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Master’s Programme in Mechanical Engineering

Reducing wood waste during Azipod-units production

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Abstract

Sustainable development and the circular economy are an important part of the development towards a more environmentally friendly and energy efficient future. This is why waste treatment and recycling are at the forefront of the European Union's new directives, while many companies are researching new utilizations for the waste generated in production. Wood is a widely used raw material in the packaging industry, and therefore wood waste is generated in many production industries more than expected. As a raw material, wood is versatile and renewable, and therefore its utilization in the circular economy is in the sights of many companies.

The thesis consists of two parts: literature research and case study. Literature research is the most comprehensive part of this thesis. It discusses the general features of Wood packaging and regulations and laws related to the recycling of wood waste. After that, the literature review deals with the packaging and transportation of the selected case study company, ABB Marine & Ports Oy. These results lead to the second part of the thesis, a case study of ABB Marine & Ports Oy's possible options for reducing wood waste using the Analytic Hierarchy Process. The case study researches five different methods and evaluates them against each other using four different criteria: cost, handling safety, (waste) reduction rate, and waste transportation emissions.

The literature research of the thesis and the results of the case study show that the utilization of wood waste is the best solution for reducing wood waste. With these methods, a 90% reduction can be achieved, with no effect on safety, and without large increases in costs. However, the final waste reductions and costs may be determined based on the current market situation and the efficiency of the recycling centers. The research also develops an Analytic Hierarchy Process-method that can be used in future research regarding the reduction of wood waste in ABB Marine & Ports Oy or other companies.

Keywords Wood waste, Azipod, AHP, Package, Circular economy

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Tiivistelmä

Kestävä kehitys ja kiertotalous ovat tärkeässä osassa kehitystä ympäristöystävällisempään ja energiatehokkaampaan tulevaisuuteen. Tämän takia jätteiden käsittely ja kierrätys ovat eturintamassa Euroopan unionin uusissa direktiiveissä, samalla kun monet yritykset tutkivat uusia hyötykäyttö mahdollisuuksia tuotannossa syntyneille jätteille. Puu on paljon käytetty raakamateriaali pakkausteollisuudessa, ja siksi puujätettä syntyy monissa tuotantoteollisuuksissa odotettua enemmän. Puu on raaka-aineena monipuolinen ja uusiutuva, ja siksi sen hyödyntäminen kiertotaloudessa on monen yrityksen tähtäimessä.

Diplomityö koostuu kahdesta osasta: kirjallisuustutkimus ja case study. Kirjallisuustutkimus on tämän diplomityön kattavin osio. Siinä käsitellään puupakkausten yleisiä piirteitä ja puujätteen kierrätykseen liittyviä määräyksiä ja lakeja. Lopuksi kirjallisuuskatsaus käsittelee valitun tapaustutkimusyrityksen, ABB Marine & Ports Oy:n paketointia ja kuljetusta. Nämä tulokset johdattelevat diplomityön toiseen osioon, case study ABB Marine & Ports Oy:n mahdollisista vaihtoehdoista puujätteen vähentämiseksi hyödyntäen Analyysihierarkiaprosessia. Case study:ssa tutkitaan viittä eri menetelmää ja niitä verrataan toisiinsa käyttäen neljää eri kriteeriä: kustannukset, käsittelyturvallisuus, (jätteen) vähennysaste, ja jätekuljetuksen päästöt.

Diplomityön kirjallisuustutkimus ja case study:n tulokset osoittavat, että puujätteen hyötykäyttö on paras ratkaisu puujätteen vähentämiseksi. Näillä menetelmillä voidaan saavuttaa parhaimmillaan 90 % vähennys pitäen turvallisuuden koskemattomana, ja ilman suuria nousuja kustannuksissa. Lopulliset jätevähennykset ja kustannukset voivat kuitenkin määräytyä nykymarkkina tilanteen ja kierrätyskeskusten tehokkuuden perusteella. Tutkimuksessa kehitetään Analyysihierarkiaprosessimenetelmä, jota voidaan käyttää jatkossa puujätteen vähentämistä koskevissa tutkimuksissa ABB Marine & Ports Oy:ssä tai muissa yrityksissä.

Avainsanat Puujäte, Azipod, AHP, Laatikko, Kiertotalous

Table of contents

Preface ... 6
Abbreviations ... 7
1 Introduction ... 8
1.1 Background ... 8
1.2 Research Problem ... 10
1.3 Objectives ... 11
1.4 Thesis structure ... 11
2 Wooden packages ... 13
2.1 Eurocode 5 ... 16
2.2 Package treatment ... 17
2.3 Package marking ... 18
2.4 Seaworthy packaging ... 20
2.5 Jointing methods ... 21
3 Laws and regulations ... 23
3.1 Waste act ... 24
3.2 Producer responsibility ... 25
3.3 Calculation and declaration of energy consumption and GHG emissions ... 26
4 Waste and by-product ... 28
4.1 Typical wooden wastes ... 30
4.2 Circular economy ... 32
5 Reduce, Reuse, Recycle ... 34
5.1 Reduce ... 34
5.2 Reuse ... 35
5.3 Recycling ... 38
6 Case study company ... 42
6.1 Azimuth propulsion system ... 42
6.2 Azipod-propulsor ... 44
6.3 Packaging at case study company ... 46
6.4 Transportation methods ... 51
6.5 Logistical prices ... 51
6.5.1 Ship expenses ... 51

6.5.2 Port expenses 52
6.5.3 Other expenses 52
6.6 Recycling costs 53
6.7 Transportation prices 55
7 AHP for wood waste analysis 57
8 Case study 60
8.1 AHP Criteria 60
8.1.1 Cost 60
8.1.2 Handling safety 62
8.1.3 Reduction rate 63
8.1.4 Waste transportation emissions 63
8.2 Analysing AHP cases 65
8.2.1 Reducing wood waste 66
8.2.2 Reusing wood waste, local 68
8.2.3 Reusing wood waste, abroad 71
8.2.4 Recycling wood waste, local 72
8.2.5 Recycling wood waste, abroad 75
8.3 AHP point calculations 78
8.4 Case study conclusion 80
8.4.1 Result discussion 81
9 Conclusion 83
9.1 Future work 84
10 References 85

Preface

In this preface, I would like to thank all the each and everyone who have supported me during my thesis process directly or indirectly. However, there are couple of people, who I'd like to offer a special thanks.

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Otaniemi, 29 May 2024
Jouni Metsälä

Abbreviations

AHP	Analytic hierarchy process
CTMP	Chemithermomechanical pulp
ELY	Centre for Economic Development, Transport and the Environment
MDF	Medium-density fibreboard
NPPO	National Plant Protection Organization
OSB	Orient strand board
PCB	Polychloride biphenyl
RMP	Rollingmwchanical pulp
TMP	Thermomechanical pulp
TTW	Tank to wheels
VCI	Vapor corrosion inhibitor
WBCSD	World Business Council for Sustainable Development
WTT	Well to tank
WTW	Well to wheels

1 Introduction

1.1 Background

Marine industry and shipping are constantly growing. Current and past global challenges might have affected their growth, but shipping by sea remains one of the most utilized ways of transporting goods across the globe. Currently, around 90% of all international trade is accomplished through maritime transportation (Mihfeld & Associates, 2018). The population of the world is also predicted to grow, with United Nations estimating that the world's population to reach around 10.4 billion in year 2100 (United Nations Department of Economic and Social Affairs, Population Division (2022), 2022). Graphs for estimated number of persons as well as estimated births and deaths in the coming years can be seen in Figure 1.

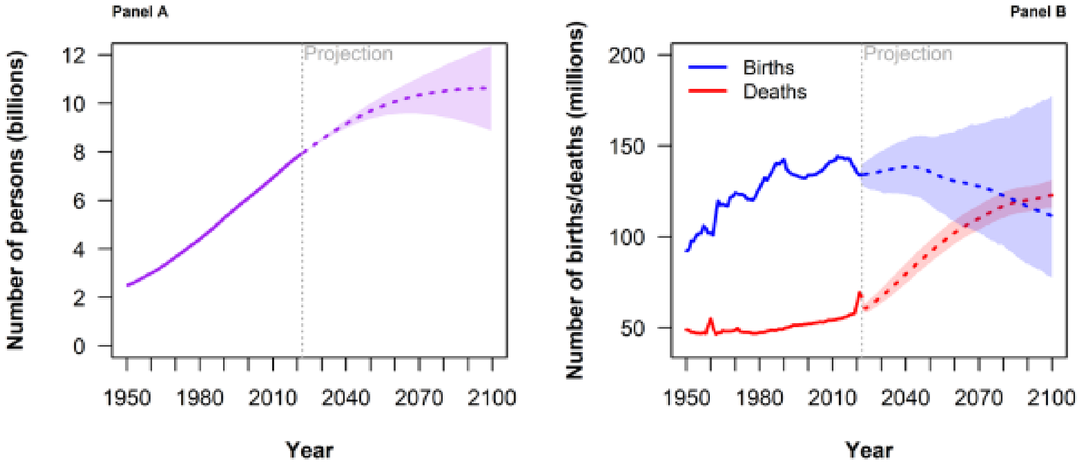


Figure 1. (United Nations Department of Economic and Social Affairs, Population Division (2022), 2022), Estimated number of persons and births/deaths (1950-2100)

With the increase in population and globalization, the market for new and sustainable technologies and solutions is also increasing. This contributes to the emergences of new market areas and the strengthening of old market areas. This in turn brings pressure to invent and develop new innovative technologies and to improve already existing ones in the direction of sustainable development when it comes to marine industry and shipping.

One of the most significant and influential enablers to growth of maritime field is the ship's propulsion system. Traditional shaft-line marine propeller propulsions are the most used propulsion system, but with energy-efficient and sustainability becoming more and more sought out options, alternative solutions are becoming common. Particularly, the azimuth thruster has proven to be a respectable solution. Its energy-efficient and accurate steering capabilities are making it the most optimal installed propulsion system for new marine crafts.

A products sustainable and environmental use is followed more closely than ever before in today's market. With optimal recycling and reuse of raw materials, energy efficiency can be improved and costs of the production, and there for the cost of product, can be reduced. This also includes the handling of all wastes generated by the manufacturer. Waste generated during the products manufacturing can and will affect the products carbon footprint. Thus, companies are interested in improving their recycling and reuse of raw materials used in their production line as well as keeping these raw materials close to the production line geographically.

Wood is a commonly used material in packaging industry. Due to woods versatile properties, it is a reliable material for many different packages and pallets. But due to its high use, many manufactures generate large amounts of wood waste, even when their manufacturing line doesn't involve wood. This is especially true in Finland, where different wood types have a large material flow (Statistic Finland, 2022). Figure 2 demonstrates the material flow for different materials, including wood, in Finland.

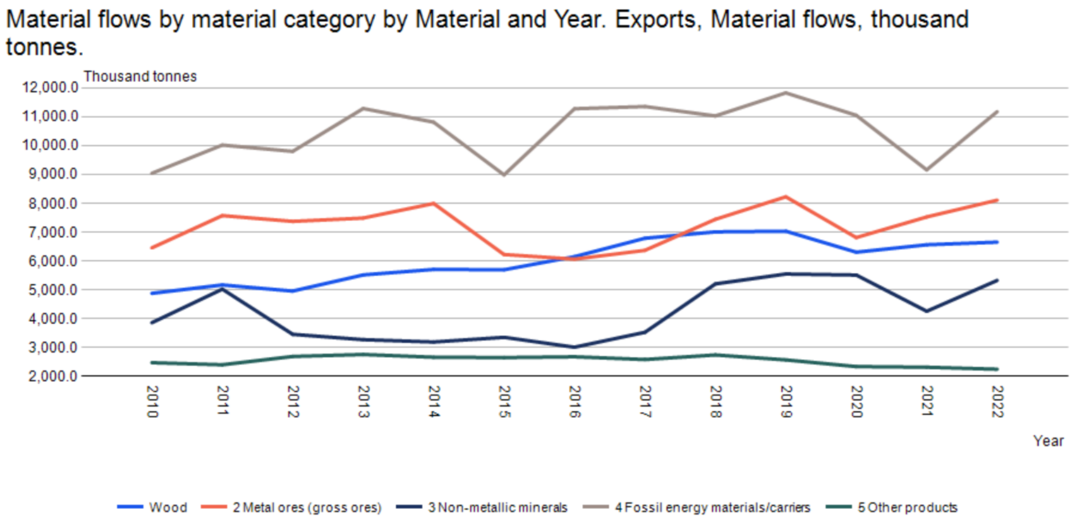


Figure 2. (Statistic Finland, 2022) Material flow of different materials per year in Finland

Wood waste consists mostly of the packages used to transport all kinds of products and items. These packages are designed to withstand transportation by sea in harsh weather while keeping the contents of the package safe and secured. Recirculating or reusing these packages and their materials is a feasible solution that many manufacturers aim to utilize, while EU Commissions has set a requirement for 30% recycling rate for wood used in packages by 2030.

1.2 Research Problem

ABB Marine & Ports is a technology leader in electrification and automation, and is currently investigating to optimize, electrify and decarbonize their own and customers operations. The aim of these actions is to preserve resources and promote net-zero future. It is this preservation of resources, which is one of the main focuses of this thesis. This is why the case study of this thesis will focus on ABB Marine & Ports. In this thesis, ABB Marine & Ports will now on be referenced as case study company (ABB, 2024).

With the interest in green policies and more sustainable production growing due to the climate change, manufacturers have started to increase the recycling of waste, while researching new methods to improve their recycling rate. Wood waste is one of the most generated packaging wastes in the manufacturing, totaling around 238 000 metric tons in year 2020 in Finland (European Union, Eurostat, 2023). Recycling and reusing raw materials are integral part of sustainable development, while playing part in company's overall profit. Companies that strive for sustainable and waste free manufacturing are paving their road to success on their own future of the field.

European Union has introduced new directive on managing packaging and packaging waste. The directive covers all packaging placed on the European market and all packaging waste, whether it is used or released at industrial, commercial, office, shop, service, household, or any other level, regardless of the material used. The targets for recycling wood from packaging waste are 25% and 30% for years 2025 and 2030, respectively. EU countries are also advised to set up to provide for the return and/or collection of used packaging and/or packaging waste, as well as the reuse or recovery including recycling of the packaging and/or packaging waste collected (Publications Office of the European Union, 2020).

Currently, many manufacturers aim to improve their recycling of wooden package wastes, one of which is the case study company. Returning used packages back to sender is one solution when the delivery comes from inside the country. The challenges arise when deliveries are made abroad. Although European Union has made legislation to ensure used package returning/collecting is made easier, the number of used resources is high when packages are retuned by sea. Thus, companies are looking ways to return wood used in packages to circulation with other means.

1.3 Objectives

The main objective of this thesis is to find a feasible method for reduce generated wood waste. But before main objective can be reached, it is vital to study recycling and waste management in general. The impact of upcoming laws and regulations regarding of wood waste and recycling must also the thoroughly studied. The goal of this thesis is to examine possible concrete methods to reduce generated wood waste, and to identify a method to achieve this objective. This requires the identification of different parameters those methods affect. For this thesis, the chosen parameters are cost, handling safety, (waste) reduction rate, and waste transportation emissions. In addition to this, the goal is to create a way to evaluate these methods against each other utilizing the chosen parameters, thus identifying the most optimal choice among these methods. To achieve these objectives, the chosen method of evaluation is Analytic Hierarchy Process. More detailed description of this method is shown in chapter 7.

1.4 Thesis structure

The thesis consists of two main sections: Theory and Case Study. The theory sections consist of analysis of wooden packages, laws and standards affecting these packages and a look into case study company. After these is a section that covers the Analytic Hierarchy Process chosen for this thesis. After that, the case study section goes through the criteria for analyzed methods, analysis of these methods, and finally conclusions for both the case study and the thesis.

Identifying the means and standards for packaging and shipping is essential for understanding the current situation. This means studying current packages used in delivering items from abroad. This also includes recognizing standard and normalized practices in developing and improving the design of different kinds of packages.

To achieve the main objective of this thesis, the appropriate rules and regulations must be studied. This includes rules and regulations for waste management, packaging and shipping as well as reusing and recirculating raw materials. After that, this thesis investigates the differences between waste and by-product, as well as the properties of typical wooden wastes, followed by a look into circular economy.

Afterwards, these sections are followed by chapter that goes through three major approaches that are chosen for this thesis; reduce, reuse, and recycle. The section explores different possible solutions to the research problem of this theses through these methods. After these chapters, the thesis covers

Analytic Hierarchy Process (AHP), that is used in this thesis to evaluate, assess, and finally identify the most suitable method to achieve the goal of this thesis.

Before the case study section, a look into the case study company is conducted. These chapters include an in-depth investigation to their manufactured product, how their packaging and transporting is conducted, and finally, brief discussion on types of most common expenses these kinds of companies pay during transportation.

Finally, a case study for Azipod® made by the case study company. The section starts with brief description of each criterion chosen for the AHP-method, followed by in depth analysis of each method chosen for evaluation in AHP-method. This means investigating the changes in cost, handling safety, reduction rate and waste transportation emissions. After these changes have been identified, the methods are compared against each other using these changes and given points depending on their performance. The section is concluded with discussion on the case study's results and finally, the conclusion of this thesis.

2 Wooden packages

The wooden packages consist of two parts: pallet and crate. Demonstrations of EURO pallets and crates are shown in Figures 3 and 4 respectively. Pallet is a platform used for transporting items, as well as handling and storing them. In Europe the EURO pallet is commonly used standard wooden pallet. Still, depending on transported items weight and dimensions, more suitable or customizable pallet is used. When securing the cargo on the pallet, multitude of different methods can be used to reduce the chances for damaging the cargo. These methods are for example lashing, locking, blocking, or fastening the goods to the pallet with bolts, screws or shrink wrapping. However, one still needs to consider the wooden material used in the pallet to ensure that the shipping process is easy to handle, regardless of the modes of transport (Ritchies Training Centre, 2018).

Figure 3. (REMMEY The Pallet Cmpany, 2024) Standard EURO pallet

Crate are used in load-bearing packages. They are designed carry the entire weight of the packaged cargo during its transportation. They can be designed to fit the cargo type, to ensure easy transportation. Crates are commonly made of wooden material, like plywood or cut timber, with timber being used in Europe over 25 million cubic meters every year in packaging. There are other used materials, but the material must be resistant and strong enough to withstand the packed cargo load and any possible damage the crate might endure during the transportation. Legal and environmental variables should also be considered as packaging is an integral part of international transaction. Thus, the material and components of the crate must be chosen according to the standards and requirements (Trasnport Information Service, 2023).

Figure 4. (Advanced Packing Solutions & Products Inc., 2024) Assortment of different types of wooden crates

While packaging items in wooden packages, the items are fastened to the pallet with bolts and screws to secure the cargo safely. This requires good insight of the used woods properties, to ensure that the wooden material used is capable in enduring the stress and fatigue caused by potentially heavy and large cargo. Other factors are also required to be considered, such as resistance against moisture and sea weather, and other affecting factors of transportation process. Therefore, hand-picking the most suitable wooden material from used packaging materials is a crucial part. Fortunately, there are numerous ways to sort the wooden material with modern, highly developed mechanical strength sorting methods. These include computer-vision measurement, specific frequency measurements, X-ray measurement and ultrasound measurement. In the traditional mechanical strength sorting method, the wooden pieces are bent, after which their modulus of elasticity is used to determine their position in strength class. Visual indicators are also used while sorting the wooden material. The number of knots, quality of timber, cracks, warping, distortion, and other faults are taken into the account. Finally, the timber's growth rings thickness are also checked (Puuinfo, Sorting sawn timber in terms of strength, 2020).

As mentioned above, sawn conifer timber can be sorted into different classes with visual and/or mechanical tests. These different strength classes and the most common strength classes used in Finland are shown in Table 1. Strength classes C14 – C30 can be sorted with either visual or mechanical test. Meanwhile strength classes C35 – C50 can only be sorted after mechanical test (Puuinfo, Sorting sawn timber in terms of strength, 2020).

Table 1. (Puuinfo, Sorting sawn timber in terms of strength, 2020) Strength classes in accordance with EN 338

Strength classes in accordance with EN 338	
All strength classes	C14, C16, C18, C20, C22, C24, C27, C30, C35, C40, C45, C50
The most common strength classes in Finland	C18, C24, C30, C35, C40

INSTA 142 is a pan-Nordic standard, that also categorizes sawn conifer timber into strength classes. It lays foundation to sorting sawn conifer timber into different strength classes shown in Table 2 using visual strength sorting. The EN 338 standard is used to approve corresponding C strength classes to the strength classes in INSTA 142. The material properties of these different strength classes are shown in Table 3. (Puuinfo, Sorting sawn timber in terms of strength, 2020)

Table 2. (Puuinfo, Sorting sawn timber in terms of strength, 2020) Strength classes in accordance with INSTA 142

Strength classes in accordance with INSTA 142	
All strength classes	T0, T1, T2, T3
Correspondence with EN 338	T0 = C14, T1 = C18, T2 = C24, T3 = C30

Table 3. (Puuinfo, Eurokoodi 5, 2019) Material properties of different wood strength classes

Strength classes		Sawn Timber		
		C18 (T1)	C24 (T2)	C30 (T3)
Characteristic strength (N/nm²)				
Bending	$f_{m,k}$	18	24	30
Tensile	$f_{t,0,k}$	10	14.5	19
	$f_{t,90,k}$	0.4	0.4	0.4
Compression	$f_{c,0,k}$	18	21	24
	$f_{c,90,k}$	2.2	2.5	2.7
Shear	$f_{v,k}$	3.4	4.0	4.0
Stiffness properties (N/nm²)				
Modulus of elasticity	$E_{0,\ mean}$	9000	11000	12000
	$E_{90,\ mean}$	300	370	400
Mean shear modulus	G_{mean}	560	690	750
Density (kg/m³)				
Density	ρ_k	320	350	380
Mean density	ρ_{mean}	380	420	460

When using solid timber on boards, crates and cases, a sufficiently strong wood must be used. For boards, a strength class of T1 must be used. For crates and cases, a T2 strength class must be used.

Wooden material can also be grade according to its appearance. Swedish standard SS-EN 1611-1 aims to grade wood in terms of its appearance, while still taking into the account properties that affect the function of the wood, such as deformations. The standard has grades from Grade G4-0 to Grade G4-4, with G4-0 being the highest quality. (Swedish Wood, 2023)

Swedish sawmill industry instructs that packaging wood should be grade G4-3, with wood type being spruce or pine. This grade allows defects that greatly affect the appearance in terms of both size and number, including decayed knots, bark-encased scars, blue stain, firm rot, through checks, wavy grain, and top rupture. Extensive deformations are also permitted, as are knot holes. Due to its poor visual appearance, G4-3 wood is not used in most wood products. According to the Swedish sawmill industry, G4-3 wood can also be used as building timber or tongued and grooved timber with sawn face. (Swedish Wood, 2012)

2.1 Eurocode 5

Eurocodes are European design standards that cover everything from basic design principles and load estimation to detailed design solutions. Eurocodes work together with implementation and product standards to form a unified whole that guides the design and implementation of structures. (European Comission, 2023)

Eurocode 5 describes designs of buildings and other civil engineering works in timber or wood-based panels jointed together with adhesives or mechanical fasteners. Wooden packages are constructed using sawn timber, plywood and OSB property. Because the packaged items can weight several tons, the package must be strong enough to withstand possible damages during transport and forces applied to the package during lifting or otherwise moving the package. The Eurocode 5 also specifies material properties for sawn timber, as well as equation to calculate stresses and forces for timber structures. (European Comission, 2023)

2.2 Package treatment

ISPM 15 standard for Regulation of wood packaging material in international trade set phytosanitary measures required to reduce the risk of pests introducing and spreading because of the international trade of wood packaging material. The standard covers wood packaging materials made of raw wood and dunnage, but not wood material used that is already processed to already be pest free, for example plywood. (IIPC, 2019). The wooden packages used in transportation of goods must also comply with standards and requirements set by numerous EN standards. This includes EN 12246 for quality classification of timber used in pallets and packaging, EN 338 for structural timber-strength classes, and EN 12248 for sawn timber used in industrial packaging.

The package must be treated in accordance with ISPM 15 standard. One of these treatments is heat treatment. This treatment can be achieved using various energy sources or processes, but they must meet the required parameters for heat treatment. These include conventional steam heating, kiln-drying, heat-enabled chemical pressure impregnation and dielectric heating. (IIPC, 2019)

During the treatment, the wood is placed in a heat chamber for the treatment. This chambers shape and size can change depending on the treated wood type as well as the quantity of treated wood. One of the possible heat treatment chambers can be observed in Figure 5. When conventional heat chamber is used, it is fundamentally required that the entire treated wood achieves a minimum temperature of 56 °C for at least 30 minutes. This includes the core of the wood material. The temperature is most commonly measure by inserting temperature sensors in the wooden materials core. The heat chamber must meet multitude of factors to be able to provide necessary requirements for the treatment. Some of these factors are:

- The chamber and its floor are both sealed and well insulated.
- A uniform flow of air is achieved around and through the wood stack.
- Fans are used during the treatment to circulate air. The flow of air must also be sufficient to maintain required temperature of the treated materials core for the required duration.
- The use of at least two temperature sensors is recommended. The sensors must penetrate to the center of the wood and should be inserted at least 30 cm from the end of a piece of wood. In case of small boards or pallet blocks, temperature sensors should be inserted to a piece with largest dimensions.

Figure 5. (Luy Machinery Equipment CO., LTD company, 2024) Example of heat treatment chamber

In a case of failure to maintain the minimum temperature, the treatment must be restarted, or the treatment time is extended. The temperature during the treatment may also be raised if it is deemed necessary. Records and calibrations of the heat treatment must be kept for auditing. (IIPC, 2019)

2.3 Package marking

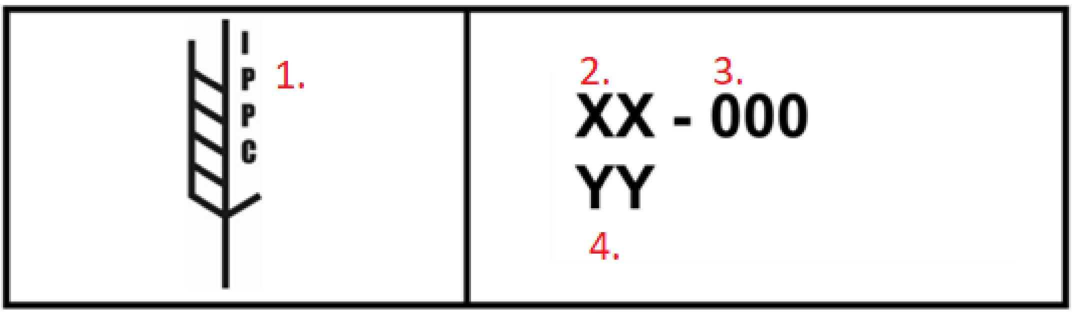
After successfully passing the treatment, the wood packaging material is marked in accordance with the standard ISPM 15. Figure 6 shows an example of mark according to the ISPM 15. The mark should resemble this example as accurately as possible, with only minor differences in the shape and size of the border. Rounded corners are allowed, as are small gaps if the border is easily recognizable. The mark consists of four different components. (IIPC, 2019)

First component is the symbol. The symbol is International Plant Protection Convention (IPPC) approved symbol. This symbol can be registered under national, regional, or international procedures. This includes a trademark or other certification or guarantee mark. The symbols must also resemble the example given in the Figure 6 as closely as possible, although it is allowed to be rotated while inside the mark's borders. (IIPC, 2019)

Second is the country code. This code must be the International Organization for Standards (ISO) two-letter country code, and it must be separated by a hyphen from the next component. (IIPC, 2019)

Third is the producer/treatment provider code. This code is assigned to the producer of the wood packaging material or treatment provider. They also apply the mark or are responsible for ensuring that appropriately treated wood is used and properly marked. This code is provided by the National Plant Protection Organization (NPPO). (IIPC, 2019)

Fourth and final symbol is the treatment code. This code is an abbreviation provided by the IPPC and differs depending on the treatment used. This code appears after the combined country and producer/treatment provider codes. (IIPC, 2019)



1. Symbol
2. Country code
3. Producer/treatment provider code
4. Treatment code

Figure 6. (IIPC, 2019) Example of the mark according to the ISPM 15 standard

The marks size, font and position can vary between different packages, but it must be both visible and legible to inspectors without the use of a visual aid. The mark must be either rectangular or square shaped, with the symbol separated by a vertical line from the code components. No other information can be present withing these borders. The marking must not be hand drawn, and red and orange colors should be avoided if possible. Any other marks considered important and useful to protect, can be provided adjacent to the ISPM 15 standard mark, but still outside of its borders. (IIPC, 2019)

2.4 Seaworthy packaging

When transporting items by sea, it is important to make sure, that the used packages are made seaworthy. Seaworthy packages must be built from strong and thick lumber and/or covered with special wrapper to reduce and eliminate any damage that the sea weather can do to the package and transported items. Examples of the seaworthy packages can be seen in Figure 7.

Seawater can damage wood if they come into contact frequently. The wood absorbs saltwater into the structure, and similarly once dried, salt crystals form in the timber cells and push the fibers apart. Although wet wood can fall victim of a fungal growth, the saltiness of seawater prevents their growth. Luckily, inner layers of the timber crate can retain their strength even if the outer layer is damaged. To achieve this, the timber used in cases and crates must be thick and strong enough. Generally required thickness for case and crate packing can be seen from Table 4. (Inspection 4 Industry LLC, 2013)

Table 4. (Inspection 4 Industry LLC, 2013) Required thickness for different types of packings

Type	Case Packing	Crate Packing
Conventional Sawn Wood	24 mm	15.5 mm
Plywood	9 mm	9 mm

The packages contents must also be kept safe and secured from any damage during transportation. To achieve this, the packages contents must be protected with a waterproof and strong plastic foil. Sealing should be done by welding to ensure that the foil doesn't come off during transportation. Furthermore, enough moisture absorbent should be used to lower the risk of corrosion from possible sea weathers effects. For moisture absorbent, silica gel is one possibility. These procedures should be applied when transporting pumps and compressors or items containing electronic parts. When transporting piping and construction materials or structural steel and steel plates for tanks, formation of rust must also be considered. Rust preventative should be used on all necessary bright and machined parts of the transported items. Possible damage to the internal parts of machinery can be prevented with appropriate lubricant containing rust and oxidation inhibitors. Care should be taken to make sure that these lubricants and absorbents are compatible among themselves and those which will subsequently be used during transportation. Transported materials should also be coated or painted according to the technical data of the material. (Inspection 4 Industry LLC, 2013)

When the gross weight of the package is no more than 1000 kg, bottom cleats with a minimum on 40 mm thickness are required. This ensures easier and safer handling when using forklifts. Packages exceeding this weight limit must provide several appropriately sized skid runners in accordance with the packages weight. The packages should be secured to the ship using metal straps. A minimum of two un-annealed steel straps should be used, attached opposite to each other with right angle, or alternative where the wood needs reinforcement. These steel straps should be applied with a stretching tool and secured with crimped steel seals. (Inspection 4 Industry LLC, 2013)

Figure 7. (Indiamart, 2024) Examples of seaworthy packages

2.5 Jointing methods

Transported items are required to be fastened on the pallet during transportation. To make sure that different kinds of items remain in place during the transportation, many types of jointing methods are used in the wooden packaging for different purposes. In general, jointing materials which are used in crates and boxes assembling, and item fastening must be used according to the corresponding EN/DIN/ISO standards. Table 5 lists commonly used jointing methods as well as their purpose in packaging industry. (Transport Information Service, 2023)

Table 5. (Issa, 2019) Different jointing methods and their purposes

Jointing method	Purpose
Hexagon and lock head bolts	For end beams and items that must be fastened on the bottom case
Nuts	For end beam and items
Washer	For end beam and items
Screw and wire nails, and nails for pneumatic tools	For joints between cases components
Strap and piano hinges, klimp fas-tener, and snaps	For holding side and end wall together with lid

In addition to these jointing methods, dowel joint is also used. They are used in wooden beams. Because the steel module is drilled into the pallet and attached to the transported goods, the wood material properties must be accurately measured to ensure proper and solid foundation for fastening the transported goods. Figure 8 demonstrates the usage of these dowel joints. However, this jointing method is not currently standardized in the packaging industry. Because of this, they might incur restrictions on their usability in packaging industry. (Domínguez;Villarino;Fueyo;& Natividad, 2023)

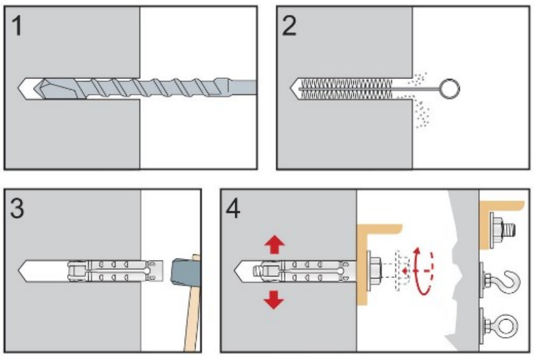


Figure 8. (Lahden Traktorivaruste, 2023) Dowel joint usage

3 Laws and regulations

Due to the increasing speed of climate change, countries are planning new laws and regulations to slow and prevent it. Thus, reducing CO_2-emissions and improving recycling are in the forefront of new laws and regulations. One of these is the Packaging and Packaging Waste Directive. The Directive aims to improve management of packaging waste and provide environmental protection while ensuring to keep the internal market functional. Latest amendment to the Directive aims to prevents packaging wastes production while promoting reusing, recycling, or any other form to recover packaging waste rather than its final disposal (European Union, 2022).

By the Directive, at the end of year 2025 European Commission wants that at least 65% of packaging wastes weight must be recycled. The recycling target for wood is 25%. And by the end of year 2030, these targets are increased to 70% and 30% for general packaging waste and for wood waste respectively. European countries are also required to have shipped packages to meet other essential requirements. These include minimizing the weight and volume of the packages so that they meet required levels of safety, hygiene, and acceptability for the packed product and for the consumers. Used hazardous materials should also be minimized or removed completely in packaging materials or any used components. Lastly, packages should be designed to be reusable of recyclable. Thus, designing a packaging material as well as organic recycling and energy recovery system are essential (European Union, 2022).

In additions to these recycling targets and requirements, systems for return and/or collection of used packages and/or packaging waste should be set up. This means, that manufacturers and shipping companies should ensure that producer responsibility schemes are established for all packaging. These schemes must provide financing or organization of the return and/or collection of used packaging and/or packaging waste. They must also include optimal waste management option, as well as guidelines for reuse and recycling of collected packages and packaging waste (European Union, 2022).

On 30 November 2022, the Packaging and Packaging Waste Directive was revised. The objective was to ensure that all packaging on the EU market is reusable or recyclable in an economically viable way by 2030. It also aims to ensure that all plastic packaging on the market can be reused or recycled in a cost-effective manner. With the revisions, generation and quantities of packaging waste are aimed to be prevented, while promoting reuse and refill. This means that all packages in EU market should be recyclable in economical way by the end of 2029. Finally, the use of recycled plastic in packaging in encouraged to enable high-quality recycling and reducing generation of new wastes (European Union, 2022).

To achieve these goals, the revision gives targets for packaging waste reduction and economic operators for selected packaging groups. Unnecessary and over-packaging are also restricted to support and encourage reuse and refill systems. Plastic packings are required to have a minimum amount of recycled content, and all packaging must have criteria for their recycling designs. Lastly, all labels of packages should be harmonized to facilitate correct consumer disposal of packaging wastes (European Union, 2022).

3.1 Waste act

Finland's Ministry of the Environment published a new national waste plan on April 6, 2022, called the Waste act. Its purpose is to guide Finland towards a sustainable circular economy. It contains goals for reducing the amount and harmfulness of waste while providing actions to achieve these goals for the year 2027, as well as prospects for national waste management until 2030. In addition to this, the Waste act's the main goals are also a significant increase in recycling and reuse of wastes. 57% of the municipal waste would be recycled and 65% of the biowaste generated from municipal waste would end up being recycled. Construction and demolition waste would be reduced and 70% of it would be used as material. The Waste act is based on the recycling goals set by the European Union and is reviewed every six years (European Union, Waste law, 2022).

The prospects of the Waste act for the year 2030 promote the material efficiency of production operations and thus natural resources and climate change mitigation activities. Material-efficient operations use as few raw materials, materials, and energy as possible, while at the same time reducing the potential harmful environmental effects of the substance or product. Reuse and recycling would have increased significantly, which would have reduced the amount of waste from the current level. Less and less dangerous substances would be used in production, so material cycles would also be harmless. The goals of the 2030 waste plan also include increasing the legislation's support for circular economy innovations and operating conditions (European Union, Waste law, 2022).

Waste management operations in municipalities are guided by regional and municipal waste management regulations, which are based on the Waste Act. The regulations are local waste management regulations that affect all residents of the municipality. The purpose of regional and municipal waste management regulations is to promote the goals of the Waste Act in accordance with local conditions. Waste management regulations can be regulations on connection to waste management, sorting, collection, and handling of waste types. The purpose of waste management regulations is to ensure the functionality of waste management in such a way that it does not cause harm to the environment and health (European Union, Waste law, 2022). In Helsinki, Helsinki region's environmental services HSY takes care of waste management regulations and is committed to the UN Sustainable Development Goals (HSY, 2024).

3.2 Producer responsibility

As mentioned in the previous chapter, companies that are categorized as producers must have necessary systems for return and/or collection of used packages and/or packaging waste. A company can be categorized as a producer if it produces electrical and electronic equipment, batteries, cars, vans or other similar cars, tires, paper products, packaged products. The manufacturers, importers and those who sell devices under their own brand are also categorized as producers and bear producer responsibility. Finally, importers of packaged products with a turnover of at least one million euros are producers. To enforce producer responsibility, producers might be subjected to a negligence fee, if they fail to organize the waste management of the products at their own expense when the products are taken out of use. (Centre of Economic Development, Transport and the Environment, 2023)

Pirkanmaa's Centre for Economic Development, Transport and the Environment (ELY Centres) supervises the implementation of producer responsibility in Finland, and it functions as a national authority. The task of the ELY centre is to compile national producer responsibility statistics and report them to the European Commission. Companies that have been accepted into the producer register can be found on the public list of the Pirkanmaa’s ELY centre. In this case, the producer responsibility is transferred to the producer association, which takes care of the producer responsibility obligations stipulated in the law. (The Centres for Economic Development, Transport and the Environment, 2023)

Another option for the company is to submit a producer registration application to Pirkanmaa's ELY centre, in which case the company is left to take care of the recycling, collection and other waste management of products subject to producer responsibility at its own expense. (The Centres for Economic Development, Transport and the Environment, 2023)

The third option is to establish a producer community together with other producers. If the company has different producer responsibility products from different producer responsibility areas, producer responsibility must be handled separately for each sector. Finnish packaging recycling company RINKI Oy, which the case study company has made a producer responsibility transfer agreement with, is a joint service company of five approved Finnish producer associations. RINKI Oy wants companies to report their packages real weight as well as different materials percentage of that weight. (Recser OY, 2023)

Producer responsibility for packaging is based on the Waste Act (646/2011) and the Government Decree on packaging and packaging waste (518/2014). Producer responsibility covers producers in the packaging industry, which are packers and importers of packaged products, with a turnover of at least one million euros. Producer responsibility for packaging applies to almost all packaging imported into the Finnish market, or for the company's own use, or placed on the Finnish market. Packaging includes everything around the product; plastic or cardboard boxes, bags, wraps and foils, cushions, pallets, transport boxes, plastic, and metal straps for fastening packages and pallets and barrels, as well as reusable boxes, bottles, pallets, roll boxes. (Ympäristöministeriö, 2011)

3.3 Calculation and declaration of energy consumption and GHG emissions

SFS-EN ISO 14083:2023: en, Greenhouse gases. Quantification and reporting of greenhouse gas emissions arising from transport chain operations (ISO 14083:2023) has been confirmed as the valid national standard. It follows the Well-to-Wheels (WTW) approach. It does not consider the emissions caused by the production or maintenance of vehicles, the construction and maintenance of transport corridors, or transport-related buildings such as terminals, stations, or airports. In addition, leakages in vehicles, such as refrigerant gas leaks, work trips of transport service provider personnel and use of office buildings are also excluded (Schmied, 2012).

The standard recommends that the calculation consider the greenhouse gas emissions and energy consumption during the use phase of the vehicles' life cycle (TTW, tank-to-wheels) and the energy consumption of the fuel-related processes used by the vehicles (production and distribution (WTT, well-to-tank)) and the energy they produce greenhouse gas emissions. In the emission calculation according to the standard, the emphasis is on considering all relevant emission sources, reporting the results and the possibility to compare the results (Schmied, 2012).

The current standard is being renewed. At the annual meeting of the World Economic Forum in Davos in January 2023, a steering document was announced to support the logistics industry's journey towards an emission-free future. The purpose of this End-to-End GHG Reporting Guidance published by the Smart Freight Centre and WBCSD (the World Business Council for Sustainable Development) is to help companies implement their carbon dioxide emission reduction strategies and to present the benefits of the international ISO 14083 standard under development (World business council, 2023). According to the international standardization organization ISO (International Organization for Standardization), the future standard is the first global standard for calculating logistics emissions (Gould, 2023). The new standard is expected to be published in 2023, after which Finland, as an ISO member, must ratify it as its new national standard.

4 Waste and by-product

One way to reduce waste is to declare it as by-product. By default, by-product is a secondary product obtained incidentally in the manufacturing process of the main product. On the contrary, waste is produced from inefficient activities that do not add value to a product or service. By-products are also usually stored in safe and clean manner to preserve them and to enable reuse. On the other hand, wastes are usually stored inefficiently and with no intention of reuse or preservation of the wastes state, example seen in both Figures 9 and 10. This can be extended to the waste collection, where waste is collected in a way that damages the waste, further reducing reusability. An example of waste collection can be seen in Figure 9.

Figure 9. (Geldof, 2024) Truck collecting wood waste

In manufacturing, wood can be generated as a waste or as by-product. The source should be determined so that applicable utilizing methods for its recycling and reusage can be determined. Wood waste can be defined as materials, objects and material mass that is generated during production process, which reuse, and recycling is insolvable, and is harmful to the environment, directly or indirectly (Ympäristöministeriö, 2011).

There are mainly three ways to divide wood waste into different categories. First is to divide wood waste based on the wooden product that has become waste as follows (Ympäristöministeriö, 2011):

- Pure wood waste: concrete boards, untreated, sawn, and planed timber, and pallets.
- Recycled wood: wood-based building boards (plywood, chipboard, fiberboard, MDF boards, decorative boards, surface laminates and parquets), painted and other surface-treated timber and heat-treated wood.
- Pressure impregnated wood: creosote, copper, chromium and arsenic impregnated wood, electric poles. Pressure-impregnated wood must always be collected separately.

Second is to divide the wood waste depending on the woods contamination rate as follows (Wood Recyclers Association, 2021):

1) Processed or deteriorated wood containing only slight or no pollution.
2) Glued, painted, stained, lacquered wood, deteriorated wood product containing no halogenated organic components or wood preservatives.
3) Wood wastes/by-products that do not belong to the previous two categories contain halogenated organic components but are not treated with wood preservatives.
4) Wood wastes/by-products treated with preservatives.
5) Polluted wood waste with a PCB (polychloride biphenyl) content higher than 50 mg/kg.

Third and most common way is to divide the wood waste depending on the grade of the wood waste. These grades and their explanations are discussed in the next chapter.

A substance or object is not a waste but a by-product if it is generated in a production process whose primary purpose is not the manufacture of this substance or object, and (Ympäristöministeriö, 2011):

1) There is certainty about the continued use of the substance or object.
2) The substance or object can be used directly as is or after it has been transformed at most in accordance with usual industrial practice.
3) The substance or object is created as an essential part of the production process.
4) The substance or object meets the product and environmental and health protection requirements related to its planned use and its use does not cause danger or damage to health or the environment.

A decree of the Government may issue more detailed regulations on the requirements for classification as a by-product. A wood waste can be turned into by-product with right handling and utilization processes. Table 6 shows annual municipal wood waste in Finland from year 2018 to 2021.

Table 6. (Tilastokeskus, 2023) Wooden municipal waste in Finland in tons

Treatment method / Year	2018	2019	2020	2021
All treatments in total	115 749	113 680	111 964	144 883
Material utilization, excluding composting and digestion	56 988	81 036	87 370	78 926
Composting and digestion	168	128	150	232
Energy utilization	58 590	31 886	24 285	64 542
Incineration	0	0	2	1 183
Landfill placement and other disposal	0	630	157	0

4.1 Typical wooden wastes

Like there are many different wood types, there are also different types of wooden waste as pointed out in the previous chapter. These differ mainly on what wood material is used, where it was used and was it treated in any way. There are four grades of wood waste, ranging from grade A to D. The wood is graded depending on its usage, treatment, and how much hazardous material it has. A visualization of the different grades and types can be seen in Figure 11. To ensure efficient and economic recycling, it is important to have comprehensive understanding on these different types of wooden wastes. (Wood Recyclers Association, 2021)

Figure 10. Storage of wood waste at case study company

Grade A contains pre-consumer waste wood and untreated packaging woods. This wooden waste usually comes from wooden product manufacturing as well as packaging and secondary manufacturer in form on joinery and pallet reclamation. They can contain nails and metal fixings with small amounts of non-hazardous surface coating. The waste of this grade can be used as landscape surfacing and the manufacturing of pellets and briquettes. (Wood Recyclers Association, 2021)

Grade B contains industrial waste wood. The wood has limited treating or coating material that is defined by end users and IED. The sources for this grade are same as grade A, but they can also come from construction and demolition operations. Due to this, they usually contain paints, plastics, glass, and coatings as well as nails and metal fixings. The most prominent usage for this grade is industrial wood processing operations such as the manufacture of panel board products. (Wood Recyclers Association, 2021)

Grade C contains municipal waste wood that is treated and non-hazardous. It contains timber that is coated and treated without creosote or copper chrome arsenic. Its sources are same as grade A and B, with addition of wood waste collected by municipal and different transfer stations. They can contain nails, metal fixings, paints, coating, glue, plastics, and rubber. Wood waste of this grade can be used in panel boards, but withing controlled volumes. (Wood Recyclers Association, 2021)

Grade D is the most hazardous grade, containing only hazardous waste wood. They contain copper chrome arsenic preservation treatments and creosote, making the wood hazardous waste. Wood waste of this grade can come from same places as the previous grade, but they mostly come from agricultural fencing, trackwork or transmission pole contractors. For this grade, only usage is disposal as hazardous waste in appropriate facility. (Wood Recyclers Association, 2021)

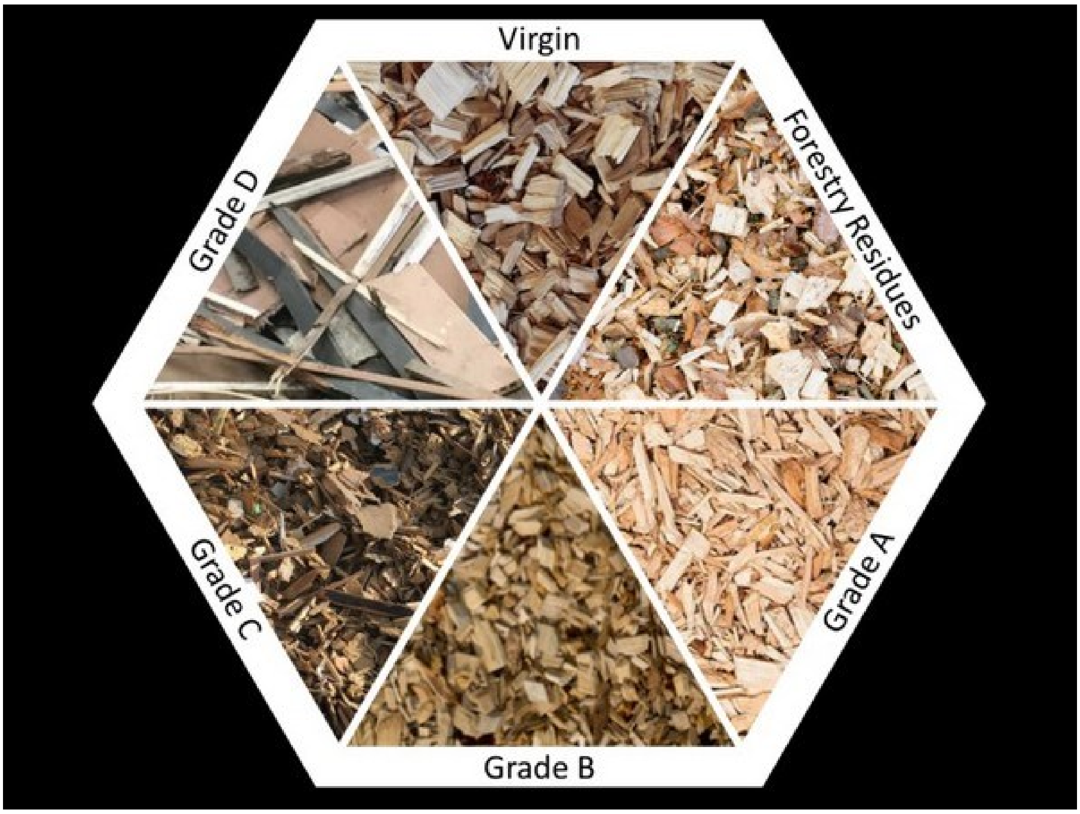


Figure 11. (Henan Richi Machinery CO,LTD, 2020) Different wood waste grading and types

From these grades, waste wood from wooden packaging is, as a rule, very clean, classified as grade B or even grade A waste wood. Although pallets made in Finland are mainly untreated wood, this is not necessarily the case with pallets imported from abroad. Thus, this can create challenges for the assessment of the wood waste class, when crushing mixed wood packages. In this case, the created, crushed wood waste, is given the worst grade known from the used mixed wood packages. In terms of recycling, it can also be seen as a problem that usable and repairable pallets end up in different waste fractions instead of being reused. (Myller, 2015)

4.2 Circular economy

The objective of circular economy is to maintain different materials and products inside the economy as long as possible. The idea is to reduce the waste and increase the production of goods. The circular economy can be promoted at different stages of the production chain. These ways include, for example, environmentally friendly product design, extending the product's useful life, maintenance, repair, reuse, and operating models related to the joint use of products, as well as the use of recycled raw materials in the manufacture of new products. These also extend to the packaging. With the right material and design, packages can be used extended periods of time, and maintained and repaired after use, to increase their life cycle. A typical circular economy model can be seen in Figure 12.

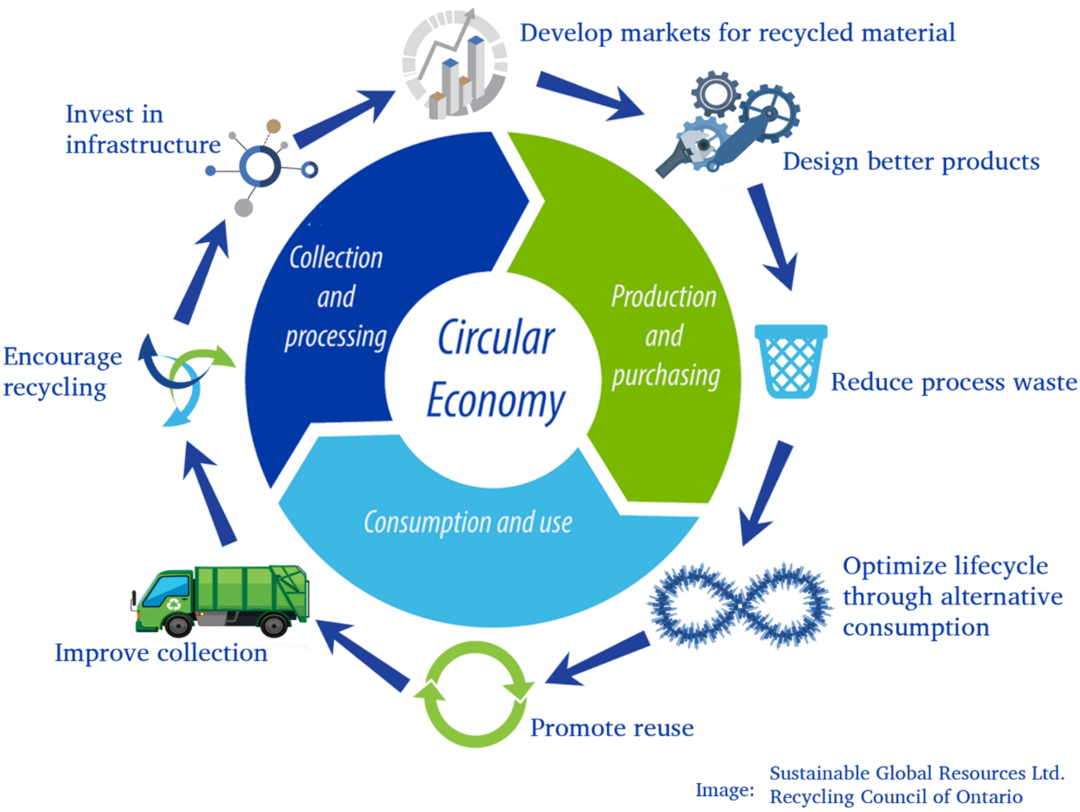


Figure 12. (Jackson, 2019) Example of circular economy

5 Reduce, Reuse, Recycle

To efficiently minimize generated waste, it is important to understand all the different methods at disposal. This thesis focuses on three different main methods. First is to simply reduce the amount of waste generated. Second is to reuse product ending up as the waste as much as possible in different ways. Thirdly and lastly, recycling the waste efficiently is important to prevent its accumulation at landfills or ending up into energy production. In an event that all these possibilities prove unusable or otherwise impossible, a correct method for the disposing of the wood packaging material must be used.

When disposing wood packaging material that is non-compliant with the ISPM 15 standard, couple methods are recommended. Disposal methods should be carried out with the least possible delay to minimize the risk of introduction or spread of pests. These methods are (IIPC, 2019):

- Incineration.
- Deep burial in approved sites. These sites should be at least 2 meters deep. This is not suitable disposal option if the wood is infested with termites or some root pathogens.
- Processing.
- Other methods that are effective for the pests of concern.
- Return to exporting country.

5.1 Reduce

Reducing wood waste can be achieved with efficient usage of wood as a raw material. Finding ways to minimize the amount of scrap left from opening wooden packages can come a long way in long term. Wood waste can also be reduced by optimizing the packages. By minimizing the required wooden material, incoming wooden waste can be reduced. Due to the size of azimuth thruster parts, the used packages are also quite large. Removing even couple millimetres from the packages thickness can greatly reduce the overall wood needed for the package's construction. Thus, the main principles to reducing the wood used in packages is to reduce the size of the package, reducing the thickness of the planks used to construct the package, and replacing some parts of the package with a different material, for example steel.

While reducing the wood in the package, other aspect of the package should be strengthened to compensate. For example, binding of the items must be made secure enough to hold the transported items in place. In some cases, they can be solely used without the need for a package.

Some of the wooden parts can also be exchanged with metal, which is more durable than wood. This would reduce the generated wood waste, but it could increase the costs. However, these costs could be compensated with the high reusability of the metal.

When designing a package, different environmental impacts must also be considered. Overpacking goods can lead to waste of resources and damage to the environment if wastes generated from these packages are not handled appropriately. But as mentioned previously, reducing resources in the package can lead to damage to the product, which can lead to disposal of this damaged product. This also wastes resources. Thus, finding an optimal package design is important in resource management. Figure 13 shows simplified graph on packaging material and environmental impact in packaging optimization.

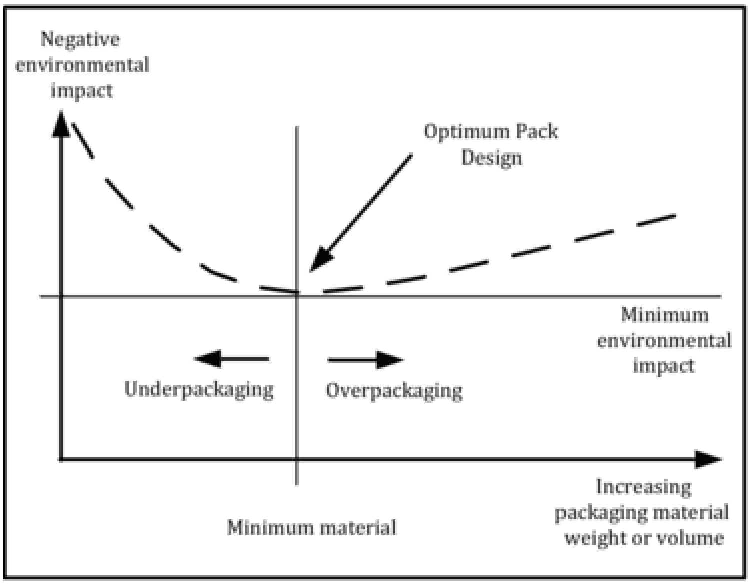


Figure 13. (Orora, 2016) Packaging optimization

One very important factor in the optimization of the boxes is their safety. The package and its binding must be designed so that they meet the safety standards of the manufacturer as well as the nations they are shipped to. These safety standards mean that even though the packages could be optimized to use less wood, they must still be safe enough to operate them with no possibilities for human injuries.

5.2 Reuse

Parts from broken wooden packages can be used to repair packages and pallets to some extent as demonstrated in Figure 14. When reusing treated wood, it is important to be aware possible hazardous materials in the wood.

Chromate copper arsenate and creosote treated wood is hazardous, and thus, harmful to the environment (Wood Recyclers Association, 2021). Used packages can also be shipped back to the sender. The reusage of packages can also be further improved by opening the packages optimally, further emphasising careful and optimal opening and handling of the packages. With this, the packages can be reused more efficiently with minimal repairs (Pirinen, 2018). The case study company is already conducting reuses and repairs on most standardized packages and pallets that they use. The challenges discussed in this thesis thus comes from the custom-made packages for the case study company's bigger products. In this case, the reusability of these packages comes in a couple of forms. For example, sending package back to their supplier.

Other possibility is using these custom-made packages to deliver other products, but unfortunately, this possibility has its own challenges. The custom-made package is made to the exact technical specifications of the transported item. Thus, the packages have different sizes and structures depending on the transported item. The package should be able to cover the whole transported item, but too big package could cause the item to move around inside the package, damaging the transported item or package during transportation. And if the package is too fragile for the item, it could break during transportation. Having a right sized package that is sturdier than what is required for the transported item is a feasible solution, but it could conflict with the package optimization discussed above and shown in Figure 13.

An alternative use, that the case study company is already utilizing in standard packages and pallets, is using these custom-made packages in repairs. This could increase the reusability of packages, as the reused material would go back into circulation, rather than end up as waste after one use. However, there are couple of limiting factors. One is the rules based on ISPM 15 standard. These rules are discussed in more detail below, but most prominent in reusability is the limit of replaced material. Only one third of the package can be replaced without conducting new heat treatment. This gives a hard limit on how much one box can be repaired. Second is the sturdiness of the package. After conducting the repairs, the package must remain strong enough to keep the transported item and personnel working with the package safe. If the package breaks during handling/transportation, it could damage the transported item or cause injury to personnel handling/transportation the package.

Figure 14. (Harvest Trading Enterprise, 2024) Pallet repair

The packages condition must also be kept up to the standard on other aspects as well. Even if the packages have been opened in a way that they could be reused, if they are stored poorly, they can become damaged enough to be determined unusable. The packages should be stored inside a warehouse, to protect them from possible effect of the weather and other external harm. If the package is left outside during winter or in a rain, the wood will decay, and the package will become unusable. If this happens, the package will turn into waste with very little possibilities for recycling or reuse (Pirinen, 2018).

If the wooden package has damaged during or after the transport, it can be repaired using appropriate wood material. According to the ISPM 15 standard, a wood packaging material that has been treated and marked according to the standard a wood package is considered repaired if approximately one third of its components are removed or replaced. In these cases, the material used in repairs must be treated wood in accordance with the standard. There are couple of exemptions, most notable being plywood. Each added part must also be marked according to the same standard. If the package is not repaired, remanufactured, or altered in any way, it does not require retreatment or any reapplication of mark indicating approved phytosanitary treatment. However, in an event of package having been repaired multiple times, and bearing multiple marking by extension, the marking should be obliterated by covering it with paint or grinding the mark away. The package must then be retreated and marked again. This is to avoid problems arising from packaging bearing multiple marks. (IIPC, 2019)

Determining the origin of package is important if for example pest are found associated with the package. Because of the multiple markings, this can prove difficult. In any case that the treatment of origin of the wood packaging material is difficult to ascertain, the material should be retreated, destroyed, or prevented from moving in international trade as wood packaging material. If the material is retreated, all previous marking should be obliterated, and new mark applied according to the ISPM 15 standard. (IIPC, 2019)

Wooden package material can also be remanufactured by replacing one third of its components. By combining various components and reassembling them into further wood packaging, remanufactured wood packaging can use both new and used components. In these cases, any old marking must be obliterated, and the wood packaging material retreated and marked according to the ISPM 15 standard. (IIPC, 2019)

From RINKI OY:S statistics, in year 2019, the wooden packages had a reuse rate of 60%. Reuse rate is the number of reuses divided by the total use of packaging, and total use of packaging is marketed plus reused packaging. (Rinki OY, 2023)

5.3 Recycling

If the wood waste cannot be used in its original form, it can be processed into other types of products. Some of these are wooden stone, wood plastic composite or cross laminated timber.

For the case study company, the wood waste could be used as raw material in fibre-based products manufacturing. The wooden packages delivered to the case study company are heat treated, making it clean wood waste. Wooden packages are grade A or B wood waste, making them clean and mostly untreated wood waste. Wood waste can be fiberized with two methods: chemical or mechanical. In chemical method, the lignin that holds wood fibres together is dissolved using cooking chemicals and heat. After the cooking phase, the uncooked fibre material is separated by sorting is subsequently cooked again. The removal of lignin is continued using oxygen delignification and/or bleaching chemicals. The bleaching chemicals are used mostly on wood waste grades C and D. The aim is to remove all possible impurities and further remove lignin from the wood. Mechanical method consists of three different methods, rollingmechanical pulp RMP, thermomechanical pulp (TMP) and chemithermomechanical pulp (CTMP). From these methods, TMP is the most efficient. After the wood processing, chips are washed. The aim of this process is to remove mechanical impurities while evening out moisture fluctuations of the raw material. Washed chips are then rubbed with disk or cone grinders. After this phase, the curl is removed from the fibre in the latency removal phase.

Wooden stone is a Finnish product, manufactured by Destaclean Oy. Wooden stone uses wood fibre with water, cement, and natural stone material to create material like solid concrete stone. Around 20-50% of the products volume is recycled wood chips. Currently, wooden stone is made using construction waste and wastes like natural wood. This means that the grade for usable wooden waste should be A. Wooden stones are a rising contender for a replacement for concrete stone, offering easier installation works due to its lower weight, while retaining similar price to normal concrete stone. Figure 15 showcases the possible usage of these wooden stones (Destaclean, 2023).

Figure 15. (Destaclean, 2023) Wooden stone

Wood plastic composite is made using wood waste like wood chips, sawdust and wood and paper waste. For plastic, disposable, and recycled plastic can be used. In addition to these, a binder is used to attach wood and plastic to each other. The material consists of 70% of wood and 30% of plastic, giving it an ecological and recyclable composition. Due to its hydrophobic feature, it could use to replace pressure-treated wood, which is considered hazardous to the environment. Unfortunately, achieving this hydrophobic feature can sometimes cause problems in the products manufacturing, as while plastic is hydrophobic, wood isn’t. (The Constructor, 2021)

Cross laminated timber consists of cross-glued board layers. Using multiple boards, a strong and sturdy building board can be built, while having it still retain relatively light weight. Figure 16 shows example of cross laminated timber. The usage of wooden waste in cross laminated timber is not yet research thoroughly. (Puuinfo, Monikerroslevy (CLT), 2023)

Figure 16. (Puuinfo, Monikerroslevy (CLT), 2023) Cross laminated timber

Wood waste can also be used in chipboard industry to produce different kinds of chipboards. Chipboards are most commonly produced by crushing the wood waste into tiny chips, which are then glued together producing a chipboard such as one shown in Figure 17. Unfortunately, the poor quality and heterogeneous of the wood waste could impact the chipboards quality. The metal residues of the wood waste could also cause issues and decline in quality. Still, with the advances of new technology, fibreboards could be produced using variety of different wood wastes in the future. Ground wood, an excellent bulking agent and moisture regulator for compost, can be co-composted with food processing waste or sewage sludge. Wooden wastes grades B, C, and D (see chapter 4.1) can be repurposed to wood fibre yarn and foam sheets by rubbing and/or boiling, if the quality and purity of the wood waste has been confirmed in advance (Rautkoski, ym., 2015). From RINKI OY: s statistics, in year 2020, 26% of the wooden packages weight was recycled. (Rinki OY, 2023)

Figure 17. (Unilin Panels, 2024) Example of chipboard

6 Case study company

The case study company specializes on designed and manufacturing their Azimuth propulsion system. These propulsion systems are used by many of different vessels, thanks to the Azimuth propulsion systems mostly vibration free functionality and low fuel consumption while in operation (ABB Oy, 2023).

6.1 Azimuth propulsion system

A vessel requires a propulsion system to be operated. Its function is to give the vessel acceleration and helps the vessel's manoeuvrability. The ship's propulsion system includes all the systems needed to produce the ship's thrust, for example the propulsion machinery and the auxiliary systems needed to operate them. It includes the equipment for transmission of propulsion power into thrust and all monitoring, alarm, safety, and control systems. Figure 19 showcases installed azimuth thrusters intended for icebreakers (ABB Oy, 2023).

The Azimuth propulsion system is a subcategory of the propulsion system, which, in addition to the thrust force, includes the direction of the thrust force with a turning propulsor. As frequency converter drives have become more common, electric propulsion systems have become dominant. The power required for propulsion is produced, for example, by a generator run by an internal combustion engine, gas, or steam turbine, and is fed into the ship's electrical network either as alternating or direct voltage. Figure 18 showcases ABB Marine & Ports Azipod propulsors different parts. (ABB Oy, 2023).

Figure 18. (ABB Marine & Ports Oy, 2019) Azipod® propulsion series in 7.5-14.5MW

In ships equipped with a rudder, the thrust produced by the propulsion system always goes in the same direction, and the change in the direction of the thrust needed to turn the ship is produced by a turning rudder. The rudder then acts as a moving control surface that produces the force that turns the ship. The rudder is located behind the propellers, where its purpose is to control the flow of water produced by the propellers. Instead of a traditional rudder and fixed propellers, the ship can be steered with turning propellers, in other words azimuth propellers (ABB Oy, 2023).

Azimuth thrusters can rotate around their turning circle 360 degrees. By turning the propeller device, the thrust produced by the propulsion system can be directed horizontally in any direction. The turning ring can be turned either hydraulically or electrically (ABB Oy, 2023).

Azimuth propeller devices are manufactured both with nozzles and without nozzles and can be divided into pushing or pulling propellers. Azimuth propeller devices are especially suitable for ships that require good manoeuvrability and maintaining the ship's steering ability is one of the requirements set for them. The machine that produces their thrust is located inside the ship's hull, which rotates the propeller via shafts and bevel gears. Typically, the mechanical transmission for the propeller is L or Z type (ABB Oy, 2023).

Azimuth propeller devices are also classified as turning, enclosed propeller devices, where the electric motor generating the thrust is connected directly to the propeller shaft and is integrated inside the propeller device housing, the so-called pod. One significant difference between these two types of turning propellers is the size of the propeller housing, as the pod-type propeller housing is often significantly larger. One of the most well-known pod-type azimuth thrusters is the Azipod manufactured by ABB (ABB Oy, 2023).


Figure 19. (Jacobs, 2014) Icebreaker azimuth thruster

6.2 Azipod-propulsor

Like other azimuth thrusts, Azipod-propulsor provides exceptional manageability thanks to its ability to turn 360 degrees around its vertical axis. However, thanks to its ability to guide the water flow directly to the propellers the Azipod-propulsor can save up to 20 percent of fuel consumption. This results far less emission production during operation than normal mechanical thrusters. Other advantages the Azipod-propulsor has is its size. Due to its smaller size comparing to traditional mechanical thrusters, it requires far less space, resulting in more flexible designing of the vessels general arrangements. It also has less gearwheels and bearing than traditional mechanical thrusters, resulting in more streamlined manufacturing (ABB Oy, 2023).

The Azipod-propulsor consist of three main modules. These are steering module, strut module and motor module. A visualization of these modules and different parts in 3d-space is shown in Figures 20 and 21. The Azipod-propulsor has a Azipod room, also known as electrical propulsor system engine room, above the steering unit. The propulsion and steering drives required for the propulsor units' operation are located there (ABB Oy, 2023).

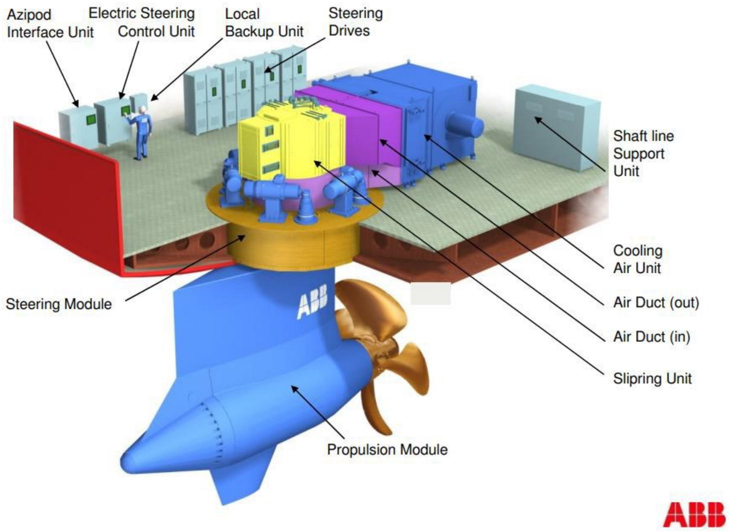


Figure 20. (ABB Group, 2012) Azipod® XO

The steering module is combination of steering bearing, gear, and motor. The slip ring unit, which is in the centre of the steering module, has all the cabling and piping going through it. A cooling air unit is attached to the steering module, which improves cooling capacity of the Azipod-propulsor, and thus, total efficiency (ABB Oy, 2023).

The strut module consists mostly of the hull of the Azipod-propulsor. It connects the motor and steering module together. It also guides the cabling and piping coming from steering module through slip ring unit to the motor module (ABB Oy, 2023).

The motor module consists of the motor, the drive end and the nondrive end. The motor modules main components are the bearings. These bearings support the main shaft at the ends of the motor module. Both drive end and the nondrive end are located at the main shaft. The propeller is attached to the main shaft and propeller bearing unit with the help of drive end. Meanwhile the nondrive end helps the thrust bearing unit to support the other end of the main shaft (ABB Oy, 2023).

The components of these modules and other components of the Azipod-propulsor units must be packaged and transported safely and efficiently to their destination (ABB Oy, 2023).

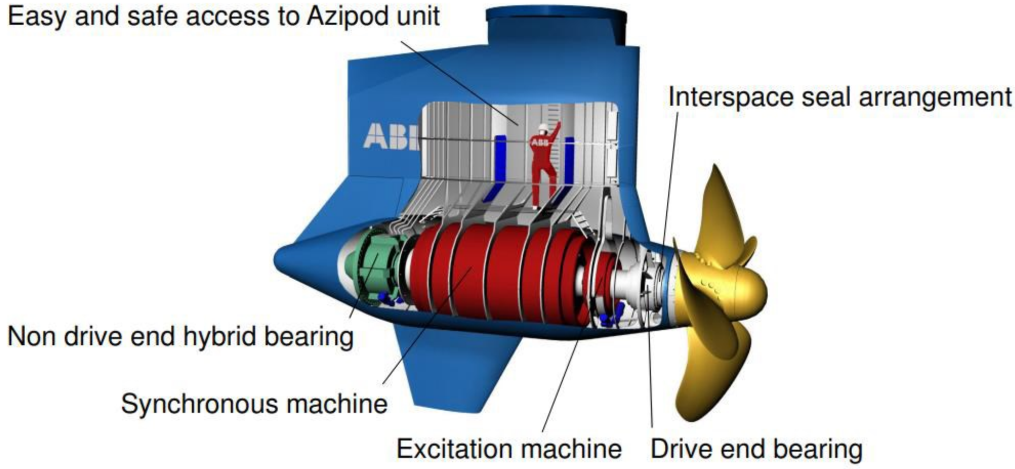


Figure 21. (ABB Group, 2012) Section view and main components of Azipod® XO propulsion module

6.3 Packaging at case study company

Most common packaging type that the case study company receives are wooden packages and pallets. The most common pallet type that the company receives is the EURO-pallet. These pallets are standardized and easily reusable and recyclable. Thus, this study focuses more on the packages that arrive to the case study company. More precisely, wooden packages that are custom made for their bigger components. Due to the size and weight of the transported components, the package is made of extremely sturdy wood. Still, the packages must be loaded and secured safely to avoid any damage to the product or harm to personnel working with the packages. However, these packages are the main source of wood waste in the case study company. Thus, the packaging and their handling must be looked at to better understand the reason for this.

According to the interviews conducted during this thesis with the personnel working at case study company, safety of the product and those working with them comes first. Due to this principle, some of the used packages are made using more wood than the standards require. Although this means that some of the used wood could be reduced, it would come at the cost of safety. For example, the pallet used in some products could technically be smaller. But this would leave the product vulnerable to damage. Thus, case study company packaging instruction instruct that the outer dimensions of the package box, package case, or pallet must always be larger than the outer dimensions of the product, as demonstrated in Figure 22 (Mandelin, ABB Packaging instructions, 2023).

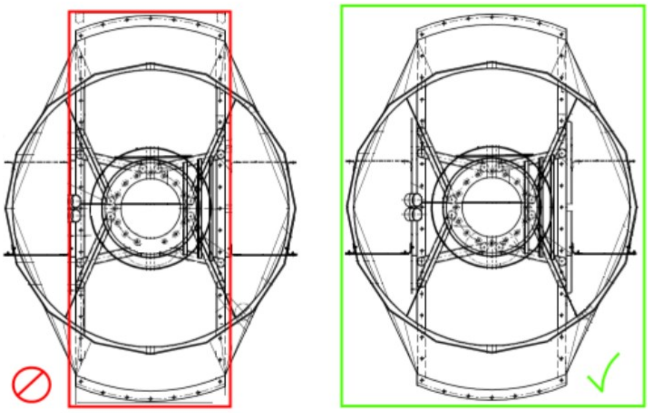


Figure 22. (Otava, 2021) Example of the required package and/or pallet size of the product.

Although optimization of the boxes using different packaging materials is excluded from this thesis, but it could be used to reduce used wood by switch parts of the box with different material or usage of binding products. For example, a metal base could be developed for transporting the blades. With the metal base and correct bindings, the blade would not need wooden package to keep it secured during transport. And with good enough protection from the weather effects, the blade can be transported safely without problems (Mandelin & Mäkinen, ABB Hamina vierailu, 2023).

To ensure safe transport of the package, the load must be secured according to the EN 12642:2006 standard. The used holding means must be able to withstand maximum forces that can occur during normal conditions. Some of the following forces are forward force, and side and back forces, them having forces comparable to 80% and 50% of the load weight respectively. A plan for securing the transported part should be made first, followed by the packaging around it. If the transported part has high centre of gravity, or extremely high weight, exceeding 5000 kg, making sure that the part itself is perfectly secured is important. In these cases, securing only the package itself is not sufficient. When transporting the goods across the sea, the load restraint equipment must be suited to withstand the corresponding forces. These forcers, longitudinal, transverse, and vertical, have forces of 80%, 100% and 100% of the load weight respectively (Otava, 2021).

As mentioned in the chapter 2.4, necessary precautions must be taken to ensure that the transported goods don’t suffer any damage during transportation. To prevent the corrosion occurring, the case study company uses vapor corrosion inhibitor (VCI), which must be nitrite-free, RoHS-compliant, and water-based. For protection against weather, the packages lid outside of the package is covered with plastic film. This has the purpose of preventing water from leaking to the plywood through the seams. The plastic film must be UVresistant, have a thickness of 150 µm or more, and fastened with staples. Additionally, it must be made for ferrous metals. Finally, no VCI materials from different manufactures must be used in one package. Metal parts of the transported goods must never be in direct contact with wood. To ensure this, the VCI film must be used to prevent this contact. This means that no packaging wood must be allowed inside the VCI film. In situations where packaging woods presence inside VCI film cannot be prevented, the woods amounts must be minimized (Otava, 2021).

The case study company has two levels for packaging protection: Normal and High. Normal level is used with Land/sea transport, with maximum outside storage of 6 months. The used protection method is only VCI film. High level is used for Sea/land transport, with outside storage of 6-24 months. In this level, brush applied inhibitor and plastic film are used in addition of the VCI film. The main aim of the normal protection level is to ensure that water doesn't leak inside the package. This is achieved with the VCI film. In high protection level, more methods are used to secure the goods condition. Unpainted metal surfaces are brush-coated with water-based VCI inhibitor. After that, the components are wrapped using VCI film, followed by wrapping using plastic films. Figure 23 demonstrates support rings packed using VCI film (Otava, 2021).

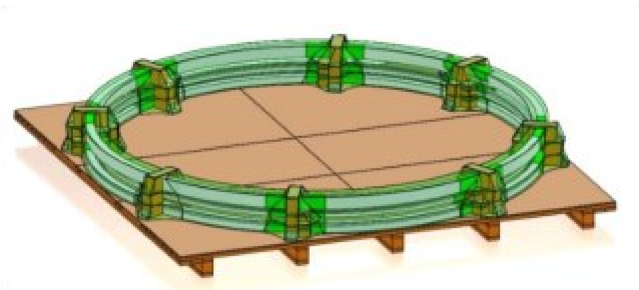


Figure 23. (Otava, 2021) Example of VCI film usage with support rings

In cases of heavy single part packages, they must be designed to be lifted and moved with only mechanical equipment. These packages are handled with forklifts, pallet trucks and cranes, using pallets designed for this kind of handling, as well as marked lifting points. A package with total weight of 30 kg and more is considered heavy single part package. The package can be divided into four different categories (Otava, 2021):

- Heavy duty cardboard packages
- Plywood packages
- Parts on pallet without separate package
- Part on supports

In these packages, it is important to use screws instead of nails in wooden structures. If the packaging doesn't have a box, the part and the outer edge of the pallet should have a 50 mm free space between them. The package must have adequate lashing points so that the part and package can be secured completely. Finally, the package component must not support the lid (Otava, 2021).

The plywood package used in heavy single part packages consists of birch plywood, with sheet metal joints, and has a thickness of 6 mm or 8 mm. The container is constructed using thick birch veneer, oven-dried solid wood, and steel. Its components are (Otava, 2021):

- a pallet base with wooden blocks
- edges with steel reinforced corners
- a cover

The product is fastened to the pallet with screws and/or supported by planks to prevent it from moving inside the package (Otava, 2021).

For seaworthy packages, the case study company recommends the usage of coniferous wood. It is important to treat and mark the wooden material in accordance with ISPM 15 standard. All the cabinets of the package should be fastened to the pallets using hex wood screws strong and long enough to secure the fastening. To minimize transported goods swaying inside the package, the cabinets should be braced to the walls of the package. Finally, packages components are attached together with screws. This gives the package the necessary rigidity and it facilitates easy unpacking at its destination. Figure 24 shows a seaworthy package according to the case study company packaging instructions (Otava, 2021).

Figure 24. (Otava, 2021) Seaworthy package according to the ABB Marine packaging instructions

The package must be strong enough and secured in a manner that it can withstand the calculated acceleration coefficients during road or sea transport. The acceleration coefficients for road and sea transport are demonstrated in Tables 7 and 8 respectively.

Table 7. (Issa, 2019) Road transport acceleration coefficients

Road transport					
Securing in	Acceleration coefficients				
	c_x		c_y		Vertically down (c_z)
	Forward	Rearward	Sliding	Tilting	
Transverse direction (c_y)	-	-	0.5	0.5/0.6	1.0
Longitudinal direction (c_x)	0.8	0.5	-	-	1.0

Table 8. (Issa, 2019) Sea transport acceleration coefficients

	Acceleration coefficients			
Sea area	Securing in	c_x	c_x	Minimum vertically down c_z
The Baltic Sea	Transverse direction	-	0.5	1.0
	Longitudinal direction	0.3	-	0.5
The North & Mediterra-nean Seas	Transverse direction	-	0.7	1.0
	Longitudinal direction	0.3	-	0.3
Unrestricted area	Transverse direction	-	0.8	1.0
	Longitudinal direction	0.4	-	0.2

6.4 Transportation methods

The packages are transported using trucks and ships, depending on the destination of the transported package. The most used route and mode of transport withing Europe is road transport using trucks, but due to poor road connections and political instabilities in some regions, maritime transport is also frequently used. For example, in most cases when shipping items from Germany to Finland a ferry from Germany to Finland, where the items are loaded to trucks and driven to their destination.

6.5 Logistical prices

In sea transportation, the expenses can be divided into three broad categories: ship expenses, port expenses and other expenses. The ship expenses consist mostly of fuel, crews pay, equipment, maintenance, and insurance. The port expenses consist of direct and indirect costs, which are divided between different parties. These are usually the shipping company and the charterers. The transport type also effects the price. From the three different transport types, shipping company pays the costs in line traffic. In freight and contract traffic, the contract determines amount of costs. (Hietaranta, 2015)

6.5.1 Ship expenses

The shipping expenses are generated due to the usage of the transportation ship. They can be divided into two groups, vessel costs and usage costs. These expenses are usually divided between the shipping company and consignor. The vessel costs consist of fuel and bunker costs. These costs can fluctuate depending on the used vessel, route of transport and current fuel prices. The usage costs consist of crews pay and food, maintenance at sea, ships maintenance and equipment and insurances needed for it. From these expenses, the crews pay and, any supplements included to those pays, are the biggest expenses among the usage costs. Although the ships insurance is done by the shipping company, the transported cargo is usually insured by the buyer or seller. (Hietaranta, 2015)

6.5.2 Port expenses

The port expenses can be divided into direct and indirect expenses. Direct expenses are related to the handling of the cargo, while indirect expenses are related to the other factors of the supply chain. The port expenses are related to the actions conducted at the port as well as actions when taking goods to the port. Domestic and international transports are indirect costs that arise when transporting goods by land to and from the port. International transports are by default usually more expensive than the domestic ones. (Hietaranta, 2015)

The storage in the port before and after sea transport are considered as direct costs. These costs are affected by the amount of storage room, their condition, and prices. These storages are usually temporary, and a storage fee is charged by the forwarding company. The storage fee is usually dependant on the amount of used storage room and the usage time. The loading and unloading of the cargo are also direct costs, and many factors can affect these costs. The ships type can affect loading and unloading costs, for example required different action in loading and unloading and time taken. The cargo handling technology and equipment at the port can also affect costs. With better technology and equipment, the loading and unloading can be done more faster and easier, lowering additional costs. (Hietaranta, 2015)

6.5.3 Other expenses

In sea transport, a large amount of expenses belongs to the other expenses. It includes cargo handling, feeder traffic and port fees, equipment rentals, other administrative costs, and customs fees. Some costs from ship and port expenses can be classified as other expenses, for example cargo handling costs. (Hietaranta, 2015)

Feed traffic costs arise when cargo is transported to ships by land. Port fees are port usage fees that are charged, for example, for ships in ports, for goods passing through the port, and for mooring and unmooring a ship. (Hietaranta, 2015)

Various devices may be needed during transport, for example for lifting, moving, keeping things cold or warm or other specified temperature. In this case, the necessary equipment can be rented for use, for which rent is paid. Administrative costs arise from several factors: the processing of transport and trade documents, as well as, for example, the salaries of the personnel who process them. (Hietaranta, 2015)

When exporting goods outside the EU, the exporter must submit an export declaration to customs. The purpose of the export declaration is to provide the customs authorities of the exporting country with information that can be used to monitor possible export restrictions and prohibitions, collect statistical data on imports and combat terrorism and crime. Through export declarations, customs can also charge a possible export duty, which, however, is not charged in the EU area. Import tax and possibly value added tax must be paid in the destination country. Paying customs duty and handling customs formalities depends on the Incoterms clause agreed in the trade agreement. For example, with the clause DDP (Delivered duty paid), the seller undertakes to pay and take care of the customs formalities. The customs value is usually based on the value of the goods. (Hietaranta, 2015)

During the trip, the ship may have to use waterways for which fees may be charged, for example the use of canals. When a ship travels from Europe to China, the use of the Suez Canal is a significant factor in shortening the journey. Due to the importance of the channel, it is used by several ships going from west to east, which creates congestion. A fee is charged for the use of the channel, which is determined by the number, size and weight of the passing vessel and the units being transported. (Hietaranta, 2015)

6.6 Recycling costs

In Finland, the waste management regulations are provisions that specify legislation. The regulations concern, for example, the sorting, collection, and transport of waste as well as the prevention of littering. The waste management regulations for the Helsinki Metropolitan Area and Kirkkonummi apply to all residents of Helsinki, Espoo, Kauniainen, Vantaa and Kirkkonummi, as well as other operators within the scope of the waste management organised by HSY. HSY charges for its recycling, depending on the recycled material and its quantity. Different prices different wood wastes are listed in Table 9 (HSY-kuntayhtymä, 2023).

Table 9. (HSY-kuntayhtymä, 2023) Prices for recycling according to HSY in 2023

Waste type	1000 liters Alv. 24%	200 liters (Garbage bag) Alv. 24%	50 liters (Box) Alv. 24%	1000 liters Alv. 0%	200 liters (Garbage bag) Alv. 0%	50 liters (Box) Alv. 0%
Pressure saturated wood	28	5.60	1.4	22.58	4.252	1.13
Coated wood	10	2	0.5	8.06	1.61	0.4
Uncoated wood	10	2	0.5	8.06	1.61	0.4
Harmful waste		Price €/kg (Alv. 24%)		Price €/kg (Alv. 0%)		
Pressure saturated wood (CCA, creosote)		2.3		1.85		

The producer responsible company pays the packaging material-specific recycling fees determined by the producer community of its choice, which Rinki invoices the companies and accounts to the producer communities. In addition to the recycling fees, a company has still in 2023 paid a one-time Rinki's joining fee and a customer fee, which Rinki has invoiced as authorized by the producer associations. However, this will change from the beginning of 2024. The packaging recycling fees, and the customer fee are based on the price list and the amount of packaging used by the company in the previous year, if the company reports to Ring. The prices applicable in 2023 will be determined according to the recycling fee price list of the producer community with which the company has an agreement. In addition, when joining, the company pays a one-time RINKI Oy joining fee and an annual customer fee. These different fees and recycling costs for wooden materials are listed in Table 10. The case study company wood waste consists almost exclusively of the "other wooden pallets and other wood packages"-category in Table 10. The recycling fees cover the recycling of the packaging that the company puts on the Finnish market and the collection of consumer packaging in Finland. The collection of packaging waste from the company's property is not included in the fees (Suomen Pakkauskierrätys RINKI Oy, 2024). Currently, the case study company pays around 400€ per each wood waste transportation (Keisa, 2024).

Table 10. (Suomen Pakkaustuottajat Oy, 2024) Recycling prices 2024 Suomen Pakkaustuottajat Oy (ALV 0 %)

Material group	Material	Recycling costs 2024	
		Consumer packages	Business packages
		€/ton	€/ton
Wood	Marked Fin-, Eur, or EPAL-pallets, rental pallets, cable reels		1.70
	Other wooden pallets and other wood packages	2.2	2.2
Business service fee (per contract)		1.20 €/ton	
Fee at least		100 €/per contract/year	
Fee at most		4 500 €/per contract/year	

6.7 Transportation prices

When transporting big packages, the transport must be marked as special transport. The transport is marked as special transport if the transport exceeds the dimensional limits permitted for normal traffic. In this case, the transport doesn't require special transport permit. However, if the transport exceeds free dimensional limits or permissible masses for normal traffic, then the transport requires a special transport permit. A visualization of these dimensional limits is showcased in Figure 25 (Centre for Economic Development, Transport and the Environment, 2023).

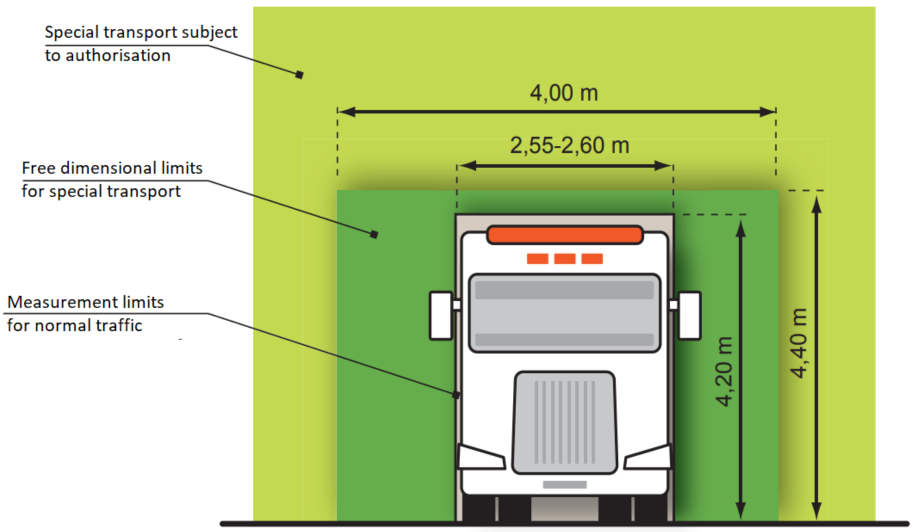


Figure 25. (Centre for Economic Development, Transport and the Environment, 2023) Measurements for different transport sizes

The special transport permit is granted by the Finnish Road Administration in mainland Finland. The permit can be granted for predefined routes or individual routes. The application for permit must specify the vehicles and trailers to be used, the load of the transport, and the dimensions and masses. Abnormal transport permit for transport when transports weights doesn't exceed the permitted weight is allowed in normal traffic in Finland has the following costs (Centre for Economic Development, Transport and the Environment, 2023):

- Transports height doesn't exceed 7 m or width doesn't exceed 6 m: 60 €.
- Transports height exceeds 7 m or width exceeds 6 m: 100 €.

Abnormal transport permit for transport when axle, bogie or total weight exceeds the authorized weights is allowed in normal traffic in Finland has the following costs (Centre for Economic Development, Transport and the Environment, 2023):

- Total weight of the transport doesn't exceed 120 tons: 120 €.
- Total weight of the transport exceeds 120 tons but is 200 tons at most: 180 €.
- Total weight of the transport exceeds 200 tons: 510 €.
- Pre-decision of transport possibility: half the price of the permit.
- Supervised bridge crossing, in addition to price of the permit 375 €.
- Cancelled or unused supervised bridge crossing: 188 €.
- Permit not admitted: 50 €.

7 AHP for wood waste analysis

Evaluating different solution models for problems similar with the one discussed in this thesis is complex due to several different criteria and parameters that need to be compared. This might prove challenging especially if some of those criteria don't have numerical values to compare with, for example handling safety or applicability. Analytic Hierarchy Process (AHP) brings a systematic approach to this problem and gives a simple way to compare different criteria and set the necessary values for them. AHP is an analysis method that can be applied in multi-criteria decision making. It enables the comparison of both concrete and conceptual factors, and it makes it easy to create comparable numerical values even for criteria that are difficult to visualize. AHP enables a clear understanding of the structures of the decision and the problem area and facilities the consideration of risks and uncertainties. The decision-making proves according to the AHP-model can be facilitated with various computer programs that help with the mathematical processing of the model and the documentation of the decision-making process. The AHP-model is well-known and is widely used as a decision-making aid. (Mind Tools, 2023)

The decision-making process according to the AHP model can be divided into three different stages as follows:

1. Divide the problem into parts and describing them as a hierarchy.
2. Determine the weight values of the criteria.
3. Define the relationships between selected options and criteria.

In the first stage, a hierarchy is created, and the problem is divided into manageable parts. Usually, dividing the problem into parts and describing it as a hierarchy starts with the general goal of the decision and continues logically with the definition of more detailed criteria, but the reverse order is also a possibility. The hierarchy can therefore be built, from the top down or from the bottom up. As a result of the first stage, a hierarchy structure is created, in which mutually comparable issues are presented by level. The hierarchy is usually visualised for easier understanding and realizing the connections between different chosen criteria. An example of this is shown in Figure 26, where the research problem of this thesis is visualized in the AHP format. (Mind Tools, 2023).

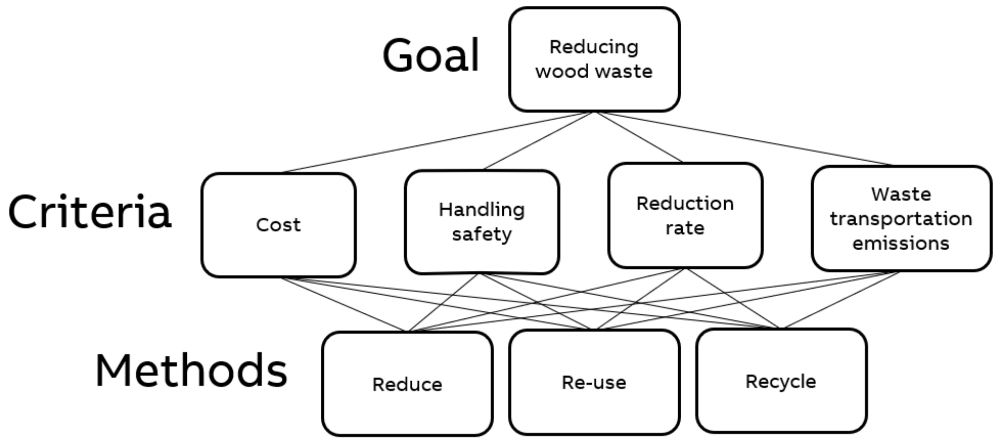


Figure 26. Example of a visualized AHP-hierarchy

In the second step, criteria at the same level in the hierarchy are compared to each other. The comparison is made in pairs by always comparing two criteria with each other and giving assessment verbally and/or numerically. The weights of the criteria are defined with the help of pairwise comparisons. The numbers from 1 to 9 are used in the pairwise comparison. The number 1 means that the criteria are equal in importance, while the number 9 means that one criterion is significantly more important that the other. The numbers in between these are used in moderate, strong or very strong importances. The rating scale is considered functional and adapts to a person's natural way of making ratings between two different things (Mind Tools, 2023).

In the third stage, the relationship between the selection options and the criteria is defined. This is done as a pairwise comparison between the different selection options, and based on this pairwise comparison, the order of priority of the options is calculated. Pure numerical values can also be used as a basis for comparing selection options (Mind Tools, 2023). The values for the Figure 27 are obtained from an interview with company subject matter experts.

	Cost	Handling safety	Reduction rate	Waste transportation emissions
Cost	1/1	1/5	1/7	1/2
Handling safety	5/1	1/1	1/2	5/1
Reduction rate	7/1	2/1	1/1	5/1
Waste transportation emissions	2/1	1/5	1/5	1/1
Total	15/1	17/5	129/70	23/2

Figure 27. Total of each column

A matrix is created as the result of the pairwise comparison that defines the weights of the criteria. Based on the matrix, reduction rate for the wood is rated seven times as important as cost, twice as important as handling safety and five times as important as waste transportation emissions. Other criteria have also been evaluated in a similar way (Mind Tools, 2023).

The weights of the criteria are calculated using matrix calculations. Different steps of this calculation are shown in Figures 28 and Figure 29. The sum is calculated for each column of the matrix. After this, the matrix is normalized by dividing all the elements of the matrix column-wise by the sum calculated in the first step. After this, the sum of all columns of the normalized matrix is one.

	Cost	Handling safety	Reduction rate	Waste transportation emissions
Cost	1/15	1/17	10/129	1/23
Handling safety	1/3	5/17	35/129	10/23
Reduction rate	7/15	10/17	70/129	10/23
Waste transportation emissions	2/15	1/17	14/129	2/23
Total	1	1	1	1

Figure 28. Normalized columns

After normalizing the columns, we can take the average value of each column to form the weight value for each criterion.

Cost	1/15	1/17	10/129	1/23	0.062
Handling safety	1/3	5/17	35/129	10/23	0.333
Reduction rate	7/15	10/17	70/129	10/23	0.508
Waste transportation emissions	2/15	1/17	14/129	2/23	0.097

Figure 29. Weight values of each row

With these calculations, we get the final weight values for each criterion. The weight of costs is 0.062, the weight of handling safety is 0.333, the weight of reduction rate is 0.508 and the weight of waste transportation emissions is 0.097. The percentage values for these weight values are shown in Table 11.

After the values for these criterions are determined in the case study, the different cases are compared with a comparison matrix using the same 1-9 rating scale. From there, the priority vector is calculated for each different criteria per case. There different priority vectors are then multiplied by the weight value of each criterion, creating the points of each case. Finally, each cases own points are summed and compared amongst themselves, to determine the most optimal case according to this study. A more detailed description of this process is shown in chapter 8.3.

8 Case study

This chapter will focus on the case study conducted on case study company regarding methods of reducing wood waste. The case study will be done using the AHP-method, and utilizing the criteria, which were calculated on chapter 7. In this case study, five different development methods were chosen. These are same as the methods discussed in chapter 5, with the reuse and recycle methods split to short-distance and long-distance options.

8.1 AHP Criteria

Different criteria are used to evaluate three chosen methods. These criteria have been determined to have the most impact on the choice of the method. The criteria chosen are, in no particular order, cost, handling safety, (wood) reduction rate, and waste transportation emissions. Using the AHP-method, these criteria are given percentage values, shown in Table 11, to correspond to their importance in the choice of method. The calculation for the percentage values was explained in chapter 7.

Table 11. Percentage weight values of different criteria

Criteria	Weight value
Cost	6.2%
Handling safety	33.3%
Reduction rate	50.8%
Waste transportation emissions	9.7%

8.1.1 Cost

This criterion is the fourth most important and it includes the increase or decrease in costs, when adapting the chosen method. The cost can consist of, for example, transportation costs and storage fees. This also includes any other increase or decrease in parameters that can correlate to costs, for example working hours. The cost can be negative, if the wood waste is sold to different company as raw material. The different costs and fees used in the calculations of this case study are discussed below, with a collection average fees and costs are shown in Table 12.

A part of the cost analysis is the transportation fees. Due to the packages big size, these fees can increase exponentially, especially when delivering them overseas. According to the conducted interviews, normal transportation and special transportation fees inside Finland are around 2 €/km and 10 €/km respectively. When transporting these packages overseas to Germany, Travemünd, the travelled distance is around 1300 km. The fees for normal transportation and special transportation are around 1 €/km and 7 €/km respectively. These transportation fees include handling and storing of transported packages (Mandelin, Kuljetusturvallisuus ja -kustannukset, 2024).

When looking at the cost of a package, two factors must be studied, the cost of raw materials and the cost of labour. As of writing of this thesis, one lumber plank used in these packages' costs around 2.5 €/m. The average density of planks used in the packages is around 370 kg/m^3. Looking at the volume and the density of one plank, we get an average price of 1.4 €/kg for plank (STARK Suomi Oy, 2024). With these, we estimate a material cost for one package to be around 1300€. For the labour costs, average hour of warehouse workers pay is 40€. The time to construct the package is around 16 hours. This would mean that the average cost of making the package is around 640€ in labour (Mandelin, Kuljetusturvallisuus ja -kustannukset, 2024). We can use the amount of generated waste to calculate an approximation of the number of packages delivered during the 6-month period. With a total of 30 000 kg of wood waste in 6-months, and a package weight of 900kg, we get around 33 packages.

According to the recycling prices from Table 10, Suomen Pakkaustuottajat Oy charges business 2 € per ton of wooden packages. They also charge business service fee, which is 1 € per ton, with minimum and maximum price of 100 € per year and 4 500 € per year respectfully. Using the example of 8 000 kg of recyclable wood, we get the recycling price of approximately 16.4 € per wood waste transportation. If we use approximation of 60 000 kg of wood waste recycled per year, this will mean that the total cost of recycling in one year is 230 €. This includes the minimum price of business service fee.

Storage space must be built or rented to keep packages, that are deemed reusable, in good condition. Packages that are not stored properly, can become unusable quickly. Renting a storage cost around 8€/m^2/month. The storage space must also be big enough, to house multiple packages and to have room for the appropriate equipment needed to move these packages around. Because of these requirements, a minimum of 50 m^2 storage space was decided.

Lastly, there are minor cost differences depending on how the recycling station uses the wood waste. There are two main ways of use: energy production and utilization as a raw material. As of writing of this thesis, the cost to utilize the wood waste as a raw material costs the provider of the waste around 60 € per ton of wood waste. As for the energy production, due to the high demand of wood as an energy source, recycling stations are willing to pay for it. Currently, the price of energy wood is around 15 € per ton. In reduce and reuse methods, the wood waste is assumed to be used in energy production. In recycle methods however, it is assumed that the wood waste is utilized as a raw material.

Table 12. Different costs and fees

Labour costs	40 €/h
Transportation fees, Finland	2 €/km
Transportation fees, abroad	1 €/km
Storage fees	8 €/m²/month
Wood costs	1.4 €/kg
Waste collection costs	400€
Utilization costs	60€/ton
Energy production costs	-15€/ton

Using the values from Table 12, we can calculate the current costs for wood waste. With a waste collection weight of 8000 kg and a package weight of 900 kg, we estimate an average of 9 packages per collection. We also estimate the number of these collections to be around 3.75 during the observation period. Table 13 demonstrates these cost calculations. Similar tables are presented at the end of each method. The presented numbers are rounded, but accurate numbers are used in calculations.

Table 13. Cost calculations

Cost or fee	Equation	Final cost
Material costs	$Package\ weight\ (kg) \div Wood\ density\ \left({}^{kg}/_{m^3}\right) \div Volume\ of\ plank\ (m^3) \times Price\ of\ plank\ (€)$	1300€
Labour costs	$Hours\ of\ work\ (hr) \times Wage\ per\ hour\ \left({}^{€}/_{hr}\right)$	640€
Cost of one package	$Material\ costs\ (€) + Labour\ costs\ (€)$	1940€
Total costs of packages	$Cost\ of\ one\ package\ (€) \times Number\ of\ packages$	64 000€
Waste collection costs	$Cost\ of\ one\ waste\ collection\ (€) \times Number\ of\ waste\ collections$	1500€
Total energy production costs	$Energy\ production\ costs\ \left({}^{€}/_{1000\ kg}\right) \times Wood\ delivered\ (kg)$	-450€
Total current costs	$Total\ costs\ of\ packages\ (€) + Waste\ collection\ costs\ (€) + Total\ energy\ production\ costs\ (€)$	65 000€

8.1.2 Handling safety

Handling safety is the second most important criteria. It is affected by the size, shape, and condition of the package, and the transportation method. From the chosen criteria, this is the only one which doesn't include any metric value. This means that the criterion is mostly define by empiric research and the statistical values, for example how many injuries or accidents occur during the chosen period. Whenever any accident or injure occur, the cause should be determined and documented to help give insight on the possible design errors and other mistakes that can cause a decrease in handling safety.

When determining the handling safety, multitude of factors need to be studied. This includes but is not limited to binding and jointing methods, and handling and dismantling of the packages. These factors affect the transported products ability to stay in the boxes on the transportation platforms and undamaged during transport, the packages' ability to be closed safely and the packages stability during transportation.

8.1.3 Reduction rate

This criterion is the most important one and is one of the core ideas behind this thesis. This criterion is determined by the amount of reduction in wood waste. In this case study, this reduction is defined in couple of ways.

First one is to utilize the wood waste in follow-up procedures. The case study company is looking into other ways to utilize their wood waste rather than using it in energy production. Preferably, they want that the wood waste would be utilized as a raw material in different industries, for example construction industry or wood products industry. So, if the wood can be sold or utilized as a raw material in follow-up procedures rather than as a fuel in energy production, it is not considered waste for the purpose of this analysis. Currently, wood used in energy production is paid for, while using the wood in follow-up procedures the supplier of the wood must pay to the recycling centre.

Second one is to reuse used packages and utilizing wood from used packages in repairs. If wood from another package is used in repairs and thus returned into circulation, it is no longer considered waste. And if the whole package can be reused, all the waste generated from that package is negated. The limiting factor of this option is discussed in chapter 5.2.

Third and final is to reduce the incoming amount of wood. This is accomplished by reducing the wood in the packages. In practice, this is the most straightforward way to reduce the amount of generated wood waste. But like all the previously mentioned criteria in this chapter, this also has its drawbacks. These are the potential reduction is handling safety and increase in costs of manufacturing these packages.

8.1.4 Waste transportation emissions

This criterion is the third most important consists primarily of the amount of CO_2 emissions that are released during the transportation of the wood waste.

This also includes the emissions generated when the wood waste is delivered to its utilization destination. The CO_2 emissions are determined by the weight of the transported cargo compared to the carbon emissions. According to numerous tests conducted by carmakers, environment agencies and traffic management authorities, every 5% increase in weight results in a 2% increase in fuel consumption (Changaroth, 2020). The Fuel economy factor, heating values and emission factors used in the calculation are found in Table 14.

$$Fuel\ Used = Distance \times Fuel\ Economy\ Factor \times \left(1 + \frac{0.4 \times Cargo\ weight}{Truck\ weight}\right)$$
$$CO_2\ \ Emissions = \ Fuel\ Used \times Heating\ Values \times Emission\ factor$$
$$Total\ Emissions = CO_2\ \ Emissions\ \ \times Number\ of\ transportations$$

Table 14. (Partnership, 2024) Variables used in the equation

Fuel Economy Factor	33.6 Litres /100 km
Heating Value	0.04 GJ / Litre
Emission Factor	74 kg CO_2 / GJ

In the methods detailed below, the wood waste is first delivered to the recycling station in Kouvola. From there it has three different destinations, depending on the method. In reduce and reuse methods it is delivered to Keltakangas. In Recycle local it is delivered to Jyväskylä. And finally, in Recycling abroad, it is delivered to Riga.

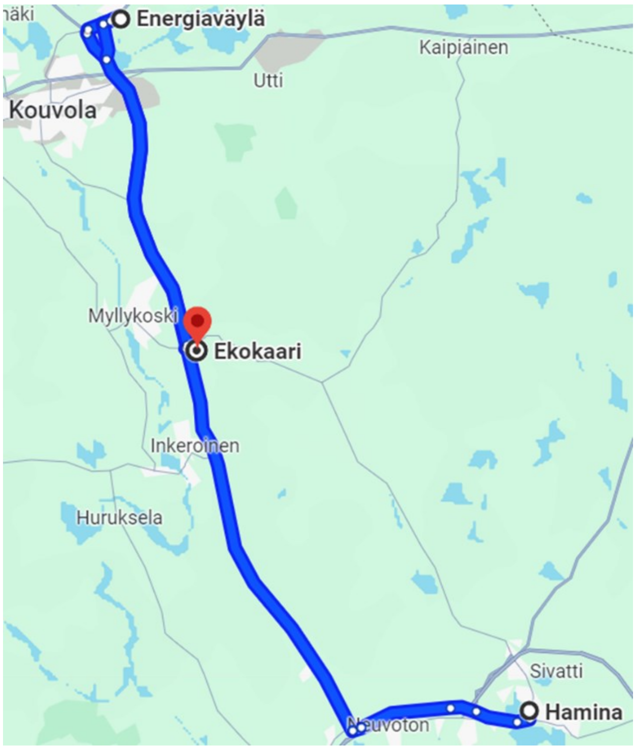


Figure 30. Example route for transporting wood waste to the current recycling station and from there to power plant

Using this example route and current waste amounts and collection times, we can calculate the current CO_2 emissions.

$$Fuel\ Used = 77\ km \times 33.6\ \frac{Litres}{1000\ km} \times \left(1 + \frac{0.4 \times 8000\ kg}{36\ 300\ kg}\right) = 28\ Litres$$

$$CO_2\ \ Emissions = \ 28\ Litres \times 0.04\ \frac{GJ}{Litre} \times 74\ \frac{kg\ CO_2}{GJ} = 83\ kg\ CO_2$$

$$Total\ Emissions = 83\ kg\ CO_2 \times 3.75 = 310\ kg\ CO_2$$

8.2 Analysing AHP cases

In this case study, we will analyse and discuss five chosen methods using the AHP-method. The methods in this case study are chosen because they present feasible solution to the challenges mentioned in this thesis. They all offer unique ways to reduce the wood waste, while offering competitive variables to the criterion discussed in chapter 8.1. The methods presented in this chapter are introduced and given a brief description in Table 15. More detailed description of each method is given at the beginning of their corresponding chapter.

The analysis will focus on the four criteria previously established and examine their changes depending on the chosen method. It should be noted that the values presented in this case study are theoretical values, as these values include multitude of variables, and are in some cases interlinked. The changes in criterion in these methods are shown at the end of each chapter below in the Tables 17, 19, 21 ,23, 25, and 26, with Table 26 compiling all these changes into one table.

Table 15. Chosen methods and their description in order of appearance

Method	Description
Reducing wood waste	Reducing the amount of wood used in the custom-made packages
Reusing wood waste, local	Reusing the custom-made packages as products, inside of Finland
Reusing wood waste, abroad	Reusing the custom-made packages as products, outside of Finland
Recycling wood waste, local	Recycling the wood waste as raw material, inside of Finland
Recycling wood waste, abroad	Recycling the wood waste as a raw material, outside of Finland

8.2.1 Reducing wood waste

This chapter looks at ways to reduce the wood required in the custom-made packages that the case study company uses. The object of this method is to reduce the amount of wood in these packages, while keeping them strong enough to withstand the transportation and keep the transported product safe and unharmed. This is done by replacing the sides of the package with thinner plywood plate. This reduces the amount of wood used in the package, while keeping the form of the package untouched.

Before this thesis, the case study company had conducted internal investigation on the possibility of reducing the wood from packages through optimization. For example, the azimuth shaft was previously transported in a package. However, this was deemed unnecessary. Bonding the shaft to the bottom pallet makes it much more secured and safer for transport. The shaft can then be covered with protective plastics, giving it protection from water and other harmful substances. The packages must be made with the accordance of ISPM 15 standard.

The wooden package used in this case study has weight of 900 kg and consists almost solely of wood. As of writing of this thesis, an average price of spruce plank is around 500 €/m^3, and the density of normal spruce plank is around 370 kg/m^3. This gives us price of around 1300 € per wooden package in raw materials. If the walls of packages are replaced with plywood, the amount of lumber is reduced in the package. This would reduce it to around 680 kg, a 25% reduction. Using the same cost for lumber plank, we have a cost of around 980 € per wooden package (STARK Suomi Oy, 2024). Reducing the size of the package would also reduce the work hours used to construct the packages. As mentioned in chapter 8.1.1, the average time to construct the current package is around 16 hours. Reducing the size of the package would not reduce the assembly time on the same scale, but we can approximate a reduction of around 2 hours of work per package. This would bring the labour cost of constructing the package to be around 560€.

The wood waste is collected from Hamina every couple of months. The size of this waste collection is around 8000 kg. With the weights of old and new package being 900 kg and 680 kg respectively, around 9 and 12 of those packages could fit in these waste transportations respectively. An average of 30 000 kg waste is transported in six months. This means that there are an average of 3.75 waste collections per six months, and that it takes an average of 48 days per waste collection. If the wood waste generated by the packages is reduced by 25%, the number of these waste collections would decrease to 3 waste collections per six months. The number of days per collection would then be 60. Because the amount of waste collections is reduced by approximately 25%, the waste transportation emissions are also reduced by roughly the same amount. This also applies to the total amount of costs related to these collections. The collection of wood waste costs around 400 €. Four collections in six months would cost around 1500 €. If these transportations are reduced to 2.8, the final cost of waste transportations would be 1100 €. The cost calculations are shown in Table 16.

Table 16. Cost calculations for Reducing wood waste

Cost or fee	Equation	Final cost
New material costs	$Package\ weight\ (kg) \div Wood\ density\ \left({}^{kg}/_{m^3}\right) \div Volume\ of\ plank\ (m^3) \times Price\ of\ plank\ (€)$	1000€
New labour costs	$Hours\ of\ work\ (hr) \times Wage\ per\ hour\ \left({}^{€}/_{hr}\right)$	560€
New cost of one package	$New\ material\ costs\ (€) + New\ labour\ costs\ (€)$	1560€
New total costs of packages	$New\ cost\ of\ one\ package\ (€) \times Number\ of\ packages$	51 000€
New waste collection costs	$Cost\ of\ one\ waste\ collection\ (€) \times New\ number\ of\ waste\ collections$	1100€
New total energy production costs	$Energy\ production\ costs\ \left({}^{€}/_{1000\ kg}\right) \times New\ wood\ delivered\ (kg)$	-300€
New total costs	$New\ total\ costs\ of\ packages\ (€) + New\ waste\ collection\ costs\ (€) + New\ total\ energy\ production\ costs\ (€)$	51 800€
Difference	$New\ total\ costs\ (€) - Total\ current\ costs\ (€)$	-13 400€

The recycling station that the case study company uses is approximately 55 km away from their production line. From there, distance to power plant that uses the wood waste as an energy source is around 22 km away. An example route to this recycling station is shown in Figure 30. Using the example of 8000 kg waste collection, we can calculate the amount of CO_2 emissions generated by this transportation. The emissions can be calculated using the fuel usage of the truck and used fuels heating value and emission factor. Using the approximated distance of 77 km, and Fuel economy factor for heavy diesel truck, 33.6 Litres/100km, we get fuel usage of 26 litres. According to numerous tests conducted by carmakers, environment agencies and traffic management authorities, every 5% increase in weight results in a 2% increase in fuel consumption (Changaroth, 2020). The truck used in this example weights around 36 300 kg without cargo. When we add the cargo, that is 8000 kg, the trucks weight is increased around 22%, meaning that the fuel usage is increased by around 8%. Thus, new fuel usage is 28 litres.

Next, CO_2-emissions are simply calculated using fuel multiplied by the fuels heating value, 0.04 GJ/Litre, and emission factor, 74 kg CO_2/GJ. This gives us an estimate of 83 kg CO_2 produced during the wood waste transportation. With the estimated cargo of 8000 kg of wood waste, we can calculate around 7.5 grams of CO_2 emissions per kilogram of wood waste. If the amount of these transportations during 6 months can be reduced from 3.75 to 2.8, the amount of CO_2 emissions generated during these 6 months can be reduced by the amount of one of these transportations, meaning a 25% reduction (Partnership, 2024).

$$Total\ Emissions = CO_2\ \ Emissions\ \times Number\ of\ transportations$$
$$= 83\ kg\ CO_2 \times 2.8 = 234\ kg\ CO_2$$

Table 17. Criteria change in the reduce method

Description	Reducing the amount of wood used in the custom-made packages			
Criteria	Cost	Handling safety	Reduction rate	Waste transportation emissions
Change	-13 400.00 €	Marginally lower	25%	-25%

8.2.2 Reusing wood waste, local

This chapter handles the reusing of wood waste. More precisely, how can the used custom-made wooden packages be reused as a product, rather than as a raw material. This is achieved by handling and opening the packages in careful and non-damaging way so that they can be used again. At the same time, too much damaged packages are repaired using packages with the same material and build. With these measures, the used packages would never become wood waste. This chapter also looks at a way to accomplish this objective near the case study company within Finland

Although the case study company recycles all the standard pallets and boxes, it faces couple challenges with the reuse of their custom-made wood packages. First challenge is their reusability in general. The platform used in the transport of azimuth blade is unique for each different blade. Because of this, the platform can rarely be used again in different blades transport. Thus, the platform turns into wood waste.

Secondly, the used wood packages are not stored properly. Due to the lack of inhouse storing, the used packages and pallets are stored mostly outside. This means that they are subject to harsh weather conditions, thus becoming unusable wood waste. The case study company would have to pay the rent and/or construction of these warehouses in the package's destination and at the manufacturing location (Mandelin & Mäkinen, ABB Hamina vierailu, 2023).

Thirdly, if the case study company wants to reuse these custom-made packages, they must first be shipped pack to the supplier. The case study company must arrange and pay the return of the used packages. The challenges arise from the packages size and their general reusability. Shipped packages can reach sizes of around 15m^2. Because of the packages size, the transport requires escort cars warning oncoming traffic. This increases the costs substantially. The packages are also designed to be used only once. This means that these custom-made packages are forced to open in a way that usually led the package to become unusable. Although not covered in this thesis, the packages should be designed in a way that makes reusing them easier to accomplish better rates in reusability.

The average cost of storage space that the case study company could utilize is around 8 €/m^2/month. It should be noted that the storage must be large enough to house multiple large packages at the same time. Since the packages can't be moved by hand, any equipment used to move these packages must also be operatable there. Still, the cost calculations consider only how much the package increases the storage costs. Thus, the cost of renting storage space for six months would cost around 2400 €. There are other factors to be considered as well, such as the infrastructure at the storage location, available and/or usable equipment at the storage, and any necessary renovation to the space to meet the standards of the case study company to name a few. This would inevitably raise the price of the storage, but negotiations are always an option to reach suitable agreement between the parties.

Repairing the packages requires work hours. We can approximate that the same amount of time goes to disassembling the package used in repairs and repairing the package as it takes to build a new one. Because we are repairing one third of the package, the amount of time used is also around the same. So around 5.3 hours to disassemble the package, and 5.3 hours to repair the package. This means that repairing a package takes around 10.6 hours total. Thus, the cost of one repaired package in labor is around 400 €. The cost calculations are shown in Table 18.

Table 18. Cost calculations of Reusing wood waste, local

Cost or fee	Equation	Final cost
Repair costs	$Hours\ of\ work\ (hr) \times Wage\ per\ hour\ \left(€/_{hr}\right)$	400€
New waste collection costs	$Cost\ of\ one\ waste\ collection\ (€) \times New\ number\ of\ waste\ collections$	900€
New total energy production costs	$Energy\ production\ costs\ \left(\frac{€}{1000\ kg}\right) \times New\ wood\ delivered\ (kg)$	-280€
Storage costs	$Storage\ rent\ fee\ \left(\frac{€}{m^2 \times day}\right) \times Storage\ size\ (m^2) \times Renting\ time\ (day)$	2400€
Total new costs	$Total\ costs\ of\ packages\ (€) + New\ waste\ collection\ costs\ (€) + New\ total\ energy\ production\ costs\ (€) + Storage\ costs\ (€)$	68 000€
Difference	$New\ costs\ (€) - Current\ costs\ (€)$	3500€

To make sure that the packages stay reusable after unpacking, the packages must be unpacked carefully and any damages to the package must be repaired according to the ISPM 15 standard. This would inevitably raise the costs because of additional work hours that are generated due to the procedures. This also has the potential to affect the handling safety of these reused packages, as they would most likely be not as durable as brand-new packages.

EUR and FIN pallets can be reused five to ten times before they can become unusable (European Union, 2019). Because the packages in this case study are subject to large forces, we use the lowest number of possible reuses. However, as found out in conducted visits to production at Hamina, most packages cannot be reused efficiently. Because of this, we approximate that only 10% of the packages can be reused this efficiently. The rest of the packages could be used to repair the reusable ones. According to the ISPM 15, no more than one third of the package can be replaced to make the package serviceable again without retreating the package. Although it is unlikely that a package is repaired to this extent, we can use this value as the theoretical absolute maximum. This would give us a theoretical maximum of 38% reduction in wood waste. This would mean that the material cost of packages would be reduced by approximately the same amount. Using the same number of days per wood waste collection as before, we get around 77 days per waste collection, lowering the amount of these collection per 6 months to approximately 2.3. The waste transportation emissions generated during that 6-month period would then be 38% lower.

$$
\begin{aligned}
Total\ Emissions &= CO_2\ \ Emissions\ \times Number\ of\ transportations \\
&= 83\ kg\ CO_2 \times 2.3 = 191\ kg\ CO_2
\end{aligned}
$$

Table 19. Criteria change in the reuse, local method

Description	Reusing the custom-made packages as products, inside Finland			
Criteria	Cost	Handling safety	Reduction rate	Waste transportation emissions
Change	3500 €	Slightly lower	38%	-38%

8.2.3 Reusing wood waste, abroad

This method handles same principles as the last method. The difference is the area of possible reusing method. While the last chapter looked at possibility of reusing the packages in Finland, this method focuses on reusing them of abroad transportation. More precisely, sending the used packages pack to their sender for possible reuse.

The difference between this and the previous scenario is the length of the journey. This means that the waste transportation emissions will be bigger compared to reusing the close by. Handling safety will also decrease due to the same reason. Reusing packages could reduce costs for transportation, but compared to reusing them on short deliveries, more time must be allocated to make sure that the packages are safe enough for oversea delivery. This could increase costs. Same as reusing packages on short distance transports, a better storage system must be developed for the used packages. This would mean either making room in the current storage space for packages or building new storage for them. From these choices, the new storage building would be more useful, although costing more in the short term, reorganizing current storage space to accommodate for the used packages would interfere with manufacturing too much.

Same as in the previous section, some form of a storage space would be required to store the used packages. The size of the package and rental/construction time would be around the same as before.

Because the packages must be strong and durable enough to withstand oversea delivery, the rate of reusability is going to be lower. Because of the high standards of seaworthy packaging, we approximate that half of the reusable packages aren’t fit for oversea delivery, so around one twentieth can be reused with the same reusability rate of five times. At the same time, we can approximate the same requirements and standards for repairing the packages as in the previous method. With these new conditions, the theorical maximum reduction rate is approximately 36%. As with previous section, we get around 77 days per waste collection, lowering the amount of these collection per 6 months to be approximately the 2.4. The waste transportation emissions generated during that 6-month period would then be 35% lower. The cost calculations are shown in Table 20.

Table 20. Cost calculations Reusing wood waste, abroad

Cost or fee	Equation	Final cost
Repair costs	$Hours\ of\ work\ (hr) \times Wage\ per\ hour\ \left({€}/{hr} \right)$	400€
New waste collection costs	$Cost\ of\ one\ waste\ collection\ (€) \times$ $New\ number\ of\ waste\ collections$	900€
New total energy production costs	$Energy\ production\ costs\ \left(\frac{€}{1000\ kg} \right) \times New\ wood\ delivered\ (kg)$	-280€
Storage costs	$Storage\ rent\ fee\ \left(\frac{€}{m^2 \times day} \right) \times Storage\ size\ (m^2)$ $\times Renting\ time\ (day)$	2400€
Total new costs	$Total\ costs\ of\ packages\ (€) + New\ waste\ collection\ costs\ (€) +$ $New\ total\ energy\ production\ costs\ (€) + Storage\ costs\ (€)$	68 000€
Difference	$New\ costs\ (€) - Current\ costs\ (€)$	3500€

$$Total\ Emissions = CO_2\ \ Emissions\ \times Number\ of\ transportations$$
$$= 83\ kg\ CO_2 \times 2.4 = 199\ kg\ CO_2$$

As with the reduction rate, handling safety follows many of the same observations as in the previous section. Longer transportation distance, and the possibility of sea transport means that the package must be more secure and strong to withstand these conditions. Thus, unloading of the truck, moving these packages, and opening these packages is going to require stronger methods and operations. These increase the risk of any accidents.

Table 21. Criteria change in the reuse, abroad method

Description	Reusing the custom-made packages as products, outside of Finland			
Criteria	Cost	Handling safety	Reduction rate	Waste transportation emissions
Change	3500 €	Lower	36%	-35%

8.2.4 Recycling wood waste, local

This chapter and the next handles the recycling method. This method focuses on recycling the wood waste. More precisely, recycling the wood waste as a raw material, not to be used in energy production. And same as in the previous methods, this method is divided into two subcategories, local and abroad. This chapter focuses on recycling the wood waste in Finland, preferably near the manufacturing. The form of utilization looked upon in this method is composting and landscaping in Jyväskylä.

According to the interview conducted with the recycling company, almost all the delivered wood waste form packages can be utilized as a raw material. In this method, the wood waste would be utilized as a supporting material for composting or landscaping. In this utilization, a large amount of the wood waste can be recycled. Thus, an approximation of 90% utilization rate will be used. This rate is directly proportional the reduction rate of this method (Keisa, 2024).

The important difference in recycling methods compared to other methods is the price of wood waste. As of writing of this thesis, wood used in energy production is in high demand. Energy production companies are willing to buy it at a price of around 15€/ton of wood waste. And as discussed in chapter 8.1.1, companies must pay around 60€/ton to have their wood waste utilized. Thus, changing the use of wood waste nets a cost increase of around 75€/ton of wood waste. The cost calculations are shown in Table 22.

Table 22. Cost calculations Recycling wood waste, local

Cost or fee	Equation	Final cost
Recycling cost	$Utilization\ fee\ \left(\frac{€}{1000\ kg}\right) \times Wood\ delivered\ (kg)$	1800€
Difference in wood waste costs	$Recycling\ cost\ (€) - Energy\ production\ costs\ (€)$	2300€
Total new costs	$Total\ costs\ of\ packages\ (€) + Waste\ collection\ costs\ (€) + Difference\ in\ wood\ waste\ costs\ (€)$	67 000€
Difference	$New\ costs\ (€) - Current\ costs\ (€)$	2300€

Handling safety during the waste transportation depends mostly on the condition of the used packages and their transportation conditions. Thus, with proper storing and handling of used packages, the handling safety can be increased. As mentioned previously, opening and handling used packages so that they can be packed efficiently and safely will decrease the number of possible accidents and other injuries. However, these procedures would inadvertently raise costs due to increased work hours per opened package. In this method, because the changes in handling of these wastes is like the current situation, the handling safety also stays on similar level.

In this scenario, the wood waste is delivered to the same recycling station as it is currently delivered to. However, the difference is that the wood waste is not used in energy production, but as a raw material for new products. Thus, the waste is delivered to other destination from the recycling centre. In this scenario, the waste is delivered to Jyväskylä, giving the distance that the waste must travel, before it can be utilized, to be around 250 km (Keisa, 2024).

Figure 31. Example route for transporting wood waste to the current recycling station and from there to Jyväskylä

Using an example route shown in Figure 31 with the distance of 250 km from Hamina to Kouvola to Jyväskylä, and Fuel economy factor for heavy diesel truck, 34 Litres/100km, we get fuel usage of 84 litres. Due to the weight increase, the fuel usage is increased to 91 litres. With the same the fuels heating value and emission factor of, 0.04 GJ/Litre and 74 kg CO_2/GJ respectively, we get an estimation of 270 kg CO_2 produced during the wood waste transportation. Compared to the current waste transportation emissions, this is an increase of 225%, 180 kg CO_2. And finally, with the estimated cargo of 8000 kg of wood waste, we can calculate around 34 grams of CO_2 emissions per kilogram of wood waste. With the example of 30 000 kg wood waste transported during 6-month period, we can calculate an estimate of 1000 kg CO_2 during that 6-month period (Partnership, 2024).

$$Fuel\ Used = Distance \times Fuel\ Economy\ Factor \times \left(1 + \frac{0.4 \times Cargo\ weight}{Truck\ weight}\right)$$

$$= 250\ km \times 34\ \frac{Litres}{100\ km} \times \left(1 + \frac{0.4 \times 8000\ kg}{36\ 300\ kg}\right) = 91.4\ Litres$$

$$CO_2\ \ Emissions = \ Fuel\ Used \times Heating\ Values \times Emission\ factor$$

$$= \ 91.4\ Litres \times 0.04\ \ \frac{GJ}{Litre} \times 74\ \ \frac{kg\ CO_2}{GJ} = 270\ kg\ CO_2$$

Table 23. Criteria change in the recycling, local method

Description	Recycling the wood waste as raw material, inside Finland			
Criteria	Cost	Handling safety	Reduction rate	Waste transportation emissions
Change	2300 €	Unaffected	90%	225%

8.2.5 Recycling wood waste, abroad

This chapter looks at ways to recycle the wood waste as raw material. And as with the chapter 8.2.3, this method focuses on recycling the waste abroad, and not in Finland. The form of utilization looked upon in this method is use in chipboard industry in Riga, Latvia.

In this scenario, the wood waste is utilized abroad. Like the previous method, the wood waste is delivered the same recycling station. However, this time it is delivered to Riga, Latvia for utilization. This is because chipboard industry is still small in Finland and can't reliably utilize large amounts of wood waste in its manufacturing.

For reduction rate, same changes can be achieved as in previous section. However, when the wood waste is used in chipboard industry, the manufacturers are stricter with the condition and quality of the wood. This means that the waste can't be utilized as effectively as in other utilization methods. According to the conducted interview, around 80% utilization rate can be achieved. And as in previous method, this utilization rate is directly proportional to the reduction rate (Parviainen, 2024).

Cost follows same changes as in the previous method and the cost calculations are shown in Table 24.

Table 24. Cost calculations Recycling wood waste, abroad

Cost or fee	Equation	Final cost
Recycling cost	$Utilization\ fee\ \left(\frac{€}{1000\ kg}\right) \times Wood\ delivered\ (kg)$	1800€
Difference in wood waste costs	$Recycling\ cost\ (€) - Energy\ production\ costs\ (€)$	2300€
Total new costs	$Total\ costs\ of\ packages\ (€) + Waste\ collection\ costs\ (€) + Difference\ in\ wood\ waste\ costs\ (€)$	67 000€
Difference	$New\ costs\ (€) - Current\ costs\ (€)$	2300€

Handling safety also follows many of the same observations as in the previous method. Due to only the destination of wood waste from recycling centre is changing, handling safety stays on relatively same level.

The emissions generated from this method is its biggest change compared to other methods. The driven distance between Hamina, the recycling station and Riga is around 520 km with the example route shown in Figure 32.

Figure 32. Example route for transporting wood waste to the current recycling station and from there to Riga, Latvia

Using the same calculations as in the previous section, we have can calculate fuel usage and CO_2 emissions for this route. With a drivable route of 520 km and cargo of 8000 kg wood waste, the fuel usage is around 190 litres of fuel. Using the same fuel heating value and emission factor, we get emission of 560 kg CO_2, totalling in 70 grams of CO_2 emissions per kilogram of wood waste. Comparing this to the current situation, this is 600% increase. And finally, with the example of 30 000 kg wood waste transported during 6-month period, we get 2100 kg CO_2 during that 6-month period (Partnership, 2024).

$$Fuel\ Used = Distance \times Fuel\ Economy\ Factor \times \left(1 + \frac{0.4 \times Cargo\ weight}{Truck\ weight}\right)$$
$$= 520\ km \times 34\ \frac{Litres}{100\ km} \times \left(1 + \frac{0.4 \times 8000\ kg}{36\ 300\ kg}\right) = 190\ Litres$$
$$CO_2\ \ Emissions = \ Fuel\ Used \times Heating\ Values \times Emission\ factor$$
$$= 190\ Litres \times 0.04\ \frac{GJ}{Litre} \times 74\ \frac{kg\ CO_2}{GJ} = 563\ kg\ CO\_2$$

Table 25. Criteria change in the recycling, abroad method

Description	Recycling the wood waste as a raw material, outside of Finland			
Criteria	Cost	Handling safety	Reduction rate	Waste transportation emissions
Change	2300 €	Unaffected	80%	600%

8.3 AHP point calculations

Table 26, Criteria change in all methods

Method, Criteria	Priority	Reduce	Reuse, local	Reuse, abroad	Recycle, local	Recycle, abroad
Cost	6.2%	-13 400.00 €	3500 €	3500 €	2300 €	2300 €
Handling safety	33.3%	Marginally lower	Slightly lower	Lower	Unaffected	Unaffected
Reduction rate	50.8%	25%	38%	36%	90%	80%
Transportation CO_2-emissions	9.7%	-25%	-38%	-35%	225%	600%

After acquiring the data from the case study, the data in the criterion is compared against each other using the same model as when determining the weight value for each criterion. The steps of these matrix calculations are shown in Figures 33 and 34. This time however, rather than comparing importance, we now compare superiority. For example, when looking at the cost, we compare the cost of one method to other, and choose which one is better on scale from 1 to 9. We do this with each method pair. The numbers in this model are acquired from an interview with company subject matter experts.

Cost	Reduce	Re-use, local	Re-use, abroad	Recycle, local	Recycle, abroad
Reduce	1/1	9/1	9/1	9/1	9/1
Re-use, local	1/9	1/1	1/1	1/3	1/3
Re-use, abroad	1/9	1/1	1/1	1/3	1/3
Recycle, local	1/9	3/1	3/1	1/1	1/1
Recycle, abroad	1/9	3/1	3/1	1/1	1/1
Total	13/9	17/1	17/1	35/3	35/3

Figure 33. Total of each column

After that, we conduct the same matrix calculations that we used when determining the weight value for each criterion in chapter 7.

Cost	Reduce	Re-use, local	Re-use, abroad	Recycle, local	Recycle, abroad
Reduce	9/13	9/17	9/17	27/35	27/35
Re-use, local	1/13	1/17	1/17	1/35	1/35
Re-use, abroad	1/13	1/17	1/17	1/35	1/35
Recycle, local	1/13	3/17	3/17	3/35	3/35
Recycle, abroad	1/13	3/17	3/17	3/35	3/35
Total	1	1	1	1	1

Figure 34. Normalized columns

When we get the weight value, or in this case, priority vector, from each method, we multiply the priority vector with the weight value of the data we used to compare the methods. In this example we used cost, so the weight value is 6.2%. This gives us the cost-points for each method. Figure 35 demonstrates the matrix for these point calculations.

Cost	Reduce	Re-use, local	Re-use, abroad	Recycle, local	Recycle, abroad	Weight value	Points
Reduce	9/13	9/17	9/17	27/35	27/35		0.041
Re-use, local	1/13	1/17	1/17	1/35	1/35		0.003
Re-use, abroad	1/13	1/17	1/17	1/35	1/35	6.2%	0.003
Recycle, local	1/33	3/17	3/17	3/35	3/35		0.007
Recycle, abroad	1/13	3/17	3/17	3/35	3/35		0.007

Figure 35. Points of cost-criteria

We the do the same for other criteria, handling safety, reduction rate and finally, waste transportation emissions. After acquiring points from each criterion and multiplying them with the designated weight value, we sum each methods own points. Figures 36, 37, and 38 show individual criterion points for handling safety, reduction rate and waste transportational emissions respectively. This gives us the total points of each method, which are shown in Table 27, and the method with the highest score is the best method according to this study.

Handling safety	Reduce	Re-use, local	Re-use, abroad	Recycle, local	Recycle, abroad	Weight value	Points
Reduce	1/1	3/1	4/1	1/3	1/3		0.055
Re-use, local	1/3	1/1	2/1	1/4	1/4		0.027
Re-use, abroad	1/4	1/2	1/1	1/6	1/6	33.3%	0.016
Recycle, local	3/1	4/1	6/1	1/1	1/1		0.117
Recycle, abroad	3/1	4/1	6/1	1/1	1/1		0.117

Figure 36. Points of handling safety-criteria

Reduction rate	Reduce	Re-use, local	Re-use, abroad	Recycle, local	Recycle, abroad	Weight value	Points
Reduce	1/1	1/2	1/2	1/7	1/6	50.8%	0.026
Re-use, local	2/1	1/1	1/1	1/5	1/4		0.046
Re-use, abroad	2/1	1/1	1/1	1/5	1/4		0.046
Recycle, local	7/1	5/1	5/1	1/1	2/1		0.233
Recycle, abroad	6/1	4/1	4/1	1/2	1/1		0.157

Figure 37. Points of reduction rate-criteria

Emissions	Reduce	Re-use, local	Re-use, abroad	Recycle, local	Recycle, abroad	Weight value	Points
Reduce	1/1	1/3	1/3	3/1	8/1	9.7%	0.016
Re-use, local	3/1	1/1	1/1	7/1	9/1		0.036
Re-use, abroad	3/1	1/1	1/1	6/1	8/1		0.035
Recycle, local	1/3	1/7	1/6	1/1	3/1		0.006
Recycle, abroad	1/8	1/9	1/6	1/3	1/1		0.003

Figure 38. Points of waste transportation emissions-criteria

8.4 Case study conclusion

Table 27. Final points for each method

Method	Points
Reduce	0.138
Reuse, local	0.113
Reuse, abroad	0.100
Recycling, local	0.364
Recycling, abroad	0.285

Evaluating the points earned by the methods as shown in Table 27, we can conclude that at a theoretical level, recycling the packages in Finland is the most suitable solutions to the challenges proposed on this thesis. They have the advantage of not affecting the handling safety in any large meaningful way and offering the best reduction rates. The cost increase in mainly due to the utilization costs of wood waste. Their significant downside is their effect of waste transportation emissions, in which they generate more emissions than currently. However, due to the weight values determined in the AHP-method, this doesn't affect their overall score much. It should still be noted when evaluating each method separately.

Reduce and both reuse methods have similar amounts of points, indicating that they all would have similar performance overall. They still have some difference in each criterion. Reduce method has advantage on the potential decrease in costs, compared to both reuse and recycle methods. Meanwhile, when comparing reuse in local and abroad, abroad has better score in all the other criterion, except for handling safety. But as discussed in chapter 8.1.2, determining the exact values for handling safety can prove difficult. Thus, the score from it could change in reuse abroad method, as it could in reduce and reuse local methods. However, the increase from these changes most likely would not increase the overall score for these methods to match the score of recycle methods.

8.4.1 Result discussion

The actual cost for adapting the methods discussed in this thesis are most likely more than shown on the case study. Some of these increases have been considered, but in practice, adopting these methods would cause increases in expenses for the case study company. These increases would most likely be inlaid in some other expenses and costs from the package supplier or the recycling station. For example, although the cost per package decreases in the reduce method, having more customized packages could increase work hours on the assembler, thus increasing their costs. One of the most impactful costs discussed in this thesis is storage space costs. We assumed, that the case study company would rent their storage space, rather than build or expand their own. This would have higher costs on the forefront, than simply renting usable storage space. However, building own storage could have advantages in the future. Building your own storage gives you a possibility to build it to match your exact standards and needs. And because the company owns the storage, they can use it on different purposes as well, for example, rent it to other companies. But owning the storage space also creates new challenges, for example time of that takes to construct the storage, where you could build it, maintenance of the storage and other expenses that come with owning a large building.

Although handling safety was one of the most important criteria in this case study, evaluating it was difficult. As stated in chapter 8.1.2, there is no exact metric value to determine it. How the reducing of wood and reusing/repairing of packages decreases handling safety is hard to predict without extensive testing. And even then, human error could cause reduction in the handling safety as well. Statistical values from chosen period could be used to evaluate it, but there are many uncertain factors that could be hard to consider. And as stated earlier, although not discussed in this thesis extensively, replacing wood with other materials and using different, stronger jointing methods could reduce wood waste and increase handling safety at the same time. However, this could affect the other criterion, more precisely cost and recyclability, negatively.

Reduction rate is the most important criterion, and main discussion point of this thesis. The reflection of this can be seen in the best method of the AHP-analysis, where recycle local method has the most points and the best reduction rate. It should still be noted that the best way to reduce waste is to not generate it at all. Ways to reduce waste should be investigated first, and after that the utilization of the generated waste. Oher point to note is that the possible utilization rates are approximated as of writing of this thesis. These rates are subject to change in the future in either direction. Better ways to utilize wood waste could increase this rate to be closer 100%. At the same time, overloading the market with wood waste could raise quality standards, lowering the rate. Both scenarios could affect the price of wood waste as well.

Finally, the transportation CO_2 emissions are calculated using theoretical values. In practice, these values would differ from the actual emissions. The destination of recycled waste is also approximated, giving the calculations small margin of error. If the recycle station changes the way it utilized the wood waste, it could increase or decrease the transportation emissions. The modes of transport could change, as well could the properties of used truck. For example, in the future the truck could run on electricity. This could increase or decrease the generated emissions, depending on the energy production method.

The data presented in this case study is intended to present the theoretical possibility for the changes in the chosen criteria. This means that the precises changes in the criteria are subject to change depending on the company's way of implementing the chosen methods. At the same time, the price of recycled wood is calculated using the price of wooden planks. The price of planks in used packages would most likely be lower. Still, this case study should give the reader some insight on how the methods chosen in this case study would affect the chosen criteria.

9 Conclusion

This thesis has brought many answers to pre-existing questions. The goal was to study wooden packages and their transportation methods. In addition to this, the goal was also to identify different methods to reduce wood waste generated from these packages and apply them to the case study company.

The literature research revealed that the packages are designed very specifically depending on the product it is used to transport, and the laws and regulations affiliated with the package. New laws, directives, and standards are planned as more sustainable and ecological manufacturing becomes more and more important. Circular economy is becoming the forefront of this new development for producers.

What became apparent during the research was a lack of information regarding the packages design. Standards or other laws regarding to the exact parameters required from the package were almost non-existent. This meant that to find information on the design philosophy of a particular package, the producer of the package had to be contacted personally. This limited the possibility of evaluating different packages amongst themselves.

Still, the study shed some light on the effects of different evaluated methods on the chosen criteria. These findings will be used by the chosen case study company moving forward with their goal of reducing generated wood waste and to promote more sustainable development. The case study company is a part of larger, global company, with many different divisions of manufacturing all over the world. This study created a framework for those divisions to adapt into their own manufacturing, and to achieve the results that they deem appropriate to contribute to the circular economy.

Using the information presented in this study and the AHP-method, the study shows that investing in the new ways of recycling wood waste is the best way to reduce the amount of wood waste. Depending on the used method, around 90% utilization rate can be achieved. This is significantly higher than any other method can achieve. However, this comes with a large increase in waste transportation emissions, as there aren't any utilization opportunities near the recycling centre. Although there are many companies near the recycling centre capable of utilizing wood waste, they don't have the capacity to utilize the amount of wood waste brought to the recycling centre. This limits the amount of possible end destinations of wood waste.

The case study also shows that the cost of implementing these methods is not high. Some methods could reduce current costs by a noticeably amount. Although cost was given the lowest weigh value, it is still an important criterion that the companies pay attention to when determining possible development opportunities. The costs calculated in the case study show an increase or decrease in costs for 6 months. When considering this, the increase in costs is small when compared to the possible reduction rate. The recycling costs consists solely of the difference between the cost of utilizing wood waste compared to the cost of wood used in energy production. If the cost of energy wood increases and/or utilization costs decrease, the total costs of these methods could be negative.

The final observation done during the research and case study was that handling safety is an important aspect, that must be considered in every part of the package's transportation. From the way that the component is packed, to the transportation method and distance, and how the package is handled at the destination. The packages investigated in the study require special tools and methods in their handling due to their large size and weight. This was one of the limiting factors in the reduce-method, as reducing too much material used in the packages would make them too unsafe to handle. This criterion worked in the favour of recycle-methods, as it remained unaffected in these methods.

9.1 Future work

This thesis focused mostly on a single example package from the case study company. There are many other packaging types delivered from and to case study company alone, not counting all the different packaging types in different case study company facilities. This means that that the thesis is only a surface scratch on the subject. The case study company has stated that it will continue to investigate and develop new ways of reducing not just wood waste, but all generated waste types. Future thesis regarding similar topics conducted by the case study company will expand the findings and conclusions of this thesis.

The data regarding the AHP-method can be expanded with more interviews and adding more parameters. The weight values might also change as the laws and regulations regarding the marine industry change, market for wood waste utilization grows, or the priorities inside the case study company change. The number of analysed methods could also be increased or expanded upon. Currently, recycling local and abroad methods only cover the composting and landscaping and chipboard industry respectively. As new ways to utilize the wood waste emerge, new methods could be investigated.

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