# LIFE CYCLE COSTING (LCC) COMPARISON BETWEEN CONVENTIONAL AND NEW TYPE OF COMPOSITE DOCTOR BLADE

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## ABSTRACT

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Abstract

Since the paper industry is an energy-intensive and using lots of all kinds of raw materials for the production, the need for more sustainable products in the paper industry is increasing and highly appreciated.

In this thesis one of the commodity products used in the paper machine, doctor blades were studied. Two different kinds of doctor blades, conventional and a new type of composite blade Royal R1 100, were selected. The purpose of this thesis was to compare and evaluate these doctor blades from a life cycle perspective and to find out the most cost-efficient and more environmentally friendly product.

The Life cycle costing (LCC) analysis is a method, which summarizes all the costs associated with the life cycle of the product and was chosen for this comparison.

The analysis was done for both of the doctor blades, where life cycle inventory was divided into four different phases: production, transportation, use and end of use.

The results of this LCC analysis showed, that one of the four phases played a key role. The use phase was for both of the doctor blades biggest factor and the outcome was very similar to the other LCC analysis done before. As a total result of this analysis, new type of doctor blade, Royal R1 100 is the preferable type of the doctor blade being more cost efficient and environmentally friendly product.

Keywords Life cycle costing, LCC analysis , doctor blade, paper industry, composite

Location Jyväskylä University School of Business and Economics

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# 1 INTRODUCTION

## 1.1 Background

Last decade in the paper industry was very uncertain due to overcapacity in certain paper grades. This has been a major factor for many paper machines and even mill closures. Same time environmental issues are coming more important and society is more aware of environmental and climate matters, setting more strict limitations to the whole industry. The paper industry takes responsibility and constantly improve the operations of environmental and sustainability issues (www.metsateollisuus.fi).

The Paper industry is known as highly energy-intensive and cost of the energy of total production is approximately 13% (Fleiter, et al., 2012). For this reason, energy efficiency is one of the key factors for the whole industry to be improved (Thollander, et al., 2008).

For the suppliers, this means that offered technologies and services have to be better and have a possibility for the paper industry to manufacture sustainable products from renewable resources (www.valmet.com).

Royalcom Oy is a Finnish company which is manufacturing a different kind of composite products. One of the products is doctor blades which are commonly used in paper and board machines. Doctor blade is wearing spare part and these blades have to be changed depending on position from 2 days to approx. 3 months. These doctor blades are used in paper industry globally approx. worth about 100 million euro. Since this is one cost and waste factor in paper production and in the doctor blade market, there has not been any major innovations, Royalcom has developed a new type of doctor blade which could be the solution for lowering costs and environmental impacts.

There are differences between different doctor blades. There are different materials used, quantities of materials used and with different dimensions used in similar kinds of positions. Mentioned aspects need more detailed research to find out the best possible way of doing cost effective and more environmentally friendly product(s).

To find out most effective option, LCC is the right procedure to define all the costs during the product's whole life. For a comprehensive analysis, the boundaries should be defined in order to include all the phases of product life (Dimopoulou, et al., 2015). In order to compare different materials and dimensions, life cycle cost (LCC) analysis was done.

## 1.2 Aim of the study

The aim of the thesis is to contribute cost comparison and environmental effects from the life cycle of doctor blades between "commonly" used carbon fiber blade and new type of carbon fiber blade made by Royalcom Oy. The comparison of the two doctor blades was done with LCC analysis. In order to achieve the aim of this thesis, two objectives were defined:

- Examine and evaluate behaviour of two different kinds of doctor blades in paper machine dryer section. This test was done in three different paper machines and differences can be seen and recommendations could be given
- Study the outcome of the commonly used blade and the new type of blade with regard to cost and environmental impact.

## 1.3 Limitations

Since the materials used in doctor blade production are bought from different suppliers and they are not willing to give data of their production method and related costs and environmental impacts, so this part of phase had to leave out of the calculations. Also, some limitations had to be done for showing environmental impacts due to lack of relevant data available or to make some calculations based on assumptions.

## 1.4 Royalcom oy

Royalcom Oy is a privately owned company, which develops, manufactures and markets different kinds of composite products for different field of industries like machinery, sport and paper industry.

The Royalcom's composite manufacturing technology is based on pultrusion. Pultrusion is a continues manufacturing process for reinforced plastics, where fibers are pulled through resin pit, then into die for forming/shaping and finally for curing (www.gwcomposites.com). In figure 1 pultrusion process.

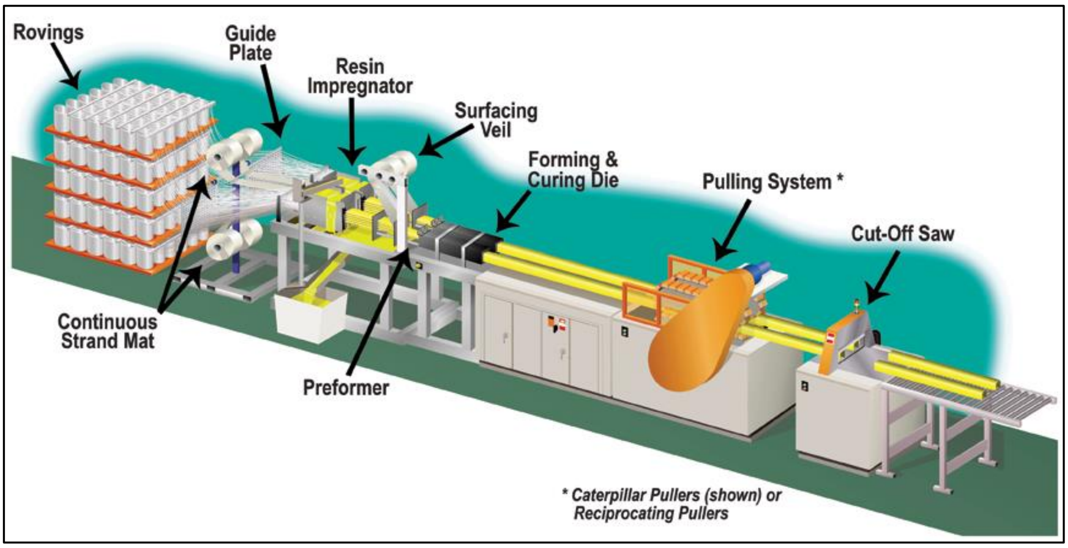


FIGURE 1. Pultrusion process (www. creativepultrusions.com)

Since the company owner's and partners have a long-term competency of the pulp and paper industry and manufacturing of composite materials, especially from different epoxies, glass and carbon fiber, the existing pultrusion technology was further developed to make from fabrics to ready-made customer product(s) (doctor blade) online. In figure 2 process flow of Royalcom's production line. This is a unique, highly automated process, which gives cost efficiency of manufacturing composite products and laminates.

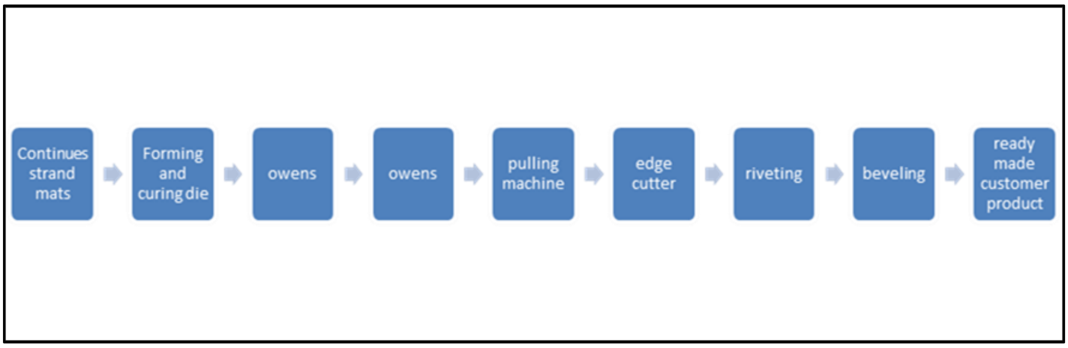


FIGURE 2. Royalcom's process flow

# 2 THEORY

## 2.1 General (Life cycle costing)

With life cycle costing (LCC) usually refers to the cost that is associated with a product or service during its life from commissioning to the end of use. The purchase price of the product includes the R&D, cost of raw materials, production, cost of use, maintenance, spare parts and end of use (Testa, et al., 2011) and it is summarizing all the costs from a product point of view (Swarr, et al., 2010). A definition of the LCC according to ISO Standard for the buildings is defined as: "*Methodology for systematically evaluating the cost of the life cycle of the period analysed, which initially defined the purpose*" (ISO 15686).

Whether the life cycle costing is done as a calculation or applied approach, the main components are:

- Investment cost for the product
- Energy cost
- Maintenance cost
- End of use cost (e.g. demolition)

The investment cost for the product is the cost, where raw material and production costs are included in the price. Sometimes, even the costs of demolition and/or scrapping are included. In the case of the commodity groups where producer responsibility exists, the producer has undertaken to take care of the future disposal of the product. Generally, this means that it is cost-free to leave it like it is (Goldstein, et al., 2010).

The Benefit to have a different view of the life cycle costing caused by the product or service during its life cycle, environmental impacts and social costs should be included. This ensures that all aspects are considered to generate an optimum solution (www.cefig.org). There is also an increased need driven by government regulations as well as consumer's interests (Andersson et al., 2011). If an evaluation is done by using the costs/kg emission, costs can be calculated for a product or service. These are the additional costs which the user will see. The price included with environmental costs will have an effect on the total price. Then costs will be higher than calculated by life cycle costing and will definitely give a different perspective (Bengts, et al. 2011).

Many analysis of the costs that climate change is causing, have been done (e.g. the Stern review). This analysis argues that very strong inputs to early actions are beneficiary and will outweigh the costs done in the future for reducing emissions of greenhouse gases. For the biodiversity loss, similar kinds of analysis are also made. These analysis are showing the magnitude of environmental issues and the importance of sustainable development (Stern, 2006).

Environmental protection in automotive industry is also big concern, because all kind of vehicles are crowing number and the challenge of reducing emissions is taken seriously to meet the targets set by EU. For this reason automotive industry is approaching this issue from several points of views. Life cycle costing is one method been used to improve complete environmental performance to find solutions for different phases not only to focus on use phase although it is main concern ( Witik et al., 2011).

When raw materials or energy are used, it costs some money. This consumption is causing environmental impacts as in emissions or the use of resources. With innovative product design, a product having same functions and performance can have a lower consumption. This way the load on the environment and costs can be reduced. If life cycle costing is taken into account at every stage, from different views and is done consistently, this would bring positive effects of energy efficiency and to better resource management (www1.eere.energy.gov).

If special parameters for environmental requirements are set and those are easier to measure and verify, environmental issues are taken more seriously and this will contribute to the development of more environmentally friendly products. For this reason, life cycle costing is selected (Goldstein et al, 2010).

## 2.2 What is the LCC?

Last decade society has become more aware of environmental issues. Same time society is more concern, e.g. how to reduce the use of natural resources. These environmental issues are thought by individuals, companies, locally and globally. Many individuals are thinking nowadays more products and services what they are buying, how these are done, are these environmentally friendly, is it ne-cessary to buy this or if bought how to maximize use (Greendelta, 2011).

The modelling structure of LCC is parallel to a Life Cycle Assessments (LCA). LCA is an analytical method, which provides an approach for evaluating of environmental impacts of product and services throughout its lifetime (Dimopoulou et al., 2012).

According to the ISO 14040(2006), LCA is a standardized process which is including four phases: goal and scope, inventory analysis, impact assessment and interpretation (Picture of phases of LCA). LCC is following this structure having phases: goal and scope, economic life cycle inventory, interpretation and reporting and review. In figure 3 phases of LCA.

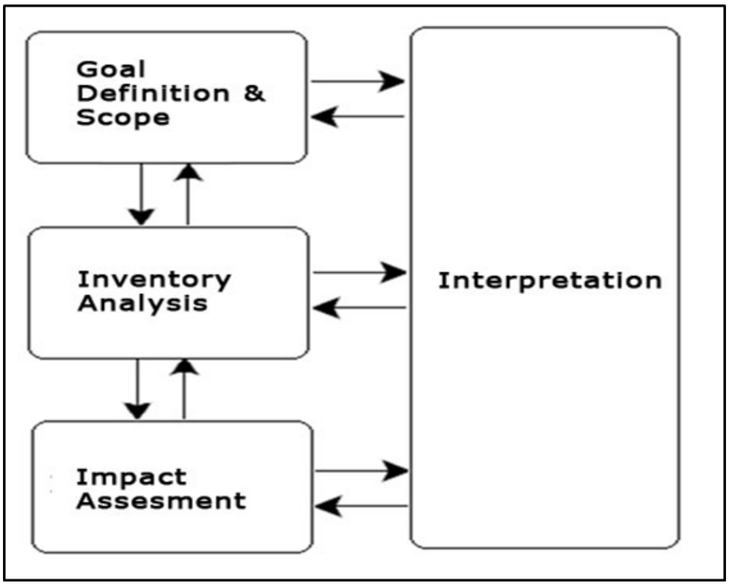

FIGURE 3. The four phases of LCA (ISO 14040)

## 2.3 Definition of goal and scope

Goal and scope is the first phase of the LCC. This phase should clearly define the purpose and method to make sure that the analysis is done properly and it is reliable. The definition of the goal should be able to define intended application, the reason for the study, the intended audience and *"whether the results are to be used in comparative assertions intended to be disclosed to the public"* (Swarr, et al., 2010).

Several requirements are included in the scope. Two of the most important are the definition of the functional unit and system boundaries. Other requirements are allocation, assumptions, and limitations the LCC (Swarr et al., 2010).

*"The functional unit which can be defined as the unit of comparison that assures that the products being compared provide an equivalent level of function or service"* (Bayer et al., 2010).

Since comparative nature of LCA, an analysis requires an equivalent definition of the system boundaries for the alternatives compared in the study, i.e. the goal definition (Tillman, et al., 1993). LCC system boundaries can be seen in figure 4.

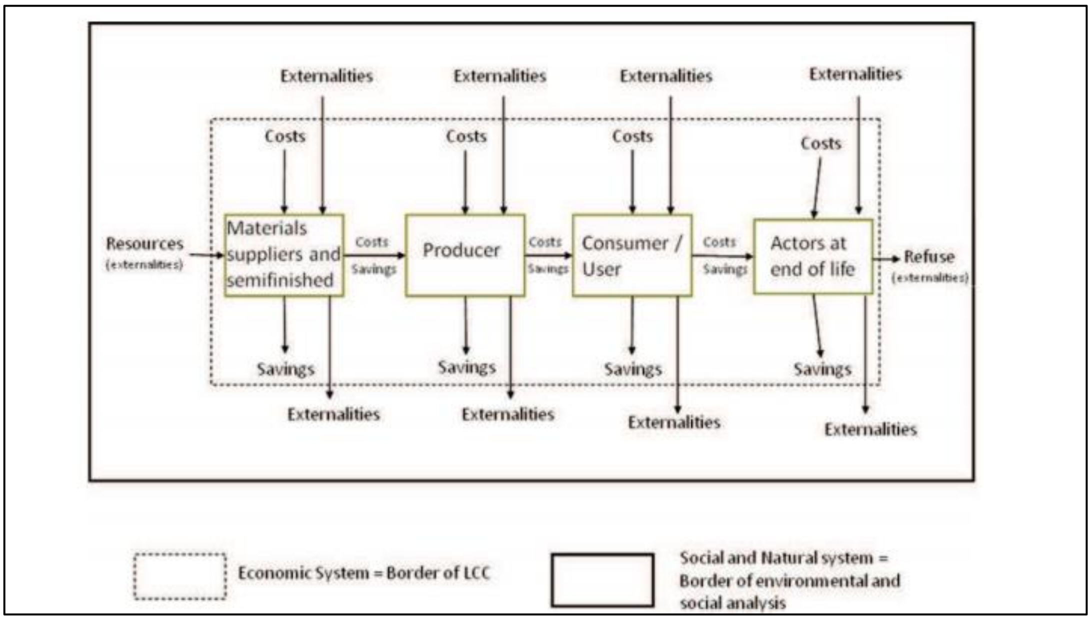

FIGURE 4. Conceptual framework (Rebitzer, 2003)

## 2.4 Economic life cycle inventory

The economic life cycle inventory is very similar to defined in the LCA. LCI evaluates the costs of the entire life cycle of the product. In this process, all stages of process should be included in order to get more accurate and reliable results (Swarr, et al., 2010). Even though LCC aims to a one-dimensional monetary unit, the problem is that this might oversimplify reality caused by market value e.g. pricing (Gluch, et al., 2004).

The main idea is to make process which is very understandable for all actors. The process should be based on in phase one determined requirements and especially on system boundaries (Rebitzer, et al., 2004). In this stage also environmental impacts for the different stage of the process should be defined and collected (Testa, et al., 2011). LCC requires following information (Swarr, et al., 2010):

- analysis of goal and scope
- product to be analyzed and its structure
- structure of cost breakdown
- product life cycle
- sources of cost data

These four objectives have to be considered very carefully when making a life cycle inventory; data issues, cost categories, allocation and discounting.

Data issues have its effect on the whole process. Available data on real LCC is more accurate than data collected from generalized tables. Real data are more time consuming to find and anyway, there are some factors which can’t be given, balance with real data and data collected from generalized tables has to be chosen based on access to the data source and how results will be used (www.solidworks.com).

Firstly, for cost categories adequate cost flows for the whole process needs to be created. Then choose which categories are used. These can be different for different parts (Duyan 2013).

The allocation procedure in a multiproduct process is a critical issue in LCC. The ISO 14040 (2006) recommends avoiding allocation if it is possible. Avoiding can be done through subdivision or by expanding system limits. If avoiding is not possible, the ISO 14040 (2006) recommends using methods, "*that reflects the physical relationship, such as mass and energy content or using other relevant variables to allocate, such as economic value of the products, which is similar to the cost allocation methods in managerial accounting*" (Guinée et al., 2003).

Discounting is done if the duration of product system is more than 2 years. Discounting rate depends on which perspective it is done, consumer, producer or government (Swarr, et al., 2010). "*Whenever the "time value of money" is consi-dered, the life cycle cost is the all the costs in the life cycle, discounted at an interest rate at some time point*" (Eisenberger, 1977).

## 2.5 Interpretation

The third phase of the LCC is the interpretation. This process is structured as in ISO 14040(2006).

Analysing all the results, reaching accurate conclusions, giving a good explanation for the limitations and give possible recommendations based on the findings in the previous phases in the process (www.solidworks.com). Identify the most significant issues "hot spots", which are the most contributors to overall impact (Swarr et al., 20101)? All the results should be given in readily, understandable in accordance with the goal and scope (www.solidworks.com). Results should be given in a single unit of measure (Swarr et al., 2010).

## 2.6 Reporting and review

The last phase of the LCC is the reporting and review. Like the previous phase, this also follows the ISO 14040 standard.

A great deal of value depends on how these results are reported to people involved. Information given has to be reliable, consistent and accurate.

For the review, critical thinking is needed. Is all information presented, is the methods used reliable and are the assumptions, data, factors, which were used in the process consistent internally and in accordance with goal and scope (Swarr et al., 2010).

## 2.7 Doctoring

### 2.7.1 Purpose of doctoring

The main purpose of all doctors in the paper machine is either to clean the roll or remove the sheet from the roll. Sometimes, both these functions are required from the same doctor and doctor blade (Leighton, 1997).

Increasing the machine speed is increasing the importance of cleanness of the roll surfaces: It has a direct effect on the continuity of the process. When speed increases, risk for paper break ups increases as well. One of the very important places when roll surface cleanness has important role, is the first cylinder of the dryer section. In this stage paper web (wet) is first time touching the heated cylinder. Impurities on the cylinder surface can easily attach to the paper surface and this way, causing runnability problems later in the dryer section or that these are marking paper to make it as non-saleable paper. In the worst case, this is causing the paper break-up immediately (Wedel, et al., 2009).

There are many suppliers for paper machine doctors Machine suppliers like Valmet Oyj and Voith Paper GmbH are delivering their own for their paper and board machines, but on the market, there are several smaller suppliers like Bonetti S.p.A, Kadant Inc and Lantier Sa, which are delivering doctors for machine suppliers or independently selling replacement doctors. In figure 5 dryer cylinder doctor.

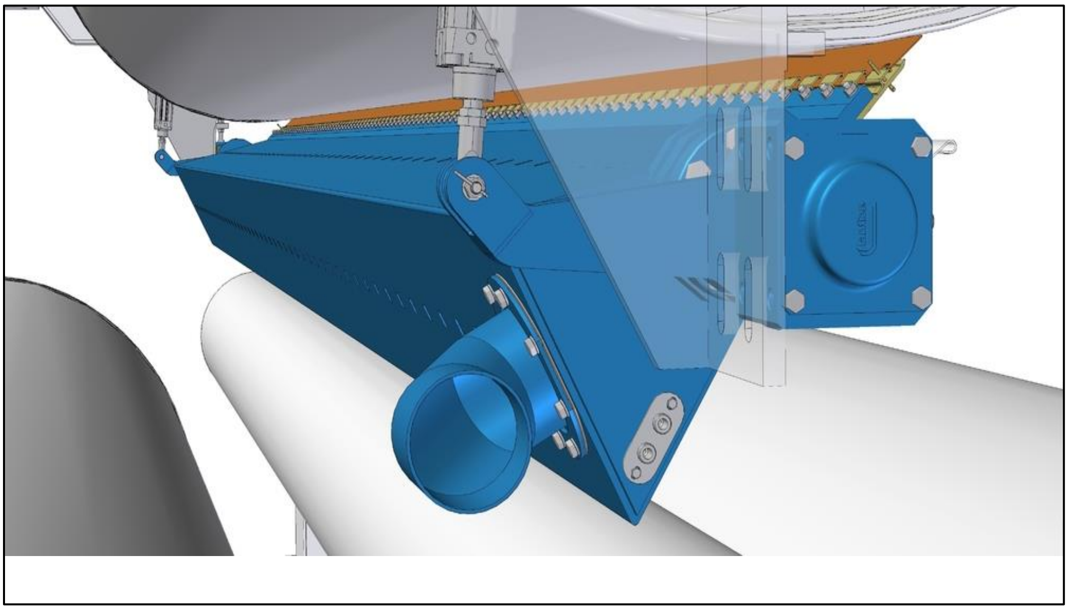

FIGURE 5. Dryer cylinder doctor (www.lantier.solutions.com)

### 2.7.2 Doctor blades

There is a huge amount of different kind of doctor blades on the market. Each supplier has their own list of blades with different dimensions and different materials.

Choosing right kind of doctor blade from many of the different possibilities can be difficult. Anyway, there are some rules and models for different materials in certain doctoring positions and part of the paper making process. One important factor is cylinder cover material, which will determine what kind of blade materials can be used.

To make it easier for choosing the right kind of doctor blade for dryer section, blades can be divided into three categories; metal blades, blades with ceramic tip and composite blades (Leighton, 1997).

### 2.7.3 Metal blades

Metal blades are the traditional blade materials used in the dryer section. There are different type of metal blades like, steel, stainless steel and bronze blades.

For these blades, price is the main competitiveness factor. These are relatively cheap compared to composite blades or blades with ceramic tip. The other very good factor for these blades are that they are very thin, only 1,0 to 1,2 mm thick and this way these have very good doctoring result (Lamort, 1995).

These blades are still used in slower machines, but modern and fast machines are not using these blades anymore, because all metal blades tend to have a high coefficient of friction and that is causing very high wearing, those tend to have a risk for sparks and this causing fire risk and some blades like bronze are melting in higher speeds (Leighton, 1997).

### 2.7.4 Blades with ceramic tip

These types of blades are relatively new on the market. As a base material all above mentioned metal blades are used and then only the blade tip coated with a hard coating. The idea behind this type of blade is to get benefits out of traditional metal blades for fast paper and board machines. With this ceramic tip these blades are able to use without risk of fire or melting.

However, the problem with this kind of blades are, that these are very expensive compared to other materials. Price can be up to 10 times higher than ordinary metal blade. Also, hardness of ceramic tip can cause excessive wearing for cylinder and that is not desired situation (Wedel, et al., 2009). See blade with hard coating in figure 6.

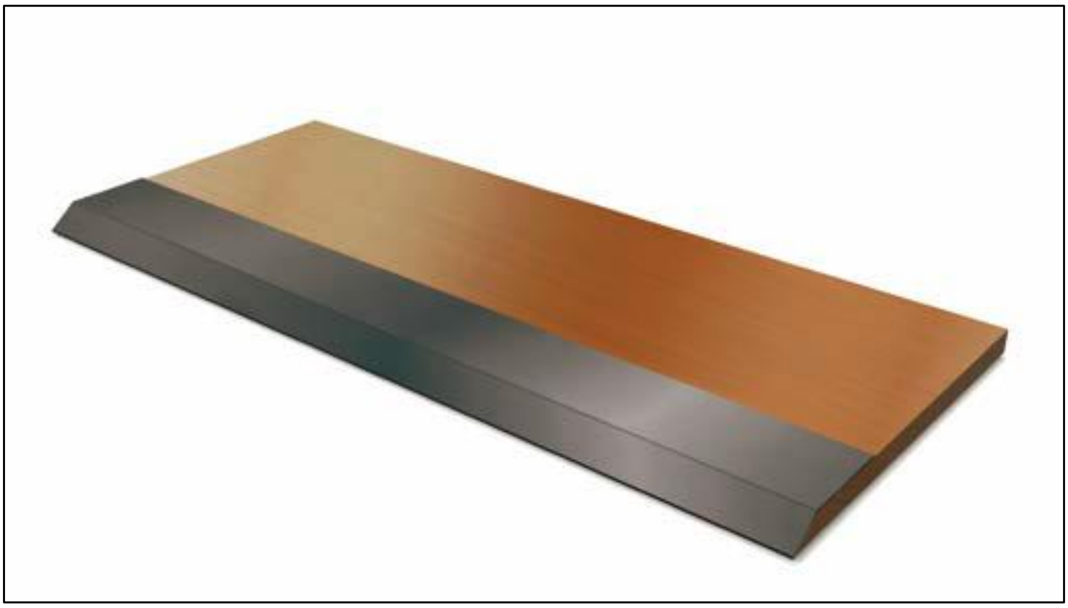

FIGURE 6. SkyTerra B Phosphor bronze with ceramic coating tip (www.voith.com)

### 2.7.5 Composite blades

Ever since paper machine speeds and capacity requirements are increased and are increasing all the time, composite blades are the most common blade type used in all kinds of positions in a paper machine as in dryer section as well.

Composite blades used in the dryer section are full glass fiber, full carbon fiber and hybrid type of these two mentioned. All of these types of composite blades have their own characteristic why these are used. Glass fiber is cheapest and full carbon most wear resistant blade and the hybrid version is everything in between. See composite blade in figure 7.

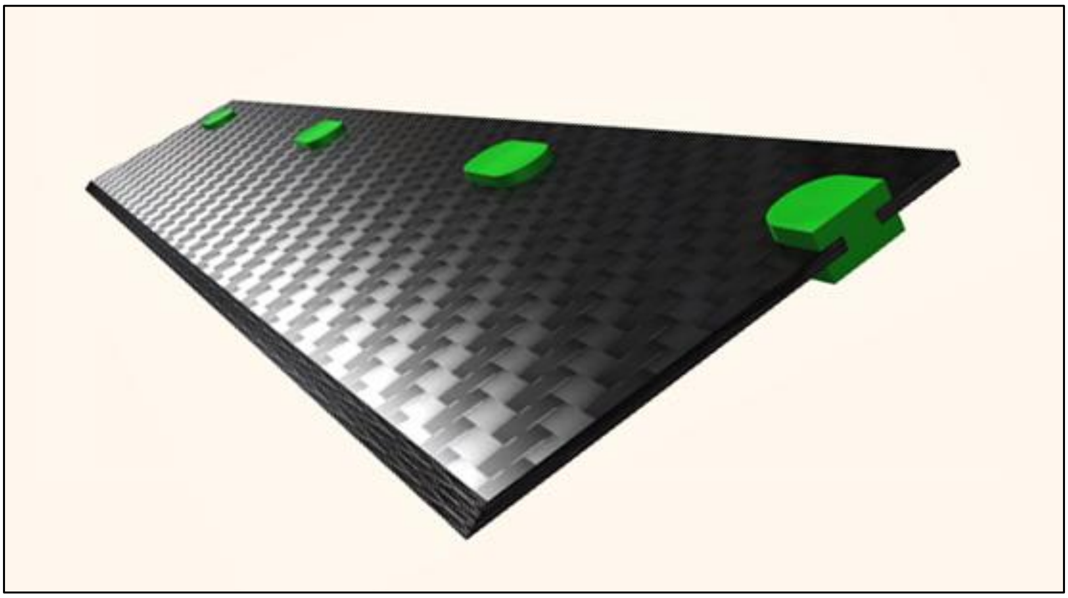

FIGURE 7. Royal 100 R1 (Royalcom product sheet)

## 2.8 Paper machine dryer section

The purpose of the paper machine dryer section is to evaporate remaining water from the paper web after the wire and the press section. Evaporation usually will start when paper web's dry content is from 40 to 50%, depending on paper grade and machine construction (Puusta paperiin, 1981).

The purpose of the drying the paper can be described in the following way:

- Remove water from the paper web to achieve desired final dry content. Usually from 93% to 96%.

- Remove water from the paper web with minimum costs.

- Remove water from the paper web as evenly as possible.

- Remove water without weakening desired paper quality.

The paper machine dryer section is divided into several dryer groups, which each of them have several drying cylinders. The purpose of this is to generate possibilities for adjustment of evaporation rate (Paperinvalmistus, 2005). See in figure 8 of paper machine lay-out and dryer groups in figure 9.

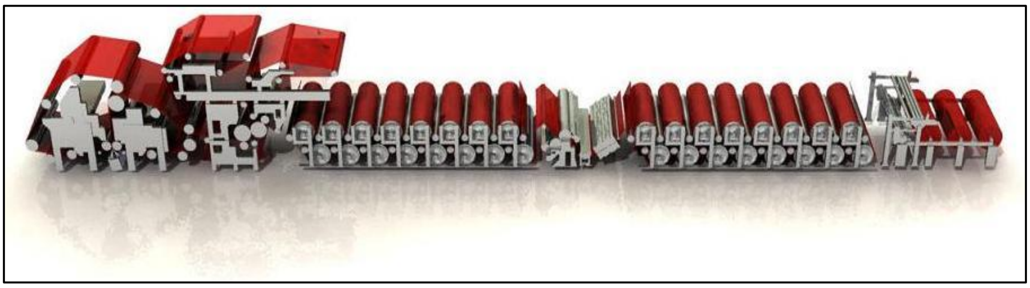

FIGURE 8. Paper machine lay-out (www.walmsleys-uk.com).

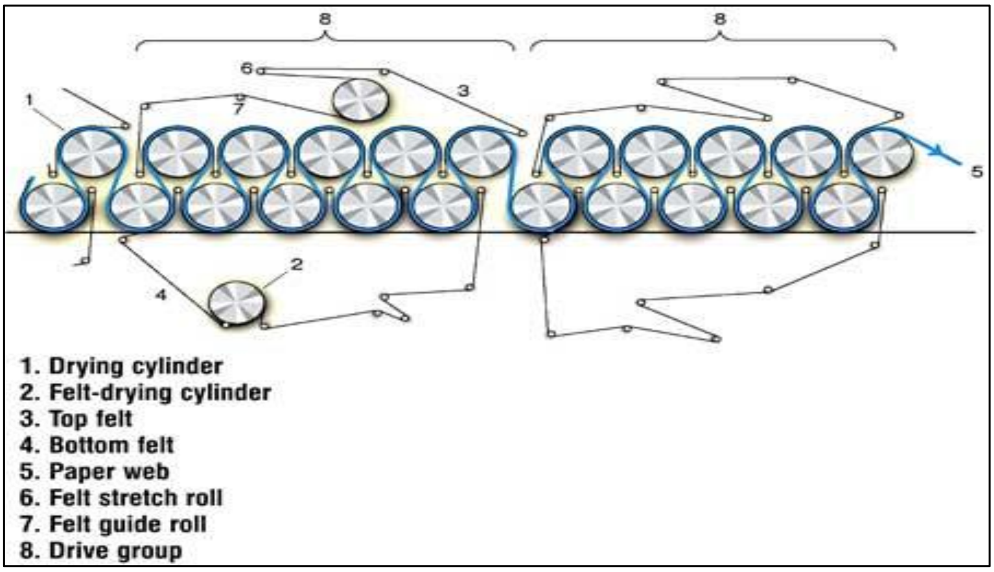


FIGURE 9. Dryer groups (www.machinerylubrication.com)

# 3 METHODOLOGY AND DATA COLLECTION

## 3.1 Methodology

In this study, Life Cycle Costing (LCC) is used as a method. LCC is a tool for the economic analysis for all costs related to product and services taking into account the complete life cycle of the product. Analysis takes into account investment, operations, maintenance and end of life costs including environmental impact (Duyan et al., 2013).

### 3.1.1 Research design

The first step of this project was to study the literature of the LCC. The idea is to find existing cost calculations of LCC in order to make a comparison of financial and environmental impacts of the two chosen doctor blades.

The next step was to choose possible paper machines which could make trial comparisons with their existing blade and Royalcom's new blade. Trials should include material wearing and measurement of possible energy savings on their dryer section.

Lastly, LCC analysis should be done and two different doctor blades to be compared. For each step, calculations were done by using Microsoft Excel.

Needed material calculation (appendix 6) is the base information, which was calculated first. The result of this calculation was used in calculations of the production cost (appendix 1), transportation cost (appendix 2) and waste cost (appendix 4). For use phase cost (appendix 3), energy consumption (appendix 5) from trials had to be calculated first. The results of these calculations are summarized in chapter 4.3.

## 3.2 Data collection

### 3.2.1 Trial machines

| | Paper machine 1 | Paper machine 2 | Paper machine 3 |
|---|---|---|---|
| Paper crade | LWC | NEWS | SC |
| Operating speed | 1400 m/min | 1550 m/min | 1650 m/min |
| Wire width | 9100 mm | 9150 mm | 10100 mm |
| Production | 300 000 tpy | 350 000 tpy | 350 000 tpy |

TABLE 1. Trial machine data.

Table 1 shows trial machines for this study. Trial machines were chosen based on paper grade. The idea was that this way trial results should give better and more trustable results. This is not the ideal amount of machines, but other machines were not interested to make this kind of trials.

### 3.2.2 Blade wear

Blade wear was collected from the above-mentioned machines. For both blade types, similar kind of collection was done.

The customer changed their conventional blades by themselves for chosen dryer groups. Blades were certain times in machine. Blades were taken out and blade wear of each blade was measured. After this, new types of blades were installed to same positions and blades were taken after a certain period out and measured.

Average blade wear was used in the calculation of needed material. Calculation of the needed material can be seen appendix 6 and blade wear collection table in appendix 7.

### 3.2.3 Energy usage

Energy usage trials were done in trial machines mentioned earlier. In each machine, two dryer groups were chosen by customer.

Energy usage measurements for each machine were done by the customer and energy usage values were given to us after the trial run. Energy usage values were collected to the table (appendix 8) and average values for each blade were calculated. The calculation can be seen in appendix 5.

### 3.2.4 Production

Production phase energy consumptions were collected from each unit which are used in our machine line. This can be seen in appendix 9.

### 3.2.5 Transportation

Transportation route is the actual route from Royalcom's manufacturing premises via locations were earlier mentioned trial machines are located.

A company van was used for calculating transportation costs. Fuel consumption and loading capacity were taken from car manufacturer's web page (www.nissan.fi).

# 4 RESULTS

The aim of this thesis is to make LCC analyses for earlier mentioned two different kinds of doctor blades. This way the most cost efficient material and environmentally friendly product can be defined. For both doctor blades, LCC analysis were done according to the procedure mentioned in chapter 2. Results of this analysis will be given according to LCC phases; goal and scope, economic life cycle inventory, interpretation and reporting and review.

Main limitations will be given in the definition of goal and scope. Assumptions and limitations for environmental variables are explained in each life cycle phases in this chapter.

## 4.1 Goal and scope

The goal for this study is to make a comparison between conventional 2mm doctor blade and 1,1mm new type of doctor blade developed by Royalcom Oy. These blades differ from each other by thickness and materials used. More detail structure can be seen in appendix 1.

The main reason and motivation for doing this study is newly developed 1,1mm doctor blade. These kinds of blades haven't been on the market and there is a reason to believe to get the cost savings and give a new perspective for consumer buying behaviour as well. At the moment one of the main reasons for a consumer to make a buying decision is the price comparison of the different suppliers. The comparison is done by price/m, which basically tells who is the cheapest, most expensive and everything between suppliers.

Results of this thesis will be shown to consumer(s) and hopefully this will lead to more advanced evaluation when consumer(s) are choosing their e.g. doctor blade suppliers.

One of the main factors to determine an LCC analysis is to define system boundary. System boundary for this analysis can be seen in figure 10. There are four different stages; production phase, transportation phase, use phase and end of use. This means that doctor blade manufacturing starts from raw materials bought from different suppliers, manufacturing of the blades, transportation for both materials from Royalcom's factory to customer premises, trial tests in customer machines as use phase and end of use for doctor blades when blades are taken from the machine and put to the dumpster.

Stages like manufacturing of carbon fiber/glass fiber filaments and sewing process of carbon/ glass fiber weaves were limited from cradle to grave process. The main reason for this is that suppliers for weaves are not giving their process flows or even energy consumption values. The main reason is the competition between different suppliers. Searching from the internet, process flows could be found, but then too many assumptions should be done and it would give totally false values for the analyses. End of use was also limited to the factory dumpster, because when asked from a paper mill, the production personnel didn't know exactly how and when the blades were picked for final disposal.

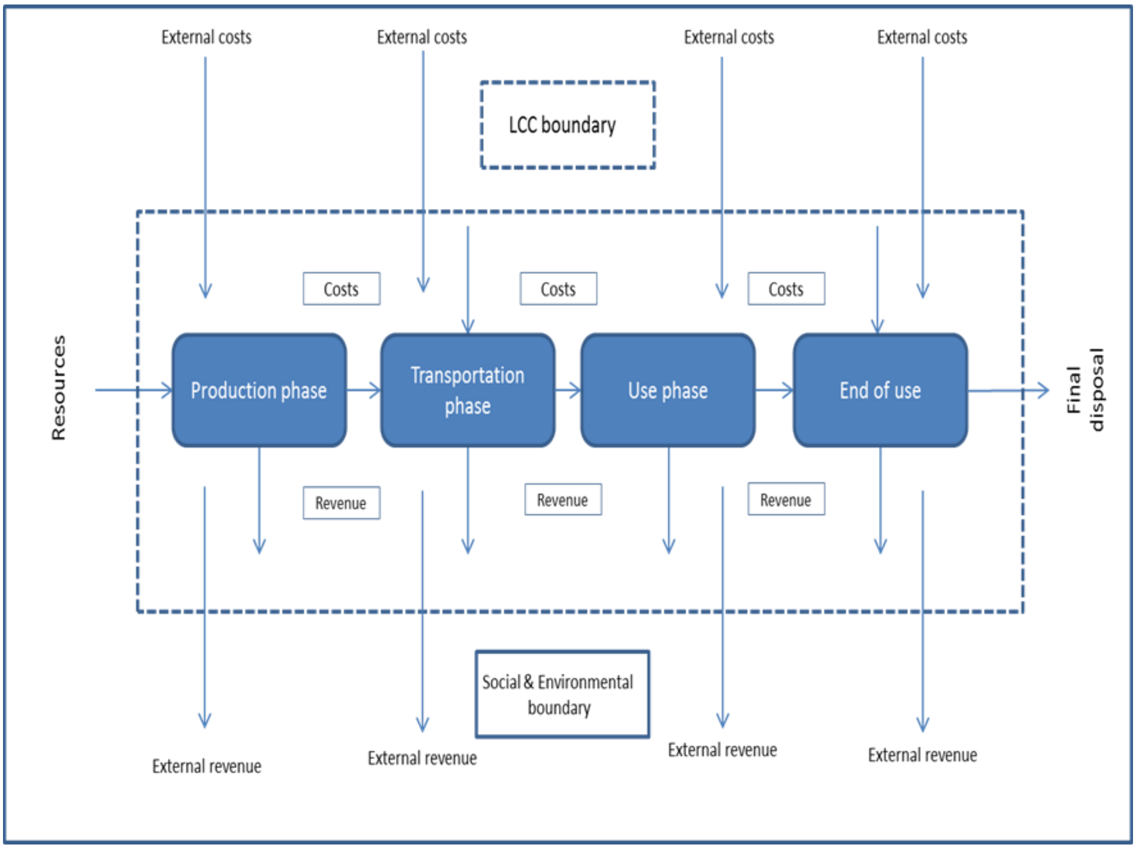

FIGURE 10. LCC system boundary.

The functional unit for this analysis is doctor blade costs in one year at paper machine dryer section (EUR/a). The reason for choosing a functional unit like this is that since doctor blades are wearing spare parts, those needs to be changed after a certain period of time, this will give the right picture of how many these blades are used annually. This is telling more than just price/m. For environmental variables, this will also give more information and hopefully give new ideas for consumers how and when these doctor blades are bought.

## 4.2 Economic life cycle inventory

### 4.2.1 Production phase

For the production costs, first needed information is how much both conventional and a new type of doctor blades needs to be manufactured. This information for the calculation gets it from trial machines. Each machine had conventional blades in the machine and before putting a new type of blades, all blades were measured to get how much each blade was worn out. The same way these new types of blades were measured after a trial period. The average wearing rate for both doctor blades were calculated based on wearing and hours been in a dryer section (mm/h).

The unused doctor blade is 75 mm wide and theoretical recommendation for a blade change is when blade width is 60 mm. This will be used as an assumption to get needed material for the production. The calculation can be seen in the appendix 6.

Next step is to calculate a cost for the production. The manufacturing process in this case is pultrusion. Each step of the manufacturing process can be seen in figure 11.

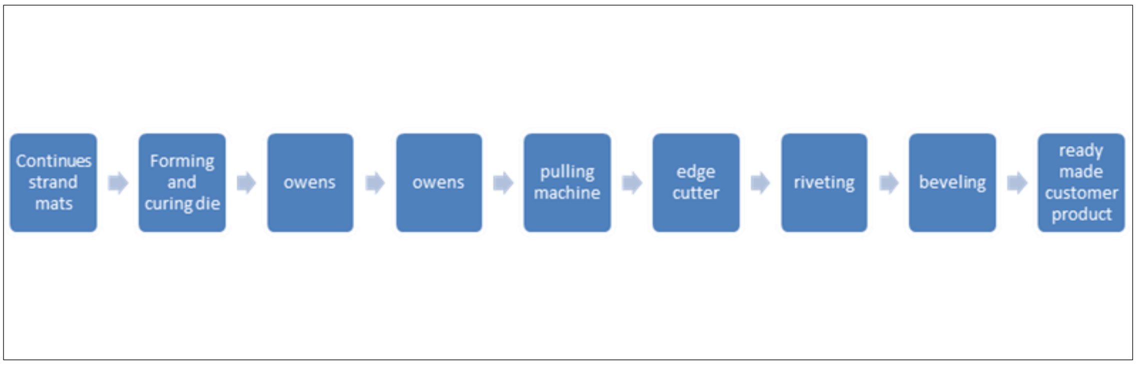


FIGURE 11. Manufacturing process flow.

Pultrusion process has different steps and each step has its own function to make a ready-made customer product and these steps require energy.

Both blades have its own structure and based on this, material cost can be calculated.

Overhead costs could be allocated but at the moment production capacity is not full, for this reason, it is easier and more practical to use same overhead cost for both materials.

All these above mentioned costs added to the cost of packaging and margin for both products and production cost is calculated. Calculation can be seen in appendix 1 and production cost of both materials can be seen in figure 12.

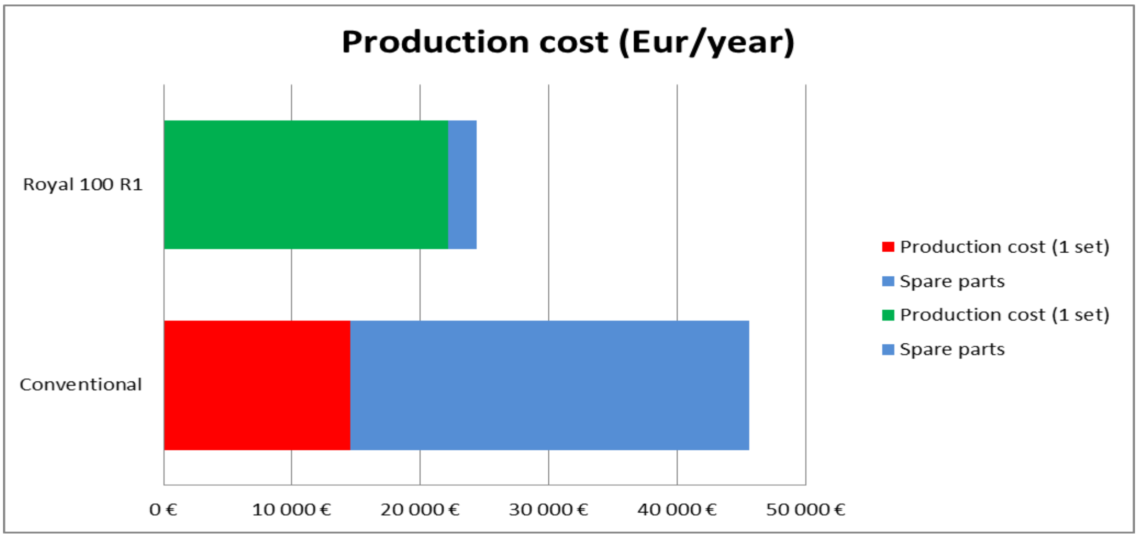


FIGURE 12. Production cost (Purchase & spare parts)

From figure 12 can be seen that production cost (purchase price) for 1 complete set of conventional doctor blades for dryer section is approx. 33% lower than Royal 100 R1. Even though the purchase price is much lower, but for doctor blades used in 1 year, according to functional unit, the cost will be 2 times higher than for Royal 100 R1. The reason for this is due to wearing rate of the conventional blades. Conventional blades need to be changed approx. 3 times/year, meaning that the spare part cost has a huge effect compared to Royal 100 R1.

From a consumer perspective, this will definitely give a reason for a different way of thinking. Too often these wear parts like doctor blades in a paper machine are only categorized by purchase price. This is not only the consumer issues. All suppliers are responsible to give this kind of information and try to push consumers for longer period time thinking as just a present.

Overall production emissions are rather low. The difference in emissions bet-ween these two products is coming from the higher production amount for conventional doctor blade.

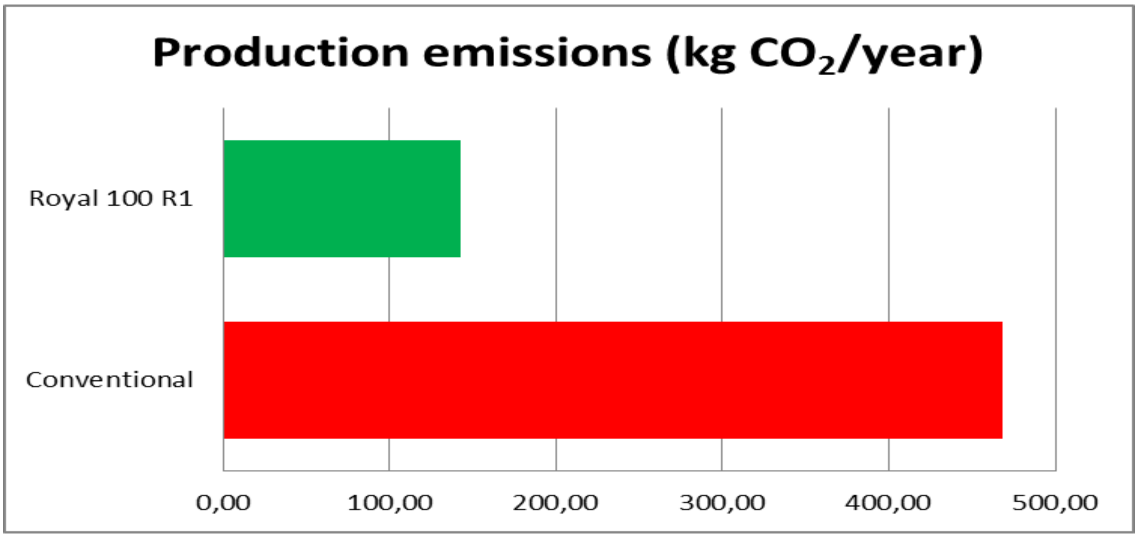


FIGURE 13. Production emissions

### 4.2.2 Transportation phase

Transportation phase could be included to use phase. The reason for showing this as a separate phase in this analysis is because transportation is a bigger cost factor and causing higher environmental impacts than it is in this case.

For this calculation, transportation cost is calculated based on needed material in trial machines. The route is limited for calculation from Varkaus via Jämsä to Rauma and back, based on the location of the trial machines.

A Company car is used as a transportation method. The transportation cost is calculated as fuel cost for driven route and the cost of the driver as driven hours. For fuel cost, 10% assumption is added because the weight of the cargo will affect fuel economy. Driven route is calculated with maximum boot capacity. This is also an assumption because normally customers are not taking so much doctor blades to their storage/time. Customers also have a bit different habits, how many blades they are taking, so for this reason, it is easier to calculate with maximum capacity.

Results show that transportation cost for the conventional blades are twice as higher than for Royal 100 R1H. Results can be seen in figure 14.

The main reason for this is, because the needed material/year is higher. This difference would be higher, because transportation cost is calculated with boot maximum capacity. If this calculation would have been calculated how customers are taking these normally, 10 pcs or maximum 20 pcs doctor blades at the time, a number of transportation times were from 4 to 10 and this would have a direct effect to transportation cost. Even higher costs are coming when these same blades are sent to e.g. China (air freight). The Cost of sending these same blades are 5 times higher and emissions are 10 times higher. Calculations can be seen in appendix 10.

The problem here is the customer behaviour. Customers are not allowed to take doctor blades for a needed material/year at one time. This is a good way to show them how much costs are higher and maybe in the future they will try to understand more and try to find a balance between short-term cost and environmental impact(figure 14), when taking doctor blades minimum amount/time.

This has an effect on emissions, which is higher due to the amount of transportations (figure 15).

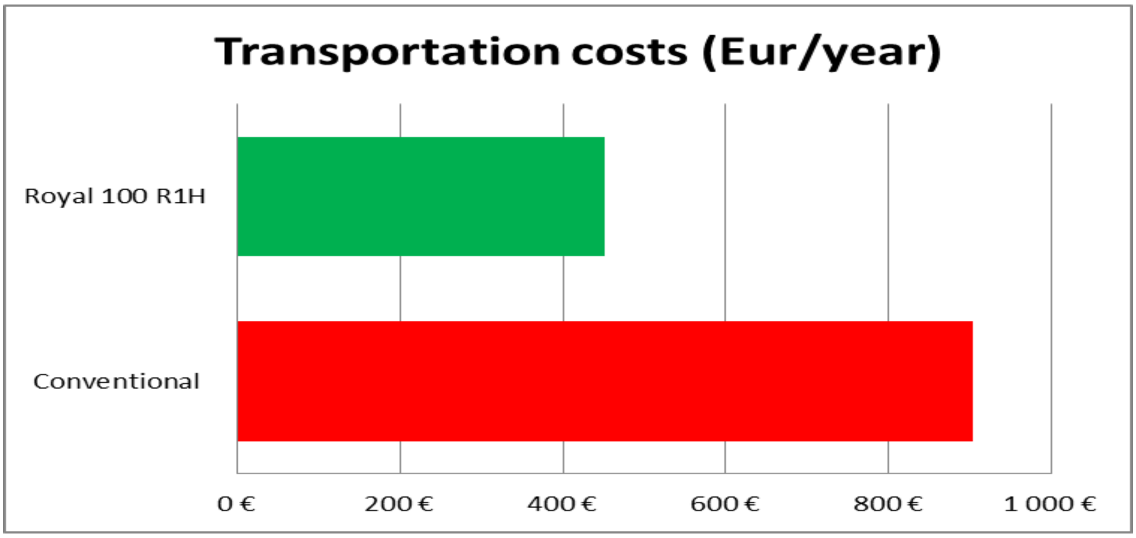

FIGURE 14. Transportation costs.

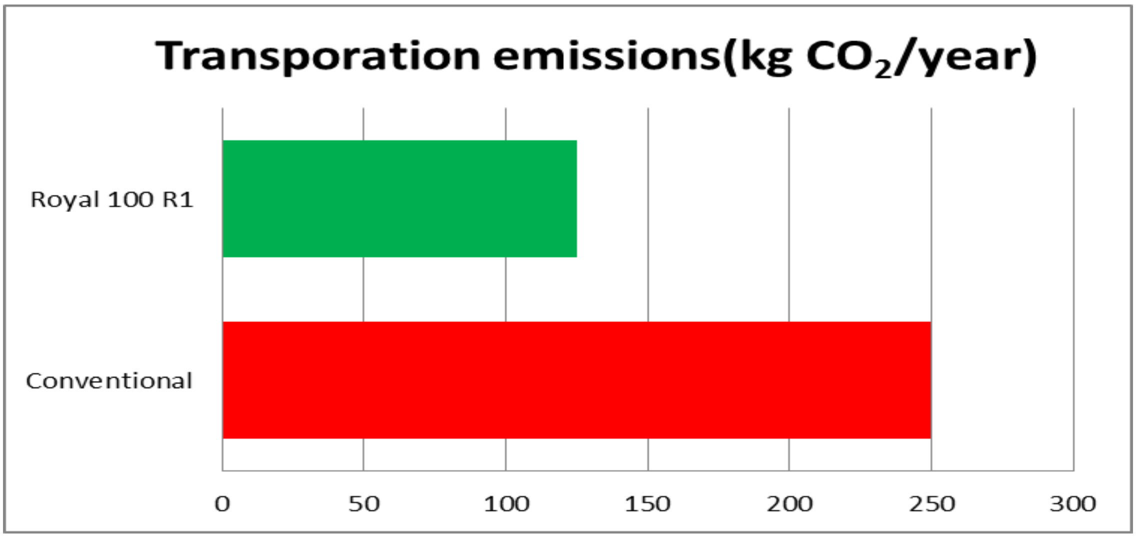

FIGURE 15. Transportation emissions

### 4.2.3 Use Phase

The use phase cost is calculated with the information got from the trial tests. Trial tests were done in three different dryer section mentioned in chapter 3. Dryer section has from 3-8 dryer cylinders and for rotating these with needed speed, different sizes of drives are used. Normally these drives vary from 150kW to 650kW. For rotating just cylinders approx. 35-40% of drive's maximum capacity is needed. Since doctor blades are loaded against cylinders, this increases drives capacity by 25%unit. This is calculated from values got from one trial machine and this will be an assumption for other two machines as well. Reference values with conventional blades were gathered from all three paper machines. A new type of blades was put into machines and 2-3 months trial tests started. The time period for trial was decided to be above mentioned, because the doctor blade wearing rate has its own effect on these results. When

doctor blade starts to wear, it has a decreasing effect on loading and the same time this will decrease the capacity of the drives. Also, reference values were given with worn blades, so this difference was eliminated.
Data were collected 5 times from each paper machine. Dates when data were collected, were selected according to a paper machine running parameters to match parameters when reference values were given. This is very important because paper machines are producing paper with several different basis weights ($g/m^2$) effecting on running speed which has a direct effect on the capacity of the drives.
For the cost of usage, average values for energy consumptions were used. A cost of usage was limited only to energy consumption and other costs like labour cost e.g. cleaning the blade in the shot down were left out. Paper machines are not running 365 days/year. Machines have their own production rate, which depends on how many e.g. shut down days and other stoppages might occur. For this calculation 90% operating rate is used for all machines. This is the average rate since that vary from 87% to 93%. Calculation for usage can be seen in appendix 3.

Results are showing (figure 16) that use phase is the biggest cost in the LCI. This is coming because of energy is needed when paper machine is running and without doctor blades production is impossible. However, results are also showing that by choosing different kind of blade, e.g. which has more carbon fiber like Royal 100 R1, some energy savings can be achieved. More important than saving just money, is the reduction of the environmental impact e.g. lowering $CO_2$ emissions from 158000 kg to 132000 kg. See figure 17.

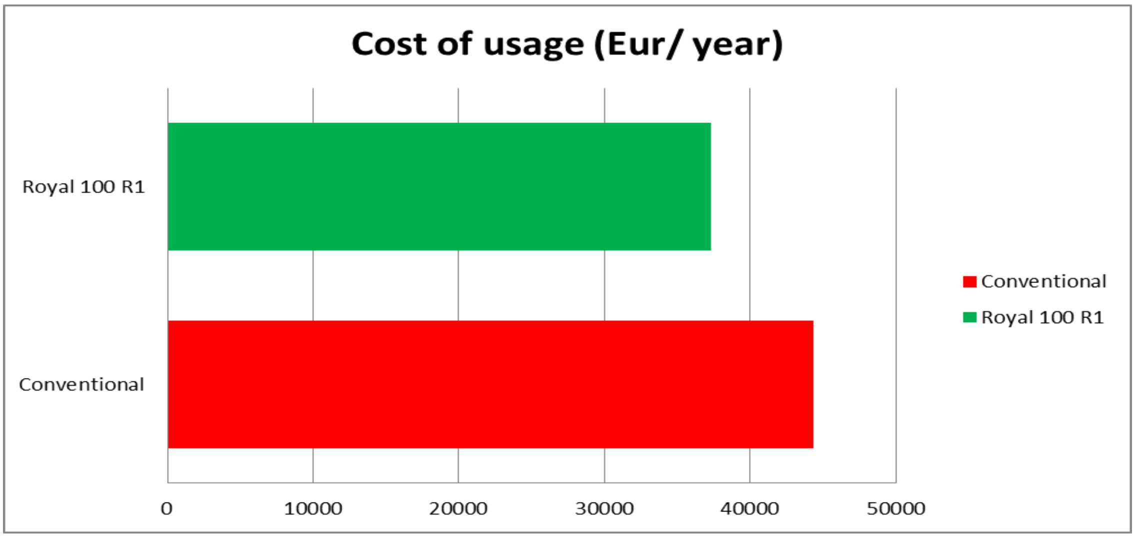

FIGURE 16. Cost of usage.

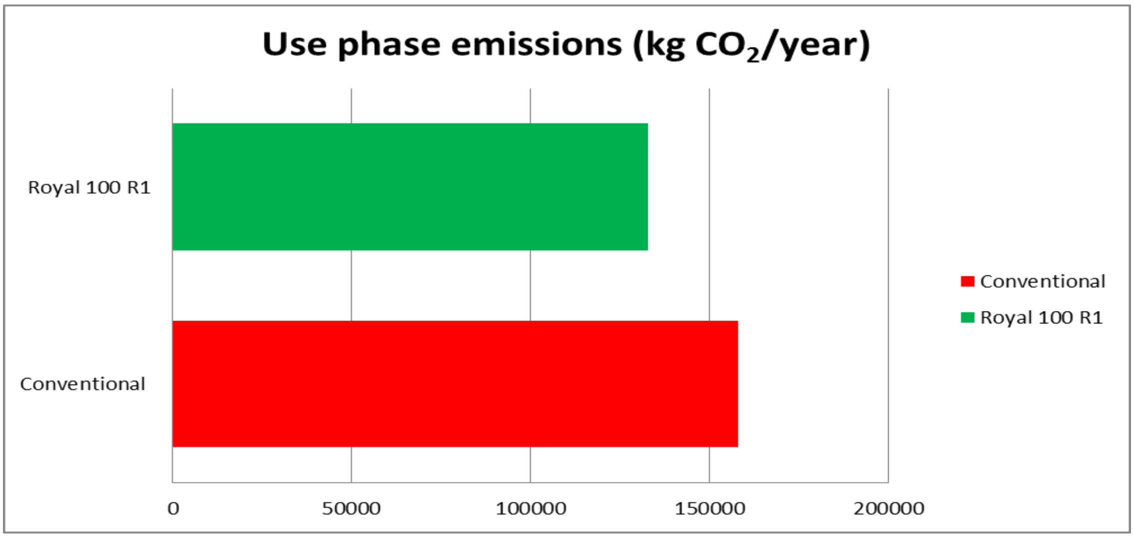

FIGURE 17. Use phase emissions.

### 4.2.4 End of use

End of use is the last phase of the LCI. This phase is handling the waste cost for the earlier mentioned doctor blades. When doctor blades have reached their minimum wearing width (60 mm), doctor blades are taken out from the machine and put to the dumpster at the paper mill.

For the calculation this minimum width will be used as an assumption for all the blades. Since these two different doctor blades have their own structure, density for the waste is calculated accordingly. Waste cost is limited to used doctor blades and does not include e.g. labour cost of cutting used blades.

End of use phase has very low-cost effect on both doctor blades (figure 18). The difference is mainly coming from spare blades. Conventional blades need to be changed more often and this is causing more waste as well. The calculation for the waste cost can be seen in appendix 4.

Even though this has a very low-cost effect on product life cycle, this cannot be neglected, because of nature of waste. Both of these materials does not decompose and change this as energy, requires special furnaces which can handle especially glass fiber. This is a challenge for suppliers to find more sustainable materials because the waste cost does not get any cheaper but more expensive. Waste can be seen in figure 19.

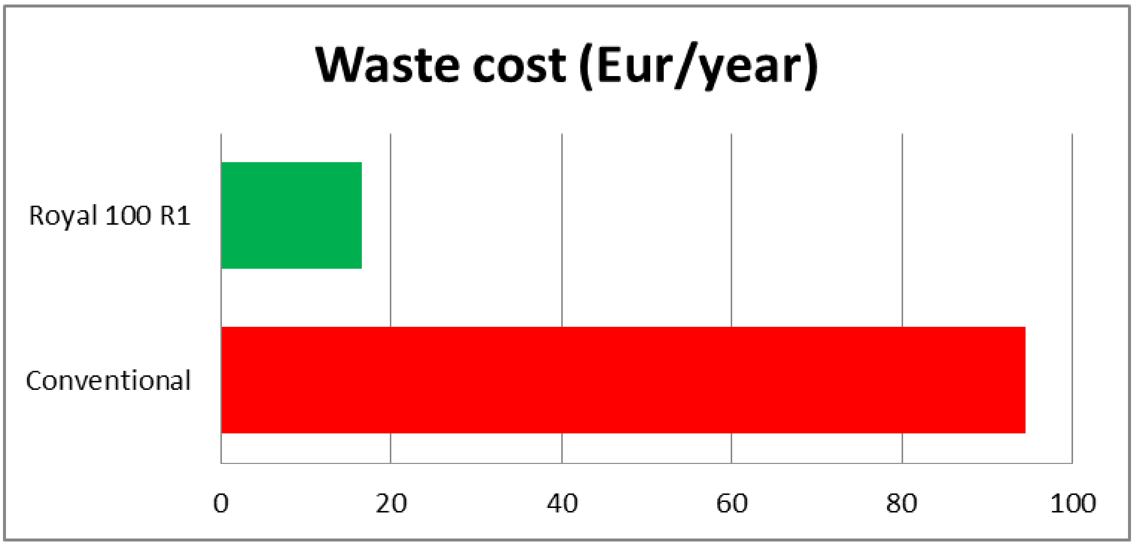


FIGURE 18. Waste cost.

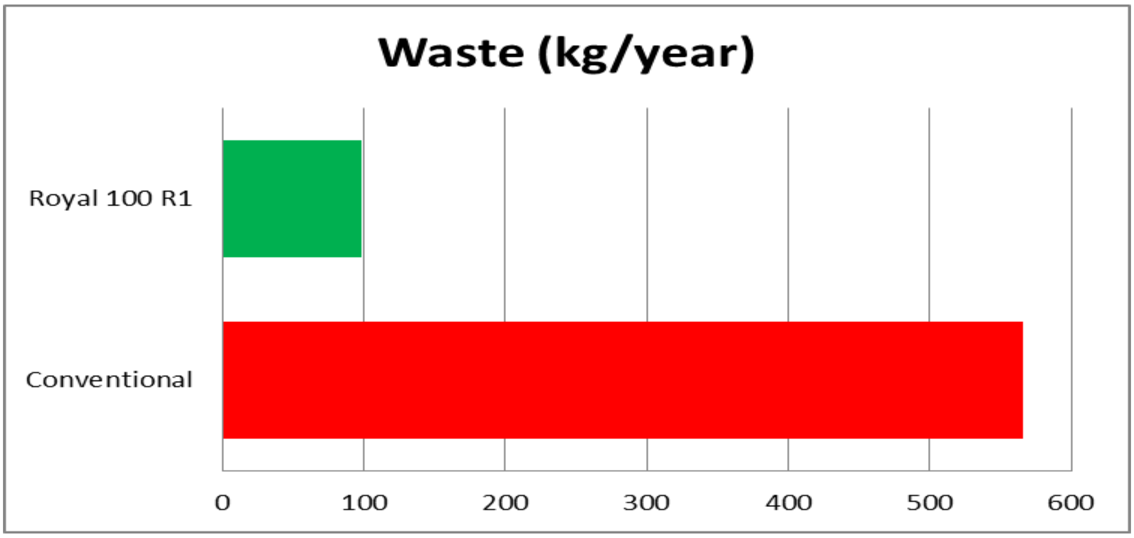


FIGURE 19. Waste

## 4.3 Interpretation

The purpose of this study was to make LCC analysis by calculating and comparing two different kinds of doctor blades. For this analysis four different phases were chosen and calculated accordingly.

Table 2 shows the results of the comparison between the conventional doctor blade and Royal 100 R1 doctor blade.

| LCC | | |
|---|---|---|
| Functional unit (eur/year) | | |
| **Economic variables:** | **Conventional** | **Royal 100 R1** |
| Purchase cost (1set) | 14 544,52 € | 22 152,15 € |
| Spare parts | 31 125,28 € | 2 215,22 € |
| Transportation phase | 902,80 € | 451,40 € |
| Use phase | 44 313,06 € | 37 278,99 € |
| End of use | 94,57 € | 16,50 € |
| Total LCC | **90 980,23 €** | **62 114,25 €** |
| **Environmental variables:** | | |
| Production Phase | | |
| kg $CO_2$/year | 467,98 | 142,91 |
| Transportation phase | | |
| kg $CO_2$/year | 249,96 | 124,98 |
| Use Phase | | |
| kg $CO_2$/year | 157,99 | 132,91 |
| End of use phase (kg) | | |
| Waste (kg) | 566,30 | 98,78 |
| Total Emissions (kg $CO_2$/year) | **875,94** | **400,80** |
| Total Waste (kg) | **566,30** | **98,78** |

TABLE 2. LCC results

Production phase shows the difference in purchase cost between conventional and Royal 100 R1 blades. Conventional blades are approximately 35% cheaper than Royal blades. The difference is coming from material cost. The interesting thing is when additional spare parts are needed, then the total cost (purchase + spare parts) is the other way round. Now Royal blades are approximately 40% cheaper than conventional blades. This difference is coming from blade wearing which was confirmed in trial tests.

As from the results can be seen that transportation phase does not have almost any kind of effect and difference between conventional and Royal blade. In this calculation, maximum transportation capacity was used and that is the main reason for low cost and low emissions. The situation would be different if the calculation would have been done by customer behavior, where many separate transportations should be done. This would have more impact on emissions than in cost. If transportation amounts are 5 to 10 times more, environmental emissions would be a second highest factor after use phase.

Use phase is the biggest cost and emission factor in this analysis. The reason for this is just the fact that the energy required by paper machine and in this case only dryer section is huge. By choosing Royal 100 R1 blade some savings in cost (15%) and in emissions (10%) can be achieved. This is definitely the "hot spot" of this study.

End of use phase has the least effect on cost or on emissions. The difference between two blades can be seen. The difference is coming, because of conventional blades are wearing faster and this way spare blades are used more. For this reason, it is also reflected in the amount of waste.

## 4.4 Reporting and review

Since these results will be used for marketing purposes, critical review is necessary. This will be reviewed based on the goal and scope, functional unit, system boundary, allocation method, cost categories, discounting and data collection.

Based on the given goal and scope on chapter 2.1 comparison between these two different doctor blades were achieved in a proper way. There was a reason to believe that cost savings can be achieved and it is possible. Another factor was to find new perspective(s) to sell these products. Environmental issues are now more concrete and hopefully, these have some effect in future when new doctor blade suppliers are chosen to paper mills.

The functional unit is one major issue when doing this kind of LCC analysis. In this case, it was chosen to be the EUR/year due to the nature of these pro-ducts. Since these parts are wearing spare parts and lifetime can vary from 1 day to 12 months, the shorter time period would not be appropriate. This would only cause additional assumptions and would make calculations to be more inaccurate.

System boundary was chosen based on the know process how Royalcom is doing these doctor blades. The results could be a little bit different if raw material manufacturing part could be included. Reason for not including this is mainly because of carbon and glass fiber manufactures are not giving their information. Another factor was that all known competitors are buying materials like we.

As earlier mentioned allocation method in this LCC analysis was not used. The allocation could have been in production phase. Since the production capacity is not 100% at the moment, there is no reason for doing this. Even though we had full capacity, the allocation would have a very minor effect on the final result.

Cost categories for this case are shown in calculations in appendices. Calculations are taking into account all the relevant different costs in different stages. Labor cost is one category which is not involved in these calculations. Anyway, this is mentioned in use phase where this could have some effect.

Discounting is not involved in this case because lifetimes of these doctor blades are less than two years. Anyway, these kinds of doctor blade supplier contracts with paper mills are usually for two years. Especially carbon fiber prices are coming down in a short period of time at the moment, because of use is expanding all the time. Within two years, price can drop easily 15-20% and then this has its effect on production phase.
Since data collection is playing a huge role in this kind of LCC analysis, this has to be critically analyzed. In this analysis, major data were collected from trial runs done in three different paper machines. The good thing is that all these machines are producing different paper grades and are running different speeds, so this way results can be relevant. To be more accurate and to be surer, trials could have been done in board machines as well. The reason for this is that, board machines are usually running with lower speeds and these dryer cylinders in dryer section are dirtier than in these trial machines. This could have an effect on the doctor blade wearing and also for energy consumptions. For this reason, when showing these results, it is necessary to mention which kinds of machines were involved in this analysis.

The production phase data collection is easy to confirm because the results are from an own production line.

Also calculations done in this analysis are pretty simple, so from this point view the results are accurate.

# 5 DISCUSSION AND CONCLUSION

The aim of the thesis was to contribute cost comparison and environmental effects of the life cycle of two different kinds of doctor blades by doing an LCC analysis. To achieve this, the objective was to examine and evaluate the behavior of these two different kinds of blades, study the outcome (cost & environmental) and to give a recommendation.

This LCC analysis was divided into four different phases; production, transportation, use and end of life. All these phases had their own parameters and some assumptions had to be used, but all the time with a clear vision of keeping analysis as equal for both.

Since this comparison was done with a totally new type of blade, similar kind of previous analysis could not be found. Anyway, the findings of this analysis were compared for a couple of analysis done for the construction industry and similarities with costs and environmental effects in different phases were found.

This study clearly shows that the preferable type of doctor blade is Royal 100 R1 compared to conventional. Based on this analysis in both cases cost and environmental perspective, some savings and less environmental impact can be achieved. Anyway, it is good to remember that to get more accurate and more general to be used in the paper and board machine environment, further studies from board machines has to be done.

## 5.1 Life cycle costing

This analysis shows two main cost categories from where differences can be clearly seen and one for environmental impact.

Production phase and use phase are those two main phases which are affecting most of the cost and can be decisive when choosing from these two materials. At the moment in the industry very common way of making a decision is to compare purchase price and neglect total cost of coming from using spare parts. Like in this case, the purchase price for a conventional blade is much cheaper, but a new type of blade in the end is cheaper because of its much lon-ger life time and less spare parts are needed. The other major factor is use phase. This is eye opening information got from trials. Usually, these doctor blades are just put into the machine and almost forget their existence. Dryer section doctor blades especially because those are not categorized as critical once. Anyway, this now shows that there is a real possibility to get energy savings.

Similar kind of findings for production phase and for use phase was found also in the study done for pedestrian bridges of different materials

(Dimopoulou, et al., 2015) and study done for two different kinds of wall material comparison (Bengts, et al., 2011).
Costs coming from the transportation phase, in general have very little effect on overall cost. In this calculation, transportation cost was calculated with maximum transportation capacity. Even though this is not the actual way of doing and if this calculation would have been done by how customers are taking these today, this would not have any major changes.

End of use has least effect on this analysis. This does not mean that it should be neglected. Both conventional and Royal 100 R1 are including materials, which are not disappearing very easily. At the moment there are places where these materials can be burned, but this technology is not very common. This means that material is ending up as landfill.

## 5.2 Recommendation for future studies

Doing this analysis has been very interesting and during this process, new things have been learned and some new ideas for further studies should be done or could be done. As earlier in this study have been mentioned, more trials should be done, especially in similar kind of positions in board machines. As this study showed the major influence is coming from the use phase, would be very interesting to know has this same kind of impact in board machine, which usually are having much lower running speeds and dryer cylinders are dirtier. Generally, board machines are having two or three times more cylinders, so this could have an even higher effect on those machines.

Another interesting idea which could be studied is new raw materials made from natural fibers. Glass fiber and carbon fiber based doctor blades have been used for decades and basically no other materials have been on the market. Since more and more natural fibers like flax and hemp are available and prices are more competitive, new blades made from these materials could be done, tested and finally commercialized.

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# APPENDIX 1

**PRODUCTION COST (Eur/year)**

| | | | | |
|---|---|---|---|---|
| Structure of blade | | | Conventional | Royal 100 R1H |
| Carbon fiber layers | pcs | | 2 | 6 |
| Glass fiber layers | pcs | | 8 | 0 |
| | | | Conventional | Royal 100 R1H |
| Production/m | m | | 2283,49 | 726,3 |
| Carbon fiber eur/m | 1,55 eur/m | | 2,90 | 9,3 |
| Glass fiber | 0,19 eur/m | | 1,52 | |
| Epoxy resin | 1,0 eur/m | | 1,00 | |
| Epoxy resin | 0,7 eur/m | | | 0,70 |
| Energy | eur/m | | 0,087 | 0,084 |
| Package | eur/m | | 0,40 | 0,40 |
| Overhead | eur/m | | 3,00 | 3,00 |
| Production cost | eur/m | | 8,91 | 13,48 |
| Margin | eur | | 11,09 | 17,02 |
| Customer Price | eur/m | | 20 | 30,5 |
| Purchase cost | 1 set | Eur | 14545 | 22152 |
| Spare parts | | Eur | 31125 | 2215 * |
| Purchase cost | | EUR | 45670 | 24367 |

* 10% for spare parts

# APPENDIX 2

## Transportation cost(Eur/year) & emissions (kg $CO_2$/year)

| | | | Conventional | Royal 100 R1 |
|---|---|---|---|---|
| Delivered blades | m | | 2283,49 | 726,3 |
| Blades/box (max) | 10 pcs | | | |
| Average blade lenght | m | | 9 | 9 |
| Blades/box | m | | 90 | 90 |
| Boxes to be delivered | pcs | | 25 | 8 |
| | | | | |
| Transportation capacity | pcs | | 17 | 17 |
| Deliveries | pcs | | 2 | 1 |
| | | | | |
| Route | Varkaus-Kaipola-Jämsänkoski-Rauma | | | |
| Distance (round trip) | km | | 874 | 874 |
| Trips | pcs | | 2 | 1 |
| Total distance | km | | 1748 | 874 |
| | | | | |
| Emissions $CO_2$* (comb.) | g/km | | 130 | 130 |
| | | | | |
| Emissions $CO_2$ /year | kg | total | 249,96 | 124,982 |
| | | | | |
| Fuel consumption | 5,39 l/km | | | |
| Diesel eur/l** | 1,332 eur/l | | | |
| Cost (Eur/year) | | | 138,05 | 69,02 |
| | | | | |
| Average speed (km/h) | 80 | km/h | 21,85 | 10,925 |
| Driver cost (Eur/h)*** | 35 | Eur/h | 764,75 | 382,375 |
| Total cost (Eur/year) | | | 902,80 | 451,40 € |

*www.nissan.fi/NV200 1,5 dCi

**http://www.polttoaine.net/Jyva_skyla_

***including employer contributions

# APPENDIX 3

Energy usage(Eur/year) & emissions (kg$CO_2$/Year)

| | Conventional | Royal 100 R1 |
|---|---|---|
| Energy usage (average) | 383,53 | 322,65 |
| Usage (25%)* | 95,8825 | 80,6625 |
| Energy price (snt/kWh)** | 5,862 | 5,862 |
| Energy usage/year (kWh)*** | 755937,63 | 635943,15 |
| Cost/year (Eur) | 44 313,06 € | 37 278,99 € |
| Emissions | | |
| Energy usage/year (kWh) | 755 937,63 | 635 943,15 |
| Emission multiplyer ($CO_2$/kWh) | 0,209 | 0,209 |
| Emissions/year (kg $CO_2$) | 157,99 | 132,91 |

*Doctor usage is approx 25% of total energy
** www.enerkiamarkkinavirasto.fi 30.5.2016
*** Papermachine operating rate is 90%
****209kg CO2/MWh (Sähkön yhteistuotantoalueiden keskimääräinen CO2-päästökerroin)

# APPENDIX 4

## WASTE COST(Eur/year) & WASTE (kg/year)

| Blade wear | | Conventional | Royal 100 R1 |
|---|---|---|---|
| Blade weight kg/m* | | 0,248 | 0,136 |
| Waste material (m) | | 2283,49 | 726,3 |
| **Waste** | **total (kg)** | **566,30** | **98,78** |
| Waste fee (Eur/kg)** | | 0,167 | 0,167 |
| **Waste cost (Eur)** | | **94,57** | **16,50** |

*Conventional 2 mm density 248 g/m
* Royal 100 R1 density 136 g/m
** Special waste cost 0,167 Eur/kg
(http://www.lhj.fi/UserFiles/lhj/File/lhj_hinnasto2013.pdf)

# APPENDIX 5

ENERGY USAGE

**Trial results/Paper machine 1**

| Dryer Group | Drive | Conventional (kWh) | Measured (Royal 100 R1) | | | | | Average |
|---|---|---|---|---|---|---|---|---|
| | | 41520 | 3.10.2013 | 14.10.2013 | 6.11.2013 | 21.11.2013 | 4.12.2013 | |
| 4th | A | 90 | 72,50 | 70,00 | 72,50 | 70,00 | 67,50 | 58,75 |
| | B | 125 | 100,00 | 100,00 | 95,00 | 95,00 | 95,00 | 80,83 |
| 5th | A | 87,5 | 80,00 | 77,50 | 72,50 | 65,00 | 65,00 | 72,00 |
| | B | 125 | 115,00 | 110,00 | 105,00 | 95,00 | 95,00 | 104,00 |
| | total | **427,5** | | | | | | **315,58** |

**Trial results/Paper machine 2**

| Dryer Group | Drive | Conventional (kWh) | Measured (Royal 100 R1) | | | | | | Average |
|---|---|---|---|---|---|---|---|---|---|
| | | 27.12.2012 | 25.1.2013 | 30.1.2013 | 4.2.2013 | 4.3.2015 | 8.3.2013 | 8.3.2013 | |
| 3rd | A | 67,20 | 60,80 | 62,40 | 57,60 | 60,80 | 60,80 | 60,80 | 60,48 |
| | B | 21,00 | 19,50 | 19,50 | 19,50 | 18,75 | 18,75 | 18,75 | 19,05 |
| 4th | A | 122,10 | 108,90 | 99,00 | 105,60 | 105,60 | 108,90 | 108,90 | 105,60 |
| | total | **210,30** | | | | | | | **185,13** |

**Trial results/Paper machine 3**

| Dryer Group | Drive | Conventional (kWh) | Measured (Royal 100 R1) | | | | | Average |
|---|---|---|---|---|---|---|---|---|
| | | 23.10.2012 | 30.10.2012 | 13.11.2012 | 19.11.2012 | 12.12.2012 | 20.12.2012 | |
| 4th | A+B | 259,7 | 248,0 | 247,6 | 246,5 | 248,7 | 242,3 | 246,6 |
| 5th | A+B | 253,4 | 220,3 | 224,2 | 219,5 | 219,0 | 220,1 | 220,6 |
| | total | **513,1** | | | | | | **467,2** |

| | Conventional | Royal 100 R1 |
|---|---|---|
| **Average total ( PM1, PM2&PM3)** | **313,53** | **322,65** |

# APPENDIX 6

NEEDED MATERIAL (m/year)

| | conventional blade (2mm) | Royal 100 R1H |
|---|---|---|
| Machine 1 | 70,1 | 73,2 |
| Machine 2 | 70,9 | 74,2 |
| Machine 3 | 72,3 | 74,4 |
| Average (mm) | 71,10 | 73,93 |

| Blade wear | Conventional | Royal 100 R1 |
|---|---|---|
| New Blade (mm) | 75 | 75 |
| Average worn blade (mm) | 71,07 | 73,93 |
| Blade wear/month (mm) | 3,93 | 1,07 |
| Maximum wearing for blade (mm) | 15 | 15 |
| Blade life time/month | 3,82 | 14,02 |
| Blade changes/year | 3,14 | 0,856 |

Number of doctor blades

| | pcs | Blade lenght (m) | Conventional | Royal 100 R1 |
|---|---|---|---|---|
| Machine 1 | 39 | 9,35 | 1146,46 | 364,65 |
| Machine 2 | 17 | 8,85 | 473,01 | 150,45 |
| Machine 3 | 24 | 8,8 | 664,01 | 211,2 |
| Needed material (m/year) | | | 2283,49 | 726,3 |
| 1 set (m) | | | 726,3 | 726,3 |
| Spare parts (m) | | | 1557,19 | 72,63 * |

* 10 % additonal for unpredictable change

# APPENDIX 7

| Date | | DOCTOR BLADE WEAR MEASUREMENT | | |
|---|---|---|---|---|
| | | | | |
| Position | | | | |
| nr | | FS (mm) | MD (mm) | BS (mm) |
| | | | | |
| 1 | | | | |
| 2 | | | | |
| 3 | | | | |
| 4 | | | | |
| 5 | | | | |
| 6 | | | | |
| 7 | | | | |
| 8 | | | | |
| 9 | | | | |
| 10 | | | | |
| | | | | |

# APPENDIX 8

**Dryer group energy consumption**

| date | time | speed | DG draw | pw | | speed | DG draw | pw | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | |
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# APPENDIX 9

PRODUCTION ENERGY(kWh/year) & EMISSIONS (kg $CO_2$/year)

Energy usage ( kWh)/production phase

| Die | Owen | Puller | Edge cutter | Reel | Riveting | Ventilation | Dust vacuum |
|---|---|---|---|---|---|---|---|
| 7,2 | 3,4 | 2 | 1 | 2 | 1 | 15 | 30 |
| | | | | | | **total (kWh)** | **61,6** |

Production energy usage/product

| | | Conventional | | Royal 100 R1 |
|---|---|---|---|---|
| Production speed | m/min | 1,04 | | 1,1 |
| | m/h | 62,4 | | 66 |
| Production time for needed material | | | | |
| | 2283,49 m | 36 hours 35 min | 726,3 | 11 hours 1 min |
| Total energy usage | kWh | 2239,16 | | 683,76 |
| Price of energy* | Eur/kWH | 0,089 | | 0,089 |
| **Energy costs** | Eur | **198,84** | | **60,72** |
| Emission factor** | kg $CO_2$/kWh | 0,209 | | 0,209 |
| Emissions | kg $CO_2$ | **467,98** | | **142,91** |

*http://www.lhj.fi/UserFiles/lhj/File/lhj_hinnasto2013.pdf
**209kg CO2/MWh (Sähkön yhteistuotantoalueiden keskimääräinen CO2-päästökerroin)
http://www.motiva.fi/files/8887/CO2-laskentaohje_Yhteenvedot.pdf

# APPENDIX 10

Conventional (Emissions/ Helsinki – Shanghai)


Emission Calculator - Cargo

From

To

Help to find city/airport

From

To

Cargo weight kg

Transportation mode

--- Airline and Aircraft type ---

Cancel

Calculate

Results

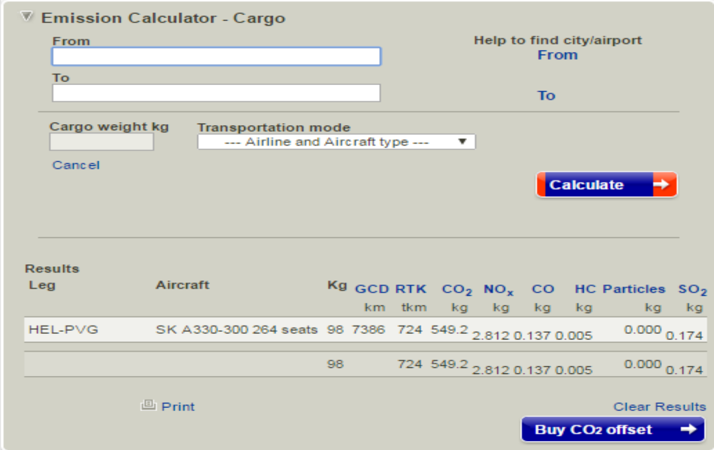
| Leg | Aircraft | Kg | GCD km | RTK tkm | $CO_2$ kg | $NO_x$ kg | CO kg | HC kg | Particles kg | $SO_2$ kg |
|---|---|---|---|---|---|---|---|---|---|---|
| HEL-PVG | SK A330-300 264 seats | 566 | 7386 | 4181 | 3171.7 | 16.238 | 0.794 | 0.029 | 0.000 | 1.007 |
| | | 566 | | 4181 | 3171.7 | 16.238 | 0.794 | 0.029 | 0.000 | 1.007 |

Print

Clear Results

Buy CO2 offset

Royal 100 R1 (Emissions/Helsinki-Shanghai)


Emission Calculator - Cargo

From

To

Help to find city/airport

From

To

Cargo weight kg

Transportation mode

--- Airline and Aircraft type ---

Cancel

Calculate

Results

| Leg | Aircraft | Kg | GCD km | RTK tkm | $CO_2$ kg | $NO_x$ kg | CO kg | HC kg | Particles kg | $SO_2$ kg |
|---|---|---|---|---|---|---|---|---|---|---|
| HEL-PVG | SK A330-300 264 seats | 98 | 7386 | 724 | 549.2 | 2.812 | 0.137 | 0.005 | 0.000 | 0.174 |
| | | 98 | | 724 | 549.2 | 2.812 | 0.137 | 0.005 | 0.000 | 0.174 |

Print

Clear Results

Buy CO2 offset

www.sascargo.com