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Options to Improve the New Zealand Engineered Wood Value Chain: Evidence from a Systematic Literature Review

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Abstract

Improving the New Zealand engineered wood value chain would result in major social, environmental, and economic benefits to the nation. Engineered wood products have environmental and building performance benefits over conventional steel and concrete. The aim of this study was to explore potential interventions to the New Zealand engineered wood value chain and to suggest options in order to improve its performance. To achieve this, a systematic literature review was conducted. This resulted in 84 retained studies, which were divided into three broad themes: product demand; chain fragmentation; and cost of production. The analysis of these themes was used to produce five suggestions to improve the performance of the value chain: increased training and education with engineered wood products; Government funding of engineered wood products in public infrastructure; investment into log allocation technology and robotics; a clear vision of the future of gene editing; and the inclusion of engineered wood products in the Emissions Trading Scheme. These options would all contribute to the improvement of the performance of the engineered wood value chain.

Introduction and Background

Improving the performance of the New Zealand engineered wood value chain has the potential to overcome major social, environmental, and economic issues for the nation. New Zealand is primarily an exporting nation and the forestry industry contributes NZ$6.9 billion of annual export revenue, which makes it New Zealand's third largest export sector (Forest Owners Association, 2019). Of New Zealand's total timber production, 84 per cent is exported (Forest Owners Association, 2019). Overall, forestry makes up 1.6 per cent of New Zealand's GDP, a significant part of the economy (Ministry of Primary Industries, 2020).

The New Zealand forestry industry produces a range of different products at both the first and the second processing stages of the value chain. These products include wood chips, pulp, poles, plywood, paper, and engineered wood (Forest Owners Association, 2019). Engineered wood products are relatively new developments that have progressed rapidly to be substitute options for steel and concrete construction (Winchester & Reilly, 2020). The most common varieties of engineered wood are glued laminated (glulam) wood, cross-laminated timber (CLT), and laminated veneer lumber (LVL).

Engineered wood has the potential to offer many benefits to New Zealand. Engineered wood products have a range of benefits over other building materials including better seismic performance, lower transport costs, and lower net carbon emissions (Winchester & Reilly, 2020; Ministry of Primary Industries, 2018). The benefit of the low net carbon emissions is attractive for the New Zealand Government as tackling climate change is a top priority. This is supported by initiatives such as the Climate Change Response (Zero Carbon) Amendment Act 2019 which aims to reduce net carbon emissions to zero by 2050 (Ministry for the Environment, 2019) and the 'One Billion Trees Programme' which aims to plant one billion trees by 2028 to offset carbon emissions (Te Uru Rākau, 2020). Engineered wood should also be attractive to the Government as it has the potential to assist in their priority of addressing the current housing crisis, which has made rent and homeownership unaffordable for many New Zealanders (Woods, 2019).

Measuring performance of value chains can be complex due to the individual characteristics of individual chains (Aramyan, 2007). This research uses an adapted version of Aramyan's (2007) Performance Measurement System (PMS) that includes four main categories. Although this was originally designed for the agri-food value chain, it is still applicable for the New Zealand engineered wood value chain. Table 1 summarises the PMS used to measure the performance of this value chain.

Table 1. Adaptation of Aramyan's (2007) PMS used to measure the performance of the New Zealand engineered wood value chain

Category	Performance Indicator
Efficiency	The ability of the chain to optimise use of its resources
Flexibility	The capability of the chain to respond to a change of environment
Responsiveness	The timeframe in which the chain responds to a request for product
Quality	The number of logs that are processed into engineered wood products

The quality indicator perhaps deserves explanation. The production of engineered wood requires good quality logs. Currently the chain struggles with getting these quality logs to the engineered wood processors and often quality logs can be wasted in other products that do not necessarily require that level of quality. So if the number of logs that get processed into engineered wood increases then that is an indicator of an increase in the overall quality of logs.

The New Zealand forestry industry needs to improve the performance of the engineered wood value chain in order to gain competitiveness over North American and European timber industries, and increase the profitability of the industry (Khoryanton et al., 2020). This is particularly important as the industry is experiencing a decline of exports, even before the arrival of COVID-19 (Forest Owners Association, 2019). Of New Zealand's main commodity exports, forestry has declined the most with a decrease of NZ$688 million from the period 1 February to 10 June 2020 compared to the same period last year (NZIER, 2020). A backlog at Chinese ports was created due to a halt of wood processing brought on by COVID-19 (Foxcroft, 2020) as well as a decline in construction demand (NZIER, 2020). The broader economic impacts of the COVID-19 pandemic may also flow to the industry, particularly as the growth of its biggest export market, China, is projected to fall by 5.6 per cent in 2020 (Ahmad et al., 2020).

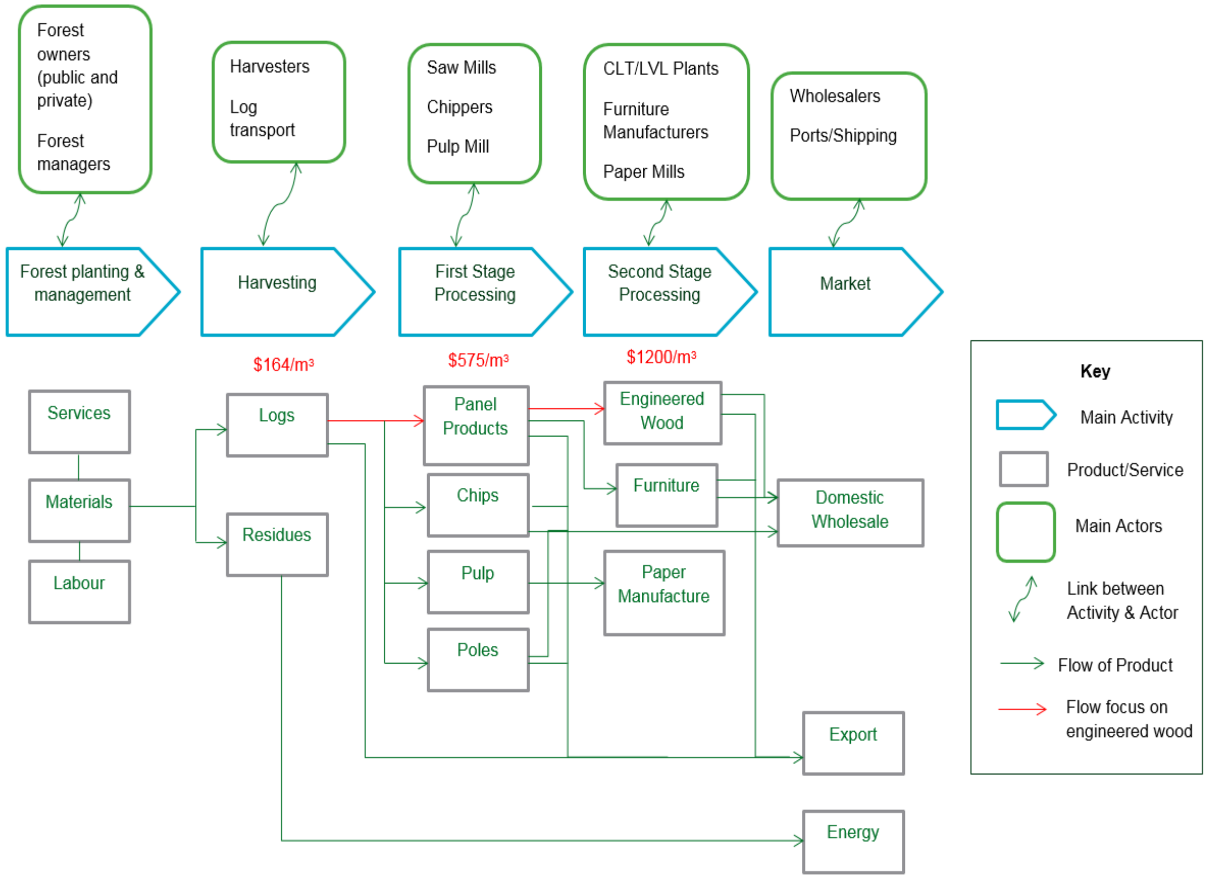
If the New Zealand engineered wood value chain could improve its performance, it could help overcome major economic, environmental, and social issues through improved economic output of the forestry industry, reduction of carbon emissions, and increased domestic high quality building materials for housing.

The broad aim of this study is to explore potential interventions to the New Zealand engineered wood value chain and make suggestions to improve its performance. The specific objectives are: to undertake an initial literature review to assess the current value chain situation and the importance of the chain; to find and review current literature related to value chains in New Zealand and abroad; to sort and summarise the literature into major themes; to use a preliminary value chain analysis of this industry and the findings to make suggestions to improve the value chain with support of the SLR; and, finally, to identify opportunities for future research to further improve the value chain.

Initial Literature Review

The term 'Value chain' was originally coined by Porter (1985). A value chain defines the activities required to create a product or service from origin and processes through to delivering the final product to the consumer (Kaplinsky & Morris, 2001). The more processes involved, the higher the cost but the expectation is that more value is added. This is true for the New Zealand engineered wood value chain. A preliminary analysis of the chain was undertaken (Cantwell, 2019) and this is reproduced in Figure 1. This figure shows how each process taken creates further value. However, the majority of New Zealand's logs are not even processed. Of the 35,684,000 logs produced in 2018, 60 per cent of them were exported in raw form (Forest Owners Association, 2019). The current chain structure imposes constraints that need to be recognised and overcome.

Figure 1. Preliminary analysis of the New Zealand Engineered wood value chain and broader forestry industry in 2019



Source: (Cantwell, 2019)

The need for strategic fit

For products to move further down the value chain it is important that “strategic fit” is achieved. Strategic fit is when there are consistent goals between the operation of the value chain and the higher-level competitive strategies of the major firms involved (Chopra & Meindl, 2012). When strategic fit is achieved there are aligned priorities between the consumer need and the value chain’s ability to satisfy it (Chopra & Meindl, 2012). This is especially true for the engineered wood value chain as it has significant environmental and social priorities as well as economic priorities. Society must be willing to pay for these benefits. As noted, the value chain is currently mostly exporting logs as an unprocessed, “commodity” product. Demand for logs is more certain and supply more predictable, which means that price becomes an important factor and margins are lower (Chopra & Meindl, 2012). As engineered wood requires second stage processing because it is earlier in its product life cycle than logs, the demand is uncertain, but margins are higher (Chopra & Meindl, 2012). The higher margins come at the trade-off of further demand uncertainty. The value chain must be in the situation that the final consumers are willing to pay the cost for the product. If more logs are to be processed into engineered wood, the value chain and competitive strategy will have to shift to achieve strategic fit.

Fragmentation of the New Zealand engineered wood value chain

Chain coordination across stakeholders is an important driver for a well performing chain (Van der Vorst, 2006). However, this is not the case for the New Zealand engineered wood value chain. The fragmentation of the New Zealand forestry industries, including engineered wood, creates chain failure which prevents more logs being processed. Chain failure is caused when the performance of the chain does not reach the optimal value both economically and for public good (Mounter et al., 2016). The value chain has uncoordinated fluctuations of supply, which at times surpass or fall short of demand, resulting in fluctuating prices (Clark, 2018). Wood processors experience boom and bust cycles depending on the New Zealand dollar exchange rates and international demand for logs (Clark, 2018). Secondly, the engineered wood value chain struggles with communication due to the high amount of small forest owners, which make up 40 per cent of the harvest (Forest Owners Association, 2019) and who have little planning and operate as spot sellers (Clark, 2018). Another of the common causes of the fragmentation of forestry value chains in New Zealand is the struggle to allocate logs to the right processor in the chain to be able to get the most out of each log. Logs reaching the processors may not necessarily have the ideal characteristics required for producing the right end product. This is particularly important for engineered wood that needs to have acceptable stiffness and low warp, and be free of defects such as dead knots (Murphy & Moore, 2018). The difficulties and inaccuracies of forest inventories and planning also contribute to the fragmentation in forestry value chains (Fragiacomo, Riu & Scotti, 2015). These issues with communication within the chain contributes to the chain’s inability to reach its optimal output resulting in chain failure. This prevents more logs being processed and causes significant issues to the performance of the New Zealand engineered wood value chain.

New Zealand housing shortage

Homeownership has become unaffordable for many first-home buyers which is now a major social, economic and political issue (Tustin, 2017). This is especially important in New Zealand, as the country values homeownership and this unaffordability may threaten its comparatively egalitarian society (Clare et al., 2018) by creating intergenerational inequity (White & Nandedkar, 2019). Engineered wood can be processed through central production of prefabricated materials and turn-key projects, which allows for rapid construction in a cost-competitive way (Hildebrandt, Hagemann & Thrän, 2017). Improving the New Zealand engineered wood value chain would help address New Zealand’s housing crisis.

The issue of the housing crisis is not limited to a shortage of supply of houses but also extends to the lack of quality housing (Clare et al., 2018). Poor-quality housing brings forth a range of issues which often harm the most vulnerable members of the community (Waterston, Barbara & Samson, 2015). These issues include poor education performance, malnutrition, increased crime, and physical and mental health issues (Waterson, Barbara & Samson, 2015). Research has shown how health and happiness increase the more people are connected to nature (Richardson et al., 2016). Being a natural material, it has been suggested that engineered wood could improve people's connection to nature (Whiting, 2020).

Building performance of engineered wood products

Engineered wood products have a range of performance advantages over other building materials which makes it an attractive building material.

Engineered wood has proven improved fire performance (Singh, Page & Simpsons, 2019; Buchan et al., 2018). Previously, it has been a perception that engineered wood products are not as fire resistant as other materials, particularly for taller buildings (Wade et al., 2018, Mallo & Espinoza, 2015). After many years, engineered wood products have seen developments in improving their fire resistance performance and now, in many cases, excel compared to other building materials (Żmijewki & Wojtowicz-Jankowska, 2017). For example, CLT can provide up to 120 minutes of fire resistance due to its cross-section profile (Żmijewki & Wojtowicz-Jankowska, 2017) and charring properties (Mallo & Espinoza, 2015).

Engineered wood's seismic resilience is another benefit of the building material. Engineered wood products do have proven seismic resilience which would make it a favourable product in areas with high earthquake activity (Iqbal & Popovski, 2017; Buchan et al., 2018). This is particularly important for New Zealand which is at high risk of earthquakes and has suffered from major events such as the 2011 Christchurch Earthquake which resulted in 185 deaths (New Zealand Police, 2012) and an estimate of NZ$40 billion in damages (National Business Review, 2018). CLT buildings are better able to dissipate the seismic energy and the CLT panels act like rigid bodies which makes the building more earthquake resistant (Tannert, 2019). Even though engineered wood is relatively earthquake resistant, there is a lot of literature investigating options to further improve this. This includes combining CLT with resilient slip friction joins (RSFJ) (Hashemi, Zarnani, & Quenneville, 2019) and with post-tensioning cables (Iqbal & Popovski, 2017).

Engineered wood products have had issues with decay if not treated. When CLT has prolonged exposure to moisture it is susceptible to common wood decay fungi, while LVL is less susceptible (Singh, Page & Simpson, 2019). There is sensitivity to this issue in New Zealand due to the "leaky building" crisis which affected many New Zealand homes that were built in the late 1980s and mid 2000s (Singh, Page, & Simpson, 2019). Treating the engineered wood products with boron biocide prevents the development of decay and the New Zealand building standards now require them to be so treated (Singh, Page, & Simpson, 2019). The boron treatments do add an additional cost but have proven to provide protection even with prolonged exposure to wet conditions (Singh, Page, & Simpson, 2019).

Environmental benefits

Engineered wood products provide greater environmental benefits compared to other building materials. Increasing the production of engineered wood products could therefore help overcome environmental challenges.

The impacts of climate change are global but New Zealand, in particular, faces significant issues. Rising sea levels, increasing frequency and duration of droughts, higher rates of weather events, and increasing temperature variance have already been seen across the world (Hopkin et al., 2015). New Zealand's dependence on agriculture, forestry, fisheries, and natural resources makes it particularly vulnerable to climate change (Hopkin et al., 2015). Neighbouring Pacific Islands are likely to be displaced from the impacts of rising sea levels due to climate change (Farquhar, 2015). This could result in increased migration to New Zealand (Farquhar, 2015), which could put even further increase housing demand. New Zealand's ability to manage its natural resources, including forestry, will be a determining factor in its capability to overcome the challenges of climate change (Ausseil, 2019).

The production of engineered wood creates less carbon emissions compared to other common building materials. Sustainability- and environmentally-beneficial products are becoming a great influence in the governance of value chains (Arfini et al., 2019). This is particularly important in the construction industry as it is a major producer of waste (Bergsdal et al., 2007) and a major contributor of greenhouse gas (GHG) emissions (Berawi et al., 2019). Calculations comparing the carbon emissions produced by engineered wood products to those produced by other conventional materials found that engineered wood production results in about 20 per cent less carbon dioxide output than fabricated metal products, 50 per cent less than iron and steel and 25 per cent less than cement (Winchester & Reilly, 2020). Due to the lifecycle of engineered wood products, including the growing of carbon sequestering trees, this makes it a low carbon alternative compared to other building materials (Mallo & Espinoza, 2015). Concrete and steel are energy intensive to manufacture, and concrete's additional weight also increases its transportation emissions (Lu, Hanandeh & Gilbert, 2017). This is important as countries aim to reduce their carbon emissions. Other environmental benefits such as being renewable and recyclable make it even more attractive to overcome environmental challenges (Evison, Kremer & Guiver, 2018).

Engineered wood products' environmental performance continues to be developed. Even though engineered wood products already have environmental advantages over other building materials, there is continued research into opportunities to further improve its environmental performance. This includes research into how engineered wood decays in landfills (Ximenes, Cowie and Barlz, 2018) and research into the high amounts of chemicals and energy used to manufacture engineered wood products, even though they are still lower than with other materials (Lu, Hanadeh and Gilbert, 2017). There are certain chemicals used to create the products, such as the petrochemical adhesives in the glue in CLT (Bui et al., 2020). These are being currently investigated, with research being done around the viability of adhesive-free engineered wood products such as adhesive-free laminated timber beams (AFLB) and adhesive-free CLT (AFCLT) (Bui et al., 2020). This shows that there are efforts to continually improve the environmental benefits of engineered wood products.

Importance of forestry employment

Improved performance of the engineered wood value chain would improve the job opportunities of what will be an increasingly important source of employment. The forestry industry is a significant source of employment in New Zealand, contributing 35,000 jobs (Ministry of Primary Industries, 2020). More land is being converted into forestry as property owners are taking advantage of the grants offered by the One Billion Tree Program (Te Uru Rākau, 2020) and net emitting companies such as Air New Zealand look to offset their carbon emissions (Air New Zealand, 2020). There are concerns about what this means for regional jobs as productive sheep and beef land is being converted to forestry, which some claim only support one third of the jobs that sheep and beef provide per hectare (McSweeny, 2020). This is relevant in the context of rural-urban migration, as many regional people have moved to urban areas such as Auckland to gain employment which puts pressure on infrastructure (Grimes et al., 2016). The engineered wood value chain mostly operates in regional parts of the country such as Nelson, Gisborne, and Rotorua. Improving the performance of the engineered wood value chain would help address the concerns of decreasing regional jobs by increasing the amount of jobs created per hectare of forestry.

Research gaps and recommendation for further research

The majority of the value chain literature is on the broad New Zealand forestry industry. For example, Baker et al. (2017) discuss some of the challenges involved with value addition in New Zealand's forestry industry but not specifically engineered wood. The challenges involved in distinct wood processes vary, particularly in a value chain where the end uses are very different. There are still gaps in research on the specific chain of engineered wood in New Zealand. This means that the nuances and unique issues of the chain are not able to be explored to improve the chain performance. From this initial literature review, further research needs to takes place into the chain failure and performance improvement opportunities, specifically for the New Zealand engineered wood value chain, in order to make improvements.

Systematic Literature Review

In order to address the aim of this research, a systematic literature review (SLR) was undertaken. Using a transparent method, a SLR allows for trustworthy results which include minimal bias in order to address the research question appropriately (Higgins & Green, 2008; Durach, Kembro and Wieland, 2017). This should also allow others to use an identical methodology and achieve the same result (Fink, 2019). It's ability to do this allows it to be used in a variety of academic disciplines such as education, business, law, and health (Fink, 2019). Using an SLR has been successful in other value chains including forestry products (Tham, Pretzch & Darr, 2020). In order to find the relevant literature, an adaption of the Fink's (2019) seven tasks for SLRs and Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) phases of systematic review (Mother et al., 2009) was used.

Databases and search terms

The two databases used to find appropriate literature were "Web of Science" (www.webofknowledge.com) and "Scopus" (www.scopus.com). Both databases are well known for their multidisciplinary content that has been successfully used in other SLRs related to primary industries (Hatab, Cavinato & Lagerkvist, 2019). The search terms that were used to find the literature are:

"Engineered wood value chain", "Engineered wood construction", "Engineered wood architecture", "Cross-laminated timber value chain", "Glulam value chain", "Laminated veneer lumber chain", "New Zealand forestry value chain", "Forestry value chain", "New Zealand engineered wood", "New Zealand forestry", "New Zealand value chain", "Value chain performance", and "Value chain interventions".

Screening criteria

The first search found 580 articles in Web of Science and 764 articles in Scopus. Strict criteria were used to establish the relevant literature. Only literature in English was used. Although literature from all geographic locations was used, there was priority placed on research done in New Zealand. Similarly, while all value chains were used to gain an understanding of possible interventions, priority was put on those that researched engineered wood and forestry product value chains. Only peer-reviewed articles were consulted. Following this screening, 84 journal articles were found to be relevant to the New Zealand engineered wood value chain.

Synthesising the results

The synthesising used was on year of publication, geographical focus of the study, and division of three different themes: product demand; chain fragmentation; and cost of production. These themes have been identified as potential opportunities of performance improvement in the New Zealand engineered wood value chain through an initial analysis (Cantwell, 2020).

Results

An example of this synthesis can be found in Table 2.

Product demand

The theme of product demand is related to the downstream section of the value chain. This is used to search for solutions to drive value chain performance for the end users. In total, 44 of the 84 relevant articles discussed qualities, opportunities, and barriers to improving product demand. Out of the three synthesised themes, product demand was the most populous. It was divided into two sub themes.

Table 2. Example of synthesis used in the SLR

Author	Year	Relevant	Study Type	Product Demand	Chain fragmentation	Cost of production	Region	Search Term
Morin et al.	2020	Yes	Quantitative	No	Yes	No	Canada	Engineered wood value chain
Dagnino et al.	2020	No	Quantitative	No	No	No	Argentina	Engineered wood value chain
Ling et al.	2020	No	Quantitative	No	No	No	Malaysia	Engineered wood value chain
Dieste et al.	2019	Yes	Quantitative	Yes	No	Yes	Uruguay	Engineered wood value chain
Lu & El Hannand	2019	No	Quantitative	No	No	No	Australia	Engineered wood value chain
Li et al.	2019	No	Quantitative	No	No	No	USA/ Canada	Engineered wood value chain
Santos et al.	2019	No	Quantitative	No	No	No	UK/ Germany	Engineered wood value chain
Liu et al.	2019	No	Quantitative	No	No	No	China	Engineered wood value chain
Long & Batchelor	2018	No	Quantitative	No	No	No	Australia	Engineered wood value chain
Ascenso et al.	2018	No	Quantitative	No	No	No	Portugal/ Italy	Engineered wood value chain
Fernando et al.	2018	Yes	Qualitative	Yes	Yes	No	USA/ Canada	Engineered wood value chain

Architecture and engineer perception

Due to the influence that architects and engineers have on selection of building materials, many papers were found on the perceptions of these users about engineered wood products. Some studies

(Januzi-Cana, 2017; Mallo & Espinonza, 2015; Li & Xie, 2013) used quantitative surveys and questionnaires to gain an understanding of the perceptions of engineered wood from engineers and architects. These results have been summarised in Table 3.

There were many positive perceptions of engineered wood products that relate to the performance of the product. The pleasing aesthetics of the product were emphasised across multiple articles. The negative perceptions were mostly associated with the lack of experience and knowledge of the products which, in a risk-averse value chain (Hurmekoski, Jonsson & Nord, 2015), can be a great barrier in improving the product demand. There were also mixed perceptions of the cost and fire resistance where some showed it as a positive while others as a negative.

Table 3. The perceptions of architects and engineers on engineered wood products

Positive Perceptions	Negative Perceptions	Mixed Perceptions
• Aesthetics • Energy efficiency • Recyclability • Flexibility and time of construction • Environmental performance • Design flexibility • Seismic performance • Thermal performance	• Building code complexities • Availability of product • Lack of experience and technical details • Lack of professional education on the products	• Cost • Fire resistance

Source: (Januzi-Cana, 2017; Mallo & Espinonza, 2015; Li & Xie, 2013)

Opportunities for government intervention

The second sub theme was the potential for governments to intervene in value chains to improve the product demand. Government intervention is not uncommon, particularly to strengthen weak parts of the chain (Larsen, 2016). When the product plays a part in the government's policy direction, intervention can be desirable (Larsen, 2016). For example, in Uganda, policies were put in place to make it easy for sawmills to enter the chain to improve the growth of the industry (Kambugu et al., 2013).

The New Zealand government has provided support in order to improve the demand of engineered wood products. This includes buildings at public institutions such as University of Canterbury's multi-storey LVL building (Buchanan et al., 2008) and the Nelson-Marlborough Institute of Technology (NMIT)'s Art and Media engineered wood multi-storey building (Holden et al., 2016). The NMIT building also included a direct investment of NZ$1 million into the design and construction from the New Zealand Ministry of Agriculture and Forest (Holden et al., 2016).

There were also more recent papers which discussed the potential of government intervention in forestry in New Zealand as COVID-19 exposed the dependence of the value chain on China (Gao & Ren, 2020). Many value chains, including forestry, in New Zealand have been built around China in order to get the scale, efficiency, and access to the world's biggest market, but the pandemic has shown the risk of disruption that comes with this (Gao & Ren, 2020). The literature found in this sub theme showed the opportunities for the New Zealand government to intervene in the engineered wood value chain.

Chain fragmentation

The theme of chain fragmentation examined potential contributors and solutions to the fragmentation involved in the New Zealand engineered wood value chain. There were 34 out of the 84 articles reviewed which discussed this theme. Again, two sub themes were identified.

Log allocation technology

Technology to assist the allocation of logs to appropriate mills was the most common solution to chain fragmentation discussed in the literature. These technologies can be found in Table 4.

Table 4. Log allocation technologies found in the literature and the benefit to chain fragmentation

Technology	Benefit
Machine learning-based models of sawmills	To simplify the data computation phase, allowing the provision of high-quality recommendations in sending the right log to the right mill.
Acoustic sensors	Can be used by LVL mills to predict the structural properties of the wood before it is processed to determine if it has the right strength to suit the LVL product. Using acoustics was a common technology solution to find the stiffness of the logs which is particularly important for engineered wood products.
'SEGMOD'	To segregate logs depending on the level of resin and acoustic velocity, allowing a reduction in the number of unprocessed logs going to export.
Computer-based decision support systems (DSS)	To provide quality data on the growth and quality of the products, as well as forecasts in order to help the forestry value chain plan and make better decisions. The technology was developed over 35 years ago by New Zealand forestry scientists.
Internet of Things (IoT) technology	Used in rough outdoor environments and can be used in New Zealand to monitor trees which would normally put workers in hazardous environments.
Blockchain integration with IoT	Allows for data integrity across the whole value chain. The fact that it is decentralized can remove the inter-competitiveness within a chain.
Light Detection and Ranging (LiDAR)	Uses near-infrared range lasers to accurately map forests, tree numbers and heights to show volumes of logs being produced.

Source: (Morn et al., 2020; Achim et al., 2011; Lowell et al., 2014; Murphy & Moore, 2018; West et al., 2013; Ziekow, Hinze & Bowen, 2019; Zhao et al., 2019; Adam et al., 2011)

The technologies in Table 4 all showed signs of being able to overcome the challenges involved with getting the right logs to each actor in the chain, and alleviating the inaccuracies of forest inventories and planning, which would assist in reducing the fragmentation in the New Zealand engineered wood value chain.

Industry leadership

The only other literature found outside of technology-based solutions related to reducing chain fragmentation was on industry leadership. Industry leadership is often a requirement of closing the fragmented gaps within a chain particularly when moving away from raw material supply and getting more products down the value chain (Baker et al., 2017). The necessities in product design, development and marketing require strong leadership (Baker et al., 2017).

This is even more important when a high proportion of the product is exported, as in New Zealand. When looking at other primary industry value chains in New Zealand, the importance of value chain governance to facilitate market location requirements was examined (Trienekens et al., 2018). Leadership was found to be the most important characteristic of value chain governance. Improved leadership results in more connected actors, and improved intelligence generation and communication (Trienekens et al., 2018). When there is strong leadership there are many benefits to be had, including trust and satisfaction between chain actors which results in improved sales and profit as chain actors are able to make major decisions in partnership (Trienekens et al., 2018). Leadership was found to be part of the solution to chain fragmentation.

Cost of Production

When focussing on the cost of production, the lens is on the upstream part of the chain that looks at the opportunities for New Zealand to get logs to processors at a lower cost to gain a competitive advantage over competitors and make it an even more desirable product. Of the 84 relevant articles, 18 were related to the cost of the production. Three sub themes were identified.

Breeding & gene editing

One opportunity to decrease the cost of production in order to stay competitive is to improve the yield, the quality of the wood, and the desired qualities of the end products. Compared to most primary industries, growing trees is a very slow process. Because of this, it is important to get the most out of each tree. Forest tree breeding has been used for many years in order to select the genetic composition of the tree that most suits the human need at that time (Ruotsalainen, 2017). Forest tree breeding is particularly common for exotic tree species such as *Eucalyptus* spp. in countries outside of Australia and *Pinus radiata* in New Zealand (Ruotsalainen, 2017). The process of breeding involves three key steps: selection, crossing, and testing (Ruotsalainen, 2017). These steps are repeated in order to enhance the desired traits (Ruotsalainen, 2017). It is found that seed crops from first-generation phenotypic or tested seed orchards provide 10-25 per cent higher forest yields (Ruotsalainen, 2017). The use of forest tree breeding can be used in order to improve the cost of production.

Gene editing has the capacity to significantly improve the production of logs in New Zealand. There are many different gene editing methods such as CRISPR/Cas and TALENs (Fritsche et al., 2018). However, gene editing can target mutagenesis on plants with no DNA template (Fritsche et al., 2018). Its ability to improve production through selecting mutagenesis is particularly important for perennial crops with slow breeding cycles (Fritsche et al., 2018). Trees fall in this category as they have long rotation times (Ruotsalainen, 2017) which makes breeding a slow process. Gene editing has an even larger importance in New Zealand because, having a small domestic market, the nation must continue its history of primary industry innovation in order to maintain its competitiveness (Fritsche et al., 2018). Research has already been done in New Zealand on other plant species including apples, pasture, and potatoes (Fritsche et al., 2018). Being able to select positive traits makes this innovation very attractive for forestry (Fritsche et al., 2018). However, the New Zealand Environment Protection Authority (EPA) decision to exclude gene editing techniques where no foreign DNA remained in the plant from Genetically Mortified Organisms (GMOs) regulations was appealed and overturned in the High Court in 2014 (Fritsche et al., 2018). This means that gene editing is regulated the same as GMOs under the Hazardous Substances and New Organisms (HSNO) Act 1996 which includes a stringent regulatory framework (Fritsche et al., 2018). New Zealand's reluctant approach to gene editing is justified by market perceptions of its multi-billion dollar food export industry (Fritsche et al., 2018). Although gene editing could improve the production of forest trees in New Zealand, being regulated as a GMO will lower the appetite for research into its benefits in forestry.

Financial rewarding of carbon sequestration

From the literature reviewed the New Zealand’s Emissions Trading Scheme (ETS) appears to be a frontier for how and if carbon sequestration will be financially rewarded. If the sequestration of carbon is financially rewarded then the cost of production will improve. New Zealand developed the ETS in order to incentivise the reduction of carbon emissions to meet the country’s obligations to the Kyoto Protocol (Adams & Cavana, 2009). The Climate Change Response (Emissions Trading) Amending Act 2008 and Climate Change Response (Moderate Emissions Trading) Amendment Act 2009 created the domestic carbon credit (the NZU) (Evison, 2017). The forestry industry was the first to join the ETS in 2008 (Adams & Cavana, 2009). As forestry blocks are carbon sequestering they are rewarded with NZUs which can be exchanged with emitting sectors but must be surrendered if the land use has changed (Evison, 2017). The forestry company, City Forests Ltd, which has 16,000 ha of forestry, has sold NZUs and this has become a significant part of its revenue for a number of years (Evison, 2017). There are doubts whether this provides long term additional income, as the harvesting of logs works on the assumption that the carbon captured in the logs is automatically emitted into the atmosphere and that the residue decays across 10 years (Evison, 2017). If the NZUs are sold it will show as a liability but will never have to be paid back if the land use is never changed (Evison, 2017). However, forestry properties that regularly supply timber will only gain carbon revenue for roughly 20 years when the NZUs gained will equal the carbon liabilities as a result of the harvest (Evison, 2017). This may mean that the long term benefit is limited and possibly less liquid with a large liability shown on the certificate of title if the NZUs are sold. In the literature reviewed it was indicated that New Zealand does intend to recognise harvested wood products, such as engineered wood, under the New Zealand ETS. How this will be calculated has not been established (Evison, Kremer & Guiver, 2018). It was recognised when reviewing the literature that the New Zealand ETS is fast evolving, which needs to be taken into account even for recent literature. The discussions in the literature indicate that, if carbon sequestration is to be rewarded, this will revolve around the New Zealand ETS.

Robotics

The use of robotics has the potential to reduce harvesting costs and create a safer work environment in forestry. Forestry blocks in New Zealand can often be on dangerous terrain which creates a health and safety risk for workers (Bayne & Parker, 2012). This increases the cost of production as compliance and management costs increase, and there would be potential fines if an accident does occur (Bayne & Parker, 2012). Including the use of teleoperated robotics in both the growth and harvesting logs can help overcome some of these additional costs. This aligns with the New Zealand government goal of reducing harvesting costs by 25 per cent (Bayne & Parker, 2012). The use of teleoperated robotics would be a great addition to the industry not only for reducing the cost of production but also for keeping workers safe. Also, while highly-skilled employment would have to increase to operate and maintain the robots, low- skill, dangerous work may decline.

Discussion

Scrutiny of the 84 relevant articles found during the systematic literature review has allowed the production of five options to potentially improve the performance of the engineered wood value chain. Each of these options would require further detailed analysis of the cost and benefits before a final decision about implementation. The first two options are clear cases of chain failure (Fleming et al., 2018) and therefore amenable to collective action within the chain. The last three options fit within the realm of market failure and require government intervention to find a solution.

Increased training and education with engineered wood products

Increased training of New Zealand construction professionals and students with engineered wood products will help build greater understanding of the products, build better leadership in the value chain, and the ability to work through building code complexities. Two of the negative perceptions of engineered wood products seen in Table 2 were lack of experience and technical details as well as lack of professional education on the products. Increasing training for professionals and students would allow them to fill the knowledge gap of the products and overcome these negative perceptions. This could include industry and Government investment into New Zealand institutes of technology, polytechnics, and universities. Not only would this increase the knowledge but it could also build the leadership capability that is needed to close the fragmentation and gain the benefits of improved product design, development and marketing (Baker et al., 2017). With an increase of knowledge and leadership capability in the chain comes the potential to work through the building code complexities of dealing with a relatively new product to the industry. Overcoming these negative perceptions would increase product demand with downstream confidence in the product. With increased product demand as a benefit that comes with overcoming negative perceptions of the chain, the major actors in the chain should invest in further training of New Zealand construction professionals and students.

Investment into log allocation technology and robotics

Further investment into the use of log allocation technology and robotics will help reduce the fragmentation in the New Zealand engineered wood value chain and reduce the cost of production. The results show that there is a strong future for log allocation technology with seven different technology options noted to assist in getting the right logs to the right processors. Although this has a range of benefits for other forestry products, it is particularly important for engineered wood products which require specific wood properties (Lowell et al., 2014). If these technologies are adopted in New Zealand, this would not only mean that more wood with these properties would reach the appropriate processor, but it would also give oversight to the processors which would help them to better plan and reduce value chain uncertainties to allow effective response (Chopra & Meindl, 2012). The enhancement of log allocation can increase the gross profit by 50 per cent due to the certainty of wood quality (Müller, Jaeger & Hanewinkel, 2019).

There are many constraints that put pressure on the cost of production that could be helped by technology, such as the rural locations of forests, often situated on harsh terrain, and the transport to mills and ports across both the North and South Islands of New Zealand. The use of teleoperated robotics also reduces the cost of production as it lowers the costs of working on forestry blocks on dangerous terrain. The combined use of log allocation technology and robotics would lower the cost of production and improve the chain performance as more logs are allocated to the right processor. Further investment into log allocation technology and robotics is required by the chain.

Government funding of engineered wood products in public infrastructure

The New Zealand Government needs to continue funding the use of engineered wood products in public infrastructure. The diffusion of knowledge for new products takes time for it to be trusted in construction (Mallo & Espinoza, 2015). The experience of these innovators and early adopters will become the proven success examples for others willing to embrace the material (Mallo & Espinoza, 2015). The Government must continue to showcase local engineered wood by supporting public infrastructure similar to what it has done at the University of Canterbury (Buchan et al., 2007) and the Nelson-Marlborough Institute of Technology (Holden et al., 2016). This also includes other infrastructure outside of buildings, such as bridges, for which New Zealand has a history of using wood products (Singh & Page, 2018) and for which countries such as Sweden are using engineered wood to construct (Wang et al., 2013). Particularly as the environmental benefits of engineered wood aligns with the Government's policy direction of combating climate change it is a natural fit for the Government to provide support. Another recent example of aligning the value chain to government policy direction is how the New South Wales State Government in Australia has announced AU$48.2 million to fund 'Tech Central' in order to attract technology businesses to Sydney (NSW Government, 2020). Australian technology company, Atlassian, will be the tenant of a 40-storey hybrid timber building in Tech Central, making it the tallest hybrid timber structure in the world (O'Sullivan, 2020). By showcasing these products, engineers and architects gain additional confidence that will encourage their use and build off the positive perception that they already have (Table 3) resulting in an increase in downstream product demand.

Engineered wood products included in the Emission Trading Scheme

Further exploration into including engineered wood products into the Emission Trading Scheme (ETS) would improve the value chain performance. There are indications that wood products may be included in the ETS (Evison, Kremer & Guiver, 2018). There needs to be further research into how this will be calculated. Creating an additional financial reward to lock carbon in engineered wood products and incentives to sell to local processors rather than export overseas, which would fall outside of New Zealand's ETS and assumes carbon is released into the atmosphere, will help improve the performance of the chain. This is especially critical for the small holders who make up 40 per cent where spot pricing is a major influence in their selling behaviour (Clark, 2018). Including engineered wood products into the ETS could incentivise more forest owners to sell to local manufacturers, resulting in overall chain improvement from increased supply. Further exploration into including engineered wood products into the ETS would incentivise forestry block owners to sell to local processors.

Clear vision on the future of gene editing

New Zealand must gain a clear vision of the future of gene editing for the benefit of the industry and the performance of the value chain. The decision to regulate gene editing as a GMO has meant that it must go through a stringent regulatory framework (Fritsche et al., 2018). The use of gene editing has great benefits in selecting positive traits of trees to improve yields and reduce the cost of production. By reducing the cost of production in the growing stage this could flow down the chain and make the cost of New Zealand engineered wood cheaper. This could have great benefits in gaining a competitive advantage, particularly over Europe which is a major producer of forestry products and also regulates gene editing as a GMO and as a result includes strict regulations (Macnaghten & Habets, 2020). This is an issue that New Zealand does have to tread carefully in due to the perceptions of gene editing which could risk its food export industry (Fritsche et al., 2018). The direction that New Zealand will go needs to be established in order for the forestry industry to move forward. Gene editing is far superior in reducing the cost of production than traditional breeding technologies. However, if it is not an option, the investment needs to be put into breeding in order to be competitive. If direction remains unclear then the resources are diluted into both areas. A clear vision on gene editing in New Zealand is needed for the forestry industry to move forward and invest in the appropriate technique to improve yields, lower the cost of production, and improve the performance of the value chain.

Conclusion

Improving the performance of the New Zealand engineered wood value chain would have major social, environmental, and economic benefits for the nation. The performance of the chain was defined by an adaptation of Aramyan's (2007) PMS outlined in Table 1. These benefits include increased economic performance, reduction of carbon emissions, creation of regional jobs, and increased availability of a high-quality building material. This relates to many of the country's goals in combating climate change, reducing the housing shortage, and economic growth. Despite these benefits, the majority of logs are exported as unprocessed logs meaning that value is lost as the value chain does not perform. This is particularly important as New Zealand forestry is in decline and may suffer further from the global economic impacts of COVID-19.

In order to provide suggestions to improve the value chain, a systematic literature review (SLR) was conducted. The use of an SLR was used to find, sort and review existing literature to address the aim to explore potential interventions to the New Zealand engineered wood value chain and offer options to improve its performance. There were 84 relevant journal articles found which were organised into the themes of product demand, chain fragmentation, and cost of production.

Based on the results of the SLR, five options were produced in order to potentially improve the performance of the value chain. One was to increase the training of New Zealand construction professionals and students with engineered wood products to close the knowledge gap of the products and build leadership in the chain. This would overcome some of the negative perceptions of the products resulting in increased product demand. It was suggested that the New Zealand Government continues to fund the use of engineered wood in public infrastructure to showcase and build confidence in the product. This increased demand in the product would help achieve the shift of strategic fit as the investment into increasing the value of the product will be matched by further willingness to pay. An additional option was investment into log allocation technology and robotics to reduce the fragmentation with better log allocation and reduce the cost of production on dangerous terrain. A need for a clear vision of the future of gene editing in order to invest directly in it or to alternatively invest those resources into breeding was also advised. Lastly, it was suggested that further exploration into including engineered wood into the Emission Trading Scheme (ETS) to incentivise forestry block owners to sell to local processors as they would get the financial reward for locking carbon. These five options would all potentially contribute to improving the performance of the New Zealand engineered wood value chain which would, in turn, allow more logs to be processed and hence the social, environmental, and economic benefits would be gained.

There are further studies required in order to assist improving the performance of the New Zealand engineered wood value chain. Firstly, further detailed analyses of the cost and benefits of the five options are required to further determine their viability. Secondly, quantitative research is needed into the economic and environmental benefits of marketing New Zealand primary exports as gene editing free versus using the technology. This would help establish the clear vision of gene editing in New Zealand. Thirdly, studies into how engineered wood could be included in the ETS would assist policy makers in the process and allow an additional incentive to process locally. Finally, it was noted that there was no mention in the surveyed literature of formal alliances or partnerships between small producers similar to other primary industries. It is established in other value chain studies that partnerships enhance value chain performance (Rich et al, 2011) yet this was not a theme identified from the SLR. It is suggested that further research is conducted into the possibility of establishing further alliances and partnerships in the value chain. These studies would contribute to the improved performance of the engineered wood value chain.

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Appendicies

Appendix Table 1.1. Table of abbreviations

Abbreviation	Definition
AFCLT	Adhesive free cross-laminated timber
AFLB	Adhesive free laminated timber beams
CAS	Cellular apoptosis susceptibility
CLT	Cross-laminated timber
CRISPR	Clustered regularly interspaced short palindromic repeats
DNA	Deoxyribonucleic acid
DSS	Decision support systems
EPA	Environment Protection Authority
ETS	Emissions Trading Scheme
GDP	Gross Domestic Product
GHG	Greenhouse gas
Glulam	Glued laminated
GMO	Genetically modified organism
HSNO	Hazardous Substances and New Organisms
IoT	Internet of things
LiDAR	Light detection and ranging
LVL	Laminated veneer lumber
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-Analysis
NMIT	Nelson-Marlborough Institute of Technology
NZU	New Zealand Unit
SLR	Systematic literature review
TALEN	Transcription activator-like effector nuclease

Appendix Table 2.1. Final selected literature from SLR

Author	Year	Relevant	Study Type	Product Demand	Chain fragmentation	Cost of production	Region	Search
Nunes et al.	2020	Yes	Qualitative	No	No	Yes	Brazil	Engineered wood value chain
Bui et al.	2020	Yes	Quantitative	Yes	No	No	Europe	Engineered wood value chain
Li et al.	2020	Yes	Quantitative	Yes	No	No	Germany	Engineered wood value chain
Winhcester & Reilly	2020	Yes	Quantitative	Yes	No	No	New Zealand	Engineered wood value chain
Ximenes, Cowie & Barlaz	2018	Yes	Quantitative	Yes	No	No	Australia	Engineered wood value chain
Lu, Hanandeh & Gilbert	2017	Yes	Quantitative	Yes	No	Yes	Australia	Engineered wood value chain
Holden et al.	2016	Yes	Qualitative	Yes	No	Yes	New Zealand	Engineered wood value chain
Morn et al.	2020	Yes	Quantitative	No	Yes	No	Canada	Engineered wood value chain
Dieste et al.	2019	Yes	Quantitative	Yes	No	Yes	Uruguay	Engineered wood value chain
Fernando et al.	2018	Yes	Qualitative	Yes	Yes	no	USA/Canada	Engineered wood value chain
Hurmekoski, Jonsson & Nord	2015	Yes	Qualitative	Yes	Yes	Yes	Europe	Engineered wood value chain
Achim et al.	2011	Yes	Quantitative	No	Yes	Yes	Canada	Engineered wood value chain
Vinden	2002	Yes	Qualitative	Yes	No	No	Australia	Engineered wood value chain
Wang et al.	2013	Yes	Qualitative	Yes	No	No	Sweden	Engineered wood construction
Ellingwood	1997	Yes	Qualitative	Yes	Yes	No	USA	Engineered wood construction
Rosowsky	1995	Yes	Qualitative	Yes	Yes	No	USA	Engineered wood construction
Wade et al.	2018	Yes	Qualitative	Yes	No	No	New Zealand	Engineered wood architecture
Figorilli et al.	2018	Yes	Qualitative	No	Yes	No	Italy	Engineered wood architecture
Kuzman et al.	2018	Yes	Qualitative	Yes	No	No	Europe	Engineered wood architecture
Kuzman, Sandberg & Haviarova	2018	Yes	Qualitative	Yes	No	No	Europe	Engineered wood architecture
Januzi-Cana	2017	Yes	Quantitative	Yes	No	No	Kosovo/Italy	Engineered wood architecture
Zmijewki & Wojitowicz-Jankowska	2017	Yes	Qualitative	Yes	No	No	Europe	Engineered wood architecture
Ross	2017	Yes	Qualitative	Yes	No	No	Canada	Engineered wood architecture
Mallo & Espinoza	2015	Yes	Quantitative	Yes	No	No	USA	Engineered wood architecture
Li & Xie	2013	Yes	Qualitative	Yes	No	No	Taiwan	Engineered wood architecture
Zumbrunnen & Fovargue	2012	Yes	Qualitative	Yes	No	No	Australia/ New Zealand	Engineered wood architecture
Kuzman, Oblak & Vratusa	2010	Yes	Qualitative	Yes	No	No	Slovenia	Engineered wood architecture

Bergsdal et al.	2007	Yes	Qualitative	Yes	No	No	Norway	Engineered wood architecture
Hildebrandt et al.	2017	Yes	Qualitative	No	Yes	Yes	Germany	Cross-laminated timber value chain
Fragiacomo, Rui & Scotti	2015	Yes	Qualitative	No	Yes	No	Italy	Cross-laminated timber value chain
Jarosch et al.	2020	Yes	Qualitative	No	Yes	No	Germany	Laminated veneer lumber value chain
Hirschmuller et al.	2018	Yes	Quantitative	No	No	Yes	Germany	Laminated veneer lumber value chain
Evison, Kremer & Guiver	2018	Yes	Qualitative	Yes	Yes	No	Australia/New Zealand	Laminated veneer lumber value chain
Childerhouse et al.	2020	Yes	Quantitative	Yes	No	No	New Zealand	New Zealand forestry value chain
Fritsche et al.	2018	Yes	Qualitative	No	No	Yes	New Zealand	New Zealand forestry value chain
Murphy & Moore	2018	Yes	Quantitative	No	Yes	No	New Zealand	New Zealand forestry value chain
Baker et al.	2017	Yes	Qualitative	No	Yes	No	New Zealand	New Zealand forestry value chain
West et al.	2013	Yes	Qualitative	No	Yes	No	New Zealand	New Zealand forestry value chain
Adams & Cavana	2009	Yes	Qualitative	No	No	Yes	New Zealand	New Zealand forestry value chain
Stringer	2006	Yes	Qualitative	Yes	No	No	New Zealand	New Zealand forestry value chain
Kambugu et al.	2013	Yes	Qualitative	No	Yes	No	Uganda	Forestry Value Chain
Hashemi, Zarnani & Quenneville	2020	Yes	Quantitative	Yes	No	No	New Zealand	New Zealand engineered wood
Singh, Page & Simpson	2019	Yes	Qualitative	Yes	No	No	New Zealand	New Zealand engineered wood
Tannert	2019	Yes	Qualitative	Yes	No	No	USA	New Zealand engineered wood
Singh & Page	2018	Yes	Qualitative	Yes	No	No	New Zealand	New Zealand engineered wood
Dal Lago et al.	2017	Yes	Qualitative	Yes	No	No	New Zealand	New Zealand engineered wood
Iqbal & Popovski	2017	Yes	Quantitative	Yes	No	No	New Zealand	New Zealand engineered wood
Iqbal	2016	Yes	Qualitative	Yes	No	No	New Zealand	New Zealand engineered wood
Iqbal et al.	2016	Yes	Quantitative	Yes	No	No	New Zealand	New Zealand engineered wood
Ardalany, Fragiacomo & Moss	2016	Yes	Qualitative	No	Yes	No	New Zealand	New Zealand engineered wood
Arnani & Quenneville	2014	Yes	Qualitative	No	Yes	No	New Zealand	New Zealand engineered wood
Ruotsalainen	2014	Yes	Quantitative	Yes	No	No	New Zealand	New Zealand engineered wood
Crews et al.	2011	Yes	Qualitative	Yes	No	No	New Zealand	New Zealand engineered wood
Buchanan et al.	2008	Yes	Quantitative	Yes	No	No	New Zealand	New Zealand engineered wood
Ziekow, Hinze & Bowen	2019	Yes	Quantitative	No	Yes	No	New Zealand	New Zealand Forestry

Pizzirani et al.	2019	Yes	Quantitative	No	Yes	No	New Zealand	New Zealand Forestry
Evison	2017	Yes	Qualitative	Yes	No	No	New Zealand	New Zealand Forestry
Morgenroth & Visser	2013	Yes	Qualitative	No	Yes	Yes	New Zealand	New Zealand Forestry
Walker	2013	Yes	Qualitative	No	No	Yes	New Zealand	New Zealand Forestry
Bayne & Parker	2012	Yes	Quantitative	No	No	Yes	New Zealand	New Zealand Forestry
Wang	2012	Yes	Quantitative	Yes	No	No	New Zealand	New Zealand Forestry
Adams et al.	2011	Yes	Qualitative	No	No	Yes	New Zealand	New Zealand Forestry
Evison	2010	Yes	Quantitative	No	No	Yes	New Zealand	New Zealand Forestry
Levack	2009	Yes	Quantitative	No	Yes	No	New Zealand	New Zealand Forestry
Walker, Cocklin & Le Heron	2000	Yes	Qualitative	No	No	Yes	New Zealand	New Zealand Forestry
Gao & Ren	2020	Yes	Quantitative	Yes	No	No	Australia/ New Zealand	New Zealand Value Chain
McDermott et al.	2020	Yes	Quantitative	No	No	No	New Zealand	New Zealand Value chain
Abroah et al.	2019	Yes	Qualitative	No	Yes	No	Ghana	New Zealand Value chain
Loosemore et al.	2018	Yes	Quantitative	Yes	No	No	Australia/New Zealand	New Zealand Value chain
Dalziel et al.	2017	Yes	Qualitative	No	Yes	No	New Zealand	New Zealand Value chain
Trienekens et al.	2017	Yes	Qualitative	No	Yes	No	New Zealand	New Zealand Value chain
Akhtar, Kaur & Punjaisri	2017	Yes	Qualitative	No	Yes	No	New Zealand/Europe	New Zealand Value chain
Lim & Loosemore	2017	Yes	Qualitative	No	Yes	No	Australia/ New Zealand	New Zealand Value chain
Sharma, Lindsay & Everton	2015	Yes	Qualitative	No	No	Yes	New Zealand	New Zealand Value chain
Lowell et al.	2014	Yes	Quantitative	No	Yes	No	New Zealand	New Zealand Value chain
Biggemann, Williams & Kro	2014	Yes	Quantitative	No	Yes	No	New Zealand	New Zealand Value chain
Tham, Pretzch & Darr	2020	Yes	Quantitative	No	Yes	No	Vietnam	Value chain performance
Khoryanton et al.	2020	Yes	Quantitative	No	Yes	No	Indonesia	Value chain performance
Arfini et al.	2019	Yes	Quantitative	Yes	No	No	Italy	Value chain performance
Zhao et al.	2019	Yes	Quantitative	No	No	Yes	Worldwide	Value chain performance
Orr, Donovan & Stoian	2017	Yes	Quantitative	No	Yes	No	Worldwide	Value chain performance
Watabaji, Molnar & Gellynck	2016	Yes	Quantitative	No	Yes	No	Ethiopia	Value chain performance
Shah et al.	2018	Yes	Quantitative	No	Yes	No	Nepal	Value chain intervention
Larsen	2016	Yes	Quantitative	Yes	Yes	No	India	Value chain intervention