ACIAR PROJECT FST/2019/128

Financial and Economic Modelling Report 5:

Final 'Forest to Mill' Module for the Mathematical Programming Model to Support Engineered Wood Product Manufacturing Decisions

Coconut and other non-traditional forest resources for the manufacture of Engineered Wood Products (EWP)

Prepared by
Tyron J. Venn, Jack W. Dorries and Robert L. McGavin
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Final ‘Forest to Mill’ Module for the Mathematical Programming Model to Support Engineered Wood Product Manufacturing Decisions

Tyron J. Venn[a], Jack W. Dorries[a] and Robert L. McGavin[b,c]

a. School of Agriculture and Food Sciences, The University of Queensland, St Lucia, QLD, 4072, Australia

b. Agri-Science Queensland, Department of Agriculture and Fisheries, Queensland Government, Salisbury, QLD, 4107, Australia

c. School of Civil Engineering, The University of Queensland, St Lucia, QLD, 4072, Australia

Executive Summary

Financial information to support engineered wood product (EWP) manufacturing investment decisions in Fiji is limited, particularly with coconut. It is critical that financial evaluations of investment opportunities accompany research activities that assess resource availability, technical aspects of EWP processing and potential markets. This project report summarises progress made on a mathematical model in R software that can generate optimal log procurement strategies that maximise the net present value (NPV) of investments to produce one-stage and two-stage EWPs. Improvements since Project Report 3 (Venn et al. 2022a) include that the module:

1. is fully integrated with the ‘mill-gate to manufactured EWP’ module (described in Project Report 4, Venn et al. 2022b);
2. can estimate financial performance as NPV rather than gross margin;
3. accounts for multiple forest types;
4. can optimise log procurement from each harvested hectare;
5. can evaluate and optimise veneer and EWP manufacturing investment opportunities simultaneously at multiple facility locations; and
6. can evaluate distributed processing versus centralised processing opportunities within a landscape (e.g. the potential for dry veneer to be produced close to the forest resource and for LVL manufacture to take place at an alternative location).

This case study demonstration in southern Queensland evaluates opportunities to process three EWP products at three potential processing locations from four log types available from three forest types, given three potential investment budget constraints (A$10 to A$20 million), which facilitated processing scales from 15,000 m^3 to 30,000 m^3 of log per annum. The model restricted the manufacture of EWPs to a large regional town (Gympie), but allowed dry veneer production at all three processing locations (Dalby, Eidsvold and Gympie).

The model found Eidsvold was the optimal dry veneering location. Optimal log procurement to maximise NPV was found to be a complex function of forest type distribution around processing locations, whether annual processing capacities or market demand were binding constraints, and the market prices for

products made from different species. The optimal mix of species tended to favour the higher value species, subject to costs to deliver those species to the milling location. Within the log mix for each species, medium quality logs (B-grade sawlogs) were always the optimal log type to procure. However, the optimal proportions of high quality (A-grade sawlogs) and low quality (top logs and small peeler logs) logs to process was sensitive to whether processing constraints were binding (i.e. aggregate processing capacity was reached). Distributed production, where dry veneer is produced at Dalby and Eidsvold (which are closer to the forest resource) and EWP manufacture takes place at Gympie, was found to be optimal for all investment budget levels evaluated.

Table of Contents

1. Introduction

The aim of the broader ACIAR project is to deliver and validate wood processing technologies to transform coconut and other currently low-value forest resources in Fiji into high-value engineered wood products (EWPs) suitable for local and international markets. Financial information to support EWP manufacturing investment decisions in Fiji is scarce, and a financial evaluation of investment opportunities is a critical complementary research activity to accompany assessments of resource availability, technical aspects of EWP processing and potential markets.

The objective of the financial and economic research in FST/2019/128 is to develop a mathematical programming model to support decision-making with respect to investments in coconut and hardwood EWP manufacture in Fiji. Dorries et al. (2021) details the rationale and guiding framework for the model. The objective function of the model will be to maximise the net present value (NPV) of investment in EWP manufacture. The decision variables that the model will optimise to maximise NPV will provide valuable information to potential investors, including:

- which forest resources should be harvested (*e.g*. coconuts and mahogany) and from where on the landscape?;
- where there is variation in log size and quality, which log types should be procured from the forest resources (*e.g*., small diameter versus large diameter logs, and short length versus longer logs)?;
- where to establish EWP manufacturing facilities, and whether veneering and EWP manufacture should occur at the same location or whether veneering should be performed closer to the resource in a decentralised business model?;
- what is the economically efficient scale of operation (log volume, labour and equipment)?; and
- which final products should be produced?

In the third financial and economic modelling project report (Venn *et al.* 2022a) for ACIAR project FST/2019/128, progress was reported on the forest to mill module of the mathematical programming model. The module accommodated four log types, five different log procurement (combinations of log types harvested) scenarios, used network analysis to estimate haul distances and mill-delivered log costs from the forest to a processing facility, and could select forest polygons to harvest that would maximise gross margins from the sale of manufactured products, subject to harvestable forest area and processing constraints. This project report demonstrates improvements made to the 'forest to mill' module since the third project report, including that the module:

1. is now fully integrated with the 'mill-gate to manufactured EWP' module (described in Project Report 4, Venn et al. 2022b);
2. can estimate financial performance as net present value (NPV) rather than gross margin;
3. accounts for multiple forest types;
4. can optimise log procurement for veneering from each harvested hectare (This allows more flexibility about which logs are put through the lathe to maximise NPV. The five log procurement scenarios examined in Project Report 3 (Venn et al. 2022a) required particular log types to always be harvested from every hectare.);
5. can now evaluate and optimise veneer and EWP manufacturing opportunities at multiple facility locations; and

6. can evaluate distributed processing versus centralised processing opportunities within a landscape (e.g. the potential for dry veneer to be produced close to the forest resource and for LVL manufacture to take place at an alternative location).

This project report presents the final work on the forest to mill module with the subtropical Queensland case study. Project report 6 will apply the forest to mill module to the Fijian context.

2. Research Method: Mathematical Model

The mathematical programming model is being developed in R software, which is freely available and capable of overcoming all limitations associated with the Excel version of this model developed by Venn *et al*. (2021). The R model framework has been developed using data from southern Queensland; however, it will be readily transferable to alternative geographic and economic contexts, although time will be required to parameterise the model appropriately. Project Report 6 will apply the forest to mill module described here to Fiji.

The mathematical model is the same as that presented in Project Report 4 (Venn et al., 2022b), except that equation 4 has been replaced by equation 3 from Project Report 3 (Venn et al. 2022a). This is because Project Report 4 used average mill-delivered log costs rather than forest polygon-specific mill-delivered log costs.

2.1 Parameters and scenarios for the southern Queensland case study demonstration of the model

All veneer and EWP processing parameters adopted are consistent with Project Report 4 (Venn et al., 2022b), unless otherwise stated. All EWP manufacturing scenarios have been evaluated over five years at a 7% real (net of inflation) discount rate. The short timeframe is sufficient to demonstrate the utility of the model while minimising model processing time. As in previous milestones, it was assumed that 30% of upfront capital expenditure on equipment would be in cash, with the remainder borrowed from a bank over 10 years at an interest rate of 6 % per annum. Spindleless lathes producing green veneer were constrained to a processing capacity of 15,000 m^3 of log per annum. In contrast, dry veneer, one-stage LVL production and two-stage LVL production was constrained by processing hours, where no more than two shifts of labour were permitted per day (3800 hours of operation per year). As we begin to apply the model to support real-world decision-making, a choice will need to be made about whether throughput volumes or labour hours (or a combination of the two) should be used to constrain production.

Facility location and processing scale scenarios

This demonstration of the model considered three potential facility locations in southern Queensland, namely Dalby, Eidsvold and Gympie. Processing up to dry veneer was permitted by the model at Dalby and Eidsvold. All stages of production, including to finished one-stage and two-stage LVL products, were permitted by the model at Gympie. Only the sale of LVL was permitted by the model in this analysis, so if processing of veneer occurred at Dalby or Eidsvold, it would be modelled as being part of a distributed production opportunity that required freight of dry veneer to Gympie for further processing into marketable LVL. The model can also optimise facility location for LVL production, but this did not form part of this case study analysis.

The 30% upfront cash requirement has been used to constrain the distribution of processing capacity across the three locations, with three budget constraints considered: $10 million, $15 million and $20 million. A $10 million budget constraint will only permit equipment purchase that can facilitate up to about 15,000 m^3 of log to be processed annually. The two higher budget constraints permit equipment purchases that can facilitate up to about 30,000 m^3 of log to be processed annually. To highlight the potential benefits of distributed production, a centralised processing scenario was evaluated with a $20 million budget constraint and no processing permitted outside Gympie. Table 1 summarises the facility location and processing scale (as limited by budget) scenarios.

Table 1. Facility location and processing scale (budget) scenarios

Scenario	Budget ($ millions)	Processing facility location	
		Opportunity for distributed production at Dalby and Eidsvold	Gympie
1	10	Yes	Yes
2	15	Yes	Yes
3	20	Yes	Yes
4	20	No	Yes

Log procurement scenario

This project report only considers the optimal log procurement scenario. That is, different log types can be procured from alternative harvested areas across the landscape to maximise net present value (NPV). Other log procurement scenarios were evaluated in Project Report 3 (Venn et al. 2022a).

Harvestable log volume per hectare

In the absence of better information, the harvestable volumes per hectare of each log type for all forest types considered were assumed to be same, which is consistent with assumptions made previous project reports. These volumes are:

1. A-grade sawlog 1.1 m^3/ha
2. B-grade sawlog 3.5 m^3/ha
3. Small peller logs 3.4 m^3/ha; and
4. Top logs 0.6 m^3/ha.

Forest resources

Three commercially important private native forest types have been considered in this analysis: spotted gum, ironbark and gum-top box. It has been assumed that 50% of the harvestable private native forest area is managed for timber production. Competition for the logs between mills was also accounted for, as described by Venn and McGavin (2020), which resulted in less resource being available with increasing distance from the processing location. The competition factors were calculated separately at each processing location. In scenarios where processing was occurring at more than one location, after a forest polygon has been harvested to supply logs for to one location, it was not available for harvesting again for any processing location during the five-year simulation period.

Figure 1 outlines the distribution of available and harvestable native forest types on the landscape and the three potential veneering locations. Given the forest resources assumptions outlined above, in total there are approximately 193,000 ha of commercially important and harvestable private native forest in the study area, consisting of 12,000 ha of gum-top box, 80,000 ha of ironbark and 100,000 ha of spotted gum. Spotted gum forest is well distributed throughout the region occupied by the three potential processing locations. Dalby is proximate to large stands of ironbark and Eidsvold is proximate to large stands of spotted gum within the region. Gympie is proximate to comparatively small areas of all forest types.

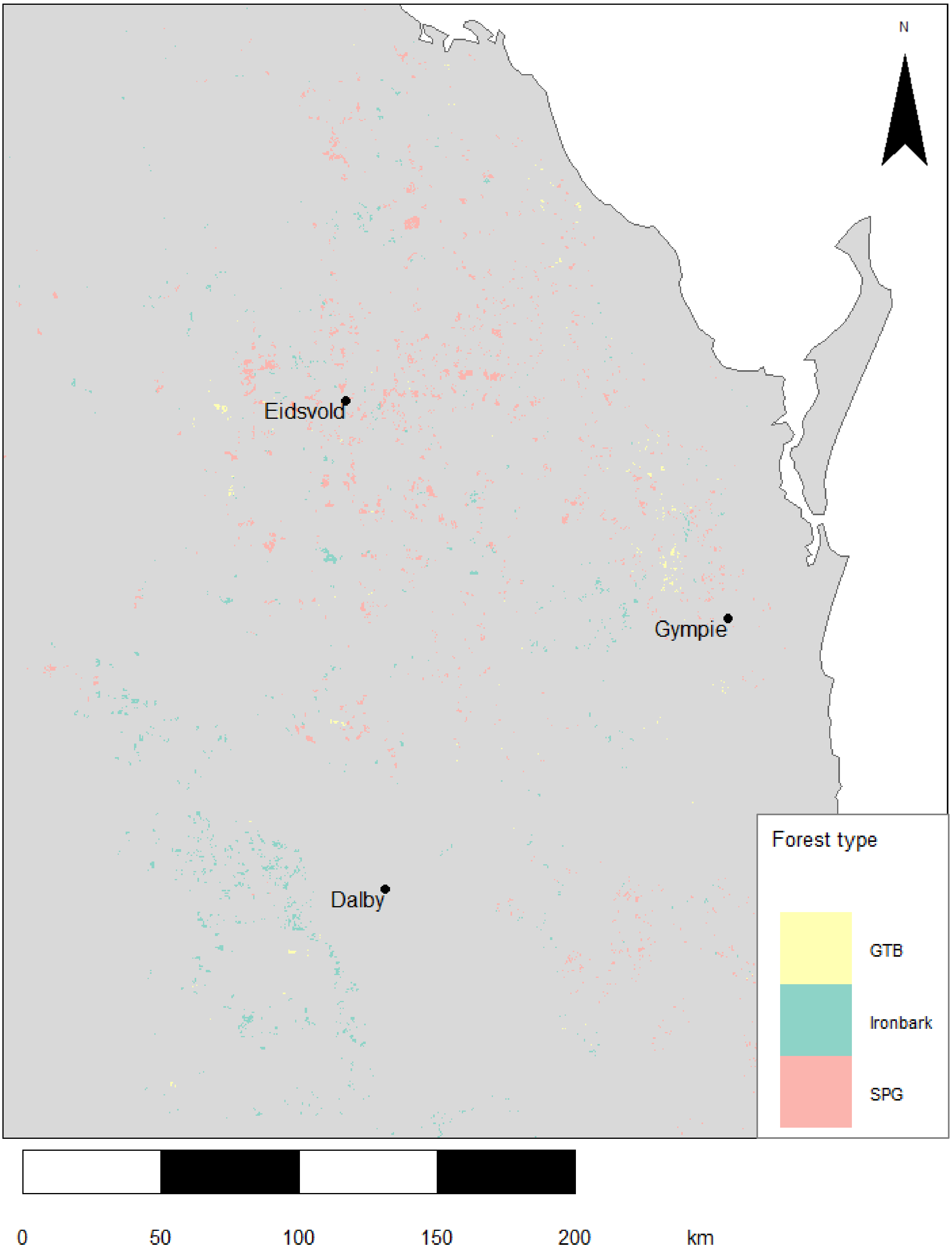

Figure 1. Distribution of the forest resource by forest type, and the three potential veneer processing locations.

Note: SPG is spotted gum forest and GTB is gum-topped box forest

Marketable products

Table 2 defines the three marketable products for this analysis. The one-stage LVL product has no particular species requirements or market demand constraint. The two-stage LVL products have species composition requirements and market demand constraints. The product species composition, market prices and demand constraints for the three products have been selected to test the model, and should not be considered a reflection of actual markets in southern Queensland.

Table 2. Marketable products considered in the analysis

Product type	Length (mm)	Width (mm)	Thickness (mm)	Species requirements (% of veneer)		Market price ($/m^3)	Market demand (m^3/y)
				Ironbark	Gum-top box		
One-stage LVL1	2400	120	35			1500	
Two-stage LVL (LVL2a)	2400	150	100	70		2000	5000
Two-stage LVL (LVL2b)	2400	150	100		100	2250	5000

3. Results from the Case Study

These results are focussed on demonstrating progress in development of the mathematical programming model. The following sub-sections discuss important findings from the optimisation, including the optimal: location(s) for veneer processing, forest areas for harvesting, log procurement for processing, and volumes of final product for each scenario and location. The results also report the average haul distances and mill-delivered log costs under each scenario, which assist the explanation of optimal solutions.

3.1 Optimal locations for veneering

In this demonstration of the model, the marketable products (one-stage and two-stage LVL) were constrained by the model to always be produced at Gympie. Table 3 reports the veneering locations that maximised NPV by scenario. It was optimal to establish veneering operations at locations where Table 3 indicates the annual harvested areas were greater than zero. The analysis revealed Eidsvold was the optimal location for veneering, with this site being the only site in Scenario 1, as well as being used for veneering in Scenarios 2 and 3. This is likely due to relatively large areas of all three forest types being available to harvest close to Eidsvold. In Scenario 2, it was also optimal to establish a veneering facility at Dalby. Only in Scenario 3 was veneering at Gympie optimal, although veneer was also produced at Eidsvold and Dalby. Scenario 4 was constrained to only allow veneering and LVL manufacture at Gympie.

Table 3. Average annual area harvested by location of veneering and forest type

Scenario	Average annual area harvested by location of veneering and forest type (ha)												Total (ha)
	Eidsvold				Dalby				Gympie				
	SPG	IB	GTB	Total	SPG	IB	GTB	Total	SPG	IB	GTB	Total	
1	778	1640	597	2988				0				0	2988
2	1952	225	662	2839	251	2374	463	3111				0	5950
3	2219	382	448	2686	4	1421	198	1591	846	159	815	1822	6099
4				0				0	1957	1125	1066	4175	4148

Notes: SPG is spotted gum forest, IB is ironbark forest, GTB is gum-topped box forest, and Total is the total area harvested for that processing facility location

3.2 Average annual area harvested

Average annual area harvested by forest type, veneering location and scenario are outlined in Table 3. In Scenario 1, large areas of ironbark were harvested for processing at the Eidsvold mill to support the manufacture of LVL2a[1]. Gum-top box was also harvested in Scenario 1 to permit the manufacture of LVL2b. The area of spotted gum harvested around Eidsvold in Scenario 1 was low relative to Scenarios 2 and 3. The focus on veneering logs to produce the higher value ironbark (LVL2a) and gum top box (LVL2b) products constrained processing opportunities for spotted gum.

In Scenario 2, the budget constraint facilitated veneering operations at Eidsvold and Dalby. Despite the scarcity and relatively high mill-delivered log cost (MDLC, see later section) of gum top box, it was optimal to process similar volumes of this species at both locations because of the high final product value. However, NPV was maximised by having each site focus on producing veneer from the forest type most common around the mill (see Figure 1). The focus at Eidsvold was spotted gum, while at Dalby it was ironbark. This minimised MDLC to achieve the NPV-maximising combination of LVL1, LVL2a and LVL2b.

In scenario 3, the addition of a veneering operation at Gympie allowed a greater emphasis on gum top box processing. Eidsvold and Dalby remained focussed on spotted gum and ironbark processing, respectively. In Scenario 4, processing is limited to Gympie, and relatively large areas of all forest types were harvested.

Although Scenarios 2 and 4 can both veneer up to 30,000 m^3 of log per year, there are large differences in the total area of harvesting between the scenarios. The smaller harvested area under Scenario 4 (to supply the same log volume) implies that there were more log types harvested from forest polygons in Scenario 4 than Scenario 2. This has the effect of lowing haul distances and costs in Scenario 4, which are higher because of the larger veneering scale at that location. Lowering haul costs was not so critical for NPV maximisation in Scenario 2 because the scale at each veneering site was half that of Gympie in Scenario 4. In Scenario 2, there was a greater pay-off chasing higher quality logs, rather than keeping haul distances low. This is explored further below.

3.3 Average annual labour hours

The analysis assumed that up to two daily 8-hour shifts could be utilised for each stage of processing which totals 3800 hours per year. Table 4 outlines the average annual labour hours employed at each stage of production. There are only two instances in Table 4 where the entire 3800 hours of labour were utilised: the manufacturing of one-stage LVL in Scenario 3; and in the veneer drying in Scenario 4. In scenario 3, the three veneering operations produced enough veneer to make available labour hours for one-stage LVL production a binding constraint. No other scenario was constrained by labour hours for one-stage LVL manufacture. Scenario 4 was the only scenario where more than 15,000 m^3 was dried at a single location. The model selected a large jet box dryer rather than two small dryers (two small dryers have more processing capacity than one large dryer but have a much higher capital cost), which resulted in the maximum dry veneering hours being reached in Scenario 4. Dry veneering capacity was a non-binding constraint in all other processing scenarios because the veneer was dried with a small dryer at each distributed veneering location.

[1] Given that this analysis is only over a five-year period, Eidsvold may not be able to maintain this same level of ironbark harvesting over a longer timeframe at a reasonably low mill-delivered log cost (MDLC).

Table 4. Average annual labour hours by mill location and processing stage

Scenario	Average annual labour hours											
	Eidsvold				Dalby				Gympie			
	GV	DV	LVL1	LVL2	GV	DV	LVL1	LVL2	GV	DV	LVL1	LVL2
1	1501	2895									3544	3449
2	1516	2871			1509	2886					3523	2299
3	1562	2812			636	1197			1242	2200	3800	2469
4									1572	3800	3391	2255

Notes: GV is green veneer, DV is dry veneer, LVL1 is one-stage LVL, and LVL2 is two-stage LVL

When maximum processing hour constraints become binding, the optimal procurement of logs is affected. These processing 'bottlenecks' indicate opportunities for NPV to be maximised through greater emphasis on minimising MDLC per cubic metre of veneer. In this case study, this resulted in greater volumes of small peeler and top logs being processed in scenarios 3 and 4, relative to scenarios 1 and 2. When processing constraints are less-binding or non-binding, NPV was maximised through greater emphasis on maximising the volume of marketable product, which resulted in relatively more A-grade sawlog volume being processed, because these logs yield a higher final product recovery. This explains the relatively high level of A-grade sawlog volume and low level of small peeler and top logs volume processed in scenarios 1 and 2, compared with scenarios 3 and 4, which is described in Section 3.4.

3.4 Average annual harvested volume

Table 5 outlines the average annual volume harvested by each mill for each scenario. With the exception of Scenario 3 (all three locations processing veneer), the green veneering throughput constraint was binding (i.e. capacity was effectively reached). In Scenario 3, a total of 45,000 m^3 of log volume per year could potentially be processed into green veneer (a maximum of three mills each processing 15,000 m^3 of log into veneer each year); however, only 33,000 m^3/y was processed, because labour hours required to process dry veneer into one-stage LVL reached the binding constraint of 3800 hours per year.

Table 5. Average annual harvested volume by mill location

Scenario	Average annual harvested volume by location (m^3/y)			Total annual log volume (m^3/y)
	Eidsvold	Dalby	Gympie	
1	14,999			14,999
2	14,999	14,999		29,998
3	14,999	6242	11,850	33,091
4			29,986	29,986

Figures 2 to 5 illustrate the average annual log volume by forest type being harvested for each processing scenario, veneering location and log type. They reveal that maximising NPV is a complex function of which forest types and log types to harvest, subject to forest type distribution around processing facilities and whether constraints on processing capacities or market demand for final products are binding. Similar to findings by Venn *et al*. (2021), B-grade sawlogs were by far the most processed log type among all scenarios. These logs are inexpensive relative to A-grade logs and achieve high recovery of veneer from log volume relative to small peeler and top logs.

In both scenarios 1 and 2, A-Grade sawlogs were the second most preferred log type harvested from spotted gum and ironbark forests. Small peelers and top logs were not harvested from spotted gum and ironbark forests in these scenarios because log resources were not scarce over the five-year simulation (mill-delivered log costs not too high) and green veneer production was a binding constraint (15,000 m^3 of log processed per year at each site) such that NPV could be maximised by maximising recovery of marketable product from larger log types from spotted gum and ironbark forests. This also had the benefit of freeing veneering capacity to process smaller log types (less veneer recovered from log volume) from the more valuable gum top box forest type.

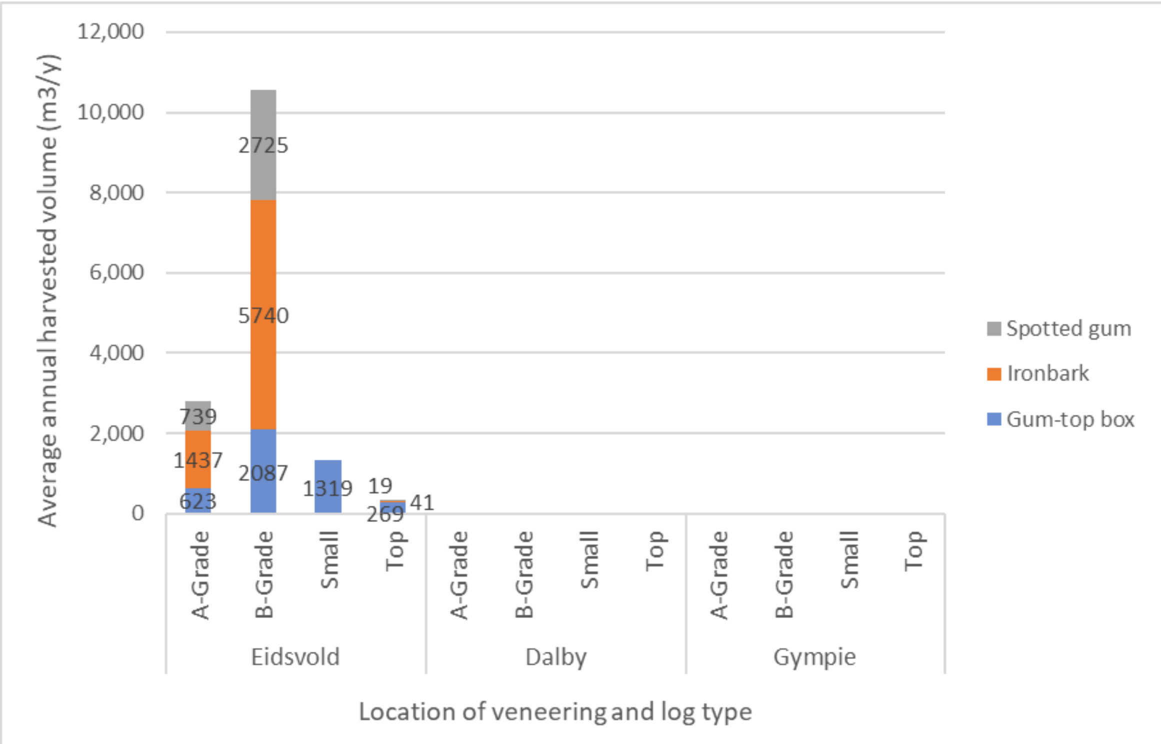

Figure 2. Scenario 1 (up to one veneering location) annual harvested volume of forest type by veneering location and log type

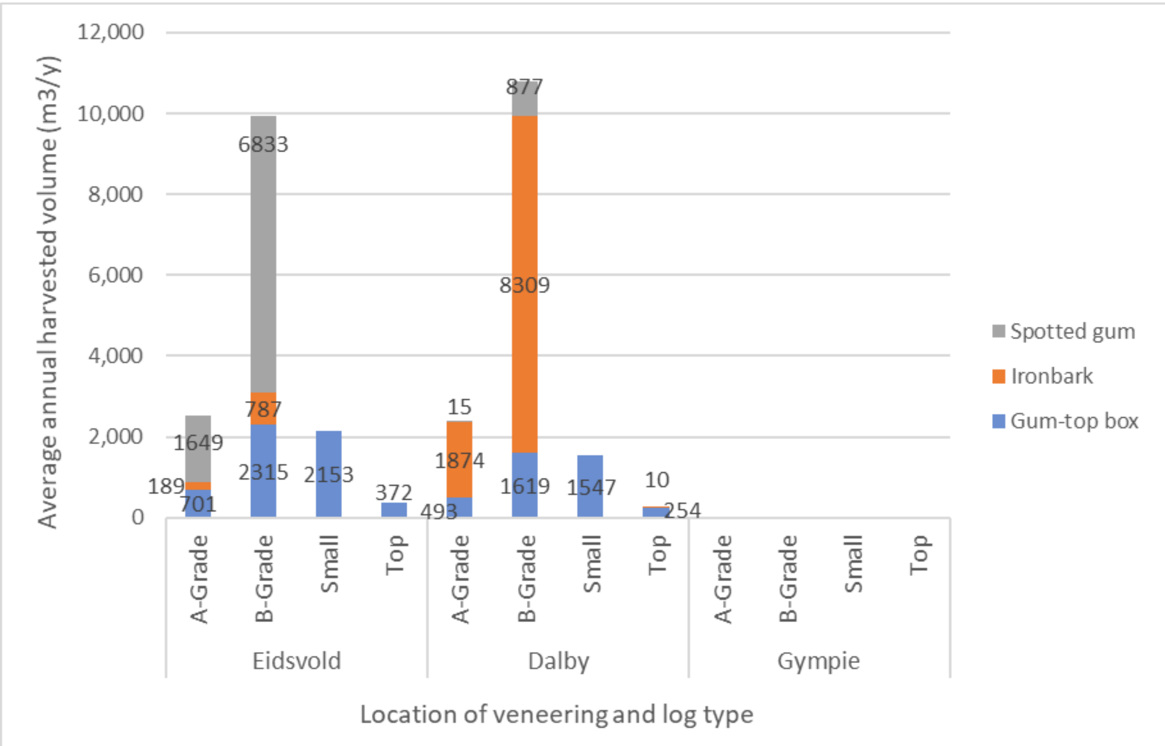

Figure 3. Scenario 2 (up to two veneering locations) annual harvested volume of forest type by veneering location and log type

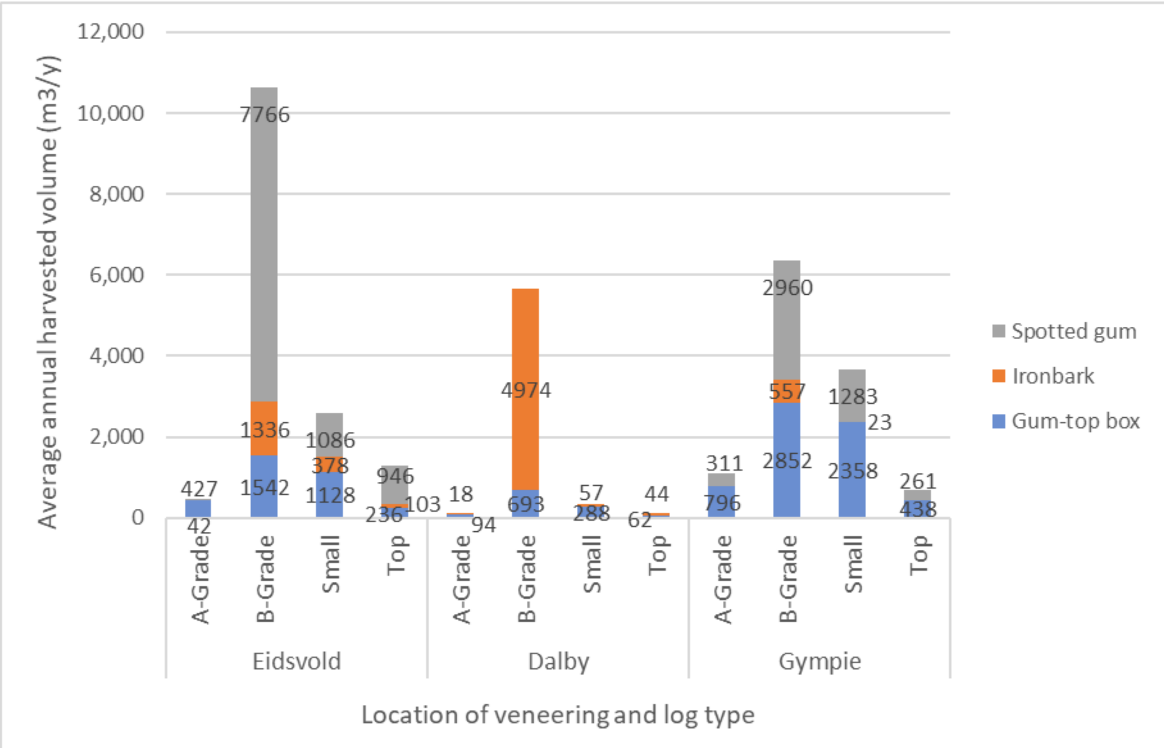

Figure 4. Scenario 3 (up to 3 veneering locations) annual harvested volume of forest type by veneering location and log type

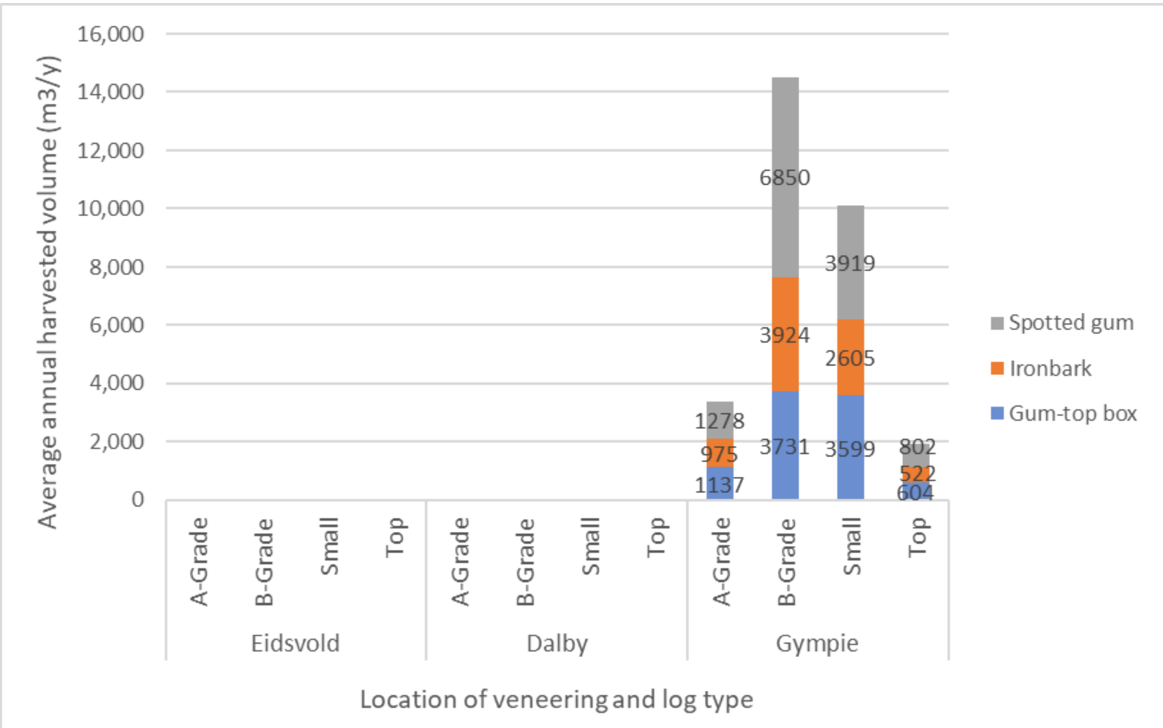

Figure 5. Scenario 4 (veneering at Gympie only) annual harvested volume of forest type by veneering location and log type

The high value of finished products of gum top box and the relative scarcity of the gum top box forest type meant that even low recovery small peelers and top logs of this species were profitable to process in scenarios 1 and 2. Only in scenario 1 were A-grade sawlogs the second most preferred log type from gum top box forests (about 95% of available A-grade logs were harvested, relative to 75% of top logs and 65% of small peeler logs)[2]. In scenario 2, essentially the entire harvestable volume of all log types in each harvested hectare of gum top box forest was harvested.

Unlike scenarios 1 and 2, green veneer production is not a binding constraint in scenario 3 (i.e. more green veneer can be produced than can be processed into one-stage LVL). Instead, labour hours for one-stage LVL production and market demand for LVL2a (ironbark) and LVL2b (gum top box) are binding constraints. Being a scarce forest type, the optimal log procurement from gum top box forests is similar to scenarios 1 and 2, resulting in almost all available log volume per hectare for all log types being harvested. The optimal harvesting strategy in spotted gum and ironbark forests in scenario 3 differs from scenarios 1 and 2. Because green veneering capacity is not a binding constraint, NPV is no longer maximised by harvesting high-recovery and high-cost A-grade sawlogs. B-grade sawlogs are still the most preferred log type, but NPV is maximised by obtaining additional volume from relatively low-cost and low-recovery small peeler and top logs.

In scenario 4, the market demand for gum top box two-stage LVL is no longer a binding constraint because insufficient volume is harvested. Owing to the high value of this product, all available gum top box volume from all log types in each harvested area is harvested. The green veneering capacity is a binding constraint in scenario 4, as it is in scenarios 1 and 2. Therefore, NPV will be maximised by increased procurement of A-grade sawlogs (relative to scenario 3) to raise final product recovery from log volume.

Table 4 indicates that drying the green veneer is a binding constraint for scenario 4. An important distinction between Scenario 4 and all other scenarios is that the optimal solution for Scenario 4 utilised a single large jet box dryer, whilst in all other scenarios a single small jet box dryer operated at each green veneering location. Although the capital costs of a large dryer are less than two small dryers, the processing capacity is less than two small dryers. Reaching the dry veneer capacity in Scenario 4 served to somewhat moderate the preference for A-grade sawlogs, because production reached the maximum volume of green veneer that can be dried.

In Scenario 4, the market demand constraint for the relatively valuable ironbark two-stage LVL product (LVL2a) is binding (all 5000 m^3 produced), and this is achieved by harvesting all available B-grade sawlog volume, 79% of A-grade sawlog volume, 77 % of top logs and 68 % of small peeler logs. The slight preference for A-grade sawlogs over the two smaller log types would free up some green veneering processing capacity to handle larger volumes of low-cost spotted gum logs which can produce the relatively low value one-stage LVL product (LVL1). All B-grade sawlogs are harvested from spotted gum forests, and A-grade sawlog volumes are not as important as they were with the ironbark harvest (lower profit margins for spotted gum LVL reduces the desirability of high-cost, high product recovery logs). Only 59 % of

[2] These percentages were calculated as follows. The harvestable log volumes by log type per hectare in Section 2.1 were multiplied by the harvested area in Table 3 to represent the available harvestable volume by forest and log type (AHV_{fl}). The NPV-maximising harvested volume by forest log type (as determined by the model) is reported in Figures 2 to 5 (HV_{fl}). The proportion of available log volume that was harvested was calculated as HV_{fl} / AHV_{fl} .

available spotted gum A-grade sawlogs are processed, along with 68 % of top logs and 57 % of small peelers.

3.5 Average annual haul distances and mill-delivered log costs

Average annual haul distances by veneering location and scenario are outlined in Figure 6. Average haul distances were found to be the highest for Scenario 4, where veneer processing was limited to Gympie. This is because in order to harvest sufficient quantities of ironbark and gum-top box for the manufacture of two-stage LVL, the Gympie mill had to haul logs from further away. In Scenario 3, each mill customed their log procurement strategy by mainly targeting the forest type with large stands close the mill so that collectively, haul distances were kept low and there was sufficient volumes of gum-top box, ironbark and spotted gum for the specific LVL species requirements (Table 2).

Average haul distances were found to be strongly related to the area of gum-top box being harvested for each mill. Since gum-top box is the most profitable forest type, mills are willing to haul gum-top box logs over greater distances than for ironbark or spotted gum. When relatively large areas of gum-top box are harvested (see Table 3), average haul distances for that mill location tend to be high. For example, the average haul distance for Eidsvold is highest in Scenario 2 (large area of gum-top box harvested) and lowest in Scenario 3 (small area of gum-top box harvested). Likewise, the average haul distance for Dalby is high in Scenario 2 (large area of gum-top box harvested) and low in Scenario 3 (small area of gum-top box harvested).

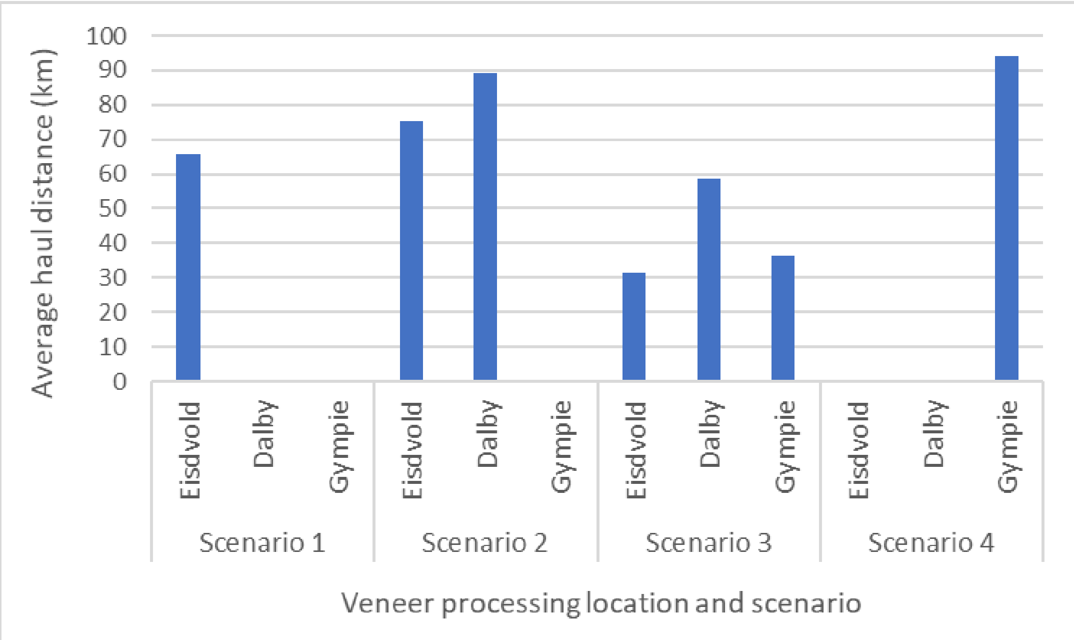

Figure 6. Average haul distances by Scenario and location

Average mill-delivered log costs (MDLCs) are illustrated in Figure 7. Reflecting the average haul distances (Figure 6), average MDLCs were highest for the 30,000 m^3 harvesting operation at Gympie (Scenario 4) and lowest for the three-veneer mill scenario (Scenario 3). Interestingly, even though there is a moderate difference in average haul distance between Scenario 1 (a single green veneer site processing up to 15,000 m^3 of log per year) and Scenario 2 (two green veneer sites each processing up to 15,000 m^3 of log per year), average MDLCs were very similar. This is because with a similar distribution of log types harvested in scenarios 1 and 2 (Figure 2 and 3), the only difference in MDLC between the scenarios is distance related, and this cost is low. For example, between 50 and 80 km from the mill, the variable haul cost was \$0.2355/m^3/km (Venn *et al.* 2021), which adds only \$3.50/m^3 for an increase in average haul distance of 15 km.

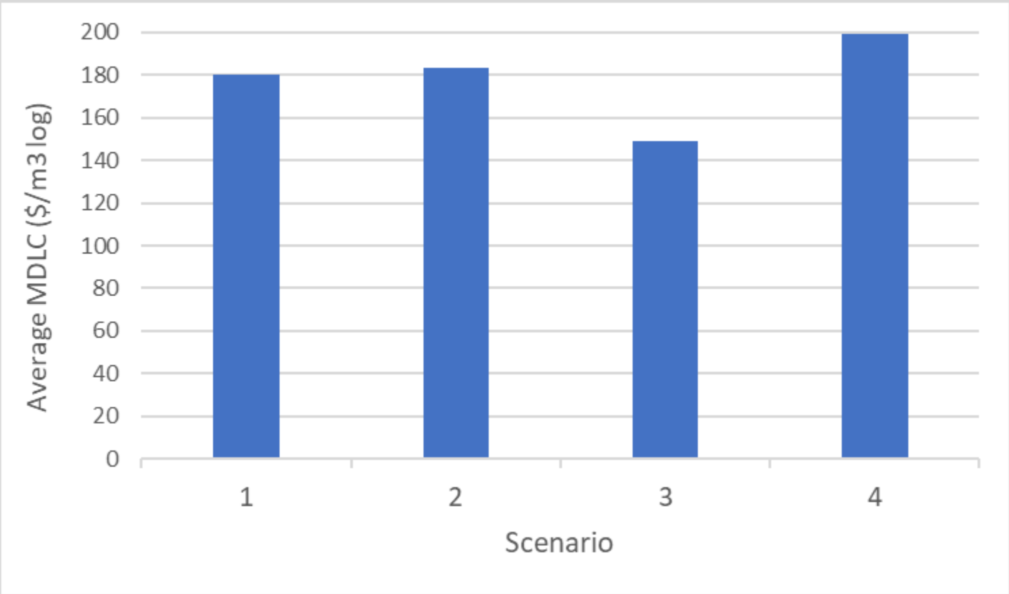

Figure 7. Average mill-delivered log cost by Scenario

3.6 Average annual LVL production

The average annual final product volumes by scenario are outlined in Figure 8. The market demand constraints described in Table 2 are being followed. That is, for both two-stage LVL products, only 5000 m^3 of each product may be sold to market each year. The volume of one-stage LVL product able to be sold to market is unconstrained. Despite the higher price of LVL2b, the limited availability of gum-top box means that for most scenarios, it is not optimal to produce the maximum LVL2b volume. The sale of LVL2a reached its maximum market volume constraint in all four scenarios since manufacturing LVL2a was highly profitable and large volumes of ironbark were able to be harvested by the mill(s) in each scenario at an affordable MDLC. The one-stage LVL product was able to utilise the spotted gum resource being delivered to the mill and was particularly valuable for scenarios 2 to 4, which had higher log processing capacities than scenario 1.

Scenario 3 resulted in the most final product volume being sold to market. The average annual log volume harvested in Scenario 3 was approximately 33,000 m^3 (Table 5), compared to about 30,000 m^3/y for Scenarios 2 and 4. Scenario 2 had a slightly higher final output volume than Scenario 4 despite the same annual log volume throughput. This is because Scenario 2 utilised a larger proportion of A-Grade and B-

Grade logs than Scenario 4, which maximised NPV by processing higher volumes of smaller-diameter log types (Figures 3 and 5).

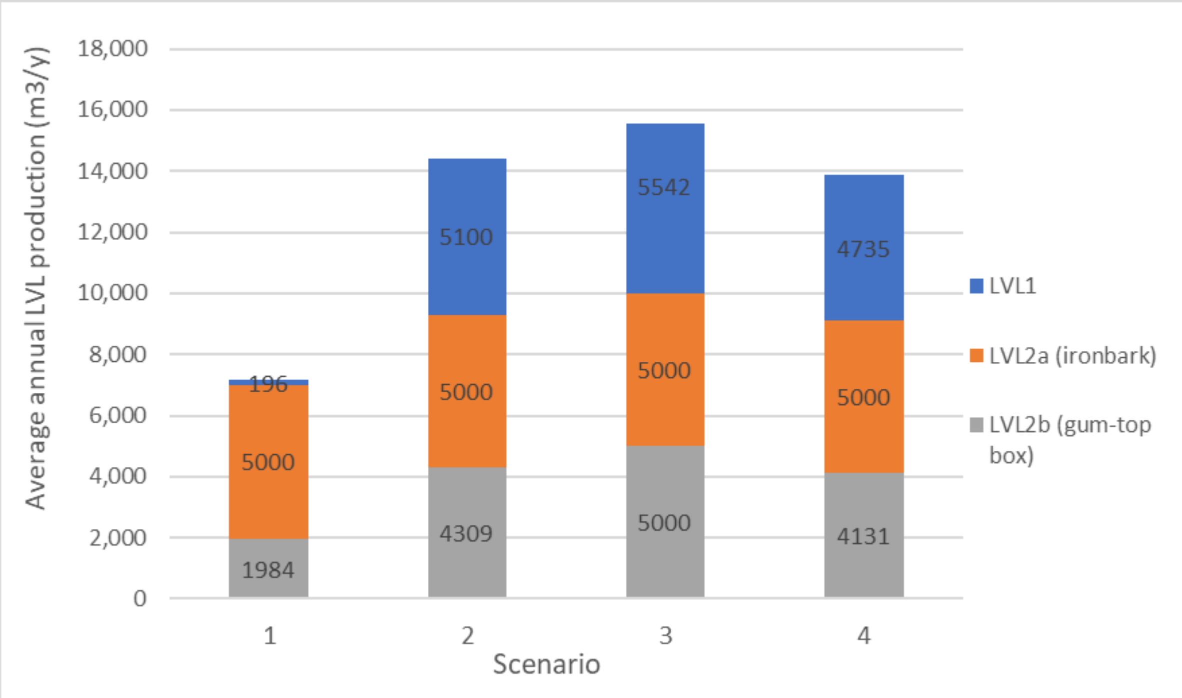

Figure 8. Average annual product volume being sold to market by scenario and product type

3.7 Net present value

Net present values (NPVs) are presented in Figure 9. The relative magnitudes of the NPVs are useful for decision-makingin this case study, not the absolute values. This is because several assumptions made about project duration and markets have put upward bias on NPV estimates. As expected, Scenario 1 (distributed production with one green veneer mill at Eidsvold and LVL production at Gympie) generated the lowest NPV. Distributed production with veneering operations at Eidsvold and Dalby and LVL production at Gympie (scenario 2) generated higher NPV than centralised production at Gympie. Scenario 3, with distributed production of veneer at three sites and LVL production at Gympie generated the highest NPV.

4. Conclusions

The forest to mill module is now capable of maximising net present value (NPV) through optimisation of log procurement and mill location. The module is appropriately accommodating spatially-explicit resource and cost variables. Constraints on maximum annual processed log volume, annual final product demand and labour hours produced rational constraints on the decision space of the model that can be explained by financial logic. Overall, the authors are very pleased with how the forest to mill module is performing.

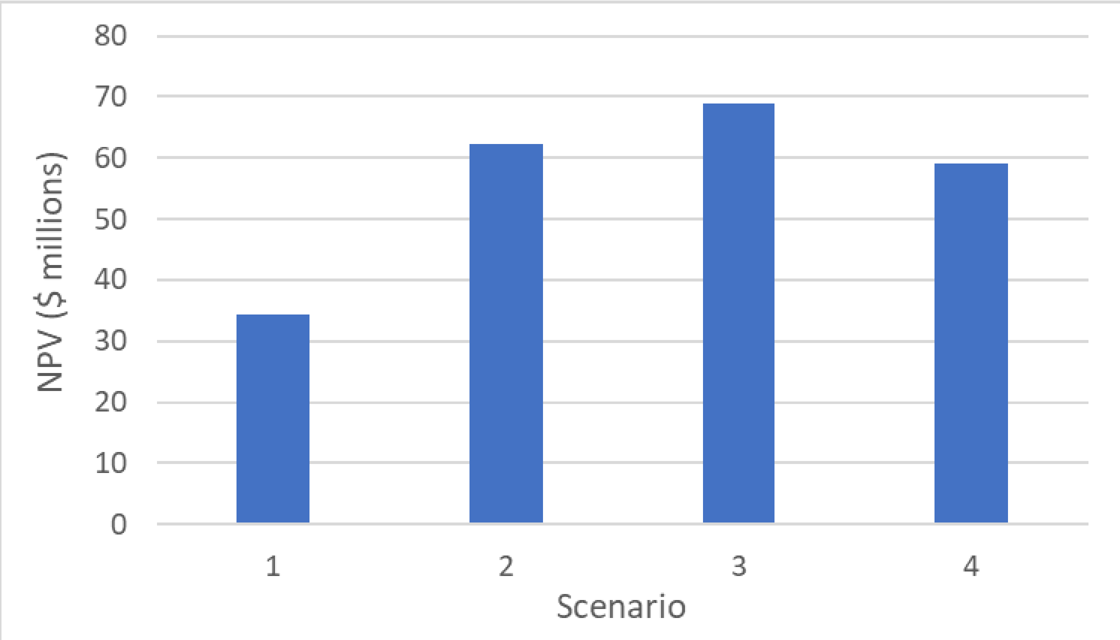

Figure 9. Net present value (NPV) by processing scenario

Although LVL2b (100% gum-top box) was the final product with the highest market price, the model oftentimes did not produce the maximum LVL2b volume. Rather, due to the scarcity and high mill-delivered log cost (MDLC) of the gum-top box resource, the model favoured production of LVL2a (70% ironbark, 30% other species). Although the market price of LVL2a was not as high as LVL2b, ironbark was more available on the landscape and therefore, mills were able to harvest large quantities at a lower MDLC, which maximised NPV.

The model is now capable of optimising log procurement. This was demonstrated in this milestone for both species (e.g the hypothetical high value of gum top box) and log type. Consistent with previous research (e.g. Venn *et al.* 2021), B-grade sawlogs were found to be the most desirable log type for all processing scenarios. The greater sophistication of this R-version of the model revealed more complex relationships between processing scenarios and optimal procurement of A-grade sawlogs, small peelers and top logs than has been published previously. The relative desirability of these three log types was affected by processing constraints. When there were no binding processing constraints (e.g. scenarios 1 and 2), NPV was maximised by processing relatively greater A-grade sawlog volumes than small peeler and top log volumes. In effect, NPV maximisation was being achieved via greater emphasis on increasing the volume of marketable product from log throughput volume (A-grade sawlogs have a high product recovery rate). When processing constraints were binding (e.g. scenarios 3 and 4), NPV was maximised by processing relatively greater small peeler and top log volumes than A-grade sawlog volumes. In effect, NPV maximisation was being achieved via greater emphasis on reducing MDLC for the binding maximum level of marketable product that could be produced and sold.

The model is also now also capable of optimising mill location, including evaluating centralised versus distributed production of veneer and LVL. In this subtropical Queensland case study, distributed production at about 30,000 m^3/y of log volume (Scenario 2) was shown to generate a higher NPV than centralised production (Scenario 4).

This document presents the final work on the forest to mill module with the subtropical Queensland case study. The next forest to mill milestone report will apply the forest to mill module to the Fijian context.

5. References

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