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LIFE CYCLE ASSESSMENT OF END-OF-LIFE OPTIONS OF DEMOLITION WASTE WOOD IN NEW ZEALAND

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ABSTRACT: The concept of circular economy (CE) in construction has become significantly more important and is recently gaining increasing attention. It proposes a change in mindset in which waste can be valued as an additional resource rather than an issue to manage and send for disposal. The approach prolongs the value of useful materials and optimizes supply chains. This research study investigates the possible environmental benefits of applying circular economic principles to the issue of demolition waste wood in order to counteract climate change. A life cycle assessment (LCA) was conducted to quantify the environmental impacts of managing waste wood across different avenues in the New Zealand construction environment. A range of alternatives were examined, such as remanufacturing the waste wood into glued-laminated timber, cross-laminated timber, and dowel-laminated timber products, recycling for particleboards, and energy recovery. The LCA results revealed that all the alternative scenarios were beneficial regarding global warming potential and abiotic depletion potential (fossil fuels), while the remanufacturing scenarios also had substantial reductions in the acidification potential of land and water, eutrophication potential, and photochemical ozone creation potential. These results advocated for adopting remanufacturing strategies in waste wood management systems to enhance sustainability and resource efficiency in New Zealand's construction industry.

KEYWORDS: Life cycle assessment, circular economy, waste wood, remanufacture, laminated timber products

1 – INTRODUCTION

With the built environment internationally contributing nearly 40% of global greenhouse gas emissions, the demand for more sustainable materials are increasing. Among various active and passive solutions and strategies developed and proposed in the existing literature, the increased use of wood has emerged as a promising solution to mitigate greenhouse gas emissions from buildings [1]. Wood is the only renewable mainstream construction material, absorbing more carbon dioxide during its growth phase than is emitted during its preparation and use in construction, thereby positively influencing carbon emissions.

Each year, a substantial amount of wood waste is produced globally. For example, in 2020, the European Union produced about 48.3 million tonnes of waste wood, with Germany, France, Italy, Belgium, and Finland as leading producers. In Brazil, approximately 30 million tonnes of wood waste is generated annually. In New Zealand, timber is the most used construction material for residential buildings. The amount of wood waste generated in New Zealand reached 450,000 tonnes in 2022. Managing the large amount of wood waste is challenging, but the circular economy (CE) concept, which views waste as a resource, offers a pathway towards sustainable development. CE aims to prolong the value of useful materials and optimizes supply chains.

Timber is a versatile construction material that can be reused, repaired, remanufactured, repurposed, recycled into various new products, or burnt for fuel when it comes to the end of life. However, despite the potential for extended life applications, the majority of demolition wood in New Zealand is sent to landfill [2]. In other developed countries, much is used in bioenergy generation [3]. While such energy recovery represents an alternative end-of-life pathway, it limits the opportunity to maximize resource efficiency and hinders progress to a CE within the timber sector.

Over the past two decades, research has focused on recycling waste wood for new construction applications,

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such as particleboards, cement-bonded boards, wood plastic composites, and concrete [4, 5]. In these practices, the waste wood is processed into wood fibre, shavings, or powder, which results in a reduction of the original material quality. The processes for maintaining solid wood's dimensional and economic qualities still need to be improved.

The concept of directly reusing solid waste wood with minor remanufacturing activities to generate high-value engineered wood products (EWPs) and examine the mechanical performance has received some attention more recently [6, 7]. To date, while such action is adopting CE principles, the quantification of the environmental benefits is less explored. This research involved conducting an initial life cycle assessment (LCA) to evaluate the input, output, energy use, and ancillary materials required in alternative options involving waste wood produced in the construction industry in New Zealand.

The objective of this study is to assess and compare the environmental impacts of managing waste wood across different avenues in New Zealand. A range of alternatives, such as remanufacturing the waste wood into glued-laminated timber (GLT), cross-laminated timber (CLT) and dowel-laminated timber (DLT) products, recycling for particleboards, and energy recovery, were examined.

2 – METHODOLOGY

2.1 LIFE CYCLE ASSESSMENT (LCA)

An attributional LCA approach was adopted in this study, considering a comparative environmental assessment of managing demolition waste wood regarding different scenarios in New Zealand. The research was undertaken in accordance with ISO 14040:2006 [8] and ISO 14044:2006 [9].

2.1.1 Scope definition

The function unit defined in this study was one tonne of demolition waste wood collected from a construction site in the Auckland hinterland. Six different scenarios, including the traditional end-of-life landfill disposal pathway, were considered. These were: (S1) GLT production (remanufacture); (S2) CLT production (remanufacture); (S3) DLT production (remanufacture); (S4) particleboard production (recycle); (S5) incineration with energy recovery; and (S6) landfill disposal. Fig. 1 illustrates the system boundaries for the six scenarios considered in this study, while Fig. 2 shows the locations of the proposed operations, which were based on the knowledge of existing operations.

As New Zealand's largest city, Auckland generates the highest volume of construction and demolition waste due to its intensive construction activities. In this study, the

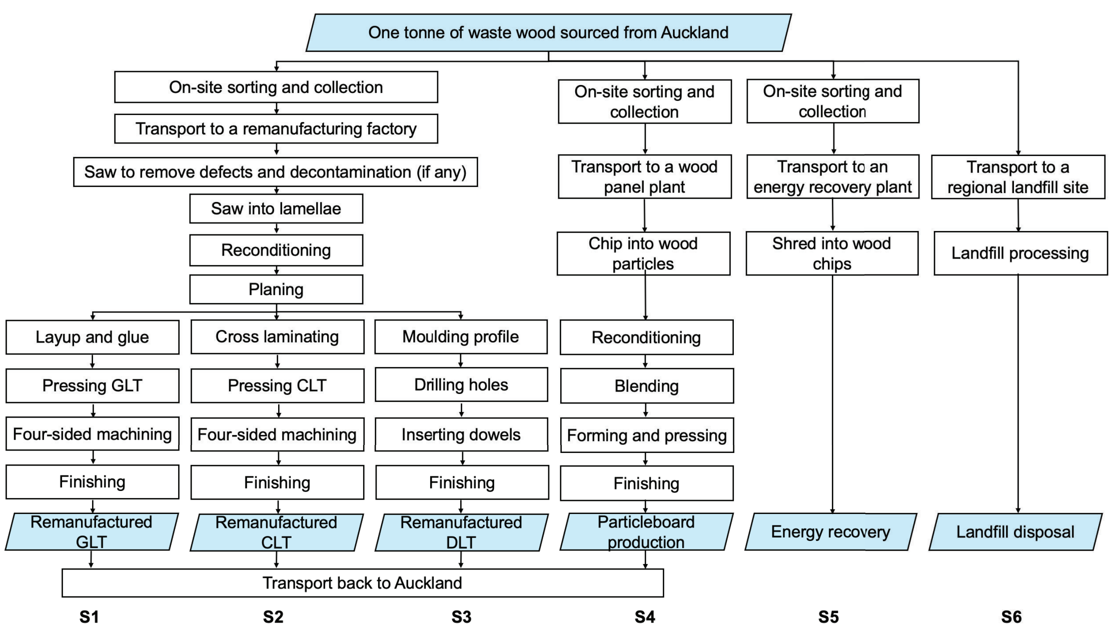

Figure 1. System boundaries of different scenarios considered in this study.

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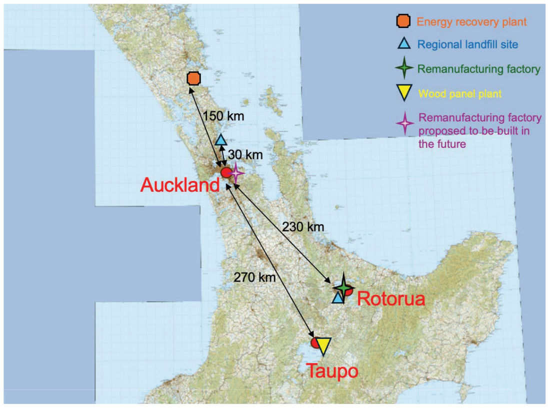

Figure 2. Locations of the proposed operations.

waste wood was proposed to be sourced from Auckland, where initial on-site sorting would be conducted to remove foreign objects, such as nails, before transportation to a remanufacturing, recycling, or energy recovery facility, depending on the scenario being assessed. The remanufactured and recycled timber products would be transported from processing facilities to building construction projects in Auckland city to support the city's increasing housing needs and densification, driven by projected population growth. Detailed descriptions of each scenario are provided in Sections 2.2.1 to 2.2.6.

The waste wood assessed in this study was Pinus radiata (Radiata Pine) grown in New Zealand, primarily in solid wood form. Chromated copper arsenate (CCA)-treated timber, which poses additional technical changes for remanufacture, was not considered in this study. Meanwhile, boron-treated timber, the predominant wood treatment in New Zealand, remains within the scope of this paper due to its comparatively lower environmental and health risks. Additionally, all remanufactured EWPs were intended to be used in mid-rise structural systems, whereas the demolition waste wood originates from residential structures.

2.1.2 Life cycle inventory (LCI) analysis

LCI analysis involves gathering necessary data and quantifying the inputs and outputs. In this study, the data included the raw material usage, for instance, the amounts of adhesives and auxiliary materials used in remanufacturing or recycling processes, the residue generation, energy consumption, and the resulting environmental impacts.

The different scenarios were modelled using SimaPro 9.5 software, with Ecoinvent v3.9.1 selected as the database

Table 1. LCI databases used in this study.

Materials/Processes	Source of Data	Geographical Scope
GLT	EPD [10]	New Zealand
Polyurethane adhesive (PUR)	Ecoinvent [11]	Global
Electricity	[12]	New Zealand
CLT	EPD [13]	New Zealand
DLT	EPD [14]	Canada
Hardwood dowel	Ecoinvent [15]	Global
Particleboard	EPD [16]	New Zealand
Melamine urea formaldehyde adhesive (MUF)	Ecoinvent [17]	Global
Paraffin wax	Ecoinvent [18]	Global
Energy recovery	EPD [10]	New Zealand
Landfill	[19]	New Zealand
Transport (freight)	Ecoinvent [20]	Global
On-site sorting	Ecoinvent [21]	Global

for this case study. Ecoinvent v3.9.1 was chosen because it is one of the most comprehensive and widely used LCI databases, providing high-quality, transparent, and internationally recognized data. To improve the accuracy of the results for the New Zealand context, the database was adjusted by incorporating data from environmental product declarations (EPDs) of locally produced timber products, as well as findings from recent studies and industry reports. Foreground data related to the remanufacturing process was obtained from consultation with local industry. However, in cases where specific information for certain materials or products was not available, international data sources were utilized. Table 1 summarises all the LCI databases used in this study.

2.1.3 Impact assessment and interpretation

The environmental impacts of each scenario were evaluated using the ReCiPe midpoint (H) and CML 2001 methods. Five environmental impact indicators were considered: global warming potential (GWP), acidification potential (AP), energy consumption, eutrophication potential (EP), photochemical ozone creation potential (POCP), and abiotic depletion potential - fossil fuels (ADPF). Finally, the environmental impacts for the six studied scenarios were compared, and the environmental implications based on the reference functional unit were discussed.

2.2 END-OF-LIFE SCENARIOS

It is proposed in this study that the demolition waste wood is collected from a construction site in Auckland. It is sorted into untreated and treated wood categories upon salvage. CCA-treated timber is identified and segregated at this step. The remaining wood undergoes manual processing, where workers remove nails, screws, and other metal fasteners. Magnets and metal detectors are used to ensure the wood is completely free of metal. The waste wood input is assumed to be relatively pure, meaning that only a small fraction (approximately 5% of the wood by mass) is discarded during the initial on-site sorting. The environmental impacts associated with the waste wood handling process, such as the energy use and emissions from manual sorting and equipment operation, were estimated based on Hemmati et al. [22].

2.2.1 Scenario 1 – GLT (remanufacture)

In Scenario 1, the demolition waste wood is transported to a remanufacturing facility in Rotorua, a central hub for New Zealand's wood processing industry, located 230 km away. At the facility, the material is remanufactured into GLT. Prior to remanufacturing, the waste wood is thoroughly sorted, graded, and decontaminated. The process begins with species and grade segregation, where workers identify the wood species and visually assess structural properties to ensure compatibility. Pieces that fail to meet the minimum strength criteria are set aside. The timber is subsequently sorted by dimensions. Larger or irregularly sized pieces are re-sawn or planed to achieve uniformity, while those that are too short for structural applications are rejected. Defect identification follows, where pieces are inspected for rot, splits, knots, or warping. Defective sections are either removed or trimmed.

Additionally, adhesives and coatings on the wood, for example, glue from old joints, paint, or sealants, are addressed by trimming or planing off the affected surfaces since clean wood surfaces are essential for achieving strong structural bonds during re-gluing. While metal contaminants such as nails, screws, and fasteners are removed in the earlier stage and recycled as scrap, the surrounding wood may suffer structural degradation. In particular, nail holes, split ends, and other localized damage often require cutting out affected sections to ensure the integrity of the final product.

Once the reclaimed wood is deemed suitable to be turned into GLT, it undergoes a remanufacturing process similar to that used for virgin wood GLT production. However, due to the generally shorter lengths of reclaimed timber, more machining and finger-jointing are required, leading to increased adhesive use. The reclaimed pieces are sawn and trimmed into standardized boards with a thickness of 45 mm and a width of 140 mm for GLT lamellae. The boards are then planed to achieve a smooth surface and uniform thickness, facilitating proper adhesive bonding. A structural PUR adhesive is applied to the mating faces of the lamellae at a controlled spread rate, typically a thin, even layer on one face of each pair, at 180 g/m². After that, the glued lamellae are assembled, pressed under high pressure to form beams, and cured. Finally, the GLT is machined on all four sides to achieve precise dimensions and subjected to quality checks, ensuring they meet structural performance standards equivalent to those of new timber despite being made from salvaged wood.

Not all input waste wood becomes part of the final GLT products, and there are inevitable losses during processing. In this context, yield refers to the proportion of the original wood volume successfully converted into finished GLT. In standard GLT manufacturing from fresh lumber, about 12 to 18% of the wood is lost as waste in the form of trimmings, sawdust, and offcuts [23]. When using reclaimed wood, the losses tend to be higher because of the additional removal of damaged sections and ineligible material. In this scenario, a processing loss of 35% is assumed, approximately double that of virgin wood, which reflects these added complexities. This results in an effective yield of 65%, which is also supported by the information obtained from the local factory. The remaining, considered unrecoverable processing residues, are sent to a landfill 4 km from the remanufacturing plant. In the following section of this study, the option of converting processing residues into energy was also explored.

The LCI data for remanufacturing one tonne of waste wood into GLT is shown in Table 2. The energy consumption data for the remanufacturing facility was obtained upon consultation with the New Zealand industry. The total electricity required for processing was determined by analysing the factory's monthly electricity consumption, correlating it with the total production output, and then allocating the energy demand per unit volume of remanufactured GLT. The estimated

Table 2. LCI for Scenario 1 - GLT.

	Unit	Amount
Input		
Waste wood	t	1
Electricity	kWh	324
PUR	kg	5.4
Transport (freight)	tkm	384.0
Output		
Remanufactured GLT	m^3	1.362
Unrecoverable processing residues	kg	331.7
Avoided production and process		
GLT production using virgin wood	m^3	1.362
Avoided transport (freight)	tkm	153.8

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electricity consumption for the remanufacturing process is 324 kWh per functional unit. The amount of PUR adhesive was calculated based on the adhesive spread rate per square meter of bonding surface and the total bonded area in the remanufactured GLT. The estimated adhesive usage is 5.4 kg per tonne of waste wood processed. The remanufacturing process yields approximately 1.362 m^3 of GLT, which is then transported back to Auckland for construction applications.

2.2.2 Scenario 2 – CLT (remanufacture)

In Scenario 2, the demolition waste wood is also transported to the remanufacturing factory in Rotorua, where it is processed into CLT. Like Scenario 1, the waste wood is thoroughly sorted, graded, and decontaminated before remanufacturing. Once the reclaimed wood is assessed as suitable for turning into CLT, it undergoes a process similar to that used for virgin wood CLT production. However, since reclaimed wood is shorter in length, it necessitates more machining and more adhesive in the finger-joints being used. The salvaged timber is sawn and trimmed into standardized boards. A high-performance structural adhesive PUR is applied to the mating surfaces, and the boards are cross stacked in perpendicular layers to form the CLT layup. The layup is then pressed under high pressure for full adhesive bonding and cured to achieve maximum strength. Once cured, the panel is machined on four sides and undergoes rigorous quality inspections to ensure it meets structural standards equivalent to new CLT products. Table 3 provides the LCI data for remanufacturing one tonne of waste wood into CLT.

Similar to what was described in Section 2.2.1, an effective yield of 65% of the original wood waste was also applied in Scenario 2. The remaining, which is deemed unsuitable for remanufacturing, is sent to the regional landfill site. The remanufacturing process is estimated to require 339 kWh of electricity and 6.7 kg of PUR adhesive per tonne of waste wood processed. The final yield of 1.396 m^3 of CLT is then transported back to Auckland, contributing to the midrise construction market as a sustainable alternative to virgin wood CLT.

2.2.3 Scenario 3 – DLT (remanufacture)

DLT is an EWP that assembles boards edge-to-edge using hardwood dowels instead of adhesives. This glue-free technique makes DLT particularly suitable for reclaimed timber, as it eliminates the risk of adhesive compatibility issues with unknown or previously treated wood surfaces. Currently, no commercial DLT manufacturing facilities exist in the country. In this scenario, the waste wood is hypothetically transported to a remanufacturing facility in Rotorua, where it is processed into DLT.

Like Scenario 1, the waste wood first undergoes sorting, grading, and decontamination to ensure only structurally viable material is used. Compared to CLT and GLT, DLT is more tolerant of surface imperfections since no adhesive bonding is involved. Once the reclaimed wood is assessed as suitable for DLT production, it follows a process similar to that used for virgin wood DLT. However, due to the shorter lengths of reclaimed wood, there may be an increased need for machining and the use of dowels to secure the product and preserve its structural integrity. The salvaged timber is first sawn and trimmed into standardized lamellae. The boards are then planed to achieve a smooth surface and consistent dimensions. Dried hardwood dowels are inserted into pre-drilled holes at regular intervals along the boards, mechanically locking the layers together. Finally, each panel undergoes rigorous quality inspections to meet structural performance standards. Table 4 provides the LCI data for remanufacturing one tonne of waste wood into DLT.

In Scenario 3, an effective yield of 65% of the original wood waste was assumed, consistent with previous scenarios. The remaining, which is deemed unsuitable for remanufacturing due to excessive damage, contamination,

Table 3. LCI for Scenario 2 - CLT.

	Unit	Amount
Input		
Waste wood	t	1
Electricity	kWh	339
PUR	kg	6.7
Transport (freight)	tkm	384.3
Output		
Remanufactured CLT	m^3	1.396
Unrecoverable processing residues	kg	331.7
Avoided production and process		
CLT production using virgin wood	m^3	1.396
Avoided transport (freight)	tkm	154.1

Table 4. LCI for Scenario 3 - DLT.

	Unit	Amount
Input		
Waste wood	t	1
Electricity	kWh	355
Hardwood dowel	kg	9.5
Transport (freight)	tkm	384.9
Output		
Remanufactured DLT	m^3	1.498
Unrecoverable processing residues	kg	331.7
Avoided production and process		
DLT production using virgin wood	m^3	1.498
Avoided transport (freight)	tkm	154.7

or size limitations, is sent to a regional landfill site. The remanufacturing process consumes 355 kWh of electricity per tonne of waste wood. This value was derived by normalizing the energy consumption from Scenario 1 and incorporating the additional energy required for drilling dowel holes. The estimated required hardwood dowel is 9.5 kg per tonne of waste wood, based on material composition data provided in the EPD [14]. The final output yield is 1.498 m³ of DLT, which is then transported back to Auckland to meet market demand.

2.2.4 Scenario 4 – Particleboard (recycle)

In Scenario 4, the wood waste is proposed to be transported to a wood panel manufacturing operation, which is located 270 km from Auckland. It is assumed that 100% of the material is sent for recycling. The waste wood is chipped into wood particles, dried to a moisture content of less than 10%, and then mixed with a water-resistant adhesive binder, melamine urea formaldehyde (MUF), in a mechanical blender. Paraffin wax is also added to provide water resistance and control the swelling caused by temporary wetting. The wood chips are then passed through the forming station, which arranges them by mass into a mattress on a steel belt. To create the particleboard, a layer of small particles is placed at the bottom of the mattress, followed by a larger core material, and finally, the fine top surface. The mattress is pressed in a hydraulic press at 200°C to cure the thermosetting resin. Once cured, the boards are cooled, stacked, sanded, and cut to size.

The LCI data for recycling the one tonne of waste wood for particleboard production is shown in Table 5. The process is estimated to require 804 kWh of electricity and 48.5 kg of resin and wax based on the material composition data provided in the EPD [16]. The final output yield is 1.623 m³ of particleboards, which are then transported back to Auckland for construction applications.

Table 7. LCI for Scenario 4 - Particleboard.

	Unit	Amount
Input		
Waste wood	t	1
Electricity	kWh	804
MUF	kg	45
Paraffin wax	kg	3.5
Transport (freight)	tkm	550.4
Output		
Recycled particleboards	m^3	1.623
Avoided production and process		
Particleboard production using virgin wood	m^3	1.623
Avoided transport (freight)	tkm	281.7

Table 5. Environmental impact results for one tonne of waste wood disposed of through energy recovery.

Environmental Impact Indicators	Unit	Energy Recovery
GWP	kg CO_2-eq	-1051
AP	kg SO_2-eq	1.14E-01
EP	kg PO_4^{3}-eq	-3.99E-02
POCP	kg C_2H_4-eq	1.92E-01
ADPF	MJ	-18,200

2.2.5 Scenario 5 – Energy recovery

In this scenario, wood waste is utilized for energy recovery. The wood is hypothetically transported to an existing energy recovery facility 150 km from Auckland. Before incineration, the wood is manually sorted to remove impurities and chipped. This process repurposes waste wood by converting it into thermal energy, which can then be used to generate electricity or heat, thereby partially offsetting the use of fossil fuels. The environmental impact results of energy recovery were derived from disposing of 1 m^3 of material at the end-of-life stage and then normalized to one tonne of demolition waste wood, as shown in Table 6. The relevant data was obtained from a local EPD, and the results were found to be consistent with the findings of Hossain and Poon [24].

2.2.6 Scenario 6 – Landfill disposal

In Scenario 6, the environmental impacts associated with the disposal of one functional unit of waste wood in landfills were assessed. Landfill disposal is the current most common method for managing wood waste in New Zealand. In this scenario, the waste wood is collected with other waste materials and transported to a regional landfill site located 30 km from Auckland for disposal purposes. The environmental impact results of landfill disposal, presented in Table 7, were derived from disposing of 1 m^3 of material and then normalized to one tonne of demolition waste wood. The relevant data was sourced from a local report, and the results were found to be aligned with those of Hossain and Poon [24]. The emissions from landfill disposal are compared with the alternative options with regard to environmental impact results.

Table 6. Environmental impact results for one tonne of waste wood disposed of through landfill.

Environmental Impact Indicators	Unit	Landfill
GWP	kg CO_2-eq	103
AP	kg SO_2-eq	2.65E-01
EP	kg PO_4^{3}-eq	3.58E-02
POCP	kg C_2H_4-eq	2.24E-02
ADPF	MJ	1,343

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3 – RESULTS AND DISCUSSION

Fig. 3 shows the comparative emissions of the six studied scenarios regarding GWP, AP, EP, POCP, and ADPF. GWP assesses the climate change impacts, AP measures emissions leading to acid rain, EP indicates nutrient enrichment effects on water bodies, POCP measures the potential of emissions to create ground-level ozone, and ADPF indicates the depletion of non-renewable energy resources.

The current practice of landfill disposal (S6) demonstrated the concerning positive values across all assessed environmental impact indicators. In contrast, the proposed remanufacturing scenarios (S1, S2, and S3) exhibited net negative emissions values due to the benefits of avoiding new productions. Among those, remanufacturing the waste wood to produce DLT (S3), an adhesive-free EWP, achieved the most significant environmental benefits, with GWP (excluding biogenic carbon) at 44.25 kg CO_2-eq/tonne, AP at -0.46 kg SO_2-eq/tonne, EP at -0.07 kg PO_4^{3}-eq/tonne, POCP at -0.39 kg C_2H_4-eq/tonne, and ADPF at -1,232 MJ/tonne.

Scenario S4, which involved recycling waste wood into particleboards, resulted in higher emissions because of the substantial electricity and auxiliary materials consumed during the crushing, blending, and forming processes. Consequently, S4 showed lower environmental benefits in GWP, POCP, and ADPF, though still better than landfill disposal (S6), and exhibited net-positive impacts for AP and EP.

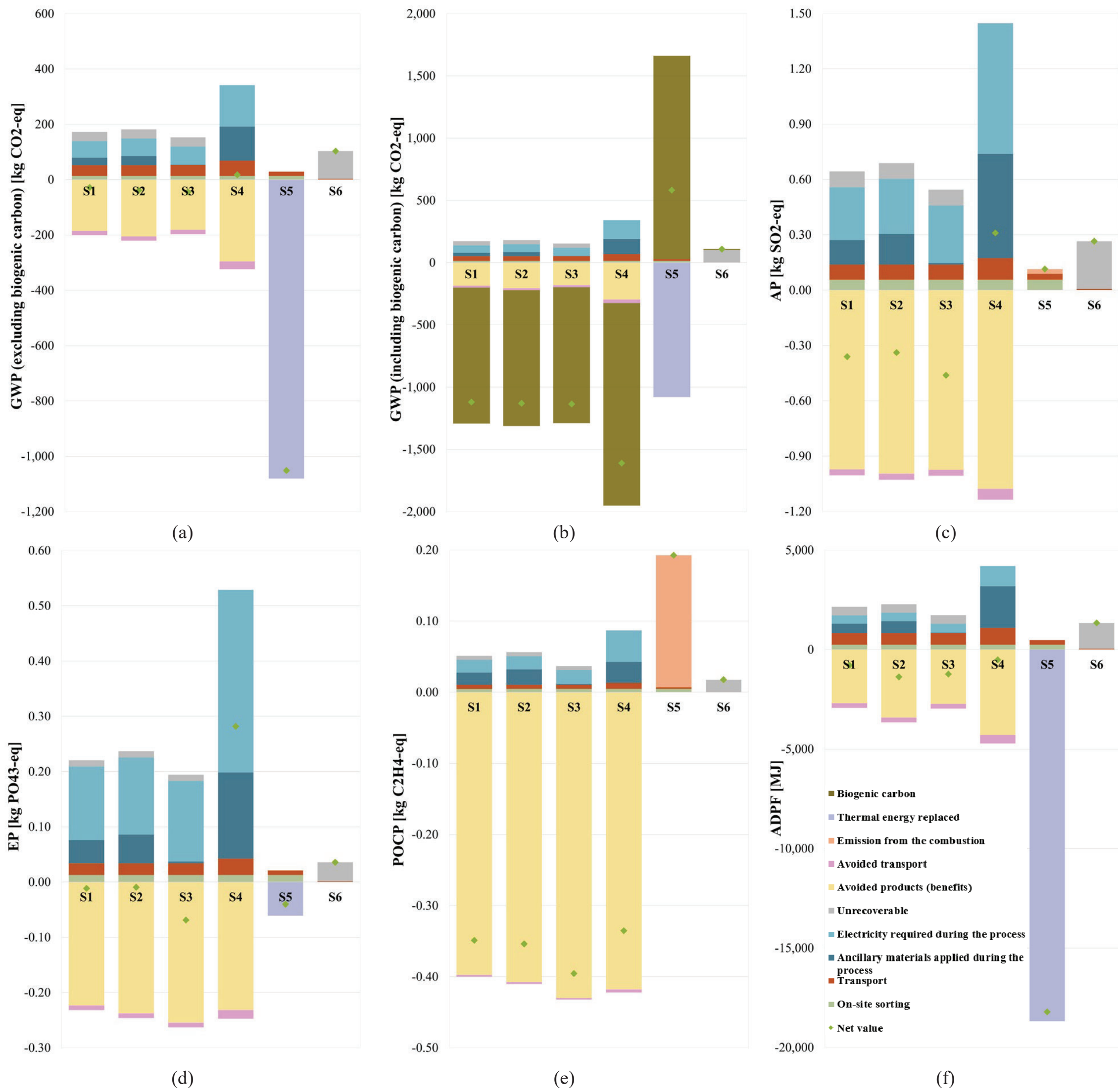

Figure 3. Comparison of the emissions of six end-of-life scenarios: (a) GWP (excluding biogenic carbon); (b) GWP (including biogenic carbon); (c) AP; (d) EP;(e) POCP; and (f) ADPF.

The energy recovery scenario (S5) reduced more than 1,000 kg of CO2-eq in GWP (excluding biogenic carbon) and over 18,000 MJ in ADPF by replacing thermal energy from natural gas. However, the combustion of waste wood releases air pollutants, which can lead to the formation of smog (POCP). Furthermore, when biogenic carbon was included in the assessment (Fig. 3b), S5 exhibited the highest net GWP emissions. The combustion of waste wood released stored biogenic carbon back into the atmosphere, negating much of the climate benefit observed in Fig. 3a.

An additional analysis was conducted to assess the environmental benefits of converting waste residue from the remanufacturing process into energy rather than disposing of it in landfills. The results are shown in Fig. 4. The differences in GWP and ADPF savings by converting waste residue from the remanufacturing process into energy were estimated to be around 390 kg CO_2-eq and 6,600 MJ, respectively. These findings suggest that utilising waste residue as a bioenergy source can serve as a viable alternative to landfill disposal, contributing to fossil fuel displacement and emissions reduction.

Conducting a comprehensive LCA involves integrating various datasets for different processes and assumptions, making the results inherently subject to uncertainties. A sensitivity analysis was undertaken to evaluate these uncertainties, focusing on transport distance, electricity

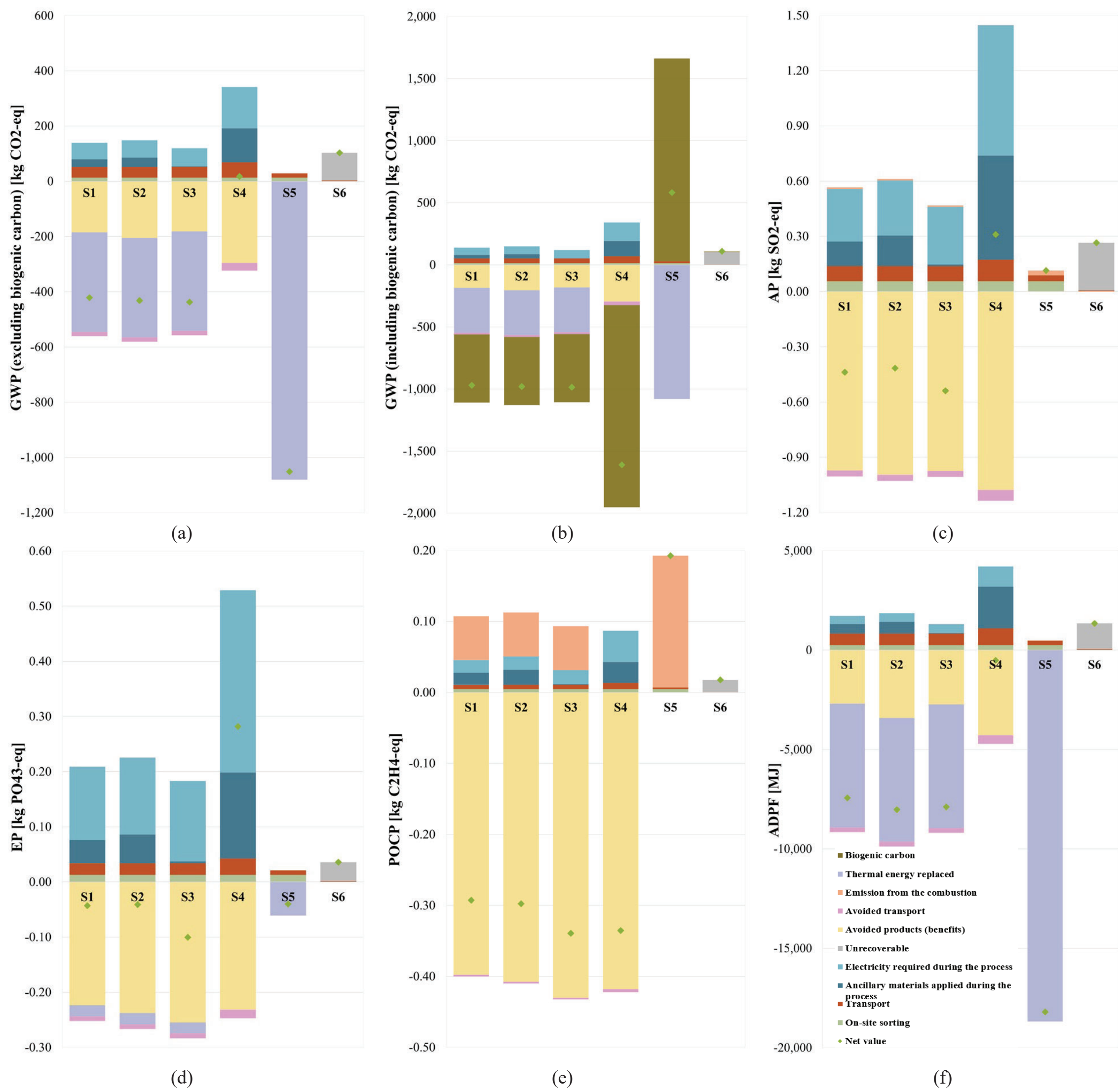

Figure 4. The emissions of the six end-of-life scenarios when converting the waste residue from remanufacturing process into energy: (a) GWP (excluding biogenic carbon); (b) GWP (including biogenic carbon); (c) AP; (d) EP;(e) POCP; and (f) ADPF.

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Table 8. Sensitivity analysis for varying transport distance, electricity consumption, and effective yield in S1.

	Transport Distance		Electricity		Effective Yield	
	-20%	**+20%**	**-20%**	**+20%**	**-30%**	**+30%**
GWP	-16%	+16%	-43%	+43%	+151%	-151%
AP	-3%	+3%	-16%	+16%	+56%	-56%
EP	-22%	+22%	-235%	+235%	+154%	-154%
POCP	-0.2%	+0.2%	-1%	+1%	+32%	-32%
ADPF	-9%	+9%	-10%	+10%	+89%	-89%

consumption, and the effective yield. Specifically, the study considered a ± 20% variation in transport distance and electricity consumption and a ± 30% variation in the effective yield, as the output yield highly depends on the quality and condition of the waste wood. The results were then compared with the base scenario. Table 8 shows the resulting GWP, AP, EP, POCP, and ADPF variations in S1 (GLT remanufacture). Among the parameters analysed, the effective yield had the strongest influence on environmental outcomes, highlighting the importance of recovery efficiency in timber remanufacturing scenarios. EP was found to be particularly sensitive to changes in electricity consumption.

However, the ± 20% variation in transport distance may underestimate the actual variation, especially considering the dispersed locations of demolition sites and reprocessing facilities across New Zealand. Fig. 5 compares the environmental impacts of producing GLT from waste wood in two different locations: Rotorua and Auckland. Across all impact categories, emissions were significantly lower when remanufacturing occurred in Auckland. The most noticeable difference was observed in EP, with a reduction exceeding 250%. Similar findings were also obtained for S2 and S3. The results demonstrate that a more localized processing approach enhances sustainability by minimizing fossil fuel consumption and transportation-related emissions.

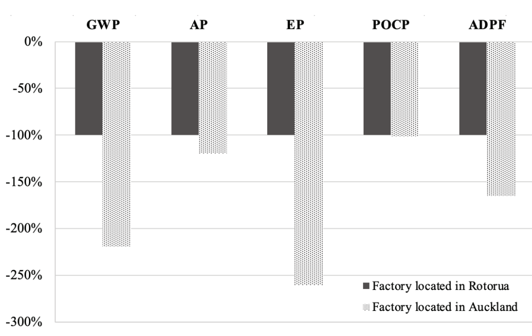

Figure 5. Sensitivity analysis for varying the location of remanufacturing factory in S1.

4 – CONCLUSION

The findings of the LCA highlight the environmental benefits of remanufacturing demolition waste wood to create value-added EWPs. A paradigm shift in the construction industry towards embracing CE strategies would be recommended by prioritizing remanufacturing within the existing waste wood management systems. However, it still faces several challenges. Variations in waste wood quality, contamination from nails, screws, adhesives, and paints, as well as inconsistencies in timber treatment, introduce complexities in processing and ensuring product performance. Some timber treatment chemicals, particularly those historically used for preservation, may release hazardous gases during reprocessing and pose environmental and health concerns, necessitating robust sorting, testing, and emission control strategies, including gas capture or filtration systems. Furthermore, the economic feasibility of remanufacturing remains a key consideration. The costs associated with collection, sorting, reprocessing, and transportation can impact the competitiveness of reclaimed wood compared to virgin timber.

While New Zealand's landfill levy has increased in recent years, it remains modest compared to international benchmarks. Nonetheless, as the global climate crisis intensifies, it is likely that both national and regional governments will implement more stringent regulatory frameworks, such as significantly higher landfill levies and carbon pricing. These measures would exert greater pressure on the construction sector to adopt CE strategies. In parallel, targeted policy instruments, including tax incentives and grants for circular activities, could help offset initial capital costs and improve the commercial attractiveness of remanufacturing operations.

In addition to economic factors, technical challenges exist. The structural characteristics of aged wood in New Zealand need to be investigated, and the resulting mechanical properties of EWPs produced from remanufacturing operations must be thoroughly assessed to meet performance and safety standards. Research into cost-effective reprocessing techniques, standardized sorting and grading systems, and market integration strategies is essential to scale the use of remanufactured timber products in New Zealand's construction sector.

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