CHALMERS

A literature comparison of the life cycle assessments of wood and recycled plastic pallets

Recycled plastic pallet using a proprietary recycling process technology compared to conventional wooden pallet

PHILIP HALLERÖD
MAEL TUREFELDT

DEPARTMENT OF MECHANICS AND MARITIME SCIENCES
CHALMERS UNIVERSITY OF TECHNOLOGY

Göteborg, Sweden, 2024

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Bachelor thesis for International Logistics Program

PHILIP HALLERÖD
MAEL TUREFELDT

Department of Mechanics and Maritime Sciences
Division for Maritime Studies
CHALMERS UNIVERSITY OF TECHNOLOGY
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Department of Mechanics and Maritime Sciences
Chalmers University of Technology
SE-412 96 Göteborg

Cover:
Wimao Impossible Plastics, batch of plastic waste produced into EUR recycled plastic pallet.

Department of Mechanics and Maritime Sciences
Chalmers University of Technology
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PREFACE

This thesis marks the culmination of our studies in the International Logistics program at Chalmers University of Technology. The program encompasses four main subjects: logistics, economics, law, and leadership, all with a strong emphasis on sustainable development. Our thesis, which aligns closely to sustainable development of logistics, focuses on literature comparisons of multiple Life Cycle Assessments (LCA). Specifically, we compare recycled plastic pallets manufactured using a proprietary technology Recycling Process Technology (RPT) with conventional wooden pallets.

We would like to specially thank Anne-Lie Kroon for her participation and guidance throughout this study. Their insights and shared data have been invaluable for us. Additionally, we are grateful for the teachers and our supervisors support, which has been instrumental for completing this thesis.

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SAMMANDRAG

Plastavfallshantering är ett kritiskt problem, med mycket plast som förbränns i dagsläget. En ny återvinningsteknik erbjuder en lösning genom att omvandla plastavfall, som annars hade förbränts, till bland annat pallar. Denna återvinningsprocess använder alltså plastavfall i en patenterad process för produktion.

Denna studie undersöker utsläppen under hela livscykeln för återvunna plastpallar i jämförelse med traditionella träpallar. Fokus ligger enbart på utsläppen från respektive studerad pall, dvs inget om utsläppens faktiska påverkan.
Resultaten baseras främst på jämförelsen mellan två livscykelanalyser (LCA), en för träpallar och en för återvunna plastpallar. CO_2-ekvivalenta utsläpp utvärderas över olika faser av livscykeln.

Studien tar också hänsyn till koldioxidlagring i kombination med energiåtervinning vid förbränningsfas för träpallar. Resultatet visar att träpallar kan bli netto-neutrala, eller till och med netto-negativa i sina utsläpp, när energiåtervinning och koldioxidlagring beaktas. På ett liknande sätt förhindrar återvinningstekniken utsläpp genom kontinuerlig återvinning av plastavfall istället för förbränning vilket resulterar i netto-negativt resultat.

Resultatet understrycker fördelarna med att använda den nya återvinningsprocess istället för förbränning, med eller utan energiåtervinning. Det finns dock flera faktorer för att nå detta resultat. Dessa fördelar är beroende av implementeringen av ett cirkulärt system för att säkerställa att upprepad återvinning sker av återvunna plastpallar. På grund av svårigheter att uppskatta långsiktiga konsekvenser antas det att återanvändningen av plastpallar alltid sker. Träpallar är mer flexibla, eftersom relevant infrastruktur finns överallt, samt att expertisen är väletablerad.

Nyckelord: plastavfallshantering, återvinning, förbränning, energiåtervinning, livscykelanalys, koldioxidlagring, återvinningsprocess, pallar

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MAEL TUREFELDT

Department of Mechanics and Maritime Sciences
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ABSTRACT

Plastic waste management is a critical issue, with lots of plastics being incinerated, a specific company offer a solution by converting plastic waste that would otherwise be incinerated into products. a proprietary recycling process technology (RPT) use this waste plastic in a proprietary process to form into new pallets.

This study looks at the entire life cycles emissions for their recycled plastic pallet compared to traditional wooden pallets. Focus lies only on emissions from the two pallets that are studied, not the impact of said emissions. The proprietary technology is exclusive to the Nordic market; thus, the study look at that geographical area for both pallets.
The findings are primarily based on the comparison between two life cycle assessments (LCA), one for wood pallets and one for recycled plastics, evaluating CO_2-equivalent emissions across different life cycle phases.

The study also considers carbon sequestration in combination with energy recovery at incineration phase for wooden pallets. It shows that wooden pallets can become net neutral, or even net negative when accounting for energy recovery with carbon sequestration. In a similar way that the RPT prevents the release of emissions through continuous recycling of plastic waste and thus also having a net-negative emission result.

The result underscores the benefits of using the RPT instead of incineration, with or without energy recovery. There are however several qualifications to arrive at this result. These benefits are contingent on the implementation of a circular system to ensure the repeated recycling of recycled plastic pallets. Because of the difficulty of estimating long-term consequences, reuse of all plastic pallets is assumed for ease of comparison. Wooden pallets are more versatile, as relevant infrastructure exist everywhere, and expertise is well established.

Keywords: plastic waste management, recycling, incineration, energy recovery, life cycle assessment, carbon sequestration, Recycling Process Technology, Nordic market, pallets

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ACRONYMS AND TERMINOLOGY

CO_2-eq	Carbon Dioxide – equivalent
DH	Dielectric heating
EoL	End of Life
GHG	Green House Gases
GWP	Global Warmth Potential
HT	Heat Treatment
LCA	Life Cycle Assessment
RPT	Recycling Process Technology
WtE	Waste to Energy

1. INTRODUCTION

A pallet is a flat transport structure that provides a stable support for goods, while also allowing efficient handling by forklift, cranes etc. All these different versatile platforms are in the sense rather similar in the context that they serve as a structural foundation that enables handling and storage. However, different pallet material boasts unique advantages and disadvantages. It is a fundamental, but modest looking, transport platform that facilitates the movement of goods globally (Leblanc, 2022; Gatu, 2010).

The EUR-pallet is a standardised wooden pallet regulated by the European Pallet Association (EPAL). It adheres to specific dimensions, and thus makes it one of the most widely used pallet types in the world. EUR-pallets are also widely used in the pallet exchange systems, which promotes reuse and recycling of pallets. The exact number of EUR-pallets varies depending on sources. The number of EUR-pallets continuously fluctuates due to them being processed, used, and recycled at different rates. Despite that, based upon statistics released from organisations such as the EPAL which collaborates, collects, and analyses data based on European production, sales, and recycling annually it can get an estimate. EPAL best claim is that there are around 675 million EUR-pallets in European circulation (EPAL, n/a).

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As organisations increasingly prioritise and take accountability for environmental and sustainable responsibility, the question emerges: which pallet material reigns supreme in terms of having lower carbon emissions and where the materials differ. Regardless, instead of declaring one material superior, organisations acknowledge the need for diverse solutions. Hence, the decision between the different transporting pallets will depend on factors such as recyclability, durability, and overall emission.
The aforementioned pressure to be environmentally friendly has led producers, all the way down to pallet suppliers, to emphasise their pro-environmental attributes. Thus, a literature comparison between wooden and composite recycled plastic pallets will be made to clarify their life cycle emissions.

In this study we will focus on the market dominated wood pallet versus the newer composite recycled plastic pallets using a proprietary recycling process. New advancements in production technologies for recycled composite pallets have made them more realistically comparable to wood pallets, especially in terms of consistency/standardisation and cost considerations.

1.1 Aim of the study

The aim of this thesis is to conduct a comparative analysis of life cycle assessments (LCA) for wood plank pallets and recycled plastic pallets. This study seeks to evaluate the emissions profiles of these two pallet types by comparing their global warmth potential (GWP) through CO_2-equivalent emissions for each pallets life cycle depending on End-of-Life (EoL) scenario. Life cycle encompass material procurement, production, distribution, use/repair and EoL phases.

1.2 Research questions

What are the differences in CO_2-equivalent emissions between recycled plastic EUR-pallets using a proprietary Recycling Process Technology and wooden EUR-pallets over their respective life cycles?

How does different End of Life scenarios avoid emissions for respective pallet?

1.3 Delimitations

Given the short timeframe for the thesis, certain limitations had to be imposed. These restrictions help maintain focus and ensure that the research remains manageable within the available time and resources.

The study disregards the effects of exchanging pallets in a geographical location. Focusing on raw data comparison. No direct communication with wood pallet producers due to lack of time and/or unwillingness to participate. Regarding the LCA's, the emissions of pallet are based on their entire life cycle, from cradle to grave. However, use phase has been largely ignored. Additionally, other EoL scenarios, such as landfilling has been ignored. Both LCA's are modelled in northern Europe. The study is disregarding the use of fumigation by methyl bromide and sulphuryl fluoride as alternatives in treatment of wooden pallets as they are not approved alternatives in the European Union. Specific scenarios are in place for this study. The results are modelled to simulate a best-case scenario for respective EoL. The results solely show the emissions, not the impact of these emissions. Repair frequency has been limited to twice per lifespan of a wooden pallet. No consideration is made regarding the economic implications of respective product in the result. No consideration for using renewable energy in production phase for either pallet. The comparison will not include other types of pallet material.

2. THEORY

2.1 Transport pallet

A pallet is a type of structured transport unit that gives a stable support for goods during movement, handling and storage. Traditionally, pallets have been made of wooden planks due to the low cost, availability and consistency of quality (Khan et al., 2019). However, new materials are slowly starting to get market exposure. In this report pallets made from recycled plastics will be benchmarked against the common wooden pallet. All pallets in this study follow standardised dimensions. However, in reality different types of pallets have different dimensions and weight. But they are all based on a four-way structured pallet. This allows the pallet to be accessible and handled from all four sides. The Europallet (EUR-pallet) is a standardised pallet within European market with some millimetre tolerance for the pallet's measurements, which is usually: 800 mm x 1,200 mm x 144m. Nevertheless, the most interesting aspect of the EUR-pallet is its interchangeability. With a standardised interchangeable transport unit comes many advantages efficacy wise, such as aiding in diminishing possible pooling of pallets or general facilitation in the movement of goods. This adaptable transport structure has a significant role in why supply chains operate in the ways they do (Kočí, 2019).

2.2 Pallet history

During World War II, the utilisation of wooden pallets experienced a surge owing to their newfound applications across various military contexts. They played a significant role in the logistics domain by ensuring the delivery of goods in optimal condition. Post-war, the recognition of their importance persisted, leading to swift adoption within the shipping sector. Within five years, many patents were filed, and certain designs began to resemble modern wooden pallets (Gatu 2010).

Approximately a decade later, their usage had become quite common. Despite this, a lack of standardisation hindered their widespread adoption across different industries. While the benefits of palletisation were evident, inconsistencies in dimensions and quality posed logistical challenges and hindered interoperability between different transportation systems and storage facilities (Leblanc 2022).

Subsequently, recognising the necessity for uniformity and standardisation, the EUR-pallet emerged as the accepted norm in Europe (Gatu 2010). This development was prompted by the demands of European Railway Companies, culminating in the establishment of the first standardised dimensions and quality criteria for wooden pallets across the continent.

Although present wood pallets bear resemblance to the original two/four-way pallets, modernisation in pallet manufacturing and general improvements in wood processing has made them more standardised, effective and efficient. In short, standardisation and tolerance, materials and manufacturing, treatment differ from the original pallets (Leblanc 2022).

2.3 New thoughts

In recent years pallets have gained attention within sustainability initiatives and have thus evolved beyond the well-known wooden pallet that has been in use for over six decades. The wooden EUR-pallet maintains a substantial advantage over alternative materials due to its interchangeability, and repairability (McCrea, 2023). However, a growing number of companies are opting for innovative sustainable solutions. As a result, manufacturers are actively exploring hybrid materials that mix the advantages of various materials to make a certain pallet a more compelling choice for many companies (Leblanc, 2022).

The use of recycled plastic in pallets has garnered significant attention due to its compelling sustainability benefits that resonate within numerous industries. Rather than resorting to the incineration of plastics, their disposal in landfills, or usage of virgin plastics, this approach encourages a circular economy where materials are recycled and reused.
Additionally, these composites pallets offer better resilience and general durability. Environmental factors are less prone to damage the composite pallets, as moisture, chemicals, insects are not a concern. This durability translates to consistency and reduced maintenance costs. While traditional wood pallets may offer; modularity, initial cost advantages, and widespread availability, the recycled plastic pallet offers many advantages long term wise, like increased durability and reduced wear and tear (Khan et al., 2021).

2.4 Material Procurement

Wood is the primary material used in the production of EUR-pallets. The procurement process involves the selection of timber for the pallet manufacturing. Currently, two main types are usually used for pallet production: Pine and Spruce wood. In this study both types of woods are used interchangeably for pallet production because of the similar density and characteristics between them, within the forestry sector (Matmatch, n.d.; Kočí, 2019). The wood is assumed to be certified according to certifications such as; Forest Stewardship Council (FSC). This simulates that the wood is sourced from sustainable forests. Additionally, wood as a material inherently involves carbon sequestration, a process where CO_2 is absorbed by trees from the atmosphere and stored as carbon. This natural phenomenon helps offsetting some of the GHG emissions. However, for logging, the use of heavy machinery, internal transportation generates significant emissions (Buonocore et al., 2014).

Biogenic carbon and carbon sequestration are interconnected terms. Biogenic carbon refers to when carbon is incorporated in the wood's biomass. The emissions might get released, but since it was recently part of the atmospheric carbon cycle it is considered carbon neutral, or even carbon negative in a well sustained forest. (Khan et al., 2021).

However, some sources are more sceptical about the claim that wood would automatically be carbon neutral. For example Cassella (2018) writes: “This “emission loophole” is way more complicated and contentious than it may appear…”. Furthermore, William Schlesinger, an EPA Science Advisory Board member says: "The big problem is you're cutting old-growth forests and expecting them to regrow, … That's totally unrealistic in 20 years and not guaranteed over 100 years.". Meaning that; only when harvested very sustainably by continually replanting seedlings, and keeping the harvested wood locked out of the atmosphere for a significant time you might reach net negative emissions.

The material procurement for recycled plastic pallets using the proprietary RPT is quite different than for other pallet materials that offer similar services, such as: primary plastic and wood-polymer composite(WPC) (Khan et al., 2021; Personal communication. A. Kroon, 2024). When speaking about recycling plastics it is common to sort them into hard plastics and soft plastics, based on different properties. In a country, like Sweden, the energy sector heavily relies on energy recovery of plastics using incineration. According to Naturvårdsverket (2022) the total amount of raw plastic material that entered the Swedish market amounted to 1.3 million tons. The same year around 1.1 million tons of plastic was incinerated for energy recovery, and 76 thousand tons used in the cement industry. This is equivalent to around 87% of the entered plastic to the market in 2020.

With the use of previously mentioned proprietary RPT, it allows for all plastic waste to be recycled (Personal communication. A. Kroon, 2024). In numerous industries, such as the fishing, scaffolding and construction industry, it is commonplace to send plastic waste directly to incineration, or even landfill - in 2016 only 0.8% of the plastic waste from the construction sector got recycled (Naturvårdsverket, 2021). This RPT offers a more sustainable alternative by attracting plastic waste from different industries and municipalities that are keen to adopt recycling over other disposal methods (Personal communication. A. Kroon, 2024).

2.5 Production of pallets

The most dominant type of pallet in use worldwide is the wooden pallet. The wood used in production of pallets mostly originates from spruce log, the logs are cut into smaller pieces in stages for the different pieces, before assembly the boards are milled to ensure uniformity (Olson, u.d.). Assembly is performed by special machines built for the task. They do the aligning and nailing together the pallet. After the assembly, the pallet needs to be treated. The wooden plank pallet needs to be treated for phytosanitary purposes to eliminate possibilities for pests and invasive species to spread to new areas. Most containers made from natural wood, with the purpose of transportation are required to go through this procedure, however processed wood product (e.g. plywood) does not need to be treated if the processing eliminates the possibilities of pests.

The International Plant Protection Convention (IPPC, 2017) explains the two processes heavily preferred by wooden pallet producers, fumigation and heat treatment. Fumigation is the process of enclosing the wooden product and replacing the natural air with a gas that kills any potential pests. The approved gases in IPPC (2017) for fumigation are Methyl Bromide and sulphuryl fluoride, with Methyl Bromide being the most common historically as the substance has great effect on a large range of pests. In pallets that are treated with methyl bromide, the emission concerns return again in the EoL stage as the gas is released again with incineration.

The European Union (2021) no longer recommend Methyl bromide as a product for fumigation as it is an ozone-depleting chemical and large quantities are usually released during the fumigation process, because of this many parts of the more developed world have heavily reduced its usage, or banned the use except for in extreme situations, like in the EU.
Heat treatment is the preferred phytosanitary method in Europe and in Sweden, the IPPC (2019) describes the two main forms of heat treatment: steam or dry kiln heat chamber (HT), and

dielectric heating (DH). HT is the more traditional form of heat treatment, by heating the pallets inside an enclosed space to a core temperature of minimum 56 °C for at least 30 continuous minutes. The temperature can be measured by either inserting measuring devices into the wood, or by using developed treatment schedules on a series of test treatments to ensure that the finished product reaches the required temperature.
DH is the usage of microwaves or radio waves for heating instead. With dielectric heating the requirements are different than with HT, the minimum temperature is 60 °C and only for one continuous minute through the entire pallet, both core and surface. (Secetariat of the International Plant Protection Convention, 2019)

The RPT of forming the pallets is today unique to Wimao Impossible Plastics and protected by patent, the process starts with the collection of the types of plastics other actors in the plastic recycling industry does not handle (WIMAO, 2024). Plastics that would be combusted for energy is instead being grinded, crushed and otherwise treated to form a granulated product. This granulated plastic mix can then be heated and mixed with other likewise mixed waste plastics from other sources to achieve the desired mix of malleability and strength. Furthermore, WIMAO (2024) says this process is designed to be able to handle many different types of plastic waste, without first sorting the different plastic grades. The process does not depend on it being purely plastic waste being processed, as materials such as textiles, glass and wooden products do not need to be completely removed before processing begins.

In a personal communication A. Kroon (2024) describes the process of forming the plastic pallets as to a pizza dough being pressed and formed into the shape of the pallet, this pizza dough-like consistency is achieved because the different plastics in the mix have different melting points. This dough is very versatile and can be used for more than just pallet production. Flower beds, car parts, medical equipment and more can be produced this way.

2.6 Pallet use & End-of-Life

The analysed materials used in EUR-pallet manufacturing have different use phases and EoL scenarios. All pallets get used differently, some more aggressively, frequently, others less. For example, forklift operators are generally pressured to work quickly and thus prioritises speed over longevity, whereas a warehouse prioritises structural soundness. Therefore, the need to disregard outlier pallet use scenarios and EoL is needed to make the literature comparison between recycled plastic (Kumpulainen & Kalliomäki, 2022) and wood LCA’s (Deviatkin & Horttanainen, 2020).

A wooden pallet proposed life expectancy is around 20 cycles if repaired twice (Deviatkin et al., 2019). This modelled amount of cycles changes depending on publishments. However, they mainly stay in the range of +/-10 cycles of 20 cycles. In a study performed by The Norwegian EPD Foundation "Environmental product declaration”(2022) the assumption of 20 cycles per wooden pallet with a 5 year lifespan before EoL is reached. That is with the assumption that the wooden EUR-pallet have been repaired 5 times during this period.

Recycled plastic pallets are comparable with wood pallets in maximum load capacity, despite weighing less and having an expected longer lifespan. EUR-pallets weigh in between 20-25kg

depending on sources (Deviatkin & Horttanainen, 2020; EPAL, n.a.), while a recycled plastic pallet weigh in at approximately 19 kg (Personal communication., A. Kroon, 2024). These properties result in lower fuel consumption during transport and reduces the replacement frequency.
Recycled plastic pallets are designed for longevity, enduring 50-100 usage cycles without the need for repair. This durability significantly reduces the need for frequent replacements, enhancing the sustainability of the logistics chain (Deviatkin & Horttanainen, 2019). In this study the number of cycles is set at an expected 66 times to mimic Deviatkin & Horttanainen (2020) study. These pallets are especially valuable in industries where hygiene, longevity, closed loop transportation, and moisture resistance are priorities (Personal communication. A. Kroon, 2024).

The longevity of a recycled plastic pallets life cycle is advantageous in many aspects. However, concerns about microplastic generation through wear and tear of these pallets are well-founded. Microplastics are defined as synthetic solid particles or polymeric matrices that are insoluble in water, with sizes being less than 5 mm. This is for both primary and secondary plastics (Wang et al., 2021). The fragmentation of plastic pallets due to wear and tear during use phase are particularly concerning due to their persistence in the environment. Once generated, microplastics from recycled plastics pallets can enter various environments, or organisms in diverse ways depending on the specific type of plastic. For example, polyethylene terephthalate (PET) is heavier than polypropylene (PP) and thus might sink in water, instead of floating (Wang et al., 2021). This makes it hard to predict their respective natural degradation and effect in the environment for this study's results.

As pallets reach the end of their usable life, proper disposal strategies become crucial. For wooden pallets, EoL options can include recycling into wood chips/pellets or other secondary products. However, incineration with energy recovery is the method analysed in this study. In contrast, the EoL treatment of recycled plastic pallets typically involves recycling the materials into new plastic products, thus closing the loop in product life cycle management. This not only helps in waste reduction but also supports a circular economy model.

2.7 CO_2 equivalent & Global Warmth Potential

CO_2-eq is used in this study to measure the emissions of various GHG, as it is a commonly used metric for comparing the equivalent emission impact of CO_2 . This conversion is facilitated by the GWP of each gas, a value that measures the heat trapped by a certain mass of a GHG compared to the heat trapped by CO_2. By focusing on CO_2-eq emissions it leads to more straightforward, and implementable, results.

2.8 LCA

LCA is a comprehensive method to evaluate the environmental impacts associated with all stages of a products life. This include material procurement/processing, production, distribution, use phase, and EoL such as recycling or different disposal methods, also referred as cradle-to-grave. The primary purpose of LCA is to identify and quantify the energy and material usage, and the emissions associated with pallets in this case but it is also a guide for how studies should be made and interpreted (Baumann & Tillman, 2020). By assessing the different factors LCA helps in making informed decisions to minimise the environmental impact at any phase of the life cycle. A LCA is methodologically structured into four stages; goal and scope, life cycle inventory, life cycle impact assessment, interpretation. These stages are defined in the guidelines provided by the International Organization for Standardization, more specifically the standards ISO 14040 and ISO 14044. These standards helps LCA being consistent, reproduced, and scientifically based.

3. METHODS

The study employed a quantitative comparison method to assess different factors, including GHG emissions converted to kg CO_2-eq at different stages in the life cycle. The objective is to compare and analyse the emissions of each pallet's life cycle under specific circumstances by conducting comprehensive review of existing literature.

3.1 Scope of the Study

Comparison of two LCA based studies on the following phases: material procurement, production, distribution, usage/repairability and disposal phase.

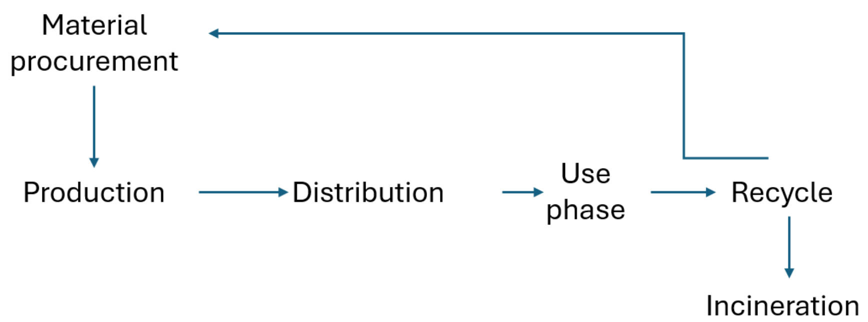

Fig. 1. LCA phases analysed in study.

3.2 Data sources

Data for the recycled plastic pallet analysis were directly sourced from a particular stakeholder in the recycled plastic pallet industry – Wimao Impossible Plastics AB. The provided LCA was made by a LCA consulting team (Kumpulainen & Kalliomäki, 2022) on the Wimao Riihimäki plant in Finland, which uses a patented RPT. The data also included a comparison against the more common Waste-to-Energy (WtE) incineration plant, which is a widespread method of dealing with plastic waste. This comparison aimed to highlight the environmental impacts and benefits of recycling plastic into pallets instead of incinerating it for energy recovery. To get data for a single pallet, the assumption was made that Riihimäki plant only manufactured recycled plastic pallet.

Data for primary plastic and wooden pallets were predominantly sourced from peer-reviewed research studies that have been performed in Finland, mostly from Deviatkin & Horttanainen's (2020) study. This includes obtaining raw life cycle and production data, as well as product information. This approach ensured that the data covered all relevant stages of a pallet's life cycle, thereby providing a robust foundation for subsequent comparison analysis.

In total, four sources were used to produce and insert emission results for this literature comparative study, as seen in Table 5, Section 4.4.

The sources were identified through a comprehensive search process. We utilised a variety of search words including 'recycled plastic pallet', 'EUR pallet,' 'emission,' 'LCA,' 'wooden pallet,' 'wood sequestration,' 'plastic pallet,' and 'composite pallet.' These keywords were strategically chosen to encompass the wide range of relevant topics related to emissions and life cycle assessments of different pallet materials.

The search was conducted primarily through Chalmers Library and ScienceDirect.com. At both, we accessed multiple academic journals, conference papers and theses. The search process involved filtering results to include only peer-reviewed articles to ensure the credibility and reliability of the data.

3.3 Software tools

NTMCalc 4.0 Basic (Network for Transport Measures Environmental Performance Calculator) is a free software tool used to provide detailed emission outputs surrounding following GHG; total CO_2, CO_2 equivalents (CO_2-eq), methane (CH_4), and nitrous oxide (N_2O) emissions for the distribution phase. The tool allows for a emissions comparison of the pallets primarily based on their weight differences. The distance used in the modelling software was selected to be 150km, solely to have a similar distance as other reviewed studies. The vehicle type used was a “Rigid truck 14-20t”, with diesel B7-EU.

3.4 Scenarios

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Scenario 1 is with a Full Truck Load (FTL) of solely stacked standardised EUR-pallets, either plastic or wood. Scenario 2 is calculated with a FTL of a predetermined load weight of 500kg and non-stacked pallets of either plastic or wood. The modelling is done by interconnecting weight and transportation. The results are displayed in table 1.

The predetermined weight of 500kg was chosen to represent a realistic and manageable load weight that consumers might typically use, providing a practical basis for comparison between different types of pallets. This weight was selected based on industry standards, ensuring that the scenarios reflect real world conditions. EPAL Euro pallets typically have a maximum dynamic load capacity ranging from 500kg to 1500kg depending on the specific type and material of the pallet. This makes 500kg a suitable weight for practical and comparative analysis.

The results from scenario 1 is used in the accumulated total life cycle emissions results as a mean of simulating transportation from producer to consumer. While scenario 2 is not used in the final results, it has been calculated to show the lack of disparity when accounting for payload. This provides an understanding of the weight differences from a consumer use phase perspective and allows for deeper diving in discussion.

Table 1

Details for distribution calculation between recycled plastic and wood pallets.

Details	Measurements Scenario 1	Measurements Scenario 2	References
Truck type	Diesel B7-EU 14-20t	Diesel B7-EU 14-20t	NTMCalc Basic 4.0
Truck Dimension	W: 2.45m L: 7.2m H: 2.7m	W: 2.45m L: 7.2m H: 2.7m	
Distance	150 km	150 km	
EUR1-Pallet Dimensions	0.8m x 1.2m x 0.144m	0.8m x 1.2m x 0.144m	
Pallet Spatial Occupation	W: 2.041m (2.45/1.2m), L: 9 (7.2/0.8m), H: 18.75 (2.7/0.144m)	W: 2.041m (2.45/1.2m), L: 9 (7.2/0.8m), H: 18.75 (2.7/0.144m)	
Total Pallets Transported	288 pallets, stacked	18 pallets + 500kg, non-stacked	

Comment: The details regarding distribution for two specific scenarios for both pallet types.

3.5 LCA's in study

The LCA standards used for conducting both reviewed studies were the standards ISO 14040 and ISO 14044. For the calculation of carbon footprint for both products the standard ISO 14067 was used in reviewed studies.

3.6 Calculations used in this study

The calculations made in this study have only been made for recycled plastic pallets, due to pre-existing data being available for wooden pallets in northern Europe.

For calculating the per pallet emissions of the procurement and production phase of recycled plastic pallets using Kumpulainen & Kalliomäkki (2022) study; the total carbon footprint result from the LCA, based on total amount of plastic recycled at Riihimäki plant, has to firstly show the CO_2-eq emissions per ton result. Thus, 362 t CO_2-eq divided with 7008 t of plastic waste resulted in 0.0517 t CO_2-eq emissions per tonne. With one tonne of recycled plastics, approximately 52.63 pallets can be produced. Furthermore, by dividing emissions per ton with 52.63 the result indicated a t CO_2-eq emission of 0.000981 per pallet. When converted to kg CO_2-eq – 0.981 – it allowed for comparison against calculated wood emissions during procurement and production phase in Deviatkin & Hottanainen's (2020) study.

For calculating the distribution phase, the total amount of pallets being distributed was calculated. Since both products had the same dimensions due to same EUR-pallet standardisation, the spatial usage in truck was the same, and thus the number of pallets as well. Truck dimensions were based on an internal cargo capacity volume of 50 m^3, or in XYZ as seen in table 1. Thereafter, the CO_2-eq emission results from NTMCalc Basic 4.0 - scenario 1 - where divided with the number of pallets in distribution as seen in table 2, to ascertain a comparison between wood and plastic pallet, as later seen in table 5.

For calculating the effect of recycling instead of incineration at WtE plant for a single recycled plastic pallet; the carbon footprint result at WtE plant was divided by the amount of tonnes plastic used in the LCA (Kumpulainen & Kalliomäkki, 2022) – which was 7008 t – resulted in approximately 1.96 t CO_2-eq emissions per tonne plastic waste incinerated. This lead to a result of 0.03726 t CO_2-eq per pallet. Lastly, by converting to kg CO_2-eq the result showed an estimated saving in emissions of approximately 37.26 kg CO_2-eq.

For the calculation of emissions per cycle, as seen in table 5, the accumulated results for each pallets' total kg CO_2-eq emissions was divided by their respective predetermined cycles for their lifespan.

4. RESULTS

4.1 Material Procurement & Production

In this part, results related to material procurement and pallet production of the two different alternatives is presented with relative numbers for each section and type.

4.1.1 Plastic Waste Material Procurement

Recycled plastic pallets are manufactured using RPT from various sources of plastic waste. Furthermore the LCA by Kumpulainen & Kalliomäkki (2022) don't have a material procurement phase due to this. See section 4.1.4. An analysis of the production of virgin plastics is not included as it is not relevant to the pallet production, the alternative of incineration is taken into account in the results.

4.1.2 Wood Material Procurement

According to Deviatkin and Horttanainen (2020) the estimated emissions (kg CO_2-eq) of material procurement and production for one single wooden EUR-pallet neighbours to 5.0 kg CO_2-eq. Material procurement for wood production contributed to 71% of the total amount of CO_2-eq, resulting in an emission approximate of 3.55 kg CO_2-eq for total material procurement. Vásquez et al. (2022) puts the production and material procurement contribution range between 3.86 kg CO_2-eq to 5.63kg CO_2-eq. According to the same authors, the percentual material procurement contribution can be higher, depending on software tools used for modelling. These studies suggest that implementing forestry optimisation strategies can play a significant role in reduciing the carbon footprint associated with material procurement.

Commented [PH4]: Lena:
Här är det ett tankehopp, eller så behöver det skrivas om då jag inte hänger med på "This indicates"

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4.1.3 Wood Carbon Sequestration

Even though the actual long-term emissions for carbon sequestration is debatable, as seen in section 2.4 and 5., it is necessary to calculate if biogenic carbon is included to make an assumption of kg CO_2-eq saved per wooden pallet when incinerating with energy recovery.

Stored biogenic carbon in a wooden pallet is around -34kg CO_2-eq per pallet (Deviatkin & Horttanainen, 2020). Once incinerated it will release back the same amount implying carbon neutrality. Meaning that the net effect of incinerating a wooden pallet with energy recovery will become net-negative, as seen in table 5.

4.1.4 Production – Recycled Plastics

LCA data from Kumpulainen & Kalliomäkki (2022) indicate that using recycled plastics reduces the carbon footprint substantially compared to virgin plastics. Specifically, the production of a single recycled plastic pallet emits only 0.981 kg CO_2-eq, as seen in section 3.6 and table 5, which is significantly less than the 60 kg CO_2-eq (Deviatkin & Horttanainen, 2020) emitted in the production of a primary plastic pallet. The treatment process in production accounts for 94.3 % of the carbon footprint due to energy requirements. The rest is 5.5% from machinery and only 0.2% from production of additives (Kumpulainen & Kalliomäki, 2022.

4.1.5 Production – Wood

The production utilises harvesting machinery and other energy draining resources when converting timber to wooden pallets. Compared to primary plastic pallets, wood pallets are considered to be more sustainable, particularly if sourced from sustainably managed forests (Khan et al., 2021; Deng et. al., 2022).

The production of one standard wooden EUR pallet results in total emissions of approximately 1.45 kg CO_2-eq. Breaking down these emissions, material procurement accounts for 3.55 kg CO_2-eq (71%), nail production for 1.35 kg CO_2-eq (27%), and electricity usage for 0.10 kg CO_2-eq (2%) (Deviatkin & Horttanainen, 2020).

4.2 Distribution & Use phase

Using NTMCalc 4.0 Environmental Performance Calculator we can roughly model the difference in GHG emissions for two pre-planned scenarios of transportation with 150 km for the distribution. This is done by applying the aforementioned weight differences in the calculations, but otherwise keeping the same factors for both scenarios.

Table 2

Different Weight Scenarios Details for table 3 & 4 GHG-emissions Calculation between Recycled Plastic and Wood pallets.

Details	Measurements Scenario 1	Measurements Scenario 2	References
Total Pallets Transported	288 pallets, stacked	18 pallets + 500kg, non-stacked	
Total Weight of Plastic Pallets	5472 kg (288 x 19 kg)	9342 kg (500 kg + 19 kg) x 18	
Total Weight of Wood Pallets	6336 kg (288 x 22 kg)	9396 kg (500 kg + 22 kg) x 18	
Weight assessment, with and without payload	19/22 = 0.864 86%	9342/9396 = 0.994 99%	

Comment: The weight details used for calculation of two scenarios in table 3 & 4 with NTMCalc 4.0 Basic. Table 2 is a continuation of Table 1.

Table 3

GHG Emissions Plastic vs Wood, Modelling FTL Pallet Distribution from Production

Scenario 1	CO_2 total (kg)	CO_2-eq (kg)	CH_4 (g)	N_2O (g)
Recycled Plastic				
Vehicle (tank to wheel)	96.96	91.92	0.07151	6.044
Fuel (well to tank)	15.44	18.58	99.30	2.648
Total	112.4	110.5	99.37	15.86
Wood				
Vehicle (tank to wheel)	112.3	106.4	0.0828	6.998
Fuel (well to tank)	17.87	21.51	115.0	3.066
Total	130.1	127.9	115.1	10.06

Comment: Derived from NTMCalc Basic 4.0, Network for Transport Measures 2024.

Table 4

GHG Emissions Plastic vs Wood, Modelling FTL Pallet w/ 500kg Payload in Transportation

Scenario 2	CO_2 total (kg)	CO_2-eq (kg)	CH_4 (g)	N_2O (g)
Recycled Plastic				
Vehicle (tank to wheel)	165.5	156.9	0.1221	10.32
Fuel (well to tank)	26.35	31.71	169.5	4.521
Total	191.9	188.6	169.6	14.84
Wood				
Vehicle (tank to wheel)	166.5	157.8	0.1228	10.38
Fuel (well to tank)	26.51	31.90	170.5	4.547
Total	193.0	189.7	170.6	14.93

Comment: Derived from NTMCalc Basic 4.0, Network for Transport Measures 2024.

As can be observed in above tables 2 & 3, the higher weight of wooden pallets compared to recycled plastic pallets will affect GHG emissions when simulating a delivery of exclusively pallets, or simulating pallet pooling transportation, using a Diesel B7-EU 14-20 ton truck. The 15.8% higher weight of a single wooden pallet almost becomes negligible when adding a 500kg payload compared to the lighter recycled plastic pallet as seen in table 4. Still, the small difference will accumulate over time/cycles.

4.2.1 Repairability & Wear and Tear

As stated previously, the main difference in repairability between wooden and plastic pallets is that wooden pallets can be repaired, while the plastic ones cannot. This makes recycled plastic pallets more susceptible to damage from negligence as Kroon (2024) describes in a personal communication, as the whole pallet needs to be remade where a wooden pallet could potentially be repaired.

According to Deviatkin & Horttanainen (2020), an estimation of 0.84 CO_2-eq for wooden pallets over 20 cycles is estimated. This includes two instances for repair per pallet. Wear and tear, like chipping and microplastaics is not included due to it being an environmental impact.

4.3 End of Life

Three separate EoL scenarios are considered; incineration (with and without energy recovery) and recycling (Wimao Impossible Plastics RPT), which is exclusive for recycled plastic pallets. However, the main scenarios considered in this study will be WtE and recycling. Nevertheless, the typical EoL scenario for recycled plastic pallets involves undergoing recycling multiple times. These pallets can be recycled up to 8 times using Wimao Impossible Plastics RPT before requiring an addition/mixing of new plastic waste to maintain structural integrity (Personal communication. A. Kroon, 2024).

For recycled plastic pallets; the resulted emissions from incineration with and without energy recovery is based on a primary plastic pallet being incinerated (Deviatkin & Horttanainen, 2020). The emissions result when incinerating a 20 kg primary plastic pallet (60 kg CO_2-eq) and the potential energy recovery (-37 kg CO_2-eq) for it using WtE has been added to table 5 by using Deviatkin & Horttanainen's (2020) study. But more importantly, the resulted avoided emissions when recycling using Wimao Impossible Plastics RPT amount to 37.26 kg CO_2-eq (Kumpulainen & Kalliomäkki, 2022), as seen in table 5.

As can be observed in table 5, the effect of carbon sequestration stored in wood slightly offset the emissions by correlated with material procurement, production and use. The study by Gasol et al. (2008) highlights that carbon sequestration in wood pallets can result in net negative CO_2-eq life cycle emissions. This factor leads to high variations in a wooden pallets carbon footprint depending on forestry sourcing. Ranging from -7.6 to -19 kg CO_2-eq per wooden pallet (Deviatkin et al., 2019). In this study, the EoL phase using incineration with energy recovery for a single wooden pallet is taken from Deviatkin & Horttanainen (2020) as seen in table 5.

Recycled plastic pallets using Wimao Impossible Plastics RPT is a method that allows for the continuous reuse of all plastics. Wimao Impossible Plastics RPT states that plastic pallets are recycled up to eight times without substantial degradation in quality (Personal communication.

A. Kroon, 2024). This does not mean that CO_2-eq emissions are released once the recycling 'limit' is reached. The requirement is to mix the already recycled plastic with at least 25% new plastic waste into the RPT (Personal communication. P. Sjösten. 2024). According to Wimao Impossible Plastics RPT they always mix in new plastic waste batches when recycling, and that means that therefore it can theoretically be recycled indefinitely.

This process of recycling can be compared to the carbon sequestration in wooden pallets with Waste to Energy (WtE) incineration. While wood inherently captures carbon during its growth, effectively storing it until the wood decomposes/incinerates. Recycling the plastic instead of incinerating it using Wimao Impossible Plastics RPT avoid the emission of approximately 37.26 kg CO_2-eq per plastic pallet as previously mentioned, using Kumpulainen & Kalliomäkki (2022) LCA WtE results.

4.4 Accumulated Results

Table 5

Results collected in table with references, with and without WtE/recycling

Stage of Life cycle	[1] Per one wooden pallet (kg CO_2-eq)	[2] Per one recycled plastic pallet (kg CO_2-eq)	References
Material Procurement	3.55	-	[1] Deviatkin & Horttanainen, 2020.
Production	1.45	0.98	[1] Deviatkin & Horttanainen, 2020. [2] Kumpulainen & Kalliomäkki, 2022
Pallet Displacement based on Scenario 1	0.44	0.38	[1] NTMCalc Basic 4.0, Table 3 [2] NTMCalc Basic 4.0, Table 3
Repair:	0.84	0	[1] Deviatkin & Horttanainen, 2020. [2] Kroon, 2024.
Total without EoL considered:	**6.28**	**1.37**	
EoL Incineration CO_2-eq emissions:	<1	60*	[1] Deviatkin & Horttanainen. 2020 [2] Deviatkin & Horttanainen. 2020 *Primary plastic pallet
EoL Incineration, avoided CO_2-eq emissions by using WtE:	-17	-37*	[1] Deviatkin & Horttanainen. 2020 [2] Deviatkin & Horttanainen. 2020 *Primary plastic pallet
EoL Recycling using Wimao Impossible Plastics RPT:	-	-37.26	[1] – [2] Kumpulainen & Kalliomäkki, 2022
Results, with incineration WtE as EoL:	**-9.55**	24.37*	[1] Deviatkin & Horttanainen. 2020 [2] Deviatkin & Horttanainen. 2020 *Primary plastic pallet
Results, with recycling EoL:	-	**-35.8**	[1] – [2] Kumpulainen & Kalliomäkki, 2022
CO_2-eq per cycle, with WtE/Recycling	-0.478 20 cycles	-0.544 66 cycles	

Comment: Benchmarking based on two separate LCA's and NTMCalc 4.0 modelling software.

The accumulated results from this study underscore the complexity between material choices, production processes and EoL scenarios in determining the emissions of both wood and plastic pallets. Most important information related to the results of the study is highlighted in bold text and numbers in table 5, as these represent the end-results examined in this study.

By avoiding the incineration of plastic parts and focusing solely on Wimao Impossible Plastics RPT recycling method, the process significantly reduces the dependency on virgin plastics. Which typically entail high GHG emission. This not only decreases the extraction and processing burdens but also mitigates landfill waste (Khan et al., 2021). This practice is parallel to the sequestration and WtE effect observed with wooden pallets, effectively reducing the net carbon emissions by retaining fossil-based emissions within the recycling cycle.

The CO_2-eq emissions per cycle for both wooden and recycled plastic pallets provides basic data on their relative climate impact. For wooden pallets, the CO_2-eq per cycle is calculated at -0.478 kg, spanning over a life cycle of 20 cycles as shown in table 5. The recycled pallets exhibit slightly lower CO_2-eq emissions per cycle at -0.544 kg, with a lifespan of 66 cycles. This improvement over wooden pallets is largely contributed to the efficient use of plastic waste and avoidance of incineration. Calculated by taking the accumulative CO_2-eq based on the specific scenario regarding each pallets emissions and dividing with the proposed number of cycles.

5. DISCUSSION

Whatever pallet material is used, wood or recycled plastic, the emissions are significant. The results in section 4.4 indicate that recycled plastic pallets reduce the carbon footprint compared to wooden pallets at almost every stage of their life cycle. Particularly striking was the lower emissions of recycled plastic pallets in the production and recycling phase. Due to plastic waste mitigation, the need for virgin plastic production/procurement could be reduced. This aligns with the study performed by Khan et al. (2021) who noted similar benefits involving wood-polymer composites (WPC).

While the climate benefits are clear, they invite scrutiny of the potential widespread adoption of recycled plastic pallets across different regions and industries. Factors, such as; variability in recycling infrastructure/capabilities, standardisation, governmental incentives need to be considered.

5.1 Carbon Sequestration & Recycling

The role of carbon sequestration in wooden pallets has significant implications in emissions result. Given the natural absorption of CO_2 by trees during their growth phase. In the study chosen, a single wood pallet is estimated to hold 34 kg CO_2-eq. These numbers are based on a study conducted in Finland and was chosen as a comparable alternative to the forestry industry in Sweden. The stored biogenic carbon in wooden pallets is estimated to potentially offset the associated emissions, leading to a reduction of up to -16 kg CO_2-eq per pallet when incinerated according to the same study (Deviatkin & Horttanainen, 2020). This biogenic carbon storage not only provides a means to mitigate greenhouse gas emissions but also highlights the importance of sustainable forest management practices, as can be further read about in section 5.8.

In contrast, the utilisation of Wimao Impossible Plastics RPT way of producing pallets introduces a new, sustainable alternative by repurposing waste materials. The LCA indicates that recycled plastic pallets significantly reduce the carbon footprint, with the manufacturing and distribution of a single pallet resulting in only 1.37 kg CO_2-eq, a big difference to the 61 kg CO_2-eq for a similar pallet made from virgin plastics. Additionally, the avoidance of WtE incineration suggests that you are hindering approximately 37.26 kg CO_2-eq emissions. Or 37 kg CO_2-eq emissions according to Deviatkin & Horttanainen (2020). Arguably, a type of sequestration is made by keeping the fossil-based material in a closed loop system.

Carbon sequestration is a divisive subject and have been discussed many times and the viability has been brought into question Cassella (2018). Depending on which source you want to choose, or depending on where the boundaries are set, the results and viability of sequestration will lead to very different outcomes as shown in the results.

Saying that a type of carbon sequestration occurs in plastic pallets is on the other hand a less controversial statement. As previously mentioned, the plastics that Wimao Impossible Plastics RPT use in their production is otherwise used for energy recovery in incineration plants. By reusing these otherwise incinerated plastics keep the carbon bound and stops it from being released, with the methods Wimao Impossible Plastics claims, they can theoretically keep these plastics in use indefinitely solely by continuously mixing plastic wastes into the production process.

5.2 Transportation emissions Considering Weight & Lifespan

In analysing the transportation phase of pallet life cycles, both weight differences and extended lifespans offer significant insights into their life cycle emissions. Recycled plastic pallets, typically weighing less than wooden pallets (19 kg compared to 22 kg for wood), inherently facilitate reduced fuel consumption. This weight reduction plays a critical role in diminishing greenhouse gas emissions within the logistics sector, aligning with broader environmental goals aimed at reducing transportation emissions.
Furthermore, the durability of these recycled plastic pallets exhibits lifespans three to four times greater than their wooden counterparts, which profoundly extends their utility. As stated by Kroon (personal communication, 2024), this longevity means that fewer pallets need to be produced, transported, and eventually disposed of, thereby enhancing the life cycle efficiency of materials used.

Consequences of the previously mentioned factors will be the need for development of new logistical solutions by companies adapting to the use of plastic pallets like this. Especially with the use of the Wimao Impossible Plastics pallets where the return and reuse is incentivised. Companies not currently using a circular system could benefit from implementing a more circular system, possibly benefiting both in an economical and environmental even by moving away from the use of one-time use pallets for example.
Integrating these factors, the cumulative climate benefits become markedly apparent. While the immediate reduction in GHG emissions from lower fuel consumption is significant, the prolonged lifespan of recycled plastic pallets further reduces the emissions by lowering the frequency of pallet replacement. Modelling the climate impact across the same operational distance and lifespan, recycled plastic pallets show a substantially lower cumulative GHG emission footprint. For instance, a single recycled plastic pallet could endure up to 80 cycles of use without needing replacement, compared to about 20 cycles (with repairs included) for a wooden pallet.

With the increased resilience of plastic pallets, the Wimao Impossible Plastics RPT can be used to reduce the need for the need of raw materials and remove plastics from the recycling rotation. This will translate into direct reduction of emissions and reduce the energy use from both manufacturing and transport.

5.3 Technological innovations

With the Wimao Impossible Plastics RPT finalized development within the last few years, there is possibility for further development with both this technology and competing companies developing similar methods of using waste plastics otherwise destined for incineration. The method of moulding plastic into commercial products is not exclusive to the production of pallets and could possibly be expanded into a larger market, examples were given in the interview with Wimao Impossible Plastics about how they have been contacted about making flower beds for example and there could also be more possibilities for further development for the technology. New markets that open could be great for increasing both usage of waste plastics. There is the possibility of emerging markets moving focus away from pallet production, if another market becomes more profitable the prices could increase for plastic pallets.

5.4 End of Life Management

The comparison between the EoL cycle of wooden and plastic pallets represented above show a comparison between with different ways of handling the EoL. As many previous studies have shown, the traditional methods of producing plastic pallets, both by virgin plastic and by other waste plastic methods, are not as beneficial and comparable to wooden pallets as the Wimao Impossible Plastics RPT. The main difference between plastic pallets, as shown by the numbers is the recycling using the Wimao Impossible Plastics RPT.

As wooden pallets reach their EoL faster than the plastic counterpart, they need replacement more often, requiring the adaptation in the results to reflect the number of cycles presented. This is an estimation done to establish a fairer comparison between the two, because of the estimated cycles for the plastic pallets are between 50 and 100 cycles, 66 are used to show a comparative number of cycles to the wooden pallet as in Deviatkin & Horttanainen (2020), as that is the number used by the study with results from many of the other data points. This is not the ideal way of conducting an analysis like this, preferably there would be interviews with wooden pallet manufacturers, transporters and users for a complete picture, attempts to reach manufacturers was made initially successfully, but no answer was returned when more specific questions were asked.

5.5 CO_2-eq per Cycle

When comparing the CO_2-eq emissions per cycle between both types of pallets, the scenarios applied are very specific, meaning that the results reflect the best-case scenario life cycle for the climate. WtE and carbon sequestration included for wood and incineration avoidance for recycled plastics. It is clear that the extended number of cycles for recycled plastics amplifies their advantage in terms of reduced carbon emissions per use. The analysis reveals that the extended number of cycles for recycled plastic pallets amplifies their advantage in terms of reduced carbon emissions per use.

5.6 Method

The original plan for the paper to perform a unique LCA for both the wooden and plastic pallets were planned but due to time constraints and limitations in available information, the decision was made to perform a literary study instead. As discussed in a separate chapter later, this brings separate issues. An alternative method could be to use interviews in a more substantial way by performing some form of interview research, as the process of performing few good interviews fell apart. Some more informal interviews or a more general survey could be performed to either have a completely different type of study or as a method of gaining more information towards this study.

5.7 Market Perspective

From the perspective of a single issue like this report, the choice would be dependent largely on the company and its internal logistics setup, therefore many would probably stay doing the same as always.

Plastic pallets are primarily marketed towards companies with implemented circular solutions, because of the desire to preserve and recover the pallet when damaged or at the end of its life cycle. Because of this, the current market is limited to closed, circular systems. The market is not small, notably when you consider larger industries not currently in a closed system, but capable of it, like e-commerce, as mentioned by Kroon (Personal communication., 2024) in the interview.

The respondent also mentioned the possibility for companies to use less pallets over time as the plastic variant have a longer lifespan than wooden pallets. As an example, told of a company currently using only one-use pallets instead of reusable. This company ordered 700 pallets a week, by converting to reusable pallets instead, they could possibly replace all one-use pallets with 3500 plastic pallets, lasting for the next three years.

Specific industries are also switching from wood to plastic because of material concerns. In several businesses, sterile production facilities are required and because of the risk for contamination from splinters and dust particles from wooden pallets, companies making batteries for example is swiftly moving over to plastic pallets.
Wooden pallets are in an advantageous position as the tried-and-true solution. It is also a readily available product, interchangeably compatible, and there are pallet producer and provider all over the globe and the ability to handle both repairs and incineration wherever located. For international exports and smaller shipments with marginal ability for or pick-ups return shipments, wooden pallets are also preferred.

5.8 Microplastics from Pallet Usage

The impact of microplastics is a critical area of concern across various sectors. This includes the pallet industry. In the context of recycled plastic pallets, such as those produced using Wimao Impossible Plastics RPT method, the potential for microplastic generation during their lifespan is an issue that warrants detailed investigation. In this study these environmental impacts have been excluded from the results as the focus lies on the CO_2-eq emissions. Still, the issue is considered an important topic.

Recycled plastic pallets, while offering substantial reductions in CO_2-eq emissions, can contribute to microplastic pollution/accumulation that originate from the wear and tear of pallets during their handling/transportation and production. Regarding the production phase using Wimao Impossible Plastics RPT, Kroon (Personal communication., 2024) implies that the microplastics generated during production phase are expected to stay within the production facility, which can be supported if management is flawless. However, it is commonly known that microplastics can quite easily escape these types of cycles, if for example cleaning is done by using pressurised water within production facility it can easily lead microplastics into industrial drainage systems (Wang et. al., 2021), and thus into other environments. Given these challenges, there are significant gaps in our understanding of the fate and transportation of microplastics during use phase, and from production. Current methodologies for microplastics vary a lot, which complicates the efforts to understand the true extent of this issue from recycled plastic pallets.

5.8.1 Wood Chips from Pallet Usage

Wood chipping environmental impacts from wooden pallets wear and tear, or sawdust from material procurement and production phase, have been hard to find due to the limited amount of studies specifically researching this type of impact. Either way, wood waste generation is an issue for wooden pallets and if not managed properly can contribute to the unwanted pollution/accumulation of biomaterial in different locations. Similar to microplastics concerns, the fate and transportation of wood chipping from wear and tear will vary, and environmental impact remain unknown. Either way, increases in emissions related to repairability will be a factor when talking about wood chipping of pallets. This, in turn makes the pallets release more CO_2-eq emissions during total life cycle. And arguably, excessive wear and tear will lead to shorter lifespan.

5.9 Forest Industry

With GHG emissions becoming more important for companies to track in recent years, tracking emissions from scope 1, 2 and 3 have become central in many sustainability reports to better track where specific emissions originate from. Scope 1 are direct emissions from any service provided, scope 2 refers to the indirect emissions and the largest, scope 3 encompasses the anything relating to the service provided.
Wooden pallets create a link to the lumber industry through these scopes to every company using them. The lumber industry in Sweden is one of the largest and is estimated to be the largest producer of CO_2-eq but because of exemptions from carbon sequestration, the industry seems to be operating with negative carbon emissions. By counting emissions with scope 1, 2 and 3, there is the possibility for double counting of emissions and if emissions can be double counted, the reduction can also be double counted. There is the possibility this could be seen as incentivized as there is a big positive for the company if they can show negative emissions.

The Swedish lumber industry have in recent years been under scrutiny by European politicians because of the controversial methods the industry preferers, clear-cutting can be seen as both beneficial and harmful depending on which viewpoint taken. The industry sees the practice as a necessity as it is an established practice, requiring no adaptation, and is an efficient lumbering process. The problem with keeping traditional methods is that change is needed to reduce emissions, so adaptation is required (Buonocore et al., 2014). Clear-cutting is being criticized because of the amount of CO_2-eq released after the clearing process is finished. As it can take decades for newly planted trees to compensate for the clearing, the process can be seen as a way for companies to move the impacts into the future, by cutting an area and then planting more threes in another, they can say they had a negative impact, despite this not coming to fruition until decades later.

Changing the way harvesting happen is also important because of the heavily reduced biological

diversity and the elimination of most of the virgin forests of Sweden. The most important metric is not always the sequestrated carbon but keeping the biodiversity up can be equally important for keeping the forests healthy by keeping the ecosystem thriving.
The advantages of using material like wood with sequestered carbon is to bind carbon and to eliminate the use of materials that would otherwise provide a negative impact. You can argue the benefits of sequestration in wooden pallets are negated when using pallets made from exclusively waste plastics, as the main benefit of preventing more CO_2-eq emissions leaking into the atmosphere is a benefit for both types of pallets. Eliminating this variable there is no longer as much in favour of the wooden pallet. Disregarding the benefits of the carbon sequestration from wooden pallets impacts the assessment of the entire lumber industry. Without these benefits, the CO_2-eq released from the industry will be among the highest in Sweden making the use of wooden pallets worse, as the pallets are not from a waste material so the material can be seen as taken directly from other markets where the impact could be greater. Instead of making pallets from boards, for example, they could instead be used in buildings, replacing concrete.

5.10 Analysis of result

It is essential to acknowledge the limitations of the data and the analysis performed in this study. The reliance on a few specific LCA studies and the assumptions made throughout the research process may affect the generalizability of the results. The limited data set and the focus on specific geographic regions further constrain the findings. Information on the distribution and use of the pallets are mainly based on assumptions and basic calculations, as such the collection of information from distributors and users could be more of a factor than assumed. Future research should aim to include a broader range of data sources and consider additional environmental impacts beyond CO_2-eq emissions, such as biodiversity loss and resource depletion. Additionally, the potential variability in recycling practices and the long-term sustainability of recycled plastic pallets need further exploration. Some comparison between logging practises in Sweden and Finland may also be relevant, to show if the sourcing is any different. These uncertainties highlight the need for cautious interpretation of the results in this study and underscore the importance of continuous evaluation and improvement of LCA methodologies.

Reaching a result of a negative total impact of any of the pallets is an indicator for the need to study the underlying numbers more closely. The conclusion that the use of wooden pallets always will reduce CO_2-eq may indicate that the carbon sequestration valued too highly, or do not consider all possible parameters, as previously discussed. As it is beneficial for all parties counting emissions to keep the negative numbers as high as possible, there could be possibilities for incentivizing misreporting by exaggerating reporting numbers.
Assumptions made in this report can be seen as ways of exaggerating the sequestration numbers. Throughout the report expectations like the assumption that pallets are always handled the same, as the material will be reused in the same way for the ease of estimation. Assumptions are also made that the industry will continue operating the same in many years and not make dramatic changes.

As discussed previously, the collection of lumber for production is not without controversy (Cassella, 2018). The collection process is under scrutiny and can be criticized in multiple ways, for instance, the use of monocultures and clear-cutting. Without proper information from the

Swedish lumber industry, and much more time, these are assumptions that need to be made but the problem with the underlying information is in large part from assumptions starting at lumber plantations.

Another problem more specific to the plastic pallets are the limited access to processing plants, currently only three exist, one in Finland and two in Sweden. Because of this, transportation to locations farther away will become less efficient as wooden pallets do not have the same limitations as there are plenty of established repairers and distributers at almost any area in need of pallets. Unnecessarily long transportation is not something considered in this report, no standard transportation distance per pallet has not been investigated and transportation distance can be a factor not considered here as the distance travelled for a wooden pallet might be longer than the plastic pallet, since the plastic pallet is marketed towards more closed systems where the manufacturer has a better chance of encouraging the return at EoL.

To have an easier comparison between the wood and plastic pallets, we expect all plastic pallets to be returned to the manufacturer at the appropriate time. This is an optimistic plan as the customer is not incentivized more than the free return. If for example one pallet breaks long before expected EoL, the user might not perceive the benefits of just sending back one pallet, or storing a broken one until more are needed to be sent. Plastic pallets do have the benefit of being made from waste materials, but the wooden pallets do have the possibility for alternative uses after the expected use time. With the popularity in recent years of finding alternative uses for old products, older pallets have been finding more uses, like the making of furniture, potentially storing the carbon for longer than expected.

6. CONCLUSION

In the evaluation of the CO_2-eq emissions of wooden and recycled plastic pallets, several critical factors have been identified that influence the choice of pallet materials in logistics. Each material offers unique benefits and challenges that are heavily dependent on the specific context of their use phase and the LCA methodology employed.

6.1 Carbon sequestration & Recycling Impact

Our results indicates that the choice of pallet material can substantially affect the emissions. Wood, with its inherent ability to withdraw and reserve carbon during their growth means that wooden pallets can be considered to have a net-negative impact on CO_2-eq emissions, depending on the life cycle and EoL management. The natural biogenic carbon sequestration associated with wood products, play a significant role in its environmental performance. However, this benefit is massively dependable on sustainable forestry practises that ensure the regeneration of harvested forest and the long-term sequestration of carbon. More research should be performed where different forestry practices are benchmarked against each other to get a clearer understanding of the management's connection with carbon sequestration.

On the other hand, while recycled plastic pallets do not involve carbon sequestration like trees, it acts as a form of carbon storage by locking in CO_2-eq emissions that would otherwise be released into the atmosphere if incinerated. By reducing the demand for virgin plastic production and minimizing waste, these pallets contribute to environmental sustainability. Their durability and theoretical potential for indefinite amounts of recycling align with circular economy principles. Meaning that the stored CO_2-eq emissions remains fixed within the material throughout the life cycle, and if recycled continues to be stored in the next life cycle and so on. However, recycling cannot be guaranteed, only incentivized.
Furthermore, the study does not consider the impact that microplastics, or wood chipping might have when released during a pallet's life cycle phases due to wear and tear or other kinds of pollution.

6.2 Dependence on LCA Approach & EoL Scenarios

The resulted emissions in this benchmarking between wood and recycled plastic pallets is highly dependent on the assumptions and scenarios considered in the life cycle phases. The parameters/scope, boundary settings (such as geographical setting) and assumptions in the life cycle critically shapes the study's outcome. For instance, if this study also researched on each pallets environmental impact the interchangeability of standardised EUR wooden pallets might enhance the outcome relating to the efficiency and utility. Essentially a wooden pallet would be used by multiple companies sequentially, which can reduce the total amount of pallets in the entire system. However, this indirect efficiency impact does not directly influence the emissions of a single wooden pallet's life cycle.
EoL scenarios also critically shape the emissions results. The choice between recycling and incinerating with energy recovery is significant. And this already excludes other EoL options such as; incineration without energy recovery, landfilling and other recycling processes. These EoL options can tremendously extend a material's lifespan and life cycle emission result.

6.3 Final Thoughts

While this study has benchmarked the correlated CO_2-eq emissions for each pallet's life cycle, it also highlights the need for more comprehensive and context specific research. Future studies should focus on exploring the environmental impact and the long-term sustainability of the materials used in pallet production. If a best-case scenario is applied and considering carbon sequestration and avoidance of incineration, then recycled plastic pallet offers a more sustainable alternative based on our parameters and result.

7. RECOMMENDATIONS FOR FURTHER RESEARCH

With this thesis as a foundation, multiple sections can be examined further in several different directions. Here will a few of the more interesting alternatives will be presented.

The potential to perform a similar study with more information is a clear alternative. By having more information to start with, more time could be focused on collecting information and performing interviews from people within the industry. Data from everything from the lumber industry, to end user, important information from each stage could be useful as first-hand information provides a more comprehensive understanding of the lifecycle of a pallet, giving more detailed results.

Studying the differences in the available plastic pallets could be an interesting topic to evaluate. A comparison between the different options available could provide benefits. The need for a more general comparison including economical, societal, and environmental analysis, providing a greater comparison between different methods of plastic pallet production.

Both pallet types have different types of wear and tear, pallets release dust and woodchips from everyday use which can be irritants or contaminants for certain industries. The possibility for microplastic contamination from use of plastic pallets is a possible health concern and environmental impacts are not examined in this report.

A major result of this study shows the need for proper handling of carbon sequestration numbers. A study detailing the process of sequestration calculations and how companies can use the numbers for negating emissions in their yearly climate report. The European Union is discussing the future of the Swedish form of lumber harvesting and a study of possible implications of forced adjustment.

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DEPARTMENT OF MECHANICS AND MARITIME SCIENCES
CHALMERS UNIVERSITY OF TECHNOLOGY
Göteborg, Sweden
www.chalmers.se

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