Commercial Packaging and Sustainability

A Framework to Measure Environmental Impacts of Commercial Packaging Solutions

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CHALMERS UNIVERSITY OF TECHNOLOGY

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SUMMARY

This thesis gives an overview about the commercial packaging solution and their environmental impacts by choosing a case study – corrugated box production. The method of framework employed to do this involves both quantitative and qualitative approach where LCA and AHP were the respective tools. The LCA results were quantified into 4 different environmental impact categories: a) Global Warming Potential b) Eutrophication potential c) Acidification potential and d) Photochemical Ozone Depletion. For AHP, 5 evaluation factors were chosen – Compostability, Design for Disassembly, Recyclability, Chain of Custody and Selling Unit Cube Efficiency and a pairwise comparison is done. The results are presented to a single AHP score. Then the current packaging decision making model is analyzed which doesn't include the environmental sustainability. A new packaging decision model is proposed that includes the framework from this thesis incorporating environmental sustainability to create a more environmentally friendly packaging solution through a consensus based decision making system. The practicality aspects of implementing the framework is also discussed so that other companies can also choose to benefit from this thesis.

Keywords: Commercial Packaging, environmental sustainability, LCA, AHP, Decision making model.

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Manavut Sunthonpaobvong & Shanmuga Kumar Suruliappan Magudapathy

Gothenburg, May 23

Table of Contents

List of Figures

List of Tables

Wordlist

Abbreviation	Definition
AHP	Analytic Hierarchy Process
AP	Acidification Potential
CI	Consistency Index
CR	Consistency Ratio
EP	Eutrophication Potential
FSC	Forest Stewardship Council
LCA	Life Cycle Assessment
LCI	Life Cycle Inventory
POCP	Photochemical Ozone Creation Potential
GWP	Global Warming Potential
SML	Service Market Logistics
SUCE	Selling Unit Cube Efficiency

1. INTRODUCTION

This thesis "Commercial Packaging and Sustainability" is done within Volvo Group's Service Market Logistics (SML) department. Volvo Group is a manufacturer of trucks, buses, and construction equipment, marine, and industrial engines. The study was set-up as part of the first few actions to be carried out that are in alignment with Volvo's new environmental policy. This policy states that the company would strive to conduct Climate-Neutral Operations and halve its carbon emissions by 2025. SML within Volvo Group is responsible for spare part supplies to the dealers worldwide as well as for designing, operating, and optimizing logistics and supply chain for all of Volvo Group's associated brands, production facilities, and distribution centers. SML also works around commercial packaging solutions.

1.1 Background

The European Federation defines packaging *as all products made of any materials of any nature to be used for the containment, protection, delivery, and presentation of goods, from raw materials to processed goods.* Traditionally, the purpose of packaging is to protect and preserve the product from damages caused during handling, transport, distribution, and storage of products (Hellström & Saghir, 2007). Such product protection is needed to ensure that the product arrives at the place of consumption safely. Apart from that, the packaging is also used to display product information and serves as an advertisement purpose to display products at a shelf in order to promote their marketing position as well as attract customers (Pongr´acz, 2007). Commercial Packaging refers to how a company sells spare parts to its dealers and end customers. According to the definition provided by Volvo, commercial packaging refers to the packaging used for spare parts which are then sold to their dealers and service stations. At SML in Volvo, a commercial packaging solution also aims to build sales kits which include the promotion material containing required information of the company, product through posters, product catalogues, etc.

Packaging, once it fulfils its main purpose which is to protect and promote the product, it is generally considered as waste. Hence, it has become a burden for the consumers as well as the environment (Sonneveld, James, Fitzpatrick, & and Lewis, 2005). In Sweden, as of 2018, about 0.58 million tonnes of packaging waste of paper, cardboard, and the corrugated paper was put on the market (Statistik Databasen - SCB, n.d.). This also comes with a lot of negative impacts that harm the environment. Sustainability in packaging has been on-trend in both academia and also the media (Byggeth & Hochschorner, 2006). Though there is an increased awareness and attention which is reflected through academia by the number of sustainability assessment tools and regulations put forth, it has not had a serious impact on the packaging sustainability in reality (Ma & Moultrie, 2018).

SML at Volvo has no history of a tool or a system to measure the environmental footprint of the spare parts and their packaging and neither decisions have taken for commercial packaging solutions had the environmental aspect into consideration. Cost and Quality have always been the two prime factors based on which decisions have been taken at SML. In line with the new environmental policy, this thesis was commissioned to look into the current environmental performance of the commercial packaging solutions and provide a foundation to conduct further projects on environmental sustainability. This study revolves around filling this gap of lack of an environmental performance measurement system at SML.

1.2 Problem Discussion

The concept of environmental sustainability has thrust into the limelight now, due to the fact that businesses have been exploiting natural resources over the years for their economic benefit. Now, the tables have turned so to say, that companies are expected to produce environmentally friendly products and reducing their overall carbon footprint. Global initiatives attempting to mitigate the climate change such as the Paris Climate Agreement, United Nation's 17 SDGs and stricter governmental laws challenge and push the companies to bring about a change in their operations that is more environmentally safe. Although this is a tough task for companies, there is also a bright side to it. It creates an economic opportunity to open-up new business gates, more collaborations. For this green transition to happen, the companies must realize the economic potential that comes with it. Companies like Volvo, have understood the importance of this transition and have taken necessary actions from the top to bottom, right from policymaking as per the CEO's environmental sustainability vision statement to the micro-level action that resonates with that vision like this thesis study.

Projects on environmental sustainability like this study, if to be implemented in real-time and have an effect, must be designed and planned with a short project lead time. This way, the company would be able to carry out several small projects successfully and still not disturb their normal routine operations. Continuous improvement projects can also be integrated with this and consequently paves the way for 'learning by doing'. For such a project to take place with a short lead time effectively, innovation is necessary for creating a strategy - a framework for a sustainable transition. For easier understanding, innovations made on environmental sustainability can be called as eco-invention. According to Gobble (2012), there also exists companies, which do not understand how innovation be brought up from environmental sustainability and how its benefits could be shared between the company and its stakeholders. It also mentions that eco-innovation is necessary for humans to live in an environment, which preserves itself for future generations. Therefore, businesses should not only focus on just producing environmentally friendly products but also listen to the customers' views. The customers here could refer to any actor in the value chain – ranging from internal customers like suppliers, Original Equipment Manufacturers (OEMs), or external customers like the end consumers. It is of utmost importance that the decision-makers who can control the value chain, its effect on the environment, and who directly deals with end consumers should consider the opinions of the other relevant actors from their supply chain. For example, in this case, Volvo could talk to its stakeholders particularly, the spare part dealers who are the end customers, and understand their actual needs and preference of the packaging, as well as to impact the sales positively. It might not be easy to implement as it sounds because gathering opinions and finding a consensus could be tricky and complex.

1.3 Aim of the Thesis

The practical aim is to propose a methodology with which SML at Volvo can start to incorporate environmental sustainability in its decision-making model. The thought process behind this is that the decision-making model should help the packaging engineers to facilitate the creation of environmentally sustainable packaging solutions backed by environmental performance information and the consensus of stakeholders' opinions.

1.3.1 Research Questions

While working on the above-mentioned thesis objective, the following research questions are aimed to be answered:

1. What practical technique backed by research can SML department use to measure the environmental impact of the commercial packaging solutions?
2. What are the main factors to consider when designing an environmentally sustainable commercial packaging solution?
    - How to gather opinions of the relevant stakeholders on these factors?
    - How do we find a consensus between different opinions from different actors on the decision-making process for an environmentally friendly commercial packaging solution?

1.4 Research Limitations

Though a specific spare part is chosen as the case study, it is only done with an idea to understand the value chain of the spare part and its journey, and the focus was rather emphasized only on the lifecycle of the packaging solution of the spare part. In LCA, the information was used from the generic database solely made for corrugated board and very limited specific site data were used owing to the difficulty of data collection as most of them are not even measured in the first place. Only five evaluation factors were chosen for the study to reduce complexity. Only one actor from each stakeholder in the supply chain was chosen for the interview process.

2. THEORY

This chapter will present the theoretical background of this thesis. It will begin with a description of the packaging and its environmental impacts which were gathered from the literature. After that, a framework to measure the environmental impacts will be introduced, and the relevant theories to this framework and the decision making in packaging solutions will be further explained. The final part in this chapter will describe the detail of the corrugated box supply chain and its environmental impacts which relate to the case study.

2.1 Packaging and Environmental Impacts

The packaging is developed mainly because, in most instances, places of production and consumption are in different locations and times. Therefore, originally, the main purpose of having packaging is to bridge the gaps between these two constraints (Pongr´acz, 2007). Nowadays, the main function of the packaging does not only satisfy such purposes but also expand to cover other aspects as well. Pongr´acz (2007) listed five main functions of the packaging, which is provided below.

- *Protection function*
  This function is to ensure that products are protected and preserved safely inside the packaging. The packaging in this aspect is used to control the product's temperature and keep the products from leakage, and spoilage. By protecting the product from spoilage, this means that the packaging can, in turn, reduce the wastes.
- *Distribution function*
  The packaging facilitates distribution processes including loading, collection, and transport. The important factor in this aspect is to ensure that the products are protected safely under the courses of transport.
- *Intermediate and advertising function*
  This function relates to marketing purposes since the packaging itself can help to intrigue customers and activate purchases. Besides, the package itself can convey product information to customers.
- *Image-component function*
  This function is to satisfy the branding purpose since the brand image can be promoted through the packaging itself.
- *Value-forming function*
  Some types of packaging serve as a function of use, for example, a squeezable tube of toothpaste which allows customers to use such products at ease.

Referring to Pongr´acz (2007), the packaging is made from varieties of materials which are generally based on the requirements of products. Nowadays, plastic, cardboard, solid wood, metal, glass, or a combination of such materials are the main sources of materials to produce packaging. The packaging can be divided into three different categories including

- *Primary packaging*
  This packaging usually contacts with the products. The aim of using this packaging is to pack a product in the form of a sale unit.
- *Secondary packaging*
  This packaging includes a cardboard box or a plastic container, which is used to pack a quantity of primary packaging.
- *Tertiary packaging*
  This packaging is used for freight transport purposes. An example of the packaging in this category is a wooden pallet.

Due to globalization, international trade has been increasing tremendously. From that aspect, the consumption of packaging has followed the same trend, and it, in turn, creates a lot of packaging wastes in society (Lo-Iacono-Ferreira, Viñoles-Cebolla, Bastante-Ceca, & Capuz-Rizo, 2019). This effect will cause various types of environmental impacts from the *cradle-to-grave* of the packaging life cycle. According to Verghese & Lewis (2007), the environmental impacts from packaging could range from land degradation to biodiversity losses which are caused by natural resources extraction in the first stage of the life cycle. In the manufacturing and transportation of packaging, the emissions generated in these processes can a serious environmental problem such as the global warming issue. Apart from that, these processes also create air and water pollutions as well as solid and toxic wastes, which require specific treatments before emitting to nature. In the use phase of the packaging, the main problems that could be observed are energy consumption and solid wastes. This waste problem in this phase will also have a direct consequence to waste disposal problems such as landfills in the final stage of the packaging life cycle. The summary of those environmental impacts is illustrated in Table 1. From such environmental impacts, the European Commission introduced measures of how to manage packaging wastes and directive imposed the rules on the production, marketing, use, recycling, and refilling of the packaging used (European Commission, 2020).

Life cycle stage	**Impacts**
Growing, harvesting or extraction of raw materials	• Land degradation • Biodiversity loss • Pollution from oil spills
Manufacture and packaging of a product	• Energy consumption • Emissions to air and water • Global warming • Solid and toxic wastes
Transport of products to wholesaler and retailer	• Air pollution • Global warming
Retailing of the product to the consumer	• Energy consumption

	• Solid wastes
Use of the product (refrigerated product)	• Energy consumption
Waste disposal and recovery	• Litter • Air emissions from landfill • Leachate from landfill in groundwater

Table 1: Environmental impacts in the different stages of the life cycle of packaging *(Verghese & Lewis, 2007)*

2.2 A framework to Measure Environmental Impacts

As packaging consumption is rising in the last few decades, this effect can, in turn, increase the environmental burden tremendously. From this aspect, several methods are developed and introduced to measure the environmental impacts caused by packaging. The examples of such tools include questionnaire, interview, observation, risk assessment, auditing, substance flow analysis, material flow analysis, life cycle assessment (LCA), streamlined life cycle assessment (SLCA) and scorecard (Huang & Ma, 2004; Pauer, Heinrich, & Tacker, 2017). From that pool of environmental assessment tools, Huang & Ma (2004) categorized those methods into quantitative and qualitative measurements. These two types of methods have their specific advantages and disadvantages depending on their applications (Pauer, Heinrich, & Tacker, 2017). From this knowledge, the examples of each method will be used as a sample to illustrate the pros and cons of qualitative and quantitative measures.

For the quantitative approach, the tools in this category will focus on numerical data, which could be referred to as monetary terms, pollution emissions, or resource consumptions. These types of data can later be converted into cost or environmental loadings. The methods in this type of measurement consist of cost and benefit analysis (CBA), material flow analysis, LCA, etc. Among these tools, LCA is one of the widely used methods. The reasons are that it is a well-established method that can accurately identify the environmental impacts of a particular system for the entire life cycle. Moreover, the LCA result can serve a marketing claim purpose (Pauer, Heinrich, & Tacker, 2017). However, LCA still has its limitations. The first weakness of LCA is the limited access to life cycle inventory (LCI) and the cost to develop such database themselves is high. Secondly, it requires LCA knowledge to interpret LCA results since its outcome is provided in scientific terms such as acidification potential or eutrophication potential, which are complicated for non-LCA practitioners. Apart from that, LCA does not consider the local context, which sometimes requires to interpret the LCA result. For example, the LCA result might indicate that this product has a negative impact on the environment because it requires high water consumption in their processes. Notwithstanding, this information indeed has to be compared with the water resource availability of that specific site so that it can be concluded whether it is harmful to the water resource or not. Finally, the impacts of using toxic substances are sometimes not included in the LCA study (Erixon, Carlson, & Pålsson, 2003).

In terms of the qualitative approach, this method will focus less on the numerical information, but rather on the qualitative data gathering from interviews or observations. The relevant studies to this approach involve how to evaluate the environmental friendliness of packaging materials from various facets, which are hard to qualify by the quantitative measures. The examples of such evaluating aspects include the prevention of contamination or communication between manufacturers and customers. One of the assessment tools that is used to address this type of information is a sustainability scorecard. This scorecard can work as a tool to evaluate sustainability performance concerning the established strategy of the organization. To develop the scorecard, the sustainability indicators have to be identified. These indicators could be either computational or qualitative KPI depending on the identified performance goal of the assessment. Examples of such indicators would be *Chain of Custody,* which expresses the ability to identify the origin of materials or *Recycle Content* of packaging materials. Since many indicators might be selected, and all of them are not equally important, Analytic Hierarchy Process (AHP) is used to develop the weight score of each factor. The strong point of this method is that the scorecard can be developed and adjusted base on the perspective, which the organization is interested in. However, the choices of indicators are observed as a drawback of the scorecard. The reason is that if too many indicators are chosen, the packaging has to be evaluated in several perspectives and it will require huge efforts to complete. However, if too few factors are selected, it will lead to an oversimplified scorecard, in which some of the important aspects might be overlooked (Pauer, Heinrich, & Tacker, 2017).

These two approaches, quantitative and qualitative measurements, focus on the different features of environmental impacts assessment. The quantitative approach emphasizes cause and effect, while the qualitative one focuses on the different perspectives of environmental performance which different people perceive. With this essence, Huang & Ma (2004) integrated these two approaches and developed a tool to measure the environmental impacts, and it is called a Multidimensional Environmental Evaluation framework. Using this tool can provide a comprehensive view of environmental impact assessment in both quantitative and qualitative measures. The detail of this framework is shown in Figure 1.

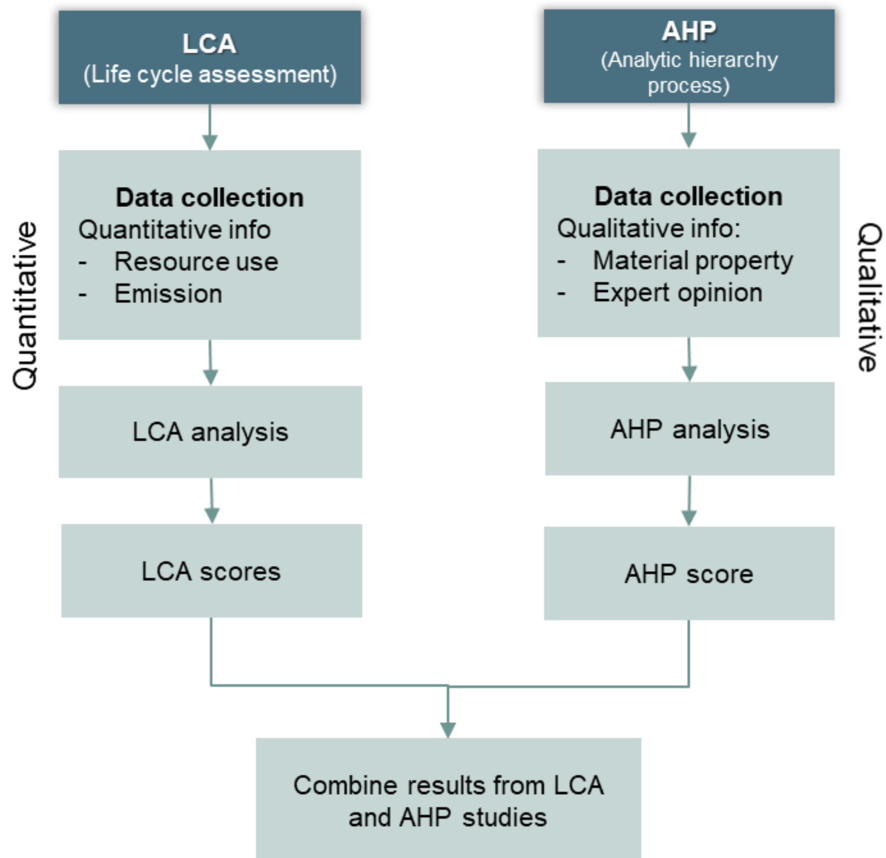


Figure 1: Framework to measure environmental impacts (Huang & Ma, 2004)

This framework adopts LCA and AHP approaches to measure the environmental impacts of both quantitative and qualitative aspects. For the quantitative aspect, the LCA approach will be utilized to process quantitative information into environmental impacts. Those quantitative data will be based on the numeric information, for example, total materials consumption, water consumption, energy consumption, and pollution emissions in the different processes. The result calculated from this calculation will be shown as an LCA score which will refer to the level of environmental impacts. In this aspect, the higher LCA score will represent higher environmental impacts (Huang & Ma, 2004).

For the AHP approach, it will be used to analyze the qualitative information which is hard to be quantified into numbers such as materials properties, materials' composability, materials' recyclability, or the ability of the company to track materials sources. This approach will begin by selecting the evaluation factors to measure the environmental impacts and then the weight score of each factor will be identified by conducting a pairwise comparison. In this aspect, the higher AHP score will represent the lower environmental impacts generated from the packaging solution (Huang & Ma, 2004).

The final step of this framework is to integrate the LCA and AHP results by using cluster analysis. The result from this analysis is a four-quadrants-graph which displays the LCA score on the y-axis and AHP score on the x-axis. The packaging alternative which has a high score in both study will be located on the upper-right part of the graph (positive x and positive y) whereas the packaging which has a low performance will be located in the bottom-left of the graph (negative x and negative y). The rest that has a high score in either LCA or AHP study and a low score in another one will be plotted in either the upper-left or the bottom-right parts of the graph. An example of the cluster analysis is illustrated in Figure 2.

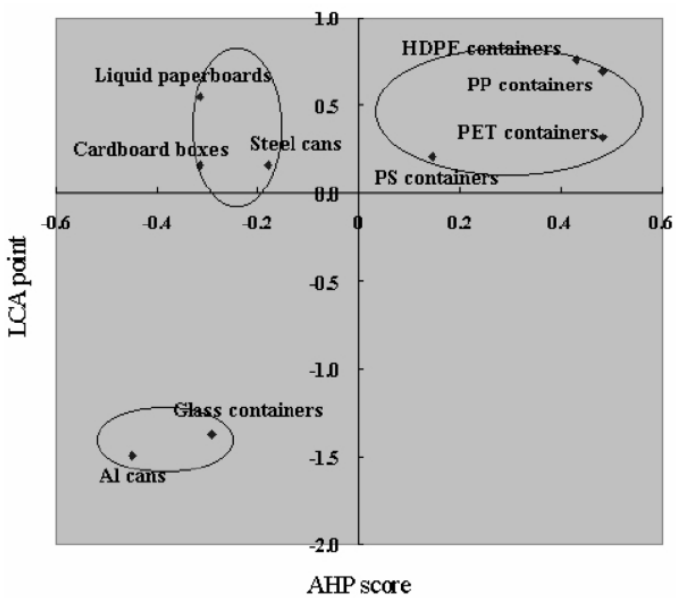


Figure 2: Example of cluster analysis (Huang & Ma, 2004)

2.3 Life Cycle Assessment

LCA is used to assess the environmental aspects and potential environmental impacts associated with a product throughout its lifecycle from 'cradle' where the raw materials are acquired through the production phase, use phase, recycling till 'grave' where the product is disposed (Baumann & Tillman, 2004).

The following are the different stages in an LCA Study according to the requirements and guidelines provided by the International Standard:

- Goal and Scope Definition (ISO 14040)
- Life Cycle Inventory Analysis (ISO 14041)
- Life Cycle Impact Assessment Phase (ISO 14042)
- Life Cycle Interpretation (ISO 14043)

The standards are applicable for both Life Cycle Analysis (LCA) and Life Cycle Inventory (LCI) studies. The practitioner may choose to interpret results only from inventory and stop the study after the Inventory Analysis. This type of study is called Life Cycle Inventory studies. On the other hand, the studies where the inventory results are used to run through different impact models are called Life Cycle Assessment studies. The type of study will, however, be determined at the Goal and Scope Definition stage.

1. **Goal and Scope Definition**

In the first step, the goal and scope definition is done between two stakeholders: LCA Practitioner and Commissioner. The practitioner refers to the one who conducts the LCA study and Commissioner refers to the one/group which pays for the project. Once the intent of the project is communicated by the commissioner, the practitioner comes up with the appropriate methodological choice.

The goal of an LCA should conduct information on the purpose of the study, the product to be studied. As per ISO 14040 guidelines, the goal should specify the following information (International Standard Organization, 2006):

- The intended application
- The reasons for carrying out the study
- The intended audience, i.e. to whom the results of the study are intended to be communicated
- Whether the results are intended to be used in comparative assertions intended to be disclosed to the public.

The scope of the study should include the system boundary, the choice of the functional unit, assumptions, and limitations depending on the purpose of the study, level of detail, and the types of environmental impact.

If the study is specific to a company or location, then a foreground primary data, which is specific to it, is needed whereas, for a generic case with varying circumstances, general background data may be sufficient.

2. **Life Cycle Inventory Analysis**

In this phase, the following activities are performed:

a. A flowchart is constructed according to the system boundaries set up in the Goal and Scope Definition
b. Data is collected and documented for all the activities of the product system.
c. Calculation of the environmental loads with reference to the functional unit.

Construction of Flowchart:

In the goal and scope definition, a preliminary flowchart is developed which then elaborated in the inventory analysis showcasing all the activities and the flows between each activity. The flowchart can be revised whenever depending on the accumulation of the data. Hence, Inventory analysis is an iterative process (Baumann & Tillman, 2004). "Collection of unit processes with elementary and product flows, performing one or more defined functions, and which models the life cycle of a product" (ISO 14044).

Data Collection:

For the Inventory analysis, both quantifiable and qualitative data must be collected. It should consist of all the inputs (materials, energy, ancillary and physical inputs), products, and emissions (to air, water, and land). There are two major types of processes for which data is collected. They are foreground and background processes of which for the former, specific data such as product specific information is collected, and for the latter, secondary data sources are used, for example, publicly available lifecycle inventory database (NCASI, 2004).

Calculation Procedure:

Once the interconnection flows are identified in the flowchart construction, all the absolute flows are converted to a quantity relative to one outflow. The choice of this reference flow is arbitrary. All the flows are then scaled relative to the reference flow and are summed together. The inventory analysis need not necessarily be done manually, as there are many verified datasets available to cover all LCI data information.

3. **Life Cycle Impact Assessment**

This phase is conducted if it is considered beforehand in the Goal and Scope definition and on which case, according to ISO 14040, it should also mention about the choice of impact categories, category indicators, and characterization models.

The life cycle inventory data of the input and output material flows like emissions, use of resources associated with the functional unit are classified into selected environmental impacts and consumption of resources (Hauschild, n.d.). The impact category could range from a local one, for example, land use to a global category like climate change.

These impacts are then modeled according to Figure 3 and the impact score is calculated and expressed in a unit common to all the contributions within the same impact category, e.g. Kg CO2. Practitioners have distinguished the impact categories into midpoint impact categories, e.g. GWP, AP, etc. and endpoint impact categories, e.g. damage to human health, damage to ecosystem quality, etc (Guine´e, 2015). Then, different emissions from each impact category are summed. This process is called characterization.

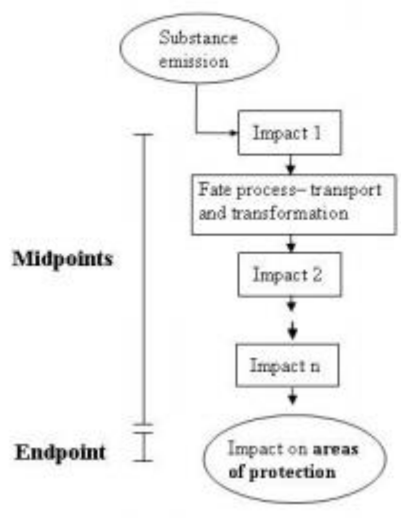


Figure 3: Schematic presentation of an environmental mechanism underlying the modeling of impacts and damages in life cycle impact assessment (Hauschild, n.d.)

The potential impacts of the inventory results are interpreted in terms of "areas of protection" of the LCIA: Human Health, Natural Environment, Natural Resources, Man-made environment (Udo de Haes et al., 1999).

The first two steps are mandatory in the impact assessment. The following steps - normalization and valuation steps are classified as optional elements (International Standard Organization, 2006).

4. Life Cycle Interpretation

The results of the Life Cycle Inventory and Life Cycle Impact Assessment are interpreted in a way that is aligned with the defined goal and scope using Sensitivity and Uncertainty Analysis.

2.4 Analytic Hierarchy Process

Analytic Hierarchy Process (AHP) is a tool introduced by Thomas Saaty in the 1970s. This technique is used to analyze complex decisions, which has both objective and subjective aspects to be considered (Moutinho, Moutinho, & Beynon, 2014). This process will help decision-makers to set priorities among different alternatives based on the established criteria. Since each evaluation criteria is not equally important, a pairwise comparison between different criteria will be conducted in order to identify the weight score of each evaluation factor. This weighted score will be referred to the level of importance of the evaluation factors. Namely, if the evaluation factor is assigned a higher weight score, this means that this factor is perceived as a more important factor corresponding to the result. In this process, the best alternative will be synthesized by trading off among different evaluation criteria. Apart from that, the consistency of evaluation results will be checked in order to reduce the bias in the decision-making process (Moutinho, Moutinho, & Beynon, 2014). Referring to Huang & Ma (2004), to implement AHP, these following steps have to be followed.

1. **Define the decision problem and goal**

The problem which requires AHP to analyze has to be a complex problem, which has multi-criteria that influence the decision-making process. The goal has to be clearly defined so that it can build a good foundation to develop criteria for performance evaluation. In some cases, assumptions corresponding to such a problem have to be made, for example, whose are perspective of the analysis? and who will be affected by this decision? (Saaty, 2008)

2. **Develop a decision hierarchy**

The decision hierarchy consists of three levels. At the top level, the goal of the problem which is developed in the previous step has to be mentioned. Then, the set of criteria used to evaluate this problem has to be identified in the middle level. The set of criteria would be referred to as an evaluation factor that could be used to assess alternative performance. Lastly, the set of alternatives has to be addressed at the lowest level. In this case, the alternatives represent the possible solutions to the identified problem (Saaty, 2008). The example of the decision hierarchy is provided in Figure 4.

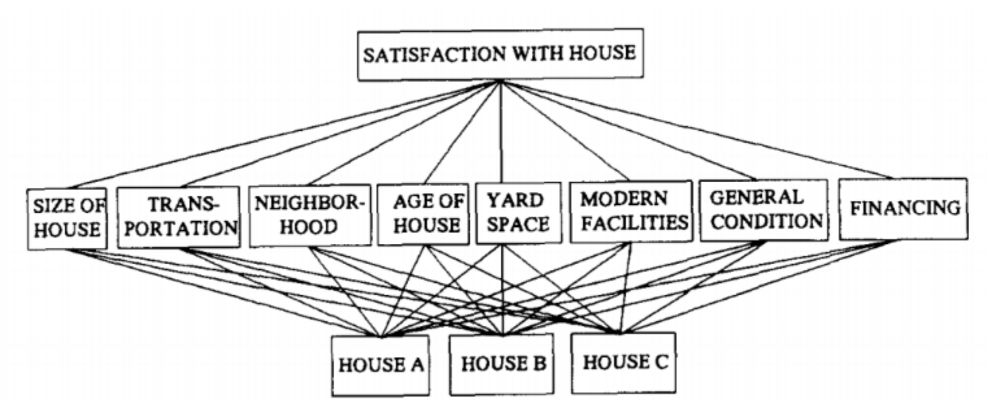


Figure 4: Hierarchy decision example (Saaty, 2008)

3. **Compute the criteria weight of each evaluation factor**

The criteria weight can be calculated by conducting a pairwise comparison between different evaluation factors. The importance of each pair of factors is compared corresponding to the goal of the decision problem. The pairwise comparison can be done by creating a pairwise comparison matric A. The matric A is m*m matric, where m is the number of evaluation factors that are used to assess the alternative performance in relation to the problem's goal. The total pairwise comparison will be conducted with respect to the number of selected factors. if the m factors are chosen, the total pairwise comparison is $\frac{m(m-1)}{2}$.

Then, each entry of a_{ij} will be performed and it will represent the comparison of the importance of the evaluation factor i to the evaluation factor j. In order to enter a_{ij}, the standard scale which is shown in Figure *5* will be used. From this table, if a_{ij} is more than 1, this means that the factor i is more important than j. On the other hand, if a_{ij} is less than 1 or has a reciprocal value, this means that the factor i is less important than j. In the case these two factors are equally important, a_{ij} is equal to 1 (Moutinho, Moutinho, & Beynon, 2014).

Intensity of Importance on an Absolute Scale	Definition	Explanation
1	Equally important	Two activities contribute equally to the objective
3	Weakly important	Experience and judgment strongly favour one activity over another
5	Essentially important	Experience and judgment strongly favour one activity over another
7	Very strongly important	An activity is strongly favoured and its dominance demonstrated in practice
9	Absolutely important	The evidence favouring one activity over another is of the highest possible order of affirmation
2, 4, 6, 8	Intermediate value between two adjacent judgments	When compromise is needed
Reciprocals	If activity *i* has one of the above numbers assigned to it when compared with activity *j*, then *j* has the reciprocal value when compared with *i*	

Figure 5: Standard score for pairwise comparison 1 (Moutinho, Moutinho, & Beynon, 2014)

After the metric A is developed, the normalized pairwise comparison is conducted by calculating from the equation (1) where l represents each column.

$$\bar{a} = \frac{a_{ij}}{\sum_{l=1}^{m} a_{lj}} \tag{1}$$

Lastly, the weight of each evaluation factor (w_i) will be calculated by averaging the entry of each row in the matric A. The calculation of weight score is shown in the equation (2).

$$w_i = \frac{\sum_{l=1}^{m} \overline{a_{\iota J}}}{m} \tag{2}$$

4. **Check the consistency**

When the decision-makers conduct a pairwise comparison, there might be some inconsistency arising. For example, if the first factor is considered as more important than the second factor while the second factor is considered as more important than the third one. The inconsistency will arise if the decision-makers value the third factor as more important than the first one. From this problem, AHP incorporates the inconsistency checking step in order to evaluate the degree of consistency in the evaluation process. This checking process can be done by calculating the Consistency Index (CI). This index can be calculated as the equation (3), where λ_{max} is the maximum eigenvalue. In the perfect situation, the consistency index will be equal to 0. However, this is not always the case, therefore, the small value of inconsistency can be acceptable if the consistency ratio (CR) is less than 10%. The CR can be calculated from equation (4), where RI is a Random Index (Moutinho, Moutinho, & Beynon, 2014). The RI value presents in Table 2.

$$CI = \frac{\lambda_{max} - m}{m - 1} \tag{3}$$

$$CR = \frac{CI}{RI} \tag{4}$$

m	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
RI	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.51

Table 2: RI value *(Moutinho, Moutinho, & Beynon, 2014)*

5. **Compute the total score of each alternative**

In order to score the alternative, the score criteria of each factor have to be developed. Then, the different alternatives will be rated base on their performance corresponding to each factor. This score will be identified as s. Once each alternative is rated, the total score of each alternative will be calculated by multiplying the weight score (w) with the rated score (s). The total score of each alternative will be calculated by the sum of the score obtained from each criterion. The equation to calculate the total score is provided in equation (5), where a is an alternative. The alternative which has the highest score will the best solution for this problem (Moutinho, Moutinho, & Beynon, 2014).

$$T_a = \sum_{i=1}^{m} S_{ia} W_m \tag{5}$$

2.5 Decision Making in Packaging Solutions

Making sense of what the problem is and figuring out what solutions might work is actually part of the problem and including stakeholders to problem-solving is crucial (Bryson & Crosby, 1992). The packaging is considered to be the central pillar in logistics, since it comes with the product right after manufacturing until the final consumption (Molina-Besch & Pålsson, 2014) which in this case, until when the dealers of Volvo empty the package and use it. The packaging design should go hand in hand with the company's environmental objectives where the focus questions are on the size of the packaging, optimizing and limiting the transportation distance, whilst using as much standardized packaging solution as possible to minimize waste. Each company uses its own set of standardized packaging solutions, which might be used by different brands owned by the same company or different companies, or sometimes even across different suppliers in the whole supply chain (Tsoulfas & Pappis, 2006).

According to Bititsios (n.d.), it is of utmost importance that key stakeholders are included in the process of packaging design. Every individual or company, who has an interest in a successful packaging solution or would benefit from such a solution, is considered to be the key stakeholders. They can range from R&D, packaging engineers, marketing, packaging suppliers, and end consumers as well. According to Wallace & Arietta (2000), the consensus is both "a journey and a destination". The journey is the process of preparing the attendees to make a decision that identifies issues and clarify questions. Consensus as a product is the outcome of this consensus-building process. It is not necessary that every attendee should agree on the details. A consensus decision only reflects a mutual understanding where the attendees agree that the individual priorities differ and still be able to come to an agreement to support a decision.

As there are a lot of companies that flood the market with products that offer more or less the same services, offers and packaging are the only possible means where the consumer differentiates the brand. With an increase in expectations from the consumers to get products from recognized brands, marketing people understand the value of packaging, and manufacturers are constantly coming up with novel packaging materials, solutions, or technologies. The designers have the most responsibility compared to other stakeholders where they have to understand the desires of the consumers, develop a meaningful design, and thereby benefiting all the stakeholders. Designers should encourage all the stakeholders by helping them to help shape, optimize a packaging solution.

2.6 Corrugated Box

In the case study of this thesis, Volvo blue box used for the main bearing kit is selected to study the environmental impacts. Thus, the following part will describe the corrugated boxes, production processes involved, its supply chain setting, and the environmental impacts that are generated in their supply chain.

A corrugated box is consisted of multiple layers of paperboards and has a fluted inner in between such layers. By having such flute liners, it can increase the strength of the packaging (Miller, 2012). This paperboard is made from cellulose fibers, therefore it provides a possibility to be recycled (Pongr´acz, 2007). Referring to Apple Ltd (2008), this type of packaging is widely used in many industries due to the following reasons.

- *Strength*
  The flute liners make the corrugated box stronger than normal cardboard.
- *Flexibility*
  Corrugated boxes are provided in different sizes. This will provide a possibility for them to be used for many types of products.
- *Recyclability*
  The corrugated box is well-known as one of the eco-friendly packaging because it is made from renewable materials which can be 100% recycled and reused.

2.6.1 Production

Corrugated box manufacturing involves several processes as shown in Figure 6. Referring to Lo-Iacono-Ferreira, Viñoles-Cebolla, Bastante-Ceca, & Capuz-Rizo, (2019), the first step is to produce paper coils which are derived from woods or recycled papers, and then such paper rolls will be transported to corrugated box manufacturing sites by various modes such as road, rail or ship. To produce a corrugated box, four types of papers could be used. These papers include (1) Kraftliner, (2) Semi-chemical fluting, (3) Testliner, and (4) Wellenstoff. For paper no. (1) and (2), these papers are made from primary fiber, while paper no. (3) and (4) are coming from recycled papers (FEFCO, 2019).

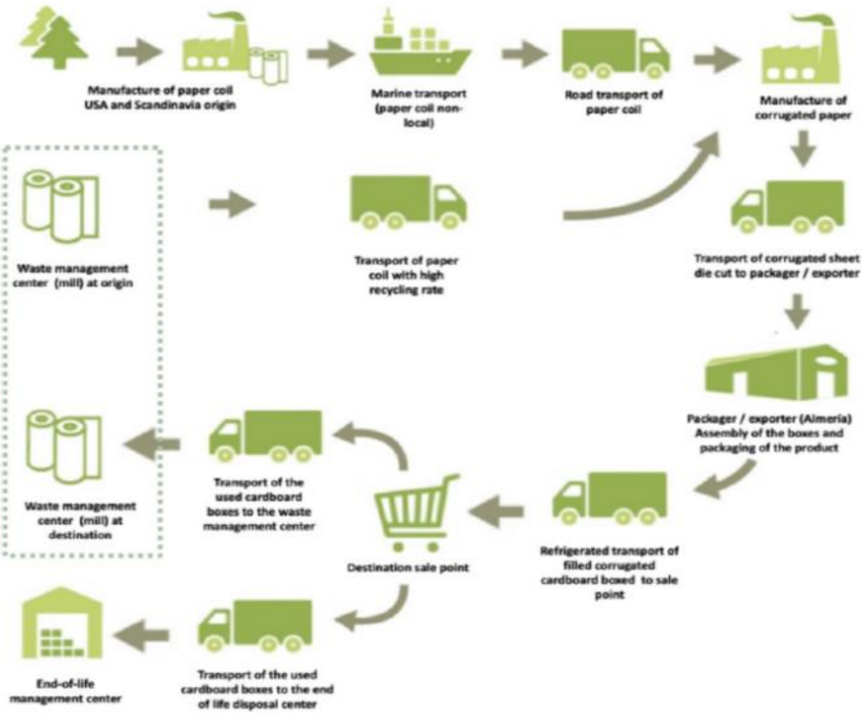


Figure 6: Corrugated box supply chain (Lo-Iacono-Ferreira, Viñoles-Cebolla, Bastante-Ceca, & Capuz-Rizo, 2019)

2.6.1.1 Paper Production

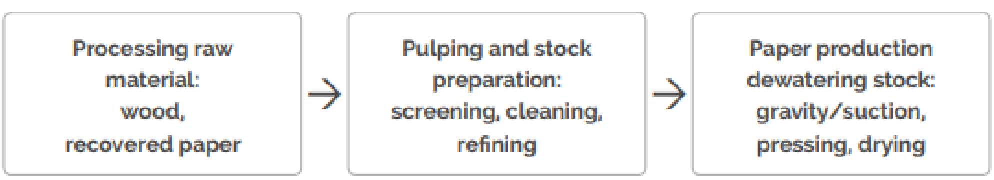


Figure 7: Outline of the paper production process (FEFCO, 2015)

The paper production process involves the following stages:

Processing of Raw Material:

- The raw material needed for the production of Kraftliner and Semi-chemical fluting comes in two forms including pulpwood logs from the woodcut from the forests, and wood chips obtained from nearby mills. The logs undergo debarking and chipping processes to form chips which will be then screened to remove dust particles. The chips can be reprocessed to correct dimensions. Now all the chips are stored in a pile.
- The raw material for Testliner and Wellenstoff is delivered as bales and are stocked according to its grade. Once the stock preparation is done, the recovered paper is then fed to the pulper machine in a ratio as per the quality required (FEFCO, 2015).

Pulping and Stock Preparation:

- The pulp for Kraftliner production is made by the kraft cooking process where active cooking chemicals such as caustic soda and sodium sulphide. This process takes place at high pressure and temperature of about 150-170 deg. C. The total pulp yield is about 55%. The pulp for Fluting production is made by the semi-chemical cooking process. Here, active chemicals such as sodium sulphite and sodium carbonate are used. The total pulp yield is about 80%. Before sending this pulp to the paper mill, they undergo defiberizing process in a refinery and then screening and washing. At the mill, the pulps are then mechanically treated to improve the strength of the paper. In order to get the final properties of the paper the right way, the pH level can be adjusted; functional chemicals, fillers, and other pulps such as recovered pulps can also be added.
- On the other hand, the dry, baled blend of paper is converted into the suspension of fibers by submerging the bales in water and agitating it. Large contaminants such as pieces of textiles, plastics, etc., are removed using a "ragger" tool. The outcome is then screened and cleaned. The pulp, concentrated to 25-30%, is heated by steam at 80-100 degrees Celsius and undergoes a dispersing treatment where the remaining contaminants along with the small fragments of paper becomes invisible (FEFCO, 2015).

Paper Production Process:

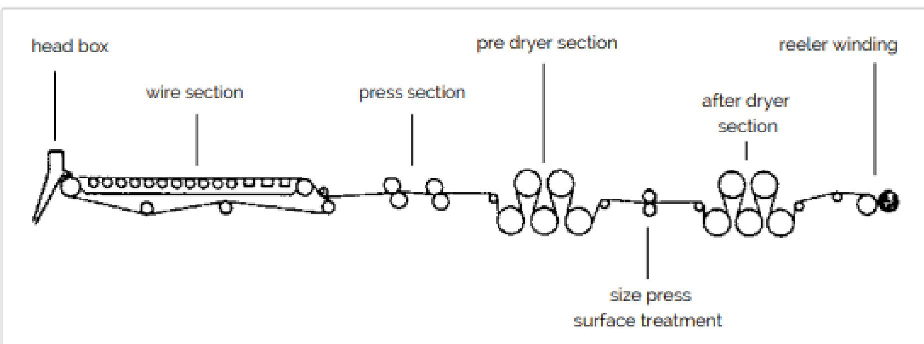


Figure 8: Example of a paper producing machine (FEFCO, 2015)

The cleaned pulp also is referred to the stock, is fed to the head box where the paper is formed and is passed through the wire. The paper is dewatered both in the wire and the press section. Now, water content from the paper is taken out. Then, the paper is initially dried by a pre dryer and then passed to the size press machine where the paper is pressed by two rolls – one on each side. The rolls also contain a starch solution which is applied to the paper to achieve enough strength and stiffness. The paper then continues to the after dryer section where any remaining water content absorbed from the starch solution is evaporated. The papers are then rolled and cut according to the customer's requirements. Kraftliner and Testliner are normally a two-ply product and therefore, they require a machine, which has two head boxes and two wires while the Semi-chemical fluting just requires only one head box as it is a one-ply product. Wellenstoff can either be a one-ply or a two-ply product (FEFCO, 2015).

2.6.1.2 Corrugated Box Production

The rolls of paper from the paper manufacturers are transported to the corrugated box producer. Corrugated board can be manufactured by any combination of different layers of recycled and/or virgin material. The paper must be specially conditioned, for instance, the fluting medium paper is conditioned in the presence of heat and steam. They are then fed between the corrugating rolls which give the paper the fluted structure. Now the corrugated medium with the one-liner on one side is then attached with the outer liner, and thus, a corrugated board is formed. The corrugated board can be double or triple walled based on the number of layers it was built on. The following are the different structures of corrugated board (FEFCO, 2015).

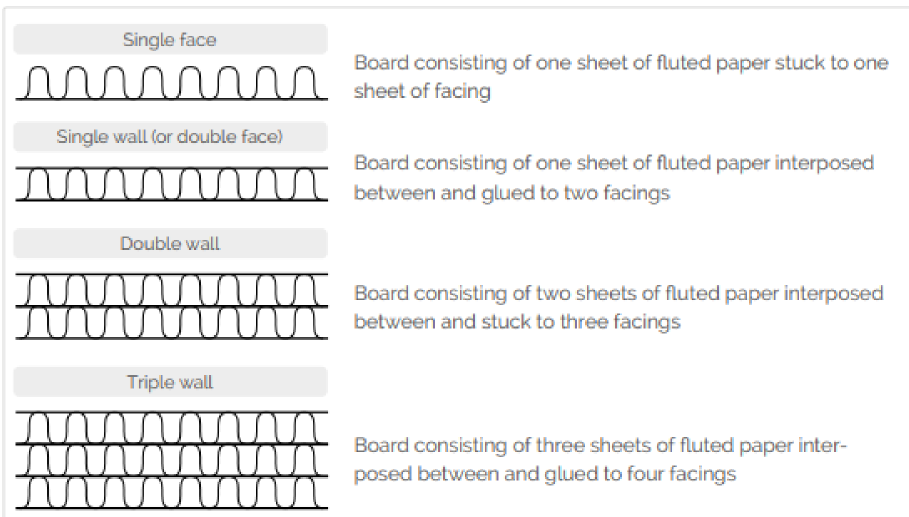


Figure 9: Different structures of corrugated board (FEFCO, 2015)

Once the corrugated boards are dried, they are then cut according to the dimensional requirements. All these processes are done by the corrugator machine. The board may be then printed based on customer's requirements, for example, color coating, bar code, and manufacturer names of the product and/or the box. The final stage is where the board is made into a box. This may be done in two ways: Regular slotting and Die-cutting. In the former, the box is made by printing, cutting, folding, and gluing into the final shape all in one operation. While in the latter, they are made on the die cutter and requires a precise cutting (FEFCO, 2015).

2.6.2 Environmental Impacts of Corrugated Box

From the corrugated box production process which is described previously, it could create several environmental problems throughout its supply chain. First of all, the packaging is made from natural resources, which means it will require materials extraction from nature. In its production process, various types of raw materials from both natural and synthetic types are used together with energy and water to produce packaging (Flaherty, 2017). As a consequence, it will generate emissions both in the air and water as well as create wastes, which require treatments before emitting to nature. The examples of the common air emissions generated from the packaging production system would be perceived as Carbon Dioxide, Carbon Monoxide, Sulfur Dioxide, or dust (FEFCO, 2019). These emitted substances can be linked to certain environmental problems such as global warming issues, acidification, or particulate matter. For the emission to water, the packaging production process can emit various types of substances such as Phosphorous and Nitrogen (FEFCO, 2019). In the same way, these substances can cause an environmental problem like eutrophication. Besides, at the end of its life, the packaging wastes are either be recovered to reproduce new packaging, disposed to the landfill, or put into the incinerator to generate energy (Eurostat, 2014). From that waste disposal process, it can cause greenhouse gas emission, which in turn links to the global warming issue.

3. METHODOLOGY

Since this is the first-ever environmental sustainability project within SML at Volvo, there was neither any environmental measurement system already present nor a framework for it. For the questions to be answered, there needed a procedure to be established and then tested on a case study to one specific part number and commercial packaging solution. This would serve as the template or a model to carry out projects in the future to measure the environmental impact for other commercial packaging solutions.

Therefore, the following milestones were expected to attain to answer the research questions:

- Develop a framework to measure the environmental impacts of commercial packaging solutions within SML quantitatively and qualitatively.
- Validate this framework by testing on a specific part number and show results.
- Integrate the proposed framework into a decision model.

This chapter will present the methods used to achieve the above-mentioned milestones. The overall method is provided in Figure 10. The method applied in this thesis will be divided into four phases including (1) gathering requirement, (2) theoretical framework selection, (3) case study, and (4) discussion. The following section will describe the research approach used in different phases.

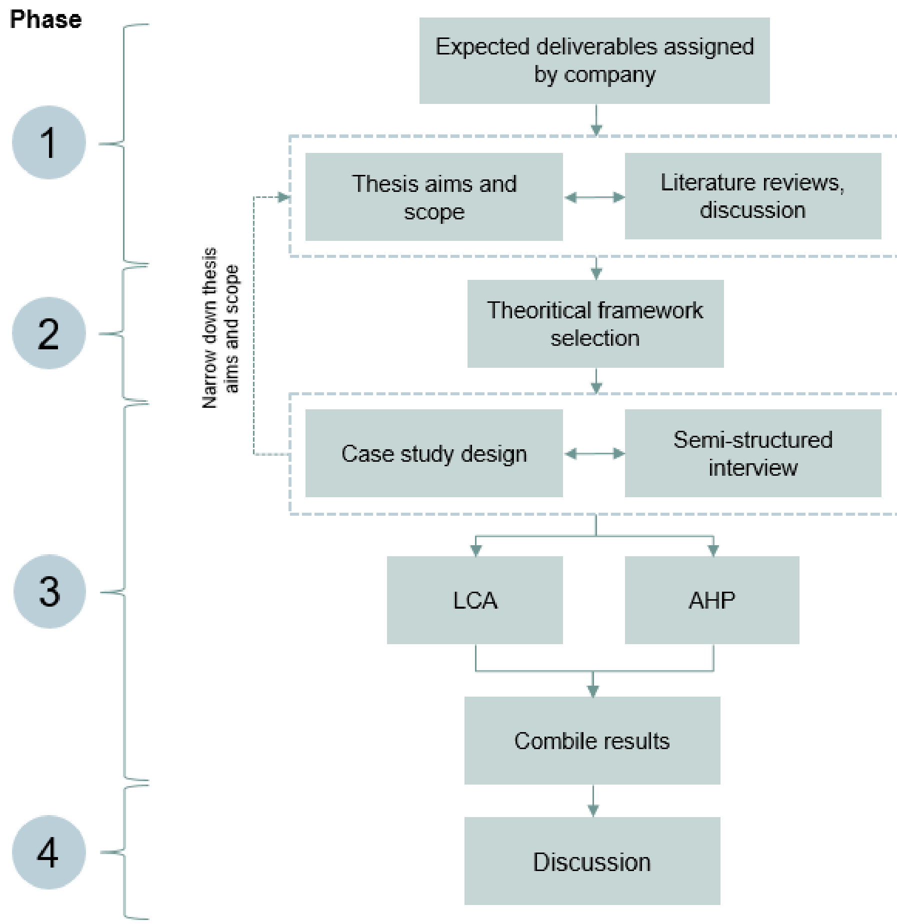


Figure 10: Methodology

3.1 Phase 1: Research Approach for Gathering Requirements

This phase started with the company assigning the expected deliverables to master thesis students. These deliverables could be used as background information for master thesis students to conduct a preliminary study for this thesis. In the beginning, this thesis consisted of three main expected deliverables including:

1st deliverable: Establish a process of how to measure the environmental impacts of the commercial packaging solutions

2nd deliverable: Develop a sustainability measurement tool to calculate the positive environmental impact from bypassing 3PLs packing process

3rd deliverable: Outline key areas of opportunities from GEMBA and determine appropriate sustainable packaging solution for each area

From these expected deliverables, literature reviews and discussions were performed to collect information regarding the company requirements to measure the environmental impacts, distribution process of spare parts, packaging solutions which the company currently uses, and practices of how to measure the environmental impacts of packaging both within the company and industry. Once the data was collected, the thesis's aims and scope were defined by master thesis students and together with the thesis mentor. Basically, the aims of this thesis were developed based on the first two deliverables, and the last one could be the area in which students could identify along the way when conducting the study for the first two. Therefore, the third one was not the main focus of this thesis. The scope of the study will cover the whole life cycle of packaging, *cradle-to-grave*. Besides, other interesting topics that are possible to study such as circular economy was also addressed in this stage, but the deliverable of this topic was not fixed due to the time constraints and results of the first two aims. The following section will describe how discussions and literature reviews were conducted.

3.1.1 Discussion

In order to deepen the knowledge about the company's requirements towards sustainability, discussions with people working in the different positions in the Commercial Packaging department and Quality Environment and Dangerous Goods department at Volvo Group Truck were held. The detail of each participant is provided in Table 3. These discussions were set up by the master thesis mentor as the aims were to introduce the students and for them to learn about the sustainability requirements of the company. Each discussion took around 10 to 30 minutes. The data that was gained from these discussions includes the company's overview, current logistics structure and practices, type of packaging used, company's driving forces towards environmental impact measurement, and important sustainability aspects of packaging which are possible to be considered in the environmental impacts assessment process.

Name	Department
Joel Larsson (master thesis mentor)	Commercial Packaging
Eva Fermheden	Commercial Packaging
Emma Chabanne	Commercial Packaging
Magnus Larsson	Quality Environment and Dangerous Goods

Table 3: Participants for project discussion

3.1.2 Literature Review

The literature review was performed to gather the information about the current practices of how to measure the environmental impacts of packaging as well as the characteristic of packaging which the company currently uses. In order to find the relevant information, electronic databases such as Chalmers Library and Google Scholar were used. *Life Cycle Assessment, Environmental Impact Assessment, Environmental Assessment, or Sustainability Indicators of plastic volatile corrosion* *inhibitor (VCI), solid woods, and corrugated box* were used as keywords to find the relevant papers and articles from such data sources.

3.2 Phase 2: Theoretical Framework Selection

In phase two, the aim is to identify the framework which will be used to measure the environmental impacts of the commercial packaging solution. As per the first two thesis deliverables which aim to measure the environmental impacts, LCA was the first tool that came up from the discussion with the company. The main reason was that it was a widely recognized procedure, which can quantify environmental impacts into the numerical term in which could be easy to make a comparison between different types of packaging solutions. In addition, LCA is considered as a well-established process with great data availability from previous studies. By following such a standard procedure and utilizing the previous life cycle inventory data, it could help to facilitate the study. Apart from this tool, the master thesis students also recognized the other important aspects in which came up from the discussions with the company. As the company's ambition aims to become a sustainable service provider by reducing CO_2 emission by 50% in 2025, several topics are under discussion within the company, which contributes to that goal. The examples of such discussing topics including:

1. Changing a material source of the corrugated box to be FSC (Forest Stewardship Council) certified
2. Changing material's choice of the corrugated box from virgin based fiber to be a recycled one
3. Removing the color coating of the corrugated box

By analyzing this information, it could be found that this qualitative data is very interesting and could be worth considering when analyzing the environmental impacts because it has direct or indirect consequences to the sustainability (Huang & Ma, 2004). However, the limitation of this information is that many of them could be hard to be quantified into a number, meaning that it could not be addressed by using the LCA approach. From the idea to incorporate such qualitative information to measure the environmental footprint, the framework introduced by Huang & Ma (2004) suggests using the Analytic Hierarchy Process (AHP) to capture the qualitative data. This tool could be used together with LCA, which is called a Multidimensional Environmental Evaluation. This framework will provide a comprehensive view of environmental impacts assessment because it covers both qualitative and quantitative evaluation (Huang & Ma, 2004).

3.3 Phase 3: Research Approach for Case Study

After the framework to measure the environmental impacts of commercial packaging was identified, master thesis students and the mentor agreed to test the selected framework by conducting a case study. The reason that case was an appropriate approach for testing the selected theoretical framework was that it allows students to study in-depth in a specific context and narrow down a board perspective into a scope, which can be researchable (Shuttleworth, 2008).

The results from this study could be used as a reference where the decision-makers at SML may choose to frame a dashboard with required numbers on the environmental performance along with inputs from the relevant actors in the supply chain, that will help to address issues, propose packaging solution alternatives, coordinate with the marketing team to satisfy promotion requirements and make a better sustainable packaging overall with lesser environmental impact.

3.3.1 Case Study Design

The first step to conduct a case study is to narrow down into a specific topic. In this case, as per the thesis aim is to measure the environmental impacts of commercial packaging solutions, selecting a spare part and its packaging used would be a first assumption to be made for this study. In this case, the main bearing kit and Volvo corrugated blue box were selected due to three main reasons.

1. The packaging solution used for the main bearing kit consists of three different packagings including plastic wrap, paperboard, and Volvo blue box. By using many types of packaging, it could influence a high environmental impact. In addition, Volvo corrugated blue box is solely made from virgin fiber-based paper. This can also be in line with the assumption of high environmental impacts from natural resource extraction.
2. There was a company interest to measure the environmental impacts of Volvo corrugated blue box since it has a blue color coating, which represents a premium brand and authenticity of Volvo spare parts. However, such value does not reach customers because the spare parts are mostly unpacked at workshops. So, customers do not actually acknowledge such branding purpose that conveys through the premium color coating box. From this point, the company would like to investigate the environmental impacts in case the blue color coating is removed.
3. There are various sizes of Volvo blue boxes that are used for a variety of spare parts. Therefore, the result of this study could apply to the other types of Volvo blue boxes which are used for other spare parts.

Next, the parties who relate to Volvo corrugated blue box production, packing process, and distribution were identified. The detail of each party is shown in Table 4. The aim of this was to conduct interviews and understand the production process of Volvo blue box, packaging processes, handling process at CDC, and dealer. The following part will describe how the interviews were conducted.

Semi-structured interview

The five interviews were conducted in a semi-structured format. The duration of each interview took around 30 minutes to 1 hour. The list of questions is shown in Appendix B. The reason that the semi-structured interview was preferred is that it is a combination of structured and unstructured interviews. With this essence, the questions can be prepared ahead of time, which makes interviewers be prepared and the interviewers can control and cover all the important aspects that are required during the interviews. Besides, it provides interviewees the freedom to express their views into the relevant topics, which in turn the interviewers can actually get more information and dig into such detail if they find it interesting (Cohen D, 2006).

Name	Company	Company role
Peter Åkerberg	FrontPac	Packaging supplier
Wojciech Kosak-Główczewski	Tenneco	Spare part supplier
Michiel Declerck	Volvo	Central distribution center in Ghent (CDC)
Jessika Bornström	Volvo	Bäckebol dealer
Emmanouil Milathianakis	Stena Recycling	Recycling company

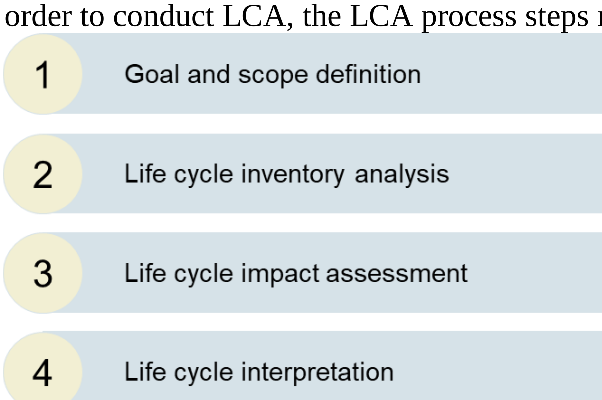
Table 4: Interviews' participants

The case study design was an iterative process. After each interview, the results of the interviews were discussed in order to redefine the questions for the next interviews. Once all interviews were done, the alternatives of commercial packaging solutions and the scope of the case study were redefined. The detail of the commercial packaging alternatives to be measured the environmental impacts in the case study is explained in point 4.1.3, Case Study chapter.

Due to the limited time constraint, the thesis aims, and scope were redefined. The thesis aim was changed to focus only on the first expected deliverable mentioned in section 3.1. For the scope, it was changed from *cradle-to-grave* to *gate-to-gate* which focuses on the upstream of the commercial packaging supply chain, in this case, the corrugated box, meaning that only the paper production and corrugated box production will be studied.

3.3.2 Research Approach for LCA

In order to conduct LCA, the LCA process steps mentioned in the literature review as illustrated



in

Figure *11* was followed.

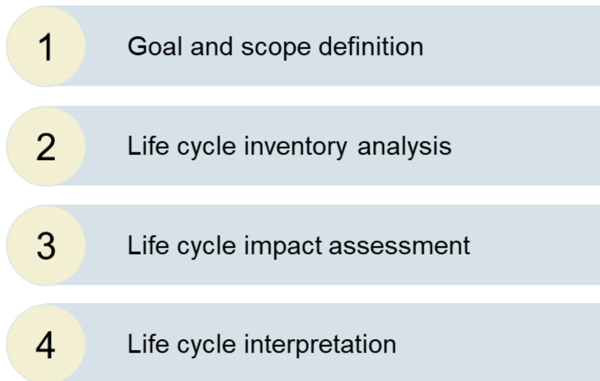


Figure 11: Research approach for LCA

1. **Goal and scope definition**

This step aims to identify the system boundary and functional unit of the LCA study. The explanation of system boundary and functional unit is provided in point 4.2.2 and 4.2.3 respectively, Case Study chapter. As mentioned in the previous section, the scope of this thesis was changed from *cradle-to-grave* to *gate-to-gate* because it will focus on the upstream of the commercial packaging supply chain. Therefore, the system boundary of this study will cover only paper production and corrugated box production.

2. **Life cycle inventory analysis**

In this step, the main aim was to collect the information for LCA analysis. As the main purpose of using LCA in this study was to measure the environmental impacts of commercial packaging solutions in the quantitative aspect, the data that was collected in this process was quantitative information such as resource uses and emissions in the production process of the selected packaging solution. Three approaches were adopted to collect such quantitative information.

- **Literature reviews**
  The literature reviews were conducted to learn about the production process of the selected commercial packaging solution, in this case, it was a Volvo blue box used for the main bearing kits. Besides, the Life Cycle Inventory (LCI) of such packaging solution was gathered from the previous LCA studies. As this case study aimed to calculate the environmental impacts of corrugated boxes, the main LCI database used in this study was applied from FEFCO (European Database for Corrugated Board Life Cycle Studies). In this database, it provides the detail of resource uses and emissions of paper production from virgin based fiber paper (Kraftliner and Semi-chemical fluting), paper production from recycled paper (Testliner and Recycled fluting), and corrugated box production. However, such information is provided in a generic term, which represents the whole corrugated box production industry in Europe. Therefore, some of the information in this database has to be adjusted by using the data assumption of the corrugated box supplier of Volvo, FrontPac. The detail of the FEFCO database is provided in point 4.2.1, Case Study chapter.

- **Questionnaire**
  A questionnaire was developed base on the LCI of the FEFCO database. This questionnaire was sent to FrontPac to gather information about materials' use, energy use, water use, emissions, and waste in the different processes of corrugated box production of FrontPac. At first, the data inventory from this questionnaire was aimed to be used as the main input to calculate the environmental impacts of the production process. However, there was a lot of information missing, especially emissions, because FrontPac does not have the system installed at their facility to measure the emissions. In order to solve this problem, the FEFCO database, which is mentioned in the previous section was instead used as a main source of information to conduct LCA and some of the information gathered from this questionnaire was used as an assumption to adjust the FEFCO data.

- **Supplier's site visit**
  A supplier site visit was performed in order to learn about the actual corrugated production process of FrontPac. The facility is located in Arlöv, Sweden. The result of this site visit was to construct the production flow of FrontPac. Besides, before visiting their facility, the questionnaire was sent to them beforehand for one week so that they could fill in the LCI data. At the end of the site visit session, it was used as a discussion to recheck the correctness of LCI data.

3. **Life cycle impact assessment**

In this step, the main aim is to use the LCI data from the previous step and then quantify them in terms of the environmental impact categories by using LCA software. To do that, it consists of two steps including selecting the LCA tool and LCA analysis.

- **Choices of LCA tools**
  There are many tools/software available in the market to conduct an LCA study such as Gabi, SimaPro, OpenLCA, etc. As there was a history of using Gabi within Volvo Group and for the ease of access of its educational license, LCA in this thesis was performed using Gabi. The database used in this software is Gabi and Ecoinvent.
- **LCA analysis**
  The inventory from the FEFCO database is listed. The LCI information would be then adjusted by the resource allocation of FrontPac and inputted into Gabi. The detail of setting resource allocation is shown in point 4.2.4, Case Study chapter. The result of this analysis will be graphically shown as the level of environmental impacts in the 11 midpoint impact categories. Then, four impact categories were picked according to the relevance of the packaging in this study. The selected categories are Global Warming Potential, Acidification Potential, Eutrophication Potential, and Photochemical Ozone Creation Potential. The detail of environmental impacts categories selection is provided in point 4.2.5, Case Study chapter. In this method, the higher score attaining from LCA means the higher environmental impacts generated from such a packaging solution.

4. **Life cycle interpretation**

In this step, the level of environmental impacts from each impact category will be summarized. However, since the LCA result will be later combined with the result from the AHP study, the environmental issues and conclusion to answer of which commercial packaging solution is more environmentally sustainable will be drawn up in the Discussion phase, where both results are summarized.

3.3.3 Research Approach for AHP

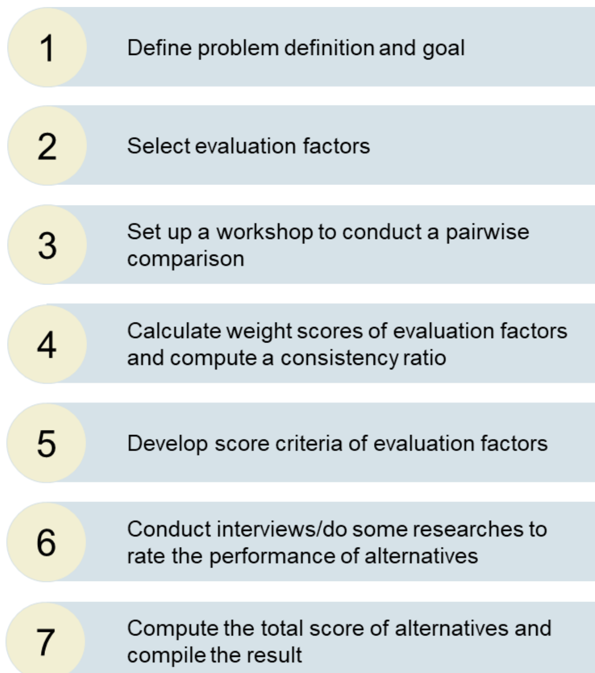


Figure 12: Research approach for AHP

As the main purpose of using AHP in this study was to measure the environmental impacts of commercial packing solutions in the qualitative aspect, the data that was collected and analyzed in this process was qualitative information such as packaging materials' properties and expert opinions. This type of information would be hard to be quantified into the number, so it could not be addressed in the LCA process. However, it still directly or indirectly causes environmental burdens. To conduct AHP, the AHP process mentioned in the literature review as illustrated in Figure 12 was followed. However, those steps were rearranged base on the project execution plan.

1. **Define problem definition and goal**

The main aim was previously determined in the case study design phase, therefore the problem definition and goal for AHP analysis were specified correspondingly. In this AHP analysis, the main goal was to measure the environmental impacts of Volvo corrugated blue boxes as mentioned in Table 8. Since the result of this analysis will be used as key information when selecting a commercial packaging solution for spare parts, this decision making will actually affect several parties in the supply chain. Therefore, throughout the AHP process, packaging suppliers, Volvo personnel from both commercial packaging department and purchasing department, and recycling company would be included to participate in the AHP analysis.

2. **Select evaluation factors**

Literature reviews were conducted to gather information about factors used to evaluate the environmental impacts of packaging and score criteria for rating evaluation factors. These evaluation factors were picked from two sources which include ISO 14021 and Packaging Sustainability Indicators - a global project led by The Consumer Goods Forum in 2010. Then, the evaluation factors were categorized into ten different groups. Among those ten, five categories of evaluation factors were disregarded because its impacts on the environment were already addressed in LCA analysis, or its uses were not relevant to the commercial packing solution. Therefore, only five evaluation factors were used to analyze the AHP process. The motivation of how each evaluation factor was selected will be described in point 4.3.1, Case Study chapter.

3. **Set up a workshop to conduct a pairwise comparison**

In order to specify the weight score of the evaluation factors, a pairwise comparison workshop was conducted. Referring to J. Marjan Hummel (2014), the pairwise comparison could be done in two ways either sending out a questionnaire or holding a workshop. In this study, the workshop approach was adopted because of two main reasons. The first one is about a small group of participants who relate to the packaging selection process. In this case study, only six people from Volvo, FrontPac (packaging supplier), and Stena Recycling (recycling company) were identified. The detail of each participant is illustrated in Table 5. From this small group of people, it could be manageable by setting up a workshop. Another reason relates to the complexity of each evaluation factor. Some of the selected evaluation factors are quite complex, hence different groups of people might understand it in different ways. By holding a workshop, it could provide a chance to set up a good understanding of each evaluation factor and its consequences in the sustainability aspect. Also, setting up a workshop will provide opportunities for different actors to share their views and find a consensus, which can eventually reduce the bias and inconsistency in the rating process.

In the workshop, each participant was asked to evaluate each pair of evaluation factors. Since five evaluation factors were selected, 10 pairs of evaluation factors had to be evaluated. Each participant was asked the same question:

Which evaluation factor do you consider is more important for developing a sustainable commercial packaging solution? And to what extent it is more important?

Once each participant came up with the rating, they would be asked to share their idea of which evaluation factor is more important and the reason to support their ideas. This meeting will allow them to discuss and learn about different perspectives of different actors in the supply chain. The meeting would follow this process until every pair of evaluation factors was rated. The example of the pairwise comparison of the first pair – Compostability VS Design for disassembly is illustrated in Figure 13. In this example, Design for disassembly is valued as a more important factor than Compostability at a score of seven. The definition of this score is explained in Figure *5*.

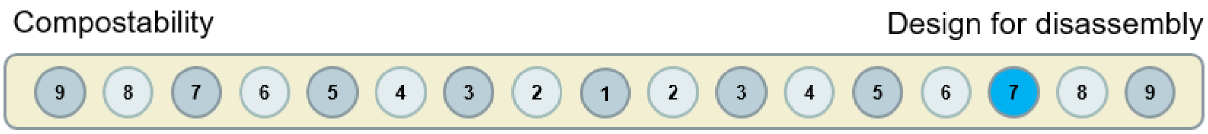


Figure 13: Pairwise comparison rating

Name	Department, company
Joel Larsson	Commercial Packaging, Volvo
Jasper Davidsen	Commercial Packaging, Volvo
Jonas Jacquemin	Commodity Buyer, Volvo
Peter Åkerberg	FrontPac
Martin Enocson	FrontPac
Emmanouil Milathianakis	Stena Recycling

Table 5: Participants of the pairwise comparison workshop

4. **Calculate the weight score of evaluation factors and compute a consistency ratio**

The weight score of evaluation factors could be calculated from the result of pairwise comparison by using the equation (1) and (2). After that, the consistency ratio would be computed based on equation (3) and (4). In case the consistency ratio is lower than the acceptance criteria at 10%. The weight score could be later used in the next step. However, if the consistency ratio is higher than 10%, re-conducing the pairwise comparison workshop might be required. In such a case, the pairs of the evaluation factors that participants have an inconsistent judgment have to be highlighted, and the participants will be again asked to adjust their judgment (Business Performance Management Singapore, 2013).

5. **Develop score criteria of evaluation factors**

The score criteria would be used to rate the performance of each evaluation factor. The example of the rating method is provided in Figure 14. In this case study, its performance of each alternative will be evaluated corresponding to the selected evaluation factors. The rating method and its scale were adopted from the framework of the Multidimensional Environmental Evaluation of Packaging Materials developed by Huang & Ma (2004). The performance as such would be measured into three levels which consist of zero, one, and two. These three ratings stand for *absolutely not fitting*, *partially fitting*, and *completely fitting* respectively. From this scale, the score criteria of how to rate each evaluation factor will be specified. Such score criteria were adopted from three sources which include the framework of Huang & Ma (2004), Packaging Sustainability Indicators, and historical data derived from the company. The detail of how to develop score criteria will be explained in point 4.3.4, Case Study chapter.

6. **Rate the performance of alternatives**

In case the consistency ratio passes the criteria, the performance of each alternative would be measured base on each evaluation factors, and its established score criteria. This step could be done by either interviewing subject matter experts such as Stena Recycling or FrontPac who have good knowledge about materials' properties, or it could be done by finding information from online sources or previous researches.

7. **Compute the total score of alternative and compile the result**

The total score can be completed base on equation (5). The alternative which has a higher score means the option that has a lower environmental impact in the qualitative evaluation.

Evaluation factors	Weight of AHP	PET bottles	HDPE bottles	PP bottles	PS bottles
Compostable[1]	0.23	0	0	0	0
Designed for disassembly[2]	0.10	1	1	2	1
Recovered energy[3]	0.13	2	2	2	2
Recyclable[4]	0.17	2	1	1	1
Reduce resource use[5]	0.20	2	2	2	1
Reusable and refillable[6]	0.05	2	2	1	1
Waste reduction[7]	0.12	1	2	2	2
Total score[8]		1.32	1.27	1.32	1.02

Figure 14: Example of AHP rating (Huang & Ma, 2004)

3.3.4 Combining Results

In this section, the results from both the LCA and the AHP studies will be combined. The environmental impacts derived from the LCA study and AHP scores will be used to indicate which alternative of the commercial packaging is more environmentally sustainable. According to Huang & Ma (2004), the LCA and AHP results will be integrated by using the cluster analysis. However, since this thesis studies only a few packaging alternatives, it is not necessary to apply the cluster analysis to combine the results. Therefore, the result, in this case, will only display the LCA and AHP scores separately.

3.4 Phase 4: Discussion

The discussion phase will be explained in four topics including (1) the LCA and AHP results summary, (2) the consensus gathered from the AHP process, (3) the practicality of the selected framework, and (4) decision-making model at SML. The following section will describe how each section will proceed.

The first section, the results summary, will discuss the LCA and AHP results and specify which packaging option has lower environmental impacts. Apart from that, the main sources that contribute to the environmental impacts of the corrugated box will be further investigated.

In the second section, the consensus gathered from the pairwise comparison meeting will be concluded. This consensus will be derived from the weight score calculated from the pairwise comparison results. In addition, the consistency ratio (CR) and the main sources of inconsistency in the process will be examined. In case the CR is higher than an acceptable level, resolving such high CR will be further investigated.

The third section will discuss the practicality of the established framework. The advantages and disadvantages of using this framework in the case study will be addressed. From these difficulties, the framework will be analyzed in terms of the practicality of applying this assessment tool in the organization.

The last section will discuss how the selected framework can be integrated into the decision-making model at SML. The new decision-making model will be developed based on the current model and the information gathered from the study.

3.5 Research Quality

Referring to Ellram (1996), in order to ensure the quality of research in both qualitative and quantitative aspects, good research has to be assessed by four important criteria including *External Validity, Reliability, Construct Validity* and *Internal Validity*. Below, each criterion will be explained and discussed as to how it can be related to this thesis work.

3.5.1 External Validity

External validity is a topic that should be addressed in the research design phase. This aspect relates to the accuracy of the case study results as to which it reflects the generalizability of the results (Ellram, 1996). In terms of this study, two main reasons support how the results of this study are applied to other studies.

Firstly, the main aim of this case study is to conduct LCA to measure the environmental impact of Volvo blue box which is used by verities of the spare parts. In this aspect, the result derived from the LCA study will be shown in a form of environmental burden per weight of the corrugated box. By having such number, it can be further used to calculate the environmental loading of other corrugated box used for other spare parts, e.g. different sizes of corrugated box, which has the same production process.

Secondly, another aspect is to measure the environmental impacts in the qualitative term by using AHP. Five evaluation factors were selected to evaluate alternatives performance. These factors were picked in the generic aspects, not specifically to study the environmental impacts of the corrugated box. In this regard, these factors can thus be used in the environmental assessment for other types of packaging solutions such as plastic bags or solid wood as well.

3.5.2 Reliability

The research reliability aims to measure the repeatability of the result. Namely, it is to assure that the same result can be achieved if conducting the same experiment (Ellram, 1996). These criteria can be related to our case study in several aspects as described below.

Firstly, the methodology used to conduct a case study is thoroughly presented, together with the interviews' guideline for different stakeholders, which is shown in Appendix B. By following the same structure, it could increase the possibility to get the same result.

Secondly, in the LCA process, the procedure of study mainly follows the ISO standard. In addition, the main data source for this analysis is developed by FEFCO, which is the accredited source of information to conduct an LCA study of the corrugated box. Apart from that, the LCA calculation part, it was done by Gabi – LCA software, meaning that it can reduce the error in the calculation part. Therefore, by following the same procedure and together with the same source of data, it could possibly lead to the same result.

Thirdly, in AHP study, the score criteria used to evaluate the performance of each packaging alternatives are established based on the studies of Huang & Ma (2004), and The Consumer Goods Forum (2010). From this aspect, as the material property of the corrugated box is standardized, the result from AHP analysis should be relatively the same unless the weight scores are adjusted.

3.5.3 Construct Validity

Construct validity is considered in the data collection phase to ensure that the study is conducted properly. To construct validity, three main elements need to be considered including *using multiple sources of the evidence, establishing a chain of events, and having key informants to review the case study* (Ellram, 1996).

3.5.3.1 Multiple data sources

This aspect aims to use multiple data sources to make a more reliable result (Ellram, 1996). Looking into the aspect of LCA study, different types of data were acquired from different means, for example, life cycle inventory information was gathered from both the FEFCO database and packaging supplier itself, corrugated box production process was studied from both literature reviews and supplier site visit. Besides, in the AHP part, evaluation factors were selected from two data sources including ISO 14021 and Packaging Sustainability Indicators by the Consumer Goods Forum 2010. Therefore, it could cover a wider aspect of the environmental impact assessment in the qualitative aspect. Apart from that, the different parties in the supply chain of Volvo blue box were invited to participate in the pairwise comparison meeting, which means that the consensus was developed based on the varieties of aspects from different roles in the supply chain.

3.5.3.2 Establish and maintain a chain of evidence

This element relates to the ability of the readers to follow and understand the study. To address this point, Ellram (1996) suggests having external reviewers to examine the report. In this thesis study, three rounds of reviews were conducted by the thesis supervisor (Ala Pazirandeh) and other master thesis students who did it as opponent groups. The details of each review are provided in Table 6.

<table>
<tr><th>Round</th><th>Objective</th><th>Reviewers</th></tr>
<tr><td>1</td><td>Planning report review</td><td rowspan="3">Thesis supervisor and opponent group A</td></tr>
<tr><td>2</td><td>Mid-term review</td></tr>
<tr><td>3</td><td>Final review</td></tr>
</table>

Table 6: Master thesis reviews' detail

3.5.3.3 Draft review by key informants

This element involves key informants from the company to review the study for their organizations (Ellram, 1996). For this point, this study had been reviewed regularly by master thesis mentors (Joel Larsson and Li Lei). Also, this thesis was presented in the management face to face meeting of the SML department and also the final thesis presentation which was held by Volvo.

3.5.4 Internal Validity

The final research design quality is internal validity. This aspect involves the causality to which the researchers have to exhibit that the outcomes of the case study are influenced by the independent variables (Ellram, 1996; Bryman, 2012). The answer to this issue will be explained in terms of the LCA and AHP studies.

For the LCA, the result will be derived as the environmental impacts in terms of Global Warming Potential, Acidification Potential, Eutrophication Potential, and Photo-chemical Ozone Creation Potential. To get these results, the CML 2001 method which is developed by the Institute of Environmental Sciences, Leiden University is used to process the emissions addressed in the FEFCO LCI data of the paper and corrugated box production. In this impact assessment method, there are several studies conducted to study and prove the correlation between emissions and environmental impacts potentials. Therefore, using the accredited impact assessment method such as CML 2001 can prove that the results are valid and related to the inputs from the selected LCI database.

In terms of the AHP study, five evaluation factors were selected to assess the environmental impacts. These factors were studied by both ISO 14021 and the Consumer Goods Forum 2010, thus it can prove this essence and relation in terms of the impacts on the sustainability aspect. In addition, in the AHP, the weight scores of each evaluation factor were identified by conducting a pairwise comparison as well as measuring the consistency ratio to measure the inconsistency and bias in the rating process. Hence, by evaluating this ratio, it can help the researcher to improve the research quality.

All of the information mentioned above could affirm the research quality in terms of *External Validity, Reliability, Construct Validity,* and *Internal Validity.* However, there are other aspects that could undermine the research quality. The first one relates to the representation of the LCA results to the Volvo case. As mentioned that the main data source that was adopted in the LCA study is the FEFCO database, by using such secondary data source, it would not fully represent the environmental impacts generated in the Volvo corrugated box production, but rather in the generic term. In addition, in this database, there are also several assumptions applied when gathering LCI information. By having such assumptions, it could also decrease the LCA result accuracy. Another aspect that could impact the research quality associates with the participants attending the pairwise comparison workshop. In this workshop, three people were representing Volvo, two people representing FrontPac, and one from Stena Recycling. From this group of people, only some people from each company could be considered as subject matter experts in the environmental field, and some of them are from the commercial side. With this regard, the result from the pairwise comparison meeting could possibly be uncertain since there is a risk of having both environmental and commercial perspectives in the environmental evaluation, which impacts the assessment result.

3.6 Integration of the Proposed Framework

If the framework has to be implemented in real-time at Volvo, it must fit in with the SML's existing functioning and their decision-making process. This is done in two steps:

- Laying out the as-is Decision-Making Model
    - Key factors to Decision making
- Proposal of the Modified Decision-Making Model i.e., Integration of the framework

Firstly, the As-is Decision Making Model was studied to understand the work and information flow leading to how packaging decisions were made, and all the key factors leading to decision making are listed. The framework and the results were explained to the mentor at Volvo, discussed the current decision-making process and the practicality in implementing the framework in real-time. Having the as-is Model as a reference, the framework from this study along with the discussions from the mentor as a guiding force, the modified decision-making model was proposed. On a macro level, this modified model will look into how SML can make decisions based on environmental sustainability. Deep down, the limitations of the framework were addressed from an industrial point of view, and then how this framework can be integrated into the existing model was explained in the section 4.5.

4. CASE STUDY

This thesis also has the element of a case study approach where the proposed framework is tested on one particular spare-part part number. This way, the framework can be validated if it suits the organization's working methods in real-time and if it can be incorporated in the future packaging decisions. Firstly, a case study approach is taken as it has the ability to carry out an investigation within its real-life context, that is, within the situation in which the study took place and also that it can be based on any mix of quantitative and qualitative approaches (Rowley, 2002). As a result, it can help explain the study's processes and the findings through complete observation, reconstruction, and analysis of the cases or different scenarios under investigation (Tellis, 1997).

Due to time constraints and the unforeseen COVID-19 situation, the application phase of the framework was done on a modest scale, yet, in a way that answers the research questions. The case description briefly provides the contents of this case study.

4.1 Case Description

There are 600,000 spare parts and hundreds of combinations of commercial packaging solutions, which are selected based on the size, volume, safety, marketing requirements of the spare parts. In this case study, one spare part and its packaging were chosen to study the environmental impacts.

The section below will firstly describe the definition of commercial packaging solution, the background information of the packaging used at Volvo. Then, the detail of the selected spare part and its commercial packaging will be further explained. Apart from that, in this case study, the selected packaging is simulated into the different scenarios and its environmental impacts are measured by conducting LCA and AHP studies. The results from both studies are then compared and answers the question of which packaging alternative is more environmentally sustainable. Finally, the integration of the framework to a decision-making model is explained in detail by analyzing the existing packaging decision-making model at Volvo and proposing the new decision-making model. The proposed model, importantly, includes a suggestion of a set of questions that a company should ask themselves with respect to packaging decisions and environmental sustainability. This is to assess their position when it comes to environmentally friendly packaging solutions and at the same time serving the main functions of packaging per se i.e., to protect the product and spread branding information.

4.1.1 Commercial Packaging

A commercial packaging solution is a specific term that is internally used by Volvo. This term refers to the retail packaging in which Volvo sells spare parts to their dealers or customers. The purposes of having this packaging solution include

- Protecting the sensitive parts during storage

- Building sale multiples and kits
- Fulfilling the branding requirement as to indicate the spare parts' authenticity as well as display its high quality and premium branding

Since the commercial packaging solution will be later packed inside another package called *Emballage* for transportation, it does not serve transport or shipping purposes. With the fact, the commercial packaging will work as the primary or secondary packaging according to the definition provided by Pongr´acz (2007). The common commercial packaging solutions of Volvo are corrugated boxes, plastic bags, and solid wood. Examples of commercial packaging and Volvo Emballage are shown in Figure 15 and Figure 16 respectively. For the environmental impacts of commercial packaging, as the commercial packaging is considered as one type of packing, its environmental impacts could be considered as the same as normal packaging, which is mentioned in point 2.1, Theory chapter.

Figure 15: Examples of commercial packaging solutions.

Figure 16: Volvo Emballage

4.1.2 Focused Spare Part and its Commercial Packaging

The chosen spare part for this case is the main bearing kit from the supplier Tenneco as shown in Figure 17. The packaging involved for this spare part includes Volvo corrugated blue box, a paperboard, and a plastic shrink wrap as shown in Figure 18, and Figure 17. Table 7 shows the dimensions of the chosen part and Volvo corrugated blue box.

Figure 17: Main bearing kits

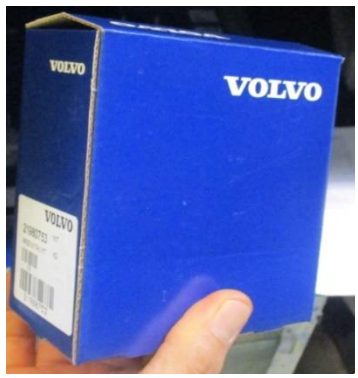


Figure 18: Volvo corrugated blue box

Parameter	Unit	Measurements
Spare part dimension (W*L*H)	mm	50*110*60
Volvo corrugated blue box dimension (W*L*H)	mm	60*110*110
Volvo corrugated blue box Weight	g	279

Table 7: Spare part and Volvo corrugated blue box's detail

The main bearing kits are produced by two companies - Tenneco and Mahle. In this case, the main bearing kits supplied by Tenneco were selected for the study. The virgin corrugated blue box used for this spare part is produced by a supplier named FrontPac while the paperboard and the plastic shrink wrap is produced by the supplier named Andra Pak. For the simplicity of the project and due to time constraints, only the Volvo corrugated blue box at FrontPac was considered in this study.

Figure 19 visualizes the whole life cycle of the main bearing kits and its packagings used. In this map, one actor at each stage was selected to understand the journey of the product throughout its life cycle. This map begins with the paper suppliers which supply paperboards to FrontPac. This paperboard will be used to produce the Volvo corrugated boxes at FrontPac's facility. After that, these corrugated boxes will be sent to Tenneco for packaging the main bearing kits. Then, these completed packing spare parts will be sent to Volvo distribution centers, and it will be finally delivered to dealers and service stations. Since there are many distribution centers at Volvo widespread across the world and so are their customers, in this map, the Volvo CDC at Ghent and the dealer located in Backeböl are displayed for the simplicity of illustration. After the spare parts are used, the packaging will be handled by waste management actors. The waste handlers for FrontPac and the Backeböl dealer is Stena Recycling.

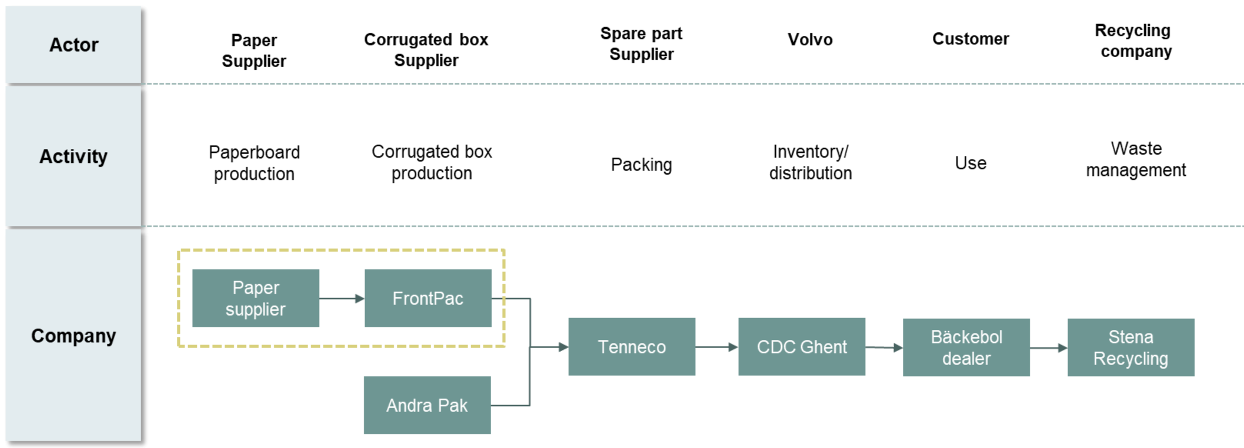


Figure 19: Represents the actors involved in the life cycle of the main bearing kit

4.1.3 Packaging Alternatives

Two alternatives of the corrugated box were chosen to study the environmental impacts. The master thesis mentor and together with students decided to study these alternatives because of the topics that are under discussions in the company. These topics include:

1. Changing material of corrugated box from virgin based fiber to be a recycled paper
2. Removing the color coating from the Volvo blue box
3. Changing a material source of the corrugated box to be FSC-certified

The detail of these alternatives is provided in Table 8.

Alternatives	Material	Color coating	FSC certified
A	Virgin	Yes	No
C	Recycled	Yes	Yes

Table 8: Alternatives to conduct a case study

At first, four alternatives were listed (A, B, C, and D). However, since the suppliers could not provide the emission data generating from the color coating process, two alternatives (B and D), which involve removing the color coating process were disregarded. Looking at the two remaining alternatives, alternative A is the current packaging solution that is used for the main bearing kit and C was developed based on the topics mentioning above.

4.2 Environmental Impact Assessment using LCA

This section will describe how the LCA study is conducted to measure the environmental impacts of Volvo corrugated blue box. In order to get the LCA result, the FEFCO database for the life cycle study of corrugated boxes is utilized. Therefore, this section will begin with the FEFCO data description. Then, the functional unit and system boundary will be specified. Later, it will describe how to set up the resource allocation. The final part in this section will show the result of LCA which is derived from LCA software, Gabi.

4.2.1 Data description from FEFCO

This section will describe the data description from FEFCO which is used as a main source of the database for conducting an LCA study. The FEFCO database is shown in Appendix C. This section will be separated into seven parts which aim to explain the materials use, energy use, water use as well as the emission to air and water generated from paper production, both primary fiber-based paper, and recycled paper, and corrugated box production. All of the resources use and emissions from the FEFCO database will be based on one ton of output in each process.

4.2.1.1 Material inputs

Two main types of material inputs are required to produce paper and these vary depending on type and grade of papers, either a primary paper or a recycled paper.

For a primary paper, it is a paper made from virgin material, in this case, it is either a Kraftliner or a Semi-chemical fluting. The main materials required to produce this paper is wood, which is reported as a *bone dry solid wood under bark*, process chemicals, and other additives. The chemicals and additives are categorized into two groups according to their function. The first one is functional additives are used to increase the paper function. The additive in this category is starch either from corn, potato, wheat, etc. Another type of them is process additives which are used to increase the production and to ensure that the process runs smoothly.

For recycled paper, Testliner, or Recycling fluting, the materials used to produce this paper are recovered paper which is either from a pre-consumer phase or a post-consumer phase. The pre-consumer recovered paper is the rejected papers from paper production, while the post-consumer paper is the paper packaging waste or newspaper which is already trashed after used by consumers. Besides, the same additives which are used to produce primary paper, both functional and process additives, are also used to produce recycled paper.

After these two types of papers are produced, they will be used as raw materials to produce a corrugated box. Different grades of papers are utilized depending on the customers' requirements. These papers are processed together with chemicals and additives. The chemical for producing corrugated boxes are glue, starch, caustic soda, borax, wet strength agent, printing ink, and varnishing agent.

4.2.1.2 Material outputs

The main output from the paper production is of course paper and the output from the corrugated box production is either a corrugated board or boxes. However, there are other saleable by-products from the Kraftliner and Semi-chemical fluting production. These by-products are tall oil and turpentine.

Apart from such outputs, residues are generated from these three production processes. For primary fiber-based paper, the common residuals are ashes, green liquor sludge, and lime mud. These residues are mostly landfilled, but the lime muds can be used as a fertilizer.

Residues from the recycled paper production are mostly organic sludge and reject from pulp preparation.

The main waste from corrugated board production is rejected paper, which can be used as the main source of materials for producing recycled paper. This material can be referred to as the pre-consumer recovered paper in the previous section.

4.2.1.3 Energy consumption

The energy used for these processes includes both processes and facilities. These energy inputs consist of steam, electricity, fossil fuels, and renewable fuels. In this case, steam and electricity are the sources of energy in the production process. The electricity is bought from the public grid, while steam is generated from natural gas through the boiler. Fossil fuel such as diesel and LPG is used for internal transportation.

4.2.1.4 Water consumption

Water is utilized in these processes and it will be returned to the natural water source such as rivers or lakes after use. This returned water will be in the form of cooling water or purified effluent water.

4.2.1.5 Transport

Transportation in this case study is divided into two types which are internal and external transport. The internal transport is already addressed in point 4.2.1.3, so it will not be considered again in this part. The transportation in this part involves how to convey papers from the paper production sites to the corrugated board plants. This transport is conducted in three modes including truck, rail, and boat. For road transport, the assumption of vehicles in this study is assumed to be the average size at >16 tons. The transport of residues is not included in this study because it is a part of the waste treatment process.

4.2.1.6 Emission to air

The emission to air is reported in terms of dust, particulates, carbon dioxide (CO_2), carbon monoxide (CO), nitrogen dioxide (NO_2), sulfur dioxide, and hydrogen sulfide (H_2S). The figures of this emission are estimated from the standard emissions data of combustion of fossil fuels, which refers to the internal transportation. The emission generated outside production facilities is not included in this study.

4.2.1.7 Emission to water

The emissions to water are reported into two categories including water output and waterborne emissions. The water output is reported in two forms including thermally polluted water, which is basically cooling water, and treated processed water. In terms of the waterborne emission, the amount of COD, BOD_5, TOC, suspended solids, total nitrogen, and total phosphorous are reported.

4.2.2 Functional unit

A functional unit is a reference unit that the inputs and output of the studied system have to be related (Baumann & Tillman, 2004). The identified functional unit will be used as a reference to convert the resources consumptions and emissions in the LCA study. In this case, the functional unit is identified as one ton of the corrugated boxes.

4.2.3 System Boundary

At first, the system boundary of the LCA study was defined according to the cradle-to-grave approach, which refers to raw materials extraction to the disposal of the end product. However, due to the limited time constraint, the system boundary was changed to focus only on the upstream of the Volvo corrugated blue box supply chain, meaning that only the paper production and corrugated box production will be taken into account. Thus, the system boundary in this case study was changed to the *gate-to-gate* approach. The system boundary is shown in Figure 19. The following activities were neglected in the study.

- Production of the main bearing kit
- Production of the plastic used for shrink wrapping of main bearing kit as it is manufactured by a different supplier Andra Pak
- The handling process at CDC and dealers
- The waste handling process

4.2.4 Resource allocation for papers

This section will describe how to calculate the resource allocation for each type of paper. Before going to such detail, the paper consumption per corrugated box and type of paper used will be explained. After that, this information will be used to compute the resource allocation factor.

4.2.4.1 Paper assumption

Table 9 shows the required paper consumption to produce one Volvo corrugated blue box. This information was gathered from FrontPac bill of materials. In one corrugated box, it consists of three layers of paper including print liner (outside), flute (middle), and inside liner (inside). According to the FEFCO database, Kraftliner and Semi-chemical fluting are used to produce corrugated boxes made from virgin fiber-based material. Therefore, the resource consumption and emissions of Kraftliner will be used to present print liner and inside liner, while Semi-chemical fluting will represent flute for alternative A. Likewise, the resource consumption and emissions of Testliner will be used to present print liner and inside liner, while Recycled fluting will represent the flute for alternative C.

Type of paper	**Required paper consumption per box (g)**	**Type of paper based on FEFCO database**	
		A	**C**
Print liner	175	Kraftliner	Testliner
Flute	145.6	Semi-chemical futing	Recycled fluting
Inside liner	125	Kraftliner	Testliner
Total weight	445.6		

Table 9: Types of paper and its consumption for each alternative

4.2.4.2 Resource allocation calculation

Referring to the FEFCO database in Appendix C, all information regarding resource consumption and emission is addressed based on one ton of output, which in this case it is either one ton of paper or corrugated box. However, the required quantity for each type of paper to produce one ton of corrugated boxes is less than one ton because the corrugated box consists of two types of papers - a normal paperboard and flute. From this fact, it requires setting up the resource allocation for each type of paper. This allocation can be determined by calculating the paper quantity requirement. Then, it will be later used as a scaling factor in Gabi to adjust the resource uses and emissions of the papers.

This section will describe how to derive the quantity required for each type of paper. The explanation of how to calculate such quantity requirements is provided in the following steps below.

1. **Calculate the proportion of the required paper consumption for each type of paper**

Base on this paper consumption per corrugated box in Table 9, it will require 300 g (175 + 125 g) of Kraftliner and 145.6 g of Semi-chemical fluting for the alternative A. In the same manner, it will require 300 g of Testliner and 145.6 g of Recycled fluting for alternative C. From this figures, in one corrugated box, the percent of Kraftliner or Testliner by weight is 67.32%, while it will be 32.68% for Semi-chemical fluting or Recycled fluting. This information is summarized in Table 10.

Type of paper	**The total paper needed (g)**	**% of paper required**
Kraftliner or Testliner	300	67.32%
Semi-chemical fluting or Recycled fluting	145.6	32.68%

Table 10: Paper consumption by type of paper

2. **Calculate the amount of paper required for each type of paper**

Referring FEFCO database in Appendix C, due to paper waste in the production process, it requires 1.1 tons of paper to produce one ton of corrugated boxes. Therefore, the required quantity of Kraftliner or Testliner to produce one ton of corrugated boxes is 0.741 ton which is derived from 1.1 multiplied by 67.32% which is the percent of Kraftliner or Testliner by weight.

Doing the same for Semi-chemical fluting and Recycled fluting, the required quantity for these two papers is 0.359 tons. These two numbers are shown in the bill of materials of the corrugated box in Figure 20. Then, these two numbers, 0.741 and 0.359, will be entered into Gabi as a resource allocation factor to adjust the resource uses and emissions in the paper production process of the FEFCO database.

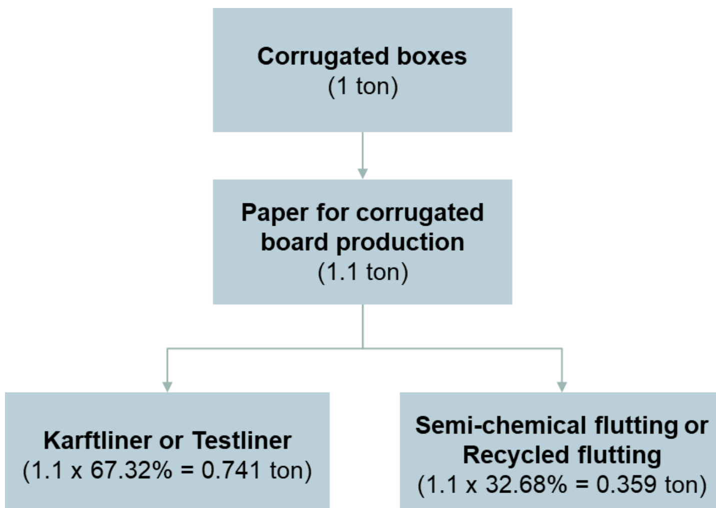


Figure 20: Bill of materials to produce one ton of corrugated box

4.2.5 Environmental impacts category selection

After inputting the FEFCO life cycle inventory as well as the scaling factors derived from the previous step into Gabi, the software will calculate the environmental impacts generated from the paper production and corrugated box production. The impact assessment method that is used in this case is CML 2001 – Jan 2016 because it is the most widely used LCA impact assessment method (Rigon, Zortea, Moraes, & Modolo, 2019). By using this method, the result of the environmental impact will be provided in 11 categories including:

- Global Warming Potential (GWP)
- Acidification Potential (AP)
- Eutrophication Potential (EP)
- Ozone Layer Depletion Potential (ODP)
- Abiotic Depletion elements (AD elements)
- Abiotic Depletion fossil (AD fossil)

- Human Toxicity Potential (HTP)
- Photochemical Ozone Creation Potential (POCP)
- Terrestric Ecotoxicity Potential (TETP)
- Marine Aquatic Ecotoxicity Potential (MAETP)
- Freshwater Aquatic Ecotoxicity Potential (FAETP)

It is generally accepted that all of the impact categories are indeed very useful information when evaluating the environmental impacts. However, some impact categories would be hard for non-LCA practitioners to understand because it requires specific knowledge in such field (Meijer, 2014). Since the main audience of this cast study is SML who is a non-LCA expert, the selection of these impact categories is required.

To select the impact categories, the literature reviews were conducted to determine what are the key impact measurements that are often considered by the actors in the industry. Since plastic bags, corrugated boxes, and solid wood are the three main packagings used by SML, the literature reviews regarding the impact categories selection of these three packagings were gathered. Besides, the impact categories selection of LCA studies adopted by Tetra Pak were also assembled because they are a big player in the packaging industry who focuses on sustainability. The impact categories selection result from such sources is provided in Table 12. From this table, it shows that the most commonly selected impact categories for these three packagings as well as adopted by Tetra Pak are Global Warming Potential/Climate Change, Acidification Potential, Eutrophication Potential, Smog Formation Potential/Photochemical oxidation. As a consequence, these four impact categories are thus selected and presented in the LCA result section. Referring to Acero, Rodríguez, & Changelog (2017); Danish Environmental Protection Agency (2005), the definition of the selected impact categories and its impacts are provided in Table 11.

Global Warming Potential	
Definition	Global warming addresses the effect of an increase in the temperature in the lower atmosphere. The potential effects of this temperature raising are the increase of the sea level and the regional climate change.
Impact indicator	Disturbances in global temperature and climatic phenomenon
Damage	• Decrease in biodiversity • Temperature disturbances • Climatic phenomenon abnormality
Substances contributing to this impacts	• Carbon dioxide (CO_2) • Methane (CH_4) • Nitrous oxides (N_2O) • CFC's (CFC-11, -12, -113, -114, -115) • HCFC's (HCFC-22, -123, -124, -141b, -142b) • HFC's (HFC-125, -134a, -152a) • Halons • Tetrachloromethane (CCl_4) • 1,1,1-Trichloroethane (CCl_3CH_3)

Unit	Kg CO_2 equivalent
Acidification Potential	
Definition	Acidification is caused by the reaction between acid gases such as Sulphur dioxide (SO_2) and the water in the atmosphere. This reaction will later form acid rain. This rain can destroy the ecosystem. In many cases, the acidification can happen from the gases generated from considerable distances.
Impact indicator	Increase of the acidity in water and soil systems
Damage	• Damage to the quality of ecosystems • Decrease in biodiversity
Substances contributing to this impact	• Sulphur dioxide (SO_2) • Sulphur trioxide (SO_3) • Nitrogen oxides (NO_x) • Hydrogen chloride (HCl) • Nitric acid (HNO_3) • Sulphuric acid (H_2SO_4) • Phosphoric acid (H_3PO_4) (note: the anion does not leach and the contribution to acidification is in practice equal to zero) • Hydrogen fluoride (HF) • Hydrogen sulfide (H_2S) • Ammonia (NH_3)
Unit	Kg SO_2 equivalent
Eutrophication Potential	
Definition	Eutrophication is an environmental problem, which is caused by the increase of chemical nutrients in the ecosystem. This issue can lead to excessive growth of plants such as algae in the rivers, which can diminish the water quality and animal populations.
Impact indicator	Increase of nitrogen and phosphorus concentrations Formation of biomass (e.g. algae)
Damage	• Damage to the ecosystem quality
Substances contributing to this impact	• The N potential, which expresses the nitrogen content of the substance, • The P potential, which expresses the phosphorus content of the substance
Unit	Depending on the impact assessment method: • Kg PO_4 - equivalent • Kg N equivalent
Photochemical ozone creation potential	
Definition	Photochemical ozone creation potential is known as summer smog. It is the environmental problem where ozone is formed in the ground level. When the concentration of this gas increases, it can be toxic to human health.
Impact indicator	Increase in the summer smog
Damage	Human health and ecosystem quality

Substances contributing to this impact	• NO_x • VOC's including CH_4 • CO
Unit	Depending on the impact assessment method: • Kg ethylene equivalent • Kg NMVOC • Kg formed ozone

Table 11: Impact categories definition

Source	Packaging in LCA study	Impact category										
		Global Warming Potential/ Climate Change	Acidification	Eutrophication	Abiotic Depletion	Smog Formation Potential/ Photochemical oxidation	Ozone Depletion Potential	Human Toxicity: PM 2.5	Total Primary Energy	Non-renewable Primary Energy	Water Consumption	Solid Waste Generation
Tetra Pak (Franklin Associates, 2014)	Tetra Recart Cartons	X	X	X		X						
Tetra Pak (Markwardt & Wellenreuther, 2017)	Shelf-stable canned food packaging - Tetra Recart - Glass jar - Steel can	X	X	X		X	X	X	X	X		
Tetra Pak (Tostivint, Beton, Massari, & Guern, 2010)	Wine package study - PET bottle - Glass bottle - Bag in Box - Stand up Pouch - Beverage carton	X	X		X				X		X	
(Puettmann, Bergman, & Oneil, 2016)	- Hardboard - Engineered wood	X	X	X		X	X					
(González-García, o.a., 2016)	Storage wood box	X	X	X	X	X	X					
(Yia, Wanga, Wennerstena, & Suna, 2017)	- Plastic bag - Corrugated box	X	X	X		X						
(Ongmongkolkul, Nielsen, & Nazhad, 2002)	Paperboard	X	X	X		X			X			X
(Civancik-Uslu, Puiga, Hauschild, & Fullana-i-Palmer, 2019)	Supermarket bags: - HDPE (1 use) - LDPE (10 uses) - PP (20 uses) - Paper (1 use) - Biodegradable bags (1 use)	X	X	X	X	X			optional		optional	
(Khoo, Tan, & Chng, 2010)	- PP bag - Bio-bag	X		X		X						

Table 12: Environmental impacts category selection

4.2.6 LCA result

This section will show the LCA results which are derived from Gabi by using LCI data from FEFCO and resource allocation factors from FrontPac. The result in this section will be provided in four categories including Global Warming Potential (GWP), Acidification Potential (AP), Eutrophication Potential (EP), and Photochemical Ozone Creation Potential (POCP). In each impact category, the results will be presented by processes which are paper production processes and corrugated box production processes.

4.2.6.1 LCA result of Alternative A

Alternative A contributes to the GWP at 1,502.76 kg CO_2 equiv. in total, and two-third of this figure is caused by the Kraftliner production. The Semi-chemical fluting production contributes to this problem at 25%, while corrugated box production contributes lesser than both of the other paper production processes.

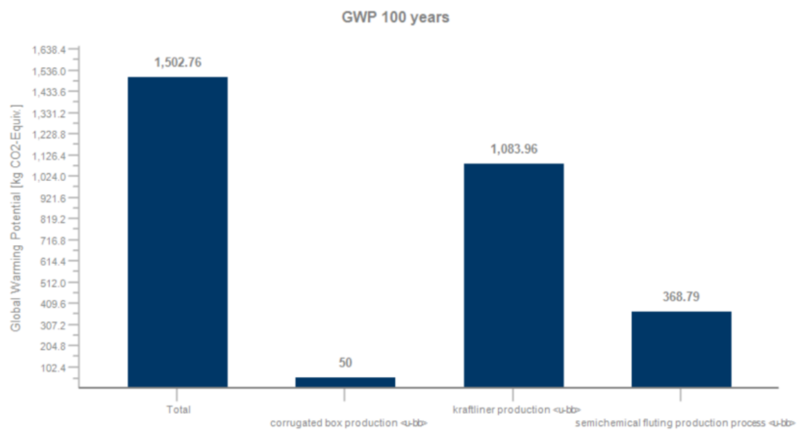


Figure 21: LCA result of alternative A - Global Warming Potential

The total contribution to AP is 1.207 kg SO_2 equiv. and over 97% of this figure is caused by paper productions, both Kraftliner and Semi-chemical fluting. The impact from the corrugated box production to AP is less than 3%.

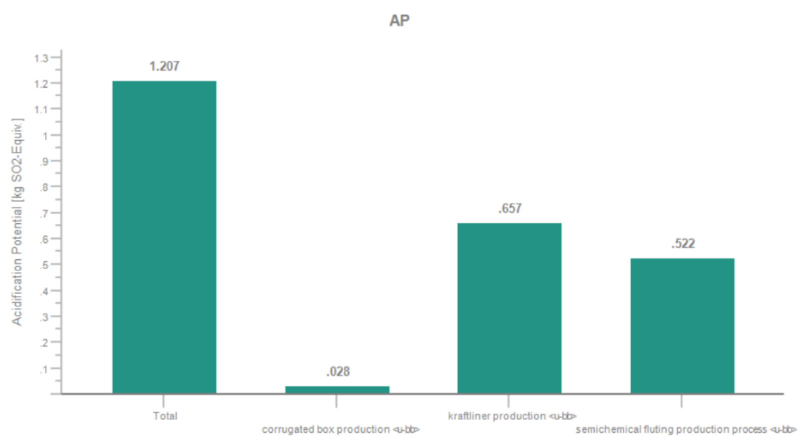


Figure 22: LCA result of alternative A - Acidification Potential

The impact on EP from alternative A is 0.624 kg P equiv. and over 95% of this problem is caused by paper productions, both Kraftliner and Semi-chemical fluting. The corrugated box production contributes to this problem by less than 5%.

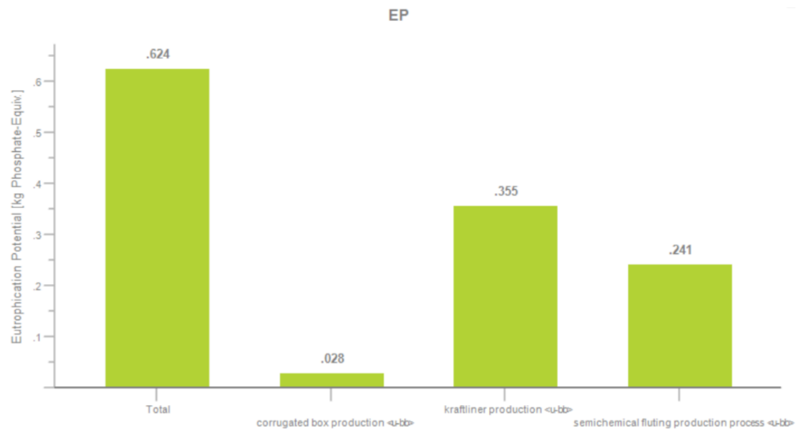


Figure 23: LCA result of alternative A - Eutrophication Potential

The total contribution to POCP from alternative A is 0.098 kg Ethene equiv. and about 98% is from paper productions, both Kraftliner and Semi-chemical fluting. The corrugated box production impacts this problem by 2%.

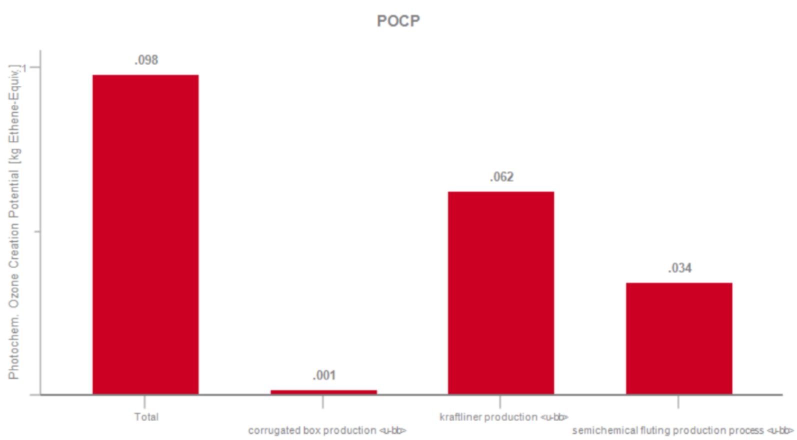


Figure 24: LCA result of alternative A - Photochemical Ozone Creation Potential

4.2.6.2 LCA result of Alternative C

Alternative C contributes to GWP at 392.85 kg CO_2 equiv. in total and almost 59% of this impact is from Testliner production. Recycled fluting and corrugated box productions impact this problem for 28% and 13% respectively.

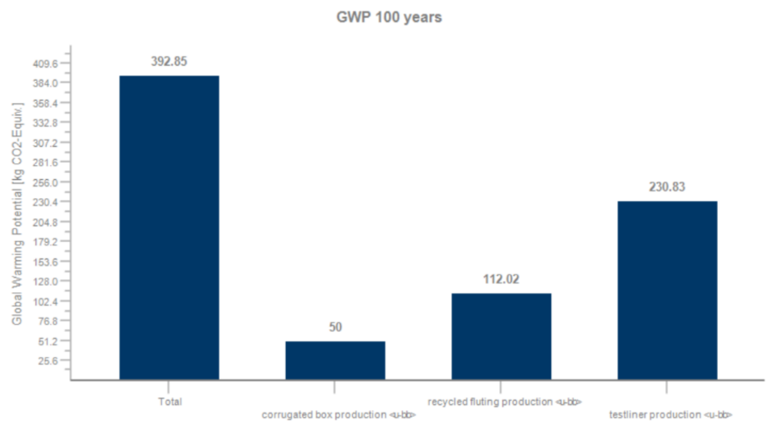


Figure 25: LCA result of alternative C - Global Warming Potential

For AP, the total impact from alternative C is 0.317 kg SO_2 equiv. and over 60% is contributed from Testliner production. The Recycled fluting process caused this problem by 30%, while the rest 10% is from corrugated box production.

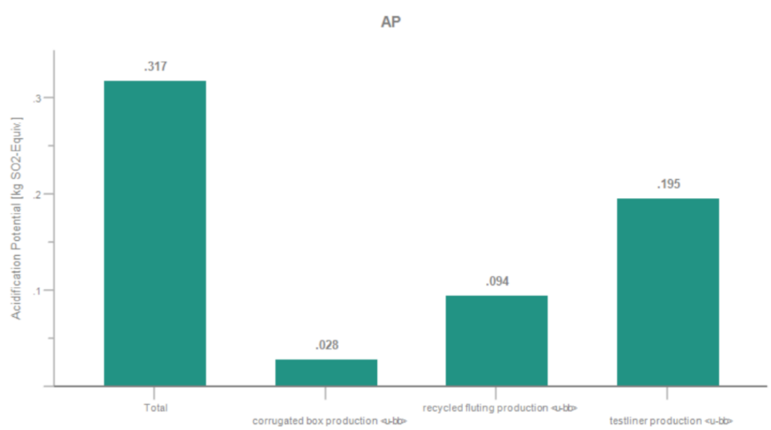


Figure 26: LCA result of alternative C - Eutrophication Potential

The total impact from alternative C to EP is 0.179 kg P equiv., which almost 57% is from Testliner production. Recycled fluting and corrugated box productions contribute to this issue by about 27% and 16% respectively.

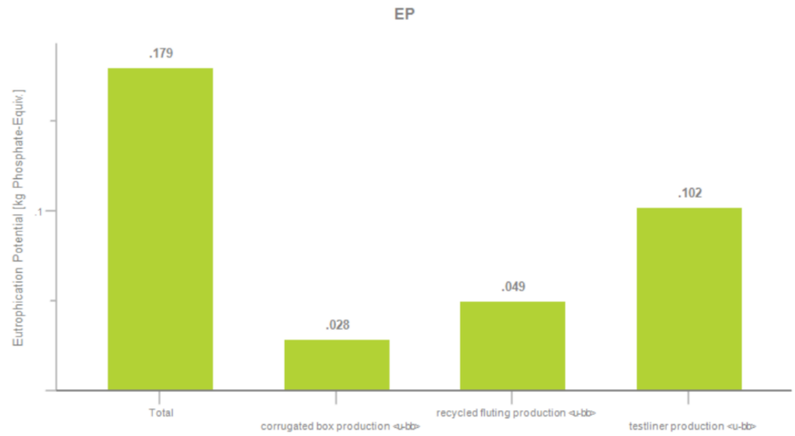


Figure 27: LCA result of alternative C - Eutrophication Potential

Alternative C contributes to POCP issue at 0.018 kg Ethene equiv. and two-third of this problem is from Testliner production. Another one-third of this issue is from Recycled production while corrugated box production impacts this problem very less.

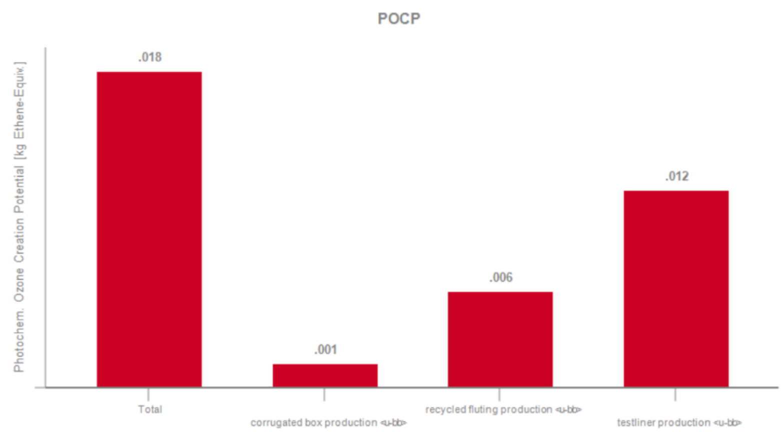


Figure 28: LCA result of alternative C - Photochemical Ozone Creation Potential

4.3 Environmental Impact Assessment using AHP

This section will describe how the AHP study is conducted to measure the environmental impacts of Volvo corrugated blue box. In order to get the AHP result, this section will follow seven process steps mentioned in section 3.3.3. However, this section will focus more on how to select the evaluation factors, how to develop AHP hierarchy decision, pairwise comparison result, and how to develop score criteria in the rating process. The last topic in this section will present the AHP result.

4.3.1 Evaluation factors selection

In order to select the evaluation factors, these three following steps as shown in Figure 29 have to be followed.

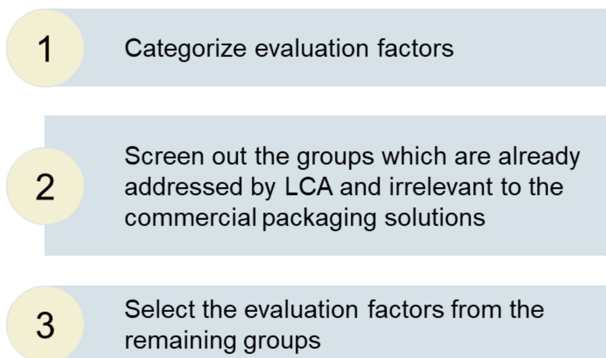


Figure 29: Evaluation factors selection process

1. Categorize evaluation factors

The evaluation factors that will be used to evaluate the performance of commercial packaging alternatives were gathered from two sources including ISO 14021 and the Consumer Goods Forum 2010. In total, there are 12 indicators from ISO 14021 and 20 indicators from the Consumer Goods Forum 2010. The list of all indicators is shown in Table 13. The factors from ISO 14021 relate to the environmental claims, while the factors from the Consumer Forum are based on ISO and European Standard (EN 13427 – 13432) which relates to the European Packaging and Packaging Waste Directive (Canadian Standards Association, 2008). The attributes from the forum will provide qualitative and quantitative information regarding the operations management and supply chain in the packaging life cycle (The Consumer Goods Forum, 2010).

Indicators from ISO 14021	**Indicators from the Consumer Goods Forum 2010**
• Compostable	• Packaging weight
• Degradable	• Total material input
• Designed for disassembly	• Packaging weight reduction
• Extended life product	• Packaging to product weight ratio
• Recovered energy	• Material waste

• Recyclable • Recycled content • Reduced energy consumption • Reduced resource use • Reduced water consumption • Reusable and refillable • Waste reduction	• Virgin material content • Recycled content • Renewable content • Chain of custody • Toxicants concentration • Water used from stressed sources • EMS use • Energy audits • Packaging recycling rate • Selling unit cube efficiency (SUCE) • Transport packaging cube efficiency • Packaging composting rate • Packaging reuse rate • Packaging energy recovery rate • Packaging landfill rate

Table 13: Evaluation factors from ISO 14021 and the Consumer Goods Forum 2010

In order to see the overview of how environmental performance can be measured from such indicators, all of these indicators are grouped into 10 different categories. The evaluation factors groups are illustrated in Figure 30.

2. **Screen out the groups in which are already addressed by LCA and irrelevant to the commercial packaging solutions**

From the 10 groups of evaluation factors, five categories of indicators were disregarded from this study because of the following reasons.

The first two groups that are disregarded from AHP are Resource Use and Toxicants categories. The main reason is that its impacts are already addressed in LCA. In LCA, water, resource, and electricity consumption are converted to emissions, which can be derived as environmental burdens. Therefore, all of the indicators that relate to this aspect including reduced resource use, reduced energy use, reduced water consumption, and total materials input should not be considered again in the AHP analysis. In the same way, packaging weight, packaging weight reduction, and packaging weight ratio address the same point as material consumption because the higher amount of resource use can link to the higher packaging weight. So, these three indicators are also out of the AHP study. For material waste, waste reduction and toxicants are already mentioned as emissions and residues in the LCI database.

Another three groups that would not be considered in AHP are Extended Product Life, Reuse/refill, and Recovered Energy. For the Extended Product Life and Reuse/refill, these factors are actually irrelevant to the commercial packaging solution. Referring to the main purpose of using this packaging, this packaging is aimed to be built the sale multiples and kits as well as satisfy branding purposes. After that, this packaging will be considered as a waste which will be later handled by a waste management actor. So, this packaging is not intended to be reused or refilled. Besides, the product life of the packaging relates to the quality of the packaging, which should be ensured at the first stage when selecting a suitable packaging for spare part. Therefore, the aspect of extending packaging life does not have to be examined when evaluating the environmental impacts. In terms of the recovered energy, this indicator is out of the company's interest since the packaging is aimed to be recyclable. By using recyclable material, it is actually more environmentally friendly because it can reduce natural resource extraction (Berg, Feber, Granskog, Nordigården, & Ponkshe, 2020).

As a result of the investigation mentioned above, there were only five indicators categories left that could be evaluated in the AHP. These five groups consist of Compostable/degradable, Recyclable, Design for disassembly, Supply chain transparency, and Efficiency.

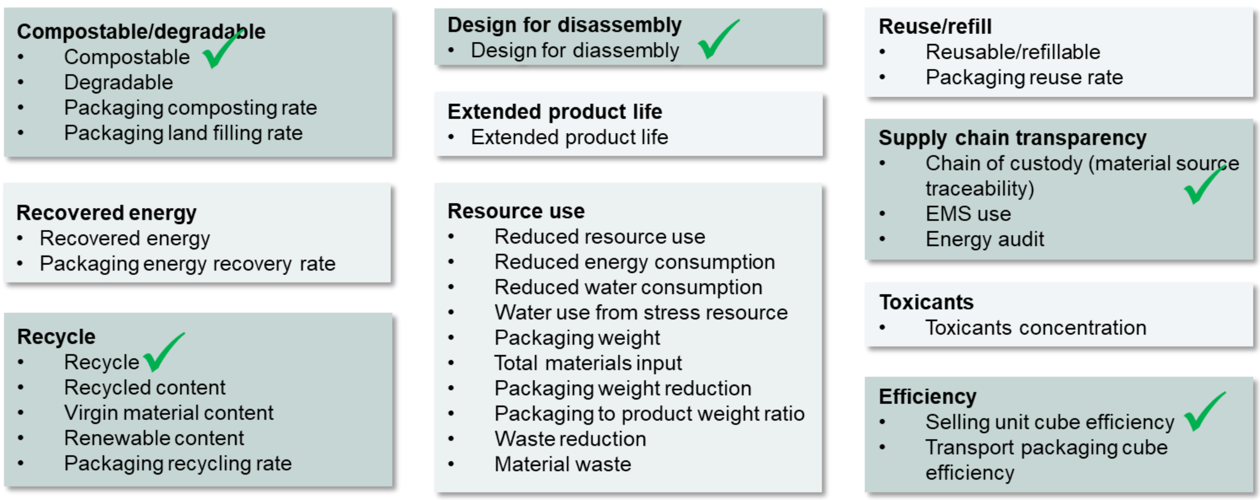


Figure 30: Evaluation factors categories

3. Select the evaluation factors from the remaining groups

In this step, two important aspects have to be considered. These aspects include how many indicators and which indicators should be included in this study. To answer the first question, PricewaterhouseCoopers (2007) said that there is no specific answer to this question since it is based on the needs of the organization. However, from their experience, they suggested that four to 10 indicators would be plausible for most companies. Besides, Wilkinson (2016) mentioned that selecting many KPI could lead to a problem of *KPI overload* where some of the KPI is not that important and redundant. This can make people losing their focus on important topics. To avoid this problem, it is sound reasoning to choose one indicator from each category. Therefore, it will be five indicators that will be chosen - one for each group. The following paragraph will describe how each evaluation factor was selected.

For the first group, Compostable/degradable, four indicators are addressed in the category. Firstly, the packaging composting rate and the packaging landfilling rate were screened out for this study because of the complexity to gather such information. In the case of packaging composting rate, it could be hard to calculate or come up with a single number to represent this indicator if the packaging consists of several types of materials, which sometimes are in the case of commercial packaging. For the packaging landfilling rate, this rate will vary depending on each geographical area, and the available data is not specified in the level of the material. This means that the landfilling rate is not a good representative to compare the environmental performance of different materials. Therefore, these two factors are not suitable for this assessment. Considering between Compostable and Degradable, Compostable would be more preferable because the compostable packaging is safer for the environment than biodegradable packaging. To explain the environmental impacts of these two bags, an example of the degradable and compostable bag from EastWaste (n.d.) will be used. The degradable bag is made from plastic which contains heavy metal, and can breakdown when exposed to the heat. With this effect, this bag can turn into many pieces of micro-plastic and pollute nature, which can be dangerous for animals if they eat such substances. However, the compostable bag is safer because it is made from natural base plants. Therefore, this bag does not emit the toxicant to nature. Besides, this bag can be broken down specifically through the composting system.

The second group is Recycle. Recyclability and packaging recycling rate is a hot topic in society nowadays as many statistics are saying that the recycling rate of some type of packaging such as plastic is relatively low. This can cause environmental problems in terms of wastes and resource extraction. As a consequence, governments in several countries imposed new regulations to increase the recycling target (Berg, Feber, Granskog, Nordigården, & Ponkshe, 2020). From this fact, the potential indicators that respond to this issue could be either Recycle, Recycle content, or Packaging recycling rate. Among these remaining three indicators, the packaging recycling rate will be firstly disregarded. This is because this indicator measures *the mass of recyclable packaging that is collected for recycling* (The Consumer Goods Forum, 2010). This means that its performance could vary geographically depending on the recycling policy in each area. Therefore, this is not a good representative indicator of this case. Considering the other two, Recycle will be more preferable than Recycling content. This is because, for certain types of materials, recycled content will rely on the supply capability of recyclable materials. For example, the supply of paper waste is higher than glass or Aluminium. According to this market constraint, it could lead to a lower recycled content of glass or Aluminium if it is compared with paper (The Consumer Goods Forum, 2010). Therefore, using this indicator can actually create a bias in the evaluation process.

The third group is Design for disassembly. In this group, there is only one indicator, which is Design for disassembly. This indicator is thus selected.

The fourth group is Supply chain transparency. This topic is one of the important issues in sustainable supply chain management (SSCM). This is because many environmental and social problems are caused by suppliers further down in the upstream of the supply chain (Tachizawa & Wong, 2014). Several topics can be addressed to increase supply chain transparency, for example, strengthening the relationship with lower-tier suppliers or reducing information asymmetries in the supply chain (Wilhelm, Blome, Wieck, & Xiao, 2016). In this group, there are three indicators including Chain of custody, Environmental Management System (EMS) use, and Energy audit. Considering these three indicators with the topics that are under discussion in the company mentioned in section 3.2, Energy audit would be out of the scope since the company does not have the policy to audit suppliers in such aspects. For EMS use, as to which SML mostly focuses on cost and quality, this can imply that there is no system in place to monitor the environmental aspect. As a consequence, this indicator could not be measured as of now. The last indicator in this category is the Chain of custody. This indicator refers to the ability of the company to trace back in the supply chain and identify the point of extraction of materials used for producing the packaging.

This factor is important in the sustainability aspect since it could help customers to ensure that the whole production process in the upstream of the supply chain does not contribute to environmental problems such as deforestation or any others. Besides, this factor can be used to address the company's interest in changing a material source of the corrugated box to be FSC certified. From these reasons, the Chain of custody is worth to be considered in this analysis.

The last group is Efficiency. Selling unit cube efficiency (SUCE) and Transport packaging cube efficiency are addressed in this category. Considering these two indicators, the Transport packaging cube efficiency would be out of scope because the main function of commercial packaging solution is to form a selling unit, and not to be used for a transportation purpose. Looking at the SUCE, the indicator is a ratio of product volumetric to packaging volumetric, which relates to the cost and performance of the packaging (Nastu, 2009). This factor is also important in the sustainability aspect since its cube efficiency impacts the resource consumption for producing packaging as well as energy consumption. For this reason, the Selling unit cub efficiency should be included in the AHP study.

In summary, five evaluation factors are selected from each category. Three of them are from ISO 14021, while the other two are from the Consumer Goods Forums 2010. The description of each selected evaluation factor is illustrated in Table 14.

Evaluation factors	**Description**	**Source**
Compostability	*A characteristic of a product, packaging, or associated component that allows it to biodegrade, generating a relatively homogeneous and stable humus-like substance.*	ISO 14021
Design for disassembly	*A characteristic of a product's design that enables the product to be taken apart at the end of its useful life in such a way that allows components and parts to be reused, recycled, recovered for energy, or in some other way, diverted from the waste stream.*	ISO 14021
Recyclability	*A characteristic of a product, packaging or associated component that can be diverted from the waste stream through available processes and programs and can be collected, processed and returned to use in the form of raw materials or products*	ISO 14021
Chain of custody	*The linked set of organizations, from point of harvest or extraction to point of purchase. Chain of custody should be tracked when supply chain reliability is questionable and where greater transparency is required. This links to the certification such as FSC*	The Consumer Goods Forum (2010)
Selling unit cube efficiency (SUCE)	*The overall volumetric measurement of packaging design efficiency for the packaging system. The calculation of selling unit cube is provided below.*	The Consumer Goods Forum (2010)

	$\frac{Volumetric\ of\ spare\ part}{Volumetric\ of\ packaging}$	

Table 14: Evaluation factors' description *(Canadian Standards Association, 2008; The Consumer Goods Forum, 2010)*

Once evaluation factors were selected, its impacts of these factors in terms of sustainability were analyzed. The impacts were discussed in both positive and negative ways, which will be later used as background information in the pairwise comparison workshop. This data will be used when deciding to answer the question of which factor is more important for developing a sustainable commercial packaging solution.

Evaluation factors	**Impacts in terms of sustainability**	
	Positive impacts (on an event of a high score)	**Negative impacts (on an event of a low score)**
Compostability	• Can be completely compostable	• Cannot be compostable
Design for disassembly	• Easier to be recycled/incinerate	• Impossible to be recycled/incinerate
Recyclability	• Need fewer resources to produce a new product. Contributes to a circular model	• More resources needed to produce a new product. More transport, costs, and emissions.
Chain of custody	• Can ensure that the operations in the supply chain are truly sustainable	• Cannot ensure the level of sustainability in the supply chain
Selling unit cube efficiency (SUCE)	• Require less storage space at the warehouse • Require fewer fillers • Higher truck transportation • Less fuel consumption per unit of transport	• Require larger storage space at the warehouse • Require more fillers • Lower truck transportation • More fuel consumption per unit of transport

Table 15: Selected evaluation factors

4.3.2 AHP hierarchy decision

After the evaluation factors were selected, the AHP hierarchy decision was built as shown in Figure 31. In the first level of the decision hierarchy, the goal of the case study was mentioned. The second level would display the packaging alternatives which were aimed to be measured the environmental impacts and the third will address the selected evaluation factors.

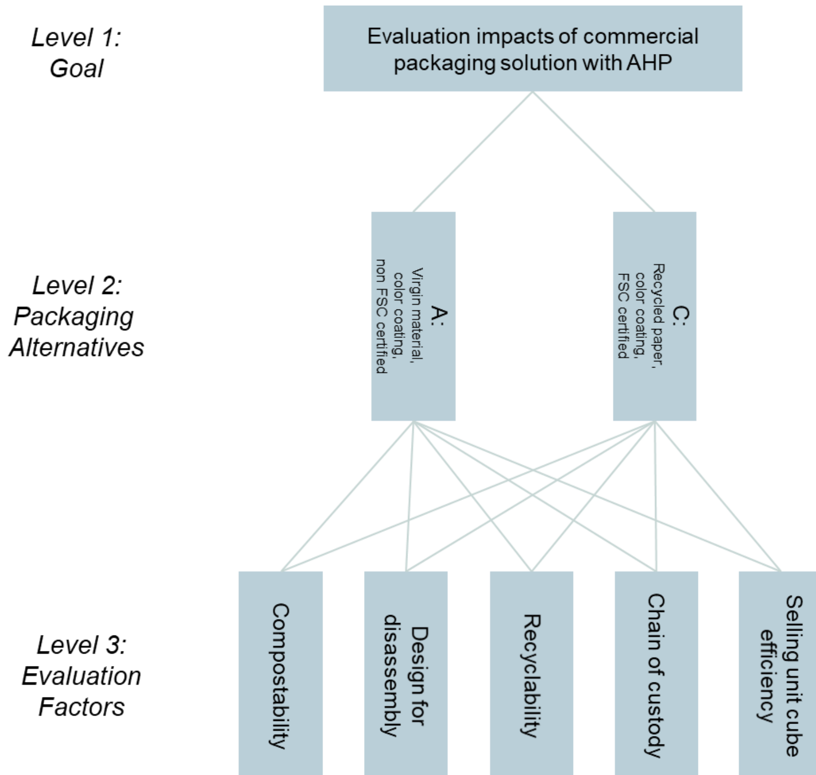


Figure 31: AHP hierarchy decision

4.3.3 Pairwise comparison result

Since the evaluation factors are not equally important when assessing the environmental impacts of commercial packaging solutions, the pairwise comparison was conducted to identify the weight score of each factor. To do that, the workshop was held, and six people from three companies participated as shown in Table 5. As five factors were selected, 10 pairs of evaluation factors had to be evaluated. In the workshop, each people would be asked to share their opinion regarding whether which factor is more important than the others, starting from the first pair to the 10th. In case different views arise, people were allowed to discuss to find the consensus. The questions used in the workshop, detail of different pairs, and the final rating score are illustrated in Figure 32. The individual scores rating of each participant is shown in Appendix D.

Looking at the detail of the individual rating of pair no. 1 to 5 and 10 in Appendix D, all participants rated the same factor as the more important one. However, the differences among them were only the rating, which each people gave. For example, in the 1st pair – Compostability VS Design for disassembly, all people selected Design for disassembly as the more important factor, but two people rated this factor as more important at the level of five, another two people rated at seven and another one person rated at nine.

For pair no. 6 to 9, two to three participants rated both factors as equally important while the rest chose the same factor as more important than another one. For instance, in pair no. 6 – Design for disassembly VS Chain of custody, two people considered these two as equally important which give the score at one, another two people chose Chain of custody at the score of five, and another one person also chose Chain of custody but in the score of seven.

Once all individual scores were gathered, the final rating of each pair would be derived from the average value of such individual ratings. The pairwise comparison rating is shown in Figure 32.

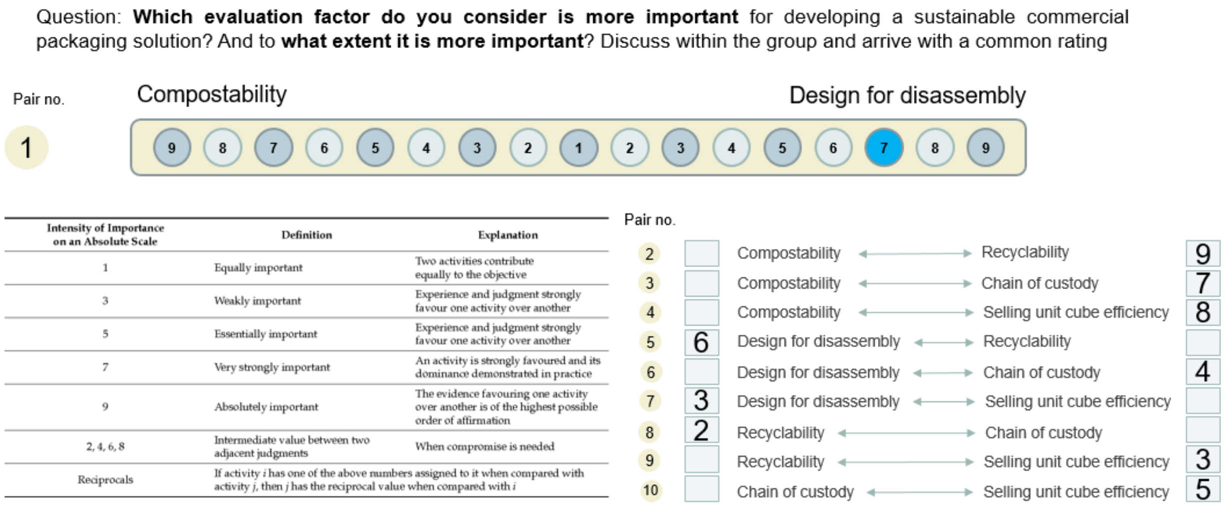


Figure 32: Pairwise comparison result

The weight score of each evaluation factor could be calculated from the pairwise comparison rating in Figure 32 by using the methodology mentioned in point no. 3. These weight scores will refer to the level of importance of each factor. The higher score in which the factor was valued means that this factor is more important for developing environmentally sustainable packaging. Apart from that, the consistency ratio was calculated by using the methodology mentioned in point no.4. Base on the AHP theory, the acceptable consistency ratio is 10%. However, the consistency ratio (CR) derived from the workshop was 39.3%, meaning that there was still an inconsistency and bias in the rating process. The calculated weight scores and the CR are presented in Table 16.

From these calculated weight scores, it shows that Design for disassembly and SUCE were considered as the top two factors which are important to develop a sustainable packaging solution. These factors are following by Chain of custody which was slightly less important compared to the first two. Then, Recyclability was perceived as the fourth one at a score of 11% while the least important one is Compostability.

Evaluation factors	**Weight score**	**Ranking**
Compostability	2%	5th (least important)
Design for disassembly	31%	1st (most important)
Recyclability	11%	4th
Chain of custody	26%	3rd
Selling unit cube efficiency (SUCE)	30%	2nd
Consistency Ratio (CR)	**39.3%**	

Table 16: Evaluation factors' weight scores

According to theory, in case the CR is higher than the acceptable level, the workshop has to be re-conducted to reduce such CR to the acceptable level at 10%. Notwithstanding, due to the situation of COVID-19 which was happening during the study period, it was not possible to hold the workshop again. According to this issue, master thesis students, the mentor at Volvo, and the academic supervisor had aligned and decided to use these weight scores to evaluate the environmental impacts, and then discuss how to fix this inconsistency in the discussion chapter.

4.3.4 Score criteria of evaluation factors

After the weight scores and consistency ratio were calculated, the next step was to develop the score criteria of each evaluation factor. To do that, the scoring system developed by Huang & Ma (2004) was deployed. The score criteria were ranged from 0, 1, and 2 which represent *absolutely not fitting, partially fitting,* and *completely fitting.* From this score criteria, the higher score refers to the lower environmental impacts of the commercial packaging solutions.

Among these five evaluation factors, the score criteria from three sources were deployed. For Compostability, Design for disassembly, and Recyclability, the score criteria developed by Huang & Ma (2004) was used, while the score criteria of Chain of custody was initiated by the Consumer Goods Forum 2010. To create the score criteria of SUCE, the data of SUCE of the Volvo spare parts, which are packed in the paper boxes, was utilized. The detail of how to establish this score criterion is described below

1. 175 spare parts which are packed in the paper boxes were gathered from the packaging database of Volvo. These 175 parts are unique in terms of both description and box dimension, meaning that these samples represent the different spare parts that are packed in the different sizes of the paper boxes.
2. 64 spare parts were randomly picked as samples to calculate SUCE. The sample size was identified base on the Central Limit Theorem (CLT) which says that

   The mean of a sample of data will be closer to the mean of the overall population in question, as the sample size increases, notwithstanding the actual distribution of the data. In other words, the data is accurate whether the distribution is normal or aberrant. As a general rule, sample sizes equal to or greater than 30 are deemed sufficient for the CLT to hold, meaning that the distribution of the sample means is fairly normally distributed. Therefore, the more samples one takes, the more the graphed results take the shape of a normal distribution (Ganti, 2019).

   From this theory, students and mentors agreed to pick the samples size more than 60 because it was the twice amount of minimum required samples that are mentioned in the CLT.

   From such selected 64 spare parts, there were only 35 of them that the drawings and spare part dimensions were available on the Volvo system named “KOLA”. Therefore, 29 spare parts were excluded. The detail of 35 spare parts is shown in Appendix E

3. The SUCE of such 35 spare parts was calculated by using the equation in Table 14.
4. From these 35 spare parts, five of them were excluded from this study because the calculated SUCE was either 0% or more than 100%.
5. From these 30 spare parts, the average SUCE is 46%. In this step, the spare parts would be divided into three groups equally which represent low, medium, and high SUCE as shown in Table 17. In this case, the packaging with a higher SUCE would be more sustainable as it requires fewer resources to produce as well as enable higher utilization of distribution. Therefore, the tier with a higher SUCE would gain a higher score in the rating system.
6. The lower and upper limits of SUCE of each tier were specified base on the highest and lowest SUCE of each group. These lower and upper limits of each tier would be used as score criteria of SUCE.

Tier of SUCE	Score criteria	Lower limit of SUCE	Upper limit of SUCE	No. of spare parts
Low	0: Absolutely not fitting	0%	41%	10
Medium	1: Partially fitting	41%	53%	11
High	2: Completely fitting	53%	100%	9

Table 17: Selling unit cube efficiency tiers

From the detail of how to construct the score criteria mentioned above, Table 18 will provide a summary of the score criteria of each evaluation factor.

Evaluation factors	Score criteria			Score criteria source
	2: Completely fitting	1: Partially fitting	0:Absolutetly not fitting	
Compostability	Can be completely composted	Can be partly composted	Cannot be composted	(Huang & Ma, 2004)
Design for disassembly	Materials consist of a single material	Materials consist of complex materials with easy disassembly	Materials consist of complex materials with hard disassembly	(Huang & Ma, 2004)
Recyclability	Can be recycled	Can be partly recycled	Cannot be recycled	(Huang & Ma, 2004)
Chain of custody	Source-certified	Known	Unknown	(The Consumer Goods Forum, 2010)
Selling unit cube efficiency (SUCE)	>0 - 41%	>41% - 53%	>53% - 100%	SUCE data from Volvo

Table 18: Score criteria of evaluation factors

4.3.5 AHP result

In this step, commercial packaging alternatives will be rated based on the selected evaluation factors, and the developed score criteria. The detail of evaluating each alternative according to selected evaluation factors is provided in the following section and the total score of each alternative is shown in Table 19.

4.3.5.1 Compostability

Most of the cardboards are compostable. However, different types of cardboard packaging have a different level of difficulties to be composted. For the corrugated cardboard, this type of packaging can be compostable as long as it can be shredded down into small pieces (Patterson & Gardener, 2018). The reason for breaking down the cardboards before composting is to speed up the composting process because it can help bacteria to reach the digestible cellulose faster. However, some types of cardboards cannot be composted, for example, the cardboards which are laminated by plastic or an Aluminium foil (HOTBIN Composting, 2018).

Looking at alternatives A and C, the difference between these two packagings is the type of paper. Alternative A is made from virgin based fiber paper, while alternative C is from recycled paper. By investigating physical appearance and checking chemicals used for these boxes, both alternatives can be broken down into small pieces and are not laminated by plastic or an Aluminium foil. Therefore, both A and C can be completely composted, so they are gained the score of two based on the established criteria.

4.3.5.2 Design for disassembly

Referring to the definition of Design for disassembly provided by ISO 14021, it is the characteristic of packaging which allows being disassembled at the end of life. The benefit of this design is to provide a possibility of packaging to be reused or recycled. This characteristic would involve the complexity of materials used for producing the packaging, for example in case the packaging consists of complex materials such as Aluminium foil, it would be harder to taken such materials apart.

For both alternatives A and C, these packagings are made from paper and they do not consist of any complex materials such as Aluminium foil that could not be dismantled at the end of its life. Accordingly, both alternatives gained a score of two based on the developed score criteria.

4.3.5.3 Recyclability

Most of the cardboards and corrugated are made from wood fiber, thus they generally can be recycled. Any forms of this packaging, damaged or undamaged, could be recycled five to seven times. To recycle such packaging, consumers have to remove the non-paper packaging materials such as fillers or bubbles wrap and keep the packaging dry and clean. It is still acceptable to keep tapes and labels on the cardboards since it will be removed in the recycling process. However, there is a condition which makes the cardboard cannot be recycled. This occasion is the contaminated cardboard with a heavy food-stain such as oil and grease. If it is such a case, it requires consumers to cut the dirty part to the trash and keep the clean part for recycling (Lallanilla, 2019; Paper Recycles, n.d.).

Considering alternatives A and C, both of them are the corrugated box made from wood fiber and are not used for food products. Therefore, there is no possibility to be contaminated by food-stain, meaning that it can generally be recycled. With this aspect, both alternatives will get a score of two. The only difference between these two is the recycling cycle because alternative A is made from virgin material, so it provides a possibility to be recycled more cycles than the alternative C. However, the alternative A can lead to other environmental problems such as natural resource extraction.

4.3.5.4 Chain of custody

Chain of custody refers to the ability of the company to identify the point of extraction of the materials used to produce packaging. To evaluate this factor, the score criteria are categorized to *source-certified* which is the most sustainable option, *known* as materials extraction source, unknown the materials extraction source.

To rate this factor, master thesis students had asked FrontPac, whether they know the extraction point of paper or not, in this case, it can refer to which do country or forest that the timbers come from?

For the alternative A, this packaging is made from virgin fiber-based paper and it is non-FSC-certified. However, FrontPac confirmed that they knew extraction point of papers and they can provide a document named "Wood Origin Statement" of Printliner which reveals the origin of timbers used for producing the Volvo corrugated blue box. In that document, it says that over half of the timbers are from Sweden, and the rest are from Finland, Brazil, Norway, and many more. The tree species are Pine, Spruce, Birch, Aspen, and Eucalyptus. With this information, alternative A will get one point since they know the origin, but it is not certified.

For alternative C, this packaging is made from recycled paper, and the assumption for this paper is an FSC-certified. Therefore, the score for this alternative will be two. Apart from that, the availability of recycled paper with FSC certified is checked. Referring to FSC (n.d.), there are three types of FSC labels including FSC 100%, FSC Recycled, and FSC Mix. The relevant label for this case is FSC Recycled which is used to ensure that *all the wood or paper in the product comes from reclaimed or re-used material.* From this information, it can confirm that there is a supply of recycled paper with FSC-certified in the market.

4.3.5.5 Selling unit cube efficiency (SUCE)

SUCE is the volumetric ratio of spare parts and packaging. The higher value of this ratio will indicate a less air space inside the packaging, meaning that the packaging is more fully utilized. This also indicates that the packaging might require less natural resources to produce, require less space for storage, and can enable higher utilization of transportation because it requires less space in the truck. The criteria to rate this factor was developed from SUCE historical data of the spare parts that are packed in the paper box.

Since the dimension of both alternatives A and C are similar, the SUCE for both is equal. Referring to the dimension of the spare part and Volvo corrugated blue box in Table 7, the volumetric of this spare part is 330,000 mm^3, and the volumetric of the box is 726,000 mm^3. From these numbers, the SUCE is equal to 45.5% and it falls into the score of one.

Evaluation factor	**Weight score**	**Alternatives**	
		A	**C**
Compostability	2%	2	2
Design for disassembly	31%	2	2
Recyclability	11%	2	2
Chain of custody	26%	1	2
Selling unit cube efficiency (SUCE)	30%	1	1
Total score		**1.44**	**1.70**

Table 19: AHP result

4.4 Result Summary

The results from the LCA and AHP studies are combined in this section. For the LCA results, the environmental impacts will be shown separately according to the selected impact categories. The AHP result will be displayed in a single score. The summary of LCA and AHP results is provided in Table 20. From this table, it indicates that alternative C has less environmental impacts than the alternative A from both LCA and AHP studies. These results will be further discussed in the discussion chapter.

Impact category	**Unit**	**LCA Result**		**AHP Result**	
		A	**C**	**A**	**C**
Global Warming Potential (GWP)	Kg CO_2-equiv	1,502.76	392.85	1.44	1.70
Acidification Potential (AP)	Kg SO_2-equiv	1.207	0.317		
Eutrophication Potential (EP)	Kg Phosphate-equiv	0.624	0.179		
Photochemical Ozone Creation Potential (POCP)	Kg Ethene-equiv	0.098	0.018		

Table 20: Environmental impact result

4.5 Packaging Decision Process in SML

Background: Within Volvo's Operations, there are many suppliers for raw materials, components, finished products, packaging, many distribution centers, and logistics service providers across the globe. Every object that goes in this supply chain needs to be packed. The items that go to the production floor need not be commercially packed as the end consumer won't see it anyway. But for every item that goes to the dealers, service stations to the end consumers, SML at Volvo commercially packs according to the branding and safety requirements. The environmental aspects were never considered in the decision-making process.

For the framework to be integrated into SML's functioning, it is important to study the existing packaging decision-making model. For the study, company-specific details were removed and are modeled in a generic way (Figure 34).

4.5.1 As-is Decision model

SML has addressed two main problems that they face including

1. The complexity of making packaging decisions increases with increased weight/size.
2. A single spare part is packed in different ways in different regions highlighting the absence of a global packaging decision system.

4.5.1.1 Basis for As-is Decision Making Model:

The following section describes the fundamentals that constitute the existing packaging decision model (*Figure 33*) that is built to overcome the problems mentioned above.

- The spare parts are categorized according to the weight of the product.
- **Safety requirements:** This determines the type and the material of packaging. Basic checks are done to check if the part is rust sensitive, fragile, and if it is an electrical part. Based on this, one out of the two types of packaging – Standard Packaging or Extra Protection Packaging is assigned. The most common packaging materials used are:
    - Standard Packaging
        - Corrugated Box
            - High-Density Corrugated Box
            - Low-Density Corrugated Box
            - Single-walled, double-walled, triple-walled Corrugated Box
    - Extra Protection (Outer Material)
        - Wrapping by Cloth, bubble plastic, shrink plastic, etc.
        - Inserts such as Styrofoam etc.
    - Extra Protection (Inner Material)
        - Antistatic box/bag, VCI bag (for rust sensitive parts), tape, etc.

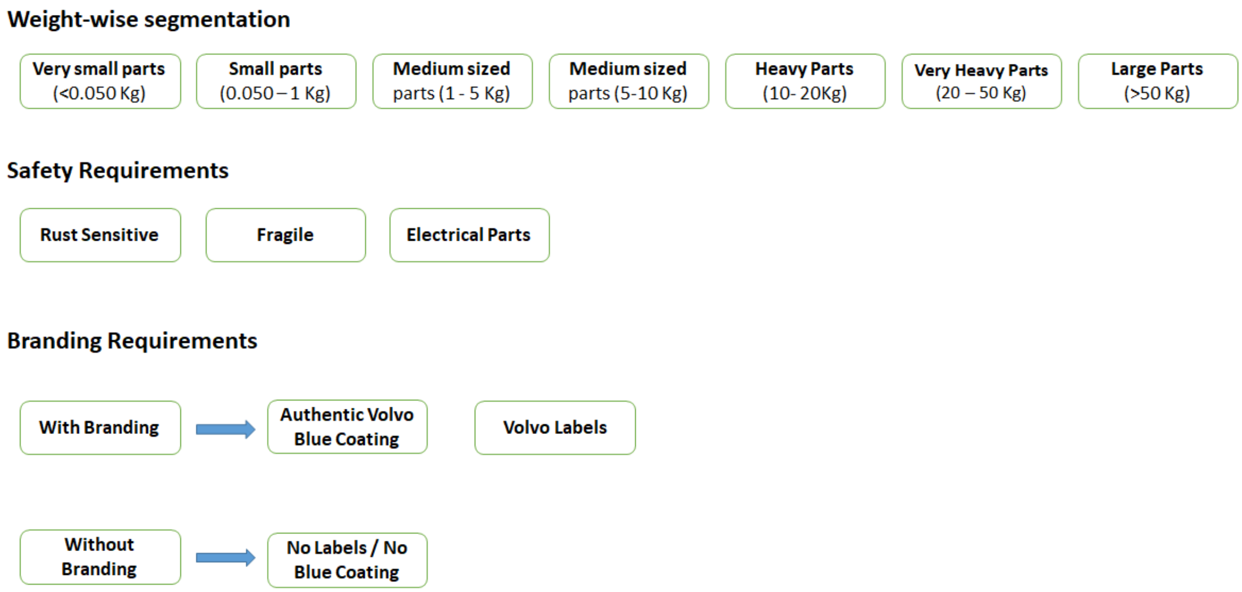


Figure 33: Basis for AS-IS Model

- **Branding requirements:** It specifies on what basis the spare parts be branded. Guidelines are as follows:
  - With Branding:
    - The part should be packed with the authentic Volvo Blue Color on the box.
    - The part should specify that it's from Volvo but can be without the authentic Volvo Blue Color – with Labels or the logo just printed on the corrugated box.
  - Without Branding:
    - The part can be packed without any labels or imprints of Volvo.

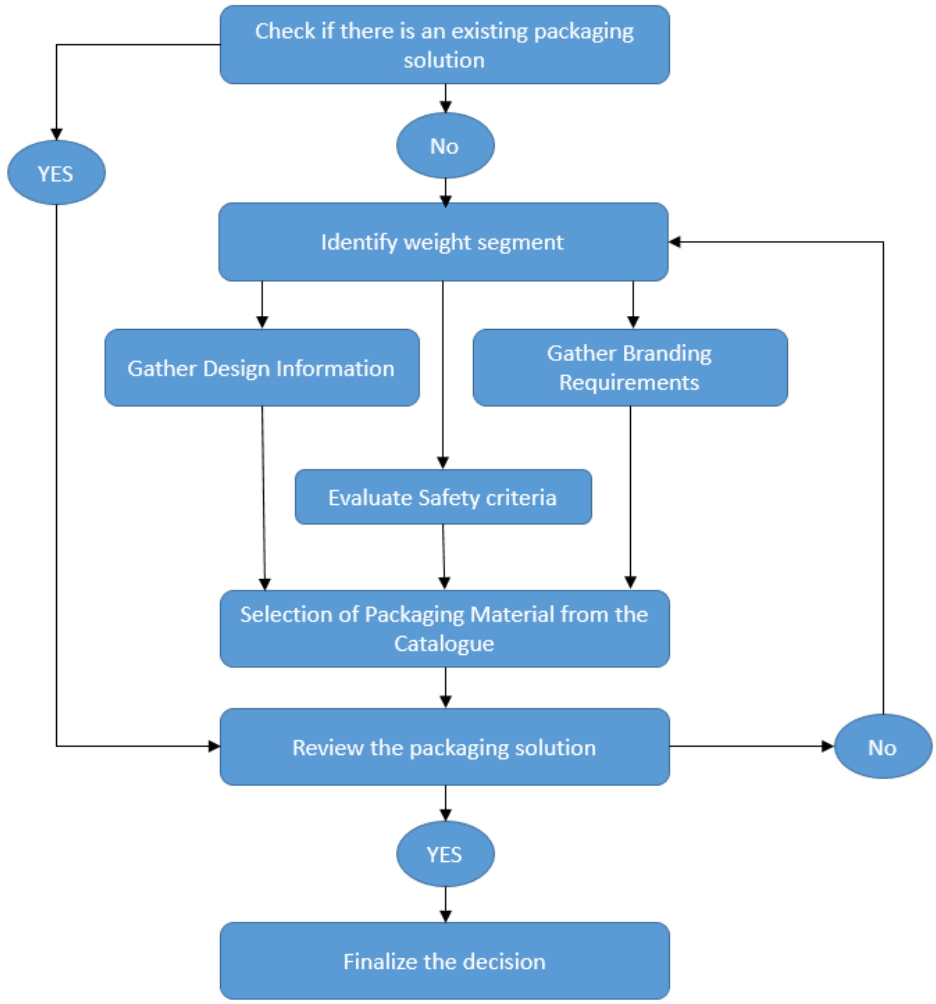


Figure 34: AS-IS Decision Model

4.5.1.2 Summary of Steps:

- Firstly, for an incoming spare part, the current packaging solution is checked and if there aren't any changes, the packaging is reviewed and the decision is finalized. If not, the spare part follows the decision-making process.
- All the spare parts are categorized into 7 different weight segments. Each spare part has its Branding Requirements and Safety Requirements
- Based on the governing factors – Design Specification, Safety Requirements, and Branding Requirements, each spare part under a particular weight segment is mapped to a packaging solution from a pool of different packaging materials, combinations in the catalog.
  For example, if a part is both rust sensitive and fragile, it would be mapped to a packaging solution where the part is sealed by a Vapor Corrosion Inhibitor (VCI) bag, outer packaging

like a virgin corrugated box, internally cushioned with paper inserts, etc. On top of that, the branding criteria are applied to evaluate if the part needs to be commercially packed with a blue box with Volvo's logo on it or just any other box.

- The final solution is reviewed if the packaging specification matches with Safety and Branding Requirements. In a few cases, this will also be done by testing the spare part with a sample of the packaging solution and then the decision is finalized.

4.5.2 Modified Decision Model

In the modified packaging decision model, the framework from the thesis is integrated. Along with Branding and Safety requirements from the As-is Model, Environmental requirements are added to govern the processes on how the packaging decision is made. This is done by having an internal discussion between the marketing department and the packaging engineers to assess how the individual requirements based on technical specifications, environmental sustainability, and marketing affect the final packaging requirements.

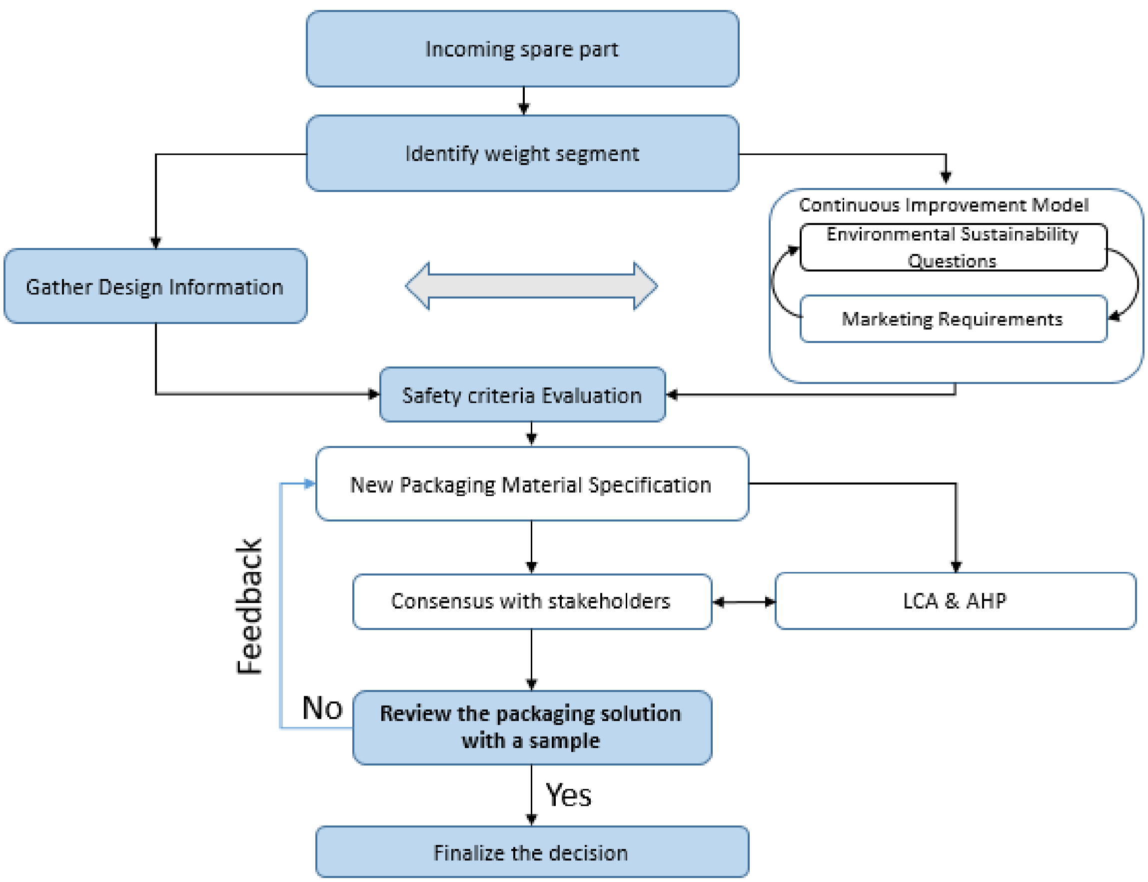


Figure 35: Modified Decision Model

4.5.2.1 Procedure

The step-by-step process of the Modified Decision model (Figure 35) is explained below.

- The spare part is selected and its weight segment is identified.
- **Design Information:** This includes the part's physical dimensions (Length, Breadth, Height, and Volume), weight, etc. This information acts as reference 1.
- **Environmental Sustainability and Marketing requirements:** This is where the internal discussion between the marketing department and branding takes place. An example of a set of questions/topics on such discussion is mentioned in the table below (Table 21)categorized into 4 types: * Product Specific * Functional * Circular Economy * Sales and Branding.

TYPE	QUESTIONS
Product Specific	1. What are the materials involved in the packaging solution? 2. Are they heterogeneous? Can the materials be separated easily? 3. What is the environmental performance of the packaging solution? 4. Is it necessary to pack the product in a virgin material? Can it be packed in recycling material?
Functional	1. What purpose is the outer packaging serve? Is protection the main reason? Or does it serve aesthetic and branding purposes? 2. Is the packaging considered to be oversized compared to the spare part? 3. What is the product's safety evaluation for different types of materials – virgin, different grades of recycled material?
Circular Economy	1. Is the packaging easy to open, reseal, and reuse? 2. Are there proper waste handling methods – composting, recycling for the material?
Sales and Branding	1. What is the shelf life of the product? 2. Is the spare part fast-moving? In other words, does the spare part sell often? 3. Does the spare part need to be packed in the Volvo Blue Box (necessary for color coating?) or just be packed in a box without color coating and put a label on it? 4. What's the justification behind the existing branding requirement for a particular spare part?

Table 21: Questions for Marketing and Environmental Sustainability

These questions are aimed to be discussed internally within the company to assess where they stand with respect to their progress in the environmental sustainability aspect and to know if the branding requirements impact or interfere in the sustainability transition progress and if yes to what extent. The thought process behind having this questionnaire is briefly explained in the Discussion section. The outcome of this step would be in the form Material specification that is expected to satisfy safety requirements as well as knowing how the product is expected to be handled throughout the lifecycle (example: no or fewer chemicals in the production phase, proper waste management in the end-of-life phase, etc.) This outcome is considered as Reference 2.

- Then, the safety evaluation is done. This will be no different from the safety evaluation in the as-is Model. Safety checks on rust, fragility, cushioning for electrical products, etc. are evaluated. This results in the New Packaging Material Specification.
- **Integration of Framework:** The new material specification is handed over to the packaging supplier and the waste handler. And this is the step where the framework from this thesis is integrated, i.e., the idea of conducting LCA and AHP that support a packaging decision process. The OEM (in this case Volvo) will facilitate the AHP discussion between the stakeholders with the suggested evaluation factors from this thesis. The LCA for the packaging can be done by the packaging supplier or the OEM could hire consultants for this. In some cases, it is also possible that the Waste handling company having LCA reports. How detailed the LCA and AHP should be is discussed in the Practicality Section in the Discussion. There expected some back and forth dialogues between the packaging supplier and the OEM to find consensus on the change of material requirements.
- Once consensus has arrived, the OEM can test the spare part with the new packaging and review if the requirements are satisfied. In a case where the requirements are not satisfied, the feedback will run on a loop, and changes in the material specification are done and then the solution is reviewed. In a case where the test is successful, the final decision is made and the changes will be made effective in the next possible production batch.

5. DISCUSSION

This chapter consists of discussions regarding the result derived from the case study. Apart from that the interesting topics such as the practicality to implement the framework the consensus in the AHP analysis as well as the decision making in packaging are included in this chapter.

5.1 Environmental Impacts of Packaging Alternatives

Referring to the Table 20, the environmental impacts derived from both the LCA and the AHP studies indicate that the alternative C, the packaging made from recycled paper with the blue color coating and FSC-certified, has a lower environmental impact in both quantitative and qualitative measurements than the alternative A, the corrugated box made from the virgin based fiber with the blue color coating and non-FSC-certified.

For the LCA results in Table 20, the environmental impacts of the alternative A are almost three times higher than the alternative C in the aspects of GWP, AP, and EP, whereas it is four times higher in POCP. Looking into the environmental impacts of alternative A in Table 22, more than 96% of the contribution is generated from paper productions, both Kraftliner and Semi-chemical fluting. Only 1 to 4% is caused by the corrugated box production process. This is also in line with resource consumption since paper production uses higher electricity, fossil fuel, water, chemicals, and additives than the corrugated box production. From this fact, it can signify that higher resource consumption can lead to higher emissions, which can consequentially increase the environmental burdens at the end. Similarly, this trend can be observed in the alternative C. The majority of emissions are also generated from the production of recycled paper - Testliner and Recycled fluting. The contribution from recycled paper production is varying from 84% to 94% depending on the impact categories, while it is about 6% to 13% of emission generated from the corrugated box. The contribution detail is provided in Table 23. Another important point that could be highlighted here is that the corrugated box production contributes more in the alternative C than A because the virgin based paper productions discharge more emissions than the recycled paper production.

From the fact that the higher emissions are generated from the paper production than the corrugated box production, it can indicate that the higher environmental impacts are generated in the upstream of the supply chain. This also affirms the statement in a sustainable supply chain, which states that many environmental are caused by suppliers further down in the upstream of the supply chain (Tachizawa & Wong, 2014). Therefore, to improve sustainability in the corrugated box supply chain, it is very important to strengthen the sustainability agenda with paper suppliers. From this fact, increasing the supply chain transparency by using materials that are certified by FSC can help to increase sustainability because this certification can ensure that the paper comes from the responsible sources.

Alternative A

Impact category	Unit	Impact per ton of corrugated box						
		Total	Paper production				Corrugated box production	%
			Kraftliner	%	Semi-chemical fluting	%		
GWP	kg CO_2 equiv	1,502.76	1,083.96	72%	368.79	25%	50.00	3%
AP	kg SO_2 equiv	1.207	0.657	54%	0.522	43%	0.028	2%
EP	kg P equiv	0.624	0.355	57%	0.241	39%	0.028	4%
POCP	kg Ethene equiv	0.098	0.062	63%	0.034	35%	0.001	1%

Table 22: Environmental impact contribution of each production - alternative A

Alternative C

Impact category	Unit	Impact per ton of corrugated box						
		Total	Paper production				Corrugated box production	%
			Testliner	%	Recycled fluting	%		
GWP	kg CO_2 equiv	392.85	230.83	59%	112.02	29%	50.00	13%
AP	kg SO_2 equiv	0.317	0.195	62%	0.094	30%	0.028	9%
EP	kg P equiv	0.179	0.102	57%	0.049	27%	0.028	16%
POCP	kg Ethene equiv	0.018	0.012	67%	0.006	33%	0.001	6%

Table 23: Environmental impact contribution of each production - alternative C

Comparing the emissions generated from the print liner/inside liner (Kraftliner or Testliner) and flute (Semi-chemical fluting or Recycled fluting), it can be observed that the print liner/inside liner production always has the higher environmental impacts than fluting production. This is because the quantity required for the print liner/inside liner is higher than the flute. As provided in Figure 20, the quantity required for print liner/inside liner is 0.741 ton, while it is only 0.359 ton for flute. From this higher paper consumption, it can lead to a higher environmental impact generated from the print liner/inside liner than the fluting productions.

In case the effect of higher quantity requirement of print liner/inside liner is disregarded and the environmental impacts per ton of paper are compared, the environmental impacts of Semi-chemical fluting of the alternative A are higher than Kraftliner in the categories of AP, EP, and POCP. On the contrary, Kraftliner has a higher impact on GWP. For the alternative C, The environmental impacts of Testliner and Recycled fluting are pretty much the same in all impact categories. This is because FEFCO applied the same data assumption for Testliner and Recycled fluting production. The detail of the environmental impact comparison of each paper is shown in Table 24.

Impact category	Unit	Impact per ton of paper			
		Alternative A		Alternative C	
		Kraftliner	Semi-chemical fluting	Testliner	Recycled fluting
GWP	kg CO_2 equiv	1,462.83	1,027.27	311.51	312.03
AP	kg SO_2 equiv	0.89	1.45	0.26	0.26
EP	kg P equiv	0.48	0.67	0.14	0.14
POCP	kg Ethene equiv	0.08	0.09	0.02	0.02

Table 24: Environmental impact comparison between different types of papers

In the respect of the AHP results, the alternative C has a better score than the alternative A. With this result, it can be marked that the alternative C is more environmentally sustainable than the alternative A. Digging into the packaging alternatives' performance respecting to the selected evaluation factors, both alternative A and C get an equal score for four out of five factors. Those factors are Compostability, Design for disassembly, Recyclability, and Selling unit cube efficiency (SUCE). The reason that makes A and C getting the same scores for Compostability, Design for disassembly, Recyclability is because the properties of the material of the corrugated box, either made from virgin based fiber or recycled paper, are the same. In terms of the SUCE of A and C, both alternatives of the corrugated box have a similar size, so the performance in this aspect is also the same. However, due to the assumption, which aims to compare between non-FSC-certified material (alternative A) and FSC-certified material (alternative C), this makes the alternative C gets a higher score than A. The alternative C is accordingly rated better in this aspect and it makes this alternative is more environmentally friendly than another one.

Even though, in this case, the AHP analysis does not distinguish the performance of the alternative A and C that much, it can be very useful when comparing the packaging which has different properties. For example, in case this AHP framework is used to compare the environmental impacts of plastic bags with paper boxes, this will be very much different in several aspects. The first one can be SUCE since the plastic bag will have a higher efficiency than a paper box. However, Compostability and Recyclability have to be thoroughly evaluated since some type of plastic bags cannot be composted and recycled. From this example, it at least shows that the scores of plastic bags and the paper box can be quantified differently, and it will make a good comparison for those types of packaging.

5.2 Consensus in AHP analysis

In the AHP analysis, five evaluation factors including Compostability, Design for disassembly, Recyclability, and Selling unit cube efficiency (SUCE) were selected to evaluate the performance of packaging alternatives. In this process, the pairwise comparison workshop was conducted to determine the weight score which will reflect the level of importance of each factor. According to the result of pairwise comparison in Table 16, it reveals that the most important factor is Design for disassembly, and it is followed by SUCE, Chain of custody, Recyclability, and Compostability as the less important factors in the decreasing order. Therefore, this is considered as the consensus generated from the workshop. The summary of this consensus is illustrated in Figure 36. This consensus was constructed based on the reasoning that, in case the packaging cannot be dissembled at the end of their life, it will provide no possibility to recycle or compost the packaging at the end of their life. Therefore, Design for disassembly is valued as one of the most critical factors by many participants. However, since SUCE and Chain of custody capture the other aspects of sustainability which are efficiency and supply chain transparency, it would be difficult tasks for participants to compare SUCE and Chain of custody with Design for disassembly. As a result, this could be one of the reasons that influence the high degree of inconsistency at the CR of 39.3% and it exceeds the acceptable criteria at 10%.

Result from the pairwise comparison

Design for dissassembly > Selling unit cube efficiency > Chain of custody > Recyclability > Compostability

Figure 36: Consensus from the pairwise comparison workshop

In order to fix the high CR, the first important step is to recheck the identified consensus in Figure 36 with the individual scores mentioned in Appendix D. From the individual rating, the result of the pairwise comparison can be constructed in three different groups. The first group is consistent pairs which all participants voted the same factor as a higher important factor (1). The second one is the inconsistent pairs, which two people voted equally important (2), and the third one has three people who voted equally important (3). The pairs' detail is provided in Figure 37. These three groups will be revalidated with the established consensus in Figure 36.

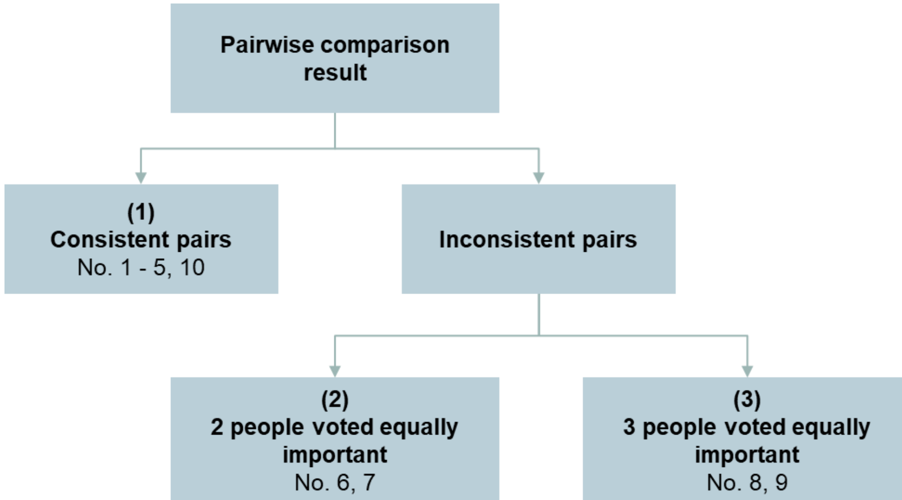


Figure 37: Pairwise comparison result - consistent and inconsistent pairs

Looking into the consistent pairs, the pairs no. 1 to 4 have consistent results where Design for disassembly, Recyclability, Chain of custody are rated as more important than Compostability. When these results combined with the outcome of pair no. 5, which Design for disassembly is considered as more important than Recyclability, it can be concluded that Design for disassembly is more important than Recyclability, and Recyclability is more important than Compostability. The combined result of the consistent pairs (1) is shown in Figure 38.

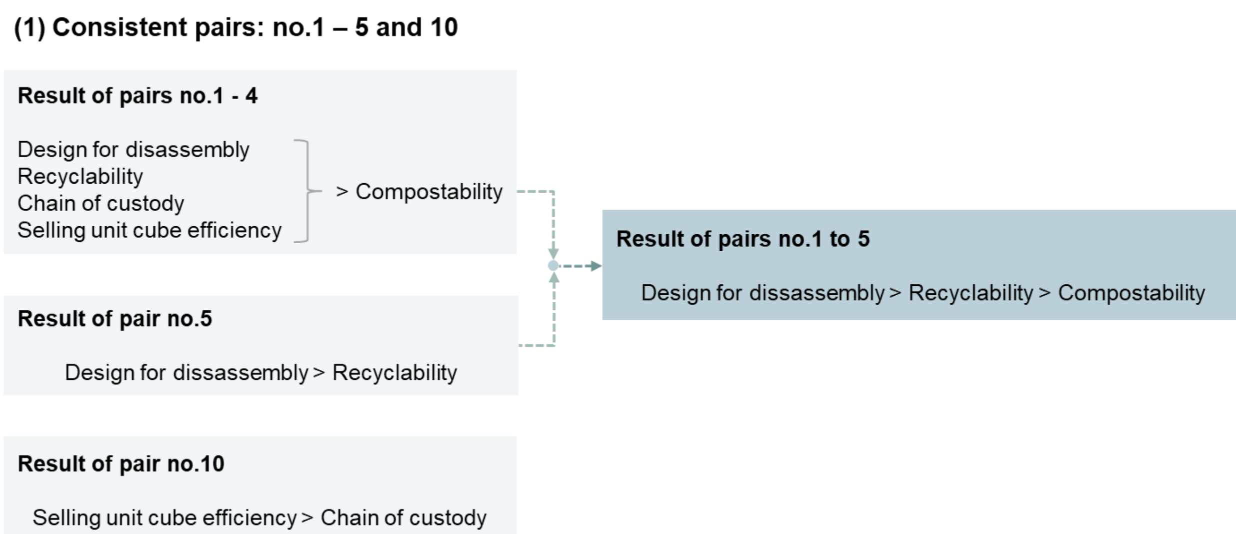


Figure 38: Combined result of the consistent pairs (1)

The next step is to integrate the result from consistent pairs with the inconsistent pairs where two people voted equally important (2). In this step, the result of consistent pairs will be consolidated with the result of pair no. 6 which indicates that Chain of custody is more important that Design for disassembly. As a consequence, the result of this integration can be concluded that Chain of custody is more important than Design for disassembly and it is following by Recyclability and Compostability. This result is shown in the flow no. 1 of Figure 39. Then, this result will be together combined with pairs no. 9 and 10 as illustrated in flow no. 2 of Figure 39. This can be summarized that SUCE is the most important factor, which is followed by Chain of custody, Design for disassembly, Recyclability, and Compostability as the less important factors. This result can be considered as a newly validated consensus, and it will be used to check with the rest inconsistent pairs no. 7, 8 (3). In case the results of either pair are conflict with this new consensus, it means that this pair may be the main source of the high inconsistency of CR

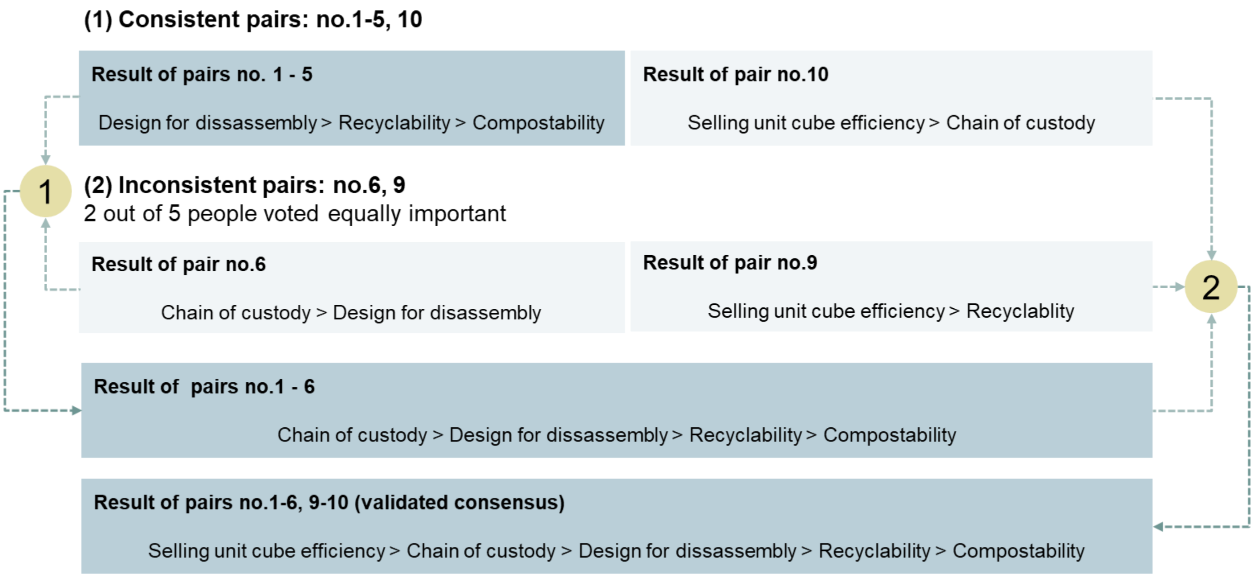


Figure 39: Combined result of the consistent pairs (1) and inconsistent pairs (2)

The result from the integration of the pairs no. 1-6 and 9-10 is checked with the inconsistent pair group (3). By validating the result with pairs no. 7 and 8, it indicates that the result of pair no. 8 also complies with the newly established consensus but pair no. 7 is a conflict as shown in Figure 40. Therefore, pair no. 7 is one of the causes of inconsistency in the AHP rating and this pair should be rerated so that the CR can be improved. In summary, after reviewing the individual score of participants, the newly validated consensus could be established and this consensus complies with the decisions of nine pairs. There is only one pair (no. 7) that does not align with this consensus. The next step is to calculate the new CR and weight score of the new consensus and observe the change.

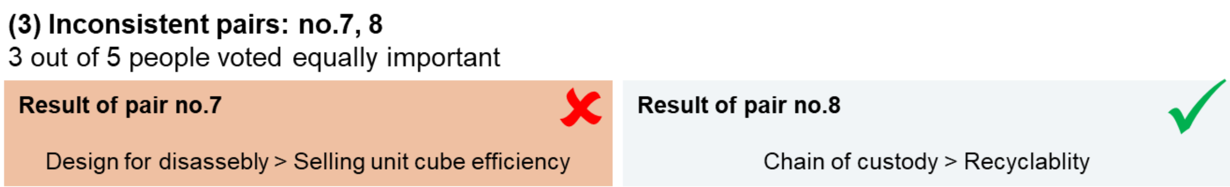


Figure 40: Validating new consensus with inconsistent pairs (3)

To simulate the case where the validated consensus is applicable and calculate new CR, the decision of pair no. 7 has to be changed to SUCE is more important than Design for disassembly. By adjusting the score of pair no. 7, it could be found that the CR can be reduced to 27% if everyone chooses SUCE is a more important factor than Design for disassembly at the score of three. The detail is shown in Table 25. This new CR is less than the previous CR at 39.3%, meaning that the degree of inconsistency and biases are reduced with the new validated consensus. The weight score from the new consensus is provided in Table 26.

Score	Consistency Ratio (CR)
1	28.5%
3	27%
5	29.5%

Table 25: CR of the new consensus

Evaluation factors	Weight score	
	Previous consensus	Validated consensus
Compostability	2%	3%
Design for disassembly	31%	21%
Recyclability	11%	12%
Chain of custody	26%	22%
Selling unit cube efficiency (SUCE)	30%	42%
Consistency Ratio (CR)	**39.3%**	**27%**

Table 26: Comparison of CR

Even though the improved CR can be observed with the newly validated consensus, it is still very important to review this newly established consensus with the participants. In case if everyone agrees to change, this new weight score can be used, otherwise, the pairwise comparison might have to be re-conducted again.

In respect of the CR at 27%, this high CR could be argued that it can undermine the AHP results since it still does not achieve the acceptance level at 10%. However, the AHP practitioners said that, based on the survey, many of AHP results end up having the CR ratio higher than 10%. The median value of CR is 16%, meaning that there are only half of the respondents who achieved the CR below 16%. The practitioners also added that, in some cases, the CR at 15% or up to 30% could be accepted depending on the number of selected evaluation factors (Business Performance Management Singapore, 2013). The reason behind this is that the higher CR could be observed if the number of considered factors increases. For this reason, it could be concluded that achieving CR at 10% is not compulsory in every project, and it is, therefore, possible to accept the CR at higher than 10% in some cases.

From this fact, it could be marked that the acceptable criteria of CR in practice are not fixed since it depends on the number of considered evaluation factors and the complexity of them. However, the acceptance level of CR could be based on the justification of the AHP practitioners to evaluate based on the complexity of the problem. Furthermore, calculating the CR should be considered as a guideline to address the level of inconsistency in the rating process, which the AHP practitioner can investigate and resolve this discrepancy to improve the AHP result.

5.3 Practicality to Implement the Selected Framework

The selected framework that is used to measure the environmental impact of commercial packaging, in this case, is the Multidimensional Environmental Evaluation framework which was developed by Huang & Ma (2004). The benefit of this framework is of providing a comprehensive view of environmental impacts measurement by considering both quantitative and qualitative aspects. Base on the original framework, three methods are adopted. The first tool is LCA which is used to quantify the environmental impacts from the quantitative information. The second one is AHP which handles the qualitative data such as the characteristics of materials. The last method is cluster analysis, which can be used to integrate the LCA and AHP results. However, this tool is not applied in this case because there are a few packaging alternatives to study the environmental impacts. Hence, it is not necessary to employ the cluster analysis. This is the difference between the original framework and the framework that is used in the case study.

Although the benefit of this framework is addressed, there are still limitations and difficulties to implement this framework in the organization. The first drawback of this framework is the difficulty to obtain the LCI data. This information is very crucial for the LCA study since the emissions addressed in this database will be quantified as the environmental burdens corresponding to the impact categories. However, many suppliers do not have the system to track and measure the emissions in their processes. This was also the problem that the students faced because FrontPac does not have the emission tracking system so that they cannot provide the data. From this fact, LCA practitioners mostly use the database that is developed from previous researches. Still, that information can provide in the general term, which requires some assumptions to adjust that database. This assumption and adjustment can impact the accuracy of the LCA results. Another difficulty still relates to the LCA part. Since one of the outcomes generated from the LCA study is the environmental problems, which are provided in scientific terms such as Global Warming Potential (GWP), Acidification Potential (AP), Eutrophication Potential (EP), Photochemical Ozone Creation Potential (POCP) and many more. These terms are sometimes not easy for non-LCA experts to understand. Therefore, it requires a certain expertise in the LCA study to process and interpret the result in the right way. This problem also concerns the audiences of the LCA results. In some cases, the main audiences of LCA results are high-level managers. Showing the results in terms of AP, EP, or particulate matters might create confusion for them. Therefore, this issue does not only relate to the people who conduct LCA but also the main audiences of the LCA result (Meijer, 2014). With these two difficulties, most of the organizations outsource the LCA tasks to the consultants who have experience in conducting LCA. In addition, these external parties can also review and certify the LCA results, which compile with ISO 14001:2004 as to disclose the results publicly.

Apart from the complications in the LCA study, fixing the inconsistency in the AHP can be considered as a difficult task. As per the case where five evaluation factors are selected, some of the factors can be conducted a pairwise comparison easily. For example, Compostability, Design for disassembly, and Recyclability which the participants have the common view that Design for disassembly is the most important one comparing to another two. However, when these three are compared with SUCE or Chain of custody, it can create confusion since these two factors address different topics in sustainability. With this fact, some participants might have different views and opinions depending on their role in the supply chain. For example, the recycling company might value Recyclability more than SUCE since it is their main task to handle wastes. On the contrary, the focal company like Volvo might perceive SUCE as the more important factor since it can reduce resource consumptions which can help the organization to decrease costs. On the one hand, these diversities in the opinions are advantageous for the discussion. On the other hand, if the participants cannot find a consensus, it can create the inconsistency and biases in the rating process of AHP and this will lead to a high CR which was also experienced in the case study. Referring to the AHP theory, the acceptable CR is 10%. However, to achieve this target, it also depends on the complexity of the selected evaluation factors. To illustrate, 10% might be easily accomplished if the less complex factors such as Compostability, Design for disassembly, and Recyclability are compared, and it might show the opposite result when comparing the more complex factors. As a consequence, Business Performance Management Singapore (2013) mentioned that more than 10% of CR can also be acceptable and it depends on the problem and objective of the projects. From this aspect, it can be noted that AHP is a process to determine the weight scores of different factors. The calculated CR can be used as an indicator for the practitioners to acknowledge the inconsistency in the rating process. It can also work as a guideline to improve the AHP results by reducing the CR, but it is not considered as a major hindrance to implementing the AHP.

From the complications to implementing the framework mentioned above, it might require a lot of time and effort to gather information and obtain the results. Apart from that, the decision making of commercial packaging selection at Volvo is sometimes a speedy process, so applying the full multidimensional framework might not be applicable in every case. From this fact, the selected framework could be reconstructed base on the ease of use, which the company can choose to use the different levels of framework base on and the complexity of the commercial packaging selection problem. This multidimensional framework can be reorganized into four different levels as provided in Table 27.

The first level is suitable when the problem is not complex and it requires quick decision making. The applicable framework to measure the environmental impacts, in this case, can be solely based on selected evaluation factors. The evaluator just checks whether the packaging complies with established criteria or not. The pairwise comparison and LCA study are not required in this situation since it will consume a lot of time. Examples of cases to apply the 1st level framework include comparing the environmental impacts of paper boxes which are made from materials with and without source-certified or comparing paper boxes with paper bags.

The second level is applicable to a more complex situation than the previous one, in which the characteristics of materials are different in several aspects. Considering this constraint, it is necessary to include a pairwise comparison to determine the weight scores, which can be handled the various facets addressing by different evaluation factors. An example to apply this 2nd level framework is to compare the environmental burdens of plastic bags with corrugated boxes. Another possible case could apply when analyzing the packaging which consists of several types of materials, which can cause difficulties in composting or recycling processes. Moreover, since

LCA is still not used in this level, some evaluation factors which address similar aspect as the LCA study such as resource consumption (total material inputs) or toxicants can also be applied. However, these newly added factors are optional depending on data availability which the company can acquire.

The third and fourth levels are the most complex choices, and the results of this study are aimed to be disclosed publicly such as sustainability reports. Since the packaging alternatives are very complex, the full multidimensional framework which consists of both LCA and AHP is required. As to use the LCA, the company can either conduct the LCA by themselves and have a third party to verify the results or outsource the LCA study to the consultants. The difference between the third and fourth frameworks is the level of LCA that is aimed to study. The third option is the easier option since the LCA study is based on the generic database that is available from the previous research. The fourth option is a full LCA which the company aims to conduct LCA in a specific case in which the LCI has to be gathered directly from the primary data sources. In this case, the fourth option will take a longer time and effort to complete.

Level	**Complexity of the problem**	**LCA**	**AHP**	
			Pairwise comparison	**Evaluation factors**
1	Low	✗	✗	• Compostability • Design for disassembly • Recyclability • Chain of custody • Selling unit cube efficiency
2	Medium	✗	✓	• Compostability • Design for disassembly • Recyclability • Chain of custody • Selling unit cube efficiency • Total material inputs (optional) • Toxicant concentration (optional)
3	High	✓ (generic database)	✓	• Compostability • Design for disassembly • Recyclability • Chain of custody • Selling unit cube efficiency
4	High	✓ (full LCA)	✓	• Compostability • Design for disassembly • Recyclability • Chain of custody • Selling unit cube efficiency

Table 27: Four ways of implementing the framework

5.4 Packaging Decision Process

The primary challenge in the selection of environmentally friendly materials is to prioritize the important issues and not just focusing on the products (Verghese & Hes, 2007). There is a complexity added to this prioritization. For a single product, every relevant stakeholder in the supply chain would have different opinions and this becomes trickier when all these stakeholders are put together in a single table for a consensus-based decision making. In this thesis' case study, while doing a pairwise comparison, it was evident through the inconsistent pairs as mentioned in section 5.2 that it is natural to have different views and understanding the participant's standpoint and priorities are crucial to be able to make a decision.

According to Hafte (n.d.), reaching consensus requires a powerful process of investing time in creating a plan, understanding each parties' priorities, and then sharing each other's views drawing towards a common conclusion. Such decision-making practice results in an effective implementation as it would be an informed decision made across the supply chain. Likewise, in the case study, the pairwise comparison that is conducted for the evaluation factors of packaging, amidst different party choosing different evaluation factor as their priority on a few cases, it was concluded that using recycled material is a better option in terms of the environmental sustainability with lesser emissions, reusing of the paper, etc., Decision-makers at Volvo are currently working on other aspects cost analysis, change of routine in the supply chain (order change, process change in the supplier site, etc.,) to bring a change to a number of different parts along with Main Bearing kit. And so, the decision-making process was also explored and the integration of this framework into the existing system is studied to get a better understanding of how a change in the decision-making process could look like that enables such decisions based on environmental sustainability. This gives credibility to AHP and pairwise comparison and that it helps in increasing the competitiveness of the supply chain. For example, a change in the requirement of packaging solutions from Volvo would mean that the packaging supplier is expected to do a significant change in their production schedule. This pushes the supplier to prove their worth to such a big player like Volvo and remain competitive in the market.

One step before implementing the framework proposed in this study is to have a discussion internally within Volvo between the marketing department and the packaging engineers where they discuss to reformulate their packaging requirements considering environmental sustainability. Through this thesis experience, it is expected that there will be a lot of trade-offs in the process of choosing a more environmentally friendly solution, for example, choosing a box without a blue coating would be environmentally friendly compared to a box with blue coating as there will be no chemicals involved in the production process. But this would mean that Volvo would not be able to market their products with the authentic blue box. If companies face such challenges finding a consensus internally to make an environmentally friendly solution and branding requirements being the barrier, perhaps there needs to be actions taken to make sustainable branding as practice.

6. CONCLUSION

This thesis was initiated based on the requirements of SML to incorporate the environmental aspects in the decision-making process of the commercial packaging selection. From this demand, the main aim of this thesis is to develop a framework to measure the environmental impacts as well as to conduct a case study to test the established framework. In this thesis, the Multidimensional Environmental Evaluation framework which was developed by Huang & Ma (2004) was chosen to measure the environmental impacts since it can provide a comprehensive view of environmental impact assessment, which covers both quantitative and qualitative aspects. To handle both perspectives, LCA is employed to process and analyze the quantitative information, whereas AHP is used to address the qualitative evaluation. In the case study, the Volvo corrugated blue box used for packing the main bearing kits was selected as the alternatives to studying the environmental impacts. At first, four alternatives of packaging were identified based on the interests of the company. However, since the packaging supplier could not provide the data related to emissions of the color coating process, only alternative A and C could be studied the environmental impacts. The system boundary of this case focuses on the upstream of the corrugated box supply chain, which is the paper production processes and corrugated box production process.

Regarding the results derived from the case study, it could be divided into two parts which are LCA and AHP results. In summary, both LCA and AHP results indicate that the alternative C, which is the corrugated box made from recycled paper, with blue color coating and FSC-certified has a lower environmental impact than the alternative A, which is the corrugated box made from virgin fiber-based paper, with blue color coating and non-FSC-certified. For the LCA study, the results are displayed in four environmental impacts categories – Global Warming Potential (GWP), Acidification Potential (AP), Eutrophication Potential (EP), and Photochemical Ozone Creation Potential (POCP). The results of these four impact categories illustrate that the alternative C has a lower environmental impact than the alternative A. This is because the paper production of the alternative A consumes higher resources than the recycled paper production of the alternative C. With these higher resource consumption of the alternative A, it will generate higher emissions, which can cause higher environmental burdens. Similarly, the AHP result also shows that alternative C is more environmentally sustainable than A since C is derived from materials, which have FSC-certified, while A is none.

Another interesting fact that is gained from the case study is regarding the consensus in the AHP study. In the AHP process, five evaluation factors including Compostability, Design for disassembly, Recyclability, Chain of custody, and Selling unit cube efficiency (SUCE) was selected to assess the performance of the identified packaging alternatives. The result of the pairwise comparison workshop shows that Design for disassembly is considered as the most important factor, whereas Compostability is the least important one. However, the calculated consistency ratio (CR) is 39.3% which is higher than the acceptance criteria at 10%. This is due to the different opinions of the stakeholders. To improve such CR, the individual rating of each participant was checked. The result from this validation indicates that the most important factor is

SUCE, while Compostability remains as the least important one. The new CR of this new consensus is 27%, which is improved from the previous consensus for 12%.

Apart from the results of the LCA and AHP studies are evaluated, the practicality of the Multidimensional Environmental Evaluation framework is also discussed. Even though this framework has a great benefit in terms of presenting the comprehensive view of the environmental impacts measurement, there still are limitations in terms of the LCI data access, and it requires LCA expertise to analyze and interpret the LCA results. Besides, the high CR is sometimes can be observed in the AHP study, and fixing such high CR could be considered as a difficult task. With this fact, it can indicate that implementing the full framework might be applicable in every case. Therefore, this framework is reconstructed into four different levels based on the complexity of the problem. In case the problem is less complex such as comparing the environmental impacts of two types of paper boards, using only the evaluation factors could also deliver the result. If the problem is more complex such as comparing the packaging which has different characteristics, the pairwise comparison is required since it has to determine the level of importance of different factors. In the most complex situation, the full framework which consists of both LCA and AHP approaches is adopted so that it can handle both quantitative and qualitative aspects of the measurement. However, the level of adopted LCA could be depending on the source of the LCI database, whether it is from generic or primary data sources.

As this is the first project on environmental sustainability in SML at Volvo, the implementation of the framework in real-time was also focused. Hence, to do that, the current packaging decision model is evaluated and presented in a generic way leaving out the confidential information. Then, a new decision model is suggested where the company would be able to assess their current stance on environmental sustainability and how the branding requirements be an obstacle in achieving an environmentally friendly packaging solution. The new method also implements the framework of this thesis of doing an LCA and AHP and building dialogues with the stakeholders to co-create a packaging decision through achieving consensus. The practicality is well received from Volvo and the framework is expected to be implemented in real-time any time soon.

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APPENDIX

Appendix A

These terms and definitions are taken from ISO 14040:2006

3.1 Life Cycle

Consecutive and interlinked stages of a product system, from raw material acquisition or generation from natural resources to final disposal

3.2 Life Cycle Assessment

Compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its life cycle

3.3 Life Cycle Inventory Analysis

Phase of life cycle assessment involving the compilation and quantification of inputs and outputs for a product throughout its life cycle

3.4 Life Cycle Impact Assessment

Phase of life cycle assessment aimed at understanding and evaluating the magnitude and significance of the potential environmental impacts for a product system throughout the life cycle of the product

3.5 Life Cycle Interpretation

Phase of life cycle assessment in which the findings of either the inventory analysis or the impact assessment, or both, are evaluated in relation to the defined goal and scope in order to reach conclusions and recommendations

3.6 Comparative Assertion

Environmental claim regarding the superiority or equivalence of one product versus a competing product that performs the same function

3.7 Transparency

Open, comprehensive and understandable presentation of information

3.8 Environmental Aspect

Element of an organization's activities, products or services that can interact with the environment

3.9 Product

Any goods or service

The product can be categorized as follows:

–services (e.g. transport);

–software (e.g. computer program, dictionary);

–hardware (e.g. engine mechanical part);

–processed materials (e.g. lubricant);

Services have tangible and intangible elements. Provision of a service can involve, for example, the following:

–an activity performed on a customer-supplied tangible product (e.g. automobile to be repaired);

–an activity performed on a customer-supplied intangible product (e.g. the income statement needed to prepare a tax return);

–the delivery of an intangible product (e.g. the delivery of information in the context of knowledge transmission);

–the creation of ambience for the customer (e.g. in hotels and restaurants).

Software consists of information and is generally intangible and can be in the form of approaches, transactions or procedures.

Hardware is generally tangible and its amount is a countable characteristic. Processed materials are generally tangible and their amount is a continuous characteristic.

3.10 Co-product

Any of two or more products coming from the same unit process or product system

3.11 Process

Set of interrelated or interacting activities that transforms inputs into outputs

3.12 Elementary flow

Material or energy entering the system being studied that has been drawn from the environment without previous human transformation, or material or energy leaving the system being studied that is released into the environment without subsequent human transformation

3.13 Energy flow

Input to or output from a unit process or product system, quantified in energy units

Energy flow that is an input may be called an energy input; energy flow that is an output may be called an energy output.

3.14 Feedstock energy

Heat of combustion of a raw material input that is not used as an energy source to a product system, expressed in terms of higher heating value or lower heating value

3.15 Raw Material

Primary or secondary material that is used to produce a product. Secondary material includes recycled material.

3.16 Ancillary input

Material input that is used by the unit process producing the product, but does not constitute part of the product

3.17 Allocation

Partitioning the input or output flows of a process or a product system between the product system under study and one or more other product systems

3.18 Cut-off criteria

Specification of the amount of material or energy flow or the level of environmental significance associated with unit processes or product system to be excluded from a study

3.19 Data Quality

Characteristics of data that relate to their ability to satisfy stated requirements

3.20 Functional unit

Quantified performance of a product system for use as a reference unit

3.21 Input

Product, material or energy flow that enters a unit process. Products and materials include raw materials, intermediate products and co-products.

3.22 Intermediate flow

Product, material or energy flow occurring between unit processes of the product system being studied

3.23 Intermediate product

Output from a unit process that is input to other unit processes that require further transformation within the system

3.24 Life Cycle Inventory analysis result - LCI result

Outcome of a life cycle inventory analysis that catalogues the flows crossing the system boundary and provides the starting point for life cycle impact assessment

3.25 Output

Product, material or energy flow that leaves a unit process. Products and materials include raw materials, intermediate products, co-products, and releases.

3.26 Process energy

Energy input required for operating the process or equipment within a unit process, excluding energy inputs for production and delivery of the energy itself

3.27 Product flow

Products entering from or leaving to another product system

3.28 Product system

Collection of unit processes with elementary and product flows, performing one or more defined functions, and which models the life cycle of a product

3.29 Reference flow

Measure of the outputs from processes in a given product system required to fulfil the function expressed by the functional unit

3.30 Releases

Emissions to air and discharges to water and soil

3.31 Sensitivity analysis

Systematic procedures for estimating the effects of the choices made regarding methods and data on the outcome of a study

3.32 System boundary

A set of criteria specifying which unit processes are part of a product system

NOTE: The term “system boundary” is not used in this International Standard in relation to LCIA.

3.33 Uncertainty analysis

Systematic procedure to quantify the uncertainty introduced in the results of a life cycle inventory analysis due to the cumulative effects of model imprecision, input uncertainty and data variability

3.34 Unit process

Smallest element considered in the life cycle inventory analysis for which input and output data are quantified

3.35 Waste

Substances or objects which the holder intends or is required to dispose of

NOTE: The definition is taken from the *Basel Convention on the Control of Transboundary Movements of Hazardous*

Wastes and Their Disposal (22 March 1989) but is not confined in this International Standard to hazardous waste.

3.36 Category endpoint

Attribute or aspect of natural environment, human health, or resources, identifying an environmental issue giving cause for concern

3.37 Characterization factor

Factor derived from a characterization model which is applied to convert an assigned life cycle inventory analysis result to the common unit of the category indicator. The common unit allows calculation of the category indicator result.

3.38 Environmental mechanism

System of physical, chemical and biological processes for a given impact category, linking the life cycle inventory analysis results to category indicators and to category endpoints

3.39 Impact category

Class representing environmental issues of concern to which life cycle inventory analysis results may be assigned

3.40 Impact Category Indicator

Quantifiable representation of an impact category

NOTE: The shorter expression "category indicator" is used in this International Standard for improved readability.

3.41 Completeness check

Process of verifying whether information from the phases of a life cycle assessment is sufficient for reaching conclusions in accordance with the goal and scope definition

3.42 Consistency check

Process of verifying that the assumptions, methods and data are consistently applied throughout the study and are in accordance with the goal and scope definition performed before conclusions are reached

3.43 Sensitivity check

Process of verifying that the information obtained from a sensitivity analysis is relevant for reaching the conclusions and giving recommendations

3.44 Evaluation

Element within the life cycle interpretation phase intended to establish confidence in the results of the life cycle assessment

NOTE: Evaluation includes completeness check, sensitivity check, consistency check, and any other validation that may be required according to the goal and scope definition of the study

3.45 Critical review

Process intended to ensure consistency between a life cycle assessment and the principles and requirements of the International Standards on life cycle assessment

NOTE 1 The principles are described in ISO 14040:2006, 4.1.

NOTE 2 The requirements are described in this International Standard.

3.46 Interested party

Individual or group concerned with or affected by the environmental performance of a product system, or by the results of the life cycle assessment

Appendix B

Questions list to Tenneco (Spare Part Supplier)

- Could you explain the packaging processes? Starting from getting a spare part until it finishes
- What are the resources used in the packing process? For example, electricity, water, etc.
- What are the raw material sourcing (supplier)?
- Could you explain the transport process from your company to the CDC?
- What is the transportation mode you use? What is the source of energy used for such transportation activity?
- How much waste do you have in your packing process? (in percent)
- How do you handle such packaging waste? What is your waste management practice which you are adopting?
- How do you manage the inventory? What is the storage condition of finished goods? Is there any damage in this process? If so, how much in percent?
- Do you measure emissions within the factory? Do you keep track of carbon footprint? Any partnerships with a recycling company?
- Do you have any relationship with the packaging supplier (Andra Pak and FrontPac)?
- Resource allocation for different processes

Questions to FrontPac (Packaging supplier) – 1st interview

- Could you explain about the production processes of blue boxes? Starting from raw material receiving until you send it to Tenneco.
- What are the resources used in the packing process? For example, electricity, water, etc.
- Could you explain the transport process from FrontPac to the Tenneco?
- How much waste do you have in your production process? (in percent)
- Do you measure emissions within the factory? Do you keep track of carbon footprint?
- Do you have any certification such as FSC for your cardboard?
- We know that you have grass fiber packaging which is considered as a more sustainable packaging solution. What are the differences between grass fiber packaging and a blue box?
- Do you work with any recycling company? Any attempts towards sustainability/circular economy?
- What are the raw material sourcing (supplier)?

- How do you manage the inventory? What is the storage condition of finished goods? Is there any damage in this process? If yes, how much in percent?
- Resource allocation for different processes
- Do you have any relationship with the packaging supplier (Andra Pak and FrontPac)?

Life Cycle Inventory Questionnaire to FrontPac

Please fill in the information only in this box color		
Focused product	Corrugated blue box no. F0346107	
Product	**Produced amount/year**	**Unit**
Total corrugated blue box no. F0346107		
Total volume		
%Allocation		
Resource consumption		
Raw materials	**Amount/year**	**Unit**
Inside		
Flute		
Outside		
Energy consumption	**Total usage/year**	**Unit**
Electricity		
Steam		
Compress air		
	Total usage/year	**Unit**
Water consumption		
Energy consumption for internal transportation	**Total usage/year**	**Unit**
Fossil fuels		
Natural gas		
Heavy fuel oil		
Light fuel oil		
Diesel oil		
LPG		
Coal		
Renewable fuels		
Biofuel (bark, scrap wood, tall oil)		
Process chemical and addictive	**Total usage/year**	**Unit**
Alum (Al2(SO4)3		
Biocides		
Borax		
CaCO3		
CaO		
Coagulant		

Colorants		
CO2		
Defoamer		
Fillers		
Glue, cold + hot melts		
H2O2, peroxide		
H2SO4		
Water based ink for flexo printing		
Varnish for printing		
Ligno sulphonate		
Lubricants		
MgO		
NaClO3		
Na2CO3 (soda)		
NaOH		
NH3		
Oxygen, O2		
PAC (polyaluminiumclorid)		
Pitch despergents		
Polymer and retention agents		
S		
Sizing agents		
SO2		
Starch, corn		
Starch, potato		
Starch, wheat		
Starch, modified		
Aluminium hydroxside		

Emission

Emission to Air	**Total emission/year**	**Unit**
Dust		
Particulates, < 2.5 um		
Particulates, > 2.5 um, and < 10um		
Particulates, > 10 um		
CO2		
CO		
NOx (as NO2)		
SOx (as SO2)		
TRS (H2S as S)		
VOCs		

Emission to Water	Total emission/year	Unit
COD		
BOD 5		
TOC		
Suspended solids		
Total Nitrogen		
AOX		
Total Phosphorus		
Chloride		
Fats and oils (Ellram, 1996)		
Sulfate		

Residue waste	Total emission/year	Unit
Ink residues		
Inorganic sludges		
Organic sludges		
Paper for recycling		
Rejects, paper related		
Rejects, other		
Starch, glue		
Lubricants and oil		

Questions to FrontPac – 2nd interview during supplier site visit

- Comparing between corrugated boxes made from virgin materials and recycle materials, what is the option that has a better quality for product protection?
- Do you think that using corrugated boxes made from recycled materials instead of a virgin one is safe enough for product protection (main bearing kits)?
- Does FrontPac conduct any testing regarding product protection? Ex. drop test or transportation test, label adherence
- What is the maximum weight in which the current blue box can accommodate?
- What is the maximum weight in which the blue box made from recycled materials can accommodate?
- Is that current blue box fully compostable or partially compostable?
- Is that the blue box made from 100% virgin materials?
- How much recycled content of the corrugated box made by recycled materials?
- We know that, for some type of materials, the recycled content varies depending on the availability of recycled materials supply, does the availability of recycled paper affect the recycled content?

- Comparing between producing corrugated boxes from recycled materials and virgin materials, what is the option that consumes higher energy?
- Comparing between producing corrugated boxes from recycled materials and virgin materials, what is the option that consumes higher water?

Questions to Volvo Central Distribution Center (CDC)

- Could you explain the process once you receiving the parts from Tennecco until you dispatch?
- What is the packaging configuration for Bäckebol dealer?
- What is the transportation mode do you use to send the spare part from CDC to the dealer in Bäckebol, Gothenburg? Which transportation company do they use?
- Do they measure emission within the warehouse and outbound transportation?
- Do you have information about electricity consumption and energy consumption used for warehouse operations?
- How do you manage inventory? Do you have any case of damage due to improper packaging?

Appendix C

LCA Database from FEFCO

		Semichemical Fluting	Kraftliner	Wellenstoff	Testliner	Corrugated Board
PRODUCT	tonne net saleable product	1	1	1	1	1
Sold by products						
Bark/wood	kg/t	0,00	3,51	0	0	0
Tall oil	kg/t	5,93	18,10	0	0	0
Turpentine	kg/t	0,58	1,30	0	0	0
RAW MATERIAL						
Wood consumption		*as bone dry weight (= 45% of tranported total wet weight)*				
Softwood logs	t/t	0	0,86	0	0	0
Hardwood logs	t/t	0,83	0,14	0	0	0
Saw mill residues, softwood	t/t	0	0,11	0	0	0
Saw mill residues, hardwood	t/t	0,07	0	0	0	0
Total wood	*t/t*	*0,907*	*1,112*	*0*	*0*	*0*
Recovered Paper	*as wet weight*	0,0978	0,3640	1,08	1,08	0
Category						
Mixed Grades	t/t	0,0104	0,14	0,588	0,588	0
Corrugated and Kraft, pre-consumer	t/t	0,0338	0,036	0,1046	0,1046	0
Corrugated and Kraft, post-consumer	t/t	0,0532	0,18	0,343	0,343	0
Newspaper and Magazines	t/t	0	0	0,001	0,001	0
Other grades	t/t	0,0004	0,0012	0,0437	0,0437	0
Purchased pulp consumption	*as bone dry weight*					
Bleached pulp	t/t	0	0,0140	0,0007	0,0007	0
Unbleached pulp	t/t	0	0,0005	0,0002	0,0002	0
Other pulp	t/t	0,0006	0	0,0025	0,0025	
Paper consumption for corrugated board production						
Total	t/t	0	0	0	0	1,1
Cores	kg/t	2,9*	1,6*	2,2*	2,2*	0
Core plugs	kg/t	0,045*	0,064*	0,04*	0,04*	0

		Semichemical Fluting	Kraftliner	Wellenstoff	Testliner	Corrugated Board
TRANSPORT OF RAW MATERIALS						
Wood						
Wood with truck	t*km	580	407	0	0	0
Wood with rail	t*km	6	387	0	0	0
Wood with boat	t*km	0	1235	0	0	0
Recovered paper						
Recovered paper with truck	t*km	15	86	349	349	0
Recovered paper with rail	t*km	0	86	6	6	0
Recovered paper with boat	t*km	0	32	28	28	0
Paper to corrugated board plants						
Paper with truck	t*km	0	0	0	0	456
Paper with rail	t*km	0	0	0	0	326
Paper with boat	t*km	0	0	0	0	1733
ENERGY INPUTS						
Steam	GJ/t	0	0	0,482	0,482	0,026
Bought Electricity	GJ/t	0,731	0,958	0,625	0,625	0,460
Fossil fuels						
Natural gas	GJ/t	0,086	1,004	3,83	3,83	0,81
Heavy fuel oil	GJ/t	0,1897	0,168	0,0012	0,0012	0,015
Light fuel oil	GJ/t	0,0186	0,079	0,0076	0,0076	0,014
Diesel oil	GJ/t	0,0096	0,022	0,0006	0,0006	0,0099
LPG	GJ/t	0	0,105	0	0	0,035
Coal	GJ/t	0,3762	0,388	0,469	0,469	0,015
Lignite	GJ/t	0	0	0,089	0,089	0
Sulphur	GJ/t	0	0	0	0	0
Peat	GJ/t	2,43	0,005	0	0	0
Total fossil fuel	*GJ/t*	*3,107*	*1,77*	*4,39*	*4,39*	*0,899*
Renewable fuels						
Biofuel (bark, scrap wood, tall oil)	GJ/t	2,016	2,991	0,160	0,160	0,011
Total renewable fuel	*GJ/t*	*2,016*	*2,991*	*0,160*	*0,160*	*0,011*
Refuse Derived Fuel	GJ/t	0	0	0,18	0,18	0
*Total fuel***	*GJ/t*	*5,12*	*4,76*	*4,55*	*4,55*	*0,91*

		Semichemical Fluting	Kraftliner	Wellenstoff	Testliner	Corrugated Board
WATER						
Input total	*m3/t*	*36,81*	*36,02*	*6,14*	*6,14*	*0,32*
Ground water fossil/non-renewable	m3/t	0	0	1,19	1,19	0,016
Ground water non fossil/ renewable		0	0,23	1,85	1,85	0,095
Surface water	m3/t	36,81	35,49	2,63	2,63	0,092
Municipal water supply	m3/t	0	0	0,42	0,42	0,28
Rain water		0	0,044	0,024	0,024	0
Other water recieved		0	0,253	0,025	0,025	0,0003
Water input-output		0,63	1,15	0,67	0,67	0,22
PROCESS CHEMICALS AND ADDITIVES, DRY MASS						
Alum (Al2(SO4)3	kg/t	1,67	3,02	0,059	0,059	0
Biocides	kg/t	0,0006	0,099	0,146	0,146	0
Borax	kg/t	0	0	0	0	0,14
CaCO3	kg/t	0	4,82	0,365	0,365	0
CaO	kg/t	0,908	3,82	0	0	0
Coagulant	kg/t	0	0	0	0	0
Colorants	kg/t	0	0,825	0,63	0,63	0
CO2	kg/t	0	2,75	0,048	0,048	0
Defoamer	kg/t	0,016	0,205	0,267	0,267	0
Fillers	kg/t	0	8,23	1,72	1,72	0
Glue, cold + hot melts	kg/t	0	0	0	0	0,65
H2O2, peroxide	kg/t	0	2,49	0,0127	0,0127	0
H2SO4	kg/t	0,25	9,11	0,0133	0,0133	0
Water based ink for flexo printing	kg/t	0	0	0	0	1,82
Varnish for printing	kg/t	0	0	0	0	0,61
Ligno sulphonate	kg/t	0	0	0,67	0,67	0
Lubricants	kg/t	0	0,07	0,08	0,08	0
MgO	kg/t	1,11	0	0	0	0
NaClO3	kg/t	0	0	0,0224	0,0224	0
Na2CO3 (soda)	kg/t	12,37	0	0	0	0
NaOH	kg/t	7,08	7,37	0,49	0,49	0,4
NH3	kg/t	12,32	0,119	0,035	0,035	0
Oxygen, O2	kg/t	0	1,56	0	0	0
PAC (polyaluminiumclorid)	kg/t	0	0	0	0	0
Pitch despergents	kg/t	0	0,078	0,294	0,294	0
Polymer and retention agents	kg/t	0,0096	1,096	0,947	0,947	0
S	kg/t	4,69	0	0	0	0
Sizing agents	kg/t	0,034	0,707	2,41	2,41	0
SO2	kg/t	0,04	0	0	0	0

		Semichemical Fluting	Kraftliner	Wellenstoff	Testliner	Corrugated Board
Starch, corn	kg/t	0	2,48	18,55	18,55	10,50
Starch, potato	kg/t	0	0,99	0,0087	0,0087	0,02
Starch, wheat	kg/t	0	4,27	30,55	30,55	1,98
Starch, modified	kg/t	0	3,57	0,427	0,427	2,64
PACKAGING MATERIALS						
not updated for paper production						
Pallet	kg/t	0	0	0,01	0,01	na
Paper, board	kg/t	2,6	0,19	0	0	7,5
PE	kg/t	0,006	0	0,015	0,015	0,67
Strapping	kg/t	0	0	0	0	0,48
EMISSIONS TO AIR						
Dust	kg/t	0,163	0,089	0,004	0,004	
Particulates, < 2.5 µm	kg/t	na	na	na	na	0,001
Particulates, > 2.5 µm, and < 10µm	kg/t	na	na	na	na	0,0004
Particulates, > 10 µm	kg/t	na	na	na	na	0,0003
CO_2 (fossil)	kg/t	314,52	115,10	280,17	280,17	50
CO_2 (biomass)	kg/t	711,61	1351,28	31,56	31,56	0
CO	kg/t	1,10	1,53	0,08	0,08	0,003
NO_x (as NO_2)	kg/t	1,37	1,02	0,36	0,36	0,02
SO_x (as SO_2)	kg/t	0,566	0,293	0,069	0,069	0,015
TRS (H_2S as S)	kg/t	0,055	0,016	0	0	0
EMISSIONS TO WATER						
Water output	*m³/t*					
Thermally polluted	m3/t	14,48	14,63	0,33	0,33	0,024
Process water after treatment	m3/t	15,88	20,20	5,26	5,26	0,18
Total	*m³/t*	*30,35*	*34,83*	*5,68*	*5,68*	*0,20*
Waterborne emissions						
COD	kg/t	5,05	5,60	0,88	0,88	0,01
BOD 5	kg/t	0,245	2,066	0,246	0,246	0,003
TOC	kg/t	2,14	2,099	0,417	0,417	na
Suspended solids	kg/t	0,312	1,118	0,430	0,430	na
Total Nitrogen	kg/t	0,554	0,129	0,064	0,064	0,033
AOX	kg/t	na	0	0,0006	0,0006	na
Total Phosphorus	kg/t	0,008	0,015	0,0065	0,0065	0,0037
As *	kg/t	na	0	0	0	na
Cu *	kg/t	na	0	0	0	na
Cr *	kg/t	na	0	0,0001	0,0001	na
Hg *	kg/t	na	0	0	0	na
Ni *	kg/t	na	0	0	0	na

			Semichemical Fluting	Kraftliner	Wellenstoff	Testliner	Corrugated Board
Pb	*	kg/t	na	0	0	0	na
Zinc	*	kg/t	na	0	0,0001	0,0001	na
pH (year average)		pH	7,10	7,46	7,81	7,81	na
Temperature (year average)		oC	na	na	na	na	na
RESIDUES, WET MASS	*dry content*						
Calcium Carbonate	75%	kg/t	0,007	8,206	0	0	0
Ink residues	50%	kg/t	0	0	0	0	0,44
Inorganic ashes (10 01 01)	80%	kg/t	2,04	17,65	3,99	3,99	0
Inorganic sludges	65%	kg/t	1,35	5,39	0	0	0
Organic sludges	35%	kg/t	36,12	3,08	64,53	64,53	1,67
Paper for recycling	90%	kg/t	0	0	0	0	147
Rejects, paper related (03 03 07)	50%	kg/t	3,52	5,76	23,16	23,16	0
Rejects, other (03 03 07)	50%	kg/t	7,05	11,52	46,32	46,32	0
Starch, glue	30%	kg/t	0	0	0	0	0,02
Lubricants and oil	100%	kg/t	0,0095	0,14	0,02	0,02	0,03

** limited data available*
"0" no input or below reporting requirements see "chemical input"
"na" not available
*** total fuel excluding Refuse Derived Fuel*

Appendix D

Individual score from pairwise comparison workshop

No.	Pair detail	Company	Evaluator	Chosen factor	Rating
1	Compostability VS Design for disassembly	Volvo	Joel	Design for disassembly	5
			Jasper	Design for disassembly	7
			Jonas	Design for disassembly	7
		Stena Recycling	Manos	Design for disassembly	5
		FrontPac	Martin/Peter	Design for disassembly	9
2	Compostability VS Recyclability	Volvo	Joel	Recycle	9
			Jasper	Recycle	9
			Jonas	Recycle	7
		Stena Recycling	Manos	Recycle	9
		FrontPac	Martin/Peter	Recycle	9
3	Compostability VS Chain of custody	Volvo	Joel	Chain of custody	7
			Jasper	Chain of custody	7
			Jonas	Chain of custody	7
		Stena Recycling	Manos	Chain of custody	9
		FrontPac	Martin/Peter	Chain of custody	7
4	Compostability VS Selling unit cube efficiency	Volvo	Joel	Selling Unit Cube Efficiency	7
			Jasper	Selling Unit Cube Efficiency	9
			Jonas	Selling Unit Cube Efficiency	7
		Stena Recycling	Manos	Selling Unit Cube Efficiency	7
		FrontPac	Martin/Peter	Selling Unit Cube Efficiency	9
5	Design for disassembly VS Recyclability	Volvo	Joel	Design for disassembly	7
			Jasper	Design for disassembly	5
			Jonas	Design for disassembly	7
		Stena Recycling	Manos	Design for disassembly	5
		FrontPac	Martin/Peter	Design for disassembly	7
6	Design for disassembly VS chain of custody	Volvo	Joel	Chain of custody	7
			Jasper	Chain of custody	5
			Jonas	Chain of custody	5
		Stena Recycling	Manos	Both Equally Important	1
		FrontPac	Martin	Both Equally Important	1
7	Design for disassembly VS Selling unit cube efficiency	Volvo	Joel	Both Equally Important	1
			Jasper	Design for disassembly	5
			Jonas	Design for disassembly	5
		Stena Recycling	Manos	Both Equally Important	1
		FrontPac	Martin/Peter	Both Equally Important	1
8	Recyclability VS chain of custody	Volvo	Joel	Chain of custody	3
			Jasper	Chain of custody	3

			Jonas	Both Equally Important	1
		Stena Recycling	Manos	Both Equally Important	1
		FrontPac	Martin/Peter	Both Equally Important	1
9	Recyclability VS Selling unit cube efficiency	Volvo	Joel	Selling Unit Cube Efficiency	5
			Jasper	Selling Unit Cube Efficiency	3
			Jonas	Selling Unit Cube Efficiency	3
		Stena Recycling	Manos	Both Equally Important	1
		FrontPac	Martin/Peter	Both Equally Important	1
10	Chain of custody VS Selling unit cube efficiency	Volvo	Joel	Selling Unit Cube Efficiency	5
			Jasper	Selling Unit Cube Efficiency	5
			Jonas	Selling Unit Cube Efficiency	5
		Stena Recycling	Manos	Selling Unit Cube Efficiency	3
		FrontPac	Martin/Peter	Selling Unit Cube Efficiency	9

Appendix E

Selling unit cube efficiency of spare parts

Part Number	Part Description	Part Number Pack Material	Type of packaging	Type of material	Inner length (mm)	Inner width (mm)	Inner height (mm)	Box volume (mm3)	Part length (mm)	Part width (mm)	Part height (mm)	Part Volume (mm3)	SUCE (%)
88800501	ASSEMBLY TOOL	72280050	BOX	PAPER	245	215	255	13432125	32	32	4	4,096	0%
9990028	FIXTURE	72280210	BOX	PAPER	670	240	200	32160000	115	97	10	111,550	0%
22578068	COMMON RAIL	72163970	BOX	PAPER	1120	180	140	28224000	878	80	55	3,863,200	14%
9996041	SPINDLE	72220000	BOX	PAPER	60	60	430	1548000	525	22	22	242,681	16%
23415875	ABSORBER	72220120	BOX	PAPER	212	77	215	3509660	212	212	15	674,160	19%
20811948	GEAR	72211760	BOX	PAPER	300	300	105	9450000	187	187	55	1,923,295	20%
21096987	BAR	72250200	BOX	PAPER	570	100	105	5985000	575	85	25	1,221,875	20%
84809793	DIRT DEFLECTOR KIT	6763106	BOX	PAPER	550	250	130	17875000	362	190	60	4,126,800	23%
23576907	OIL PRESSURE GAUGE	883702	BOX	PAPER	85	85	85	614125	59	59	59	205,021	33%
23417575	POSITION LAMP	6763034	BOX	PAPER	65	65	110	464750	86	54	40	185,416	40%
21255206	AIR DRYER	72280020	BOX	PAPER	200	180	360	12960000	277	138	138	5,275,188	41%
22889891	ACTUATOR SERVICE KIT	72230250	BOX	PAPER	70	70	250	1225000	50	50	200	500,000	41%
1069372	SHIFT YOKE	72250180	BOX	PAPER	125	85	260	2762500	110	202	51	1,137,960	41%
23391483	AIR CYLINDER	8260046	BOX	PAPER	140	95	345	4588500	320	68	90	1,958,400	43%
22934521	ROOF HATCH	6763011	BOX	PAPER	900	190	1200	205200000	777	987	124	94,712,027	46%
21632060	TOGGLE SWITCH	72230020	BOX	PAPER	57	25	70	99750	51	21	44	46,113	46%
1667966	SLEEVE	6763098	BOX	PAPER	65	65	70	295750	50	50	56	140,000	47%
23763152	CLUTCH	6763086	BOX	PAPER	270	230	200	12420000	233	233	112	6,080,368	49%

21932631	ATTACHING CLAMP	72230100	BOX	PAPER	96	96	58	534528	96	78	35	262,080	49%
21783501	CHECK VALVE	72230050	BOX	PAPER	90	40	85	306000	82	68	28	156,128	51%
1524889	DIFFERENTIAL SIDE GEAR	72220090	BOX	PAPER	177	107	158	2992362	139	139	80	1,545,680	52%
23227102	ACTUATOR	6763032	BOX	PAPER	125	125	130	2031250	130	127	65	1,073,150	53%
23334704	HAND PUMP	6763044	BOX	PAPER	180	100	230	4140000	80	130	211	2,193,360	53%
22862610	BEARING BOLT	72230240	BOX	PAPER	135	65	135	1184625	105	105	65	716,625	60%
23285401	BOX	72220080	BOX	PAPER	165	89	203	2981055	241	132	62	1,972,344	66%
23082628	RETAINER	72220040	BOX	PAPER	240	105	78	1965600	216	78	78	1,309,498	67%
22867288	FORK	6763087	BOX	PAPER	364	145	360	19000800	341	336	115	13,176,240	69%
1651247	FLANGE YOKE	72220200	BOX	PAPER	166	165	170	4656300	150	150	144	3,240,000	70%
22277959	AIR PRODUCTION MODULATOR	6763025	BOX	PAPER	375	245	195	17915625	203	191	333	12,911,409	72%
1653842	INPUT SHAFT	72220010	BOX	PAPER	130	125	130	2112500	133	133	90	1,580,063	75%
21870635	FUEL FILTER HOUSING	72250070	BOX	PAPER	270	230	200	12420000	280	235	144	9,475,200	76%
22359636	ELECTRIC FAN	72250280	BOX	PAPER	350	89	350	10902500	340	340	82	9,479,200	87%
20547286	BUSHING KIT	72230210	BOX	PAPER	80	80	165	1056000	155	93	93	1,340,595	127%
23098231	GEAR HOUSING	72230200	BOX	PAPER	165	85	70	981750	180	100	80	1,440,000	147%
23239363	RECEIVER DRYER	72220140	BOX	PAPER	300	110	110	3630000	569	230	397	52,045,747	1434%

Table 28: Selling unit cube efficiency of paper boxes

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