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Carbon Footprint of New Zealand Laminated Veneer Lumber

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Use of this Study

This study provides carbon footprint data for laminated veneer lumber produced in New Zealand. Any results used in the public domain must include a link to this report in full.

Acknowledgements

The author would like to thank the following people for data provision and explanation: Philip Wilson and James Cameron (Nelson Pine Industries), Bill Hayward and Kevin Dumbleton (Carter Holt Harvey), and Paul Jordan and Dave Kirkland (Juken New Zealand). In addition, for support in other areas: John Andrews, Stephen John, Jeff Seadon and James McDevitt.

Glossary

CHH	=	Carter Holt Harvey Woodproducts Ltd
CO_2-e	=	Carbon dioxide equivalents, a unit allowing measurement of the contribution of each different greenhouse gas to a global warming potential figure by converting the mass of one gas into the equivalent mass of carbon dioxide.
EF	=	Emission Factor, how much of a given emission is associated with a standard unit of a process
LVL	=	Laminated Veneer Lumber, an engineered wood product that consists of thin layers of wood (veneer) glued and pressed together, to form a strong and uniform building material.
GWP	=	Global Warming Potential, a measure of how much a given mass of greenhouse gas is estimated to contribute to global warming relative to carbon dioxide.
GHG	=	Greenhouse Gas, a gas that contributes to global warming.
JNL	=	Juken New Zealand Ltd
LCA	=	Life cycle assessment, a method of evaluating environmental impacts of products and services
NPI	=	Nelson Pine Industries Ltd
System Expansion	=	Expansion of system boundary to incorporate changes in other systems (for example an increase in wood waste for energy may result in a decrease in natural gas consumption)

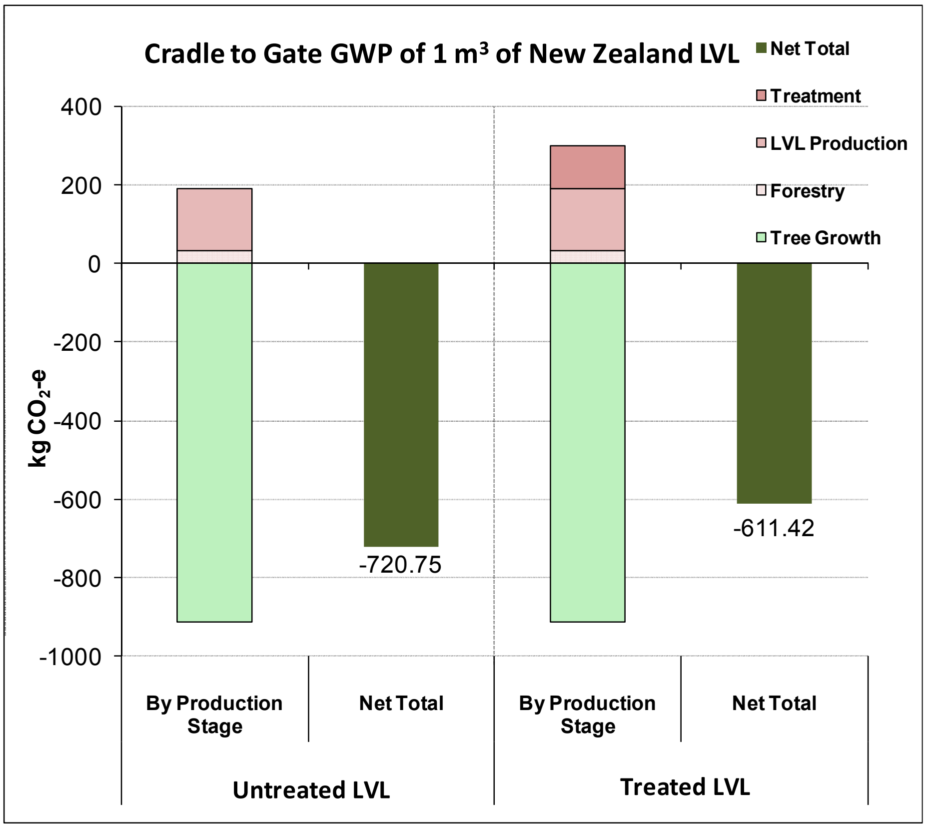
Summary

Laminated veneer lumber (LVL) is an engineered wood product that consists of thin layers of wood (veneer) glued and pressed together, to form a strong and uniform building material. In New Zealand, the main manufacturers of LVL are Nelson Pine Industries, Carter Holt Harvey and Juken New Zealand. Primary data was collected from these manufacturers, as well as secondary data from literature, and this data was used to evaluate the carbon footprint, described in kilograms of CO_2-equivalents (kg CO_2-e). The data collection process and templates, as well as calculation methods, were based on the 'Guidelines for GHG Footprinting for Engineered Wood Products', developed by Scion in 2009 (Sandilands and Nebel, 2009).

This study found that the dominant 'cradle-to-gate' global warming potential emissions from New Zealand-made LVL are from the LVL production process (159 kg CO_2-e). Within the LVL production process, production of the resin and purchased electricity contribute approximately 40% and 39% to the GWP impacts, respectively. Forestry emissions came to 32 kg CO_2-e per m^3 LVL, and treatment with preservatives resulted in GWP emissions of 109 kg CO_2-e per m^3. Due to the large uptake of carbon (as CO_2) during tree growth, the finished product is effectively a carbon storage medium. The LVL in this study was calculated to contain 249 kg of biogenic carbon per cubic metre, which is the equivalent of 912 kg of CO_2. Net cradle to gate carbon blances for untreated and treated New Zealand LVL are −721 and −611 kg CO_2-e per m^3 LVL respectively, shown with other stages in the table below.

Cradle to gate GWP Results for 1m^3 of LVL produced in NZ

Process	kg CO_2-e / m^3
Tree Growth	-911.75
Forestry	31.99
LVL Production	159.01
Treatment	109.33
Untreated LVL (Cradle to gate)	**-720.75**
Treated LVL (Cradle to gate)	**-611.42**



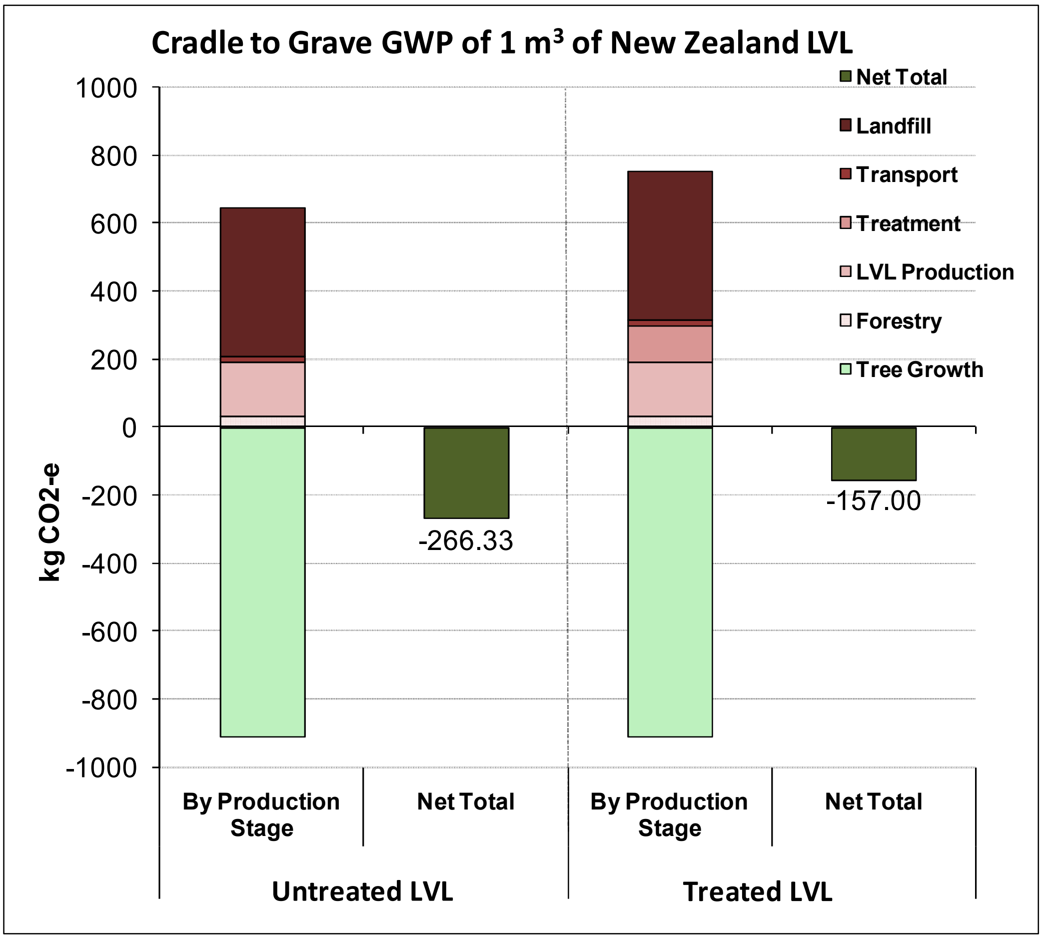
GWP Results for 1 m^3 of LVL produced in NZ (Cradle to gate scenario)

The cradle to grave carbon footprint for New Zealand-produced untreated LVL, transported within, used and disposed of within NZ in a current average landfill, has total global warming potential emissions of 645 kg CO_2-e and total uptake of 912 kg CO_2-e, resulting in net storage of 266 kg CO_2-e. This figure is aided by long-term carbon storage in landfill, plus capture and flaring of methane.

Multiple other scenarios were investigated in this project, including treatment of LVL for external use, transport to international destinations, and different end of life disposal options. The net total GWP storage for H3-treated LVL produced, used and disposed of in NZ to 157 kg CO_2-e per m^3. Transportation emissions from shipping LVL to international destinations ranged from 22 to 114 kg CO_2-e per m^3; these figures represent Australia (the closest international destination) and the Middle East (the farthest international destination) respectively.

Finally, end of life processes can change the life cycle GWP profile of LVL significantly. This study found than depending on wood decomposition rates, landfill gas capture rates in landfills and whether the gas is flared or used for energy generation can significantly impact the final results. An unmanaged landfill with no landfill gas capture results in carbon emissions from landfill of 762 kg CO_2-e per m^3 of LVL, while a NZ landfill in 2050 is estimated to result in total emissions of 403 kg CO_2-e per m^3 of LVL. A sensitivity analysis showed that the estimated decomposition rate of LVL has a large impact on final results. Is is noted that decomposition rates in this project have been estimated using data for timber, and addition of resin and treatment chemicals is likely to slow decomposition from these estimations. Also investigated was the possibility of incineration of the LVL at the end of its life. This scenario resulted in release of all carbon within the product, removing any storage benefit, but can offset 328 kg CO_2-e per m^3 of LVL (based on New Zealand heat and electricity profiles).

For use in further projects, it is recommended that the base (cradle to gate figure) of -721 kg CO_2-e per m^3 of LVL be used, followed by addition of treatment, transport and disposal emission values that represent the specific situation. This study provides estimates for all figures, though more detailed data may be available in the future - especially for international disposal procedures.



GWP Results for 1 m^3 of LVL produced in NZ (Cradle to grave scenario)

Table of Contents

Introduction

General Introduction

Climate change is an important environmental issue that affects the entire globe. With increasing awareness of the impacts to and causes of climate change, demand for lower-impact products and services also increases. A starting point for assessing a product's impact to climate change is completion of a 'carbon footprint'. This type of study evaluates the potential impacts to climate change that a product or service has, based on its output of greenhouse gases (GHGs). Results of a carbon footprinting study can be used for hot-spot analysis within a production chain to find areas for improvement, as well as for comparisons with similar products.

This project involved evaluating a carbon footprint for laminated veneer lumber (LVL). LVL is an engineered wood product that consists of thin layers of wood (veneer) glued and pressed together, to form a strong and uniform building material.

Background

In early 2009, Scion completed a streamlined life cycle assessment (LCA) for Carter Holt Harvey (CHH), which looked at energy consumption and GHG emissions from production of LVL. This study highlighted a number of data gaps, and the need for further work to ensure an accurate figure.

After the work was completed, contact was made with Nelson Pine Industries (NPI), who had undertaken work examining the GHG emissions from the production of their LVL. The two different studies were not conducted as a collaborative effort; thus the differing methods resulted in inconsistent emission coefficients for LVL production in New Zealand (NZ). It became apparent that involvement of the third main LVL manufacturer in NZ – Juken NZ Limited (JNL) – could result in a consistent carbon footprint for LVL produced in NZ.

It was proposed that the methodology of GHG emissions calculations would be standardised, and data from CHH, NPI and JNL be aggregated to evaluate a fair and consistent figure for GHG emissions from LVL produced in NZ.

Guidelines for Greenhouse Gas Footprinting

The data recording and calculations for this project have followed the 'Guidelines for GHG Footprinting for Engineered Wood Products' (Sandilands and Nebel, 2009). These guidelines provide a format for data recording, and make recommendations for units, time scales and other parameters. Each process is assigned an 'emission factor', to assign a certain quantity of GHG emissions to a standard unit. Exact emission factors will be described in Section 5, Data from Literature Sources.

The guidelines state that they:

"… are based on a specific GHG Footprinting methodology for the forestry sector (including wood-based products) (Nebel and Drysdale, 2009) that has been developed as part of the MAF project "New Zealand GHG Footprinting Strategy for the Land-based Primary Sectors" as well as the international (ISO) standards for Life Cycle Assessment; ISO 14040, and ISO 14044, and on the PAS 2050:2008 specification for the life cycle assessment of GHG emissions.

These guidelines will take the user step-by-step through these four phases of a GHG footprinting study, as set out in the ISO standards for Life Cycle Assessment…"

Phases of a Life Cycle Assessment Study

The project follows the four phases of a Life Cycle Assessment, as defined in ISO 14040 (ISO, 2006).These stages are:

1) Goal and scope definition

2) Life Cycle Inventory (LCI)

3) Life Cycle Impact Assessment (LCIA)
4) Life Cycle Interpretation

The goal and scope definition stage involves defining all aspects of the goal of the project, the scope (including cut-off rules and allocation procedures), the functional unit, and anything else that needs to be defined before data collection begins. Once these preliminary decisions have been made, data collection (creation of the life cycle inventory) can begin. Once all data relevant to the life cycle of the product in question is collected, the inventory is normalised to the functional unit, and the LCIA stage can begin. In a carbon footprint, the LCIA involves one impact category only, which is global warming potential (GWP). After the impacts have been quantified, the final stage of life cycle interpretation can be applied, where the results are broken down by stage and an in-depth analysis is performed. This is shown graphically below in Figure 1.

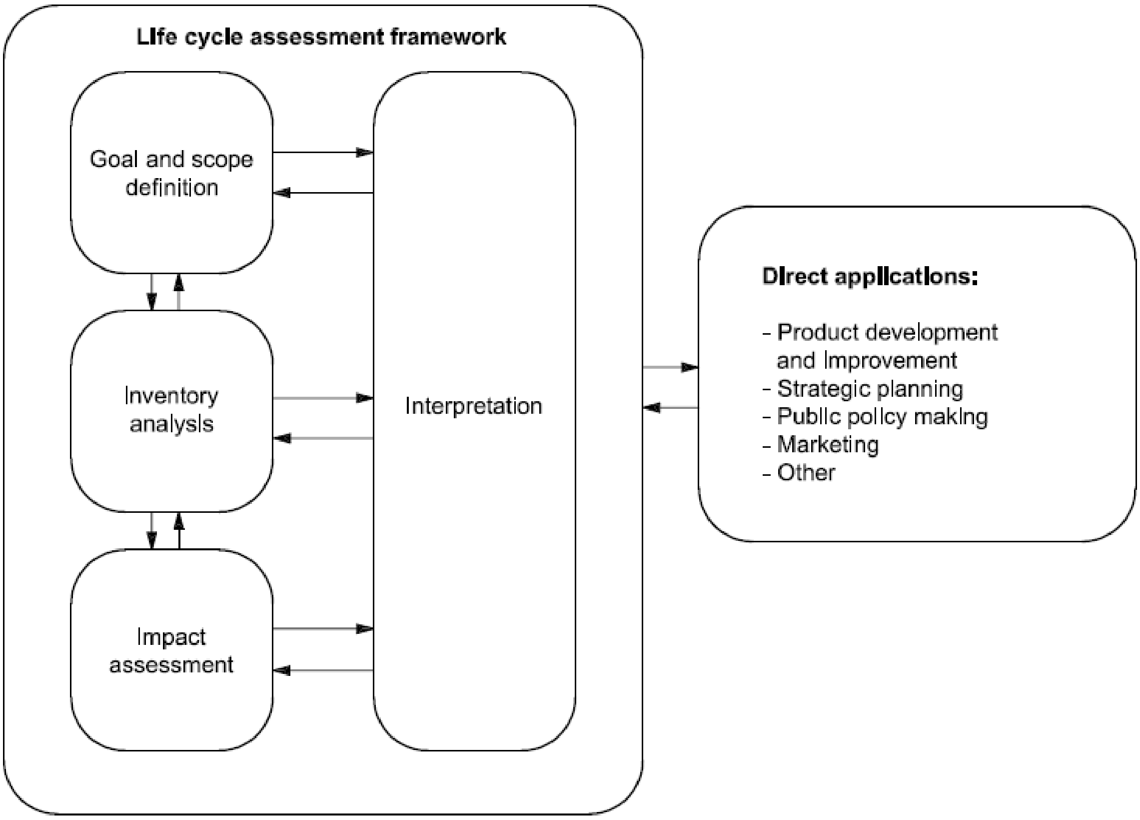


Figure 1: The phases of an LCA as defined by ISO 14040 (ISO, 2006)

Goal & Scope Definition

Goal

The reason for undertaking this work is to evaluate a GHG figure for LVL that is based on science and actual NZ data. The figure will stand up to criticism, and as accurately as possible represent what really happens in the life cycle of NZ LVL.

Therefore the goal of this project has been defined as:

To provide a robust and accurate Greenhouse Gas (GHG) emissions figure for laminated veneer lumber produced in New Zealand, to be published and made available for use in further studies.

Scope/System Boundary

The data recording and calculations for this project have followed the 'Guidelines for GHG Footprinting' (Sandilands and Nebel, 2009). The system begins at the forestry stage (including growing of the trees), then includes transport of logs to the LVL plant, all processes within the LVL production system, packaging, transportation to end users, 50 years in use (IPCC, 2006) and finally the end-of-life scenario that is deemed to be appropriate for the destination country – either landfilling or incineration. Treatment has been included as a separate process, as LVL can be produced as treated or untreated LVL. Emissions from retail activities have been excluded as they are not expected to have an impact on final results. Emissions from land use change have also been excluded due to high variability in data and the lack of a consensus on how land use impacts can be incorporated in LCA (Heinrich, 2007).

The reference year chosen for the processes was the 2007-08 financial year. Results of this study could vary from year to year, which is why the most recent 'normal' year has been chosen, prior to the economic downturn. The total time period investigated in this study is 100 years, in line with the Scion guidelines and PAS 2050 (BSi, 2008, Sandilands and Nebel, 2009). This 100 year time period begins with 30 years of tree growth, followed by production and 50 years of use, and finally disposal, which is made up of 20 years in landfill. extension of this decomposition time period has been investigated in a sensitivity analysis, for the sake of transparency.

The audience of this work is likely to be designers, architects and researchers who can use the emission factor in their work. This work has been critically reviewed in accordance with ISO 14044 by John Andrews at Landcare Research.

A quantitative measure of uncertainty has not been included in this study because the combination of different uncertainty formalisms is often mathematically impossible and, even in cases when feasible, not theoretically sound; consequently this is an active area of research and development of the LCA method (Reap et al., 2008). Data validation has been included, and this can be seen in

Appendix I: Data Validation.

Functional Unit

The functional unit in this project was 1 m^3 of LVL produced in NZ. This unit was chosen after discussions with the manufacturers involved in the project. Cubic metres were the most common measure of quantities of LVL produced and distributed.

Allocation

The allocation method chosen in this project reflects the method defined in the guidelines. This recommends that where allocation cannot be avoided, it shall be on the basis of mass {Jungmeier, 2002 #68}. This means that where any process in the LVL production chain produces two (or more) co-products (for example bark and de-barked logs), the environmental impacts of those logs are split following the total mass of each output. Burdens from disposal of waste products are included as burdens on the main product.

Impact Categories

It is possible to include a range of impact categories in any LCA. Depending on the impact assessment method, categories such as acidification, ozone layer depletion, human toxicity and freshwater aquatic ecotoxicity can be included. In this project, the goal was to evaluate a 'carbon footprint, which is a total GHG emissions figure. For this reason, only one impact category was chosen: global warming potential. The choice of a single impact category is not recommended by ISO 14040 for a full LCA study, and this is the reason for describing this study as a 'carbon footprint' rather than an LCA.

Global warming potential 100 Years (GWP_{100}) is a measure of how much a given mass of greenhouse gas is estimated to contribute to global warming. It is a relative scale which compares the gas in question to that of the same mass of carbon dioxide. A GWP is calculated over a specific time interval and the value of this must be stated whenever a GWP is quoted or else the value is meaningless. Carbon dioxide has a GWP of exactly 1 (since it is the baseline unit to which all other GHGs are compared). Another important gas is methane, with a GWP of 25 and on the extreme end of the scale are gases such as SF_6 (sulfur hexafluoride) with a GWP of 22,800 (this gas has been used as an insulating gas in double glazed windows in Europe).

Note that a substance's GWP depends on the time horizon over which the potential is calculated. A gas which is quickly removed from the atmosphere may initially have a large effect but for longer time periods as it has been removed becomes less important. Thus methane has a potential of 25 over 100 years but 72 over 20 years; conversely sulfur hexafluoride has a GWP of 22,800 over 100 years but 16,300 over 20 years. (IPCC, 2007) The GWP value depends on how the gas concentration decays over time in the atmosphere. This is often not precisely known and hence the values should not be considered exact. For this reason when quoting a GWP it is important to give a reference to the calculation. In this report, GWP values from the IPCC Fourth Assessment Report have been used wherever possible (IPCC, 2007).

LVL Production Process

Flow Diagram and Process Description

Figure 2 shows a basic flow chart of the LVL production process. Individual production lines may vary from this diagram, yet the basic process remains the same.

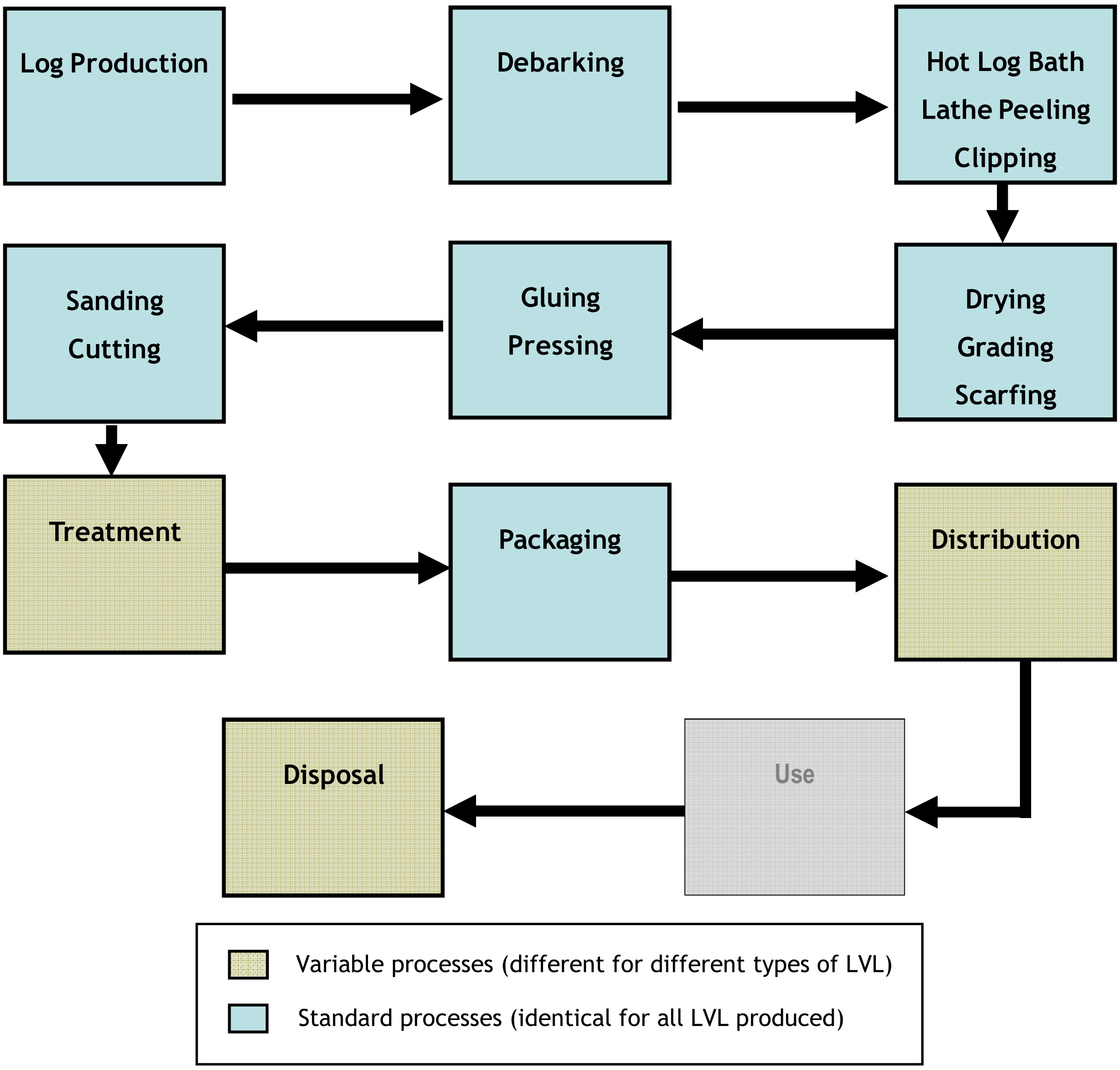


Figure 2: Basic flow chart of the LVL production process

The following is a very general description of the LVL production process, based on discussions with the LVL manufacturers. It is intentionally general, as to not divulge manufacturer-specific processes.

Log Production: Log production is out of the system boundary of this project – the LVL production process begins as logs are delivered to the log yard.

Debarking: All bark is removed from the logs.

Hot Log Bath: The logs are conditioned in hot water. When logs have reached the required core temperature they move on to the peeling process.

Lathe Peeling: The logs are peeled to produce the (wet) veneer.

Clipped to Size: The veneer is clipped into sheets of required size.

Veneer Drying: The veneer sheets are put through a drying process to remove most moisture.

Structurally & Visually Graded: The sheets are graded dependent on quality

Scarfing: The veneer edge is scarfed (cut to allow a join) for a uniform thickness at the joints between veneer sheets.

Glue Applied: At this stage any insecticides or other additives required can be added. The veneers are then coated with phenol formaldehyde adhesive.

Press: Once the veneers have had glue applied the veneers are passed through a press & curing process. This ensures complete resin cure and an LVL billet is formed.

Cut to Width: The billets are ripped to widths required.

Treatment: A certain proportion of the LVL is treated to H3 standard, for outdoor use.

Packed and Wrapped: LVL is packed as per shipping requirements, usually using steel strapping and plastic wrap.

Distribution: LVL is distributed to its destination.

Disposal: The LVL is disposed in landfills (standard practice in NZ and most overseas destinations) or incinerated (standard practice in some overseas destinations). Because of the uncertainties surrounding waste disposal practices in the future, exact methods of disposal at the end of the lifetime of the LVL products cannot be known. For this reason, a range of options have been explored in more detail in the 'End of Life' chapter.

Primary Data

General

The Microsoft Excel sheets which accompany the Guidelines for GHG Footprinting for Engineered Wood Products were customised by Scion and sent out to manufacturers to populate. Once populated, the sheets were sent to Scion for aggregation.

Inputs and Outputs

The total aggregated in- and output materials, energy and emissions for LVL production at the NZ manufacturing sites are shown in Table 1. The table includes the in- and outputs, followed by the amount and units per cubic metre of LVL produced, an emission factor for the in-/output with units, the total GHG emissions for that in/output and a comment/reference.

Table 1: Inputs and Outputs of the LVL Production Process

Internal inputs and outputs

Input/output	Name of Input/Output	Information	Quantity/ m^3 LVL	Unit
Internal Inputs	TOTAL heat/steam produced on-site	Quantity	**3.03**	MWh
Internal Outputs	Total green wood produced for use as boiler fuel	Quantity	**0.21**	t
	Total dry wood/shavings/saw dust produced for use as boiler fuel	Quantity	**0.18**	t

External Inputs and Outputs

Input/Output	Name of Input/Output	Information	Quantity/ m^3 LVL	Unit
External Inputs	Total logs in	Quantity	**1.46**	m^3
		Transportation (truck)	**248.60**	t km
	Total boiler fuel purchased	Quantity	**0.08**	t
		Transportation (truck)	**1.06E-05**	t km
	Total diesel use - forklifts	Quantity	**2.33**	l
	Total diesel use - trucks	Quantity	**1.18**	l
	Total other fuel - LPG	Quantity	**0.02**	l
	Total electricity used	Quantity	**0.26**	MWh
	Total natural gas	Quantity	**0.01**	GJ
	External veneer purchased in	Quantity	**0.13**	m^3
		Transportation (truck)	**30.07**	t km
	Water	Quantity	**0.84**	m^3
	Caustic	Quantity	**0.19**	l
		Transportation (truck)	**0.04**	t km
	Antifoam	Quantity	**7.76E-06**	l
	Boiler Chemicals	Quantity	**1.06E-04**	l
	Salt	Quantity	**2.00E-04**	t
		Transportation (truck)	**0.03**	t km

External Inputs	Lubricants	Quantity	**0.02**	l
	Composer Glue	Quantity	**0.15**	kg
		Transportation (truck)	**0.03**	t km
	Composer String	Quantity	**0.45**	kg
		Transportation (truck)	**0.09**	t km
	Phenol Formaldehyde Resin Solids	Quantity	**0.024**	t
		Transportation (truck)	**6.675**	t km
	Fillers (bark/walnut/wheat flour)	Quantity	**0.006**	t
		Transportation (truck)	**1.621**	t km
	Modal (glue extender)	Quantity	**0.001**	t
	Caustic (NaOH)	Quantity	**0.001**	t
	Insecticide	Quantity	**0.042**	l
		Transportation (truck)	**0.017**	tkm
		Transportation (ship)	**0.13**	tkm
	Paint	Quantity	**1.16**	l
		Transportation (truck)	**1.03**	t km
	Ink	Quantity	**0.02**	l
		Transportation (truck)	**0.01**	t km
	Steel Strapping	Quantity	**3.74E-04**	t
		Transportation (truck)	**0.13**	t km
	LDPE Wrap	Quantity	**5.69E-04**	t
		Transportation (truck)	**0.19**	t km
	Cardboard	Quantity	**1.14E-05**	t
		Transportation (truck)	**7.57E-04**	t km
External Outputs	Total green chip sold	Quantity	**0.24**	t
	Any waste wood to landfill	Quantity	**0.01**	t
		Transportation (truck)	**0.39**	t km
	Other waste total	Quantity	**0.00**	t
		Transportation (truck)	**0.05**	t km
	Boiler Ash waste total	Quantity	**0.03**	t
		Transportation (truck)	**0.49**	t km
	Waste Water	Quantity	**0.08**	m^3

Inputs and Outputs for Treatment

Chemical treatment for LVL that is to be used in outdoor situations has been included in this project as a separate process, as not all LVL is treated in this way. The inputs and outputs for this process were different for each manufacturer, and therefore to ensure protection of confidential data, the chemicals have not been specified. It can be assumed that this process is treating the timber to an H3 standard, which is described as "Exposed to the weather, above ground or protected from the weather but with a risk of moisture entrapment" (NZS, 2003). The inputs and outputs of this process are shown below in Table 2.

Table 2: Inputs and outputs of the LVL treatment process

Internal Inputs and Outputs				
Input/output	**Name of Input/Output**	**Information**	**Quantity/ m^3 LVL**	**Unit**
Internal Inputs	LVL to be Treated	Quantity	**1**	m^3
Internal Outputs	Treated LVL ready for packaging/shipping	Quantity	**1**	m^3
External Inputs and Outputs				
Input/Output	**Name of Input/Output**	**Information**	**Quantity/ m^3 LVL**	**Unit**
External inputs	Diesel (forklifts)	Quantity	**0.74**	l
	Electricity	Quantity	**0.11**	MWh
	Treatment Chemicals	Quantity	**45.39**	l
		Transportation (truck)	**9.08**	t km
	Water	Quantity	**0.18**	l

Inputs and Outputs for Distribution

Finished LVL products are distributed around the world. The outputs for distribution are grouped into the main destinations for the final LVL products: NZ, Australia, Japan, USA, Middle East and ‘other’. ‘Other’ comprises a mixture of international destinations. Table 3 shows how much of the average cubic metre of LVL is sent to each destination.

Table 3: Input and output table for LVL distribution

Internal Inputs and Outputs				
Input/output	**Name of Input/Output**	**Information**	**Quantity/ m3 LVL**	**Unit**
Internal Inputs	Packaged LVL	Quantity	**1**	m^3
External Outputs	LVL to NZ	Quantity	**0.09**	m^3
	LVL to Australia	Quantity	**0.26**	m^3
	LVL to Japan	Quantity	**0.20**	m^3
	LVL to USA	Quantity	**0.06**	m^3
	LVL to Middle East	Quantity	**0.35**	m^3
	LVL to Other Locations	Quantity	**0.05**	m^3

Data from Literature Sources

Forestry

Two studies have been completed to evaluate a GHG coefficient for forestry in NZ. The first of these is a Scion report to the Ministry of Agriculture and Forestry (MAF), completed as part of the 'GHG Footprinting Strategy for the Land-Based Primary Sectors' project. (Sandilands et al., 2008) This report came to a final emissions figure of 10 kg of CO_2-e per cubic metre of roundwood (under bark) for wood grown in NZ, excluding cartage.

The other study that has looked at GHG emissions from forestry is McCallum's carbon footprint report for Nelson Forests Ltd. (McCallum, 2009). This report came to a final GHG figure of 18.7 kg of CO_2 equivalents per cubic metre, which includes 6 kg of CO_2 equivalents for cartage. Excluding this, the figure becomes 12.7 kg of CO_2 equivalents per cubic metre of roundwood under bark.

Due to the McCallum report being directly applicable to one of the three manufacturers included in this LVL study, the GHG figure from that report (12.7 kg of CO_2 equivalents per cubic metre of roundwood under bark) has been used. This is also a more conservative approach, as the higher of the two available figures is used. Data from McCallum has also been used for transport distances, and combined with the diesel emission factor from Table 4.

Inputs to Production

Emission factors for fuels and electricity in NZ have been evaluated by Andrew Barber from Agrilink (Barber, 2009). Diesel, liquefied petroleum gas (LPG), natural gas and electricity are all used in LVL production, and the emission factors for these have been taken from the Barber report. These emission factors are shown below in Table 4. These figures have been calculated using LCA methodology, however emission factors have been using older GWP values from the second IPCC assessment report (IPCC, 1995). In saying this, these figures are likely to be the most accurate for NZ fuels and electricity.

Table 4: Fuel and electricity emission factors used in this project from (Barber, 2009).

Emission Source	Unit	Emission Factor (kg CO_2-e per unit)
Diesel	l	3.108
LPG	kg	3.357
Natural Gas	MJ	0.06096
Electricity (2008)	kWh	0.2375

Some work has been done on emission factors for NZ materials used in the building industry, and where possible these figures are used (Nebel et al. 2009). The materials from this work that are used in this project are paint, steel (strapping) and plastic wrap. The steel figure is for 'steel sheet' which differs from steel strapping; this is used as a proxy for strapping as there is no specific data for that product.

For some materials, NZ-specific emission factors are difficult to source. In this case, an international database was used as a source of environmental impact data. The database used in this project was the ecoinvent database (Frischknecht et al. 2005). This database was used for water (emissions involved in extracting water), caustic production (sodium hydroxide solution), salt production, cardboard production and landfill operations.

A significant component of LVL is the resin that binds the layers of veneer (phenol formaldehyde resin). The exact composition of the resin varies, as each resin manufacturer will use a proprietary recipe - for this reason emission factors may vary slightly. The most appropriate resin emission factor has been used, which is based on recent data for a resin produced and used in NZ. The emission factor for Dynea 'PREFERE 15L112' phenol formaldehyde resin has been used, which is 1.20 kg CO_2 equivalents per kg of wet resin mix. In calculations, resin solids content has been used as a basis for comparison, to allow more accurate estimation of other resin types, which can vary in solids content.

For some minor materials involved in the LVL production process, information was unavailable and therefore the emissions resulting from these materials were excluded. These products include boiler chemicals (such as antifoam), composer string, and insecticide. These materials make up approximately 0.1% of the total mass of 1 m^3 of LVL, and are expected to make up an insignificant percentage of the total GWP figure for LVL – this has been checked in preliminary analyses.

Treatment

Depending on the final intended application, LVL can be treated chemically to improve resistance to insects and diseases. While the production of LVL can include some treatment in the main process (for example using termiticides for product bound for Australia), in general treatment for LVL for external use happens after production of the raw product. This process has been kept separate, as not all LVL is treated in this way. Treatment involves the use of diesel and electricity, and for these, the Barber data (shown above in Table 4) is used. Due to the lack of information around the specific fungicides and insecticides used, the main physical data for the treatment comes from the solvents used, which are white spirits (for which an emission factor for paraffin is used) and dichloromethane. Ecoinvent data is used for the emission factors for production of paraffin and dichloromethane, which are 0.83 and 3.39 kg CO_2 per kg, respectively.

Transport

Transportation of materials to the LVL production sites is accounted for where possible. This involved obtaining data from each manufacturer pertaining to the source of their materials, and averaging the data. Due to the uncertainties and wide range of data surrounding delivery of NZ materials to the production sites, a generic truck model from the ecoinvent database was used (with the exception of logs, as explained below). This model was "transport, lorry >32t, EURO3", and had an emission factor of 0.12 kg CO_2-e per t km.

For road transportation of logs to the LVL production site, the emission factor used is based on NZ-specific data. It is a combination of Nelson Forests transport data with NZ-specific diesel emission factors (McCallum, 2009; Barber, 2009). An assumption was made that log trucks are full on the incoming journey and empty on the outbound journey. Therefore the fuel use figure is an average of the full fuel use (2.31 km/l) and the empty fuel use (1.85 km/l) figures, coming to a total of 2.08 km/l. This is equivalent to 0.481 l/km. These figures also assume a full load of 30 m^3 (30 tonnes, assuming a wet wood density of 1000 kg/m^3). Therefore the fuel use would be 0.016 litres per t km.

Table 5: Transport emission factors used in this project

Transport Type	Emission Factor (kg CO_2-e / t km)	Source
Road transport (miscellaneous materials)	0.11669	Ecoinvent (transport, lorry >32t, EURO3) (Frischknecht et al., 2005)
Road transport (logs to LVL plant)	0.0498	(McCallum, 2009; Barber, 2009)
Road transport (LVL to final destination)	0.100 (0.056 kg CO_2-e / **m^3 km**)	
Ocean transport (Large Container Ship)	0.01311 (0.00734 kg CO_2-e / **m^3 km**)	(DEFRA, 2009)

For road transportation of finished LVL products, the same NZ-specific data was used, however because the trucks are third-party freight trucks (not logging trucks), they are likely to be full almost all of the time. This results in an emission factor which uses the fully-laden fuel use figure (1.85

km/l, or 0.541 litres per km) and only a one-way distance, from production site to final destination. Assuming a load of 30 m^3 (16.8 tonnes of LVL at density of 0.56 t/m^3), this is a fuel use figure of 0.032 litres per tonne-km, or 0.018 litres per m^3-km. These figures are then multiplied by the diesel emission factor in Table 4 to get the road transport emission factor. The distances assumed in this project are 100 km for transport of LVL to the nearest port (where the LVL is being exported), and 300km as an average distance for transport of LVL to a final NZ destination (where NZ is the country where the LVL is used).

For international shipping, ocean freighting is used. Data from manufacturers suggests that most LVL product is exported in containers, and so for the shipping emission factor, a recent study from the UK Department for Environment, Food and Rural Affairs has been used (DEFRA, 2009). Within this, the category 'large container ship' has been used. The ports used to calculate shipping distances are Wellington, Sydney, Los Angeles, Tokyo and Dubai, and distances are found online.[1] Fuel use figures are combined with emissions data from Barber (2009) to come to the final emissions factors, measured in kg CO_2-e per t km, shown in Table 5.

Retail Operations and Use

Emissions from the use phase of the LVL have been excluded as they are expected to be negligible. A time period of 50 years has been assumed for the use phase, in keeping with the IPCC Guidelines for National Greenhouse Gas Inventories (IPCC, 2006).

End of Life

The actual disposal method of the LVL product at the end of its life – which could be 50 years or more into the future – will not be known at the production stage. For this reason, two options are modelled – landfill disposal and incineration.

Behaviour of wood in landfill is a complex issue. In the 2006 IPCC National Greenhouse Gas Inventory guidelines, it is stated that:

"The reported degradabilities especially for wood, vary over a wide range and is yet quite inconclusive. They may also vary with tree species. Separate DOC_f [fraction of organic cabon that decomposes] values for specific waste types imply the assumption that degradation of different types of waste is independent of each other [sic]…scientific knowledge at the moment of writing these Guidelines is not yet conclusive on this aspect".

There are also a range of scientific papers which present vastly different decomposition rates for wood. In this study, the decomposition of the wood is assumed to reach a maximum of 18%, and the product of carbon decomposition is assumed to be 50% carbon dioxide, and 50% methane (Ximenes et al., 2008, IPCC, 2006). The 18% figure is the only reference found that uses evidence in the form of wood products removed after a length of time in a landfill (Ximenes et al., 2008). This figure was given for softwood after 46 years in landfill; this has been used as a conservative estimate, as only 20 years of landfill emissions would be included in the 100-year timeframe. In addition, anecdotal evidence would suggest that a compressed, coated and treated engineered wood product would decompose more slowly than bare softwood, making the decomposition rate in this project likely to be an overestimate, particularly for treated LVL.

Decomposition of the resin component has not been taken into account. Of the methane produced, 10% is oxidised to CO_2 as the landfill is assumed to be a managed landfill (IPCC, 2006). Three different landfill types are modelled: an unmanaged landfill (with no methane capture), an 'average' NZ landfill in 2010 (where 51% of the methane is captured), and a future prediction (for 2050 instead of 2110 as this is the farthest prediction that MfE figures include) for a managed NZ landfill, where 60% of the methane is captured (MfE, 2008). Of this methane, not all will be used for energy generation – some is flared. As of 2007, 6 out of 11 NZ landfills with methane capture technology generated energy (MfE, 2007). Using these figures, an assumption has been made that 43% of captured methane is used for energy generation, and 57% is flared. For a future (2050) scenario, it has been assumed that 90% of captured methane is used for energy generation.

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[1] http://www.searates.com/reference/portdistance/

For modelling of incineration, it is assumed that complete combustion occurs, releasing all stored CO_2-e. This scenario is therefore an assumption of no permanent carbon storage. In the future, it is unlikely that wood products would be incinerated without energy recovery. Therefore, this scenario assumes the energy produced from burning the wood waste is used for cogeneration of heat and electricity. This heat could be utilised by industry, displacing heat from natural gas, and the electricity could replace electricity from the national grid. The GWP impacts of these displacements (using current NZ environmental data from Barber, 2009) have been taken into account. All assumptions for end of life processes are detailed in Table 6.

Table 6: End-of-life assumptions used in this project

Process	Assumption	Source
% of dry wood that is carbon	50%	(Sandilands and Nebel, 2009)
Decomposition of carbon in wood in landfills	18%	(Ximenes et al., 2008)
% of carbon converted to methane	50%	(IPCC, 2006)
% of carbon converted to CO_2	50%	
Methane captured (unmanaged / current NZ landfill / 2050 NZ landfill)	0% / 51% / 60%	(MfE, 2008)
% of non-captured methane that oxidises in landfill	10%	(IPCC, 2006)
% of captured methane used for energy (unmanaged, current NZ landfill, 2050 NZ landfill)	n/a, 43%, 95%	(MfE, 2007)
Electricity produced per kg methane (in methane cogeneration plant)	16.65 MJ	Ecoinvent (Frischknecht et al., 2005)
Heat produced per kg methane (in methane cogeneration plant)	30.525 MJ	Ecoinvent (Frischknecht et al., 2005)
Calorific value of wood waste	15.68 GJ/tonne	(BKC, 2010)
Efficiency of wood cogeneration plant	60%	(Connell Wagner, 2007)
% of energy output as electricity	25%	
% of energy output as heat	75%	
CO_2-e associated with 1 MJ NZ electricity (for offsetting)	0.066 kg CO_2-e	(Barber, 2009)[2]
CO_2-e associated with 1 MJ NZ heat from natural gas (for offsetting)	0.061 kg CO_2-e	

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[2] See 'Uncertainties and Sensitivity Analyses' section for more detail regarding offset electricity mix

Results & Discussion

Overall Results

All individual manufacturer data for the production, treatment and distribution of LVL was aggregated into average figures, and combined with emission factors, to come to total GWP figures. Additional data surrounding emissions from forestry and end-of-life processes was included in calculations, to evaluate a complete ‘cradle-to-grave’ emissions figure for NZ-produced LVL. The results for each stage from forestry to final product at the factory gate (‘cradle to gate’) are shown below in Table 7.

Table 7: GWP Results for each cradle to gate life cycle stage for NZ-produced LVL

Process	kg CO_2-e / m^3
Tree Growth	-911.75
Forestry	31.99
LVL Production	159.01
Treatment	109.33
Untreated LVL (Cradle to gate)	**-720.75**
Treated LVL (Cradle to gate)	**-611.42**

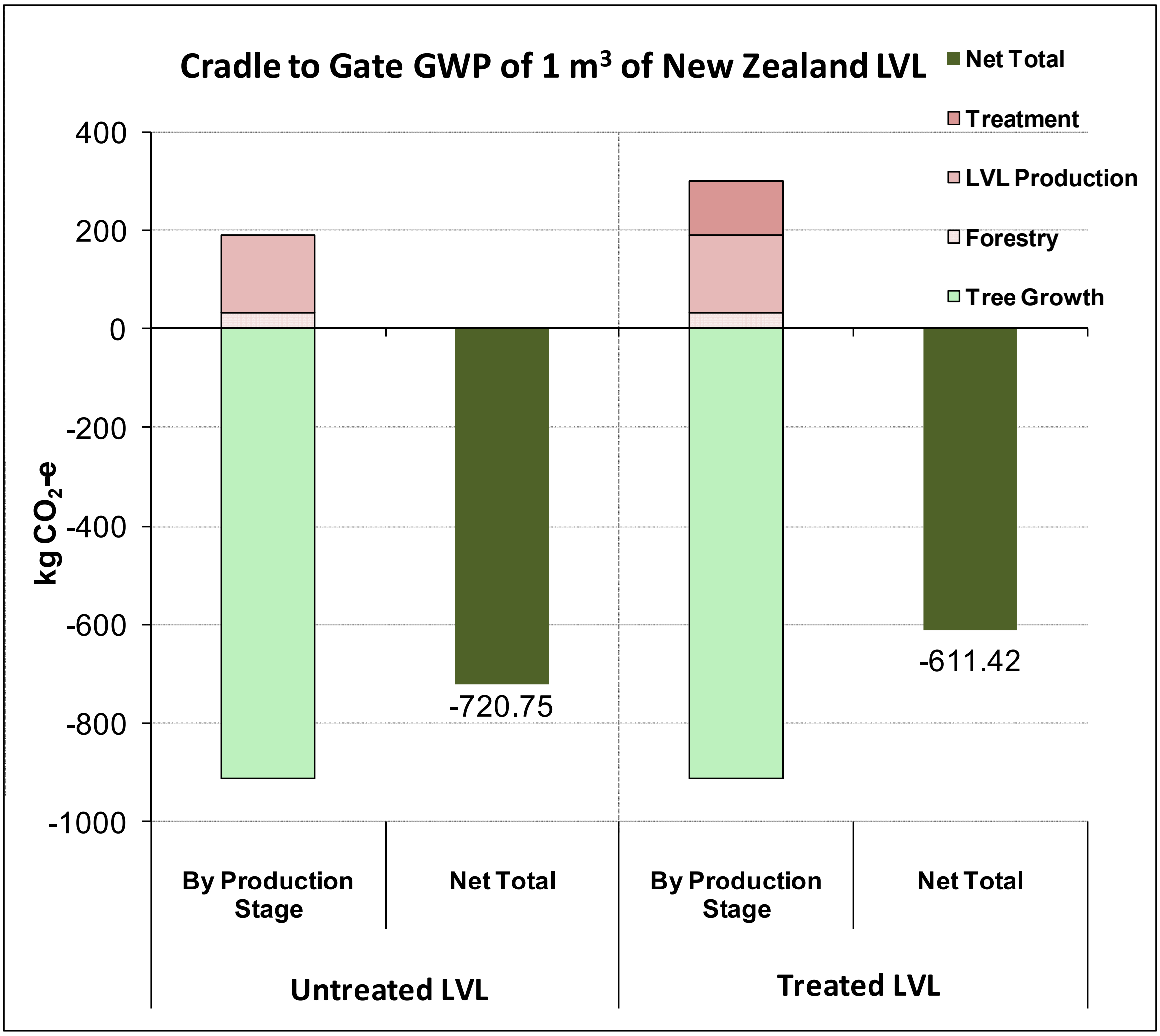

Figure 3: Cradle to gate GWP of 1 m^3 of LVL, produced in New Zealand

It is clear from these results that the production of LVL has the largest contribution to the total GWP figures, with a total figure of 159 kg of CO_2-e per m^3 of LVL. Within the LVL production process, production of the resin and purchased electricity contribute approximately 40% and 39% to the GWP impacts, respectively. Following production, chemical treatment of the LVL can add a significant amount to the GWP figures, as it is an energy-intensive process which uses solvents and other chemicals with significant upstream GWP emissions (109 kg $CO_{2\text{-e}}$ per m^3 of treated LVL). Forestry processes (including transport of logs to the factory) contribute 32 kg of CO_2-e per m^3 of LVL. The cradle to gate results are displayed graphically above in Figure 3.

Transport can add anywhere from 17 to 114 kg of CO_2-e to the GWP figures, depending on the destination (Table 8). Using transport destination data from Table 3, a weighted average figure was produced, to get an idea of the average transportation impact of 1 m^3 of LVL produced in NZ.

Table 8: GWP results for transportation of NZ-produced LVL

Process	kg CO_2-e / m^3
Transport to NZ locations	16.80
Transport to Australia	22.35
Transport to Japan	74.88
Transport to USA	85.32
Transport to Middle East	114.48
Transport to Other Locations	60.53
Weighted Average for Transport	**70.15**

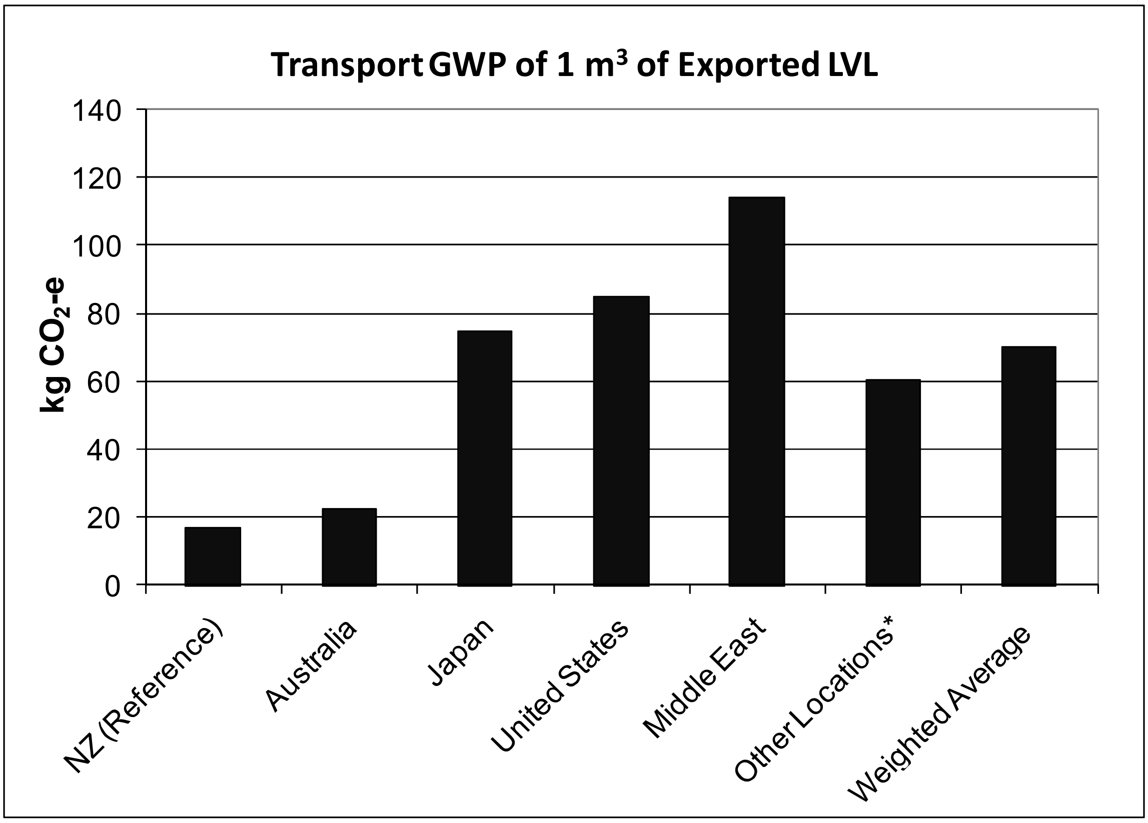

Figure 4: Transport GWP of 1 m^3 of untreated LVL, produced in NZ and exported internationally

* The 'Other Locations' category uses an average transport distance as a proxy, as distances in this category can vary considerably.

At the end of the products' life, the overall impacts for likely end of life scenarios result in GWP emissions. The total net life cycle GWP values however, remain negative, either due to carbon storage in landfills, displacement of energy from other sources, or a combination of the two. Unmanaged landfills have the highest GWP emission (762 kg CO_2-e), while a well-managed landfill, capturing 60% of the methane and using almost all of this for energy generation will result in the smallest GWP emission of 355 kg CO_2-e. Incineration with energy recovery results in emission of -584 kg CO_2-e; this figure is reduced considerably due to offset of conventional energy.

Table 9: GWP Results for end-of-life processes for New Zealand-produced LVL

Process		kg CO_2-e / m^3
CO_2- e Stored in 1 m^3 LVL prior to disposal		**-911.75**
Unmanaged landfill (0% methane capture)	Landfill impacts (gas emissions)	761.65
	Heat and electricity offset	0.00
	Total	**761.65**
Current NZ Landfill (51% methane capture)	Landfill impacts (gas emissions)	456.95
	Heat and electricity offset	-19.32
	Total	**437.62**
2050 NZ Landfill (60% methane capture)	Landfill impacts (gas emissions)	403.17
	Heat and electricity offset	-47.69
	Total	**355.48**
Incineration	Emission of all carbon as CO_2	911.75
	Heat and electricity offset	-327.80
	Total	**583.95**

Laminated Veneer Lumber within New Zealand

New Zealand consumes both untreated and H3-treated LVL products. The GWP of these two options has been calculated, including all stages from forestry until the disposal of the products in a landfill (the disposal method that is currently used in NZ). The total GWP emissions from the production, transport and disposal of these products (cradle to grave emissions) are 645 and 755 kg CO_2-e per m^3 for untreated and treated LVL, respectively. Taking into account CO_2 uptake from tree growth, net total life cycle GWP emissions are -266 and -157 kg CO_2-e per m^3 for untreated and treated LVL, respectively. The results are displayed graphically in Figure 5 below, and also in Table 10. These figures assume the LVL is produced, consumed and disposed of completely within NZ.

Looking at the breakdown of processes, landfill emissions make the largest contribution to GWP emissions, followed by the production of LVL. Landfill emissions make up 68% of the GWP emissions for untreated LVL, and 58% of the GWP emissions of treated LVL, while the production emissions make up 25% and 21% respectively. Treatment (for the treated LVL) makes up 14% of the GWP emission figure. Forestry makes up a maximum of 5% of the figure, and transport a maximum of 3%.

Table 10: GWP Results for each cradle to grave life cycle stage for LVL within New Zealand

Process	kg CO_2-e / m^3
Tree Growth	-911.75
Forestry	31.99
LVL Production	159.01
Treatment	109.33
Transport	16.80
Landfill (inc. energy offset)	437.62
Untreated LVL (Cradle to grave)	**-266.33**
Treated LVL (Cradle to grave)	**-157.00**

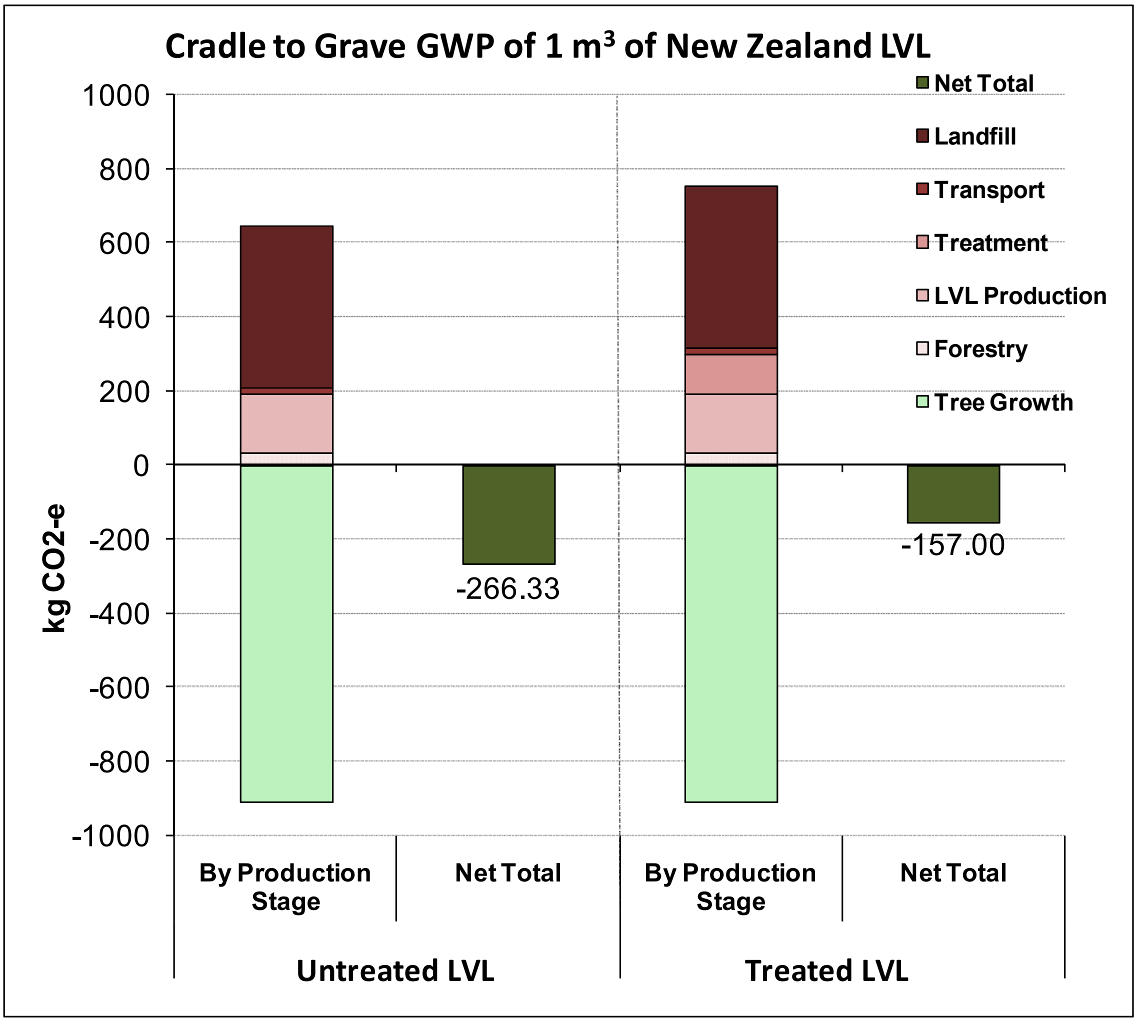

Figure 5: GWP of 1m^3 of LVL, produced, used and disposed of in New Zealand

New Zealand Laminated Veneer Lumber sent to International Destinations

Most of the LVL produced in NZ is exported to destinations around the world. This affects the GWP in two areas – transport, for the shipping around the world, and end of life, as different countries dispose of wood waste in different ways. The transportation component contributes between 22 and 114 kg of CO_2-e per m^3 of LVL exported, which for untreated LVL equates to between 10% and 37% of the total pre-disposal emissions, depending on the destination. Of the international destinations, Australia had the lowest transport GWP figures and the Middle East the highest; this is directly related to the shipping distance involved. For treated LVL, shipping makes up between 7% and 28% of the total pre-disposal GWP emissions.

Due to uncertainties surrounding the method of disposal for LVL in overseas countries (especially when considering future disposal options), both the landfill and the incineration scenarios are possible scenarios. The difference in GWP that these scenarios make is displayed (appropriating NZ data for overseas data) in Figure 6. Clearly the carbon storage benefit from landfill disposal has a significant impact on the overall GWP, storing and/or offsetting 146 kg CO_2-e per m^3 over the incineration scenario. The conclusion that can be drawn from Figure 6 is that, based on a range of assumptions, landfilling of waste LVL results in lower GWP results than incineration for both treated and untreated timber. This graph should be used as indicative only, as the uncertainties for end of life processes are expected to be very high. Wood decomposition rates, incineration practices, electricity grid mixes and methane capture rates will all vary in each specific situation. A lookup table for these results is provided in Appendix III: Emission Lookup Tables, for use in further reports.

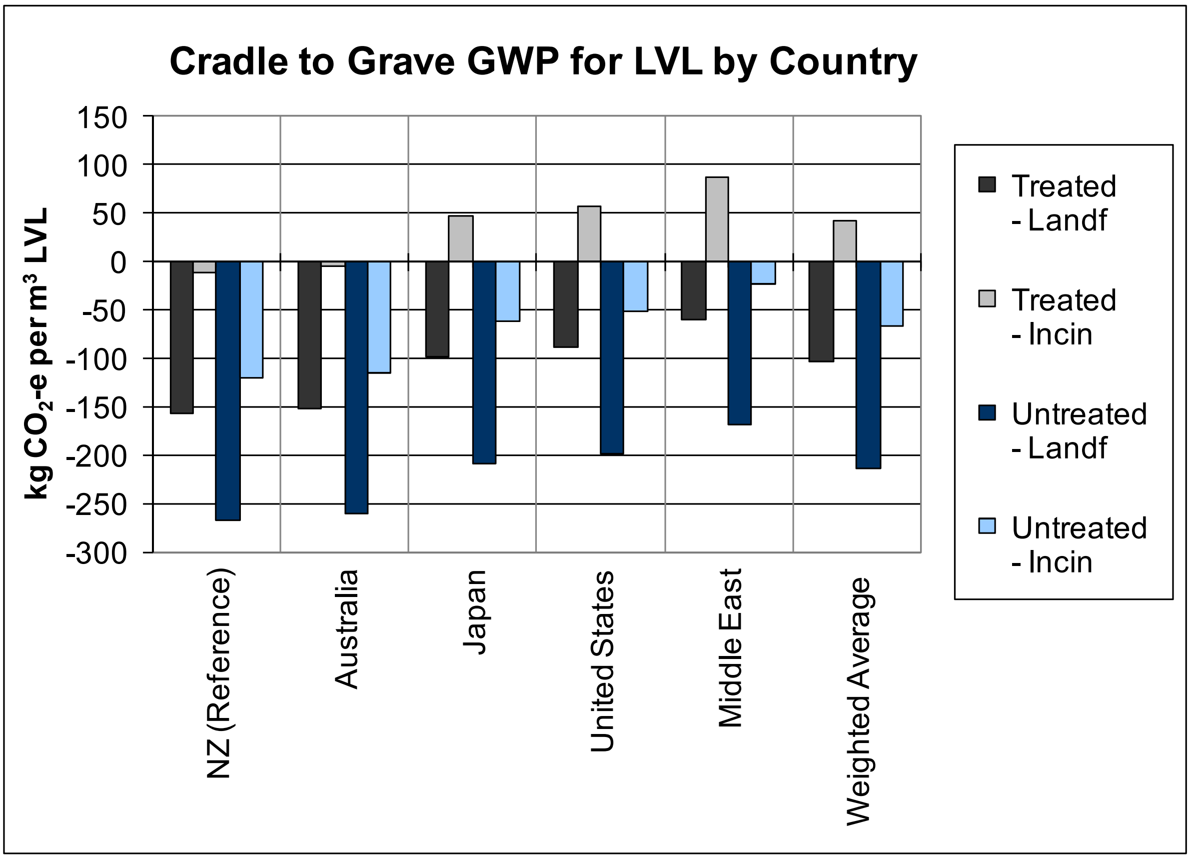

Figure 6: Total (including end of life) GWP of 1 m^3 of LVL, produced in NZ and exported internationally (Landf = landfill; Incin = incineration)

Uncertainties and Sensitivity Analyses

Areas of uncertainty

The following list of uncertainties highlight and investigate the limitations of these results:

End of life - Wood Decomposition

As mentioned in the Results & Discussion section, the uncertainties surrounding end of life processes are expected to be very high. For this reason, multiple scenarios have been included in this study. It is recommended that if the results of this report are used in further studies, that the most recent and applicable (e.g. country-specific) end of life data is used for disposal or incineration of LVL.

A sensitivity analysis on the decomposition of wood in landfill has been performed, and results are shown in Figure 7. The figure of 18% decomposition (over 46 years) has been used as the base scenario for calculations in this project (Ximenes et al. 2008), and because this extends beyond the 100-year timeframe of the project, it is considered a conservative estimate. The IPCC uses default figures for wood of 43% degradable organic carbon, and a total of 50% decomposition of this carbon with a half-life of 23 years (which is within the scope of this study) (IPCC, 2006). Results using the IPCC results for 20 years (the scope of this study) and 50 years (well beyond the scope of this study) are shown.

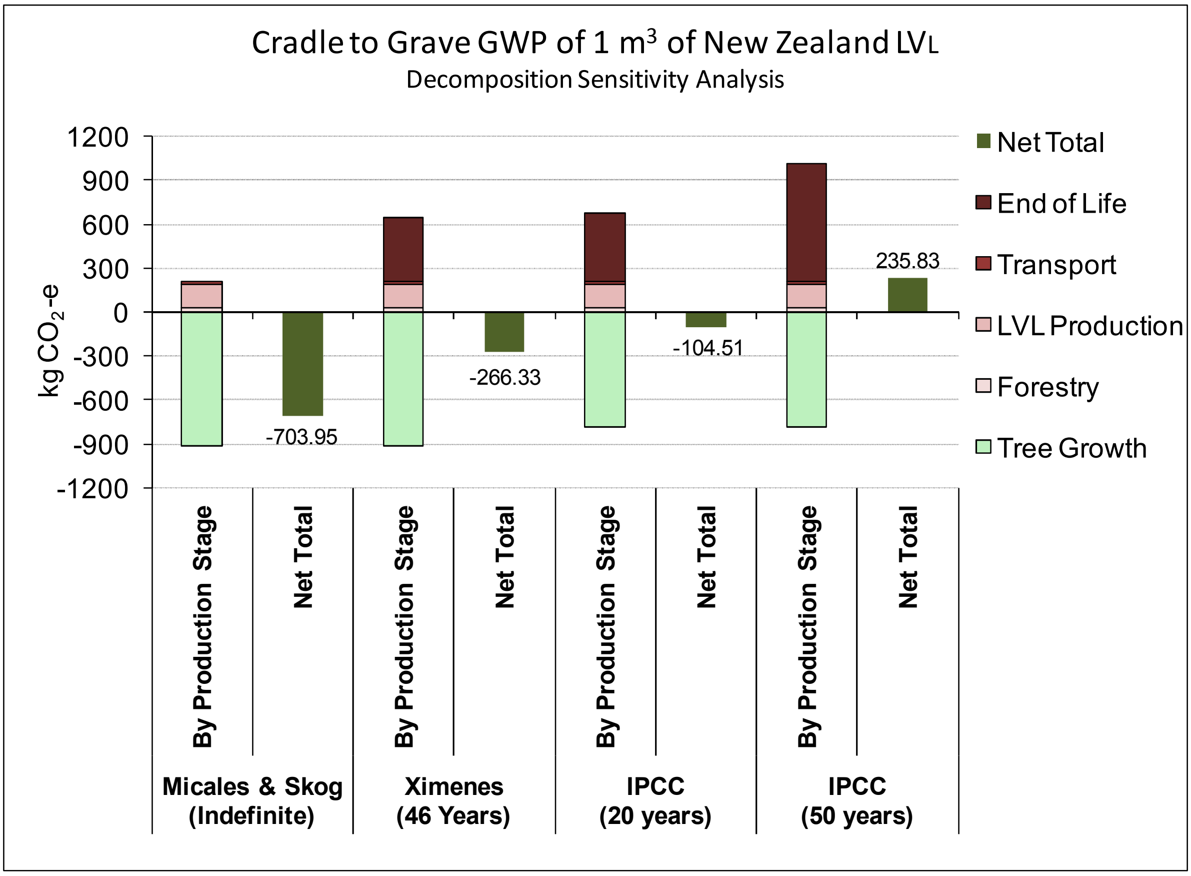

Figure 7: Effect of decomposition in landfill, comparing 18% decomposition (Ximenes et al., 2008) with 0% (Micales and Skog, 1997) and IPCC first-order decay models (IPCC, 2006), assuming the current (51%) methane capture rate (MfE, 2008).

Another paper discussing the decomposition of forest products estimates that 0-3% of the carbon in wood is ever emitted as landfill gas (Micales and Skog, 1997). The lower value has been used to show the low extreme of decomposition estimates, which results in a large net storage of carbon in landfill. These results show that the ‘end of life’ stage is very important to the LVL life cycle – if the decomposition of wood products in landfill is higher than expected, then incineration may become a more favourable choice (with regards to GWP) for disposal. It is also very likely that for treated LVL in landfill, decomposition rates will be much lower than the default figure used in this report, making landfilling look more feasible from a GWP perspective.This same princple may apply for LVL in landfills in very dry countries, where decomposition rates may be slowed.

End of life – Electricity Substitution (System Expansion)

The end of life stage for LVL in this study considered two options: landfilling of LVL, and incineration. To examine the full impact of these scenarios, ‘system expansion’ has taken place, which results in a change in demand for heat (assumed to be conventionally generated from natural gas) and electricity. In the base calculations, electricity is assumed to be the average grid mix, which is deemed as an acceptable proxy for the ‘short-term marginal’ electricity mix, for small changes in demand using the International Reference Life Cycle Data System (ICLD, 2010). While it is difficult to predict the electricity source that waste LVL would substitute, it is likely that the ‘short-term marginal’ electricity mix is ‘peak’ demand, which in NZ is likely to be generated from thermal (gas and coal) sources.

With this in mind, a sensitivity analysis has been undertaken investigating substitution of the average grid mix (the base scenario in this report), electricity from coal, and electricity from natural gas. This analysis is to investigate the significance of changes in electricity source, as opposed to estimating three realistic scenarios. Results for the landfilling of LVL found that the overall net results differed by a maximum of 3% (untreated) and 5% (treated) from the base scenario, and thus these results are not investigated further. Results for incineration found that end of life impacts decrease by 39 kg CO_2-e per m^3 of LVL if electricity from coal is substituted, and increase by 7 kg CO_2-e per m^3 LVL if electricity from natural gas is substituted. This shows that if waste LVL is incinerated and the electricity replaces electricity from coal, the overall GWP is a larger net offset than the base scenario. These results are another indicator that transparency at the end of life stage is essential, as assumptions for energy displacement can have a significant bearing on results.

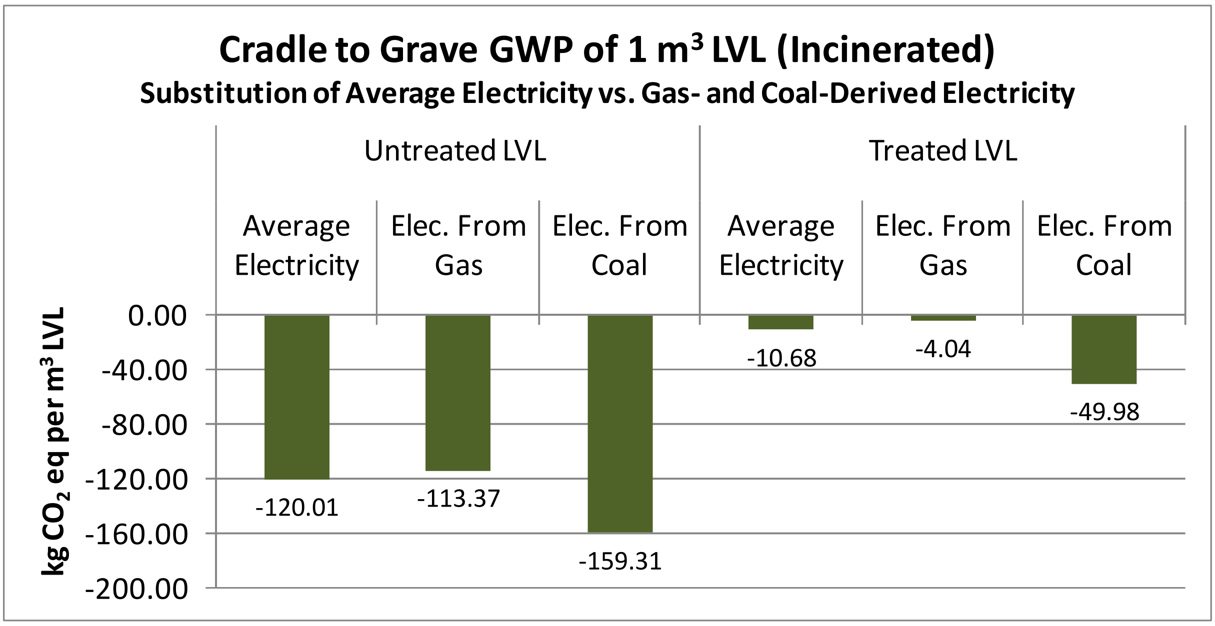

Figure 8: Sensitivity analysis of LVL incinerated in NZ, with generated electricity assumed to displace average electricity, electricity from natural gas, and electricity from coal, respectively.

Shipping

Shipping emission factors are available from a variety of sources, though they can vary wildly. Data from the International Maritime Organization estimates emissions from container ships range from approximately 12 to 35 grams of CO_2-e per tonne-kilometre (Buhaug et al., 2008). Using a density of 560 kg/m^3 for LVL, this works out to be 7 to 20 grams of CO_2-e per m^3-kilometre. Previous work by McCallum (2009) put the figures at around 5 to 7 grams of CO_2-e per m^3-kilometre. The effects of different shipping emission factors for treated LVL are displayed in Figure 9. The NZ figures remain unchanged as no international shipping is undertaken, so have been excluded from the results.

The total GWP figures for the transport stage (in kg CO_2 per m^3 LVL) range from 17-51 for Australia, 53-194 for Japan, 60-223 for the USA and 80-302 for the Middle East. For treated LVL the transport stage makes up 5-15%, 15-39%, 17-43% and 21-50% respectively of the total GWP emissions figure. These results show that transport emission factors can make a significant difference to the total GWP figure of LVL, and that the significance depends on the total distance travelled.

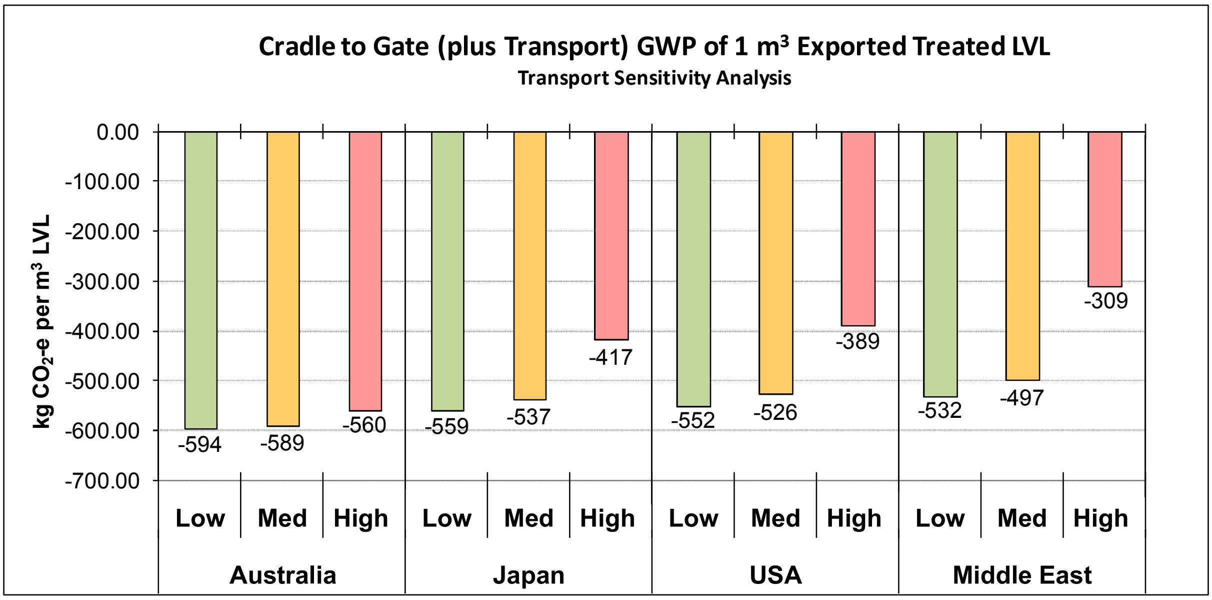

Figure 9: Sensitivity analysis of the shipping stage for NZ LVL (different emission factors shown in the graph: low = 5 g, med = 7.34 g (base scenario), and high = 20 g CO_2-e per m^3 km respectively)

Resin

The adhesive resin in LVL makes up a significant proportion of its mass (around 10%), and also is the second-largest single contributor to the cradle-to-gate carbon footprint of untreated LVL after electricity. For this reason, it is clear that good data for resin is needed. The figure used is from Dynea (a manufacturer of resin products), and is specific to ‘PREFERE 15L112’ phenol formaldehyde resin, which one of the manufacturers uses. A broad sensitivity analysis is undertaken below in Figure 10 on the following page. The figure shows that doubling or halving the resin impacts will affect the GWP significantly. For untreated NZ LVL, a doubling of the resin impacts would increase the cradle to gate emissions by 60%, resulting in a change to the overall cradle to gate figure of 15%. When considering treated LVL, the total cradle to gate carbon storage is decreased by 13% when the resin impacts are doubled. This sensitivity analysis shows that accurate resin data is important for an overall carbon footprint of NZ-produced LVL.

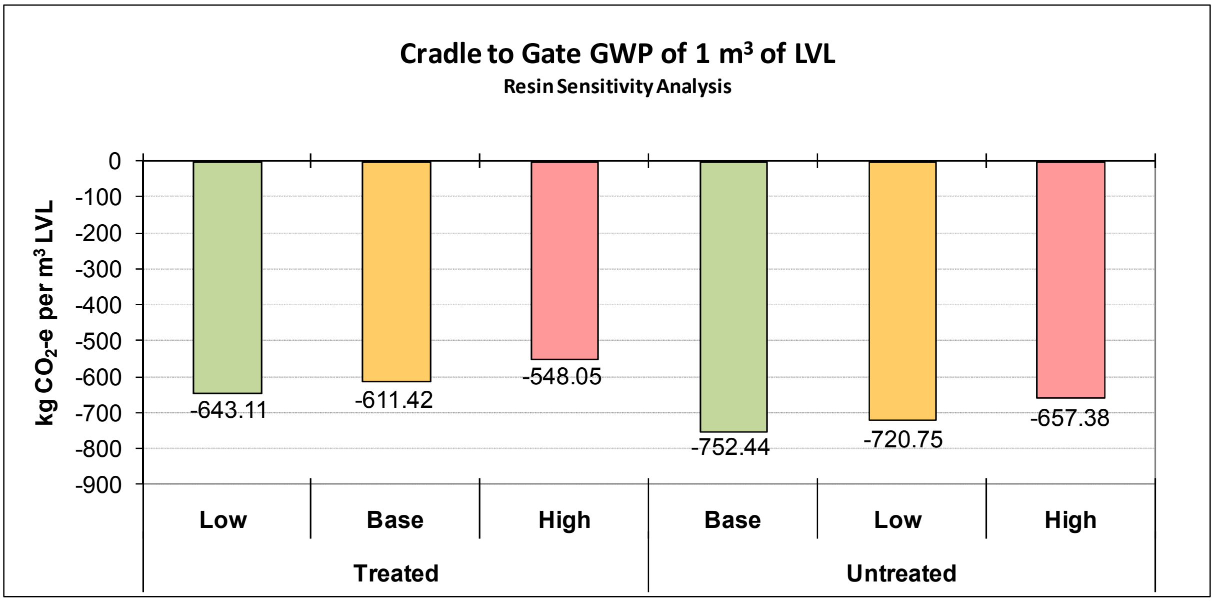

Figure 10: Sensitivity analysis of the resin used in NZ LVL (different resin solids emission factors used: low = 1.3 g, normal (unlabelled) = 2.6 g, high = 5.2g CO_2-e per kg resin solids respectively)

Conclusions and Recommendations

This study used primary data from manufacturers and the latest available emissions data to calculate the total carbon footprint of 1 m^3 of LVL produced in NZ.

The recommendation for further use of this report is that the base cradle-to-gate figures of 191.00 kg of CO_2-e emitted, and 912 kg of CO_2-e stored per m^3 of LVL be used, resulting in a combined figure of -721 kg CO_2-e. Following this, addition of relevant figures for treatment, transport and end of life processes must be added. Figures in this report can be used as default values or, if more applicable data is available, it should be used for these additional processes.

Many different scenarios are investigated using different transportation distances, different end of life options, and choosing between treated and untreated LVL. A base scenario for NZ would likely be 1m^3 of untreated LVL, transported within NZ and disposed of in a current landfill. This scenario results in positive contributions to GWP (emissions to the atmosphere) of 645 kg CO_2-e, and carbon uptake equating to 912 kg CO_2-e, resulting in a net storage of 266 CO_2-e. For treated LVL in NZ, an additional emission of 109 kg CO_2-e occurs. This brings the total GWP emissions figure to 755 kg CO_2-e, and again taking into account carbon uptake of 912 kg CO_2-e, results in a net storage of 157 kg CO_2-e. Note that is strongly advised to present results in a stage-by-stage form, as aggregated results and net totals can be misleading, and reduce the transparency significantly.

For exported LVL, it is recommended that cradle-to-gate figures are combined with the treatment, transport and end of life values that correspond to the actual situation. This study found that transport values for exported LVL ranged from 22 (Australia) to 114 (Middle East) kg CO_2-e emitted per m^3 of LVL exported. In addition, the method of disposal at the end of the product’s life could result in 355 (future landfill) to 762 (unmanaged landfill) kg CO_2-e per m^3 being emitted. Another option investigated was incineration of waste LVL, which would be used for energy generation and could result in CO_2 emissions of 584 kg CO_2-e per m^3 of LVL (using current NZ electricity and natural gas data as a basis for substitution).

It should be kept in mind that these results apply to one impact category only, and that a study such as this should not be interpreted as a complete broad-ranging environmental assessment. These results show the potential impact of LVL products on climate change. This study could be updated in the future if any new end of life processes are developed in NZ, or if more robust decomposition data is found for engineered wood products in landfill.

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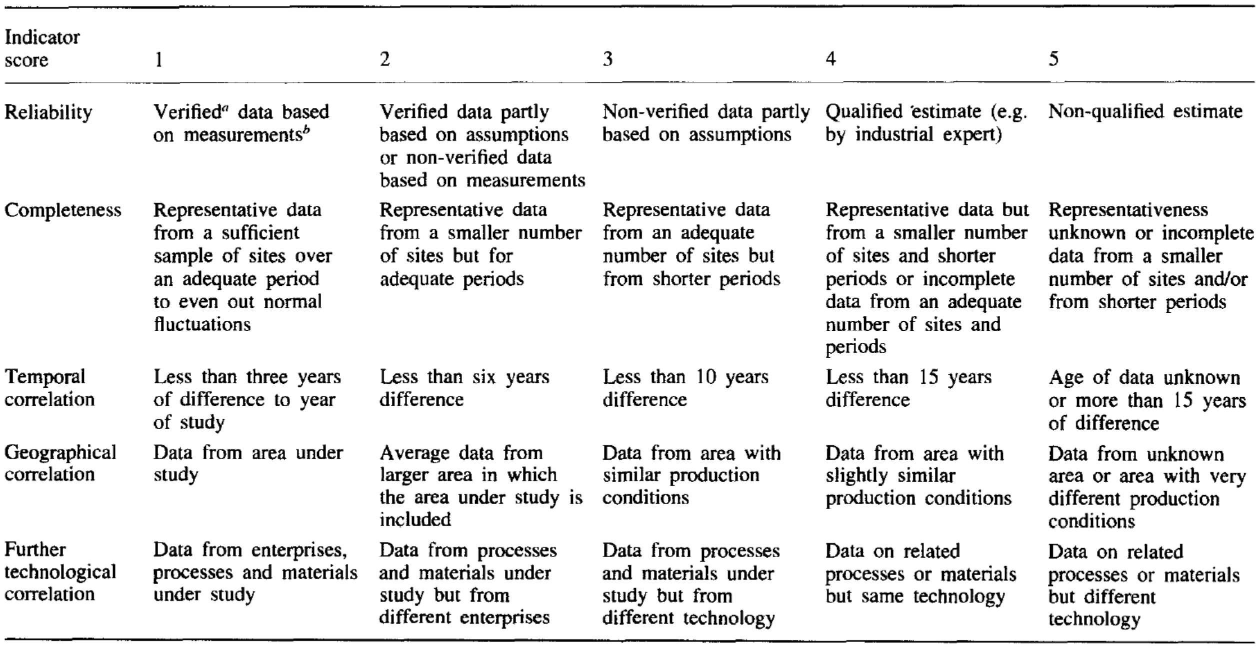
Appendix I: Data Validation

Data validation has been performed using the 'pedigree matrix' as described by Weidema and Wesmaes (Weidema and Wesnæs, 1996), shown below in Table A 1. All emission factors and sources are listed on the following page in Table A 2, and primary data is ranked in Table A 3. Grey lines mean that no data was available for those particular products or processes.

Table A 1: The 'pedigree matrix' used for data validation in this study (from Weidema and Wesnæs, 1996)



Indicator score	1	2	3	4	5
Reliability	Verified[a] data based on measurements[b]	Verified data partly based on assumptions or non-verified data based on measurements	Non-verified data partly based on assumptions	Qualified estimate (e.g. by industrial expert)	Non-qualified estimate
Completeness	Representative data from a sufficient sample of sites over an adequate period to even out normal fluctuations	Representative data from a smaller number of sites but for adequate periods	Representative data from an adequate number of sites but from shorter periods	Representative data but from a smaller number of sites and shorter periods or incomplete data from an adequate number of sites and periods	Representativeness unknown or incomplete data from a smaller number of sites and/or from shorter periods
Temporal correlation	Less than three years of difference to year of study	Less than six years difference	Less than 10 years difference	Less than 15 years difference	Age of data unknown or more than 15 years of difference
Geographical correlation	Data from area under study	Average data from larger area in which the area under study is included	Data from area with similar production conditions	Data from area with slightly similar production conditions	Data from unknown area or area with very different production conditions
Further technological correlation	Data from enterprises, processes and materials under study	Data from processes and materials under study but from different enterprises	Data from processes and materials under study but from different technology	Data on related processes or materials but same technology	Data on related processes or materials but different technology

Table A 2: Data validation of emission factors using the pedigree matrix

Emission Factors	Reference	Reliability	Completeness	Temporal Correlation	Geographical correlation	Technological Correlation
Forestry (1 m^3 wood)	McCallum	2	1	2	2	1
Log Transportation	McCallum & Barber	1	3	1	2	1
Diesel (+use)	Barber	2	1	1	2	1
LPG (+use)	Barber	2	1	1	2	1
Electricity (+ use)	Barber	2	1	1	2	1
Natural Gas (+use)	Barber	2	1	1	2	1
Truck transportation of other goods	Ecoinvent	2	2	2	5	3
External veneer purchased in	Internal to this project	3	1	1	1	1
Water	Ecoinvent	2	2	2	5	3
Caustic	Ecoinvent	2	2	2	5	1
	Ecoinvent					
Antifoam						
Boiler Chemicals						
Salt	Ecoinvent	2	2	2	5	3
Lubricants	GaBi	2	2	2	5	1
Composer String						
Phenol Formaldehyde Resin Solids	DYNEA	2	3	1	1	1
Fillers (walnut/wheat flour)	Ecoinvent	3	4	2	5	3
Modal (glue extender)						
Insecticide						
Paint	NZ Materials (Nebel)	2	2	1	2	1
Ink	NZ Materials (Nebel)	2	4	1	2	4
Steel Strapping	NZ Materials (Nebel)	2	2	1	2	1
Low Density Polyethylene	NZ Materials (Nebel)	2	2	1	2	1
Cardboard	Ecoinvent	2	2	2	5	3
General waste to landfill	Ecoinvent	2	2	2	5	3
Boiler Ash to landfill	Ecoinvent	2	2	2	5	3
Water use	Ecoinvent	2	2	2	5	3
Waste water treatment						
H3 Treatment Chemicals	Ecoinvent	2	3	2	5	5
Transport Distances for finished LVL (Land)	McCallum & Barber	4	3	1	2	n/a
Transport Distances for finished LVL (Sea)	DEFRA (2009)	2	1	1	2	n/a
Paraffin	Ecoinvent	2	3	2	5	1
Melamine formaldehyde Resin (in place of polyamide)	Ecoinvent	2	4	2	5	4

Table A 3: Validation of primary data from producers collected in this study

Primary Data Quality	Reliability	Completeness	Temporal Correlation	Geographical correlation	Technological Correlation
Primary data from Producers	2	1	1	1	1

Appendix II: IPCC Waste Model

The IPCC uses a first order decay (FOD) model to estimate decomposition of organic waste in landfills (IPCC, 2006). This is based around two main parameters, the fraction of the waste that is degradable organic carbon (DOC) and the fraction of this DOC that decomposes (DOC_f). The values, as well as other IPCC default parameters for wood, are shown below in Table A-4.

Table A-4: IPCC assumptions for decomposition of wood waste (IPCC, 2006).

DOC	DOC	0.43
DOC_f	DOCf	0.500
Methane generation rate constant	k	0.030
Half-life time ($t_{1/2}$, years):	h = ln(2)/k	23.1
exp1	exp(-k)	0.97
Process start in deposition year. Month M	M	13.00
exp2	exp(-k*((13-M)/12))	1.00
Fraction to CH_4	F	0.500

EQUATION 3A1.2
FIRST ORDER DECAY EQUATION

$$DDOCm = DDOCm_0 \bullet e^{-kt}$$

Where:

$DDOCm$ = mass of degradable organic carbon that will decompose under anaerobic conditions in disposal site at time t

$DDOCm_0$ = mass of DDOC in the disposal site at time 0, when the reaction starts

k = decay rate constant in y^{-1}

t = time in years.

Figure A-1: FOD equation used in IPCC Waste Model (IPCC, 2006)

The assumption has been made that 1 m^3 of LVL has a mass of 560 kg, of which approximately 63.7 kg is resin. This leaves 497.3 kg of wood and organic fillers. Using the default IPCC assumption that 43% (213.8 kg) of this is degradable organic carbon (DOC), and 50% of the DOC (106.9 kg) will decompose (DOC_f), leaving 106.9 kg of carbon in landfill. This means that the total indefinite carbon storage would be 106.9 kg of carbon, which is the equivalent of 392 kg of CO_2. To this, landfill emissions must be added.

For the case of 20 years in landfill, we use the equation from Figure A-1 where:

- $DDOCm_0$ = 106.9
- k is 0.03, and
- t is 20

This works out at 58.67 kg of carbon, which is the fraction of DOC_f that remains in landfill after 20 years. It is not the amount that decomposes (this is a mistake in the DDOCm term in Figure 11). If we then add this to the carbon that will not decompose (the fraction of DOC that is not DOC_f) which is 106.9 kg, we come to a total stored carbon figure of 106.92 + 58.67 = 165.59 kg.

After 30 years the stored carbon remaining in landfill drops to 150.39 kg, after 40 years it drops to 139.12 kg, and after 50 years it reaches 130.78 kg.

These figures are then used as the basis for landfill calculations, which take into account landfill gas generation, methane capture and flaring, methane oxidation in landfill, energy generation from captured methane and offset of conventional energy sources from landfill gas usage. The co-efficients used for these calculations are listed in Table 6 in the main body of this report.

Appendix III: Emission Lookup Tables

The following table displays the GWP emissions, in kg CO_2-e per m^3 of LVL, broken down by life cycle stage and country. The end of life scenarios used are based on NZ data, and thus should be used with caution for other countries. Regardless, these figures should give an approximation of life cycle impacts for NZ LVL used abroad.

Table A-5: GWP for each stage of the life cycle of NZ-produced LVL

	Tree Growth (Carbon Uptake)	Forestry	Manufacturing	Treatment	Transport	End of Life	
						Landfill	Incineration
NZ (Reference)	-911.8	32.0	159.0	109.3	16.8	437.6	583.9
Australia					22.3		
Japan					74.9		
USA					85.3		
Middle East					114.5		
Other Locations					60.5		
Weighted Average					70.1		

Table A-6 below displays cradle to grave GWP emissions, in kg CO_2-e per m^3 of LVL, broken down by country. This table has been constructed using data from Table A-5 above.

Table A-6: Total cradle to grave GWP for NZ-produced LVL, by country

	Total Carbon Footprint (kg CO_2-e/ m^3 LVL)			
	Treated LVL		Untreated LVL	
	Landfilled	Incinerated	Landfilled	Incinerated
NZ (Reference)	-157.0	-10.7	-266.3	-120.0
Australia	-151.5	-5.1	-260.8	-114.5
Japan	-98.9	47.4	-208.2	-61.9
USA	-88.5	57.8	-197.8	-51.5
Middle East	-59.3	87.0	-168.6	-22.3
Other Locations	-113.3	33.0	-222.6	-76.3
Weighted Average	-103.7	42.7	-213.0	-66.7