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MASTER THESIS

Cost Competitiveness of Recycled Sawn Timber Compared to Virgin Sawn Timber

FOR THE ATTAINMENT OF THE ACADEMIC DEGREE

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Puutuoteteollisuus ry

Technik

Gesundheit

Medien

Declaration under oath

I, Tomi Haikonen, born on February 19, 1998, in Artjärvi, hereby declare under oath that I have written this Bachelor thesis independently and without external assistance, and that I have not used any sources or aids other than those cited. Furthermore, I hereby affirm that I have identified as such all passages taken verbatim or in substance from the sources used.

This thesis has not been submitted, in the same or a similar form, to any other examination committee in English or abroad, nor has it been published.

14.5.2026

Date

Signature

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Abstract / Tiivistelmä / Zusammenfassung

This study investigated the cost competitiveness of recycled sawn timber to virgin sawn timber under current industrial conditions. The background of the study was the growing need to find alternative raw material sources for virgin sawn timber production, while also aiming to identify higher value uses for demolition wood waste, which is currently used for energy recovery or downcycled into lower-value wood-based products like example particleboards. The research was based on a combination of empirical observations from the Puuloop demolition pilot in Porvoo, Finland, as well as secondary sources such as industry cost estimates, literature, and market reference prices for virgin sawn timber in the Nordic countries. Scenario-based cost modelling methods were used to compare the cost structures of virgin and recycled sawn timber under different recovery and processing conditions. The results indicate that the recovery rate is the most significant factor affecting the cost competitiveness of recycled sawn timber. Under favourable recovery and cost conditions, recycled sawn timber could reach or even fall below the selected market price level compared to virgin sawn timber. However, assuming lower recovery rates and higher processing costs, recycled sawn timber was not cost-competitive. The study suggests that recycled sawn timber has realistic market potential, but its competitiveness heavily depends on efficient sorting, material recovery, and cost-effective processing.

Key words: Recycled wood, sawn timber, cost competitiveness, circular economy, demolition wood.

Tutkimuksessa tutkittiin kierrätetystä puutavarasta tuotetun sahatavaran kustannuskilpailukykyä verrattuna neitseelliseen sahatavaratuotantoon nykyisissä teollisuusolosuhteissa. Tutkimuksen taustalla on kasvava tarve löytää vaihtoehtoisia raaka-aineen lähteitä neitseellisen sahatavaran tuotannolle, samalla kun pyrittiin tunnistamaan purkujätteen korkeamman arvon käyttökohteita. Nykyisin purkujätettä käytetään energian talteenottoon tai kierrätetään alhaisemman arvon puupohjaisiksi tuotteiksi, kuten esimerkiksi lastulevyiksi. Tutkimus perustui yhdistelmään empiirisiä havaintoja Puuloop-purkupilotista Porvoosta, sekä sekundäärisiä lähteitä, kuten alan kustannusarvioita, kirjallisuutta ja sahatavaran pohjoismaisia markkinaviitehintoja. Skenaariopohjaisia kustannusmallinnusmenetelmiä käytettiin vertaamaan neitseellisen ja kierrätetyn sahatavaran kustannusrakenteita eri talteenotto- ja käsittelyolosuhteissa. Tulokset osoittavat, että kierrätyspuun kustannuskilpailukykyyn vaikuttaa eniten kierrätysaste. Suotuisissa talteenotto- ja kustannusolosuhteissa kierrätetty sahatavara voisi saavuttaa tai laskea valitun markkinahintatason alapuolelle verrattuna neitseelliseen sahatavaraan. Talteenottoprosenttien ollessa alhaisemmat ja käsittelykustannukset korkeat, kierrätetty puu ei ollut kustannuskilpailukykyistä. Tutkimus ehdottaa, että kierrätetyllä puulla on realistinen markkinapotentiaali, mutta sen kilpailukyky riippuu eniten materiallin lajittelusta, talteenotosta ja kustannustehokkaasta käsittelystä.

Avainsanat: Kierrätyspuu, sahatavara, kustannusvertailu, kiertotalous, purku puu

In dieser Masterarbeit wurde die Kostenwettbewerbsfähigkeit von Schnittholz aus recyceltem Schnittholz im Vergleich zu Schnittholz aus Primärholz unter den derzeitigen industriellen Bedingungen untersucht. Hintergrund der Studie war die wachsende Notwendigkeit alternative Rohstoffquellen für die Schnittholzproduktion aus Primärholz zu finden, wobei gleichzeitig das Ziel verfolgt wurde hochwertigere Verwendungsmöglichkeiten für Abbruchholzabfälle zu ermitteln. Diese werden derzeit häufig zur energetischen Verwertung genutzten oder zu minderwertigeren Holzprodukten, wie beispielsweise Spanplatten, „downgecycelt“. Die Untersuchung basierte auf einer Kombination aus empirischen Beobachtungen aus dem „Puuloop“-Abbruchpilotprojekt in Porvoo, Finnland, sowie auf Sekundärquellen wie Kostenschätzungen der Industrie, Literatur und Marktreferenzpreisen für Schnittholz in den nordischen Ländern. Es wurden szenariobasierte Kostenmodellierungsmethoden verwendet, um die Kostenstrukturen von Schnittholz aus Primärholz und recyceltem Holz unter verschiedenen Verwertungs- und Verarbeitungsbedingungen zu vergleichen. Die Ergebnisse zeigen, dass die Rückgewinnungsrate der wichtigste Faktor ist, der die Kostenwettbewerbsfähigkeit von recyceltem Holz beeinflusst. Unter günstigen Rückgewinnungs- und Kostenbedingungen könnte recyceltes Holz das ausgewählte Marktpreisniveau im Vergleich zu Primärholz erreichen oder sogar unterschreiten. Unter der Annahme niedrigerer Rückgewinnungsraten und höherer Verarbeitungskosten war recyceltes Holz jedoch nicht wettbewerbsfähig. Die Studie legt nahe, dass recyceltes Holz ein realistisches Marktpotenzial hat, seine Wettbewerbsfähigkeit jedoch stark von einer effizienten Sortierung, Materialrückgewinnung und kosteneffizienten Verarbeitung abhängt

Schlüsselwörter: Recyceltes Holz, Schnittholz, Kostenwettbewerbsfähigkeit, Kreislaufwirtschaft, Abbruchholz.

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1 Introduction

Climate change is becoming increasingly noticeable, with warm winters and unbearably hot summer days now part of everyday reality. It has already caused major damage to different species of wood, which are suffering due to warming, drought and reduced moisture levels. Norway spruce is the dominant tree species in Europe, but it is now dying out. It may be difficult and almost impossible to provide or obtain the same volumes or species of wood as today. Wood is being used more in construction, but if the amount of virgin sawn timber starts to decline significantly, new alternatives must be found. One such option would be recycled sawn timber. (Jandl, 2020)

This thesis examines whether recycled sawn timber can compete with virgin sawn timber and what factors influence the material costs. The study focuses on comparing the cost structures of recycled and virgin sawn timber, particularly paying attention to raw material procurement, processing requirements, and comparing end-product prices. By analysing these cost components, the aim of the study is to provide insight into the economic viability of recycled wood as an alternative raw material in the sawn timber industry.

The study was carried out in collaboration with the Finnish Wood Products Industry Association (Puutuoteteollisuus Ry), through whom a pilot experiment related to the topic was carried out. The pilot was conducted in Porvoo Finland, and it was focused on different demolition methods for the building and how to extract the material as intact as possible while also being efficient.

In this study, the cost structure of recycled sawn timber was evaluated and compared with that of virgin sawn timber using available literature, empirical data, and market-based product references. The comparison was linked to commercially available virgin sawn timber products of corresponding dimensions, specifically 48 × 98 mm and 48 × 148 mm. This approach makes it possible to assess the cost competitiveness of recycled sawn timber against real market products while also identifying the key cost factors and process-related challenges that influence its industrial feasibility.

Finally, the main findings of the study are summarised, and the cost competitiveness and economic viability of recycled sawn timber compared to virgin wood are assessed. Based on the results, recommendations and suggestions for future research are presented.

1.1 Relevance of the Topic

At present, sawn timber production is based almost entirely on virgin wood, while large amounts of wood are simultaneously removed from buildings through demolition and renovation. In many cases, this material is either burned for energy or recycled into lower-value products such as particleboard. Although these uses extend the life of the material to some level, they still represent forms of downcycling rather than higher-value circular reuse of wood.

In recent years, variations in raw material prices, together with stricter environmental regulation and growing circular economy targets, have increased interest in alternative wood resources. Recycled wood has the potential to serve as a secondary raw material, but its use in higher-value applications such as sawn timber remains limited. (European Council, 2023)

Currently, the recycled sawn timber used is sold by small operators, but the volumes are small. They can potentially process the material, for example by planning or otherwise treating it, but it is not strength-graded and is therefore not suitable for load-bearing structures because its limitations a strength class. This is why the market is focused on interior design, such as ceilings, floors, and furniture. (Re:claimed, 2025)

While previous studies have addressed wood recycling and the cost structures related to virgin wood-based products separately, no previous studies were identified that directly compare the cost competitiveness of recycled sawn timber with virgin sawn timber. As a result, there is limited understanding of the economic conditions for recycled sawn timber to compete with traditional products. Also, potential customers may not view recycled wood products as equally reliable or trustworthy as products made from virgin wood. (Re:claimed, 2025)

This thesis addresses these shortcomings by analysing and comparing the cost structures of recycled and virgin sawn timber, with the aim of evaluating the economic viability of recycled sawn timber under current industrial conditions and how it should be developed.

1.2 Aims & Research Questions

The main objective of this thesis is to evaluate the cost competitiveness of recycled sawn timber compared to virgin sawn timber. The study focuses on identifying the main cost factors affecting the production costs of both material flows and on assessing the economic viability of recycled sawn timber under current industrial conditions.

To achieve this objective, the study examines and compares the main cost components of recycled and virgin sawn timber production, particularly those related to material input and processing. The purpose of the analysis is to identify the main factors influencing cost and to examine which conditions currently limit or support the competitiveness of recycled sawn timber. The study also considers what kinds of changes would be required for recycled sawn timber to compete more effectively with virgin wood.

The research is guided by the following research questions (RQs):

RQ1: Is sawn timber made from recycled wood cost-competitive compared to virgin sawn timber?

RQ2: What are the cost components of recycled sawn timber and the factors influencing costs that affect its cost competitiveness?

RQ3: Under what conditions could recycled sawn timber become economically competitive with virgin wood?

1.3 Methods

This chapter explains how the study was carried out. The thesis combines a literature review with an empirical analysis of secondary data to examine the cost competitiveness of recycled sawn timber compared to virgin sawn timber. The literature review was used to build the background and context for the topic, while the empirical part focuses on comparing the cost structures and the main cost-related factors affecting both material flows.

1.3.1 Literature Research

The literature research provides the theoretical and practical background for this study. The sources used includes scientific articles, industry reports, technical publications, and statistical sources related to wood recycling, reclaimed wood, sawn timber production, and the cost structures of wood-based products. In addition to published literature, field reports, case examples, and observations from the Porvoo demolition pilot were used to support the understanding of recycled wood availability and the practical challenges related to its handling and processing.

The literature was used to build an overall understanding of current wood recycling systems and to identify the main technical and cost-related factors relevant to this thesis. It also helped define the key concepts used in the study and provides a basis for the comparative cost analysis presented in the empirical part of the thesis.

1.3.2 Empirical Data Analysis

The empirical part of this study is based on the analysis of secondary data obtained from industry reports, publicly available statistical sources, and observations from the Porvoo demolition pilot case study. The data is used to estimate and compare the cost structures of recycled and virgin sawn timber. The comparison was carried out using cubic metres (m^3) as the common unit of analysis and is supported by price assumptions and reference values relevant to the selected sawn timber dimensions.

The empirical analysis focuses on the main cost-related factors affecting the production of recycled and virgin sawn timber, particularly material input and processing. The aim is to identify the key cost components and to assess under what conditions recycled sawn timber could become economically competitive with virgin sawn timber. The data sources, assumptions, and modelling approach used in the analysis are described in more detail in “5 Project and data collection”.

2 Construction and Demolition Waste & Emissions

In 2022, the construction and demolition sector produced almost 40% of all waste and accounted for 12% of all greenhouse gas emissions in the EU. (EuRIC, 2025) Due to its size and environmental importance, the sector plays a key role in discussions on waste management, resource efficiency and emission reduction. The following chapters provide an overview of the history of wood recycling and examine the waste volumes in Europe, a particular focus on construction and demolition waste. The chapter also provides an overview of emissions associated with waste and their overall significance.

2.1 The European Green Deal and the New European Bauhaus Initiative

The European Green Deal is a strategic policy framework proposed by the European Commission, aiming to make the European Union climate-neutral by 2050. This would make Europe the first climate-neutral continent in the world. The initiative aims to transform the EU into a clean, resource-efficient, and competitive economy while ensuring that economic growth is decoupled from resource use. The policy framework is based on the 2015 Paris Agreement and sets legally binding climate targets through the European Climate Law accepted in 2021. (European Commission, 2024)

The Commission has established a Just Transition Fund (JTF) to support both workers and regions in developing new skills and adapting to the green economy. The clean transition must be fair and equitable for all, and therefore support will be given to the most vulnerable and those most affected by climate change. Other funds aiding includes the Social Climate Fund, the EU Solidarity Fund and the EU Services Mechanism. The Social Climate Fund provides targeted funding for energy efficiency, building renovation and investments related to clean heating. The Services Mechanism and the Solidarity Fund provide support to those most in need, such as after climate disasters. (European Commission, 2024)

Achieving climate neutrality requires significant investments in clean energy sources and low-carbon infrastructure. Within the framework of the European Green Deal, the European Commission has mobilised both public and private financing to support the transition to sustainable and energy-efficient buildings. Programs such as NextGenerationEU and REPowerEU aim to accelerate investments in clean technologies and building renovations, encouraging the adoption of low-carbon building solutions across the entire European Union. (European Commission, 2024)

In addition to larger climate policy tools, the European Commission has introduced initiatives that focus specifically on the built environment. One such initiative is the New European Bauhaus, which aims to translate the goals of the European Green Deal into practical solutions for urban environments and their buildings. The initiative promotes sustainable, inclusive, and aesthetically high-quality living environments while encouraging the use of recycled materials and innovative building practices. By combining sustainability, design, and social inclusion, the New European Bauhaus supports the transition towards climate-neutral construction and increased recycling of building materials in Europe. These policies are expected to increase the interest in wood-based construction materials. (European Union, 2024)

The goal of the New European Bauhaus is also to support the transition towards a more circular economy in the construction sector. By encouraging the use of sustainable and bio-based construction materials, the initiative promotes solutions that reduce environmental impacts throughout the entire lifecycle of buildings. Attention has been paid to materials that binds carbon and enable circular economy resource flows, such as wood and other bio-based construction materials. The initiative also supports innovation projects that explore the reuse and recycling of building materials to reduce dependence on virgin raw materials and improve material efficiency in the construction sector. (European Union, 2026)

These political developments highlight the growing importance of sustainable and circular construction materials in the European construction sector. As interest in bio-based and recycled materials grows, understanding the cost competitiveness of recycled materials compared to virgin wood becomes increasingly important.

2.1.1 10R

The 10R framework focuses on keeping materials and components in use by promoting recycling, reuse, and repurposing instead of disposal. The circular economy provides a framework for reducing the use of materials and resources in construction and manufacturing. A 10-point circular economy framework has been developed to provide advice and assistance to companies. The circular economy could reduce up to 70% of global greenhouse gas emissions. At the same time, the need for virgin materials would decrease as more recycled materials could be used. This guides decision-makers and companies to recover materials, extend the useful life of products and move away from waste management solutions such as burning and landfill, which are generally also the cheapest solutions. (Malooly & Daphne, 2023)

10R framework is a useful tool for visualizing and understanding the different stages of resource use and waste management in a circular economy (Figure 1).

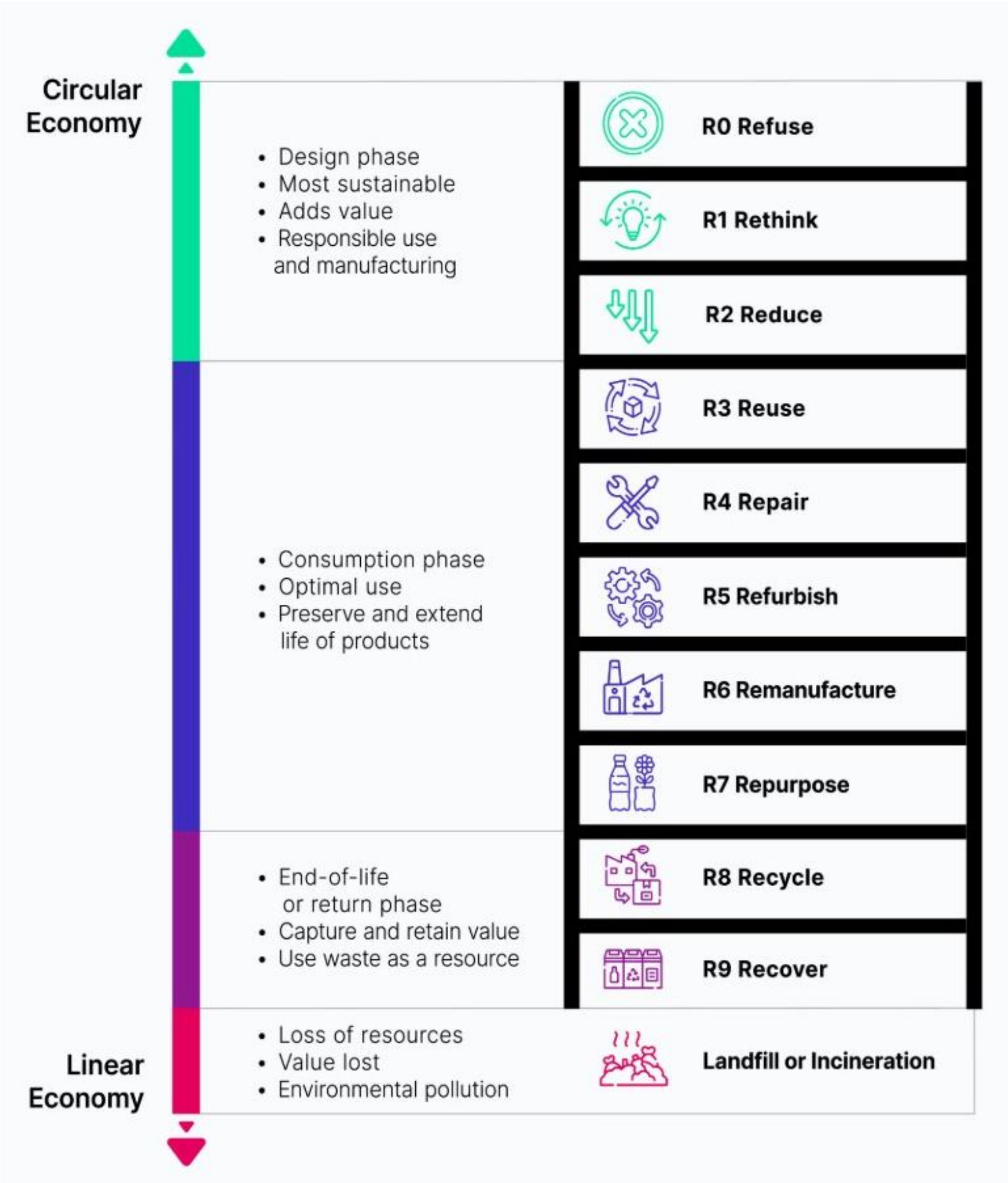

Figure 1. The 10R framework and its stages within the circular economy. (Malooly & Daphne, 2023)

Ten different strategies are defined in total of three main categories. The lower the number, the more effective the strategy is in reducing resource use and maintaining material value. As the numbers increase, the strategies move closer to traditional waste management solutions and become less circular. Lower-numbered strategies are typically applied at the beginning of the value chain, while higher-numbered strategies relate to end-of-life stages.

As we can see from the Figure 1, the strategies can be grouped as follows:

- Short cycles focus on smarter product use and manufacturing: R0 Refuse, R1 Rethink, R2 Reduce.
- Medium cycles focus on extending product life: R3 Reuse, R4 Repair, R5 Refurbish, R6 Remanufacture, R7 Repurpose
- Long cycles focus on material recovery: R8 Recycle, R9 Recover.

Each strategy is explained in more detail below:

R0 – Refuse means avoiding the use of harmful or unnecessary products and materials altogether. This can include, for example, replacing disposable products with more sustainable alternatives or eliminating the use of environmentally harmful raw materials at the design stage.

R1 – Rethink emphasizes redesigning products and services so that they can be shared, rented or used together. The aim is to reduce the need for individual consumer ownership and thus reduce overall consumption.

R2 – Reduce refers to reducing the use of raw materials, energy and resources in production and use. This can be achieved, for example, by optimizing manufacturing processes, making products lighter or improving their energy efficiency.

R3 – Reuse refers to the reuse of products as they are without significant modification. Examples include second-hand markets such as flea markets or refillable packaging.

R4 – Repair emphasizes the repair of broken or worn-out products rather than their disposal. This extends the product's lifespan and reduces the need to manufacture new products.

R5 – Refurbish refers to the refurbishing or upgrading of old products to meet modern requirements. This is particularly common in electronics, where the technical components of devices can be updated without replacing the entire product.

R6 – Remanufacture refers to the process of reusing components that are in good condition to make a new product. This often happens on an industrial scale, for example in the reuse of machinery, vehicles or electronic components.

R7 – Repurpose means using a product or its parts for a completely new purpose. For example, old industrial materials can be used to make furniture or building materials.

R8 – Recycle means reprocessing materials into raw materials for new products. Recycling is an important part of the circular economy, but it is considered less efficient than the higher R strategies, as it often requires a lot of energy and processing.

R9 – Recover refers to the recovery of waste, for example in energy production by incineration or composting. This is the last option when the material can no longer be used or recycled more efficiently.

These strategies represent a fundamental change: they force consumers to think about consumption and companies to think about product design from a new perspective and new innovations in waste management. The important idea is to create a product with its entire life cycle in mind: waste is not just something to be burned or taken to a landfill, it is a resource to be harnessed. (Malooly & Daphne, 2023)

Although achieving a fully closed material loop is an ambitious goal, it is possible to significantly reduce waste and improve resource efficiency. The adoption of these strategies can create new economic opportunities, support innovation, and contribute to more sustainable resource use in the future. (Malooly & Daphne, 2023)

2.2 History of Wood Recycling

The history of wood recycling dates to the earliest days of humanity, when recycled tools have been discovered. Later, as people settled into villages, evidence of reused architectural material has been found. However, the biggest difference between recycling in history and today is the direction the material takes after its first use. Historically, wood and wood products were reused and repaired. Nowadays, wood recycling is more about breaking down the product into smaller pieces and then using them to make new products, generally with the help of adhesive. Another big difference between history and the present is that if timber is reused as is, it usually goes to a different purpose nowadays. In the old days, material obtained from the demolition of an old barn was used to build a new barn. Nowadays, material obtained from barns is most often used elsewhere than in a new barn, for example, as an interior design element. Most of the wood harvested today is used for high-quality panels and flooring. (Longleaf Lumber, 2026)

The development of industrial mass production, the huge increase in population, and consequently human consumption at the turn of the 20th century also meant an increase in waste. During the golden age of consumption in the 1950s and 60s, countries' economies grown, but so did the amount of waste. There were no recycling methods in use, and trash was scattered throughout the streets. However, in the 1960s, people became aware of environmental policy and the fact that our planet cannot sustain this kind of activity. Although the roots of nature protection date back to the late 19th century, it was only after World War II that the seriousness of the situation was recognised. (Longleaf Lumber, 2026)

Currently, wood recycling is heavily focused on the panel, and particularly the particleboard industry. The reuse and recycling of old sawn timber, boards, and logs appear to take place on a much smaller scale. Companies selling recycled wood have added freshly sawn wood to their selection, and up to half of the selection may be something other than recycled wood itself. However, this also suggests that the market for reclaimed sawn timber remains relatively limited compared to conventional wood products. (Longleaf Lumber, 2026)

2.3 Construction and Demolition Waste in Europe

In 2022, the amount of waste generated by households and economic activities in the European Union totalled 2,233 million tonnes, or 4,991 kg per capita. The construction industry was the largest producer of waste, accounting for 38%. The next largest sectors were mining and quarrying (23%), waste and water services (10%), industry (10%), households (9%), the services sector (5%) and energy-related waste (3%) (Figure 2). (Eurostat, 2024)

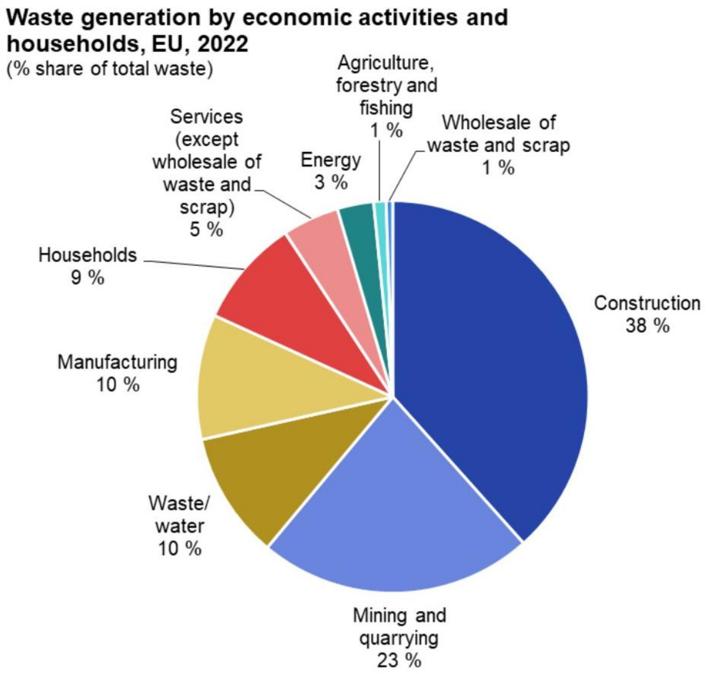

Figure 2. Waste generation by economic activities and households at EU in 2022. (Eurostat, 2024)

Finland generates the highest amount of waste per capita in the European Union, with an average of almost 20 tonnes per person. The EU average is 5 tons, so Finland's waste amounts are almost four times the average. Other countries that produce more than 10 tons of waste per capita are Estonia, Romania, Luxembourg and Bulgaria. Outside the European Union, Serbia (over 25 tons) and Liechtenstein (over 10 tons) produced the most waste (Figure 3). (Eurostat, 2024)

The countries mentioned above, where waste volumes are high, have large mining and quarrying activities. Most of this waste generated is classified as significant mineral waste (Figure 3). In Finland, Sweden, Luxembourg and Bulgaria the share of mineral waste is as much as 82-91% of all waste generated. In Estonia, more than half of the total waste consists of mineral waste, while most of the remaining waste is generated by oil shale-based energy production. (Eurostat, 2024)

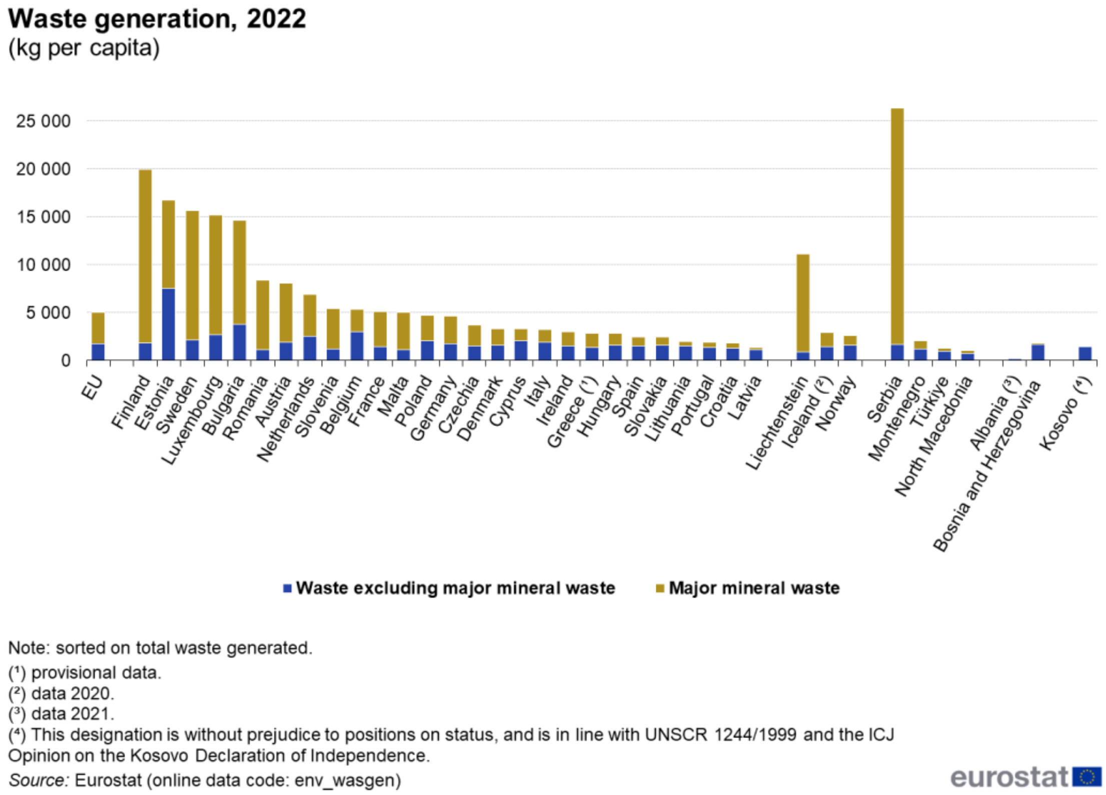

Figure 3. Waste generation in Europe. Countries from Finland to Latvia are members of the European Union, while the remaining countries are European countries outside the European Union. (Eurostat, 2024)

2.3.1 Wood Waste in European Union

In 2020, the European Union (EU27) produced a total of 48.28 million tonnes (Mt) of wood waste. Of this, 3.89% (1.88 Mt) was classified as hazardous waste. The largest sector producing wood waste is the "manufacturing industry", which includes the production of wood and paper products. It accounts for 38.77% of the total. The next largest were waste management (21.71%), construction (17.79%), household (10.58%), services (8.93%) and others (2.22%)(Figure 4). (Pazzaglia & Castellani, 2023)

Figure 4.Wood waste produced and treated in EU-27 in 2020. Data source Pazzaglia & Castellani, 2023.

Of the total 48.28 Mt of wood waste generated in the EU-27, 21.45 Mt was used for energy recovery, and 18.51 Mt was recycled for further use. Only 0.24 Mt, or less than 1% of the total, ended up in landfill. This indicates that most of the wood waste was directed to some form of recovery rather than final disposal. (Pazzaglia & Castellani, 2023)

The policies of the European Union and its member states play an important role in shaping how wood waste is utilized. Although energy recovery remains the most common treatment route for wood waste, recycling also plays a significant role, particularly in the board industry. For example, the particleboard industry uses recycled wood waste and in Italy, particleboard consists of 95% wood waste. In other countries, the proportions vary significantly: in Belgium and Denmark, the proportion of recycled material in particleboard is 50-70%, and in large particleboard countries such as Germany, the proportion is 15-30%. The proportions, of course, vary between companies. For example, at the Kronospan factory in Tortosa, Spain, the new factory makes particleboard from 100% recycled material, but the recycling proportion of particleboard in Spain is the same as in Germany, i.e. 15-30%. (Pazzaglia & Castellani, 2023) (Kronospan, 2023)

On September 14, 2022, the European Parliament implemented the revised Renewable Energy Directive (RED III), which aims to increase the share of renewable energy in the European Union's total energy consumption to at least 42.5% by 2030. The directive also sets sectoral targets, including an indicative target for the share of renewable energy in heating and cooling in buildings to be at least 49%. These political objectives have a significant impact on the utilisation of wood waste, as energy use remains the most common form of wood waste treatment in Europe. The growing demand for renewable energy may increase competition between the use of wood waste for energy and material cycles, which could affect the availability of wood waste for material use and increase pressure to utilise alternative raw material sources in the wood-based industry. (European Council, 2023)

2.3.2 Greenhouse Gas Emissions in the EU

In 2023, the EU's greenhouse gas footprint was 4.1 billion tonnes of carbon dioxide equivalent (CO2). This is 21% higher than its production-based savings. Although the footprint has decreased by over 20% since 2010, those are big amounts that accelerate global warming. (Eurostat, 2025)

The largest economies also have the largest consumption: Germany has the highest consumption in the EU at 903 million tonnes. The next largest are France at 551 million tonnes and Italy at 535 million tonnes. A better comparison is made when looking at emissions per capita. This shows that the largest emitters are Cyprus (14.8 tonnes per capita), Ireland (14.1 tonnes per capita) and Luxembourg (12.6 tonnes per capita). Germany, which has by far the largest total consumption, has emissions per capita of 10.8. This makes them the largest emitters when comparing total emissions and per capita results. (Eurostat, 2025)

When greenhouse gas emissions are considered by economic activity, the construction sector represents a distinct source of emissions in the EU’s greenhouse gas footprint. Emissions arise not only from on-site construction activities, but also from the production of materials and downstream processes, including the treatment of construction and demolition waste (Eurostat, 2025) It is estimated that buildings and construction are responsible for around 30-40% of EU energy-related greenhouse gas emissions, taking into account both the energy consumption of the activities and the emissions from the materials. A significant part of these emissions originates from the production of materials, such as cement, steel and wood-based products, highlighting the importance of material choices and waste management practices in emission reduction strategies. (EuRIC, 2025)

3 Log Procurement and Reception Measurement in Sawmill Production

The following sections outline the most important stages involved in the early production process of sawn timber, from log procurement to reception measurement at the sawmill.

3.1 Log Procurements

The process of turning wood from the forest into finished sawn timber is long and involves many stages (Figure 5). It begins with an agreement between the forest owner and the forestry company, which specifies the value of the logs, the price of the work, and who will transport the logs to the forestry company's sawmill. (Varis, 2018, s. 55)

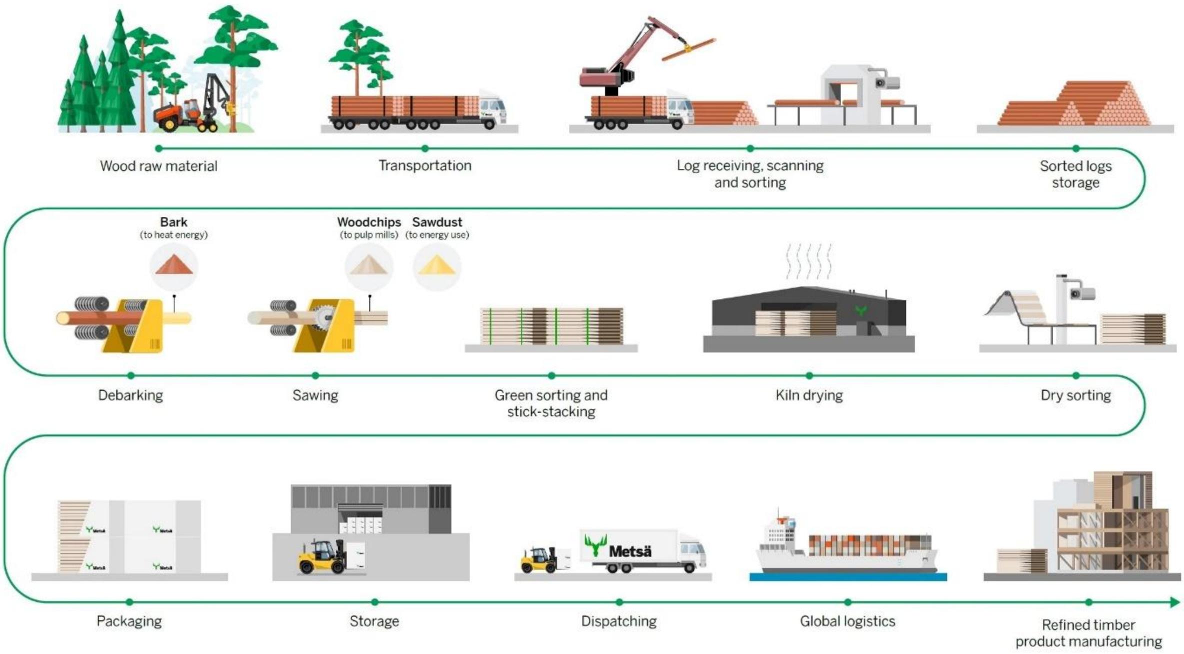

Figure 5. Sawn timber production process (Metsä Fibre, 2026)

In the forest, a harvester cuts and measures each log (Figure 6). This information provides accurate data on the size and quality of the logs and their suitability for different uses, which facilitates production planning. The logs are sorted into separate stacks according to tree species, quality, and intended use, and stacked by the roadside. From there, the logs are transported for further processing either directly by truck or by truck to the railway station and then by train.

Spruce stem										Example table
Length Diameter	312	370	430	460	490	520	550	580	610	Total
150	0	0	0	0	100	0	0	0	0	100
160	0	1	5	9	40	18	12	5	10	100
170	0	1	5	9	40	18	12	5	10	100
180	0	1	5	9	40	18	12	5	10	100
200	0	1	5	9	40	18	12	5	10	100
220	0	0	14	22	19	12	15	8	10	100
240	0	0	14	19	19	15	15	8	10	100
260	0	0	12	18	18	16	18	8	10	100
280	0	0	12	17	20	15	18	8	10	100
300	0	0	15	15	15	18	17	10	10	100
320	0	0	18	12	13	17	20	10	10	100
340	0	0	10	10	26	17	17	10	10	100

Figure 6. Example of a distribution table. The cross cutting is steered by value, distribution and volumes. Parameters linked to these can be as quality definitions or forbitten lengths or sizes. (Varis, 2018, s. 52)

Production planning is an important part of sawmill operations, as it affects production efficiency, profitability, and delivery reliability. Its purpose is to make the best possible use of available raw materials while meeting customer requirements related to quality, quantity, and delivery schedules. In sawmills, production planning is especially challenging because wood is a naturally variable raw material, and each log differs in size, shape, and quality. (Varis, 2018, ss. 57-62)

Production planning covers the entire value chain from wood procurement to customer deliveries and is usually divided into long-term, medium-term, and short-term planning. Long-term planning supports strategic decision-making, while medium- and short-term planning focus more on production optimization and scheduling. Over time, sawmill production planning has developed from manual methods into more advanced simulation tools and integrated information systems, which have improved the accuracy and efficiency of the planning process. (Varis, 2018) When the logs arrive to sawmill, their top and bottom diameters, length, bend, tapering, and volume are measured. At same time, the operator can perform visual quality grading. After this, the logs are conveyed further and directed to their designated log pockets. (Varis, 2018, s. 63)

Before debarking, the logs undergo both visual and mechanical inspection. In visual sorting, the operator rejects defective logs and separates customer grades for the sawmill's production needs by eye. They are assisted by automation systems that vary from line to line, depending on how accurately the sorting needs to be done and how fast the production speed needs to be maintained. Current lines use 3D and X-ray technology, which allows logs to be sorted more accurately and reduces the operator's workload. However, an operator is still needed to inspect the logs for defects that cannot be detected by X-ray equipment, such as blue stain, knots, or pitch pockets. (Varis, 2018, s. 66)

In geometric log measurement, the most important measurement variables are volume, length, and top diameter. When receiving logs and sorting them at the sawmill, the shape of the logs must be considered: if logs are crooked, this will result in yield loss during sawing. Measuring logs is important so that the forest seller can obtain information about the quality of the logs, their quantity, how many logs will be rejected, and the reasons for rejection. It is also important for the sawmill to know the dimensions of the logs to assess their utilization in the sawing process and set the sawing program in advance when the logs arrive at the sawmill. (Varis, 2018, s. 66)

3D measuring devices and X-ray scanners are commonly used for geometric measurement of logs. During measurement, the log's progress is monitored with a pulse sensor, and lateral movement detection enables accurate determination of longitudinal shape factors. Camera technology can also be used to estimate the sorting diameter of logs when the logs are not frozen, and bark is at least partially missing. The measurement is based on detecting both debarked and bark-covered areas. (Varis, 2018, ss. 67-68)

After scanning, the logs are transferred to debarking stage. The most common debarking method is rotor debarking. It is both the most cost-effective and gentle on the trunk, which is why it is used especially in the sawn timber and plywood industries. In this method, the logs are fed into the machine one at a time, so the size and quality requirements of the wood determine whether rotor debarking is possible and sensible. It is not appropriate to debark logs that are too small and/or of poor quality with a rotor debarker. In the Nordic countries and North America, debarking machines are placed in the sawing line, whereas in Central and Southern Europe they are in the log sorting area. (Varis, 2018, s. 74)

Debarking removes impurities such as stones and metal pieces attached to the bark, but to identify any metal pieces that may be inside the log, a magnetic metal detector is usually placed after the debarking machine. Based on this, logs containing metal are diverted from the process into a designated storage compartment, from where they are transferred separately for further processing. Logs that are too small or too large can also be transferred to similar raw log compartments, as they often cause problems in later stages of the process. (Varis, 2018)

When the debarking machine is integrated into the sawing line, its reliability becomes critical, as the performance of the entire production line depends on it. Debarking before sawing ensures cleaner logs, which can reduce blade maintenance needs and improve process efficiency. It can also support more accurate log measurements, as the effect of bark does not need to be estimated and the measurements is based directly on the actual wood material.

At the same time, delaying debarking has practical advantages. Logs remain cleaner and less slippery during storage and handling. Also, bark can help slow down drying warm weather. The placement of the debarking machine therefore depends on several factors, including measurements accuracy, log yard logistics, production efficiency, and regional pricing practices. In some markets, such as Central Europe, where payment is based only on debarked wood volume, debarking before measurements is economically justified. In addition, placing debarking earlier in the process can support sawmill capacity management by ensuring a steady supply of debarked logs for sawmill. (Varis, 2018, ss. 74-75)

3.2 Processing Logs into Sawn Timber

Sawn timber production is a highly automated process in which individual steps follow a defined sequence. The process presented here reflects a typical Nordic sawmill layout and is illustrated in Figure 7. (Kokkonen, 2020)

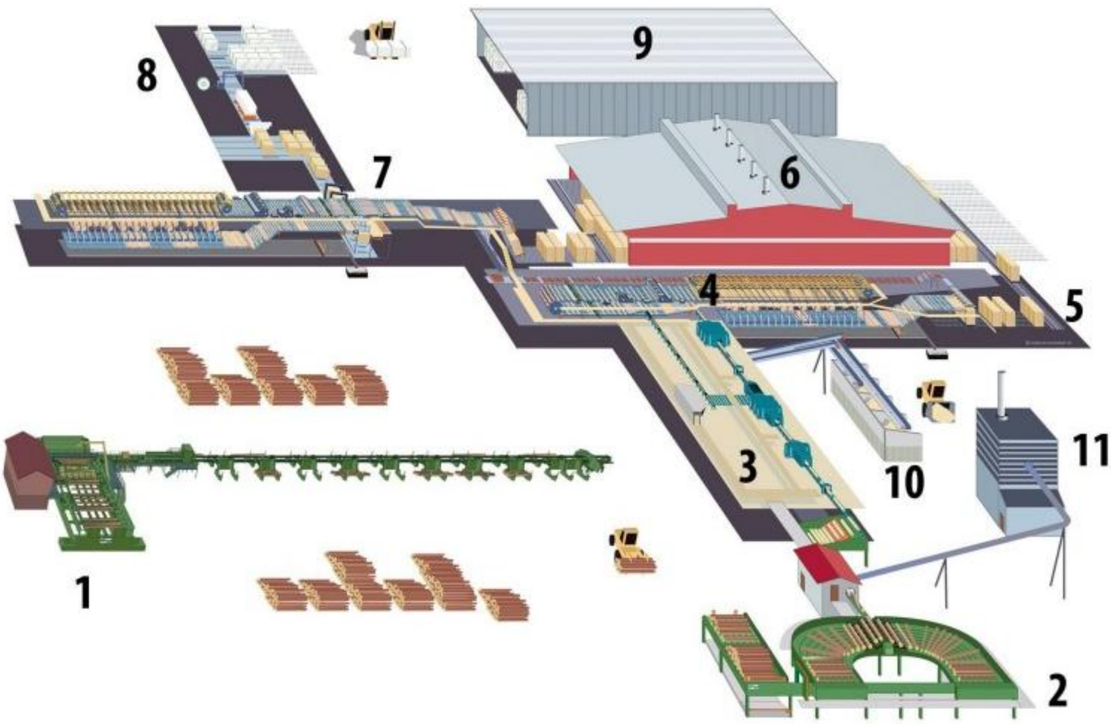

Figure 7.Process from logs to sawn timber in typical Nordic sawmill. (Kokkonen, 2020)

The sawing process begins at the log sorting line and log storage area (1). Logs are fed into the sawmill through the debarking process (2). The main sawing line, where logs are converted into sawn timber, is in the sawing hall (3). Fresh sawn timber is transferred to the dimension sorting unit, also referred to as the green sorting line (4), and subsequently stacked with stickers into drying kiln charges (5). Drying is carried out in kiln chambers and continuous kilns (6). After drying, sawn timber is sorted into final quality grades at the grading line (7). The sawn timber is packaged into delivery units at the packaging line (8). Finished packages are transferred to storage, where they await dispatch and transportation (9). By-products generated during sawing, such as wood chips and sawdust, are conveyed from the chipper through screening to silos (10). In addition, the sawmill is equipped with a heat plant that uses bark from the debarking process as its primary fuel (11). (Kokkonen, 2020)

The aim of the sawing process is to combine cross-cutting and rip-cutting so that the sawn timber meets the buyer's quality and dimensional requirements as closely as possible. To this end, different sawing patterns are used to make efficient use of logs with different characteristics. In Nordic sawing, the log is typically split symmetrically in the middle, which enables a highly standardized and automated production process. This method is known as block sawing, and it is particularly well suited to flat, straight coniferous logs and supports high production efficiency. In Central and Southern Europe, sawing practices are generally more flexible and often based on cross-cutting or asymmetrical sawing patterns. These methods allow for better adaptation to varying raw material quality but generally result in lower standardization and automation. (Varis, 2018, s. 83) (Niemz;Teischinger;& Sandberg, 2023, ss. 1101-1102, 1110)

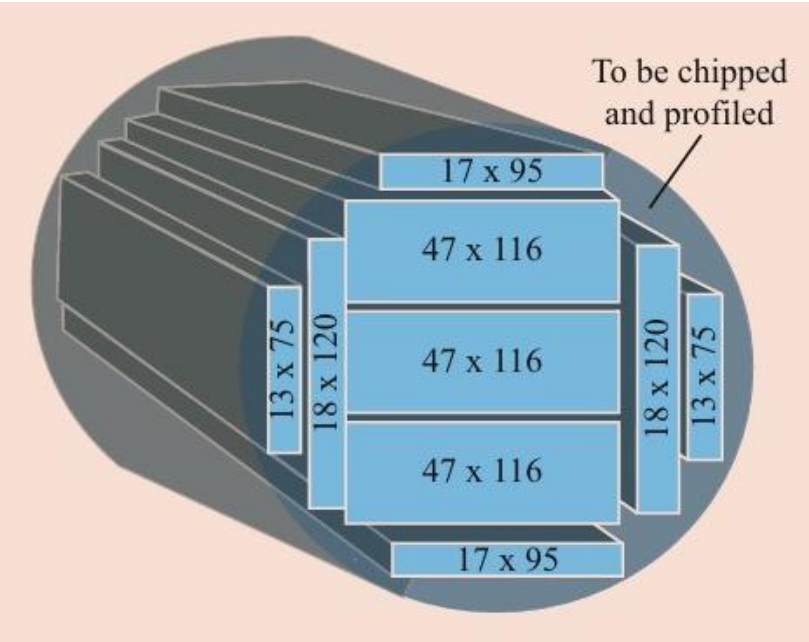

Figure 8. An example of a block-sawing pattern used to convert logs into boards and planks that meet the dimensional requirements (dimensions in millimetres) of a specific sawn timber order. (Niemz;Teischinger;& Sandberg, 2023, s. 1101)

To produce one cubic meter of sawn timber, approximately 2.2 m³ of logs are needed. 0.7 m³ is converted into wood chips, 0.3 m³ of sawdust and 0.2 m³ of to bark. Block-sawing (Figure 8) is the most common sawing method used in the Nordic countries, and it is traditionally carried out in two stages. First, two sides of the log are cut, and a specified number of side and surface boards are separated from these sides. The resulting is then turned 90 degrees, and the sides of the log are cut and split, separating the surface and side boards as well as the specified amount of centre wood. Sawing is the final stage of block-sawing process, in which the heartwood is separated into individual pieces of sawn timber. The pieces of sawn timber produced at this stage fetch the highest price when sold, and this stage of processing is also the most demanding. (Varis, 2018, s. 82) (Puututoreteollisuus ry, 2023)

Approximately 15% of sawmill sales revenue comes from by-products such as bark, sawdust, and wood chips. Among these, wood chips are economically the most significant, as they are widely used in the pulp industry and account for most of the by-product revenue. Sawdust and bark are mainly used as energy sources within the sawmill or sold for other industrial uses. (Varis, 2018, ss. 102-103) (Niemz;Teischinger;& Sandberg, 2023, ss. 1124-1128)

Once the logs and cants have been sawn into timber, the material is sorted according to its dimensions and quality. After sawing, the fresh sawn timber is sorted according to its dimensions and quality. This initial sorting phase, often referred to as green sorting, separates the boards into different categories before drying. The process is typically automated and uses scanning or machine intelligence systems to identify the dimensions and characteristics of each piece. The sorted sawn timber is then transferred either to intermediate storage or directly to the stacking area before drying. (Varis, 2018, ss. 119-120)

Different dimensions and quality grades are sorted into separate compartments, from which the sawn timber is transferred either to intermediate storage or directly to sticker stacking. The loads are generally stacked mechanically in a package that is as uniform as possible. Between each layer, spacers are placed perpendicularly, which allow the drying air to pass freely through the load. This enables even filling of the drying chamber and controlled air circulation, and thus also the desired drying result. (Varis, 2018, ss. 127-128)

Before drying, sawn timber is stacked into kiln loads using spacers placed between the layers to allow controlled airflow and minimise deformation during drying. The arrangement of the stacks varies depending on the timber dimensions and product type. Proper stacking and handling are important for maintaining product quality and achieving efficient drying. (Varis, 2018, s. 129)

The moisture content of wood significantly affects its dimensional stability, mechanical behaviour, and suitability for different applications. Freshly sawn timber therefore needs to be dried to the required moisture level before further use. Drying is an important stage in sawmill production, as it affects both product quality and production costs. (Varis, 2018, s. 130) (Niemz;Teischinger;& Sandberg, 2023, s. 1169)

At sawmills, drying wood and heating buildings requires large amounts of heat and energy. For this reason, most sawmills have their own heating plant. They use bark, chips and sawdust from side streams as fuel. The moisture content of the material to be burned also plays a big role: if it is too moist, it will not burn properly or cleanly enough, and if it is too dry, it may burn too quickly, reducing the full utilization of its energy potential. Some sawmills may also have enough fuel for electricity production. In some cases, even enough electricity to sell, which allows the sawmill to earn additional income. (Varis, 2018, ss. 143-146)

After drying, the sawn timber is transported to the final sorting and cutting lines, where the boards are levelled, cut to their final lengths, and sorted according to quality and dimensional requirements. Modern sorting lines operate at a high level of automation and are designed to achieve an efficient material flow while maintaining product quality. (Varis, 2018, ss. 147-150)

3.3 Certificates

Certificates are impartial third-party issued documents that can ensure a product, material, process, or organization meets predefined standards or conditions. Generally, certifications, regardless of the field, are linked to responsibility, and therefore end customers demand services and products from companies that have the relevant industry certification. (Puuinfo, 2023)

In the wood industry, forest certification is proof that the material comes from sustainably managed forests. Forests are certified because it can provide a market advantage for the forest owner when selling the forest. The use of forests is constantly increasing, so it is very important that forests are used and managed responsibly. Therefore, the biodiversity of forests is preserved, and the original idea of forest certification has indeed been the protection of forests. (Puuinfo, 2023)

Forest certifications do not just mean that the forest is certified, but that the entire production process from raw material to finished product has been done responsibly. For the forest owner, obtaining certification is voluntary, many large forestry companies prefer or require certified sawn timber in their sourcing practices. (Puuinfo, 2023)

There are many different types of forest certification systems, but the most widely used globally are FSC and PEFC. Many wood products used in construction also require CE marking, as it is a requirement for selling in the market, and without it, the product is much harder to sell in Europe that can ensure a product, material, process, or organization meets predefined standards or conditions. Generally, certifications, regardless of the field, are linked to responsibility, and therefore end customers demand services and products from companies that have the relevant industry certification. (Puuinfo, 2023)

3.3.1 The Forest Stewardship Council (FSC)

The Forest Stewardship Council (FSC) is an international, non-profit forest certification system aimed at promoting environmentally sustainable, socially responsible, and economically viable forest management. FSC is the first internationally recognised forest certification system, and it was introduced in 1993. FSC certification is based on uniform international principles and criteria that guide forest use, ensuring, for example, the protection of biological diversity, water bodies, soil, as well as the rights of local communities and workers. Certification is voluntary and can only be carried out by an independent third party through an audited process that ensures compliance with the requirements. The FSC system also includes the so-called Chain of Custody, which allows tracking the movement of certified wood raw materials through the supply chain from the forest to the finished product. The FSC label (Figure 9) on a product thus serves as proof that the wood comes from responsibly managed forests and that the entire supply chain meets the requirements set by the certification. (Forest Stewardship Council, 2026)

Figure 9. FSC certification mark on JYSK furniture, indicating that the wood raw material of the product comes from responsibly managed forests. (JYSK, 2026)

3.3.2 Programme for the Endorsement of Forest Certification (PEFC)

Programme for the Endorsement of Forest Certification (PEFC) is an international forest certification system that promotes ecologically, socially, and economically sustainable forest management. The PEFC certification system was established in 1999 at the initiative of European forest owner organisations as an alternative to FSC. PEFC was established to specifically meet the forest certification needs of small and family forest owners, as there was no certification system available suitable for small ownership. About 25% of the world's forests are owned by smallholders and families (Figure 10). (Puuinfo, 2023) (PEFC, 2026)

PEFC is the world's largest forest certification system. There are nearly 300 million hectares of PEFC-certified forests worldwide, and almost 30,000 companies are part of the certification for tracking the origin of wood. The PEFC headquarters is located in Geneva, Switzerland, and national member organisations are responsible for maintaining the certification system in their respective countries. For example, in Finland, PEFC's activities are managed by PEFC Finland – Suomen Metsäsertifiointi ry, and in Austria, by PEFC Austria. (PEFC, 2026)

The PEFC system of each country must be internationally approved by PEFC. It requires that the nationally developed system meets both PEFC's international requirements for forest management and the International Organization for Standardisation (ISO)'s general requirements for certification. (PEFC, 2026)

PEFC forest certification promotes sustainable forestry. Sustainable forestry refers to the management and use of forests in a way that supports their biological diversity, productivity, regeneration capacity, and vitality. Sustainable forestry also aims to promote ecological, economic, and social activities related to forests at local, national, and global levels now and in the future. (PEFC, 2026)

Figure 10. PEFC certification mark applied to the end of a log. The certificate indicates that the wood raw material comes from forests that meet the requirements of sustainable forest management. . (Energie-Experten, 2024)

From Figure 11 we can see that PEFC certification is clearly the dominant system in most European countries, especially in Northern and Central Europe. For example, in Finland, Austria, Germany, and Norway, a significant portion of the forest area is PEFC-certified, often over 60 percent of the total area. This suggests that PEFC has become the dominant certification system as part of the European forestry operational environment. Since a large portion of the raw material is already certified at the forest level, certification in these countries does not necessarily constitute a significant additional cost for individual operators, but rather a basic market requirement. (Maesano, ym., 2016) (PEFC, 2026)

The geographical distribution of FSC certification is more uneven. In some countries, such as Poland, Croatia, and Belarus, the share of FSC-certified forest area is very high, while in many Western European countries, its share is significantly lower. This reflects differences in national forest policies, ownership structures, and market orientations. FSC is often stronger in countries where export markets—especially Central European and global markets—impose stricter sustainability requirements. (Maesano, ym., 2016)

From the Figure 11, it can also be observed that in several European countries, the overall coverage of certification (FSC + PEFC) is very high. This means that certification is not a marginal phenomenon, but a central part of the market structure for wood raw materials. Certification often functions as a practical market requirement in many areas, especially in the construction and furniture industries. (Maesano, ym., 2016)

Country	Total Forest Area [ha] Certified by FSC	Total Forest Area [ha] Certified by PEFC	Forest Area [ha][1]	% FSC	% PEFC
Austria	575	2,755,452	3,984,766	0.01%	69.15%
Belarus[2]	4,901,127	8,397,100	8,808,000	55.64%	95.33%
Belgium	20,910	289,050	644,316	3.25%	44.86%
Bosnia-Herzegovina	1,519,235	0	2825610.66	53.77%	0.00%
Bulgaria	409,674	0	4,243,943	9.65%	0.00%
Croatia	2,038,296	0	2,765,570	73.70%	0.00%
Czech Republic	49,544	1,845,321	2,781,117	1.78%	66.35%
Denmark	199,557	253,285	513,380	38.87%	49.34%
Estonia	1,177,048	1,836,260	2,507,262	46.95%	73.24%
Finland	461,787	19,687,046	24,710,879	1.87%	79.67%
France	19,827	7,930,166	16,484,273	0.12%	48.11%
Germany	971,913	7,350,877	10,686,950	9.09%	68.78%
Hungary	320,963	0	2,025,927	15.84%	0.00%
Ireland	447,219	0	754,069	59.31%	0.00%
Italy	50,944	778,356	10,055,403	0.51%	7.74%
Latvia	1,749,109	1,683,641	3,257,020	53.70%	51.69%
Lithuania	1,066,170	0	2,112,123	50.48%	0.00%
Luxembourg	20,535	31,185	94,023	21.84%	33.17%
Nederland	125,734	0	353,444	35.57%	0.00%
Norway	346,385	9,098,302	16,009,703	2.16%	56.83%
Poland	6,879,591	7,304,356	9,705,967	70.88%	75.26%
Portugal	336,838	236,385	3,993,956	8.43%	5.92%
Romania	2,554,089	0	7,662,622	33.33%	0.00%
Russia[3]	25,541,794	2,018,554	882,170,000	2.90%	0.23%
Slovakia	142,483	1,242,760	2,198,592	6.48%	56.53%
Slovenia	249,649	10,210	1,202,073	20.77%	0.85%
Spain	194,284	1,689,975	19,906,722	0.98%	8.49%
Sweden	12,054,376	9,812,789	32,339,842	37.27%	30.34%
Switzerland	695,871	182,377	1,370,514	50.77%	13.31%
Turkey	2,908,707	0	20,480,747	14.20%	0.00%
Ukraine[3]	1,401,352	0	9,274,000	15.11%	0.00%
United Kindom	1,560,434	1,351,505	4,553,679	34.27%	29.68%
Europe	70,416,019	85,784,952			

Figure 11. The share of FSC and PEFC certified forests in the total forest area by country in Europe. (Maesano, ym., 2016)

3.3.3 CE marking

The CE marking (Conformité Européenne) is a European Union conformity marking that indicates that a product meets the health, safety, and environmental protection requirements set by EU legislation. The marking is mandatory for many product groups before they can be sold in the European Economic Area (EEA). With the CE marking, the manufacturer declares that the product meets all applicable EU directives and regulations, allowing the product to be sold and moved freely within the EU internal market regardless of the country of manufacture. (European Comission, 2021) (Your Europe, 2026)

The CE marking is not a quality certificate or an approval granted by an authority, but the manufacturer's own declaration of conformity of the product. The manufacturer is legally responsible for ensuring that the product meets all EU requirements. For this purpose, the manufacturer must identify the applicable regulations for the product, conduct a conformity assessment, prepare technical documentation, and sign the EU Declaration of Conformity. (European Comission, 2021) (Your Europe, 2026)

Once these steps have been completed, the CE marking can be affixed to the product. The marking indicates to authorities and the market that the product's safety, health effects, and environmental impacts have been assessed in accordance with EU legislation. At the same time, it supports the functioning of the EU internal market by ensuring uniform product safety requirements and fair competition conditions for companies. (European Comission, 2021) (Your Europe, 2026)

In summary, the CE marking serves as a key mechanism in the EU internal market, as it enables the free movement of products while ensuring that the products placed on the market meet uniform safety and environmental requirements. (European Commission, 2024) (Your Europe, 2026)

Figure 12. Example of CE-marked sawn timber. (eSawmill, 2026)

4 Reclaimed Wood Processing and Technical Constraints

The processing of recycled wood involves several stages that affect the material's quality, usability, and technical suitability in later applications. Unlike virgin sawn timber supply chains, recycled wood streams originate from heterogeneous sources and therefore require specific collection, sorting, and processing methods before further use. This chapter examines the key stages and limitations associated with the processing of recycled wood. It describes the collection (Figure 13) and pre-sorting of recycled wood, an overview of typical waste wood processing routes, including material recycling and energy recovery, and analyses the role of contamination and impurity removal, particularly in terms of physical and chemical impurities, which affect processing efficiency and material quality.

Figure 13. Example of mixed waste wood originating from construction and demolition activities prior to sorting and processing. (Weima, 2026)

4.1 Collection and Preliminary Sorting of Reclaimed Wood

The collection and sorting of recycled wood are the first and most important stages in the material recycling chain. Unlike the procurement of new wood in a controlled environment, recycled wood comes from sources such as demolition sites, where the material is mixed with other building materials and can vary considerably in quality, dimensions, and condition. Recycled materials are mainly used in low-quality applications, even though recycling rates are high. However, this means that recycled materials and their use should be developed in a direction where the product would be much higher in value than it currently is. (EuRIC, 2025) (European Enviroment Agency, 2020)

Unlike virgin wood obtained from controlled forest management chains, recycled wood comes from demolition sites where materials are generally mixed and there is often no documentation or documentation that can be fully relied upon regarding their composition and structural condition. The limitation of such information makes it considerably more difficult to predict demolition material flows and their composition, thus complicating the planning of selective material recovery. (European Enviroment Agency, 2020)

Selective demolition and a focus on sorting on site are essential ways to improve the quality of recycled materials and enable more valuable recycling opportunities. Preliminary sorting at the demolition site involves separating wood-containing components from other building materials and grouping them according to their visible characteristics before transport to further processing facilities. This stage has a direct impact on the efficiency of later stages. (European Enviroment Agency, 2020)

The stages of construction waste treatment may vary depending on the company, region, country and site. In principle, the most effective method is to sort the waste generated at construction sites into separate fractions at the point of origin. At this stage, it is not necessary to separate different types of wood waste. However, in some areas, clean or untreated wood waste may be sorted separately, meaning that, for example, boards and coated wood are directed to the energy fraction. Both mixed construction waste and sorted wood waste are often transported directly to the recycling plant. In some cases, waste may first be temporarily stored and pre-sorted at a transfer station. Wood waste is also transferred from the transfer station to the recycling plant, where different types of wood waste are kept separate from each other. Wood waste is crushed and metal (magnetic and non-magnetic) impurities are separated from it. Depending on the recycling plant, wood-based waste is also separated from mixed construction waste as much as possible for its own process. In some cases, depending on the location, mixed construction waste may still end up being sent directly to landfill. (Myller, 2015)

4.2 Typical Treatment Routes for Wood Waste

In a circular economy, there are various strategies for extending the life cycle of materials and preserving their value for as long as possible. These strategies are generally described through the 10R framework, which ranges from higher-value options such as reuse and remanufacturing to lower-value routes such as recycling and energy recovery. 10R is discussed in more detail in section (2.1.1 10R). In the context of wood waste, various utilisation routes can be identified depending on the level of processing and the value retained in the material. Table 1 below describes typical examples of circular economy strategies applied to the wood sector.

Table 1. Typical examples of circular economy strategies applied to the wood sector. (Niemz;Teischinger;& Sandberg, 2023) (Nwamaka Ikenze; Vasileios Rizos; Luca Nipius, 2024) (Bioenergy Europe, 2023) (Myller, 2015) (Piccardo & Hughes, 2022)(own table)

	10R Strategy	Application in wood sector	Typical example
H	R3 Reuse	Direct reuse of timber componer	Reclaimed beams reused in construction
	R5 Refurbish	Celaning and surface treatment of reclaimed wood	Planing and repairing used boards
	R6 Remanufacture	Processing reclaimed wood into new timber products	Resizing reclaimed timber into standard dimension
L	R8 Recycle	Processing wood waste into new wood-based maerials	Particleboard production
	R9 Recover	Energy recovery from waste wood	Combustion of wood chips in biomass plants

As shown in Table 1, many current wood waste utilisation methods are located at the lower levels of the circular economy hierarchy, particularly in recycling and energy recovery. Higher-value strategies, such as reuse, refurbishment, and remanufacturing, aim to preserve the structural value of wood materials for a longer period. However, in practice, the implementation of these strategies is often limited by contamination, variations in material quality, and logistical constraints. As a result, most recycled wood ends up at lower levels such as R8 and R9.

In practice, the processing route of waste wood is largely determined by the level of contamination and the quality of the material. For this reason, waste wood is generally classified into different categories based on the level of contamination. Waste wood can be classified into three categories based on the level of contamination. (Bioenergy Europe, 2023)

- Class A: untreated, solid wood, natural wood (pallets, boards, beams, sawdust). They can be used in the wood industry or as fuel.
- Class B: all types of wood waste that may be contaminated with glues, varnishes, etc. (particleboard, furniture and joinery products, painted or treated wood). They are used as fuel and a small part is recycled in industry.
- Class C: wood treated or impregnated with preservatives (fence posts, wooden railway crossings). They can only be recovered as energy under certain conditions. (Bioenergy Europe, 2023)

The handling of wood waste in the European Union is shaped by pollution levels, economic incentives, and regulatory frameworks. The dominant processing route remains energy recovery, while material recycling accounts for a smaller but significant portion of the overall wood waste stream. (Nwamaka Ikenze; Vasileios Rizos; Luca Nipius, 2024)

A significant portion of wood waste in the EU is directed to energy recovery facilities due to the lower quality of the material or its contamination. Recycled wood chips are delivered as fuel for energy production to power plants. The quality of recycled wood chips affects which power plants can use this fuel. A typical power plant that uses recycled wood chips is an industrial multi-fuel boiler, where recycled wood chips are burned together with other solid fuels such as forest biomass, peat, and coal. By using recycled wood chips, power plants can reduce and replace the use of peat and coal. Power plants that use recycled wood chips are usually fluidized bed boilers and produce electricity, heat, and steam depending on local energy needs. (Myller, 2015)

Material recycling primarily takes place in the panel industry, where recycled wood constitutes a significant portion of the raw material input in several member states. However, structural reuse and applications of higher-value materials remain limited, and they are currently more pilot-type experiments than industrial applications. (Nwamaka Ikenze; Vasileios Rizos; Luca Nipius, 2024)

Due to the EU's increasing renewable energy targets, competition between energy recovery and material recycling has intensified. As the demand for biomass increases, waste wood becomes an attractive fuel source, which may reduce the availability of suitable fractions for recycling. This creates a structural tension between the use of recycled materials and the goals of renewable energy policies. (Nwamaka Ikenze; Vasileios Rizos; Luca Nipius, 2024)

At system level, variations in quality, contamination levels and logistical constraints influence whether waste wood is directed towards material recycling or energy recovery. Regulatory uncertainty regarding end-of-waste criteria and differences in national waste management systems continue to influence processing decisions. Therefore, although wood waste has significant material recycling potential, its actual utilisation path is strongly determined by economic and political conditions, not just technical feasibility. (Nwamaka Ikenze; Vasileios Rizos; Luca Nipius, 2024)

4.3 Contamination and Impurity Removal

Waste wood is rarely a homogeneous material. Unlike virgin wood from controlled forestry supply chains, waste wood comes from buildings and structures that have been in use, renovated, and exposed to various treatments over decades. During their service life, sawn timber products and wood elements may be coated, bonded to other materials, or chemically treated. As a result, collected wood waste typically contains both physical and chemical impurities that make it difficult to reuse as a material. (Faraca;Boldrin;& Astrup, 2019)

The heterogeneity of wood waste is not limited to visible impurities but also includes variations in structure and composition. Differences in origin, age, intended use, and previous treatment lead to significant differences in material properties and various impurities. Since the quality and composition of collected wood waste can vary considerably between collection sites, this limits the processing of wood waste as a uniform raw material. There is therefore no single standardized way to process wood waste. This variability increases the need for inspection, sorting, and quality control before recycling. (Pazzaglia & Castellani, 2023) (Faraca;Boldrin;& Astrup, 2019)

Wood waste is therefore inherently more complex to process than virgin wood. Impregnated and chemically treated wood cannot be processed in the same way as untreated wood because it contains preservatives and additives. Various surface treatments, such as paints, varnishes, and adhesives, further alter the composition of the material and can hinder recycling processes. In addition, wood waste streams may contain foreign substances such as metals, stones, glass, and other components other than wood, which must be separated before further processing. These foreign substances must be removed, as they cause problems in later stages of wood processing, such as dulling the blades. As mentioned above, identifying and removing such impurities requires additional labour time, and technical equipment, which increases the overall processing costs. (Faraca;Boldrin;& Astrup, 2019)

The heterogeneity of the material is therefore both a quality problem and a technical constraint in the recycling chain. If impurities are not removed to a sufficient level, they can impair the performance of processing equipment, compromise the quality of recycled products, and limit the range of possible end uses. Effective impurity management is therefore a requirement for improving the resource efficiency of wood waste and enabling the recycling of more valuable materials. (Faraca;Boldrin;& Astrup, 2019)

4.3.1 Physical Impurities in Waste Wood

Physical impurities in waste wood mainly consist of metals, stones, and other foreign substances to wood. Fasteners, such as nails, screws, hinges, and clips, are often embedded in construction wood because of previous uses. Additionally, pieces of plastic or detached parts from other structures may remain in the collected wood components. Metals are the dominant and problematic material in collected wood waste streams, and they constitute most identified physical impurities. (Faraca;Boldrin;& Astrup, 2019)

Metals create specific challenges in mechanical processing. Even small metal pieces can cause significant wear or damage to crushers, shredders, and downstream processing equipment. As a result, pre-treatment stages such as magnetic separation, screening, and manual inspection are often required before the subsequent processing stages of the material. However, the complete removal of embedded or hidden harmful materials from wood is difficult, especially when they are not visible on the surface of the material. This increases operational complexity and may reduce processing efficiency. (Faraca;Boldrin;& Astrup, 2019)

In addition to metals, incorrect components can include plastics, textiles, and neutral materials that end up in the wood waste stream due to insufficient separation at the source. Such heterogeneity reduces the overall cleanliness of the material and complicates automated sorting systems. Mixed materials may require additional screening and manual quality control to meet the demands of industrial users. Although certain impurities, such as small plastic pieces, may be technically acceptable in some applications, such as particleboard production, their presence still affects the consistency and predictability of the secondary raw material. (Faraca;Boldrin;& Astrup, 2019)

Physical contamination also affects the variation between collection sites. The proportion of materials other than wood varies significantly according to local sorting practices and the origin of the waste. This variation limits the possibility of processing waste wood as a standardized secondary raw material and increases the need for quality control before industrial use. For this reason, the effective identification and removal of physical impurities is essential not only to protect the equipment but also to ensure the stability of the material's quality and to enable more valuable recycling pathways. (Faraca;Boldrin;& Astrup, 2019)

4.3.2 Chemical Contamination of Waste Wood

In addition to physical impurities, waste wood often contains chemical impurities originating from surface treatments and preservation processes. These include paints, varnishes, adhesives, coatings, and wood preservatives or impregnating agents commonly used in outdoor and construction applications. Such treatments alter the chemical composition of the material and have a significant impact on its recyclability and potential recycling destinations. (Faraca;Boldrin;& Astrup, 2019)

Impregnated wood is classified as hazardous waste, which includes, for example, wood treated with creosote oil and wood treated with impregnating agents containing arsenic and chromium. On the other hand, wood impregnated with copper-based impregnating agents that are free of chromium and arsenic is generally considered to be ordinary waste. The amount of hazardous waste will decrease in the future as pressure-treated wood impregnated with harmful substances is gradually phased out. (Pirhonen;Heräjärvi;Saukkola;Räty;& Verkasalo, 2011)

Impregnated and otherwise chemically treated wood cannot be treated in the same way as untreated wood, as the additives it contains may cause environmental and regulatory restrictions. Preservatives, coatings, or binders may limit the use of recycled wood in high-value recycled products and may require separate treatment or alternative uses. (Faraca;Boldrin;& Astrup, 2019) (Alakangas;Kurkisuo;Tikka;& Frederikson, 2024)

For example, according to the wood classification guidelines used in Finland, chemically treated material – such as glued, varnished, coated, or painted wood – must not contain halogenated organic compounds or heavy metals in concentrations that exceed those typical of natural wood in the country of origin. This highlights the importance of identifying chemically contaminated materials at an early stage, as mixing them with cleaner materials can reduce the overall quality and recyclability of the wood waste material. (Alakangas;Kurkisuo;Tikka;& Frederikson, 2024)

Chemical contamination is therefore both a material quality issue and a regulatory constraint. Effective separation of treated and untreated wood materials is essential to improve the predictability, safety, and technical feasibility of recycled wood use.

4.4 Emerging technologies in reclaimed wood processing

Due to challenges related to contamination, material heterogeneity, and uneven material quality, efforts have been made to develop new technological solutions for the identification, sorting, and processing of recycled wood materials. In recent years, several advanced technologies have been researched to improve the separation and classification of wood waste from construction and demolition debris, with the aim of increasing the share of material recycling and enabling higher value.

One of the most important areas of development is the use of automatic identification technologies, particularly computer vision, to detect contaminated wood waste. Recent studies have investigated the application of deep learning and computer vision systems for identifying contaminated elements in construction and demolition waste streams. These systems analyse waste images and automatically identify various materials and contaminants, such as plastics, metals, or treated wood. Automatic identification technologies can significantly improve the accuracy and speed of sorting processes compared to manual inspection, and they can reduce the number of materials unsuitable for recycling. (Alwis;Bazli;& Arashpour, 2025)

Near-infrared spectroscopy (NIR) has also been tested for classifying waste wood materials and has been found to be a promising technological method. NIR spectroscopy enables the identification of different wood species, coatings, and chemical treatments by analysing the spectral properties of the material. In studies comparing different classification methods, it can be demonstrated that NIR-based techniques can effectively recognize between untreated wood, treated wood, and other materials present in mixed waste streams. Improved waste material classification can support more accurate sorting and help direct suitable fractions towards material recycling instead of energy recovery. Currently, NIR-based technologies are already used in industrial sorting systems, often in combination with other sensor technologies such as X-ray scanners., where the proportion of recycled material can be as high as 100%. (Mancini & Veli-Matti Taavitsainen, 2024) (Kronospan, 2023)

In addition to automated identification and spectral analysis technologies, research has also focused on the fractionation and characterisation of construction and demolition waste. The aim of fractionation methods is to separate mixed waste streams into different material fractions based on physical and material properties. Improved fractionation processes enable a better understanding of the composition of waste wood streams and help identify fractions suitable for recycling or reuse. By improving the separation of cleaner wood parts from mixed waste streams, such technologies can increase the availability of secondary wood raw materials for industrial applications. (Osama et al., 2026) (Osama;Nagore Izaguirre;& Jalel, 2026)

Although many of these technologies are still under development or are primarily applied in research and pilot phases, they represent an important and correct direction for improving recycled wood processing systems. The development of advanced identification and sorting technologies can significantly increase the efficiency of wood waste recycling and enable a wider use of recycled wood in higher-value applications. (Korba;Lekawska-Andrinopoulou;Chatziioannou;Tsimiklis;& Amditis, 2025)

5 Project and data collection

This chapter presents the project's context, empirical background, and the cost modelling framework used in this study. It begins by introducing the commissioning body, Puutuoteteollisuus ry, and the Porvoo Puuloop deconstruction pilot in Finland, which provided the practical context and part of the empirical foundation for the study. Next, the data and assumptions used in the cost modelling are described, including yield assumptions, pricing principles, cost components of virgin and recycled sawn timber, and the market reference prices used in the comparison. Together, these form the basis for the cost analysis presented in the “6 Results”-section.

5.1 Puutuotteollisuus ry

Puutuoteteollisuus ry (The Finnish Wood Products Industry Association) is a confederation for Finnish woodworking and wood products industry companies. It serves as the common voice and support for the wood product industry in Finland, addressing policymakers, authorities, and other stakeholders. The association's goal is to strengthen the position of the wood product industry as a significant player in the bioeconomy and to promote the use of wood-based products as a sustainable and renewable material. (Puutuoteteollisuus ry, 2026)

Puutuoteteollisuus ry serves its member companies by promoting the economic and industrial policy conditions, competitiveness, and end-use of wood products, for example, in construction. Additionally, the organization coordinates and supports research and development activities in the sector in collaboration with research and educational institutions, and companies. (Puutuoteteollisuus ry, 2026)

The organization's roots extend back to the 1940s, when the collective advocacy of the Finnish wood product industry began to organise into its current form. Puutuoteteollisuus ry has more than 2 400 companies, the largest of which are Stora Enso, UPM, and Metsä Wood. Through these member companies, the activities of Puutuoteteollisuus ry indirectly or directly affect over 66,000 employees in Finland. (Korkman & PuutuoteteollisuusRy, 2026)

5.2 Puuloop Demolition Pilot in Porvoo, Finland

In autumn 2025, a pilot project was carried out in Porvoo, Finland, where an old log-framed wooden house was demolished as efficiently as possible, but with gentle handling of the material. The aim of this study is to examine how a wooden building can be demolished in a manner that allows the maximum possible amount of sawn timber and other wooden parts to remain suitable for reuse. In addition, the study seeks to develop demolition and sorting practices that enable sawn timber to be directed primarily towards material reuse rather than energy recovery or crushing. The study also aims to identify practically sufficient models that are viable in terms of labour requirements, space needs, and costs. This pilot did not focus on the reuse of log frames. (Puutuoteteollisuus ry, Double Round Oy, 2025)

The pilot project was a log-framed detached house in Porvoo, built in the early 1900s. (Figure 14). What made the house special was that it had two separate layers of exterior cladding boards (**Virhe. Viitteen lähdettä ei löytynyt.**). The inner layer was nailed directly to the log frame without intermediate battens. Between the outer and inner outer lining was a bitumen windbreak boards and ventilation bars. (Puutuoteteollisuus ry, Double Round Oy, 2025)

Figure 14.The demolition site is a 1900s log-frame detached house. (Puutuoteteollisuus ry, Double Round Oy, 2025)

Figure 15. 1: Log frame. 2: Inner exterior cladding(green). 3: Bitumen windbreak board. 4: Ventilation bars (not visible). 5: Outer exterior cladding(white). (Puutuoteteollisuus ry, Double Round Oy, 2025)

At the construction site, an excavator carefully dismantled the wall in large pieces to the ground, where the dismantlers manually separated the wooden parts of the wall from each other and sorted them into 6 to 7 different piles based on dimensions and material condition. Finally, when the piles were ready, the bundles were tied and lifted onto a pallet for transport.

All bundled materials were transferred to Forssa for further sorting. During further sorting, all metal parts such as screws and nails were removed from the material, and broken parts were cut off from the pieces. (Puutuoteteollisuus ry, Double Round Oy, 2025)

5.2.1 On-Site Demolition and Initial Sorting in Porvoo

Figure 16. The outer exterior cladding (white) has been removed using excavator and laid on the ground (Puutuoteteollisuus ry, Double Round Oy, 2025)

Demolition work in Porvoo was carried out with the assistance of an excavator, where the wall structures were dismantled in large elements and lowered to the ground for further processing (Figure 16). This method allowed for controlled handling of the material and separation of the wooden parts from other building layers after removal. The sorting was done primarily on the ground rather than directly from the wall, which reduced breakage and improved workplace safety. (Puutuoteteollisuus ry, Double Round Oy, 2025)

The original plan was to use different demolition methods on each of the four walls to compare their effects on material preservation. However, after the first wall was demolished, it was found that excavator-assisted demolition was both efficient and gentle enough to preserve the reusable sawn timber. As a result, the same method was applied to the next two walls. The last wall was partially demolished by hand to allow for some kind of comparison between different organ building methods. However, this approach proved to be significantly slower and did not result in a noticeably higher material yield. Additionally, manual dismantling was not possible to reach the higher parts of the structure, which made mechanical assistance necessary in any case. The same demolition approach was also applied to the roof structure, which yielded a substantial amount of intact sawn timber suitable for further processing (Puutuoteteollisuus ry, Double Round Oy, 2025)

Figure 17.The dismantling was done by hand on the ground. (Puutuoteteollisuus ry, Double Round Oy, 2025)

During the demolition phase, special attention was paid to separating the wooden parts from other materials after the wall elements had been brought down (Figure 17). The recovered sawn timber and other wood materials was sorted on-site into preliminary grades based on dimensions and visible condition, after which the material was bundled and prepared for transport. The on-site sorting process required a significant amount of space, which highlighted practical limitations to applying similar sorting practices at smaller or more confined demolition sites. All bundled demolition wood suitable for further processing was later transported from the Porvoo location to Forssa for further sorting and material handling. (Puutuoteteollisuus ry, Double Round Oy, 2025)

5.2.2 Further processing in Forssa

Demolition wood was transported from the site on two pallets, a total of 8,420 kg. Of these, 5,360 kg was wood waste and 3,060 kg of material suitable for sorting. In addition, three separate loads (logs, wood waste, sawdust) left the site, which were not weighed because they were delivered directly for further use. The total mass removed from the demolition site was 17,000 kg, of which 8,580 kg was other construction waste. The transport from Porvoo to Forssa (154 km) was carried out with an N3-class Euro 6 truck, and the transport emissions were estimated to be approximately 124 kg CO_2e per load of wood. The wood suitable for further sorting was bundled and tied. (Puutuoteteollisuus ry, Double Round Oy, 2025)

The recovered sawn timber and other wood material was further sorted in a cold storage facility in Forssa. The operations carried out on-site were limited to basic processing operations such as removing nails, cutting to length, and assessing the condition of the sawn timber (Figure 18). More advanced processing steps, such as surface treatment or paint removal, were not possible at the Forssa and are therefore considered part of the later stages of the overall process. (Puutuoteteollisuus ry, Double Round Oy, 2025)

Figure 18. Processed reclaimed sawn timber sorted into categories based on dimensions and surface treatment in Forssa, Finland. (Puutuoteteollisuus ry, Double Round Oy, 2025)

The tools used in the secondary sorting stage were measuring tapes, hammers, pliers, a cross-cut saw, and permanent markers. The work was completed by three people on the first day and four people on the second day. The total duration of the secondary sorting stage was approximately eight hours, during which about 35% of the bundled sawn timber was processed. (Puutuoteteollisuus ry, Double Round Oy, 2025)

The Finnish Forest Centre conducted strength grading using a spike meter and the results are shown in the **Virhe. Viitteen lähdettä ei löytynyt.**. The amount of strength-sorted material was approximately 0.5 m³ (approximately 210 kg), density approximately 420 kg/m³. The test took approximately 2 hours for two people (one tester and one recorder). Strength grading was done according to the INSTA 142 standard. (Puutuoteteollisuus ry, Double Round Oy, 2025)

Table 2 Visual strength grading and characteristics of sawn timber. Measurements conducted by the Finnish Forest Centre. In "Limiting characteristic" SO means "sound knot" and LO mean "loose knot". (Puutuoteteollisuus ry, Double Round Oy, 2025)

Piece No.	C30	C24	C18	Reject	Length (cm)	Dimension	Wood species	Moisture (%)	Limiting characteristic
1	x				202	50*100	Spruce		
2	x				226	50*100	Spruce		
3		x			247	50*100	Spruce		Edge knot
4		x			184	50*100	Spruce		Knot sum
5		x			166	50*100	Spruce		
6		x			117	50*100	Spruce		Edge knot
7		x			148	50*100	Spruce		Edge knot
8		x			163	50*100	Spruce		Edge knot
9			x		184	50*100	Spruce		Knot sum
10		x			290	50*100	Spruce	12.7	Mechanical damage
11		x			272	50*100	Spruce		SO
12			x		291	50*100	Spruce		Mechanical damage
13				x	204	50*100	Spruce		SO
14			x		221	50*100	Spruce		LO
15			x		184	50*100	Spruce		SO
16			x		294	50*100	Spruce		Warp, twist
17		x			268	50*100	Spruce		
18		x			172	50*100	Spruce		SO
19				x	222	50*100	Spruce		Demolition damage
20			x		219	50*100	Spruce	11.4	LO
21				x	279	50*100	Spruce		Demolition damage
22		x			240	50*100	Spruce		SO
23		x			320	50*100	Spruce		LO
24		x			230	50*100	Spruce		Demolition damage
25			x		190	50*100	Spruce		Knot sum
26			x		200	50*100	Spruce		Knot sum
27		x			213	50*100	Spruce		Demolition damage
28			x		455	50*100	Spruce		SO
29		x			201	50*100	Spruce		Knot sum
30			x		286	50*100	Spruce	13.9	SO
31		x			288	50*100	Spruce		
32			x		230	50*100	Spruce		SO
33			x		227	50*100	Spruce		Demolition damage
34		x			200	50*100	Spruce		
35		x			212	50*100	Spruce		SO
36			x		260	50*100	Spruce		LO
37		x			304	50*100	Spruce		SO
38		x			380	50*100	Spruce		Demolition damage
39		x			240	50*100	Spruce		
40				x	226	50*100	Spruce	11.5	Spike knot / inclined
41			x		219	50*90	Spruce		SO
42	x				201	50*180	Spruce		

The report by the Finnish Forest Centre (**Virhe. Viitteen lähdettä ei löytynyt.**) reveals the strength classes, lengths, dimensions, wood species, possible moisture content, and characteristics such as various knots of the tested pieces. (Puutuoteteollisuus ry, Double Round Oy, 2025)

Moisture measurement was taken with a pin meter, where two pins/electrodes are inserted into the wood. The meter measures the electrical resistance of the wood, which varies with moisture content, and gives the result as a percentage of moisture. The meter must be calibrated separately for each wood species. In this testing, all the samples tested were from the moon. (Puutuoteteollisuus ry, Double Round Oy, 2025)

One very common way to strength grade sawn timber is using C strength classes. There are ten in total, of which C14-C30 can be sorted either visually or mechanically, and strength classes C35-C50 only mechanically. C24 is the most common strength class found in building material stores, as it provides the required strength for the most common building applications. (Puutuoteteollisuus ry, Double Round Oy, 2025)

This strength classification was selected for pieces with dimensions, or size, of 50x100 mm. Strength grading can be performed on pieces that are at least 22 mm thick and 45 mm wide. From the Table 1, we can see that, except for only four pieces, all the test specimens belong to at least strength class C18, and some even to class C30. This indicates that the wood material is in good condition. (Puutuoteteollisuus ry, Double Round Oy, 2025)

Features like knots can affect sawn timbers strength class, but they don't necessarily define it entirely. For example, based on the Table 1, pieces with a lap joint are generally classified as strength class C24. However, the weakening of strength caused by a knot depends particularly on its relative size, or SO value (relative knot size), which describes the ratio of the knot diameter to the board width. Therefore, a single characteristic, such as knot type, is not sufficient to determine the strength class; the location and size of the knots are also relevant in strength classification. (Puutuoteteollisuus ry, Double Round Oy, 2025)

5.2.3 Puuloop Summary

The Puuloop demolition pilot in Porvoo showed that controlled, excavator-assisted demolition can enable the recovery of reusable sawn timber in a technically feasible and efficient way. The results also indicated that material preservation depended more on the building's structural design and construction methods than on whether the demolition was carried out manually or mechanically. In practice, excavator-assisted demolition appeared to be the more practical approach in terms of work efficiency, material yield, and safety, whereas fully manual demolition did not significantly improve material recovery and made the process slower. (Puutuoteteollisuus ry, Double Round Oy, 2025)

On-site sorting enabled the initial separation of reusable sawn timber, but it also highlighted practical limitations related to space requirements and the workflow at the demolition site. Therefore, more detailed sorting and material assessment could be carried out more efficiently at a centralised facility under controlled conditions. Further processing and visual strength grading showed that a significant portion of the recovered sawn timber met structural strength requirements, which confirmed the technical potential of demolition wood and enables this type of material recycling. (Puutuoteteollisuus ry, Double Round Oy, 2025)

Overall, the pilot demonstrates that material-oriented demolition can support the reuse of construction sawn timber when the demolition method is gentle enough. The material requires further processing, such as removing metals and any surface materials like paints. These findings provide a practical basis for assessing the scalability, economic feasibility, and environmental impact of reusing demolition wood. (Puutuoteteollisuus ry, Double Round Oy, 2025)

5.3 Data Used in Cost Modelling

The cost competitiveness analysis presented in this study is based on a combination of empirical observations and secondary data sources. Empirical data were obtained from the Porvoo Puuloop demolition study in Finland, where the recovery rates and processing characteristics of recycled wood materials were observed. Secondary sources include industrial statistics, market price estimates, and published literature related to sawn timber procurement, sawmill production, and wood waste processing in the European Union.

5.3.1 Yield Assumptions

Cost modelling is based on defined material recovery principles for both virgin roundwood and recycled wood. Yield is a very important parameter in the comparison, as it directly affects the raw material requirement per cubic meter of finished sawn timber.

A conversion factor of 2.2 cubic meters of roundwood per cubic meter of sawn timber was used for virgin sawn timber. This general assumption reflects the typical yields of industrial sawmills in northern conditions. The by-product distribution per cubic metre of sawn timber was assumed as follows: approximately 0.7 m³ (32%) wood chips, 3 m³ (14%) sawdust and 0.2 m³ (9%) bark. (Puututoreteollisuus ry, 2023). These by-products may generate additional revenue streams; in this study the primary focus remains on the cost per cubic metre of sawn timber. However, it is important to know and understand the impact, usability, and yield of side streams.

The recovery rate of recycled sawn timber was estimated based on the observations from the Porvoo demolition pilot and supporting literature. (Puutuoteteollisuus ry, Double Round Oy, 2025). Unlike virgin sawn timber, recycled sawn timber does not follow a uniform dimensional structure and contains parts that must be removed due to damage, contamination, or structural defects, such as cracks or metals. The proportion of the material used after cutting and removing impurities was thus defined as a scenario-based parameter. The yield is assumed to be lower than in traditional log handling due to the variation in material quality. Since raw material costs constitute the largest cost component in the sawmill industry, even small changes in efficiency significantly affect overall costs and competitiveness.

5.3.2 Price Modelling

Table 3. Cost components included in the price modelling framework for virgin and recycled sawn timber. (own table)

Cost Component	Virgin Wood	Recycled Wood
Raw material	Log price	Assumed negligible/scenario_based
Material yield	2.2m^3 logs -> 1m^3 timber	Scenario_based recovery rate
Primary processing	Sawing & handling	Reprocessing & resizing
Drying	Included	Not included (baseline)
Sorting/impurity removal	Not required	Included
Planing	Included	Included
Overheads	Included	Included

Table 3 summarises the main comparable cost components. The construction is applied to both virgin and recycled sawn timber production routes to make the results comparable. Naturally, the cost components are not entirely identical, but they have been defined to be conceptually as comparable as possible.

In the following sections, the cost components and their values for virgin and recycled wood will be explained in more detail. These values will later be used to calculate the results in the "6 Results".

5.3.2.1 Virgin Wood Cost Components

Since raw material costs constitute the largest portion of a sawmill's production costs, the price of wood has a significant impact on the total cost calculated per cubic meter of sawn timber. In the modelling, the average wood price in Finland is used, which has been obtained from the Finnish sawlog price calculator (Metsälehti, 2026). The prices are updated weekly, so it is highly likely that the prices at the time of reading the work will be different from those at the time of writing. On week 7 (16-22.2.2026) spruce roundwood price is **71,63€/m³** and this is price that is used in this study. This price is a standing sale-price, and it means that the forest owner sells the forest to the buyer and the buyer takes care of the cut down and transportation of the roundwood. (Varis, 2018)

The cost structure of the sawmill has been based on the "Cost Structure of the Sawmill Industry" graph found in the Sawmill Industry book. (Varis, 2018, s. 31).

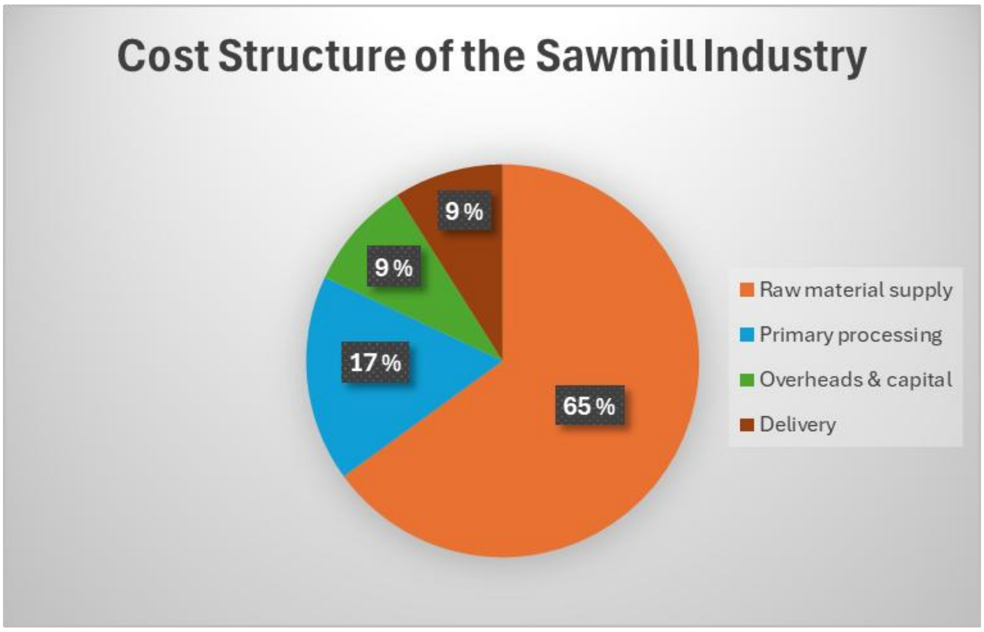

Figure 19. The cost Structure of the Sawmill Industry is based to information from "The Sawmill Industry handbook" (Varis, 2018). (own figure)

Figure 19 illustrates the total cost structure of producing one cubic meter (1 m³) of virgin sawn timber in a typical Nordic sawmill. The percentages represent the distribution of total production costs per cubic meter and do not include profit margins.

The procurement of raw materials accounts for approximately 65% of the total production costs. This category includes the roundwood purchase price, logging operations, and the transportation of roundwood to the sawmill. Since raw material costs constitute the largest portion of total expenses, variations in wood prices significantly impact overall manufacturing costs. The first processing accounts for approximately 17% of the cost structure. This category includes labour, energy consumption, and maintenance related to sawing, drying, and planing operations. Although these activities are not always presented separately in industry statistics, they are included in the operating cost categories. Maintenance costs and capital costs account for approximately 9% of the total costs. These include administrative costs, investments in machinery, and other fixed costs necessary to maintain production capacity. Finally, delivery and logistics also account for approximately 9% of the total costs. This includes outgoing transportation and freight costs related to sales. Since the market reference prices used in this study are in line with delivered export prices, transportation costs have been included in the production cost structure to ensure comparability.

It is important to note that this figure represents the internal cost distribution calculated per cubic meter of sawn timber produced and does not represent the final market price. The market price may exceed production costs depending on prevailing market conditions and profit margins. In addition to the compiled cost structures, there are many underlying factors that affect the final costs.

One of the most critical factors is the yield of the material. This study uses a conversion factor of 2.2 cubic meters of roundwood per cubic meter of sawn timber (Puututoreteollisuus ry, 2023). This reflects typical industrial sawmill conditions in Northern Europe. Since the supply of raw materials constitutes the largest part of the total production costs, even small changes in yield significantly affect the price per cubic meter. Lower yield increases effective raw material costs, while higher recovery efficiency improves competitiveness.

Energy costs also affect production costs, especially in drying operations, which consume a lot of energy. Although energy constitutes a smaller part of the total costs compared to raw material procurement, variations in energy prices can have a significant impact on the competitiveness of total costs, especially during unstable market conditions. The capacity utilisation rate also plays a significant role in cost efficiency. Fixed costs, including capital investments and administrative expenses, are spread over the total production volume. When the sawmill operates at a high utilisation rate, the fixed costs per cubic meter decrease. Conversely, a lower utilisation rate increases the cost drain per production unit. By-products partially cover production costs. During sawing, chips, sawdust, and bark are produced, which are sold to the pulp, panel, or energy industries. These by-products increase the overall economic profitability of the sawmill and reduce the net production costs of sawn timber per cubic meter.

Together, these parameters emphasise that the cost structure of producing virgin sawn timber is determined not only by the roundwood prices, but also by technical efficiency, operational performance, and market conditions. Although several operational factors, such as changes in energy prices, utilisation rates, and variations in wood quality, can affect production costs, this study primarily focuses on the structural cost differences between virgin and recycled sawn timber routes. Therefore, energy prices, utilisation rates, and other operational variables are treated as standardised baseline conditions in the modelling. The goal is not to simulate short-term market disturbances, but to analyse the cost structure and competitiveness of two material flows under comparable conditions.

5.3.2.2 Recycled Wood Cost Components

Since detailed cost breakdowns for the processing of recycled sawn timber are not widely available in the literature, the percentages were estimated by adapting the cost structure of a traditional sawmill (Varis, 2018) and adjusting it to reflect the absence of raw material costs and drying, as well as the additional labour identified in studies on recycled sawn timber during the preparation phase (Falk & Guy, 2007; Brütting et al., 2020).

In waste management, the term "gate fee" refers to the charge applied for receiving a certain amount of waste at a processing or recycling facility. Gate fees are commonly used to cover the operational costs, maintenance costs, labour costs, and capital costs of the facility, and they vary according to location and type of waste. Prices differ between private customers and businesses, and business-specific rates are typically not publicly available.

In practice, the procurement costs for demolition and other wood waste for recycling can vary greatly. In some cases, recycling facilities charge a gate fee for receiving low-quality wood waste, meaning that the waste producer must pay for the disposal of the material instead of delivering it for free. For example, in the United Kingdom, reported gate fees for low-quality wood waste have ranged from £20 to £30 (approximately 23–34 €) per tonne, and in some cases even up to £60 (approximately 70€) per tonne, depending on the quality of the material and market conditions. In other situations, such as municipal recycling centres that operate on a pay-as-you-go system, certain isolated wood waste batches can be accepted free of charge, while other larger waste items incur a fee. Based on the reported gate fee ranges, three possible and realistic processing cost scenarios were defined: 20€/t (low), 35€/t (medium), and 50€/t (high). These scenarios represent different levels of sorting, processing, and labour in the handling of recycled wood. (Letsrecycle; Josh Doherty, 2021)

At the same time, there may be a small market price for high-quality wood waste if downstream users (e.g., wood-based panel manufacturers or biomass energy producers) have demand, although this is not universal and heavily depends on local market structure and processing capacity. Therefore, in the context of this study, the procurement cost of recycled wood is treated as a scenario-based parameter, ranging from negative (i.e., the payment the facility receives for accepting the material) to zero cost and positive purchase price.

According to the Porvoo deconstruction pilot, approximately 36% of the transported demolition wood was estimated to be suitable for further sorting (Formula 1). However, due to the final sawing, impurity removal, and other processing, additional material waste is generated. The sorting suitability share (α) is calculated as the ratio between the mass assessed as suitable for further sorting and the total demolition wood mass transported from the site.

$$\alpha = \frac{M_{sorted}}{M_{total}}$$

Formula 1. Sorting suitability share, defined as the proportion of demolition wood mass assessed as suitable for further processing relative to the total transported demolition wood mass.

where

α	share of demolition wood suitable for further sorting
M_{sorted}	material suitable for sorting
M_{total}	total demolition wood mass transported

Using the values applied in this study

$$\alpha = \frac{3060}{8420}$$

$$\alpha = 0.363 \approx 36\%$$

In the modelling, the return of sorted material to usable sawn timber is treated as a processing yield parameter. Five scenarios have been defined: very low (50%), low (60%), medium (70%), high (80%), and very high (90%) recovery from the sorting process. When the original sorting share of 36% is combined, the total usable yield relative to the entire log mass is approximately 18% (very low) 22% (low), 25% (medium), 29% (high), and 32% (very high). The overall recovery rate ($R_{overall}$) is defined as the final usable sawn timber output relative to the total demolition wood mass. It is calculated by multiplying the sorting suitability share (α) by the processing yield (β) from the sorted stream (Formula 2):

$$R_{overall} = \alpha \times \beta$$

Formula 2. Overall recovery rate of recycled wood, calculated as the product of the sorting suitability share and the processing recovery yield from the sorted material stream.

where

$R_{overall}$	Final usable sawn timber output relative to total demolition wood mass
α	*sorting suitability share*
β	processing yield from sorted stream

Using the values applied in this study

$$R_{overall} = 0.36 \times 0.50 = 0.180 \approx 18\%$$

$$R_{overall} = 0.36 \times 0.60 = 0.216 \approx 22\%$$

$$R_{overall} = 0.36 \times 0.70 = 0.252 \approx 25\%$$

$$R_{overall} = 0.36 \times 0.80 = 0.288 \approx 29\%$$

$$R_{overall} = 0.36 \times 0.90 = 0.324 \approx 32\%$$

This overall recovery rate forms the basis for the cost modelling of recycled wood in this study. 50%, 60%, 70%, 80%, and 90%, the resulting overall recovery rates are approximately 18%, 22%, 25%, 29%, and 32%.

To ensure comparability with the virgin sawn timber production route, all costs of recycled wood were expressed per cubic meter of sawn timber used. Since the procurement and handling costs of demolition wood are typically reported on a mass basis (€/t), it was necessary to convert them into volumetric units.

The conversion was carried out using the assumed density of the demolition wood pieces (ρ), which is expressed in tonnes per cubic meter (t/m³). The average density value for the demolition wood was assumed to be 0.5 t/m³ and it is called “bulk density”. This value is consistent with the reported density ranges for spruce, which typically vary around 400–500 kg/m³ depending on moisture content and material conditions. The selected value allows for a direct comparison between recycled wood and virgin spruce roundwood. The bulk value for recycled wood is higher because it is due to impurities, coatings, material heterogeneity, and possible moisture variations. The cost of the feed material per cubic meter was calculated as follows (Formula 3):

$$C_{input} = P \times \rho$$

Formula 3. Conversion of mass-based cost to volumetric cost for input material, obtained by multiplying the unit price per tonne by the assumed bulk density of demolition wood.

where

P	cost per tonne of material (€/t)
ρ	bulk density of demolition wood (t/m³)

The feed cost was divided by the total recovery percentage to determine the effective cost per cubic meter for usable sawn timber (Formula 4):

$$C_{usable} = \frac{C_{input}}{R_{overall}}$$

Formula 4. Effective cost per cubic meter of usable sawn timber, calculated by distributing input-related costs over the final recovered output volume.

where

$R_{overall}$	Final usable sawn timber output relative to total demolition wood mass

This approach reflects the fact that all input-related costs must be distributed over the final usable output volume.

Because market conditions for recovered wood vary, procurement cost was treated as a scenario-based parameter. Procurement prices can be negative (gate fee received), zero, or positive (purchase price), depending on the material quality and local market conditions. Using the previously mentioned conversion principles, the procurement cost per cubic meter for usable sawn timber was determined.

Since precise industrial cost data for processing recycled sawn timber is not publicly available, the gate fee levels for wood waste were used as an indicator of processing costs. Gate fees typically reflect the combined cost components of material reception, sorting, processing, labour, and facility operation. Handling costs were defined per tonne of incoming material and converted to volume costs using the assumed densities and recovery parameters described above. However, it is important to note that these prices are consumer prices. Business prices are not publicly available.

Based on the price ranges reported in the literature, three processing cost scenarios (low, medium, high) were defined per tonne of incoming material. These scenarios were then converted into costs per cubic meter of wood used. The scenario-based approach enables sensitivity analysis and reflects the uncertainty related to the development of recycled wood product value chains.

The handling cost per cubic meter of the sawn timber to be used was calculated as follows (Formula 5):

$$C_{proc} = \frac{C_{proc} \times \rho}{R_{overall}}$$

Formula 5. Processing cost per cubic meter of usable recycled sawn timber, derived from the processing cost per tonne of input material, bulk density, and overall recovery rate.

where

C_{proc} processing cost per tonne of input material (€/t)

In addition to procurement and handling costs, the production of recycled wood involves expenses such as planing, finishing, administration, capital costs, and logistics. These stages are comparable to the post-processing processes of traditional sawmilling, as the end product and delivery requirements are similar.

Therefore, these costs were estimated using relative proportions derived from the cost structure of a traditional sawmill (Varis, 2018). Downstream cost parameter (*K*) was defined as a proportion of the total production costs of virgin sawn timber (Formula 6):

$$K = s_K \times C_{virgin,total}$$

Formula 6. Downstream cost parameter for recycled sawn timber production, estimated as a proportional share of the total production cost of virgin sawn timber based on conventional sawmill cost structure data.

where

s_K	proportional share of downstream cost (maintenance, capital, logistics)
$C_{virgin,total}$	total production cost of virgin sawn timber (€/m³)

This approach maintains methodological consistency between the two production routes and avoids introducing additional assumptions related to the handling of recycled wood. The total cost of recycled sawn timber per cubic meter used was calculated as the sum of the acquisition cost, processing cost, and post-processing cost (Formula 7):

$$C_{recycled.total} = C_{acq.usable} + C_{proc.usable} + K$$

Formula 7. Total production cost of recycled sawn timber per cubic meter of usable output, calculated as the sum of acquisition cost, processing cost, and downstream costs.

where

$C_{recycled.total}$	Total cost of recycled sawn timber (€/m³ usable output)
$C_{acq.usable}$	Acquisition cost per cubic meter of usable sawn timber
$C_{proc.usable}$	Processing cost per cubic meter of usable sawn timber
K	Downstream cost parameter (€/m³ usable)

The main structural difference between the routes for virgin and recycled wood lies in the distribution of cost components. In the production of virgin wood, the procurement of raw materials constitutes the dominant cost component, where in the processing of recycled wood, material costs may be minimal, while processing and labour costs become significant due to low recovery rates and additional manufacturing stages. This cost structure is used in the Results section as the basis for comparative analysis.

5.3.2.3 Market Reference Prices (Fastmarkets)

Sawmills generally do not reveal business-to-business (B2B) sales prices. Producer-level market price estimates were derived from Fastmarkets price assessments, which are based on industry-reported transaction data. Although the prices are estimates, they are suitably indicative to be used for comparison. (Neuvonen & Narayan, 2025)

Monthly European Wood Product Price Assessments – Pilot					
Sawn Timber – Nordic exports to Europe – Delivered (€ per m³)	November 2025	October 2025	September 2025	Nov-Oct Midpoint Change	Oct-Sep Midpoint Change
Germany					
Spruce – Sawfalling 44-50×150 mm	310 - 325	310 - 325	310 - 325	0.00%	0.00%
Spruce – Sawfalling 63×150 mm	310 - 325	310 - 325	310 - 325	0.00%	0.00%
Spruce – Sawfalling 50×100 mm	300 - 320	300 - 320	300 - 320	0.00%	0.00%
France					
Spruce – Sawfalling 44-50×150 mm	290 - 325	290 - 325	295 - 325	0.00%	▼0.81%
Spruce – Sawfalling 63×150 mm	290 - 320	290 - 320	295 - 320	0.00%	▼0.81%
Spruce – Sawfalling 50×100 mm	290 - 325	290 - 325	295 - 325	0.00%	▼0.81%
Benelux					
Spruce – Sawfalling 47×150 mm	305 - 320	305 - 320	310 - 320	0.00%	▼0.79%
Spruce – Sawfalling 50×100 mm	305 - 320	305 - 320	310 - 320	0.00%	▼0.79%
Spruce – Planed Construction Timber 50×75 mm	360 - 380	360 - 380	360 - 380	0.00%	0.00%
United Kingdom					
Spruce – Sawfalling 44-50×150 mm	295 - 315	295 - 315	300 - 320	0.00%	▼1.61%
Spruce – Sawfalling 50×100 mm	295 - 315	295 - 315	300 - 320	0.00%	▼1.61%
Pine – US: 50×150 mm	305 - 325	305 - 325	310 - 330	0.00%	▼1.56%
Pine – V: 38×150 mm	280 - 310	280 - 310	280 - 310	0.00%	0.00%
Pine – V:25×100 mm	285 - 310	275 - 300	275 - 300	▲3.48%	0.00%
Pine – VI:25×125 mm	230 - 245	230 - 245	230 - 245	0.00%	0.00%

Figure 20. Monthly European price assessments for Nordic sawn timber exports by country and dimension (€/m³. (Neuvonen & Narayan, 2025)

To ensure the practical significance of the comparison, the analysis focuses on commonly used structural dimensions of 48×98 mm and 48×148 mm. These dimensions represent standard-sized sawn timber dimensions that are widely used in both the Nordic countries and elsewhere in Europe.

Although the market price assessment table lists slightly different nominal dimensions (e.g., 44–50×150 mm, 50mm×100 mm), these are considered technically equivalent to the selected dimensions. A small dimensional deviation does not significantly affect the cubic meter-based price comparison used in this study. To ensure consistency and avoid artificial averaging across multiple markets, Germany was selected as the reference export market for Nordic spruce sawn timber. Germany represents one of the largest and most stable destination markets for Nordic sawn timber.

The price information was obtained from the Fastmarkets Nordic export price assessment (Figure 20) specifically from the rows corresponding to spruce sawn timber sizes 44–50×150 mm and 50×100 mm, delivered to Germany. The reported monthly price for the 44–50×150 mm size ranged from 310 to 325€/m³, while for the 50×100 mm size, it ranged from 300 to 320€/m³.

Based on these observed price ranges, three price levels were defined for modelling purposes (low, medium, and high) for each product category. These values are used in comparative cost analysis as representative producer price levels. They are listed in Table 4.

Table 4. Selected market reference prices used in the comparison. (Neuvonen & Narayan, 2025) (own table)

Product category	Equivalent study dimension	Low price (€/m^3	Medium price (€/m^3)	High price (€/m^3)
44-50 × 150 mm	≈ 48 × 148 mm	310	317.5	325
50 × 100 mm	≈ 48 × 98 mm	300	310	320

To make a comparison with market reference prices, estimated selling prices for recycled sawn timber were calculated. Since the values calculated in this study represent the production costs of recycled sawn timber rather than the final selling prices, it was necessary to adjust the pricing to reflect realistic market conditions.

The calculation of pricing was based on the relationship between the production costs of virgin sawn timber and the selected market reference prices. The pricing factor was determined by dividing the market reference price by the corresponding production cost of virgin sawn timber (Formula 8).

Formula 8: Pricing factor calculation based on market reference price and production cost.

$$Pricing\ factor = \frac{Market\ reference\ price\ €/^3}{Production\ cost\ of\ new\ timber\ €/m^3}$$

This calculation was performed using all the selected market reference price levels presented in Table 4, which cover different product dimensions and price ranges. The resulting factors describe the relationship between production costs and observed market price levels.

To reduce sensitivity to individual price points and simplify the analysis, a set of representative pricing factors was defined based on this. These factors were then applied to the calculated production costs of recycled sawn timber (Formula 9).

Formula 9: Estimated selling price calculation for recycled sawn timber.

$$Estimated\ selling\ price\ €/m^3 = Production\ cost\ €/m^3\ \times\ Pricing\ factor$$

These estimated price levels are used in section "6.3 Comparison Between Virgin and Recycled Sawn Timber" to evaluate how recycled sawn timber could be positioned relative to observed market reference prices.

6 Results

In this chapter, the results of the cost modelling and comparative analysis of recycled wood are presented. The results are organised to show how the economic competitiveness of recycled sawn timber develops according to different assumptions and scenarios.

First, the production cost of virgin sawn timber is calculated. Next, the production costs of recycled sawn timber are presented under different recovery rates and cost scenarios. These are then compared to evaluate the relative cost competitiveness of recycled sawn timber. Finally, the estimated selling prices of recycled sawn timber are compared with selected market reference prices to assess its potential market position.

6.1 Production Cost of Virgin Sawn Timber

As mentioned in section “5.3.2.1 Virgin Wood Cost Components," the roundwood cubic meter price used in this study is **71.63€/m³**. The conversion factor used is 2.2 m³ of logs per cubic meter of sawn timber (Varis, 2018). The raw material costs are calculated as based on the assumptions presented in the “5.3 Data Used in Cost Modelling”.

$$C_{logs} = 2.2 \times 71.63 = \mathbf{157.59€/m}^3$$

Formula 10. Raw material cost per cubic meter of virgin sawn timber calculated using the conversion factor and roundwood price assumptions presented in the “5.3 Data Used in Cost Modelling”.

Since the procurement of raw materials accounts for approximately 65% of the production costs of virgin sawn timber, the total costs were estimated as follows:

$$C_{virgin.total} = \frac{157{,}59}{0{,}65} = \mathbf{242.44€/m}^3$$

Formula 11. Total production cost of virgin sawn timber derived from the raw material cost using the proportional cost share of procurement defined in the “5.3 Data Used in Cost Modelling”.

Table 5 presents the estimated production cost structure of virgin sawn timber. The total production cost was calculated based on the assumed roundwood price, conversion factor, and typical cost shares of Nordic sawmills. Using the roundwood price of **71.63 €/m³** and a conversion factor of 2.2 m³ of logs per cubic meter of virgin sawn timber, the estimated raw material cost was approximately **157.59 €/m³** (Formula 10). Based on this and the selected cost structure assumptions, the total estimated production cost of virgin sawn timber was calculated to be approximately **242.44 €/m³** (Formula 11)

Table 5. Production cost structure of virgin sawn timber per cubic meter based on the assumed roundwood price, conversion factor, and conventional sawmill cost shares.

Cost component	€/m³	Share (%)
Raw material procurement	157.59	65
Primary processing	41.21	17
Overheads & capital	21.82	9
Logistics	21.82	9
Total	**242.44**	**100**

Based on the calculated value, an estimate of the virgin sawn timber per cubic meter is obtained from the internal production costs, and it does not include profit margins. Market prices may vary due to factors such as fluctuations in demand, contractual terms, transportation distances, and revenues from by-products generated during sawing. It is also important to remember that the impact of the raw material, i.e., the roundwood price, is very significant. In this formula, the calculation of the total cost is entirely based on the price of the roundwood, and it can change by several euros within a week. This will then also affect the prices of other cost components.

6.2 No Production Cost of Recycled Sawn Timber

The production cost of recycled sawn timber was calculated using the recovery rates, procurement cost scenarios, and processing cost parameters defined in “5.3.2.2 Recycled Wood Cost Components”. The calculations were performed for five recycling scenarios (very low, low, medium, and high and very high), which correspond to overall recovery scenarios of approximately **18%**, **22%**, **25%**, **29%**, and **32%**.

Procurement and processing costs were first converted from mass-based units (€/t) to volume-based costs (€ /m³) using assumed density and recovery parameters. The downstream cost parameter was obtained from the production cost of virgin sawn timber, which was calculated in section “6.1 Production Cost of Virgin Sawn Timber”.

The cost of demolition wood used in the production of recycled sawn timber was treated as a scenario-based parameter to reflect variations in its availability and pricing. In this study, demolition wood could be received at no cost, purchased at a positive price, or accepted in exchange for a gate fee, depending on material quality and local conditions. This approach allows the impact of raw material cost on the final product to be evaluated. Processing costs were estimated using representative gate fee levels for wood waste processing, which reflect the combined costs of material reception, sorting, processing, labour, and facility operation.

In addition to procurement and processing costs, the production of recycled sawn timber also includes post-processing costs such as planing, finishing, administration, capital costs, and logistics. These costs were estimated using relative cost shares obtained from the cost structure of a traditional sawmill, which was presented in “5.3.2.1 Virgin Wood Cost Components”.

According to the assumptions made in section “5.3.2.2 Recycled Wood Cost Components”, three procurement cost scenarios (**0 €/t**, **10 €/t**, and **20 €/t**) and three processing cost scenarios (**20 €/t**, **35 €/t**, and **50 €/t**) were calculated. These values represent different market and operational environments in the processing of recycled sawn timber. The calculations were performed for all combinations of procurement and processing costs according to three return scenarios (**18%**, **22%**, **25%**, **29%**, and **32%**). Results are shown on Table 6, Table 7, Table 8,Table 9 and Table 10.

Table 6. Total production cost of recycled sawn timber at 18% recovery. (own table)

Acq (€/t) \ Proc (€/t)	20€/t	35€/t	50€/t
0 €	140.41	182.07	223.74
10 €	168.19	209.85	251.52
20 €	195.96	237.63	279.29

Table 6 presents the calculated production costs for recycled sawn timber, assuming an overall recovery rate of approximately **18%**. This represents the lowest recycling forecast considered in the study.

The results show that production costs vary significantly according to procurement and processing costs. When the demolition wood is obtained for free (**0€/t**) and the processing costs are low (**20€/t**), the production cost of recycled sawn timber is **140.41€/m³**. However, when procurement costs and processing costs increase, the production cost of the final product is significantly higher. For example, when the procurement cost is **20€/t** and the handling cost is **50€/t**, the production cost rises to **279.29€/m³**.

Table 7. Total production cost of recycled sawn timber at 22% recovery. (own table)

Acq (€/t) \ Proc (€/t)	20€/t	35€/t	50€/t
0 €	131.15	165.77	200.39
10 €	154.30	188.92	223.54
20 €	177.44	212.06	246.69

Table 7 presents the calculated production costs assuming an approximately **22%** recovery rate. Compared to the previous **18%** recovery scenario, a higher recovery rate reduces unit production costs across all procurement and processing cost combinations. For example, when the procurement cost is **0€/t** and the processing cost is **35€/t**, the production cost decreases from **182.0€/m³** (Table 5) to **165.77€/m³.**

Table 8. Total production cost of recycled sawn timber at 25% recovery. (own table)

Acq (€/t) \ Proc (€/t)	20€/t	35€/t	50€/t
0 €	124.85	154.85	184.85
10 €	144.85	174.85	204.85
20 €	164.85	194.85	224.85

Table 8 presents the calculated production costs assuming a recovery rate of **25%**. As the recovery rate increases, the production cost continues to decrease across all procurement and processing cost scenarios. When procurement costs rise by **20€/t** and handling costs reach **50€/t**, the production cost is **224.85€/m³**. Compared to the **22%** recovery scenario (Table 7), the production cost is over **20€/m³** lower with the same procurement and handling cost assumptions.

Table 9. Total production cost of recycled sawn timber at 29% recovery. (own table)

Acq (€/t) \ Proc (€/t)	20€/t	35€/t	50€/t
0 €	119.33	145.19	171.06
10 €	136.57	162.43	188.30
20 €	153.82	179.68	205.54

Table 9 presents the calculated production costs assuming **29%** recovery rate. Compared to the previous scenario, a higher recovery rate further reduces the production costs of recycled sawn timber. For example, when the procurement cost is **0€/t** and the processing cost is **35€/t**, the production cost decreases to **145.19€/m³**, compared to **154.85€/m³** in the **25%** recovery scenario.

Table 10. Total production cost of recycled sawn timber at 32% recovery. (own table)

Acq (€/t) \ Proc (€/t)	20€/t	35€/t	50€/t
0 €	116.10	139.54	162.98
10 €	131.73	155.16	178.60
20 €	147.35	170.79	194.23

Table 10 presents the calculated production costs assuming a **32%** recovery rate. The results show a clear relationship between the recovery rate and production costs: higher recovery rates lead to lower unit production costs. In this scenario, the highest production cost is **194.23€/m³**. This is approximately **30€/m³** lower than in the **25%** recovery scenario (Table 7), where the highest production cost reaches **224.85€/m³**. It can also be noted that in the most expensive scenario, i.e., when the processing cost is **50€/t** and the procurement cost is **20€/t**, the results of a **32%** recovery are even over **85€/m³** cheaper than when the recovery is **18%**. This difference has a clear impact on cost competitiveness.

The results show a consistent relationship between the recovery rate and production costs in the production of recycled sawn timber. Although procurement and handling costs affect the overall cost level, the most significant factor for cost competitiveness is the recovery rate.

When the recovery rate increases from **18%** to **32%**, the unit production cost decreases significantly across all cost combinations. This demonstrates that improving material recovery and thus yield in deconstruction wood processing is a key factor in enhancing the economic viability of recycled sawn timber compared to virgin sawn timber.

6.3 Comparison Between Virgin and Recycled Sawn Timber

In this section, the production costs of recycled sawn timber are compared to those of virgin sawn timber. The production costs of virgin sawn timber were estimated in section "6.1 Production Cost of Virgin Sawn Timber" to be **242.44€/m³**. The costs of recycled sawn timber were calculated based on different recycling rates, procurement costs, and processing cost scenarios, which were presented in section "6.2 No Production Cost of Recycled Sawn Timber".

From the Figure 21, we can observe that with these selected values and scenarios, recycled wood is cheaper to produce than virgin wood. With recovery rates of **25%**, **29%**, or **32%**, the production costs of recycled wood remain below the price of virgin wood in each scenario. The largest differences compared to virgin sawn timber occur when the price of recycled material is **0€/t** and production costs are **20€/t**. Then the differences are over **100€/m³** cheaper compared to virgin saw timber. When the material price (**20€/t**) and production costs (**50€/t**) are high, the final product price naturally rises close to or even above that of virgin sawn timber. In three scenarios, the price of recycled sawn timber is higher: when the recovery rate is **18%** and the material price and production costs are **10€/t & 50€/t** and **20€/t & 50€/t**, or when the recovery rate is **22%** and the material price and production costs are **20€/t & 50/t**.

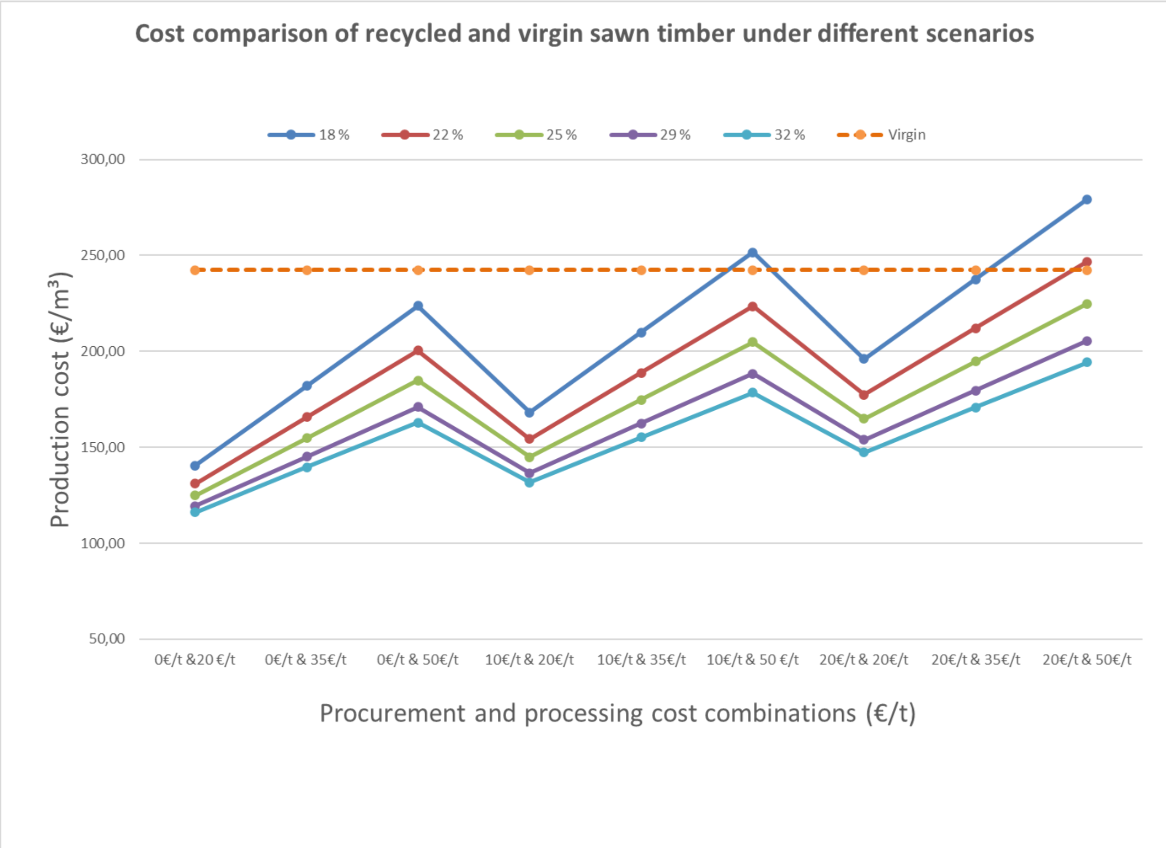

Figure 21. Production costs of recycled sawn timber with different procurement and processing cost combinations at varying recovery rates. The orange dotted line represents the production costs of virgin sawn timber (242.44€/m³), and it is used as a comparison for different recycled sawn timber scenarios. (own figure)

This trend is consistent with the results presented in section "6.2 No Production Cost of Recycled Sawn Timber", where the return rate was identified as the most significant factor affecting production costs. In this comparison, the focus is on how these cost changes affect competitiveness compared to the virgin sawn timber. The results suggest that recycled sawn timber can be cost-competitive across a wide range of scenarios. When procurement and processing costs remain low or reasonable, recycled sawn timber is consistently cheaper than new sawn timber at all recovery rates. In higher cost scenarios, the difference between recycled and virgin sawn timber decreases, and recycled sawn timber will become more expensive at lower recovery rates. However, as the recovery rate increases, the cost difference decreases and can turn favourable for recycled sawn timber.

In summary, the comparison shows that although cost levels affect final production costs, competitiveness is primarily determined by the ability to achieve sufficient recovery rates and maintain cost control in processing.

Table 11. The cost difference between recycled and virgin sawn timber (242.44€/m³) in various procurement and processing cost combinations with varying recovery rates. The scenarios where the price of recycled sawn timber is over 100 euros/m³ cheaper than virgin sawn timber are marked in dark green. In green, it is marked as 50-100€/ m³. Light green is 0-50€/m³ and red when the price of recycled sawn timber is higher than the price of virgin sawn timber. (own table)

	18 %	22 %	25 %	29 %	32 %
0€/t & 20€/t	-102.03	-111.29	-117,59	-123.11	-126.34
0€/t & 35€/t	-60.37	-76.67	-87.59	-97.25	-102.90
0€/t & 50€/t	-18.70	-42.05	-57.59	-71.38	-79.46
10€/t & 20€/t	-74.26	-88.14	-97.59	-105.87	-110.71
10€/t & 35€/t	-32.59	-53.52	-67.59	-79.01	-87.28
10€/t & 50€/t	9.07	-18.90	-37.59	-52.14	-63.84
20€/t & 20€/t	-46.48	-65.00	-77.59	-88.62	-95.09
20€/t & 35€/t	-4.81	-30.38	-47.59	-62.76	-71.65
20€/t & 50€/t	36.85	4.25	-17.59	-36.90	-48.21

The results on Table 11 show that cost competitiveness is achieved in most scenarios, as most of the values are negative. The most favourable cases are marked in dark green, indicating that recycled sawn timber can be over **100€/m³** cheaper than virgin sawn timber. These cases occur when procurement and processing costs are low and the recycling rate is moderate or high. Red indicates those situations in scenarios where recycled sawn timber is more expensive than virgin sawn timber. These situations occur when both procurement and processing costs are high and the recycling rate is low.

In summary, it can be concluded that Table 11 supports the conclusion that recycled sawn timber can be economically competitive with virgin sawn timber in a wide range of situations, but this competitiveness largely depends on achieving sufficient recovery rates and avoiding excessively high acquisition and processing costs. It is also important to note that changes in procurement and handling costs can significantly increase the production costs of recycled sawn timber, and in some cases make it clearly more expensive than virgin sawn timber.

6.4 Comparison of Recycled Sawn Timber Prices with Market Prices

In this section, the estimated selling prices for recycled sawn timber are compared to selected market reference prices for virgin sawn timber. In this analysis, aim is to assess how recycled sawn timber could be positioned in the market as a finished product.

To make the comparison more accurate, the estimated selling prices for recycled sawn timber were calculated using reference price factors obtained from the relationship between the production costs of virgin sawn timber and selected market reference prices. These formulas are explained in section “5.3.2.3 Market Reference Prices (Fastmarkets)”. These allow for a more comparable comparison of the price levels of recycled sawn timber with the observed market price levels (Table 12).

Table 12. Selected market reference prices for two different dimension categories (48mm x 98mm and 48mm x 148mm) and the corresponding pricing factors used in the market comparison. The pricing factors were calculated by comparing the selected market reference prices to the estimated production cost of virgin sawn timber (242.44 €/m³). (own table)

Product category	Marked price level	Market referense price(€/m^3)	Pricing factor
48 × 98 mm	Low	300	1.24
48 × 98 mm	Medium	310	1.28
48 × 98 mm	High	320	1.32
48 × 148 mm	Low	310	1.28
48 × 148 mm	Medium	317,5	1.31
44 × 148 mm	High	325	1.34

These pricing factors were then applied to the calculated production costs of recycled sawn timber to estimate potential selling price levels. This allows the comparison presented in Table 13 and Table 14, which shows under what conditions recycled sawn timber could remain within a realistic market price range.

The “Best case” is not included in Table 13 and Table 14 because in this scenario the estimated selling price remains constant across all recovery rates. This is because the production cost in the “Best case” scenario does not vary with the recovery rate in the same way as in the reasonable and worst-case scenarios. As a result, repeating the same value in each recovery rate column would not add analytical value to the comparison and would make the heat map unclear.

For the **48×98** mm dimension group, the estimated “Best case” prices range from **105.21–112.00 €/m³** according to the selected market price level. For the **48×148 mm** dimension group, the corresponding values range from **108.61–113.70 €/m³**. In both cases, these values remain clearly below the selected market reference range, indicating strong market competitiveness in more favourable production situations.

Table 13. Estimated selling prices of recycled sawn timber (€/m³) for the 48 × 98 mm dimension category under “Moderate” and “Worst case” production cost scenarios at varying recovery rates. The dark green cells indicate estimated selling prices that are below 300€/m³, while the lighter green indicates when the selling price is between 300-325€/m³. Red cells indicate price levels when they are over 325€/m³. (own table)

	Moderate case			Worst case		
Recovey rate (%)	Low	Medium	High	Low	Medium	High
18	225.77	233.05	249.33	346.32	357.49	368.66
22	205.55	212.19	218.82	305.90	315.76	325.63
25	191.99	198.21	204.40	278.81	287.81	296.80
29	180.04	185.84	191.65	254.87	263.09	271.31
32	173.03	178.61	184.19	240.85	248.61	256.38

The same comparison was then carried out for the **48 × 148 mm dimension** category, using the corresponding market reference prices and pricing factors (Table 14).

Table 14. Estimated selling prices of recycled sawn timber (€/m³) for the 48 × 148 mm dimension category under "Moderate" and "Worst case" production cost scenarios at varying recovery rates. The dark green cells indicate estimated selling prices that are below 300€/m³[33], while the lighter green indicates when the selling price is between 300-325€/m³. Red cells indicate price levels when they are over 325€/m³. (own table)

	Moderate case			Worst case		
Recovey rate (%)	**Low**	**Medium**	**High**	**Low**	**Medium**	**High**
18	233.05	238.52	243.97	357.49	365.87	374.25
22	212.19	217.16	222.13	315.76	323.16	330.56
25	198.21	202.85	207.50	287.81	294.55	301.30
29	185.84	190.20	194.55	263.09	269.16	275.42
32	178.61	182.80	186.98	248.61	254.44	260.27

Table 13 and Table 14 show that under the Moderate case scenario, recycled sawn timber remains within a realistic market price range across all analysed recovery rates. In both product categories, the estimated selling prices for the **48×98 mm** dimension group range from **173.03€/m³ to 249.33€/m³**, while the corresponding price range for the **48×148 mm** dimension group is from **178.61€/m³ to 243.97€/m³**. These values remain clearly below the selected market price range of **300–325€/m³**, which suggests that recycled wood could be sold at a competitive price level, even if production costs are not at their lowest.

The weakest market position is evident in the "Worst case" scenario, especially at the lower **18%** and **22%** return rates. The highest price for the dimension **48×98 mm** is **368.66€/m³** and for the dimension **48×148 mm** it is **374.25€/m³** when recycling rate is **18%.** With a recycling rate of **22%**, the results improve slightly, but they are in the same price range as virgin sawn timber or, more expensive: for the **48×98 mm** dimension, the estimated prices are **305.90€/m³**, **315.76€/m³**, and **325.63€/m³**, while for the **48×148 mm** dimension, the prices are **315.76€/m³**, **323.16€/m³**, and **330.56€/m³**. This means that at this return rate, recycled sawn timber is close to or slightly above the selected market reference range, depending on the product group and pricing level.

As the recovery rate increases, the estimated selling prices decrease significantly. At a **25%** recovery rate, most of the "Worst case" scenario values fall below the selected market reference area, and only the highest pricing level of the **48×148 mm** dimension group reaches **301.30/€m³**, which is the same price level as the assumed selling price of virgin sawn timber. At **29%** and **32%** recovery rates, all estimated selling prices in both product categories remain below the selected market reference area, even in the "Worst case" scenario. Thus, it can again be noted that the recovery rate has a very significant impact on the final price.

Overall, the results suggest that recycled sawn timber could achieve market-relevant selling price levels across a wide range of conditions. The results indicate that maintaining sufficiently high recovery rates is important for recycled sawn timber to remain commercially competitive, especially in less favourable production cost conditions.

7 Discussion and Conclusion

The aim of this study was to assess the cost competitiveness of sawn timber made from demolition wood compared to virgin sawn timber and to determine whether recycled sawn timber could achieve realistic market price levels under different recycling and cost conditions. The study was based on a combination of empirical observations from the Porvoo Puuloop deconstruction pilot and secondary data sources, including industry cost estimates and market reference prices for Nordic sawn timber.

Based on the results, the most significant factor affecting the cost competitiveness of recycled sawn timber is the recovery rate. As recovery rates increased, production costs decreased significantly, bringing the estimated selling prices closer to, and in many cases below, the price level of virgin sawn timber. In moderate scenarios, the estimated prices for both analysed dimensions, 48×98 mm and 48×148 mm, remained below the selected market reference range of virgin sawn timber, 300–325 €/m³. This suggests that recycled sawn timber may have realistic market potential under favourable conditions. At the same time, the results also indicate that recycled sawn timber is not always cost-competitive. At lower recovery rates, such as 18% or 22%, and with high processing cost assumptions, the estimated selling prices rise to the same level as or above those of virgin sawn timber. This highlights how strongly the competitiveness of recycled sawn wood depends on both recovery efficiency and processing costs.

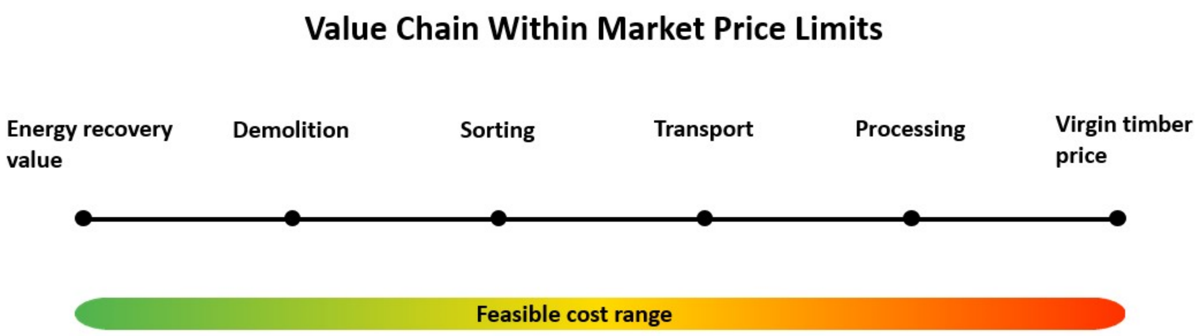

Figure 22. Simplified illustration of the economic range available for recycled sawn timber processing between the energy recovery value of demolition wood and the market price of virgin sawn timber. The colour gradient illustrates the narrowing economic margin as processing costs approach the market price level of virgin sawn timber (own figure)

In addition to the scenario-based cost modelling, the economic feasibility of recycled sawn timber can also be viewed through a simplified economic range approach (Figure 22). At the lower end of the value chain, demolition wood has a low baseline value as an energy source, while the market price of virgin sawn timber defines the upper economic limit for recycled sawn timber products. Between these two limits, all processing stages, such as sorting, transport, and processing, must remain economically feasible. If the accumulated costs exceed the market price level of virgin sawn timber, recycled timber is unlikely to remain competitive.

Since the results of this study indicate that recovery rate is one of the most important factors affecting the cost competitiveness of recycled sawn timber, improving material recovery should be considered a key area for future development. This begins already at the demolition site, where sorting practices should be as efficient as possible so that all demolition wood with potential for further use can be directed to reuse, while only material unsuitable for further processing is incinerated or crushed.

The further sorting and preparation of demolition wood waste should increasingly be supported by mechanised solutions to reduce manual labour and improve efficiency. At the same time, it is important that the technologies used do not unnecessarily damage the demolition wood material during handling, for example when removing nails or other metal parts. If the removal process causes excessive damage to the material, the final recovery rate may decrease significantly.

From a practical and industrial perspective, it would also be beneficial if the cleaning and pretreatment of demolition wood were carried out by a specialised external company rather than by the sawmill itself. This could allow sawmills to receive larger volumes of cleaner and more homogeneous material that can be processed more efficiently within existing production systems. In turn, this could improve production efficiency, reduce costs, and strengthen the competitiveness of recycled sawn timber.

The results should nevertheless be interpreted with caution. The study is based on simplified cost assumptions and estimated market prices, and the modelling approach is strongly scenario dependent. In particular, the results are highly sensitive to assumptions related to recovery rate and processing costs. Small changes in recovery efficiency or processing costs may significantly affect the estimated competitiveness of recycled sawn timber. Furthermore, not all possible influencing factors could be considered due to data limitations and the non-industrial nature of the pilot study. Therefore, the results should not be interpreted as universally applicable market predictions. However, the results provide an indication that recycled sawn timber has the potential to compete with virgin sawn timber under favourable conditions.

The pilot study revealed that the strength of recycled sawn timber is generally very good, making the product more competitive. This increases the range of potential applications for the material. Depending on the applications, recycled sawn timber can already be sufficiently dry and does not need to be dried again. In this way, significant cost savings can be achieved since the drying process is one of the most energy-consuming and therefore one of the most expensive production costs. (Puutuoteteollisuus ry, Double Round Oy, 2025) (Korpunen, 2015)

From a market perspective, recycled sawn timber is unlikely to succeed as a separate product category and will more likely need to compete within existing sawn timber markets. This means that recycled sawn timber and other recycled wood products must be able to fit into established value chains and customer expectations rather than relying on the creation of entirely new markets. In practice, customers are generally unlikely to pay significantly higher prices for recycled wood products unless additional value, such as environmental benefits or a lower carbon footprint, can be clearly demonstrated. In many cases, recycled products are expected to match the price level of conventional alternatives. For industrial use, it is therefore important that recycled sawn timber can be integrated into existing production processes as efficiently as possible, for example through applications such as finger jointing.

Based on the results of this study, it is important to remain realistic and understand what it takes for recycled sawn timber to succeed in the market. It should be remembered while sustainability considerations are increasingly emphasised, it is often the price that decides in the market. If the price of recycled sawn timber or other similar recycled wood products cannot be made competitive, their market potential may remain limited, and thus the investments may not lead to sustainable market adoption. The topic needs further investigation to find ways to effectively clean demolition wood at reasonable prices and to determine which are the most sensible products for recycled wood, such as CLT, GLT, sawn timber, etc. Overall, the results suggest that recycled sawn timber has realistic market potential under favourable recovery and processing conditions, but long-term competitiveness will depend on efficient material recovery, controlled processing costs, and successful integration into existing industrial value chains.

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