



ADVANCING ENHANCED WOOD MANUFACTURING INDUSTRIES IN LAOS AND AUSTRALIA

Effect of facility location on the financial feasibility of LVL manufacturing and the potential of distributed production models in subtropical eastern Australia



**Written by Jack Dorries, Tyron Venn, Robert McGavin
and William Leggate – March 2020**

VALTIP 3

This publication has been compiled by Jack Dorries, Dr Robert McGavin and William Leggate, Forest Products Innovation, Department of Agriculture and Fisheries, and Dr Tyron Venn, School of Agriculture and Food Sciences, The University of Queensland.

© State of Queensland, 2020

The Queensland Government supports and encourages the dissemination and exchange of its information. The copyright in this publication is licensed under a Creative Commons Attribution 4.0 International (CC BY 4.0) licence.

Under this licence you are free, without having to seek our permission, to use this publication in accordance with the licence terms.



You must keep intact the copyright notice and attribute the State of Queensland as the source of the publication.

Note: Some content in this publication may have different licence terms as indicated.

For more information on this licence, visit <https://creativecommons.org/licenses/by/4.0/>.

The information contained herein is subject to change without notice. The Queensland Government shall not be liable for technical or other errors or omissions contained herein. The reader/user accepts all risks and responsibility for losses, damages, costs and other consequences resulting directly or indirectly from using this information.

Contents

- 1.0 EXECUTIVE SUMMARY..... 1**
- 1.0 INTRODUCTION 1**
- 2.0 SUBTROPICAL EASTERN AUSTRALIA CASE STUDY 1**
- 3.0 METHODS..... 1**
 - 3.1 CASE STUDY SCENARIOS EXAMINED..... 2
 - 3.1.1 *Log procurement scenarios* 2
 - 3.1.2 *Facility location scenarios*..... 2
 - 3.1.3 *Processing scale scenarios*..... 3
 - 3.1.4 *Distributed production scenarios*..... 3
 - 3.1.5 *Manufacturing processes and final product scenarios*..... 4
 - 3.2 MODEL PARAMETERS FOR THE SUBTROPICAL EASTERN AUSTRALIA CASE STUDY..... 4
- 4.0 RESULTS 1**
 - 4.1 FINANCIAL PERFORMANCE OF INTEGRATED PROCESSING FACILITIES..... 1
 - 4.2 FINANCIAL PERFORMANCE OF DISTRIBUTED PROCESSING OPERATIONS 5
- 4.0 DISCUSSION..... 8**
- 5.0 CONCLUSION 12**
- 6.0 REFERENCES 13**
- 7.0 APPENDIX..... 16**
 - APPENDIX 1: SENSITIVITY OF NET PRESENT VALUE OF PRODUCT MANUFACTURE TO CHANGES IN LEVELS OF SEVERAL IMPORTANT MODEL PARAMETERS 16

1.0 Executive summary

The global decline in availability of large sawlogs due to reasons such as reduced native forest areas and poor silvicultural practices, is encouraging wood processors to consider investments in technology capable of efficiently utilising small, non-traditional log types. However, there is a dearth of information about the financial performance of such investments. This paper is the first to describe a discounted cash flow financial model to evaluate LVL manufacturing opportunities among different potential facility locations, in addition to estimating the financial feasibility of distributed wood production regimes. Application of the model to subtropical eastern Australia revealed that the mix of log types procured for EWP manufacture significantly impacted the financial performance due to the combined effects of mill-delivered log cost, product recovery from log volume and processing rates, which vary by log type. Strong economies of scale were present with EWP production in the analysis. Encouragingly for forest growers and wood processors, the optimal strategy for an EWP manufacturing facility processing a log volume of 30 000m³/y required 42.6% of log volume to be small logs. The model revealed that one-stage LVL manufacture was profitable at larger scales of production; however, the superior investment alternative was the production of two-stage LVL. While processing logs and converting them into EWPs within one facility proximate to the forest will always be most profitable, the analysis highlighted that distributed production operations, where a facility close to the forest produces and transports dry veneer to an EWP manufacturing plant located far away from the resource, can allow the manufacturing plant to profitably increase its levels of production. The advantages of distributed production models are extended if the entire operation is owned by a single vertically-integrated business. The model framework was demonstrated with an application to subtropical eastern Australia; however, the methodological framework and parameter levels are likely to be suitable for forestry decision-making environments outside Australia.

1.0 Introduction

The demand for sustainable, low-embodied energy, wood-based building products is increasing at a time when wood production from native forests globally is in decline (Warman 2014). Many countries are becoming increasingly reliant on shorter rotation timber plantations that are harvested before producing the large sawlogs that are historically supplied from native forests. Also, many countries currently have large volumes of small, low-grade plantation or native forest logs that are destined for low-value products such as landscaping, woodchips and bioenergy (Leggate *et al.* 2017). Forest growers and wood processors are seeking more efficient uses of the available log resources. One potential adaptation strategy for wood processors adjusting to the declining availability of large logs is to convert small diameter logs into veneer using spindleless rotary veneering technologies for veneer-based engineered wood product (EWP) manufacture.

Research by the Queensland Department of Agriculture and Fisheries (DAF) has demonstrated the potential to use emerging spindleless rotary veneering technologies to process hardwood plantation and native forest logs of sizes and qualities previously considered unmerchantable (i.e. less than 30 cm diameter and 2.6m length) (McGavin *et al.* 2014a, b; McGavin *et al.* 2015a, b, McGavin and Leggate 2019). That research has shown that spindleless rotary veneering can recover much higher proportions of marketable product from smaller sized logs than can be achieved through conventional sawing. Indeed, for small native forest *Corymbia citriodora* logs, spindleless rotary veneering produced double the marketable product recovery of sawing, and the resulting veneer contained visual qualities and mechanical properties well suited to the manufacture of veneer-based EWPs (McGavin and Leggate 2019).

Currently, the majority of Queensland's private native forests are in a state of low productivity due to decades of poor management that has resulted in a high stocking of trees that do not meet traditional product specifications for sawlogs, electricity distribution poles and bridge girders (Queensland CRA/RFA Steering Committee 1998, MBAC Consulting Pty Ltd. 2003a, b, Bureau of Rural Sciences 2004, Burgess and Catchpoole 2016). A major reason these forests are not being silviculturally treated to increase productivity is the cost of thinning trees that do not have logs that meet traditional product specifications and, therefore, little or no value can be recovered to offset the thinning costs. Spindleless rotary veneer processing could offer a financially viable manufacturing opportunity to efficiently utilise these under-utilised hardwood logs and facilitate the necessary silvicultural treatment in native forests to increase their productivity and ensure future supplies of traditional sawlogs, poles and girders.

In subtropical eastern Australia, the timber industry is seeking information to support their tactical and strategic veneer and EWP investment decisions, including:

- which log types should be procured?
- where should processing facilities be located?
- what scale of production should be targeted?
- which final products should be produced (i.e. how much value-adding)?

The objective of this paper was to assess how the location of veneer and EWP manufacturing facilities affect the financial performance of product manufacture. In addition, the potential of distributed processing operations was investigated where dry veneer is produced at a location proximate to the log resource and transported to an alternative facility for EWP production. This scenario could offer the advantage of reducing log haulage costs and providing greater access to harvestable forests by having the veneer processing facility located close to the

resource and only transporting veneer (without the waste generated from processing) to a product manufacturing facility that may be located remote from the forest (e.g. closer to an established town) for infrastructure support benefits, improved access to skilled labour, and better access to markets.

This report will expand research from Venn and McGavin (in press) and Venn *et al.* (in press) which determined the financial performance of veneer and veneer-based EWP manufacture for processing facilities harvesting logs from subtropical eastern Australian native forests. Laminated veneer lumber (LVL) was the veneer-based EWP chosen for analysis. The analysis has assumed the processing facilities are located in subtropical eastern Australia; however, the methodological framework and many parameter levels (e.g. number of employees and processing rates of inputs into outputs by stage of production) are likely to be suitable for application to many other wood processing decision-making environments domestically and internationally.

2.0 Subtropical eastern Australia case study

Subtropical eastern Australia has been defined as the 24.4 M ha area illustrated in Figure 1, encompassing northern New South Wales (NSW) and southern Queensland (QLD). There are 2.42 M ha of commercially important and harvestable (net of management restrictions) private native forests in the region (Francis *et al.* in press). There are also 3.0 M ha of production native forests on state land in this region, although the proportion of the state land area that is commercially important and harvestable was not available at the time of publication. The commercially important hardwood native forest types are predominantly uneven-aged and mixed-species, dominated by the genera *Eucalyptus* and *Corymbia*.

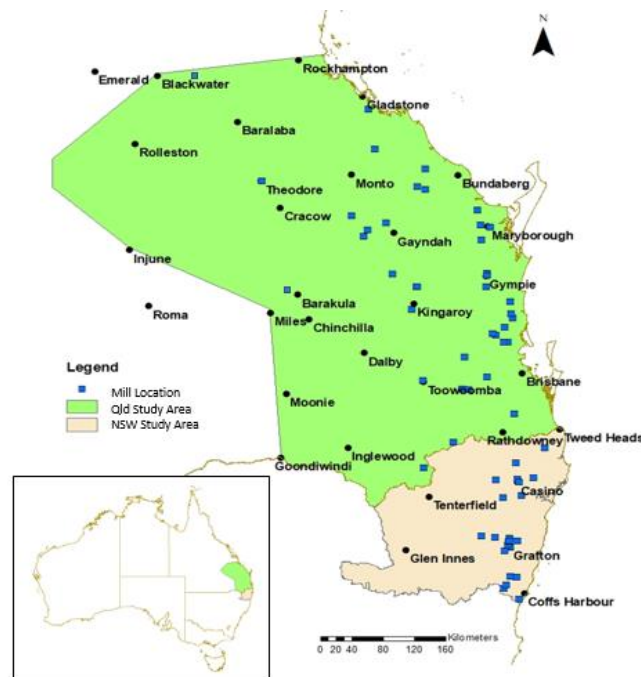


Figure 1. Case study area

Historically, 50% to 70% of annual hardwood log volume requirements in Queensland for the timber industry in this region have come from private native forests (Carron 1985, DPI Forestry 1998, Jay and Dillon 2016, State of Queensland 2016, Francis *et al.* in press), and this proportion appears set to rise. This is problematic, because, despite their relatively large geographic extent, many decades of ‘high-grading’ without follow-up silvicultural treatment has resulted in the accumulation of substantial volumes of suppressed, small trees (less than 30 cm diameter at breast height (DBH)), which are unlikely to ever attain the specifications of target traditional log types.

Previous studies have revealed that spindleless rotary veneering is able to efficiently and profitably process small diameter logs for the manufacture of EWPs (McGavin *et al.* 2014a, McGavin *et al.* 2014b, Gilbert *et al.* 2017, Leggate *et al.* 2017, Khoo *et al.* 2018, McGavin and Leggate 2019, Leggate *et al.* 2019, Venn *et al.* in press). Utilising small diameter logs would not only help to sustain the timber industry’s viability and their regionally important employment and income in the short to medium term, but potentially facilitate necessary silvicultural treatment to increase forest productivity and ensure long-term supplies of traditional sawlogs, electricity poles and bridge girders. Long-term growth plots indicate that silvicultural treatments increase forest productivity by a factor of between three and four (Lewis *et al.* in press-a).

3.0 Methods

This paper describes an aspatial discounted cash flow financial model to support veneer processing and LVL investment decisions as an extension at an existing processing facility (e.g. a sawmill). The model has been developed in spreadsheet software that is readily available to wood processors. The model has been populated with production and cost parameters that are likely to be broadly representative of veneer processing facilities in eastern Australia, having been collated from a literature review, quotes from equipment suppliers, and discussions with key informants within the industry. Following development of the model, three separate meetings were held with different industry experts to review and validate model parameters.

The financial model consists of six processing modules. Venn and McGavin (in press) described the first module, which is an aspatial mathematical ‘forest to mill’ model that defines the forest available to supply logs within a circular area or fraction of a circular area around a processing facility. Commercial and harvestable forest area, log volume per hectare of alternative log types, and competition for logs with other log processors can be defined for each 10 km concentric ring (a ‘haul zone’) radiating out from the processing facility. The model also requires inputs of maximum haul distance, stumpage prices, cut snig and load costs, fixed and variable log haul costs, and a harvest return interval. The harvest return interval is the minimum time between commercially viable harvests for a hectare of forest.

The ‘forest to mill’ module also includes a mathematical model that can optimise log procurement to maximise profitability of wood processing (rather than purely minimising mill-delivered log costs). This requires parameter estimates for rate of processing and recovery of final products from log volume for different log types. The ‘forest to mill’ module provides log volume and mill-delivered log cost information by log type to the remaining modules for each facility location, log procurement and processing scale scenario examined (described below).

Venn et al. (in press) described the next five modules which consisted of four processing modules and one financial performance module. The four processing modules take log inputs provided by the ‘forest to mill’ module or intermediate products from other processing modules and convert these inputs into final products. In this case study, each of these four modules cover one stage of processing, namely green veneer production (from logs), dry veneer production (from green veneer), one-stage LVL manufacture (from dry veneer), and two-stage LVL manufacture (from one-stage LVL). Each processing module considers information about the equipment used, the capital costs of buildings and equipment, method of purchase (cash or loan), asset life and salvage value. The model requires inputs of equipment utilisation rates, processing rates of inputs and the recovery of outputs from inputs, as well as rates of consumption of energy, water, boiler feedstock, glue, packaging and other consumables. Where appropriate, these modules multiply market prices by recovered product volume to estimate annual revenues.

The ‘financial performance’ module takes cost and revenue information from the first five modules to facilitate a discounted cash flow analysis. Four investment performance metrics are calculated by the model; NPV, internal rate of return (IRR), the payback period for up-front capital cost (in year zero), and mean costs of production and profit per cubic metre of final product. When calculating mean costs of production per cubic metre of final product, all buildings and equipment capital costs are amortised over the investment period, such that the discounted sum of the annualised capital costs is equivalent to the present value of these

capital costs. The financial performance module facilitates sensitivity analyses for all parameters.

The remainder of this section defines the scenarios examined and the model parameter levels adopted for the subtropical eastern Australia case study.

3.1 Case study scenarios examined

This report has evaluated the financial performance of LVL manufacture for 54 scenarios. These include three log procurement scenarios, two facility location scenarios, three processing scale scenarios, and two final product type scenarios. Eighteen distributed production scenarios are also defined below.

3.1.1 Log procurement scenarios

Four hardwood log types have been examined: A-grade sawlogs; B-grade sawlogs; small peeler logs; and top logs. Small-end diameter under bark (SEDUB), harvestable volumes per hectare for selective harvesting regimes permitted in the study area, and stumpage and harvest costs are listed for each log type in Table 1, and described further in Venn and McGavin (in press). Unless otherwise specified, all dollar amounts reported are Australian dollars¹. A and B-grade sawlogs are traditional log types with which the hardwood industry is familiar. Small peeler logs and top logs are proposed new log types with which the industry has limited to no experience. Small peeler logs are from the bole of small diameter and suppressed trees. Top logs would typically be left among the residue following a traditional native forest harvest. These logs could be in the bole of a felled tree above a sawlog, but below crown break, or could be within the crown.

The following three log procurement scenarios have been evaluated:

1. small peeler logs and top logs;
2. small peeler logs, top logs, B-grade sawlogs and A-grade sawlogs; and
3. optimal procurement of logs to maximise NPV.

In log procurement scenario 1, the veneering facility only utilises small peeler logs and top logs. Other log types from each harvested hectare are procured for processing into non-veneer product types (e.g. sawnwood) and are not considered further in the analysis. In log procurement scenario 2, all four log types from every harvested hectare are utilised for LVL manufacture. In log procurement scenario 3, all four log types can be processed, but the model optimally procures particular log types within the study area to maximise NPV.

Table 1. Log and harvest cost parameters

Parameter	Log type		
	Small peeler or top log	B-grade sawlog	A-grade sawlog
SEDUB (cm)	25	35	45
Harvestable volume (m ³ /ha)	3.4 / 0.6	3.5	1.1
Stumpage costs (\$/m ³)	40	55	110
Cut, snig and load costs (\$/m ³)	66 / 48	43.5	43.5

3.1.2 Facility location scenarios

Since it is not uncommon for sawmills in the study area to haul logs up to 400 km, and because the study area is on the east coast of Australia, the analysis assumes that logs can be

¹ In April 2020, A\$1 = US\$0.60.

harvested from a semi-circular area to maximum distance of 400 km from the veneering facility. The facility location scenarios differ in terms of how the harvestable forest area is distributed around the facility. Two facility location scenarios have been adopted from Venn and McGavin (in press):

- A. No harvestable resource within 50 km of the processing facility, 3.55% of the landscape between 51 km and 100 km, and 7.3% of the landscape thereafter to 400 km; and
- B. 21.3% of the landscape between 0 km and 100 km, and then 6.1% of the landscape thereafter to 400 km.

Scenario A reflects likely resource conditions for a processing facility located distant from the forest (e.g. within a township). Scenario B has been designed to reflect a processing facility located in close proximity to commercial and harvestable forests.

3.1.3 Processing scale scenarios

Empirical evidence from an existing spindleless rotary veneering operation in Australia that is processing hardwood logs suggests 15 000 m³/y of log throughput is achievable with one full-time spindleless rotary veneering line. This analysis considers three processing scales: (1) a part-time operation at 7500 m³/y of log; (2) a full-time operation processing 15 000 m³/y of log; and (3) a full-time operation processing 30 000 m³/y of log with two spindleless rotary veneering lines.

3.1.4 Distributed production scenarios

This analysis also examines scenarios where one veneer processing facility in location B processes dry veneer and transports it to an LVL plant in location A. Costs of distributed production of veneer and LVL are likely to be higher than for one integrated facility, as there will be additional costs from handling, transporting and receiving the veneer, as well as an additional cost of profit mark-up applied by the veneering facility.

Nonetheless, distributed production can reduce average mill-delivered log costs and may overcome limitations of log supply for manufacturing facilities located far away from the resource (such as facility location A). Thus, distributed production has the potential to expand the range of technically and financially feasible production scenarios.

Distributed production has been evaluated for 18 scenarios. Two final product types (one-stage and two-stage LVL); three log procurement scenarios (1, 2 and 3); three processing scales for veneering at location B that would supply feedstock to an LVL manufacturing facility at location A. The veneer processing scale scenarios are:

1. one 15 000 m³/y of log veneering facility;
2. one 30 000 m³/y of log veneering facility; and
3. two separate 15 000 m³/y of log veneering facilities.

Costs per cubic metre of dry veneer production for each of the 18 scenarios have been taken from the log procurement and processing scale scenarios for integrated dry veneer production, which includes packaging the dry veneer at the veneering facility. Freight to, and handling costs at the receiving LVL plant have been considered over the range of \$20/m³ to \$40/m³ of dry veneer. Furthermore, this analysis assumes that a profit mark-up of 10% has been applied to the cost of veneer supplied to the LVL plant.

For each distributed production scenario, costs at the facilities have been summed, and gross profit (revenues minus costs of production), tax payable (gross profit multiplied by the tax rate of 30%), and after tax profit (gross profit minus tax payable) have been calculated.

3.1.5 Manufacturing processes and final product scenarios

Two final product scenarios have been assessed: (1) one-stage LVL; and (2) two-stage LVL. The dimensions of these products adopted for analysis are indicated in Table 2.

Table 2. Final product dimensions

Final product	Length (m)	Width (m)	Thickness (mm)
One-stage LVL	2.40	0.12	35.0
Two-stage LVL	2.40	0.15	100.0

Hardwood logs delivered to the veneering facility are pre-conditioned (heated) and docked to 2.6 m length billets. Billets are then fed into a rounding-debarker lathe to produce a cylindrical billet prior to veneering (Leggate *et al.* 2017). Next, the billets are processed through a spindleless lathe and green veneer ribbons are recovered until the residual cylindrical peeler core at the centre of the billet is reached. The ribbons are clipped to length and proceed on-site to be dried.

Green veneer sheets are dried in a conventional jet-box dryer to a moisture content of approximately 5%. Dry veneer is graded in accordance with AS/NZS 2269.0:2012 (Standards Australia 2012) and clipped to remove damage that may have occurred during the drying process. Under distributed production scenarios, dry graded veneer is packaged and transported from the veneering facility to the LVL plant. If integrated production is assumed, the dry veneer will then proceed on-site to be manufactured into one-stage LVL.

One-stage LVL manufacture has been modelled assuming traditional plywood production equipment is used. This restricts the LVL section length to billet length (2.6 m), less necessary end-trimming. LVL panels are produced from gluing together twelve dry veneer sheets with phenol formaldehyde adhesive (PF) and pressed in a cold press for six minutes before being placed in a hot press for twenty minutes to cure the adhesive. If one-stage LVL is sold, the LVL panels are sawn and sanded to the final dimensions and packaged for freight to market. The one-stage LVL product examined here is assumed to substitute for sawn timber in applications where high mechanical performance is required (e.g. in multi-storey construction).

If production continues beyond one-stage LVL manufacture, three one-stage LVL panels are pressed together in a cold press for eight hours with resorcinol formaldehyde adhesive (RF) to form a larger dimension product that cannot be manufactured in a conventional one-stage process. The two-stage LVL panel is then sawn and sanded to the desired dimensions and packaged for freight to market. In this case study, the two-stage product is assumed to be an electricity pole cross-arm that can substitute for solid wood or fibreglass cross-arms.

3.2 Model parameters for the subtropical eastern Australia case study

The financial model has been populated with processing, product recovery rate, cost and revenue parameters that are broadly representative of the operating environment in subtropical eastern Australia. These estimates have been collated from a literature review and empirical research from Venn *et al.* (2020), Venn and McGavin (in press) and Venn *et al.* (in press), quotes from equipment suppliers, and discussions with key informants within the timber industry.

All LVL manufacturing scenarios have been evaluated for a 30-year project life at a 7% real (net of inflation) discount rate. All buildings and equipment constructed or installed at the beginning of the investment period are assumed to have been purchased with 30% cash and

the remainder borrowed at 6% per annum over 10-years. All equipment purchased in later years to replace items that have reached the end of their useful life are paid from operating cash in the year of acquisition. To account for building construction, and equipment acquisition, delivery and installation, only half the log volume applicable for the processing scale is assumed to be processed in the first year of production. Profits have been taxed at 30%.

Table 3 reports the total commercial and harvestable native forest area by haul distance available to the veneering facility, adjusted to account for competition for the resource from existing sawmills. Listed haul distances are Euclidean distances from the forest to the processing facility. To account for the reality that roads do not run in straight lines from the forest to the facility, a ‘windy road’ factor has been adopted to inflate Euclidean haul distances in Table 3 by 30%. Consistent with current industry practice, the maximum haul distance was set to 400 km and the harvest return interval 30 years.

Table 3. Forest area and haul cost parameters by haul distance from the facility

Haul zone	Haul distance of forest to facility (km)	Commercial and harvestable forest area available to the facility by facility location scenario (ha)		Fixed haul costs (\$/m ³)	Variable haul costs (\$/m ³ /km)
		A: 0% < 50 km, 3.55% for 51 to 100 km, 7.3% thereafter	B: 21.3% < 100 km, 6.1% thereafter		
1-3	0-30	0	30,000	10.33	0.3856
4-5	31-50	0	53,333	21.90	0.3153
6-8	51-80	21,667	130,000	28.21	0.2355
9-10	81-100	20,000	120,000	35.28	0.2007
11-20	101-200	347,222	288,889	39.29	0.1731
21-30	201-300	578,704	481,482		
31-40	301-400	810,185	674,074		
Total		1,777,778	1,777,778		

The harvestable log volume, stumpage, cut, snig and load costs reported in Table 1 apply to each harvestable hectare. Fixed haul costs in Table 3 are haul costs for the shortest haul distance in the particular haul distance range, and variable haul costs are the costs per cubic metre per kilometre thereafter. Fixed and variable haul costs for 101 km to 200 km also apply to distances over 200 km.

Model parameters adopted for equipment utilisation rates, product processing rates, final product recovery rates from log volume, manufacturing costs and market prices for LVL in subtropical eastern Australia are reported in Table 4. Utilisation rates indicate the fraction of working hours over a year that the equipment is actually processing inputs. Processing rates of inputs indicate the average volume of inputs that can be processed per working hour, given the utilisation rate. For this analysis, green veneer recovery rates have been estimated using log sweep and taper values of 0.005 m/m and 0.0075 m/m, respectively, which are average levels for small diameter *Eucalyptus* and *Corymbia* native forest and plantation logs processed in multiple recent veneering studies (e.g. McGavin *et al.* 2014a, McGavin and Leggate 2019). Annual input volume, processing rates and number of pieces of equipment determine labour hours required.

Total capital costs in year zero are reported by processing scale and final product in Table 4. Note, that the part-time (7500 m³/y) scale utilises the same equipment as the 15 000 m³/y scale but operates fewer hours per annum. Capital costs are cumulative with value-adding. For example, the total capital costs of manufacturing one-stage LVL is the sum of the capital costs of green veneer, dry veneer and one-stage LVL. When the asset life is reached for any particular piece of equipment, the asset has zero residual value and requires replacement at its

listed capital cost. At the end of the project (30 years), all capital items that are not at the end of their asset life are assumed to have a residual value of 5% of its purchase cost.

Annual maintenance and insurance costs are estimated as a proportion of capital costs in year zero, as specified in Table 4. Key informants from industry indicated that non-labour operating costs were best integrated within the financial model in one of two ways. Some non-labour operating costs were more easily considered as costs for a particular processing scale, which have been reported as a cost per cubic metre of log volume processed in Table 4. As with capital costs, these costs are cumulative with increasing value-adding. However, other non-labour operating costs were more easily considered per unit of final product. These costs are not cumulative, *i.e.*, only costs listed for the particular final product of interest are relevant.

Table 4. Veneer and LVL utilisation, processing and recovery rates, non-labour production costs and market prices

Parameter	Final product			
	Green veneer	Dry veneer	One-stage LVL	Two-stage LVL
Utilisation rate of equipment and machinery (%)	65 (Eight-foot lathe)	85 (Dryer)	50 (Hot press)	80 (Cold press)
Processing rates of input (m ³ /h)	9.0 m ³ /h of small peeler/top logs, 10.27 m ³ /h of B-grade sawlogs, or 11.94 m ³ /h of A-grade sawlogs per lathe	4.08 m ³ /h of green veneer per small dryer or 5.95 m ³ /h of green veneer per large dryer	2.5 m ³ /h of dry veneer per hot press	0.4 m ³ /h of one-stage LVL per cold press
Recovery of final product (% of log volume)				
<i>Small peeler and top logs</i>	69	52	43	42
<i>B-grade sawlog</i>	79	59	49	48
<i>A-grade sawlog</i>	84	63	52	51
Capital costs in year zero (\$ millions)				
<i>7500 & 15 000 m³/y scale</i>	4.38	0.82	1.95	0.89
<i>30 000 m³/y scale</i>	8.50	1.36	2.65	1.22
Annual maintenance parts and insurance per year (% of capital costs in year zero)	5 and 1.5	5 and 1.5	5 and 1.5	5 and 1.5
Non-labour operating costs that vary by processing scale (\$/m ³ of log processed)				
<i>Electricity</i>	2.67	6.67		4.0 ^a
<i>Water</i>	0.69			
<i>Boiler feedstock</i>	4.32			
<i>Consumables, compliance and marketing</i>	0.80	0.33	1.23	1.30
Non-labour operating costs that vary by marketable output (\$/m ³ of final product)				
<i>PF glue</i>			58.40	60.00
<i>RF glue</i>				4.72
<i>Packaging</i>	1.99	1.99	0.24	0.24
Freight to market (\$/m ³ of final product)				
<i>7500 m³/y</i>	60	60	60	60
<i>15 000 m³/y</i>	55	55	55	55
<i>30 000 m³/y</i>	50	50	50	50
Market price (\$/m ³)			1000	1375

Note: a. Industry experts were unable to segregate energy consumption for one-stage and two-stage LVL manufacture. The additional energy cost of converting one-stage LVL into two-stage LVL is marginal, because the additional processing is limited to gluing one-stage LVL in a cold press for eight hours. In the analysis, regardless of whether one-stage or two-stage LVL is produced, the electricity cost of \$4/m³ of log is applied once. This electricity cost is cumulative with the drying and veneering electricity costs.

Table 5 reports the estimate from industry experts of the number of full-time equivalent (FTE) employees required per shift at each stage of production. Each shift is eight hours per day, five days per week, 48 weeks per year, for a total of 1920 hours per year. Processing rates of inputs in Table 4 are used by the financial model to determine the annual number of hours of labour required for each processing stage by log procurement scenario and processing scale. Up to three 8-hour labour shifts per day are accommodated in the model for all processing

stages, except administration. Only one administration shift is required per day. Total hourly labour costs (including on-costs) are reported for each position.

Table 5. Labour requirements by stage of production and processing scale

Position by stage of production	Total labour cost (\$/FTE/h)	FTEs per shift by processing scale (m ³ /y of log)		
		7500	15 000	30 000
Administration				
Manager	114	0	1	1
Senior administration	61	0	1	1
Supervisor	61	1	0	1
Quality control supervisor	61	0	1	1
Administration support	34	1	1	2
<i>Total administration employees</i>		2	4	6
Green veneer production				
Maintenance	61	0.25	0.25	0.5
Vehicle operators	42	1	1	2
Machine operators	42	2	2	4
Machine assistants	34	2	2	3
<i>Total number of employees for green veneer production</i>		5.25	5.25	9.5
Dry veneer production				
Maintenance	61	0.25	0.25	0.25
Machine assistants	34	3	3	4
<i>Total number of employees for dry veneer production</i>		3.25	3.25	4.25
One-stage LVL production				
Supervisor	61	1	1	1
Maintenance	61	0.25	0.25	0.25
Machine operators	42	5	5	8
Machine assistants	34	3	3	3
<i>Total number of employees for one-stage LVL manufacture</i>		9.25	9.25	12.25
Two-stage LVL production				
Machine operators	42	1	1	2
<i>Total number of employees for two-stage LVL manufacture</i>		1	1	2

Production at the 7500 m³/y and 15 000 m³/y scales are with the same equipment and processing rates. Therefore, Table 5 reports these two scales as having almost identical labour requirements for the hours they are operating. However, the 7500 m³/y facility is only operating part-time. Labour requirements are cumulative across all processing stages. For example, if one-stage LVL is produced, then total labour needs at the facility will be the sum of administration, green veneer, dry veneer and one-stage LVL. The additional number of workers required for two-stage LVL manufacture is low because producing two-stage LVL only requires gluing one-stage LVL and charging in a cold press for eight hours. It is assumed that some labour in one-stage LVL manufacture can assist with charging the cold presses for two-stage LVL manufacture. Non-integers in Table 5 reflects a part-time role.

4.0 Results

Optimal proportions of log types for log procurement scenario 3 to maximise NPV are reported in Table 6. Table cells with zero indicate that the log type was not procured for the particular combination of processing scale and facility location scenarios. Cells in Tables 6 and 7 with ‘n.a.’ were combinations of processing scale and facility location scenarios that were not technically feasible due to insufficient log volume over the 30-year investment period. Much higher proportions of small peeler and top logs are utilised in facility location scenario A, relative to B, because less forest area was available for harvest close to the facility. It was therefore optimal to procure more low-processing efficiency small logs to reduce mill-delivered log costs. Small volumes of A-grade sawlogs are procured at processing scales of at least 15 000 m³/y. In contrast to Table 6, the constant proportions of log types under log procurement scenarios 1 and 2, irrespective of processing scale and facility location, were 100% small peeler and top logs for the former, and 12.8% A-grade sawlog, 40.7% B-grade sawlog and 46.5% small peeler and top logs for the latter².

Table 6. Optimal proportion of log types in log procurement scenario 3 by processing scale and facility location

Log type	Proportion (%) of logs by log type to maximise NPV by processing scale (m ³ /y of log) and facility location					
	7500		15 000		30 000	
	A	B	A	B	A	B
A-grade sawlog	0.0	0.0	5.6	0.0	n.a.	2.2
B-grade sawlog	73.9	95.3	54.6	90.7	n.a.	55.3
Small peeler or top log	26.1	4.7	39.8	9.3	n.a.	42.5

Despite large differences in log mixes between log procurement scenarios 1, 2 and 3, Table 7 reveals that average mill-delivered log costs for each log procurement scenario were similar for any particular combination of facility location scenario and processing scale. However, there are large differences in mill-delivered log costs between processing scales and facility location scenarios. For example, average mill-delivered log cost for log procurement scenario 2 at the 15 000 m³/y of log processing scale, was \$166/m³ for facility location A and \$135/m³ for facility location B.

Table 7. Average mill-delivered log cost by processing scale, facility location and log procurement strategy

Log procurement scenario	Average mill-delivered log cost (\$/m ³) by processing scale (m ³ /y of log) and facility location					
	7500		15 000		30 000	
	A	B	A	B	A	B
1	163	131	n.a.	138	n.a.	n.a.
2	155	131	166	135	n.a.	141
3	152	126	164	132	n.a.	137

4.1 Financial performance of integrated processing facilities

The after tax NPVs for the manufacture and sale of one-stage and two-stage LVL are illustrated in Figures 1 and 2, respectively. The two panels within each figure report the NPVs for each facility location scenario and, within each panel, a bar represents a combination of

² For log procurement scenario 2, the proportions are consistent with the harvestable volumes per hectare for each log type reported in Table 1.

log procurement and facility scale scenarios. Missing bars in the figures indicate that log procurement scenario and processing scale was not technically feasible, due to insufficient forest resource to support these scenarios.

One-stage LVL production was financially viable at processing scales of at least 15 000 m³/y, for log procurement scenarios 2 and 3, at both facility location scenarios, although this was marginal for location A. Facility location B was the only location where one-stage LVL production with log procurement scenario 1 generated a positive NPV, although this was also marginal. Two-stage LVL production was profitable for all scenarios evaluated.

Figures 1 and 2 predict strong returns to increasing level of value-adding. For example, for facility location B at the 30 000 m³/y scale, the NPVs of one-stage and two-stage LVL were \$18 million and \$55 million, respectively. There are also economies of scale present. For example, a doubling of processing scale for one-stage and two-stage LVL manufacture from 15 000 m³/y to 30 000 m³/y for facility location B and log procurement scenario 2, increased NPV by factors of 3.85 and 2.45, respectively. Figures 1 and 2 also highlight that for any combination of facility location and processing scale scenarios, NPV is greatest for log procurement scenario 3 and lowest with scenario 1. NPV is also affected substantially by facility location scenario (proximity to the forest resource), with the expected result that NPV is greatest with Scenario B.

Figures 3 and 4 illustrate average costs of production by processing stage, market price and profit after tax per cubic metre of final product for one-stage and two-stage LVL, respectively. For any combination of facility location, processing scale and log procurement scenarios, average costs rise with increasing value-adding because of progressively lower recovery of marketable product from log volume.

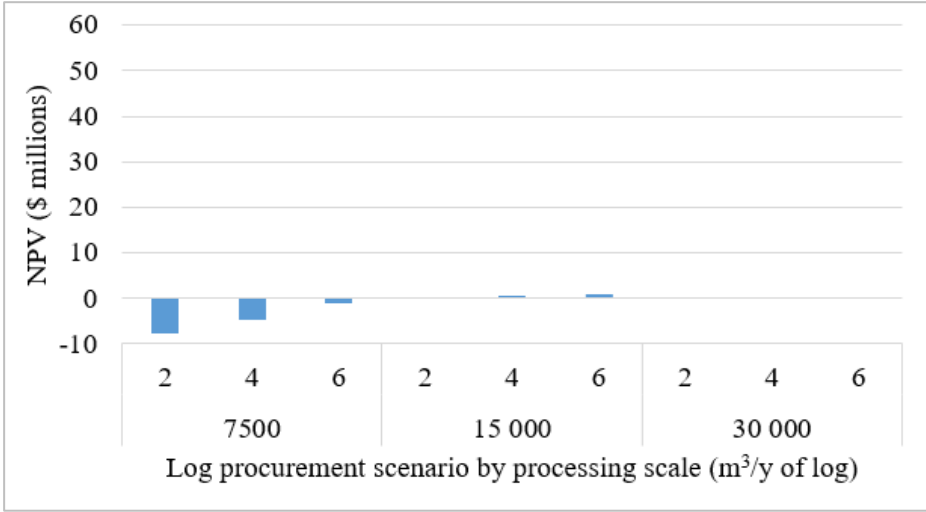
Figures 3 and 4 highlight the extent to which value-adding can increase profitability per cubic metre of final product. For example, profit per cubic metre of final product for log procurement scenario 2, at the 15 000 m³/y processing scale and facility location B, increases from 78/m³ for one-stage LVL to \$298/m³ for two-stage LVL.

Figures 3 and 4 highlight the increasing returns to scale that are achievable with all final products. For LVL manufacture, it is the combination of the increasing profitability per cubic metre of final product and the increasing volume of product that results in the large increases in NPV with scale, which are illustrated in Figures 3 and 4.

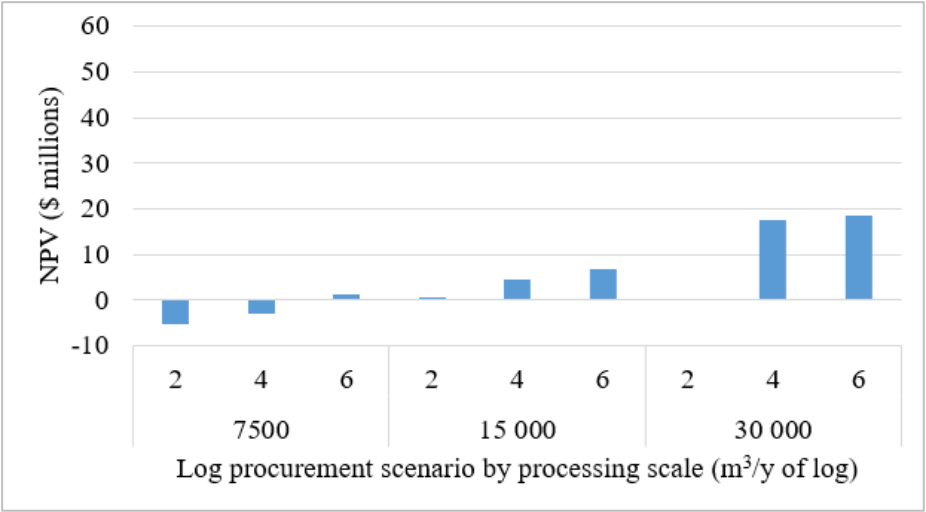
Figures 3 and 4 indicate the effect of log procurement scenario on costs of production can be substantial. For example, for two-stage LVL production at facility location B and a processing scale of 15 000 m³/y of log, profit ranged from \$251/m³ to \$322/m³ of two-stage LVL, depending on the log procurement scenario. The relatively small difference in mill-delivered log costs between the log procurement scenarios (\$132/m³ to \$138/m³ of log; Table 7) suggests effects of log procurement strategy on financial performance are driven more by rates at which alternative log types can be processed and the recovery of marketable product from log volume. The benefit of optimal log procurement (scenario 3) is greater at smaller processing scales and for higher levels of value-adding. The benefit diminishes with increasing scale, because haul costs increase and capital costs are distributed over larger final product volumes.

Figures 3 and 4 also provide another measure of the impact of facility location on the financial performance of an operation. For example, the profitability of two-stage LVL manufacture for log procurement scenario 2 at the 15 000 m³/y processing scale was \$46/m³ greater at facility location B than location A.

Figure 1. NPV of the manufacture and sale of one-stage LVL

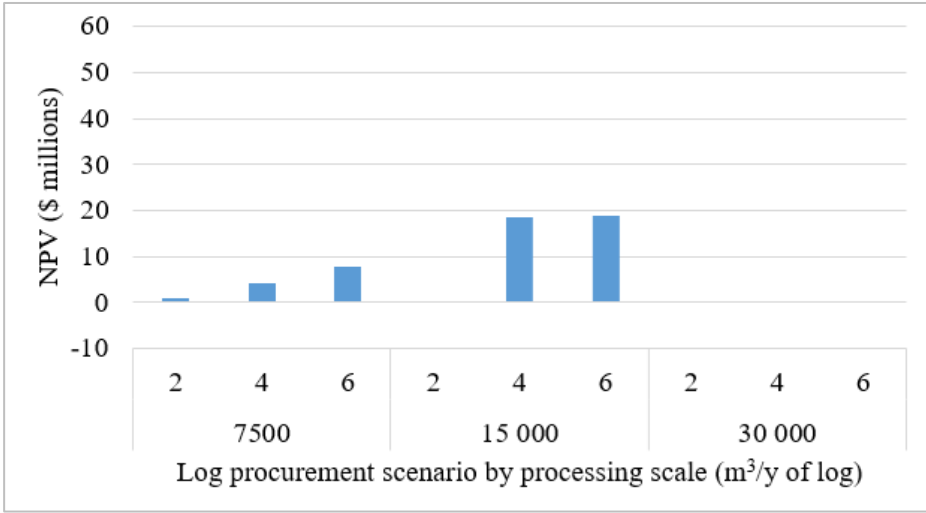


(a) Facility location A

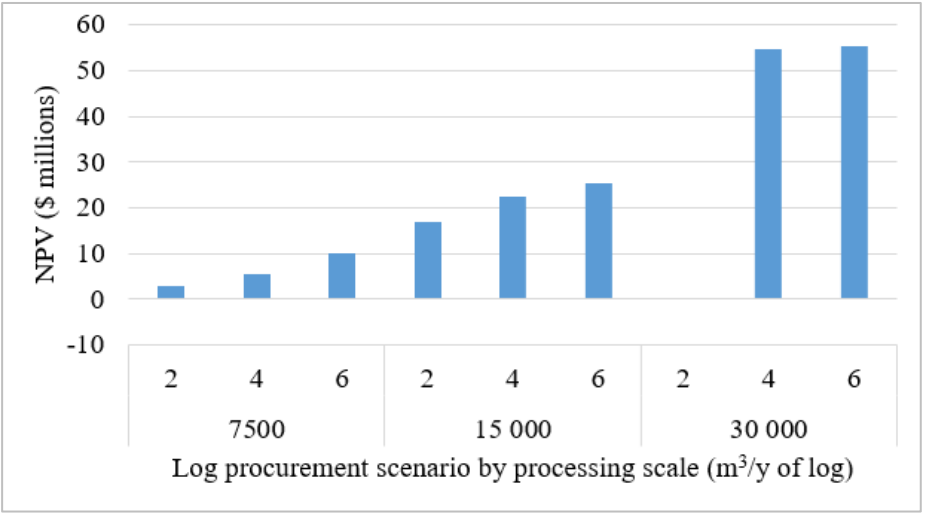


(b) Facility location B

Figure 2. NPV of the manufacture and sale of two-stage LVL

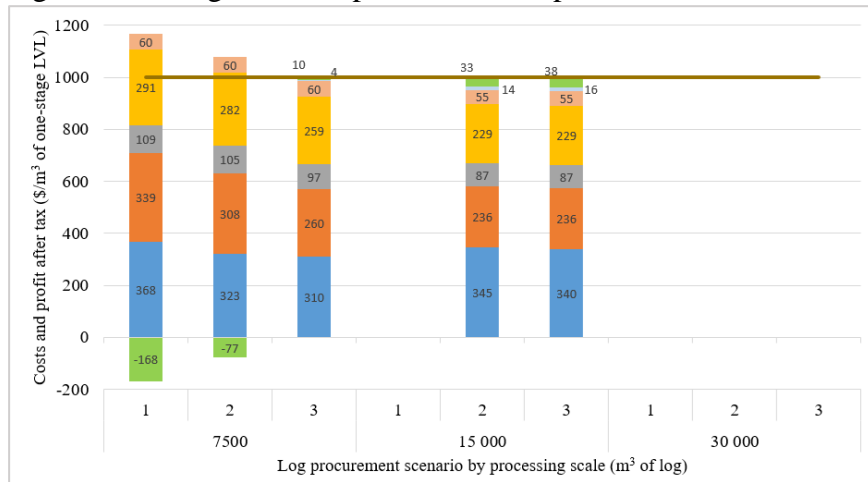


(a) Facility location A

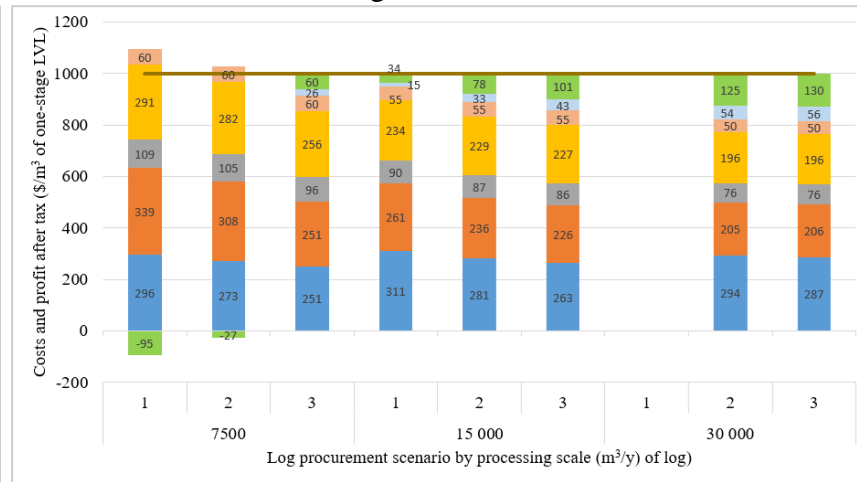


(b) Facility location B

Figure 3. Average costs of production and profit after tax for the manufacture and sale of one-stage LVL



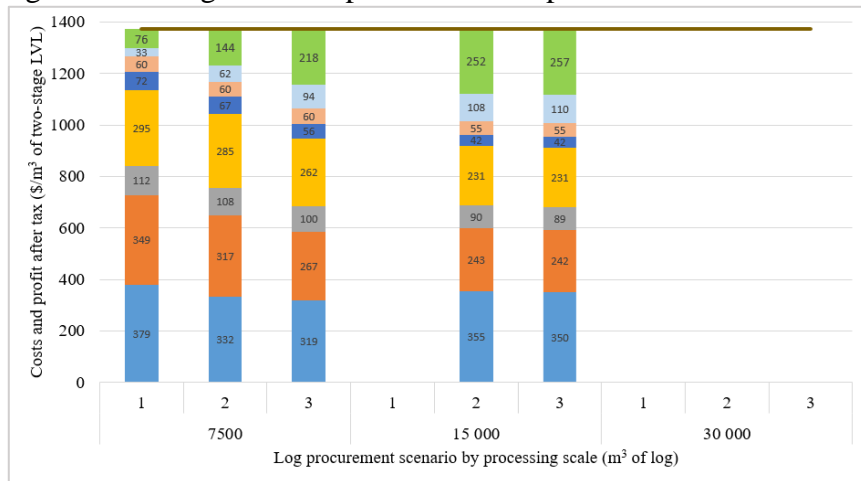
(a) Facility location A



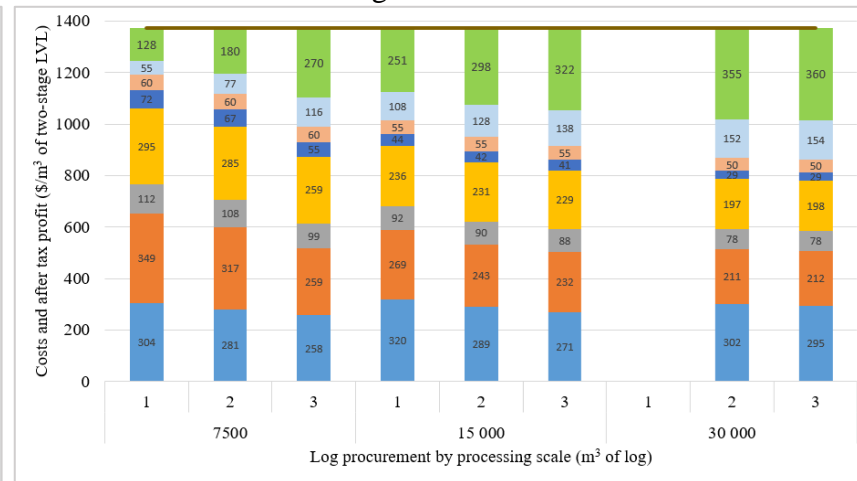
(b) Facility location B

■ Mill-delivered log cost
 ■ Green veneering
 ■ Jet drying
 ■ One-stage LVL manufacture
 ■ Freight to market
 ■ Company tax
 ■ Profit after tax
 — Market price

Figure 4. Average costs of production and profit after tax for the manufacture and sale of two-stage LVL



(a) Facility location A



(b) Facility location B

■ Mill-delivered log cost
 ■ Green veneering
 ■ Jet drying
 ■ One-stage LVL manufacture
 ■ Two-stage LVL manufacture
 ■ Freight to market
 ■ Company tax
 ■ Profit after tax
 — Market Price

Sensitivity analyses have been performed for six parameters that NPV is most sensitive. Alternative discount rates of 4% and 10% have been assessed. Base case parameter levels have been increased and decreased by 20% for mill-delivered log costs (the sum of stumpage, cut, snig, load and haul costs), equipment utilisation rates (rates for all processing stages assessed together), capital costs throughout the life of the investment, labour costs and market prices. The results of sensitivity analyses are presented in Appendix 1.

The financial performance of one-stage LVL production is highly sensitive to the market price; a 20% increase in price results in all one-stage LVL scenarios being profitable, irrespective of facility location and processing scale, while a 20% decrease in market price results in none of these scenarios being profitable. The 7500 m³/y scale for one-stage LVL at location A is only financially viable with a higher market price. At the 15 000 m³/y scale, pessimistic levels for any single model parameter make one-stage LVL manufacture unprofitable at facility location A. At facility location B, one-stage LVL manufacture at the 7500 m³/y scale is only financially viable for log procurement scenario 3, and only with optimistic parameter levels. The profitability of one-stage LVL manufacture for log procurement scenarios 2 and 3 at processing scales of at least 15 000 m³/y is robust against changes in all parameters except market price. Log procurement scenario 3 performed the strongest in the majority of the sensitivity analyses.

The profitability of most two-stage LVL manufacturing scenarios are highly robust against changes in parameter levels. There are only two cases where negative returns have been projected. First, at the 7500 m³/y processing scale, profitability of two-stage LVL is sensitive to market price for both facility locations. Second, at facility location A, negative returns have also been projected for the 7500 m³/y processing scale for pessimistic levels of any parameter. On balance, two-stage LVL manufacture at processing scales of at least 15 000 m³/y has been revealed as the superior investment option.

4.2 Financial performance of distributed processing operations

Figure 5 illustrates the profitability of one-stage and two-stage LVL where dry veneer is produced at a facility at location B and is purchased by a manufacturing plant at location A. The x-axis has the three distributed production scenarios considered; one veneering facility processing 15 000 m³/of log; one veneering facility processing 30 000 m³/y of log; and two separate veneering facilities processing 15 000 m³/y of log each.

Freight to, and handling costs at the receiving LVL plant were considered over the range of \$20/m³ to \$40/m³ of dry veneer. The analysis found that among the scenarios analysed, the cost of producing and delivering the dry veneer to the LVL plant would be between \$494/m³ to \$651/m³. The distributed production analysis also assumes the veneering facility attaches a profit mark-up of 10% above the costs listed above. Therefore, under distributed production operations, the LVL plant would have to pay between \$543/m³ and \$651/m³ for dry veneer delivered to the manufacturing facility.

Yellow and orange points in Figure 5 represent the possible after-tax profit level of one-stage and two-stage LVL for distributed production operations when the price paid for dry veneer delivered to the LVL plant is lowest (yellow point) to when it is highest for that particular scenario (orange point). The line connecting these points represents after-tax profits of one-stage and two-stage LVL shipping and handling costs between this range.

³ Minimum cost of producing dry veneer is with one or two veneering facilities processing 15 000 m³/y of log each; log procurement scenario 3; low shipping and handling costs. Maximum cost is with one or two veneering facilities processing 15 000 m³/y of log each; log procurement scenario 1; high shipping and handling costs.

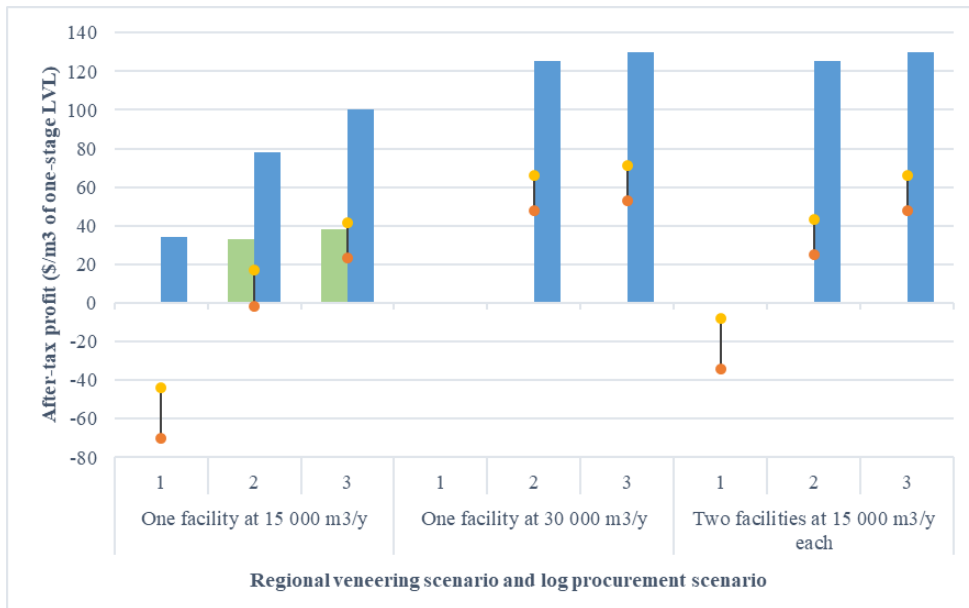
For comparative reasons, the profitability of integrated production has been included in Figure 5. Each green bar represents the after-tax profit level for an integrated facility in location A and a blue bar represents the profit level for an integrated facility at location B, as determined in Figures 3 and 4. All distributed production scenarios were technically feasible except for a single veneering facility processing 30 000 m³/y of log operating under log procurement scenario 1.

The distributed production analysis revealed four notable findings. First, all distributed production scenarios are expected to be profitable, except one-stage LVL for log procurement scenario 1, and one-stage LVL at the 15 000 m³/y scale for log procurement scenario 2 and high shipping and handling costs. Not surprisingly, for any particular processing scale and log procurement scenario, if LVL manufacture can be performed at facility location scenario B (blue bars), this will be more profitable than having to purchase dry veneer from another facility to location A.

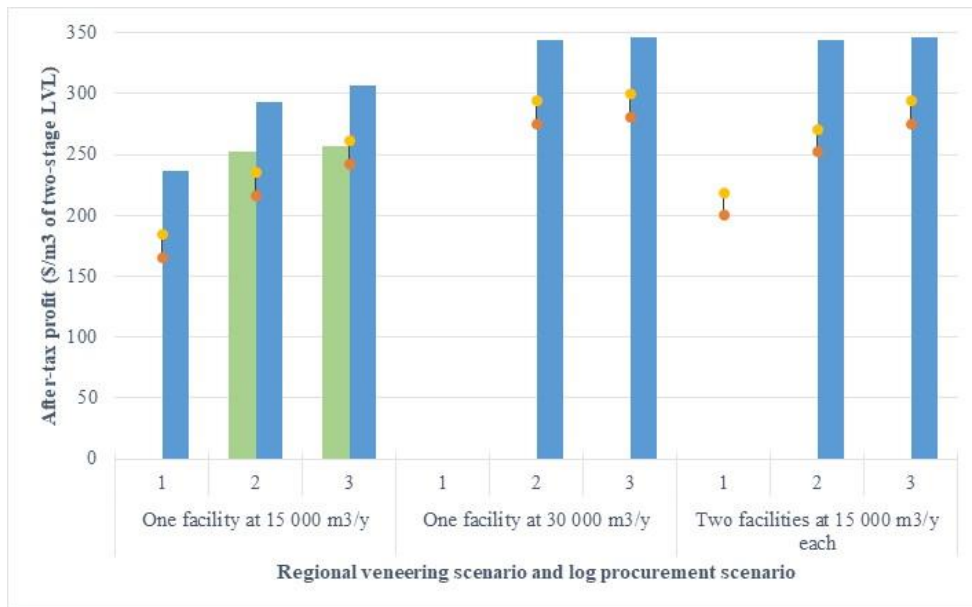
Second, distributed production allowed for the greatest number of scenarios to be technically feasible (i.e. sufficient log resource to supply a particular LVL processing scale). A distributed production regime is the only mode an EWP manufacturing facility at location A can use to achieve a log processing scale of 30 000 m³ per year. In fact, distributed production with two 15 000 m³/y veneering facilities was the only scenario to make log procurement scenario 1 technically feasible at the 30 000 m³/y processing scale for one-stage and two-stage LVL

Third, strong economies of scale with LVL production highlighted elsewhere in this report are present in the distributed production scenarios. Despite lower mill-delivered log costs when two 15 000 m³/y veneering facilities supply dry veneer to an LVL facility, the economies of scale gained by receiving veneer from one 30 000 m³/y veneering facility always generates higher profits for both one-stage and two-stage LVL production, *ceteris paribus*. Furthermore, the profitability of two 15 000 m³/y veneering facilities supplying one 30 000 m³/y LVL facility is always greater than one 15 000 m³/y veneering facility supplying one 15 000 m³/y LVL facility, *ceteris paribus*.

Fourth, an integrated facility at location A at the 15 000 m³/y scale with log procurement scenario 2, will generate higher returns than a distributed production process. Log procurement scenario 3, however, resulted in the profits of integrated production falling within the range that distributed production would also be expected to yield. These were the only scenarios where integrated production at facility location A was technically feasible.



(a)



(b)

Figure 5. After-tax profit of distributed production for (a) one-stage and (b) two-stage LVL

4.0 Discussion

An extensive international literature review did not reveal estimates of NPV, costs of production and processing coefficients for spindleless rotary veneering and LVL manufacture against which the findings from this study could be compared. The levels of veneer recovery from log volume adopted in this study are consistent with international estimates from several studies that have considered small and large diameter hardwood and softwood logs (Kewilaa 2007, Wang and Dai 2008, Belleville *et al.* 2018).

A comparison of the potential impact of strategic and tactical decisions on NPV will always be somewhat subjective, depending on the range in the parameter levels evaluated. However, for this analysis, the importance of strategic and tactical decisions associated with LVL manufacture in decreasing order of their impact on NPV were found to be the:

1. product manufactured (level of value-adding);
2. processing scale;
3. log procurement strategy (log types processed); and
4. facility location (proximity to forest).

The level of value-adding had the greatest impact on NPV, with substantially higher returns with value-adding as exemplified by the higher returns of two-stage LVL. This is consistent with industry experience in Sweden and Finland (Roos *et al.* 2001, Lahtinen and Toppinen 2008, Brege *et al.* 2010). The strong financial returns to two-stage LVL and, to a lesser extent one-stage LVL manufacturing, suggests Australian processors could learn from the experience of Nordic European counties. Singer and Donoso (2007) found that large-scale production of relatively low-value products was the comparative advantage of wood processors located within the extensive and fast-growing plantation forest estates of Chile, where log costs are comparatively low. The subtropical native hardwood forests of eastern Australia are shrinking in terms of the area managed for timber production, and are not fast-growing, which supports the case for an emphasis on value-adding as revealed by the financial analyses performed in this report.

Decisions of processing scale had the second greatest impact on NPV, with strong economies of scale achieved with increases in production. However, findings in this study of limited profitability at small scales need to be interpreted with caution, as the 7500 m³/y processing scale was deliberately examined as a part-time operation with the hourly processing capacity of a 15 000 m³/y operation. The financial performance of a full-time operation at 7500 m³/y has not been investigated and it is challenging to hypothesise whether such an operation (presumably utilising lower cost, but also lower processing capacity equipment) would be viable.

The third most important decision was the tactical choice of which log types to procure and process. The financial model highlighted that a simple focus of log procurement officers on log size or mill-delivered log cost, is insufficient to maximise profitability. This conclusion was also reached by Dobner Jr. *et al.* (2013) for veneer production from *Pinus taeda* logs in Brazil. Log procurement scenario 3 maximised profitability by preferentially utilising B-grade sawlogs, then small peelers and top logs, and finally, A-grade sawlogs. B-grade sawlogs were optimal for processing because of their moderate mill-delivered log cost relative to A-grade sawlogs, and their high product recovery from log volume and rate at which they can be processed, relative to small peeler logs and top logs. Log procurement scenario 1 performed comparatively poorly, because it only utilised small peeler and top logs which incurred high mill-delivered log costs and yielded low rates of recovery. Log procurement scenario 2

performed poorly in comparison to scenario 3 because it utilised relatively large volumes of valuable A-grade sawlogs, in addition to small peeler and top logs.

The motivation to utilise small peeler and top logs in the study area, particularly to encourage and offset the costs of silvicultural treatment, warrants further comment. Figures 1 to 5 revealed log procurement scenario 1 was always the least profitable, and only generated positive returns with two-stage LVL manufacture. It can be deduced from Figures 3 and 4 how much log costs would have to fall so that the profitability of log procurement scenario 1 would be comparable with scenarios 2 and 3. For example, at the 15 000 m³/y processing scale at location B, the difference in profit level of two-stage LVL manufacture under log procurement scenarios 2 and 3, relative to scenario 1, has a value equivalent to \$23/m³ of log and \$33/m³ of log, respectively⁴. Therefore, reducing the stumpage price paid to landholders for small peeler logs and top logs from the base case level of \$40/m³ to between \$7/m³ and \$17/m³ would make log procurement scenario 1 as profitable as scenarios 2 and 3.

Although the returns to log procurement scenario 1 are relatively low, the opportunity costs associated with using small peeler and top logs are also low, because they are not presently in high demand in the study area. In contrast, A-grade and B-grade sawlogs are actively procured by sawmills. A-grade and B-grade sawlogs may generate higher returns when processed into particular roundwood or sawnwood products, rather than LVL⁵. Therefore, investment in veneering small peeler logs may be a more appealing prospect than this analysis indicates. Furthermore, log procurement scenario 3 maximises profitability by utilising substantial volumes of small peeler and top logs at larger processing scales (42.6% of log input at the 30 000 m³/y scale; Table 6). While this case study does not justify the adoption of log procurement scenario 1 by processing facilities, utilising small peeler and top logs within a mix of log types is optimal. Therefore, establishment of hardwood LVL manufacturing facilities in subtropical eastern Australia does have the potential to develop new markets for small logs.

Access to and utilisation of small peeler logs will be impacted by potential changes to forest policy, codes of practice for native forest silviculture and harvesting on private land, tree marking and sales practices on state-owned lands, and the diversion of logs from traditional sawlog markets to veneering (Leggate *et al.* 2019). Therefore, findings reported about scenarios utilising large volumes of small peeler and top logs should be applied with caution. Existing forest policy for a large proportion of state-owned land in the study area requires that only traditional log types can be harvested, preventing development of new log types, such as small peeler and top logs, as the timber industry evolves (McAlpine *et al.* 2005, McAlpine *et al.* 2007, Burgess and Catchpoole 2016). At the time of publication, the code of practice on private land was under review, and some proposed changes may affect permissible silvicultural practices and harvestable volumes. The major policy implication arising from this study is that opportunities for processors in the region to profitably adopt LVL processing technologies will be enhanced by state government forest policy and codes of practice for private land that permit utilisation of small logs, particularly from suppressed trees that will never attain the specifications of traditional log types. A market for small logs will also help

⁴ For example, the increased profitability of two-stage LVL manufacture at the 15 000 m³/y processing scale under log procurement scenario 2, relative to scenario 1 is \$47/m³ of LVL. Subtracting this difference from mill-delivered log costs for Scenario 1 (\$320-\$47) indicates profitability of these two scenarios would be identical if mill-delivered log costs in scenario 1 were \$273/m³ of LVL. Given 42% product recovery from log volume (Table 4), that is equivalent to a mill-delivered log cost of \$115/m³ of log, which is \$23/m³ lower than reported in Table 7.

⁵ No estimates of gross margins or profitability of sawn hardwood production have been made in this study or published elsewhere for subtropical eastern Australian hardwoods.

facilitate the silvicultural treatments necessary to increase the productivity of private native forests in sub-tropical eastern Australia.

The fourth most important strategic or tactical decision was facility location. This was being driven by mill-delivered log costs, with facilities proximate to forests being more profitable (facility location B). If an integrated manufacturing facility had to be located at facility location A for technical or logistical reasons, it would not be able to feasibly obtain enough log volume to process 30 000 m³/y under any log procurement scenario. However, through distributed production models, where dry veneer is produced from one or more facilities proximate to the forest and transported to an EWP manufacturing facility at location A, a scale of 30 000 m³/y is achievable, regardless of the log procurement scenario targeted. Furthermore, if an LVL facility had challenges procuring sawlogs, or managers choose not to produce veneer from sawlogs, such that only small peeler and top logs are utilised (log procurement scenario 1), an integrated facility at the 30 000 m³/y scale would not be technically feasible given the parameter levels adopted, regardless of facility location. However, the assessment of distributed production revealed that it is technically feasible to have two 15 000 m³/y veneering facilities utilising small peeler and top logs at facility location B and supplying one 30 000 m³/y two-stage LVL manufacturing facility. For two-stage LVL manufacture under this scenario, profits are expected to be greater than 195/m³ of LVL. Although this is low relative to other log procurement scenarios, it does still represent a strong return.

The significantly greater number of technically feasible scenarios available to the EWP manufacturer under distributed production regimes highlight its competitive advantage over integrated facilities distant from the forest resource. Distributed models also provide an opportunity for processors to locate its manufacturing facilities to urban areas that will provide assistance to other aspects of their operation such as infrastructure support benefits, improved access to skilled labour, and better access to markets. While the profitability of distributed production was not as high as integrated production at location B, all distributed production scenarios, generated positive returns comparable to those for integrated facilities at location A, with the exception of one-stage LVL production with log procurement scenario 1.

The distributed production analysis assumed that an LVL manufacturer at location A purchases dry veneer from a processing facility at location B. However, if the entire operation is owned by a single vertically-integrated business, the benefits of distributed production would be much greater. This would remove the profit margin attached to the purchase of dry veneer, which in some scenarios represents a significant cost to LVL production. Savings from vertical integration of distributed production operations are estimated to be up to \$71/m³ of one-stage LVL and \$51/m³ of two-stage LVL. Under this scenario, distributed production will always be more profitable than integrated facilities at location A but marginally lower than integrated facilities at location B.

There are five assumptions embedded within the design of scenarios that should be considered when interpreting results. First, log procurement scenario 3 assumes alternative log types can be optimally procured from the landscape surrounding the processing facility. This may be difficult to achieve in practice, as described in Venn and McGavin (in press). In contrast, log procurement scenarios 1 and 2 can be regarded as 'near feasible', because the contractual arrangements necessary to achieve them are no more burdensome for contracted parties than existing operations.

Second, the processing facility is assumed to use a biomass boiler that is largely (although not entirely) supplied by on-site wood residues to generate the necessary heat for log steaming and veneer drying. If electricity or natural gas was used to generate all of this heat instead,

this would add substantially to annual energy costs, although there would be potential capital savings in not requiring a biomass boiler.

Third, integrated production scenarios and the LVL plant in the distributed model assumed an expansion of activity at an existing processing facility (e.g. a sawmill). Consequently, the analysis did not consider land acquisition costs and non-labour costs of administration (e.g. office space, stationery, telecommunications). Fourth, the model assumes market acceptance of new hardwood LVL products commencing in year one, but there are likely to be challenges promoting adoption in some markets (Evison *et al.* 2018). Fifth, while the analysis did consider the impact of company tax on financial performance, it did not account for tax benefits arising from asset depreciation. This suggests the financial performance of LVL manufacturing scenarios that generated a positive return have been slightly underestimated.

5.0 Conclusion

This analysis found that the manufacture of two-stage LVL products was generally projected to be highly profitable. Many one-stage LVL scenarios evaluated were estimated to be marginally to moderately profitable. It was revealed that, in decreasing order of impact on profitability of an LVL manufacturing operation, the strategic and tactical decisions in subtropical eastern Australia are the product manufactured (level of value-adding), processing scale, log procurement strategy (log types processed), and facility location (proximity to forest). A single integrated facility processing logs into veneer and then manufacturing LVL proximate to the forest was found to be most profitable. However, if technical or logistical constraints prevented a single integrated facility being located close to the log resource, then the financial analysis highlighted opportunities for profitable distributed production of LVL, with veneer produced close to the log resource, before being shipped to an LVL manufacturing facility.

Strong economies of scale existed with LVL manufacture. The analysis also revealed that the log procurement strategy can substantially affect profitability. Although B-grade sawlogs were revealed to be the most profitable log type to process into LVL, maximising NPV at the 30 000 m³/y processing scale required 42.6% of logs to be small, non-traditional log types (small peeler and top logs). Therefore, if LVL manufacture with native forest logs becomes more common in subtropical eastern Australia, the demand for small logs is likely to rise. This would be a 'win-win' opportunity for landholders and processors (and associated regional communities), because increased utilisation of small logs is likely to facilitate and offset the costs of silvicultural treatment in degraded forests, and increase forest productivity, as well as future harvestable volume and value. Forest policy that permits the utilisation of small, suppressed trees is necessary for the timber industry in subtropical eastern Australia to take full advantage of the short and long-term opportunities with hardwood veneer and LVL manufacture.

6.0 References

- Belleville, B., A. Redman, P. Chounlamounty, V. Phengthajam, S. Xiong, L. Boupaha, and B. Ozarska. 2018. Potential of veneer peeled from young eucalypts in Laos. *BioResources* **13**:7581-7594.
- Brege, S., T. Nord, R. Sjoström, and L. Stehn. 2010. Value-added strategies and forward integration in the Swedish sawmill industry: positioning and profitability in the high-volume segment. *Scandinavian Journal of Forest Research* **25**:482-493.
- Bureau of Rural Sciences. 2004. An Analysis of Potential Timber Volumes from Private Native Forest Available to Industry in South East Queensland. SEQ PNFI Integration Report 21 June 2004, Department of Agriculture Fisheries and Forestry: Canberra.
- Burgess, J., and K. Catchpoole. 2016. Supporting private native forests in Queensland. *Australian Forest Grower* **39**:30-31.
- Carron, L. 1985. A History of Forestry in Australia. Australian National University Press, Canberra.
- DAF (Queensland Department of Agriculture and Fisheries). c2019. Private native forest management: South-eastern Queensland. Queensland Department of Agriculture and Fisheries, Brisbane. Available at URL: <https://www.publications.qld.gov.au/dataset/private-native-forest-resource-extent-and-condition/resource/56cf2996-f5e5-4553-a607-3ca799601bf0>.
- Dobner JR., L. Nutto, and A. Higa. 2013. Recovery rate and quality of rotary peeled veneer from 30-year-old *Pinus taeda* L. logs. *Annals of Forest Science* **70**:429-437.
- DPI Forestry. 1998. An Overview of the Queensland Forest Industry. Department of Primary Industries, Brisbane.
- Evison, D., P. Kremer, and J. Guiver. 2018. Mass timber construction in Australia and New Zealand - status, and economic and environmental influences on adoption. *Wood and Fibre Science* **50**:128-138.
- Francis, B., T. Venn, T. Lewis, and K. Catchpoole. in press. Chapter 4: A review of the private native forest resource, with a focus on economic contributions. *in* T. Lewis, T. Venn, B. Francis, S. Ryan, J. Brawner, N. Cameron, A. Kelly, T. Menzies, and K. Catchpoole, editors. Improving the productivity of the subtropical private native forest resource. Forest and Wood Products Australia, Melbourne.
- Gilbert, B., H. Bailleres, M. F. Fischer, H. Zhang, and R. McGavin. 2017. Mechanical properties of rotary veneers recovered from early to midrotation subtropical-hardwood plantation logs for veneer-based composite applications. *Journal of Materials in Civil Engineering* **29**:[https://doi.org/10.1061/\(ASCE\)MT.1943-5533.0002055](https://doi.org/10.1061/(ASCE)MT.1943-5533.0002055).
- Jay, A., and A. Dillon. 2016. Modelling the outcomes of different silvicultural approaches in the private native forests of north-eastern New South Wales. *Australian Forestry* **79**:85-95.
- Kewilaa, B. 2007. Effects of wood species and log diameter on veneer recovery. *Journal of Tropical Wood Science and Technology* **5**:49-56.
- Khoo, P., P. H'ng, K. Chin, E. Bakar, M. Maminski, R. Raja-Ahmad, C. Lee, S. Ashikin, and M. Saharudin. 2018. Peeling of small diameter rubber log using spindleless lathe technology: evaluation of veneer properties from outer to inner radial section of log at different veneer thicknesses. *European Journal of Wood and Wood Products* **76**:1335-1346.

- Lahtinen, K., and A. Toppinen. 2008. Financial performance of Finnish large-and medium-sized sawmills: the effects of value-added creation and cost-efficiency seeking. *Journal of Forest Economics* **14**:289-305.
- Leggate, W., R. McGavin, and H. Bailleres, editors. 2017. A Guide to Manufacturing Rotary Veneer and Products from Small Logs Australian Centre for International Agricultural Research, Canberra.
- Leggate, W., R. McGavin, and T. Lewis. 2019. An assessment of native forests in Queensland for the potential supply of small-diameter, peeler logs for spindleless lathe rotary-veneer processing. *BioResources* **14**:9485-9499.
- Lewis, T., J. Brawner, T. Menzies, S. Ryan, B. Schulke, B. Francis, and T. Venn. in press-a. Chapter 5: The effect of silvicultural treatments on forest growth rates and development of a decision support tool to determine forest value. *in* T. Lewis, T. Venn, B. Francis, S. Ryan, J. Brawner, N. Cameron, A. Kelly, T. Menzies, and K. Catchpoole, editors. Improving the productivity of the subtropical private native forest resource, Melbourne. Forest and Wood Products Australia, Melbourne.
- Lewis, T., T. Venn, B. Francis, S. Ryan, N. Cameron, and A. Kelly. in press-b. Chapter 3: Extent and condition of the private native forest resource. *in* T. Lewis, T. Venn, B. Francis, J. Brawner, N. Cameron, A. Kelly, T. Menzies, and K. Catchpoole, editors. Improving the Productivity of the Sub-tropical Private Native Forest Resource. Forest and Wood Products Australia, Melbourne.
- MBAC Consulting Pty Ltd. 2003a. South East Queensland Private Native Forest Inventory. A report prepared for the Commonwealth Government Department of Agriculture, Fisheries and Forestry, and Timber Queensland, Natural Heritage Trust and Bureau of Rural Sciences, Canberra. Available at URL: http://www.agriculture.gov.au/abares/publications/display?url=http://143.188.17.20/andl/DAFFService/display.php?fid=pe_brs90000002636.xml, accessed 17 July 2017.
- MBAC Consulting Pty Ltd. 2003b. Western Hardwoods Region Queensland Private Native Forest Inventory. A report prepared for the Commonwealth Government Department of Agriculture, Fisheries and Forestry, and Timber Queensland, Natural Heritage Trust and Bureau of Rural Sciences, Canberra.
- McAlpine, C., A. Peterson, and P. Norman. 2005. The south east Queensland forests agreement: Lessons for biodiversity conservation. *Pacific Conservation Biology* **11**:3-13.
- McAlpine, C. A., T. A. Spies, P. Norman, and A. Peterson. 2007. Conserving forest biodiversity across multiple land ownerships: Lessons from the Northwest Forest Plan and the Southeast Queensland regional forests agreement (Australia). *Biological Conservation* **134**:580-592.
- McGavin, R., and W. Leggate. 2019. Comparison of processing methods for small diameter logs: sawing versus rotary peeling. *BioResources* **14**:1545-1563.
- McGavin, R., H. Bailleres, F. Lane, D. Blackburn, M. Vega, and B. Ozarska. 2014a. Veneer recovery analysis of plantation eucalypt species using spindleless lathe technology. *BioResources* **9**:613-627.
- McGavin, R., H. Bailleres, F. Lane, J. Fehrmann, and B. Ozarska. 2014b. Veneer grade analysis of early to mid-rotation plantation Eucalyptus species in Australia. *BioResources* **9**:6565-6581.

- McGavin, R., H. Bailleres, J. Fehrmann, and B. Ozarska. 2015a. Stiffness and density analysis of rotary veneer recovered from six species of Australian plantation hardwoods. *BioResources* **10**:6395-6416.
- McGavin, R., H. Bailleres, M. Hamilton, D. Blackburn, M. Vega, and B. Ozarska. 2015b. Variation in rotary veneer recovery from Australian plantation *Eucalyptus globulus* and *Eucalyptus nitens*. *BioResources* **10**:313-329.
- Queensland CRA/RFA Steering Committee (1998), *SE 1.4 An Inventory of Private Forests of South East Queensland*. Department of Natural Resources: Brisbane.
- Roos, A., M. Flinkman, A. Jappinen, G. Lonner, and M. Warensjo. 2001. Production strategies in the Swedish softwood sawmilling industry. *Forest Policy and Economics* **3**:189-197.
- Singer, M., and P. Donoso. 2007. Internal supply chain management in the Chilean sawmill industry. *International Journal of Operations and Production Management* **27**:524-541.
- State of Queensland. 2016. Queensland Forest and Timber Industry. An Overview. Department of Agriculture and Fisheries, Brisbane.
- Venn, T. in press. Chapter 9. The potential for silviculture in Queensland's private native forests to improve returns to landholders and generate economic benefits in regional communities. *in* T. Lewis, T., Venn, B., Francis, S., Ryan, J., Brawner, N., Cameron, A., Kelly, T. Menzies, and K. Catchpoole, editors. *Improving the productivity of the subtropical private native forest resource*. Forest and Wood Products Australia, Melbourne.
- Venn, T., and R. McGavin. in press. Chapter 17. Mill-delivered log cost and gross margins. *in* McGavin, R., W. Leggate and J. Dorries, editors. *Increasing the Value of Forest Resources through the Development of Advanced Engineered Wood Products*. Forest and Wood Products Australia, Melbourne.
- Venn, T., J. Dorries and R. McGavin. in press. Chapter 18. Financial performance of veneer and laminated veneer lumber production using suboptimum quality log resources. *in* McGavin, R., W. Leggate and J. Dorries, editors. *Increasing the Value of Forest Resources through the Development of Advanced Engineered Wood Products*. Forest and Wood Products Australia, Melbourne.
- Venn, T., R. McGavin and A. Ergashev. 2020. Accommodating log dimensions and geometry in log procurement decisions for spindleless rotary veneer production, *Bioresources* **15**(2), 2385-2411.
- Wang, B. J., and C. Dai. 2008. Impact of mountain pine beetle-attacked lodgepole pine logs on veneer processing. *Wood and Fiber Science* **40**:397-411.
- Warman, R. 2014. Global wood production from natural forests has peaked. *Biodiversity Conservation* **23**:1063-1078.

7.0 Appendix

Appendix 1: Sensitivity of net present value of product manufacture to changes in levels of several important model parameters

Table A1. Facility location A, sensitivity of NPV of one-stage LVL manufacture to changes in levels of several important model parameters

Parameter	Level	NPV (\$ millions) by processing scale (m ³ /y of log) and log procurement scenario								
		7500			15 000			30 000		
		1	2	3	1	2	3	1	2	3
Average mill-delivered log cost	-20%	-5.04	-2.32	-1.68		4.91	5.27			
	Base	-7.63	-4.74	-3.97		0.57	0.99			
	+20%	-10.36	-7.20	-6.37		-4.20	-3.63			
Utilisation rate	-20%	-9.62	-6.73	-5.99		-2.61	-2.12			
	Base	-7.63	-4.74	-3.97		0.57	0.99			
	+20%	-6.35	-3.41	-2.64		2.79	3.21			
Capital cost	-20%	-4.69	-1.84	-1.15		3.30	3.73			
	Base	-7.63	-4.74	-3.97		0.57	0.99			
	+20%	-10.61	-7.68	-6.91		-2.02	-1.58			
Labour cost	-20%	-5.92	-2.97	-2.23		3.98	4.40			
	Base	-7.63	-4.74	-3.97		0.57	0.99			
	+20%	-9.40	-6.51	-5.76		-2.97	-2.54			
Market price	-20%	-15.17	-12.56	-11.84		-14.41	-13.90			
	Base	-7.63	-4.74	-3.97		0.57	0.99			
	+20%	-1.01	1.94	2.69		12.61	13.06			
Discount rate	4%	-9.18	-5.22	-4.16		2.13	2.73			
	Base	-7.63	-4.74	-3.97		0.57	0.99			
	10%	-6.58	-4.36	-3.77		-0.32	0.00			

Note: missing value indicate that this scenario is not technically feasible i.e. insufficient resource over the 30-year duration.

Table A2. Facility location A, sensitivity of NPV of two-stage LVL manufacture to changes in levels of several important model parameters

Parameter	Level	NPV (\$ millions) by processing scale (m ³ /y of log) and log procurement scenario								
		7500			15 000			30 000		
		1	2	3	1	2	3	1	2	3
Average mill-delivered log cost	-20%	3.02	6.10	6.86		22.63	23.06			
	Base	0.83	4.08	4.89		18.43	18.91			
	+20%	-1.38	2.02	2.90		14.24	14.76			
Utilisation rate	-20%	-0.89	2.33	3.13		15.36	15.86			
	Base	0.83	4.08	4.89		18.43	18.91			
	+20%	1.98	5.23	6.05		20.67	21.15			
Capital cost	-20%	3.73	6.85	7.64		21.34	21.84			
	Base	0.83	4.08	4.89		18.43	18.91			
	+20%	-2.12	1.18	2.02		15.75	16.23			
Labour cost	-20%	2.35	5.61	6.42		21.84	22.33			
	Base	0.83	4.08	4.89		18.43	18.91			
	+20%	-0.69	2.53	3.34		15.09	15.52			
Market price	-20%	-7.71	-4.64	-3.83		2.42	2.85			
	Base	0.83	4.08	4.89		18.43	18.91			
	+20%	8.40	12.09	13.02		34.29	34.82			
Discount rate	4%	2.69	7.25	8.39		27.48	28.15			
	Base	0.83	4.08	4.89		18.43	18.91			
	10%	-0.22	2.23	2.85		13.01	13.37			

Note: missing value indicate that this scenario is not technically feasible i.e. insufficient resource over the 30-year duration.

Table A3. Facility location B, sensitivity of NPV of one-stage LVL manufacture to changes in levels of several important model parameters

Parameter	Level	NPV (\$ millions) by processing scale (m ³ /y of log) and log procurement scenario								
		7500			15 000			30 000		
		1	2	3	1	2	3	1	2	3
Average mill-delivered log cost	-20%	-3.01	-0.99	0.39	4.13	8.05	10.21		24.81	25.38
	Base	-5.08	-2.84	-1.32	0.51	4.60	6.88		17.67	18.43
	+20%	-7.16	-4.91	-3.15	-3.37	1.06	3.49		10.49	11.46
Utilisation rate	-20%	-7.00	-4.83	-3.19	-2.85	1.60	4.03		10.98	11.75
	Base	-5.08	-2.84	-1.32	0.51	4.60	6.88		17.67	18.43
	+20%	-3.81	-1.63	-0.15	2.65	6.75	9.05		21.42	22.19
Capital cost	-20%	-2.16	-0.18	1.25	3.02	7.22	9.61		21.56	22.32
	Base	-5.08	-2.84	-1.32	0.51	4.60	6.88		17.67	18.43
	+20%	-8.02	-5.78	-4.09	-2.08	2.13	4.45		13.75	14.53
Labour cost	-20%	-3.38	-1.25	0.23	3.82	7.91	10.21		23.18	23.94
	Base	-5.08	-2.84	-1.32	0.51	4.60	6.88		17.67	18.43
	+20%	-6.79	-4.60	-2.96	-2.99	1.28	3.49		12.15	12.91
Market price	-20%	-12.29	-10.42	-10.94	-13.17	-8.97	-6.72		-7.42	-6.41
	Base	-5.08	-2.84	-1.32	0.51	4.60	6.88		17.67	18.43
	+20%	1.16	3.52	3.70	11.63	16.50	19.21		41.39	42.10
Discount rate	4%	-5.69	-2.62	-2.78	2.05	7.79	10.99		27.33	28.40
	Base	-5.08	-2.84	-1.32	0.51	4.60	6.88		17.67	18.43
	10%	-4.62	-2.90	-2.99	-0.36	2.72	4.44		11.97	12.54

Note: missing value indicate that this scenario is not technically feasible i.e. insufficient resource over the 30-year duration.

Table A4. Facility location B, sensitivity of NPV of two-stage LVL manufacture to changes in levels of several important model parameters

Parameter	Level	NPV (\$ millions) by processing scale (m ³ /y of log) and log procurement scenario								
		7500			15 000			30 000		
		1	2	3	1	2	3	1	2	3
Average mill-delivered log cost	-20%	4.72	7.34	9.07	20.34	25.74	28.66		61.68	62.17
	Base	2.99	5.65	7.47	16.86	22.32	25.33		54.54	55.22
	+20%	1.23	3.93	5.85	13.38	18.90	22.00		47.39	48.27
Utilisation rate	-20%	1.29	3.92	5.72	13.65	19.25	22.36		47.66	48.34
	Base	2.99	5.65	7.47	16.86	22.32	25.33		54.54	55.22
	+20%	4.11	6.78	8.62	19.00	24.55	27.61		58.44	59.12
Capital cost	-20%	5.81	8.37	10.16	19.54	25.22	28.37		58.78	59.45
	Base	2.99	5.65	7.47	16.86	22.32	25.33		54.54	55.22
	+20%	0.06	2.80	4.68	14.17	19.63	22.65		50.22	50.90
Labour cost	-20%	4.47	7.15	8.99	20.15	25.73	28.80		60.23	60.91
	Base	2.99	5.65	7.47	16.86	22.32	25.33		54.54	55.22
	+20%	1.48	4.12	5.93	13.56	18.98	21.86		48.85	49.53
Market price	-20%	-5.17	-2.79	-2.89	2.07	6.44	8.84		22.83	23.57
	Base	2.99	5.65	7.47	16.86	22.32	25.33		54.54	55.22
	+20%	10.43	13.61	14.25	31.47	38.14	41.75		86.03	86.64
Discount rate	4%	5.72	9.45	9.85	25.25	32.96	37.21		79.62	80.58
	Base	2.99	5.65	7.47	16.86	22.32	25.33		54.54	55.22
	10%	1.41	3.42	3.63	11.83	15.92	18.18		39.48	39.99

Note: missing value indicate that this scenario is not technically feasible i.e. insufficient resource over the 30-year duration.