts. To support these efforts, new equipment and technological upgrades were planned, as well as training of mill personnel.

Some of the initial Key Performance Indicators (KPIs), measuring the success of the contract implementation were agreed upon between SKF and mill management:

- A goal of 87% Overall Equipment Efficiency
- Reduced consumption of bearings and lubricants,
- Agreed-upon number of hours of application engineering to redesign of troublesome equipment
- Agree-upon number of hours of on site skills training for internal personnel

Reduced bearing consumption is a key measurement, but not a full responsibility taken by SKF. The costs of those products are not included in the fix cost of the contract. The KPI is in monetary terms, rather than a measure of the number of bearings consumed.

Overall Equipment Efficiency is in an industry-standard way of improving processes (OEE, 2012). When bearings are not maintained properly, they are a common cause of equipment failure, which is a crucial part of OEE. As equipment fails, unnecessary energy is consumed to no use. OEE is therefore a measurement of energy efficiency related to bearing function in the mill.

The number of hours to be spent on application engineering and skills training is to support the efficiency of the contract and its purpose in general.

2.5 Special Issues

It seems as the interests of the mill are as high performance bearings as possible, or even a new technological solution that offers higher availability, better resource efficiency and eventually higher profitability. It could be summarized as addressing the need of performance to the lowest possible cost. This is how the initial wants were expressed. This raises another interesting and important aspect of IMS for SKF internally: the aspect of keeping close cooperation between maintenance and product development. The people working with maintenance are the ones knowing the customers and their processes the most. These individuals possess great knowledge of what performance is sought at the mill. The language of sales units and operational units seems to diverge in some ways, giving rise to direct conflicts. Maintenance people have a completely different approach, being able to form a bond with the customer of mutually beneficial cooperation and long-term agreements. Numbers are not the importance, but rather the possibility to understand customer needs that matters in the long term. If large improvement potentials are discovered during the assessment and activities inside the arrangement of an IMS, a close bond to product development can enable rapid understanding of new product needs, which enables higher performance products and higher customer satisfaction.

3 Environmentally assessing pulp

This section discusses the environmental assessment model that is used to assess the environmental impact of pulp and changes over time as a result of the IMS activities. This model is then presented as a simple input-output figure that illustrates how IMS can influence the impact on climate change derived from the pulping process.

The section outline discusses the following points:

- how does a pulp mill function in producing pulp?
- what aspects of that production is most significant in its effects on climate change?
- how can the IMS influence those aspects?

The section ends with discussion possible ways of transforming energy production into comprehensive environmental impact information.

3.1 The pulping process

The information is based on a two-day educational programme with The Packaging Greenhouse, an organisation owned by the Paper Province, a consortium of actors in the paper industry in mid-Sweden, unless otherwise stated (The Packaging Greenhouse, 2012). Additional information is from interviews with two Senior Maintenance Consultants and one Maintenance Strategy Consultant at SKF during the summer and early autumn of 2012.

3.1.1 Pulping Basics

The basic process of making paper starts with the raw material of wooden logs. They enter the wood yard by truck or train and are debarked before they are cut to small chips and stored in silos or on the ground in large piles. The chips are transported into a chemical cooking process that separates the wood fibres from the lignin, which is a kind of glue. The fibre is mixed with water and poured onto a formation track in a think layer. This layer is dewatered in several steps to leave only a carpet of fibres with a low content of water that is strong enough to be rolled onto cylinders or cut into sheets and stacked in bales. These bales are the production output, commonly referred to as air-dried tons (adt) of pulp.

The lignin that is separated from the wooden fibres is refined through several steps to eventually turn into a fuel. It is then combusted in a recovery boiler. The energy freed is used to recover the cooking chemicals and is also converted to electrical and steam energy. The energy production, based on the wooden raw material, means that the pulping process is roughly 100%, or slightly higher self-sufficient in steam and electrical energy.

3.1.2 Energy efficiency in pulping

Bearings constitute a crucial aspect of the energy efficiency in in a pulp mill in several ways, the two most salient being:

- The pure friction of the bearing and efficiency of supportive systems directly determine how much energy is consumed by rotating equipment.

- Failure of a bearing results in downtime for the mill. Downtime usually means that energy is consumed by machinery being inactive, but no pulp is produced.

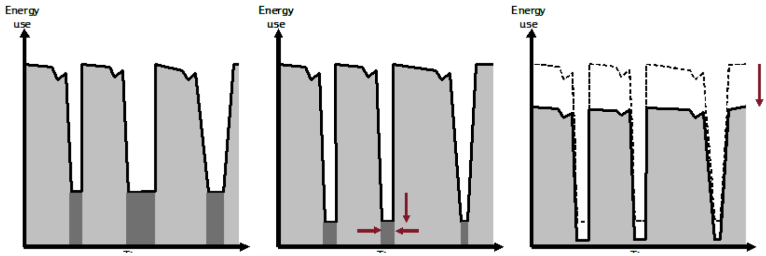

Figure 2: energy use versus time in the pulp mill. The peaks represent energy consumption during operation and the gaps energy consumption at downtime. They do not reach bottom in the leftmost part as machinery does have certain consumption, also at stand by. In the middle the red arrows illustrate how efficiency measures aim at closing the gaps in terms of time, and lowering the "floor" of energy consumed during the downtime. The leftmost part illustrates the efforts of reducing energy consumption during operation. In all of these parts, bearings and proper maintenance play a relevant and important role to energy consumption and productivity.

Downtime is illustrated in the left most part of Figure 2 as the gaps between the production peaks. Energy is consumed in all stages, even as machinery is down for failure. The height of the peaks can thus be seen as related to bearing friction, and the height of the gaps as the energy wasted during failure. The middle part illustrates the efforts of closing the gaps and lowering the energy consumption during failure. This is to increase productive time and thus produce as much pulp per time and energy consumption as possible. The right hand part illustrates lowered energy consumption during operation, which to some extent can be targeted by the IMS activities. By providing maintenance on the bearings in use, both aspects of downtime and operational energy efficiency can be addressed which can lower the overall energy consumption of the mill.

3.1.3 Energy self-sufficiency

As the mill is self sufficient in energy production, any surplus energy can be exported to the local grid, offsetting other means of production that could be generating net greenhouse gas emissions, such as coal-fired electrical energy production. The surplus energy that is exported to the grid is therefore dependent on the maintenance activities of the contract, according to the above description. Offset of local energy production is thus identified as being the most significant influence on climate change that SKF maintenance activities have. Pulping is involved in environmental impacts in a range of areas, but due to the focus of this study, all else but greenhouse gas emissions as arising due to changes in exports of electrical energy to grid is considered outside the boundaries on the environmental assessment.

3.1.4 Simple input-output model

The input-output model used in the environmental assessment illustrates the relationship between pulp produced and electrical energy exported to local grid. The circles labelled 1 and 2 in Figure 3 together constitute the relation between the pulp produced and the electrical energy produced, both being products of the raw material used as input. The relationship established is therefore unit of energy exported per unit of pulp produced or MWh / adt (air-dried tonne), which is the functional unit of this study.

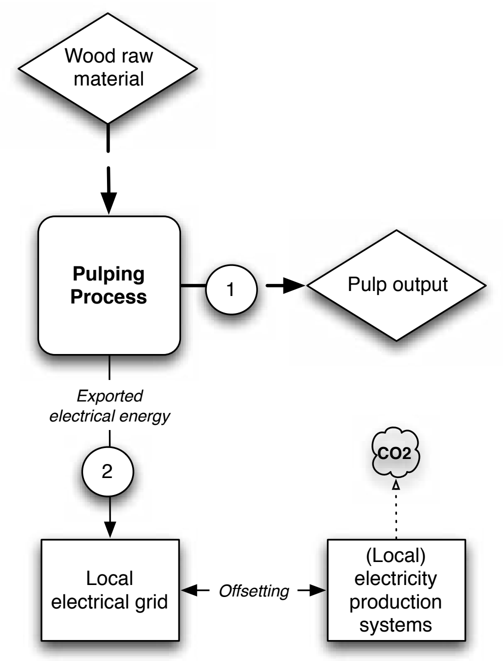

Figure 3: simple input-output model of the pulping process. Only flows relevant to this study are depicted. The circles labelled 1 and 2 represent the flows of output pulp and exported electrical energy respectively, and together these flows constitute the functional unit of this study; the export of energy per unit of pulp produced in MWh / adt (air-dried tonne).

3.2 Translation to CO2-eq

Changes in export of electricity to local grid are quantified in terms of tons of CO2-eq "saved" or “induced” due to this change. This translation is done as an impact assessment, which is a concept borrowed from LCA methodology, and is done in order to make the results more comprehensive and communicative (Baumann & Tillman, 2004).

3.2.1 Choice of offset electricity generation

In order to make that quantification, the local electricity generation is examined to establish a connection between energy production and CO2-eq emissions. There is a diverse energy production portfolio in the region of the mill, covering a range of mature and emerging electricity-producing technologies (see Figure 4). Hydropower produces the largest share at close to 60% of Canada’s electrical production, followed by fossil fuels (coal, natural gas and oil) at 28% and nuclear at 12%. Wind, bio-energy and other sources currently provide only about 2% of Canadian electricity production (CEA, 2006).

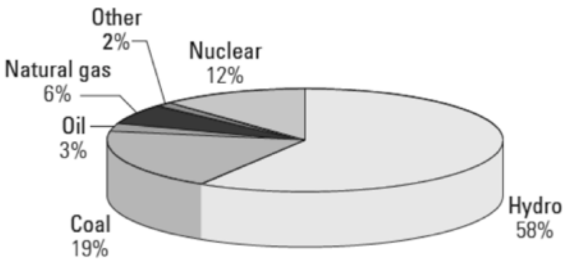

Figure 4: the Canadian energy mix (CEA, 2006)

Table 1 depicts the electricity production sources in Canada and estimated emissions of CO2-equivalents per GWh (WEC, 2004).

In order to make the quantification the choice must between marginal and average data is examined. Marginal technologies are defined as the technologies actually affected by the small changes in demand typically studied in prospective, comparative life cycle assessments. Using data on marginal technologies thus give the best reflection of the actual consequences of a decision. Average data in turn is the average of all the energy that is produced, and is typically used when the availability of data to find the marginal technology is non-sufficient or when long-term changes are to be examined (Weidema et al, 1999).

Table 1: various types of electricity generation technologies and their carbon footprint, expressed in terms of amount of CO2-eq emitted per GWh of electrical energy produced (WEC, 2004)

Generation type	Amount of CO2-eq per GWh (tons)	Comments
Hydro	Up to 100	*Depending on the local mix*
Coal	800-1000	*Without carbon sequestration*
Nuclear	Low or negligible	
Natural Gas	400	
Oil	600-700	

According to Weidema et al (1999) the choice between average and marginal data should not be made arbitrarily, but rather based on what the specific situation is and what technology is affected by the change in demand. By using a five-step model concerning the time horizon, the magnitude of the effect, general trends of the energy market, capacity adjustment options of the technology in question and what technology is most likely to be preferred in the situation; the decision can be made more actively. When applying that model, this situation would render coal-fired energy production as the most probable technology used to cope with the changes in demand. Mostly because the geographical area of the mill is almost completely provisioned by coal-generated electrical energy, the technology is cheaper to adjust than the nuclear and hydro energy also present in the Canadian mix. Hydro and nuclear power are technologies that do not easily allow for market fluctuations to change production output. Even if nuclear and hydro capacity should increase, it will be a planned increase as a result of political decisions upon which small changes in market volume will have little influence. Added to this, coal is one of the cheapest sources of energy in Canada, which would make even more probable that this is the marginal production of electricity (CEA, 2006). Based on this argumentation, marginal electricity production will most likely be mainly coal fired. With marginal data, the exported energy will reduce greenhouse gas emissions according to the following:

- 0,9 tons of CO2-eq per MWh of energy produced.

3.3 Assessment Results

Data is collected over the first four years of contract duration. The section presents data on pulp production output, export of energy, the export in relation to production and finally makes the attempt to transform these results into greenhouse gas emissions.

3.3.1 Pulp production

Figure 5 illustrates the monthly production of pulp over the time scale. The trend line suggests a slight decrease according to the data in Table 2. The total decrease is about 10 per cent over the four years.

Table 2: the trend line characteristics of Figure 5. The bottom row suggests a total change of almost 10 per cent over time.

Trend line data	
N	48
Starting value	39558,28
Monthly change	-80,41
Ending value	35698,77
Total change (%)	-9,76

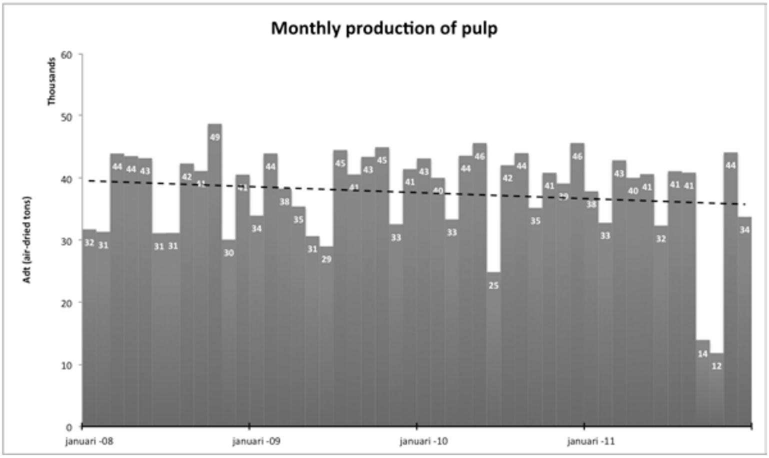

Figure 5: production of pulp in the case study. The staples represent monthly production of thousands of tons adt (air-dried ton). The trend line suggests a decline in production by roughly 10 per cent over the fours years depicted.

3.3.2 Export of electrical energy

Figure 6 illustrates monthly export of electrical energy over the same time scale. The trend line suggests a slightly larger decrease of about 13 per cent, as suggested in Table 3, containing trend line data.

Table 3: trend line characteristics of Figure 6. The bottom row suggests a decline of slightly more than 13 per cent.

Trend line data	
N	48
Starting value	10,555
Monthly change	-0,029
Ending value	9,145
Total change (%)	-13,354

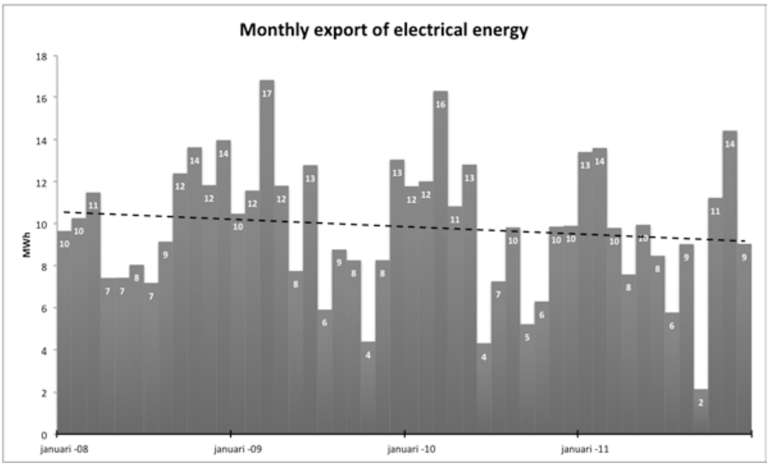

Figure 6: monthly export of electrical energy as a residue of pulp production. The export declines over time by about 13 per cent as suggested by the trend line.

3.3.3 Exported electricity per pulp

It starts to get interesting as the amount of exported electricity is divided by the amount of pulp produced. Figure 7 illustrates that relation, and reveals a significant decline of about 15 per cent, as suggested in Table 4.

Table 4: trend line characteristics of Figure 7. The bottom row suggests a decline of more than 15 per cent.

Trend line data	
N	48
Starting value	0,283
Monthly change	-0,001
Ending value	0,239
Total change (%)	-15,329

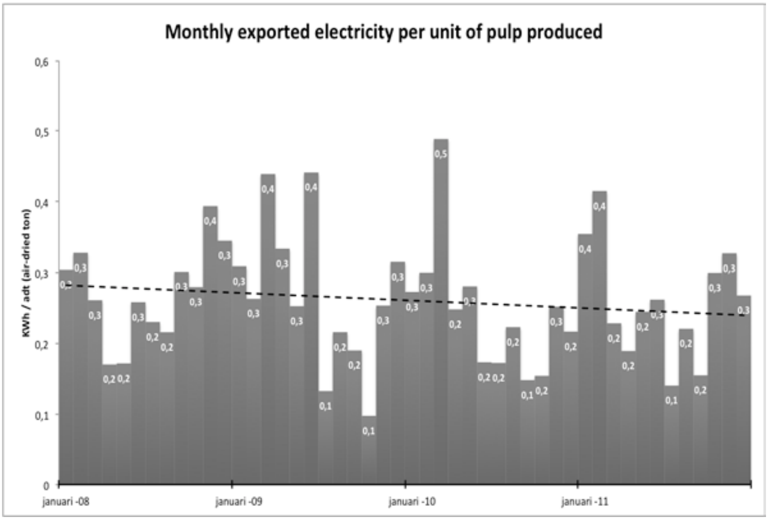

Figure 7: monthly exported electrical energy per unit of pulp produced. As seen previously, both production output of pulp and export of electrical energy had decreased over time, however the trend line suggests that exports decreased the most.

3.3.4 Green house gas emissions

The export of electrical energy per unit of pulp was aggregated to a yearly value, in order to facilitate comparison between the years. Since the conversion factor is 0,9 and the relation is linear, the green house gas intensity per ton of pulp declines with the same 15 per cent, as does the export of electricity per unit of pulp illustrated in the previous Figure 7. Figure 8 below illustrates the emissions per unit of pulp on a yearly average level. The offset declines every consecutive year between 2008 and 2010, while the last year of 2011 saw the highest total offset.

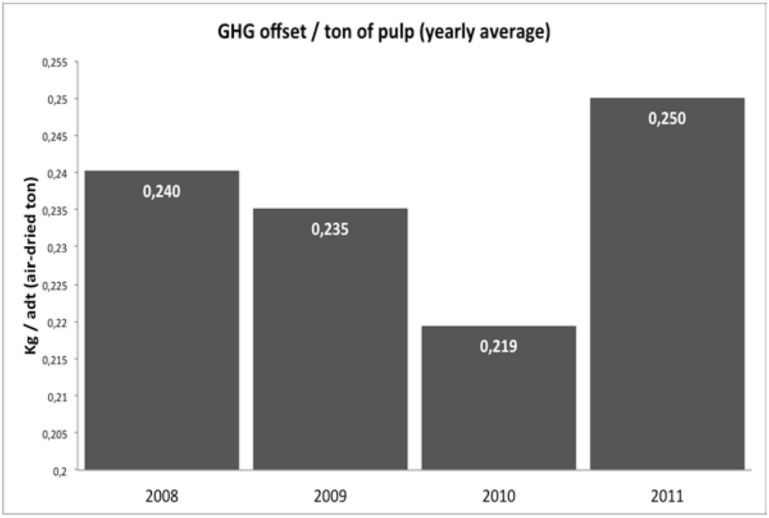

Figure 8: Greenhouse Gas emission offset by the export of electrical energy. The numbers are based on a yearly average of exports per unit of pulp produced. A trend might be precipitous to suggest, however, the last first three years bears witness of a continuous decline, balanced by the third year representing the largest amount of tons offset.

3.4 Analysis of Results

Energy efficiency is identified as one of the main goals of the maintenance contract. Furthermore, it is identified that energy efficiency is directly linked to exports of electrical energy to the grid, and that is also where the mill influences climate change through the offsetting of green house gasses in local energy production. The trend shows a decrease of that export per unit of pulp by about 15 per cent over the first four years of the study, as measured on a monthly basis. Interesting to notice is that the last year of measure produced the highest amount of emissions per unit of pulp produced, reaching about 4 per cent more than the first year of 2008, even though the two previous consecutive years of 2009 and 2010 saw a yearly decline and a thus a worsening of environmental performance.

It appears that 4 years of time is a little short time to make more comments on the sudden increase of the last year. The trend might be changing beyond the data points. What can be seen is simply that the bearing maintenance activities has not been able to increase the amount of electricity that is exported to the grid to offset green house gas emissions. Since the contract focuses on bearing operational efficiency and energy consumption in particular, these results are somewhat surprising. Speculations can be made on if the surplus energy is spent on increasing production beyond a certain efficiency point of the mill, inducing a production level that is less and less optimal from an energy perspective. Perhaps, if the profit made from selling the extra pulp produced is larger than the extra costs of energy per unit of pulp, such action could be motivated from an economical point of view. It seems somewhat more complex from an environmental ditto.

4 The IMS as a PSS

Product-Service Systems have been claimed to support environmental goals by some researchers. Alas, there are not so many examples and environmental assessments of such systems made in connection to the theory. In this and following sections, an effort to fill that gap is made by connecting the environmental assessment presented in previous sections to theoretic findings on PSS and how they can or perhaps cannot support environmental goals. This founds a theoretic frame of reference and a basis for suggestions on how the maintenance contract in the case can be developed to further support environmental goals.

4.1 Defining the concept of PSS

The concept of systems of bundled products and services is not something new. In fact, economies of wealthy industrialized countries have undergone significant structural changes where services have gained new prominence and the relative contribution of traditional manufacturing to these economies has diminished (White et al, 1999). For environmental reasons, there is also a need to do so. Businesses need to develop new models of profit generation and to move from increasing product sales to offering alternative service solutions to ease the impacts on the environment (Naturvårdsverket, 2005). As late as November 2012, the newly appointed head of the Swedish Recycling Industry stated in an interview that there is a need to offer new ways of generating business that is disconnected from the flow of material products. By continuously selling more stuff to generate value, the equation won't match (Wijkman, 2012). Seen from a business perspective, the combination of products and services can help to develop a completely new business strategy, enabling a closer connection to customers or diversifying away from competitors. The resulting functional economy is argued to be eco-efficient, with less need for ownership of products and eventually with less virgin material overturn connected to product consumption and volume sales (White et al, 1999).

As being a contributing part to such functional economy described above, Product-Service Systems (PSS) have been developed as ways to add service content onto existing products, to create a combined offer more capable of satisfying customer needs (Goedkoop et al, 1999). Another definition would be: "an innovation strategy, shifting the business focus from designing (and selling) physical products only, to designing (and selling) a system of products and services which are jointly capable of fulfilling specific client demands" (UNEP, 2002). This concept has also been named functional sales, servitization, servicizing or servitization, names which all mean basically the same (Lifset, 2000). In the scope of this study, they are commonly referred to as PSS, if nothing else is explicitly stated.

4.1.1 Product Dependence

For SKF in our case study, bearing sales constitute a key driver of profit generation. Simultaneously, increased production of bearings brings increased environmental loads. A PSS potentially enables a decoupling of value creation from sales volume, by targeting quality of offers instead of amount of products sold as a key driver of profit. The PSS can remove focus away from an ownership of a specific product, to instead focus on the usage and service generated through a product. A PSS could eventually lead to a decrease of product throughput since ownership remains at the manufacturer and customer only pay for the utilization of the product (Goedkoop et al, 1999; Manzini & Vezzoli, 2002; Tukker, 2004). If the products are included in a performance-based contract, it is transformed from being a driver of profit, to being a driver of cost. If a manufacturer is selling performance, e.g. uptime in a process industry and is including the provision of consumables and products, these material products then constitute a cost for the manufacturer. Compared to the situation where the manufacturer of that same product is selling the product only, and thus depends on high volume sales to generate, the PSS relationship can build upon a performance-based solution and creating incentives to reduce the amount of products needed to fulfil the service. Reducing the dependence on products to generate value could thus be argued to enhance the environmental performance of the manufacturer.

Resolving the product dependence issue is touched upon by Reiskin (2001) in the model of aligned interests (Figure 9). The model is built around the reasoning that, as a manufacturer approaches a customer with a product, in a traditional situation the goal would be to maximize the number of products sold and the price for each product. For the customer, it is rather more important to spend as little money as possible to fulfil a certain need, thus there is a direct conflict in interests between the two parties. In the PSS relationship, Reiskin argues, the interests can become more aligned by the fact that both parties seek to optimize performance. This is mostly due to the change of motivation of the manufacturer form focusing on volume sales, to focusing on offering a performance or a function to as low costs as possible. The customer would want that same performance to as low costs as possible. The only disagreement would be the price of the delivery (Reiskin et al, 2000). The PSS is thus a new way of generating value that changes the relationship with the customer from a single point transaction, to an on-going relationship in which the manufacturer continues to provide services to the customer throughout the life of the PSS (Lockett et al, 2011).

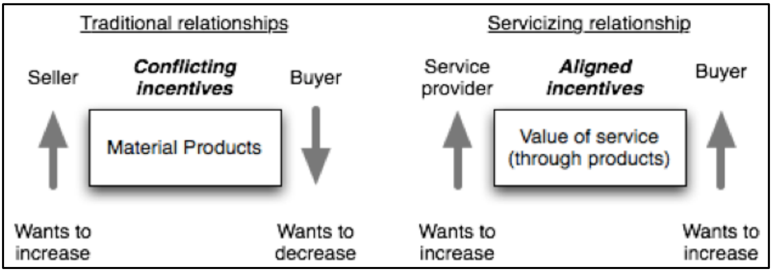

Figure 9: Reiskin's model of aligned interests. On the left is a traditional manufacturer - customer relationship where interests diverge. On the right is the Servicizing relationship, where interests are aligned to a larger extent (Reiskin et al, 2000).

4.1.2 Product impacts

Not only is it interesting to reduce the amount of products needed to fulfil a need in environmental terms, it is also important to consider the impact of each product that is actually utilized. As White et al (1999) discusses there are many sources of environmental impacts concerning Product-Service Systems; but perhaps the most interesting ones being sales volume and products impacts. The sales volume is by White regarded as *non-use impact*, and the product impact is regarded *use impact,* see Table 5 and Table 6.

4.1.3 Internalizing costs

As White et al (1999) argue, a key condition to arrive at reduced impacts of products and reduced sales volume of products the internalization of costs. A prerequisite for this internalization is that the contract is performance based and the manufacturer is free to deliver performance with whatever product capable of delivering that performance. To reduce dependence on sales volume, there is a need to include the price of the product in the offer. As products constitute a cost, it is in the interest of the manufacturer to focus on reducing the product throughput per offer. Focus is turned to quality of delivery rather than sales volume (White et al, 1999). In a bearing maintenance contract, it would mean to include the cost of bearings. By taking a whole responsibility, incentives to reduce the costs of delivery, and thus the number of bearings needed to fulfil a service are generated.

As regards the impact of each product, the use related impacts described by White et al, could lead to improved performance of the product in use, thus potentially reducing its environmental load. Integrating maintenance activities to product development to allow for a greater information exchange can support such improvements.

Table 5: White's table of how impact reductions can be sourced from a servitization offer. Non-use impacts are depicted as well as some conditions that are required for the reductions to occur (White et al, 1999).

	Source of impact reductions	**Conditions to achieve reductions**
Use impacts	Via product design	Use related environmental costs are internalized, and these costs may be reduced by better design of the product.
	Via increased turnover	Servicizing drives more rapid turnover of product stock in use combined with progressive efficiency improvements in consecutive model years.
	Via more optimal operation of existing product	• Use-related environmental costs are internalized, and these costs may be reduced by more optimal operation. • Where the product is a cost rather than a profit center, and more optimal operation extends product life/reduces product consumed.

Another example would be how a laundry service provider internalizes the electricity costs and thus creates incentives to reduce electricity consumption of the laundry machines providing the service. Another example would be a bearing manufacturer that sets targets on energy consumption of bearings in use. Reducing product dependence was previously argued to increase environmental performance of the manufacturer, and respectively, the use phase of the products can enhance the environmental performance of the customer. For the pulp mill purchasing the maintenance service with costs of bearings included and targets set on performance, each unit of pulp is potentially manufactured with fewer resources needed.

White et al further discusses some ways to reduce the use related impacts: product design and product turnover. When designing the products, it would be in the interest of the manufacturer to minimize costs connected to providing the product, and increase potential for repairs, remanufactures or recycling of it. This is because the profit of the manufacturer depends on two things: the cost of product provision and the revenue from its utility function. Both are under the control of the manufacturer, which makes it rational to minimize the whole life cycle costs of the products, and maximize the utility function of it. The customer does not have to consider other things than the price versus utility relationship. Increased turnover can lead to quicker technology upgrades and the removal of old technology. A third example would be the car pool, where the life time of the cars in the pool can be set to 3 years, and after this period they will be taken back to the production facilities and upgrades with newer and cleaner technology. This is possible since the manufacturer pays for the costs of the car during its time in the pool, and it will therefore be rational to reduce them and replace expensive old technology as often as possible (White et al, 1999).

Table 6: Non-use impacts as described by White et al (1999). The sources of impacts reductions can be seen in the reduction of sales volume, reductions in materials mobilized per unit or improved environmental performance of non-use processes.

	Source of impact reductions	**Conditions to achieve reductions**
Non-use impacts	Via reductions in number or volume of product manufactured	The product is a cost rather than a profit center, providing incentives for any of the following: • more durable products • products of a larger service capacity, via the realization of economies of scale • more efficient utilization of products in use
	Via reductions in the volume of materials mobilized per unit	The product has economic value at end-of-life, or where end-of-life costs are internalized — in either case stimulating reclamation activities.
	Via improved environmental performance of non-use processes.	The product has economic value at end-of-life, or where end-of-life costs are internalized — in either case stimulating reclamation activities.

The non-use impacts are not only achieved via reductions in sales volume, but also in reduction in materials mobilized per unit or by improved environmental performance of non-use processes. The extended responsibility of the manufacturer can provide ways of considering environmental issues earlier in the product development stage (Öhlund, 2000). This can lead to new design-for-recycle or design-for-remanufacture strategies, as well as the development of take-back programs. It could further pronounce features such as extended lifetime, reparability, remanufactureability and recyclability, as most costs concerning efficient usage and efficient disposal of products are internalized and in the end paid by the manufacturer. Selling performance in this way could help reaching factor 4 or even factor 10 in total energy efficiency (Weizsäcker, Lovins, & Hunter Lovins, 1998; Tukker, 2004).

4.1.4 Types of PSS

There are many types of PSSs that can support the conditions described by White et al as supportive of reduced impacts. Tukker (2004) made an extensive review of the literature on PSSs and sorted them into stereotypical categories in a model with relation to whether they are more oriented towards products or more towards services (see Figure 10). Depending on how they are categorized, the potential of impact reductions change. Eight types of PSSs are defined and sub-ordinated into three main categories according to the following determinants:

A. The first category is product-oriented, with some service on top. Value creation is defined upon a product.

B. The second category is use-oriented services, where the product stays in ownership of the provider.

C. The third category is result-oriented where the client and the provider in principal agree on a result and no specific, pre-determined product is involved.

The three categories consist of the following eight types of PSSs, each with specific potential of supporting environmental aspects:

1. Product related services are usually maintenance contracts, or take-back agreements based on a product that the provider has sold.

2. Advice and consultancy refers to the product provider giving advice on the most efficiency use of the product sold. Optimizing logistics or organizational arrangements are examples of this type.

3. Instead of selling a product and transferring ownership, the lease arrangement lets a customer use a product without owning it. Issues such as repairs, upgrades and control stays with the ownership that remains at the product provider. The customer pays regular fee, which normally renders individual and unlimited access to the product.

4. Product renting or sharing resembles the leasing contract, with the difference in the fact that the customer does not have unlimited or individual access to the product. The same product is sequentially used by many customers.

5. Product pooling is largely the same as the two previous types, but the product is in this case use simultaneously by the customers, as in a car pool.

6. Activity management / outsourcing is a type of PSS where a part of an activity or a company is outsourced to a third party, usually performance-based under some control indicators that ensures quality of the service provided. Important is however, that this must not alter the way an activity is undertaken at all.

7. Pay per service unit is a common type of PSS usually known as pay-per-print or pay-per-laundry services. All

the costs stemming from the provision of the service are internalized by the provider, as are the costs of the product itself

8. The last type, functional result, is the other end of the spectra where the provider is completely free from technological requirements to deliver the agreed upon result.

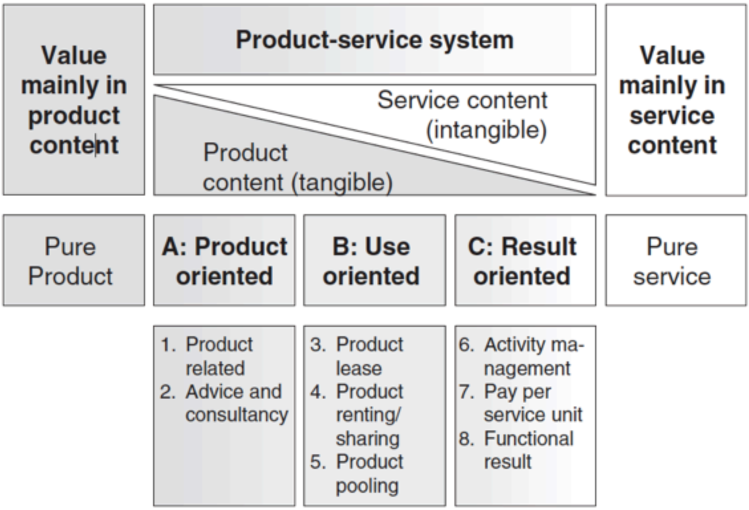

Figure 10: Tukker's 3 PSS categories and the 8 respective types. Depending on the category, varying environmental impacts reductions can be expected (Tukker, 2004)

The Table 7 below illustrates how the eight types of PSSs can promote environmentally beneficial aspects. Depending of the type of offer, most of the PSSs have the potential to render reduced environmental loads, except for the situation of leasing. This offer could actually lead to increased environmental loads if the leasing contract induces irresponsible behaviour of the user that imposes unnecessary stress on the leased object, potentially reducing aspects such as its life time and reparability features.

Table 7: Tukker's illustration of how a PSS might induce reductions in environmental impact depending on what type of PSS it is (Tukker, 2004).

PSS type	Impacts compared to reference situation (product)				
	Worse	Equal	Incremental reduction (<20%)	Considerable reduction (<50%)	Radical reduction (<90%)
1. Product-related service		←------	------→		
2. Advice and consultancy		←------	------→		
3. Product lease	←------	------	------→		
4. Product renting and sharing		←------	------	------→	
5. Product pooling		←------	------	------→	
6. Activity management		←------	------→		
7. Pay per unit use		←------	------	------→	
8. Functional result		←------	------	------	------→

4.1.5 Barriers and limitations

The provision of function is a complex matter and there might be many barriers to achieving environmental benefits. Depending on the agreement, the customer - manufacturer relationship and the specific product etc. the environmental gains can vary from minor to radical. Tukker (2004) concludes that it is not an automatic result that a PSS generate environmental benefits. Therefore each system should be carefully planned and executed in order to generate as large environmental benefits as possible, aligned with business interests. The least problematic systems to implement might at best lead to incremental improvements. A few PSSs can actually lead to worse performance, an example being in the case where leasing of a product leads to less responsible behaviour of the user.

Why do not all companies engage in PSS? Mont (2001) discusses around some of the common barriers and concludes that the lack of customer understanding, lack of supporting policy frameworks, lack of management support and lack of passionate champions inside of the companies are some of the most important barriers to developing and deploying a new PSS (Mont, 2001). White et al (1999) discusses the difficulties in seeing the environmental potential of the PSS and the fact that organizations engage in the systems rather for the business potential then for environmental performance improvements. Öhlund (2000) identifies a list of several obstacles for the provider offering PSS:

Financial obstacles:

- The PSS provider need to take over some financial risk from the customer, since the responsibility of the product performance is crucial to profit in a different way.

- The need to internalize costs such as maintenance and spare parts for the product that used to be income drivers can negative effect the providers' profits.

New relationship to the customer:

- Low level of market maturity and lack of understanding of lifecycle perspectives is an obstacle for getting acceptance for new business solutions and the customers must rely on the knowledge of the provider to a larger extent.
- There can be difficulties in pricing the new offers correctly.
- There are difficulties in customize service offers appropriately and according to customers varying needs in sale situations, which makes it hard to develop sales standards and check lists.
- The new role of the customer and the provider requires negotiating procedures to change and the actors have altered leverage tools when payment is done on the basis of performance.
- The PSS requires the provider to be able to satisfy a larger part of its customers needs, hence integrating closer and spending more time with customers to develop tailor-made solutions.
- The provider that utilizes distributors to a large extend, need to develop and handle a new relationship to them.

Organizational changes:

- Organizational changes need to be made in order to be able to provide the offers to customer needs to be handled in terms of creating new departments and new organizational structures.

- Corporate culture may need to be adjusted for the organization not only to perceive but also portray itself as being a “service provider”.

Even though the intents might be to increase the environmental performance with the PSS, these listed barriers might prevent the organization from successfully implement such systems and thus improvements of environmental performance might never see the light of day.

4.1.6 Summary of the PSS concept

A PSS can reduce the impacts of a product, or increase the environmental performance of a product in its usage situation. To create incentives for this, it is important to internalize the costs of the products, its operation or is disposal phase. This requires, at least to some extent performance-based payment; that the offer is made based on the utility of the delivery, rather than the amount of products to be transferred. Impacts are both use related and non-use related. Both dimensions can be targeted with a PSS. There are many types of PSS that have varying potential for promoting environmental benefits. The PSS aligns the interests of a manufacturer and a customer by focusing on the utility of a product, rather than the product *per se*.

There are conclusively some important barriers to successful implementation of PSSs, arising due to financial, organizational and relationship misconceptions. These barriers can possibly be overcome by departing with the goal to align interests according to the model by Reiskin, and to communicate a clear message throughout both the internal organization and to the customer vis-à-vis these interests in order to share a clear vision and to ensure the anticipation of set goals. The PSS must be carefully planned and executed in order to target real customer needs. It is likely to be time consuming and complex, and thus require close integration with customers through extended knowledge of their needs.

4.2 Analysis

This section analyses the qualitative information gathered on the Integrated Maintenance Solution from a PSS theory perspective.

4.2.1 The IMS as a PSS

By definition, the Integrated Maintenance Solution is "market packages or "bundles" of customer-focused combinations of goods, services, support, self-service and knowledge" or a system of products, services, networks of "players" and supporting infrastructure that continuously strives to be competitive, satisfy customer needs and have a lower environmental impact than traditional business models". The definitions of a PSS match very well with the ones of the IMS.

4.2.1.1 Product Dependence

It has been argued that a PSS can provide incentives to reduce the dependence on sales volume to drive profit and environmental loads. In the case study, spending on bearing was a specific target, but the costs were not internalized. Based on additional data, Figure 11 represents spending on bearings that has drastically been reduced the two first years of the contract. Even though the direct correlation between the physical units and the costs is largely unknown, this decline can give a hint of the potential of the IMS. A study under progress as this report is written, has identified some probable characteristics of the relationship between bearing spending and actual bearing consumption measured by weight. This relationship seems to be a one-to-one relationship, but is still uncertain (Diener, 2012). With a one-to-one direct correlation, the amount of bearings needed to fulfil the service dropped by more than 40 per cent. However, the reduction in costs can have roots in many other variables not investigated by this study. These might include changes in distribution chains or change of bearing brands used in the mill. Only monitoring and setting targets for bearing consumption seems to be a "middle-way" of doing it, rendering economic incentives for SKF to reduce the consumption of the products, as there is a potential performance based bonus to earn from reaching those targets.

However, if that part is larger than the economic benefits of selling a high volume of products is not possible to discern in this study. It does however seem viable that the point that Reiskin (2001) makes concerning shared or diverging interests, is to some extent missed. There still exists incentives to focus on sales volume, and interest therefore not be argued to be aligned according to the model. From the examination of the Integrated Maintenance Solution (IMS) some of the main interests of the parties were found. By traditionally selling bearings only, there would be an apparent divergence of interests, according to the theory described by Reiskin. Through the IMS, the wants of SKF seem better aligned to the wants of the mill. SKF are creating incentives to produce bearings that deliver higher performance over a longer time period, and get paid for it; this could decrease the importance of bearing sales volume. In this case, the KPIs set up specifically target spending on bearing and lubrications; two important SKF provided products. The reduction in those products would mean reduction in SKF profit, assuming that the bearings are provided by SKF. The IMS agreement brings profit through performance, not through sales volume, which fits better with the interests of the pulp mill.

Table 8: describes the characteristics of the trend line in Figure 11. The bottom row suggests a decrease of more than 40 per cent over the whole time series.

Trend line data	
N	24
Starting value	0,566
Monthly change	-0,010
Ending valye	0,318
Total change (%)	-43,828

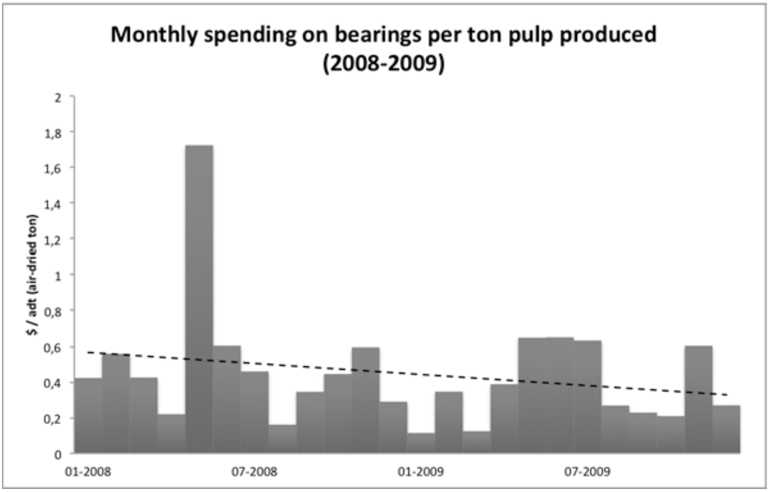

Figure 11: monthly spending on bearings during the years of 2008 and 2009. The trend line suggests a decrease over time. Note that it is spending in dollar value, and not an amount of actual products in metric terms.

4.2.1.2 Types of PSS

According to Tukker's categorization, the IMS would need to be spanning more than one of the categories. Maintenance contracts are specifically mentioned as defining the types in the first category that are product related but with service on top. The IMS must be considered to be product based as the PSS are in this category. This is due to the relatively low integration of SKF in the basic technology systems in the pulping process in general, as they are considered to be suppliers of a component that is well known and is key to the functioning of much equipment currently in place. However, as the IMS at least to some extent is performance based, and that a specific goals often is to reduce the volume of products sold, the IMS travels through the categories all the way up the third one. The PSSs in this category are result oriented, where a result is agreed upon and the choice of technology is indifferent. The IMS does not completely fall into this category, but it would definitely be too narrow to place it into the first category only. According to Tukker, this means that the environmental benefits generated by the IMS can range all the way from incremental up to radical or major, and the actual outcome would be more dependent on how the specific IMS contract is set up, and what KPIs are used. If a completely new technology system would be invented, that could radically alter the product consumption, or the energy efficiency of the mill, the IMS could provide a proper channel and agreement through which such a technology upgrade could be installed and utilized. The IMS would in such a case be an enabler of radically improved environmental performance of perhaps both the customer and the manufacturer, seen to the environmental impact per value generated. According to one of the strategic maintenance consultants, there were few restrictions to what the IMS could include in terms of radically improving equipment or systems of equipment. This increases the potential of the IMS to actually be able to support larger environmental goals, when set up properly. Table 9 describes the theoretical aspects of the IMS with the theoretical aspects described in section 4.1. From the table it can be seen that the stereotypical categories that Tukker described are probably rare in real scenarios. Rather, they probably look more like the IMS, spanning over many categories.

Table 9: describes the properties of the SKF IMS as a PSS in a summarized manner. The aspects presented in the theoretical section 4.1 are matched to the SKF IMS. As the table reveals, many aspects of an environmentally beneficial PSS are partly reached, something that opens up for future improvements of the product-service offer.

Aspects of a PSS	Matched by the SKF IMS
Cost internalization	No, bearings are a part of the contract, but costs are kept at the customer.
Performance-based	To some extent. Agreed-upon goals are made, but only as a component I a monthly fee.
Independent of product / technology	In the long term, potentially. Systems can be redesigned. In the short term, arguably not, as bearing maintenance constitute a small part of plant total maintenance.
Agreed upon goals (aligned interests)	Yes, at least partly.
Product or service based	Product based

4.2.1.3 Product impacts

White (1999) described some sources of impact reduction and what conditions are valid for such reductions to occur in a PSS setting. The use impacts are divided in "via product design", "via increased turnover" and "via more optimal operation of existing product". The IMS seems to provide some means for product development to integrate close to customers needs, as the SKF offer focuses more on those needs than sales volume. As White mentions, optimal design of products can reduce the environmental impact of bearings in pulp mills, and an excellent source of improvements in design can come from the experiences drawn when working with IMS activities. If SKF can design products that are more cost, material and energy effective, large economic gains can be made as performance level and thus profit is retained at a high level but costs driven down. However, there seems to be a lack of integration to fully support this. Based the targets set up, and an internal perception of SKF as a product-delivering manufacturer only.

White also mentions more rapid turnover as a means of reducing the environmental impact, and even though bearings can be manufactured to last virtually forever, new technology continuously arrives that can provide even more effective operation. In such a case, the IMS contract enables SKF to, where it can be cost effective, change older bearings to newer, more effective ones, even though the lifetime of the old bearing had not expired. If, at the same time, all bearings are manufactured for recycling or any type of recovery, the material losses must not be large in such an exchange. Many of these activities are left undiscovered in the current case. No KPIs were set up for bearing remanufacture, recycling or reuse and no KPI touched upon any agreement of continuously replacing old technology with newer. SKF does not internalize the costs of operation of the bearings (energy), which is a key to create economic incentives to realize such efforts. This could provide an explanation to the lack of such KPIs mentioned. Although SKF had influence on what KPIs were set up, no specific targets were set on export of electrical energy or something with a similar direct relation to environmental impacts.

4.2.1.4 Barriers and limitations

The cultural and organizational changes to alter the mind set of the current way of making profit in the SKF organization will probably require much attention and claim much time. But as interests align better business can be made, to some extent aligning the interests between business and the environment as well. It is clear that the contract was developed without specific concern for environmental goals, which, according to theory, would be likely to leave such goals unattended. Possible is that as Mont (1999) described, the lack of goals will lead to lack of understanding, lack of coherence and lack of dedication to those goals. There are obvious financial risks in internalizing the costs of bearings into the contract. This constitutes a barrier that must be overcome in order to reach a wider independence of sales volume.

5 Discussion

5.1 Environmental Assessment

The aim of the study is twofold. The first is to find a logical and structured way to assess the environmental impact of pulp as a result of bearing maintenance, and the conduct it.

5.1.1 Creating the assessment

This study has followed a logical structure to examine the circumstances and ecological surrounding in which a pulp mill acts, as described under section 3. This structure was developed through in-depth discussions with experts at SKF, involved in the IMS contract through their positions as maintenance managers, business development managers and maintenance strategy consultants among others. The assessment required a thorough examination of how the bearing supplier and the maintenance contract, the mill and ecosystems find a common interaction spot. This spot was found to be the export of electrical energy to the local grid. Several aspects were discussed and examined to arrive at this point, a point that achieved consensus among the experts involved. The assessment it self borrowed logics from the LCA methodology described earlier and allowed for a final quantification of the results in terms of green house gas emissions.

5.1.2 Results of the assessment

The analysis of the resulting data discussed the somewhat surprising fact that exports seemed to decline, meaning a worsened environmental performance over time. Bearing maintenance focusing on bearing efficiency and energy consumption in the mill might have had positive effects in many ways, but the export of energy per unit of pulp declined at a rate of about 15 per cent over the course of the first 4 years. This reveals that the relationship between product or production efficiency and environmental systems is not so clear-cut. At the end of the day, even if pulp mill internal energy consumption decreases, it will not have an impact on the ecological surrounding systems until it can actually influence those systems by a reduction in green house gasses emitted. Since the mill is self-sufficient in energy, its operation is largely carbon neutral, but still the surplus energy could then be used to offset other sources of energy production. This has, however, not been the case during the first four years of the contract.

5.2 The contract as a PSS

The second aim was to analyse the contract itself more closely, to reveal how it can be developed to support environmental goals even more efficiently, using literature findings on Product-Service Systems. The analysis showed that the IMS fits very well into the definition of a PSS according to literature and that its characteristics provide some potential of targeting environmental goals. Some results of that could be seen in the first part, as green house gas emissions per unit of pulp was reduced. However, it has also been found that one of the most salient conditions for reduction in environmental impact of value creation for the manufacturer lies in the internalization of costs. Both costs of product, and costs of using the products can be internalized, according to literature. The case study analysis reveals that the IMS contract internalizes neither. The use related costs seems more difficult to internalized in this case, as bearings in operation are just a small part of a large facility, and the costs directly related to them is practically not interesting to seek. However, the costs of bearings seem to be an area where improvement can be made. Including bearings in the fix fee of the offer, rather than just setting targets for the reduction of costs could enable a closer integration between SKF and the customer pulp mill. It could provide incentives for SKF to reduce the sales volume of the bearings in order to reduce the own costs of delivering the service, with profit levels intact. As has been seen in the barriers listed, this requires a vast cultural change within SKF, needing to transform the vision of the company to a service delivering firm rather than just a product-selling manufacturer.

5.2.1 Goals and targets

The IMS is a flexible PSS. The discussions with IMS experts has clarified that it is broad enough and capable of dealing with environmental goals, through the establishment of the proper KPIs. It also has the potential to include redesigning or substitution of technologies and / or complete industry processes. However, the extent to which the IMS is capable of targeting environmental goals is heavily dependent on the focus the involved consultants have. Their ability to "think out side of the box" seems important, and not only perceived customer needs. In this case, it seems the KPIs that were put up are based on interests other than explicit environmental goals. Examples of such explicit goals can be handling of disposal of waste or recovery of old SKF products when reached end of life. If ways of extracting value from these processes for SKF today are limited, they might also not be further developed or explored in the SKF contract. An interesting area for improvement could be to explore the possibilities of what could be included in a PSS contract in the future. There are generally no other inherent boundaries in the contract that would directly prevent such activities to be included. The issue seem to lay at the contractor and specific goals on what the revenue is based on and what priorities the contractor make when calculating the value added at the customer site as well as the economic return to SKF. Some general transformation in the business could be needed in order to extend the vision of people working with IMS to include these relatively new areas of value creation.

5.2.2 Organizational and cultural change

By dealing with organizational changes inside of the improvement activities of the Integrated Maintenance Solution (IMS), SKF possess a powerful channel to change. Many of the barriers described in the theoretical section concerns misconceptions of the value offered, of the new relationship between manufacturers, suppliers and customer or the sharing of risks. To include the "softer" cultural aspects of the new working strategies could be an effective way of dealing with such barriers. What might also be interesting connected to cultural and organizational change, must be the SKF internal cultural change. During the interviews, it has become clear that the IMS as a concept is widely known but is referred to in many varying ways. People seem to have differing perceptions of the importance of such way of working and integrating with customers. If the scope of the set up IMS contract is determined by the SKF contractor skill and focus to a large extend, the same large extend of its potential results can stem from internal cultural and organizational change as well as from training in environmental strategies, goals and problems. If SKF contractors can identify environmental issues and connect them to customer needs and wants, the possibility to set up proper KPIs that target goals that are common for SKF, the customer and the environment could increase. The current dogma seems to be slightly simplifying, merely using availability as a proxy for environmental benefits.

5.2.3 Mutually beneficial

It has become apparent to some extent that there can be benefits to engage in creating mutually beneficial partnerships with key customers and keep developing those to render environmentally beneficial business. The idea that removed focus from products can remove the dependency and thus the need for continuously increasing overturn of them, is not hard to accept in theory. Troublesome as it might be, it does seem like there is a need to extend the scope away from merely looking into ones own activities, into seeing how whole value chains and product life cycles affect the environment surrounding us.

SKF can improve data collection strategies, to support further assessments on the matter in the future. With better documentation and structured collection of data according to specific parameters, more information can be gathered over time to produce more viable conclusions on the efficiency and impacts of IMS activities, both on environmental and business issues.

SKF could develop environmental criteria, or checklists, or environmental KPIs to discuss with the customers and find win-win situations. Examples can be bearings sent to remanufacture, the usage of bio-based lubricants or creating a closed loop of bearings/lubricants through tighter supplier networks and SKF integration. A KPI could be set to measure how large share of all bearings that are sent back to be re-engineered to be usable again. Another KPI could be set to reflect the amount of remanufactured bearings currently in use. The IMS potential might furthermore be hindered by cultural problems inside of the SKF organization. Good discussions with maintenance people, but not with sales or purchasing people. Stated as a barrier to successfully implementing a PSS, internal organizational culture is very important.

5.3 Validity analysis

It must be properly acknowledged that the connection between the pulp mill energy consumption and the functionality of bearings has not been perfectly assessed. It is held as an assumption based on estimations of experts and individuals involved in the processes. Even though this entails some weakness, it still does provide a direction and a sign to what might be important and what might not be in future studies.

The data collection for the environmental assessment stretches over four years. As this report is being written, another years has passed by in operation. In industrial circumstances, fours years might be a little short for the implementation of new technical solution, the redesign of troublesome equipment or the slow cultural change management process to have effect. Some trends are still visible and offer a picture of the current situation.

The study does not claim to be general for all pulp mill or all bearing maintenance contracts, but rather provides an example of how a PSS can be set up, environmentally assessed and approached in a qualitative manner. It surely provides insight into improvements that can be made on the contract in order to generate more environmentally beneficial business.

Some information on pulp processing and the maintenance activities comes form actors that cannot be considered objective in all matters. This might of course constitute a problem regarding validity of the data. However, the must trustworthy source of information comes from the people working with the activities on a day-to-day basis. Further studies might seek to widen this picture with information form other sources.

6 Conclusions

The introduction of this report brought some important aspects of contemporary consumption and production patterns and their relation to global environmental loads. It departed from the findings that a Product-Service System could be a tool to reduce the dependence on product overturn to generate value, and that this could also provide higher performing products that reduce the environmental impact of secondary products they contribute to produce. The study has used a case study of a bearing manufacturer, engaging in something can could be identified as a PSS with a pulp mill. The system is in the case a maintenance contract that aims at providing bearings to the pulp mill and offer maintenance to support optimal functioning of the bearings in their use to produce pulp. An environmental assessment has been utilized, which showed that over the fours initial years of measurement, the environmental impact of pulp has increased. This in terms of green house gas emissions that can be traced to energy consumption, something intimately connected to bearings and their functionality in this specific case. This can be interpreted as a lack of clear goals to enable such a reduction. Goals of the contract were set up to increase overall effectiveness of the mill, but that seems to be inefficiency as a replacement for explicit environmental goals. Product or production efficiency is this not as simple as a proxy for environmental performance.

Furthermore, the study showed that product dependence is likely to have decreased, even though spending cannot be equalized with actual product consumption. This shows that the contract is efficient in achieving set up goals. Put in the perspective of the environmental assessment, this is a sign that the maintenance could be efficiency also in reaching environmental goals. If they are made explicit, as was spending on bearing, they might very well as effectively be reached. In this case, no specific environmental goals were set in terms of green house gasses, and as a result, none were met.

The qualitative assessment of the contract, and the analysis made on the basis of literature findings of Product-Service Systems provided some insight in how it might be developed to further support environmental goals in the future. The improvement suggestions include, internalizing the cost of the bearings, increasing knowledge and focus on the potential of a PSS and setting explicit environmental goals for each contract, specifically adapted to every situation. For SKF, a good start for such goals could perhaps be found in the environmental policy of the customer.

From the perspective of SKF or the pulp mill, it might be arguable if environmental performance should not be measured in terms of green house gasses reduced by the offsetting of external energy production. However, in this study this has been identified as being the most significant relation to emissions affecting climate change. In another case study, this might be different, which is why a detailed and careful examination of the connection to surrounding ecological systems must be made in each specific case. Just equalizing efficiency with environmental benefits, might not be proper or relevant at all.

7 Further Work

There are a couple of important aspects that makes continued studies on the topic important. Firstly, the data collection is important. More detailed data, over a longer time period, spanning more determinants of environmental performance could render a more complete assessment and make possible more precise estimations on the potential of this specific PSS. For a manufacturer such as SKF wanting to assess the environmental importance of a service like the IMS, it is very crucial to start by securing operations and activity data. In order to develop its business around environmental goals, data must be gathered properly on contemporary business.

To establish a certain connection between bearing spending and actual product consumption is highly interesting and would allow for a quantification of environmental impacts resulting from a reduction in spending. This is, as mentioned earlier, currently being undertaken. Such results would have been useful in this study, but must unfortunately be left out for future efforts.

In order to generate more general guidelines on how to improve the IMS, more studies of the same kind needs to be conducted. Surrounding systems must be more closely analysed, perhaps taking into consideration other impact categories or other variables or environmental loads that pulp put on the ecosystems. Certainly, other industries are interesting as well. The IMS is applied in a wide range of segments, which could render more generalizable guidelines as well.

8 References

Baumann, H., & Tillman, A.-M. (2004). *The Hitch Hiker's Guide to LCA*. Lund: Studentlitteratur AB.

Baumann, H., Boons, F., & Bragd, A. (2002). Mapping the green product development field: engineering, policy and business perspectives. *Journal of Cleaner Production* , 409-425.

T S Baines, H W Lightfoot, S Evans, A Neely, R Greenough, et al.. (2007). State-of-the-art in product-service systems. *Journal of Engineering Manufacture , 221* (10), 1543-1552.

Baines, T. S., Lightfood, H. W., Benedittini, O., & Kay, J. M. (2009). The servitization of manufacturing: A review of literature and reflection on future challenges. *Journal of Manufacturing Technology Management Emerald Article: The servitization of manufacturing:* , 547-567.

Brunklaus, B., Thormark, C., Baumann, H. (2010): Illustrating limitations of energy studies of buildings with LCA and actor analysis, *Building Research & Information*, 38:3, 265-279

CEA. (2006). *Power Generation in Canada: A guide.* Ottawa: Canadian Electricity Association.

Diener, D. (2012). Life Cycle Management - Closing the Loop.

DMI (2013), Welcome to DMI, http://www.dmi.ca, accessed on 2013-02-07.

Fishbein, B., McGarry, L., & Dillon, P. (2000). *Leasing: A Step Toward Producer Responsibility.* New York, NY: INFORM.

Goedkoop M. J., van Halen, C., te Riele H., Rommens, P. (1999). *Product Service systems, Ecological and Economic*

Basics. Amersfoort: Report for the Dutch ministries of Environment (VROM) and Economic Affairs (EZ).

Gonza´ lez-Garcı´a S, e. a. (2009). Environmental impact assessment of total chlorine free pulp fromEucalyptus globulus in Spain. *Journal of Clean Prod* .

Hanssen, O. J. (1998). Environmental impacts of product systems in a life cycle perspective: a survey of five product types based on life cycle assessments studies. *Journal of Cleaner Production* , 299-311.

Jönsson, Å. (1999). Including the Use Phase in LCA of Floor Coverings. *International Journal of LCA* , 321-328.

Jackson, A., & Jackson, J. (2009). *Environmental Science - The natural environment and human impact.* Essex, England: Pearson Education.

Lifset, R. (2000). Moving from Products to Services. *Journal of Industrial Ecology , Editorial*, 1-2.

Lockett H., Johnson M., Evans S., Bastl M. (2011). Product Service Systems and Supply Network Relationships: An Exploratory Case Study. *Journal of Manufacturing Technology Management* , 293-313.

E. Lopes, A. Dias, L. Arroja, I. Capela, F. Pereira (2003). Application of life cycle assessment to the Portuguese pulp and paper industry. *Journa of Cleaner Production* , 51-59.

Naturvårdsverket. (2005). *Sustainable Consumption - Research and Policies.* Stockholm: Swedish Environmental Protection Agency.

Maclean, H. L., & Lave, L. B. (1998, July). A Life-Cycle Model of an Automobile. *Environmental Policy Analysis* , 322-330.

Manzini, E., & Vezzoli, C. (2002). A strategic design approach to develop sustainable product service systems: examples taken from the ‘environmentally friendly innovation’ Italian prize. *Journal of Cleaner Production* , 851-857.

Mont, O. (2001). Clarifying the concept of Product-Service Systems. *Journal of Cleaner Production* , 237-245.

Mont, O. (2000). *Product Service Systems: Final Report.* Stockholm: Naturvårdsverket.

OEE. (2012). *OEE Factors*. Retrieved 12 05, 2012 from OEE Overall Equipment Effectivenes: http://www.oee.com/oee-factors.html

Ortiz, O., Castells, F., & Sonneman, G. (2008). Sustainability in the construction industry: A review of recent developments based on LCA. *Science Direct, Construction and Building Materials* , 28-39.

Stahel, W. R. (1986). Product life as a variable: the notion of utilization. *Science and Public Policy* , 185-193.

SKF (2006), SKF Integrated Maintenance Solution, http://www.skf.com/files/510097.pdf, Acessed on 2013-02-07.

Reiskin, E., White, A., Kaufmann Johnson, J., Votta, Thomas J. (2000). Servicizing the Chemical Supply Chain. *Joural of Industrial Ecology* .

Tukker, A. (2004). EIGHT TYPES OF PRODUCT–SERVICE SYSTEM: EIGHT WAYS TO SUSTAINABILITY? EXPERIENCES FROM SUSPRONET. *Business Strategy and the Environment* , 246-260.

Teece, D. J. (2010). Business Models, Business Strategy and Innovation. *Long Range Planning* , 172-194.

The Packaging Greenhouse. (2012). Från stock till papper. (O. Karlsson, Compiler) Karlstad.

UNEP. (2002). *Product-Service Systems and Sustainability - Opportunities for sustainable solutions.* Interdepartmental Research Centre, Innovation for the Environmental Sustainability. Paris: United Nations Environment Programme Division of Technology Industry and Economics (DTIE) Production and Consumption.

US EPA. (2008). *Direct Emissions From Stationary Combustion Sources.* US Environmental Protection Agency.

WWF. (2012). *Living Planet Report 2012.* Gland, Switzerland: WWF International.

Vandermerwe, S., & Rada, J. (1988). Servitization of Business: Adding Value by Adding Services. *European Management Journal , 6* (4), 314-324.

WEC. (2004). *Comparison of Energy Systems Using Life Cycle Assessment.* London: Word Energy Council.

Weizsäcker, E. U., Lovins, A. B., & Hunter Lovins, L. (1998). *Factor Four - Doubling Wealth, Halving Resource Use - A Report to the Club of Rome.* London: Earthscan Publications Limited.

Weidema, Bo P., Frees, N., Nielsen, A-M. (1999). *Marginal Production Technologies for Life Cycle Inventories.* Landsberg: International Journal of LCA.

Wijkman, A. (2012, 11). (M. Dyberg, Interviewer) ReCycling.

Wikipedia. (2012, 10 05). *Standard Cubic Foot*. Retrieved 11 31, 2012 from Wikipedia - The free encyklopedia: http://en.wikipedia.org/wiki/Standard_cubic_foot

White, A. L., Stoughton, M., Feng, L. (1999). *Servicizing: The Qiet Transition to extended producer responsibility.* U.S.

Environmental Protection Agency Office of Solid Waste. Tellus Insitute.

Öhlund, G. (2000). *Environmental and Developmental Perspectives of Functional Sales.* Division of Integrated Product Development, Department of Machine Design. Stockholm: Universitetsservice, US.

What can maintenance services of the bearings used in a pulp mill do to reduce the environmental impact of the pulp mill and its products? This report explores this topic by a two-folded approach. First by creating a custom environmental assessment of the pulp products and then by analysing the bearing maintenance activity from a Product-Service System perspective. The latter part renders guidance on how the maintenance service can be oriented towards lowered impact in the future.