ACIAR PROJECT FST/2019/128

Financial and Economic Modelling Report 6:

Fijian Application of the ‘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
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Fijian Application of the 'Forest to Mill' Module for the Mathematical Programming Model to Support Engineered Wood Product Manufacturing Decisions

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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 EWPs in Fiji. The 'forest to mill' and 'mill-gate to manufactured EWP' modules have been integrated in the mathematical model to perform the analysis for this report. The forest to mill module has been parameterised with log resource and mill-delivered log cost information applicable for Vanua Levu and Taveuni. The model accommodates coconut, mahogany and pine log resources.

Recoveries of veneer from log volume for the three resource types accounts for the log geometries of the species. In the absence of Fijian EWP processing information, all other processing parameters in the mill-gate to manufactured EWP module are applicable for southern Queensland. Therefore, projected financial performances of processing scenarios should be regarded as indicators of relative performance, not absolute performance. This case study demonstration Fijian application considered three potential facility locations: Savusavu where all stages of EWP manufacture were permitted, and a location in Bua and another on Taveuni, where only dry veneer manufacture was permitted. As part of a distributed production model, the dry veneer could then be transported to Savusavu for manufacture into two-stage EWPs. Centralised and distributed EWP manufacturing scenarios were considered at two log processing scales (15,000 m^3/y and 30,000 m^3/y). One two-stage EWP product was considered for each resource, which in decreasing order of modelled EWP market price were coconut, mahogany and pine.

Given parameter levels adopted in this analysis, the most profitable log resource was coconut and the least profitable was mahogany. At the 30,000 m^3/y scale, it was profit maximising to harvest approximately 92% of the senile coconut palms on Vanua Levu and Taveuni over 30 years (at an average rate of 21,000 m^3/y). About 6500 m^3/y of pine and 2500 m^3/y of mahogany were also

processed. Strong economies of scale were revealed, and distributed production at Bua generated a substantial increase in NPV relative to performing all log processing at Savusavu.

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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?

Project Reports 3 and 5 (Venn *et al.* 2022a; 2023) summarised progress in development of the forest to mill module of the mathematical programming model and its application to a study area in southern Queensland. This milestone demonstrates the application of this module to Vanua Levu and Taveuni, Fiji.

2. Research Method: Mathematical Model, Processing Scenarios and Parameters for Vanua Levu and Taveuni, Fiji

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 mathematical model is the same as that described 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). In previous project reports, the R model framework had been developed using data from southern Queensland. In this milestone, datasets and parameters for forest resources, mill-delivered log costs and final product recoveries from log volume relevant to Vanua Levu and Taveuni, Fiji, have been adopted. All other log processing parameters and costs remain at levels appropriate for the southern Queensland study area from Project Report 5 (Venn et al. 2023). For example, electricity and labour processing costs for southern Queensland have been adopted as Fijian dollar costs. Clearly this is problematic, and we caution that the net present values reported for alternative investments in Fijian EWP manufacture should be regarded as indicative of relative performance between scenarios, not absolute performance. Parameterising the model for log processing in Fiji will be the focus of Project Report 8.

2.1 Objective function and decision variables

The model has been developed to maximise the net present value of investments in EWP manufacture on Vanua Levu and Taveuni, Fiji, over 30 years at a 7% real (net of inflation) discount rate. Decision variables in the model are:

1. Which forest resources should be harvest over space and time?
2. Which log types within harvested forests should be procured for processing into EWPs?
3. Which potential processing locations should be developed for veneer and EWP manufacture?
4. Can production of veneer and EWPs at different sites increase profitability?
5. What scale of manufacture should be undertaken at each processing site?
6. Which final product types should be produced?

2.2 Facility locations and processing scenarios

This demonstration of the model considered three potential facility locations on Vanua Levu and Taveuni only; Savusavu, the Bua location and the Taveuni location, as indicated in Figure 1. All stages of manufacture up to finished two-stage LVL products were permitted by the model at Savusavu. The model only permits manufacture up to the dry veneer stage at the Bua and Taveuni mill locations. The model then transfers dry veneer from Bua and Taveuni to Savusavu for LVL manufacture.

Four alternative LVL manufacturing scenarios were evaluated for small-scale (15,000 m3/y) and large-scale (30,000 m3/y) log processing taking place at up to three locations. Up-front investment in millions are indicated in parentheses:

1. Small-scale at Savusavu ($8.0);
2. Large-scale at Savusavu ($13.2);
3. Small-scale at Savusavu, and small-scale Taveuni ($13.2); and
4. Large scale at Savusavu, and small-scale at Taveuni and Bua ($23.6).

2.3 Forest and log resources of Vanua Levu and Taveuni, Fiji

Three commercially important forest types have been considered in this analysis: senile coconut plantations, *Pinus* plantations of Fiji Pine Ltd., and the mahogany plantations of Fiji Hardwoods Ltd. The spatial distributions of these resources and the location of ports that facilitate movement of logs and intermediate and final processed products between islands are illustrated in Figure 1 for Viti Levu, Vanua Levu and Taveuni. Only the forest resources on Vanua Levu and Taveuni have been included in the analysis reported in this milestone. The only relevant ports for this analysis are those in southern Taveuni and at Savusavu on Vanua Levu.

Figure 1. Distribution of forest resources, potential milling locations and ports in Fiji

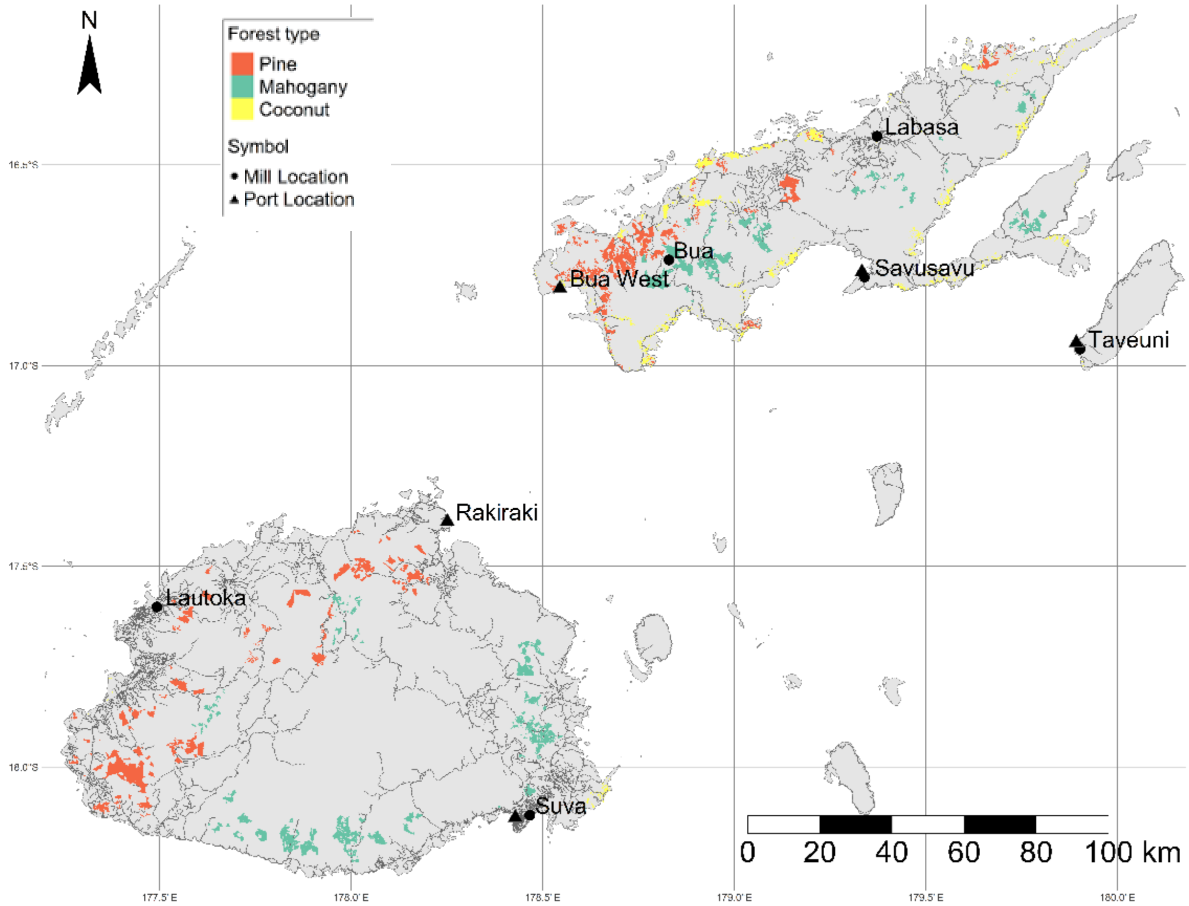


Table 1 reports the forest and log resources on Vanua Levu and Taveuni. Analysis of the spatial data suggests there are 14,456 ha of coconut plantation available on Vanua Levu and Taveuni. The pine and mahogany plantation areas are reported for Vanua Levu only. Fiji Hardwoods supplied spatial information, including date of mahogany plantings in each polygon. Based on advice from Fiji Hardwoods, the harvest return interval for mahogany was assumed to be 35 years.

During discussions with Fiji Pine Ltd., it was revealed that 30% of their total lease area throughout Fiji of 84,000 ha has been planted to pine. In the absence of better data. this analysis has assumed that 30% of the area of each Fiji Pine polygon has been planted, for a total area pine in Fiji of 25,200 ha. It has also been assumed that 50% of pine polygons (which were randomly selected) are available for harvest in year 1. The remaining pine polygons were assumed to become uniformly randomly available (50%/29 years) for harvest between years two and 30 of the simulation. The harvest return interval for pine is assumed to be 30 years in this case study.

Table 1. Forest and log resources on Vanua Levu and Taveuni

Forest plantation resource	Forest area	Log type	Log volume (m^3/ha)[1]	SEDUB (cm)[2]	Log sweep (m/m)[3]	Log taper (m/m)[3]	Competition factor (% available for EWP)
Coconut	14,456	Coconut	47.7	0.2 to 0.28	0.01	0.005	100
Mahogany	16,935	G1B	13.4	0.7 to 0.78	0.05	0.02	25
		G2B	18.5	0.6 to 0.68	0.05	0.02	25
		G3B	27.8	0.5 to 0.58	0.05	0.02	25
		G4B	21.5	0.4 to 0.48	0.05	0.02	25
		G5B	2.6	0.3 to 0.38	0.05	0.02	100
Pine	9262	Butt	90	0.28 to 0.36	0.0	0.01	25
		Middle	65	0.22 to 0.3	0.0	0.01	25
		Top	45	0.18 to 0.26	0.0	0.01	25

Notes: 1. Log volume for coconut is 0.71 m^3/tee multiplied by 60 senile trees per hectare. Log volume for mahogany is from historic averages provided by Fiji Hardwoods. Log volume for pine in Fiji is a place-holder based on Venn et al. (2022c).

2. Logs are assumed to be uniformly distributed throughout the range of SEDUB for each log type. The coconut range is a place-holder based on discussions with project partners. The Mahogany distributions of SEDUB are based on log grading rules used by Fiji Hardwoods. The range of SEDUB in pine is based on a taper function for *Pinus caribaea* reported by Venn et al. (2022c).
3. Log sweep and taper for coconut and pine are assumptions made by the authors and subject to change. Log sweep and taper for mahogany has been guided by log grading rules provided by Fiji Hardwood. B-grade logs have "larger taper" than A-grade logs and presently we assume A-grade logs have 1cm/m taper, while B-grade logs have 2cm/m taper. B-Grade logs have 5 cm to 12 cm taper over 3.5 m of log length. Therefore, this case study analysis assumes the worst case for log sweep in B-grade logs.

To maximise the NPV of EWP manufacture, the model can choose to acquire none, one or multiple log types from each polygon of each plantation forest resource. Logs of all species are assumed to be docked to 2.6 m lengths for veneering, and they have the sweep and taper characteristics reported in Table 1. For each log type, it is assumed there is a uniform distribution of logs within the range of small-end diameter under bark (SEDUB) reported in Table 1. The competition factor indicates the proportion of the standing resource of that log type that is potentially available for EWP manufacture given competition with other log buyers.

In the absence of better data, it has been assumed that 60% of the coconut trees on each hectare (equivalent to 60 stems per hectare) of each coconut plantation polygon are senile and available for harvest. Log volume has been calculated with Smalian's formula for the uniformly distributed range of SEDUB, a 2.6 m log length and the reported taper for coconut logs. Log volume per hectare assumes 60 harvested trees per hectare and six 2.6 m logs per harvested tree.

Fiji Hardwood Ltd. provided historic harvest data per hectare for 15 log types. There are five log grades classified according to centre log diameter, which has been adopted in this study as the SEDUB in Table 1. For each log grade, there are three log qualities, A (best), B and C (worst). These qualities are a function of log sweep and taper. In this analysis only B-grade logs have been considered, defined as logs with sweep of (5 cm per m) and taper of (2 cm per m). The historic mean volume per hectare of each log type has been adopted in this analysis and uniformly distributed over logs within the range of SEDUB reported in Table 1.

The green and dry densities (12% moisture content) adopted for coconut, mahogany and pine are reported in Table 2. These densities are important for quantifying haul costs for logs and dry veneer (for distributed production scenarios), because trucks have weight limits.

Table 2. Green and dry densities adopted for coconut, mahogany and pine

Species	Green density (kg/m^3)	Dry density (kg/m^3)
Coconut [1]	900	700
Mahogany [2]	700	550
Pine [3]	990	550

Note: Dry density is at 12 % moisture content

Sources: 1. (Rodriguez et al., 2009; Nolan et al., 2019).

2. Chaves & Goudzwaard (no date) provided a dry density (12% misture content) estimate and green density has been calculated using the estimate of green veneer moisture content of 30.54% from Anoop et al. (2014)

3. *Pinus caribaea* in Australia (Bootle 2002).

2.4 Mill-delivered log costs

Mill-delivered log costs include the stumpage, cut, snig, and load costs in Table 3, as well as the haul costs outlined in Table 4. In the analysis reported in this project report, there is only one sea shipping route modelled from Taveuni to Savusavu, for which the cost is F$500/12 tonne truck. Illustrative examples of mill-delivered log costs for mahogany G3B and pine middle logs are illustrated spatially in Figures 2 and 3, respectively.

Personal communication with Fijian forestry experts indicated F$10 per tree is a likely current stumpage price for coconut logs. This equates to approximately F$15/m^3 (rounded up), with one senile coconut palm expected to yield 0.71 m^3 of log volume. Stumpage prices adopted for pine are place-holders based on literature from the 2010s, as Fiji Pine has not been willing to share information with the project team as yet. Meetings were held with four logging contractors and millers on Vanua Levu to estimate cut, snig and load costs for coconut and pine.

Table 3. Log costs excluding haul costs from the forest to the mill

Species	Log type	Costs (F$/m^3)					Mahogany only (F$/m^3)	
		Stumpage	Cut, snig and load	Reforestation and license fees	Other mahogany costs [1]	Total cost	Rate	Price
Coconut[1]	Coconut	15	21.5			36.5		
Mahogany[2]	G1B	30.61	45.62	75	109.50	260.73	320	489.2
	G2B	26.06	45.62	70	106.35	248.03	285	446.1
	G3B	20.21	45.62	60	102.30	228.13	240	387.0
	G4B	5.95	45.62	40	92.43	184.00	130	247.4
	G5B	2.01	45.62	30	89.70	167.33	100	204.4
Pine[3]	Butt	50	20			70		
	Middle	40	20			60		
	Top	30	20			50		

Note: 1. Estimates of coconut stumpage was taken from literature and the cut, snig and load costs were provided by three logging contractors in Vanua Levu who have not harvested coconut commercially, but do have experience with pine and native forests.

2. All mahogany costs were provided by Fiji Hardwoods. 'Other mahogany costs' include logyard costs (F$7.02/m^3), tax (defined in text), overheads (F$9.45/m^3) and other unspecified costs costs (F$22.43/m^3).

3. Pine stumpage prices from Venn et al. (2022c). Cut, snig and load costs were provided by three logging contractors in Vanua Levu who have experience with pine.

Table 4. Haul costs from the forest to the mill

Haul zone	Round-trip distance (km)	Haul cost (F$/m^3/km)
1	0-30	0.618462
2	30-50	0.387061
3	50-80	0.309928
4	80-100	0.395632
5	100-140	0.335639
6	140-180	0.290644
7	180-220	0.263648
8	220-260	0.24565
9	260-300	0.232794
10	300-340	0.223152
11	340+	0.215653

The Fiji Hardwoods price schedule for Mahogany in 2022 is indicated in the far right column of Table 3 and should be interpreted as a mill-delivered log cost. It includes a $60/m^3 of log haul fee. The stumpage for mahogany is 13% of gross profit, where gross profit is defined as:

Mahogany gross profit = Rate – Cut, snig and haul – Other mahogany costs [eq. 1]

The Fiji Hardwoods 'rate' for mahogany is defined as:

Mahogany Rate = Price – Tax - Reforestation and licensing fees - an assumed average $60 haul fee [eq. 2]

where Tax = (Price - Reforestation and licensing fees) x 0.09

The cost of all log types at the log landing that has been adopted for analysis is the 'Total cost' column in Table 3. For Mahogany, this is considerably less than Fiji Hardwoods' price minus their assumed average haul of $60/m^3$. However, as described above, the analysis has assumed the worst case for log sweep with B-grade logs, which will reduce recovery from log volume. The authors will work with Fiji Hardwoods to derive an acceptable cost at the landing.

Figure 2. Mill-delivered log costs for mahogany G3B to Savusavu

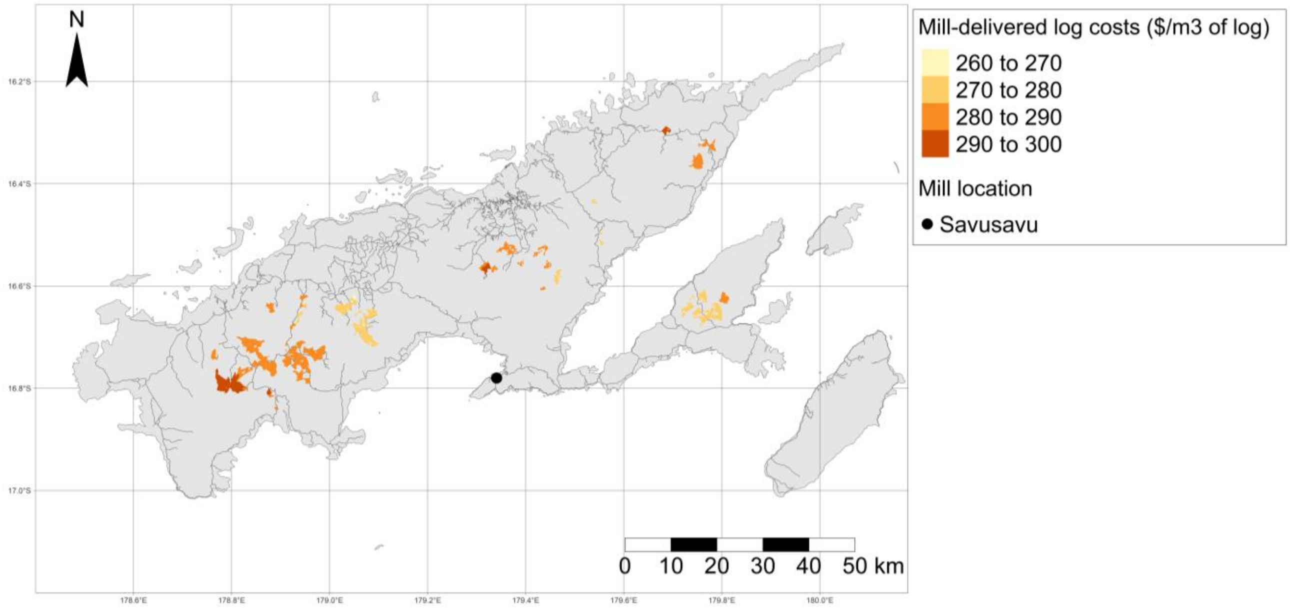
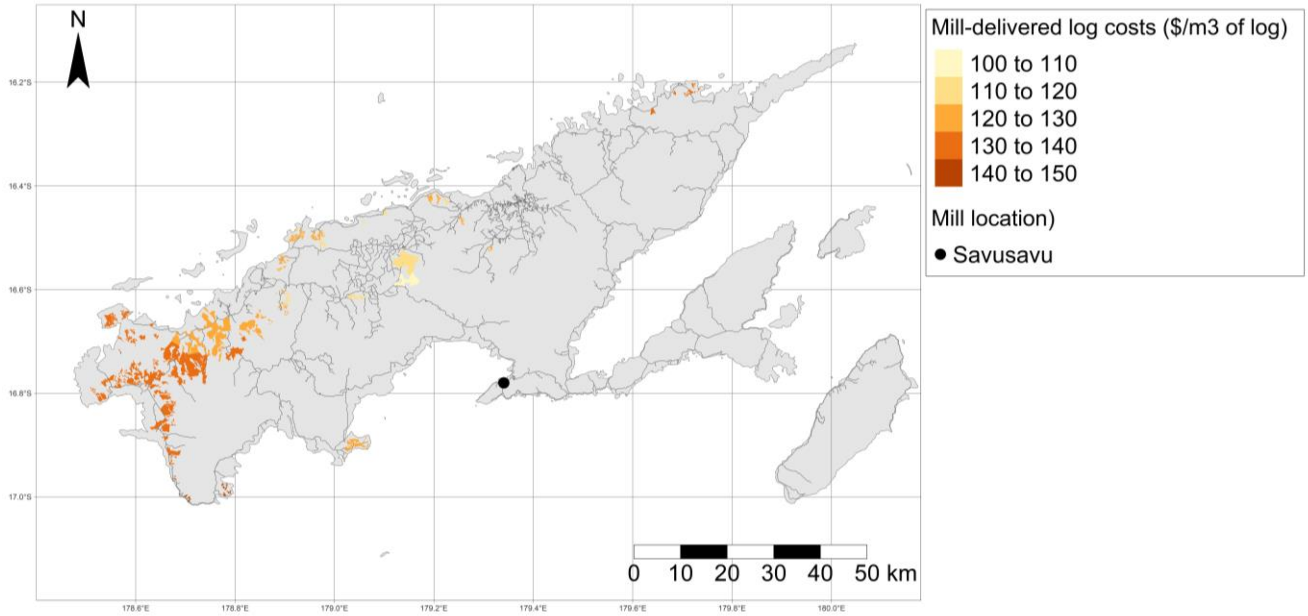


Figure 3. Mill-delivered log costs for pine middle logs to Savusavu



The haul costs outlined in Table 4 have been provided by Fiji Hardwoods and adopted for all log types. The costs are for a round-trip distance from the forest to a particular mill and back to the forest. For example, for a round trip distance of 60 km, the haul cost per m^3 will be F$18.59 (60km x $0.309928). If coconut logs or dry veneer are transported from Taveuni to Savusavu, the haul cost incurred will be: the road transport from the Taveuni forest (or mill for dry veneer) to the Taveuni port, the shipping cost from Taveuni port to Savusavu port with an appropriate payment for the truck driver's time, and then road haul from the Savusavu port to the Savusavu mill.

2.5 Log processing parameters and costs at the mill

All parameters for costs and equipment utilisation rates for veneer and EWP manufactire, and the methods to estimate product recovery from log volume are consistent with Project Report 4 (Venn et al. 2022b), unless otherwise stated. As in other project reports in this series, 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, although multiple lathes can potentially be purchased. 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).

Table 5 reports recoveries of product from log volume by species and log type at various stages of production that have been adopted in the analysis. The relatively low recovery of mahogany veneer from log volume is due to the 0.02 m/m of taper and the high level of allowable sweep in B-quality logs. For example, a 2.6 m log with a SEDUB of 0.74 m will have and large-end diameter under bark (LEDUB) of 0.792 m and 0.13 m of sweep (=2.6*0.05). The log volume is 1.20 m^3; however, the sweep means the SEDUB after log rounding will be 0.61 m, and rounded log volume will be 0.76 m^3 (volume of a cylinder). The volume of green veneer recovered from a log with SEDUB of 0.61 m and a peeler core of 4.5 cm is 0.756 m^3. Thus, green veneer recovery from log volume is 63%. Estimates of recovery for dry veneer and LVL were taken from Venn et al. (2021); dry veneer recovery is 75% of green veneer; one-stage LVL and two-stage LVL recoveries are 83.3% and 81% of dry veneer, respectively.

Table 5. Recovery of product from log volume by species and log type at alternative stages of production

Species	Log type	Fraction of product recovery from log volume by processing stage			
		Green veneer	Dry veneer	One-stage LVL	Two-stage LVL
Coconut	Coconut	0.545	0.409	0.341	0.331
Mahogany	G1B	0.602	0.451	0.376	0.366
	G2B	0.554	0.415	0.346	0.336
	G3B	0.494	0.370	0.308	0.300
	G4B	0.416	0.312	0.260	0.253
	G5B	0.314	0.236	0.196	0.191
Pine	Butt	0.792	0.594	0.495	0.481
	Middle	0.730	0.548	0.456	0.444
	Top	0.664	0.498	0.415	0.403

2.6 Marketable products

Table 6 defines the three marketable products examined in this analysis. Only single species two-stage LVL products have been considered. The assumed 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 Fiji.

Table 6. Marketable products considered in the analysis

Product type	Length (mm)	Width (mm)	Thick (mm)	Species requirements (% of veneer)			Market price ($/m^3)	Market demand (m^3/y)
				Coco	Mahog	Pine		
Coconut two-stage LVL	2400	150	100	100			2100	10,000
Mahogany two-stage LVL	2400	150	100		100		1900	10,000
Pine two-stage LVL	2400	150	100			100	1200	10,000

3. Results from the Case Study Analysis for Vanua Levu

The scenarios analysed were designed to test and demonstrate progress in development of the mathematical programming model for Fiji. These scenarios are intended to represent log resource availability and optimal procurement of resources, but not to accurately represent processing opportunities. Processing will be addressed in Project Report 8.

3.1 Optimal log procurement by scenario

In this demonstration of the model, the marketable two-stage LVL products were constrained by the model to be produced at Savusavu. In Scenarios 3 and 4, processing of logs to the dry veneer stage was permitted at Taveuni and Bua (the latter in scenario 4 only) to test the model's ability to evaluate the financial viability of distributed production. Tables 7 and 8 report the average annual area and log volume harvested for processing at each veneering location, which maximised the NPV for the scenario. Figure 4 illustrates the harvested polygons processed by scenario over the 30-year simulation.

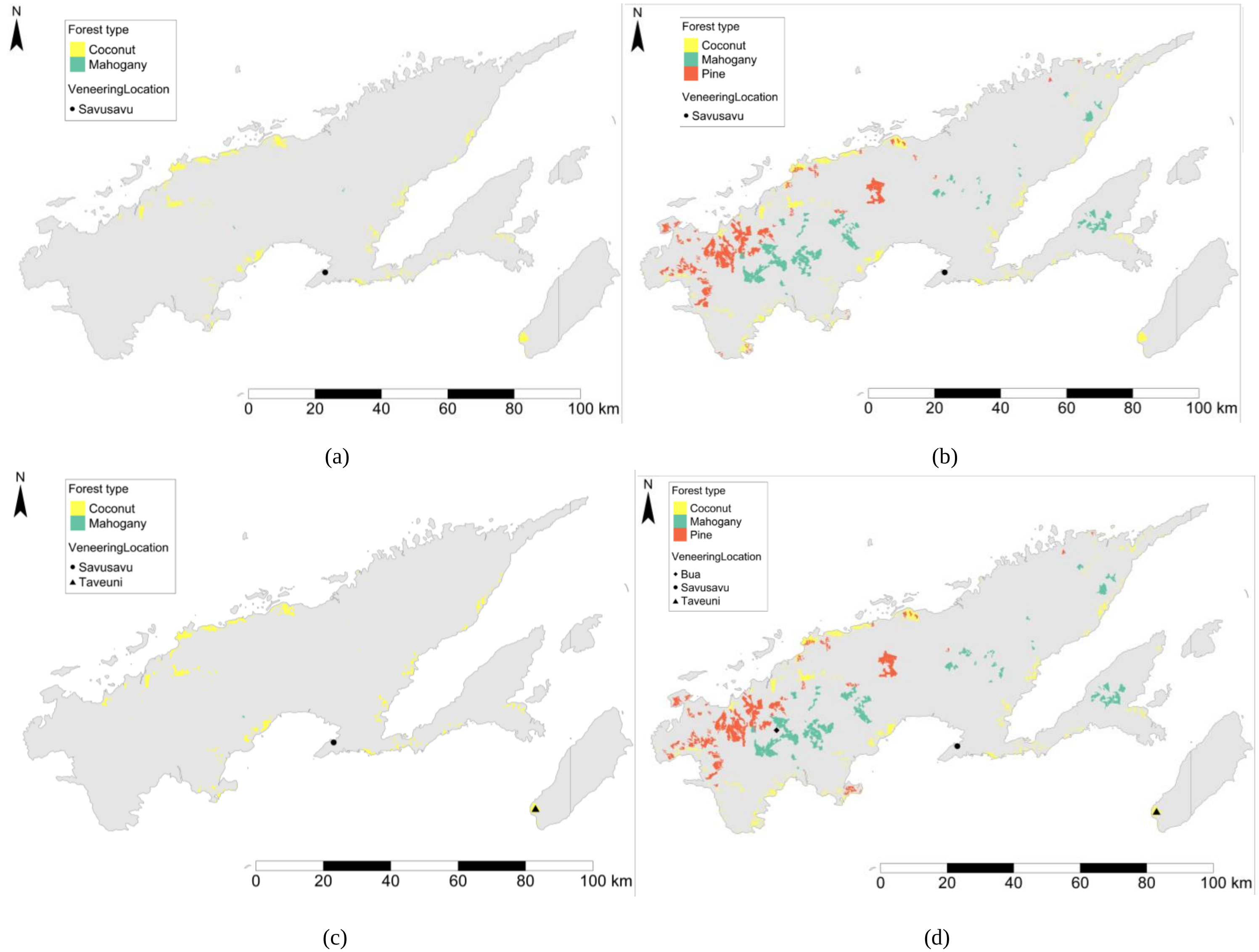
Table 7. Average annual area harvested by location of veneering and forest type

Scenario	Average annual area harvested by location of veneering and forest type (ha)												Total (ha)
	Savusavu				Taveuni				Bua				
	Coco	Mahog	Pine	Total	Coco	Mahog	Pine	Total	Coco	Mahog	Pine	Total	
1	315	2	0	317	0	0	0	0	0	0	0	0	317
2	441	506	255	1202	0	0	0	0	0	0	0	0	1202
3	315	1	0	316	20	0	0	20	0	0	0	0	336
4	351	268	140	759	20	0	0	20	69	271	110	450	1230

Table 8. Average annual log volume harvested and processed by mill location

Scenario	Average annual harvested volume by location (m^3/y)			Total annual log volume (m^3/y)
	Savusavu	Taveuni	Bua	
1	14,997			14,997
2	29,988			29,988
3	14,995	971		15,966
4	27,112	971	14,932	43,015

Figure 4. Harvested polygons by LVL manufacturing scenario (a) small-scale at Savusavu; (b) large-scale at Savusavu; (c) small-scale at Savusavu and Taveuni; and (d) large-scale at Savusavu and small-scale at Taveuni and Bua.



There was sufficient resource available for 30-years of production in all scenarios modelled. In scenarios 1 and 3, essentially only coconut was procured for small-scale processing because of the high market value associated with coconut LVL and there being sufficient coconut resource to supply 15,000 m^3/y of log volume over the 30-year simulation period. There is an error in the Taveuni coconut dataset in R, which only recognises 600 ha of coconut plantation on the island. In scenario 1, this Taveuni resource is shipped to Savusavu for processing. The reporting of annual harvested area and volume for Taveuni in Scenario 3 (and Scenario 4) is misleading. The Taveuni coconut resource is actually fully processed within a few years at a mill on Taveuni, not eked out at low levels over the 30 years. The dry veneer is then shipped to Savusavu for further processing.

In Scenario 2, large-scale processing at Savusavu included the harvest of 92% of the coconut resource on Vanua Levu and Taveuni over 30 years, which averaged 21,000 m^3/y. The remaining 9000 m^3/y processed in scenario 2 consisted of higher quality pine and mahogany logs, namely pine butt logs (5739 m^3/y), G1B mahogany (1655 m^3/y), G2B mahogany (863 m^3/y) and pine middle logs (733 m^3/y). The number of pine and mahogany hectares harvested to achieve these volumes appears relatively high, but that is because of the competition factor, where it has been assumed that only 25% of the resource is assumed to be available for LVL manufacture due to competition with other mills (see Table 1).

In Scenario 4, which had large-scale processing at Savusavu and small-scale dry veneer production at Taveuni and Bua, the same area and volume of coconut resource was processed as in Scenario 2. However, processing of the coconut logs was distributed between the three sites. Figure 5 indicates the breakdown between milling locations and log types of the 43,000 m^3/y of log volume harvested in this scenario. Interestingly, mahogany G3B and G4B logs and pine top logs were procured in this scenario, but were not procured in Scenario 2. Therefore, despite the much higher volume processed in scenario 4 relative to Scenario 2, the annual harvested area is similar (see Tables 7 and 8). Comparison of Figure 5 with Figure 1 suggests that Scenario 2 obtained logs from the majority of forest polygons on Vanua Levu. Further research is necessary to check whether the area of available forest became a binding constraint in Scenario 4, which encouraged greater utilisation of lower quality log types in order to expand production.

Given that pine logs were preferred to mahogany logs in Scenario 2 for maximising NPV, it is interesting to consider what caused the relative increase in mahogany logs compared to pine logs in Scenario 4. At this stage, it is not clear to what extent this may be due to the remaining pine resources being relatively high cost due to long haul distances, the distributed processing at Bua (which lowered mill-delivered log costs for pine and mahogany), or the labour hours for LVL manufacture becoming a binding constraint (see section 3.3). Given the assumed low recovery from mahogany logs, processing the mahogany logs into dry veneer at Bua before transporting to the Savusavu mill would reduce the cost of mahogany LVL considerably more than it will reduce the costs of pine LVL. Further research is required to investigate.

Figure 5. Average annual harvested volume by log type and location for scenario 4.

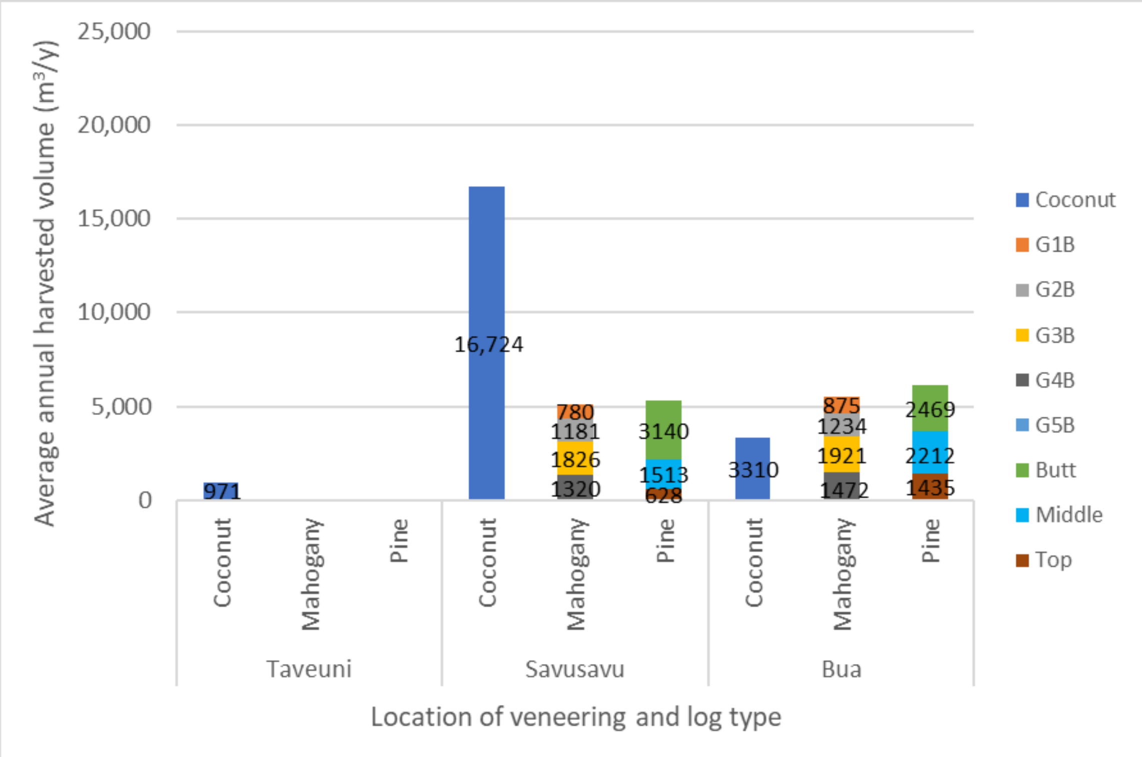


Figure 6 indicates that the model sensibly only processed logs from Taveuni at the Taveuni mill in Scenario 4. The mill at Bua was constrained to 15,000 m^3/y (small-scale) and the NPV of scenario 4 was maximised by procuring logs from forests close to that mill. The large-scale Savusavu mill procured logs from far and wide, and also received dry veneer from Bua and Taveuni. Figure 6 and Figure 7 indicate that expanding production at Bua could be optimal to reduce average return haul distances for logs in Scenario 4. The feasibility of having a large-scale mill at Bua deserves further investigation.

3.2 Haul distances and mill-delivered log costs

Figure 7 reports average return haul distances for logs to each processing facility for each scenario. The average haul distances at Taveuni and Bua are much lower than for Savusavu, indicating potential benefits of distributed production. The average return distance at Savusavu for Scenario 4 is lower than for Scenario 2 because of the mills at Bua and Taveuni, and probably also because in polygons closer to the mill, more log types are being harvested per hectare in Scenario 4 than in Scenario 2.

Figure 6. Mill at which harvested polygons were processed in scenario 4

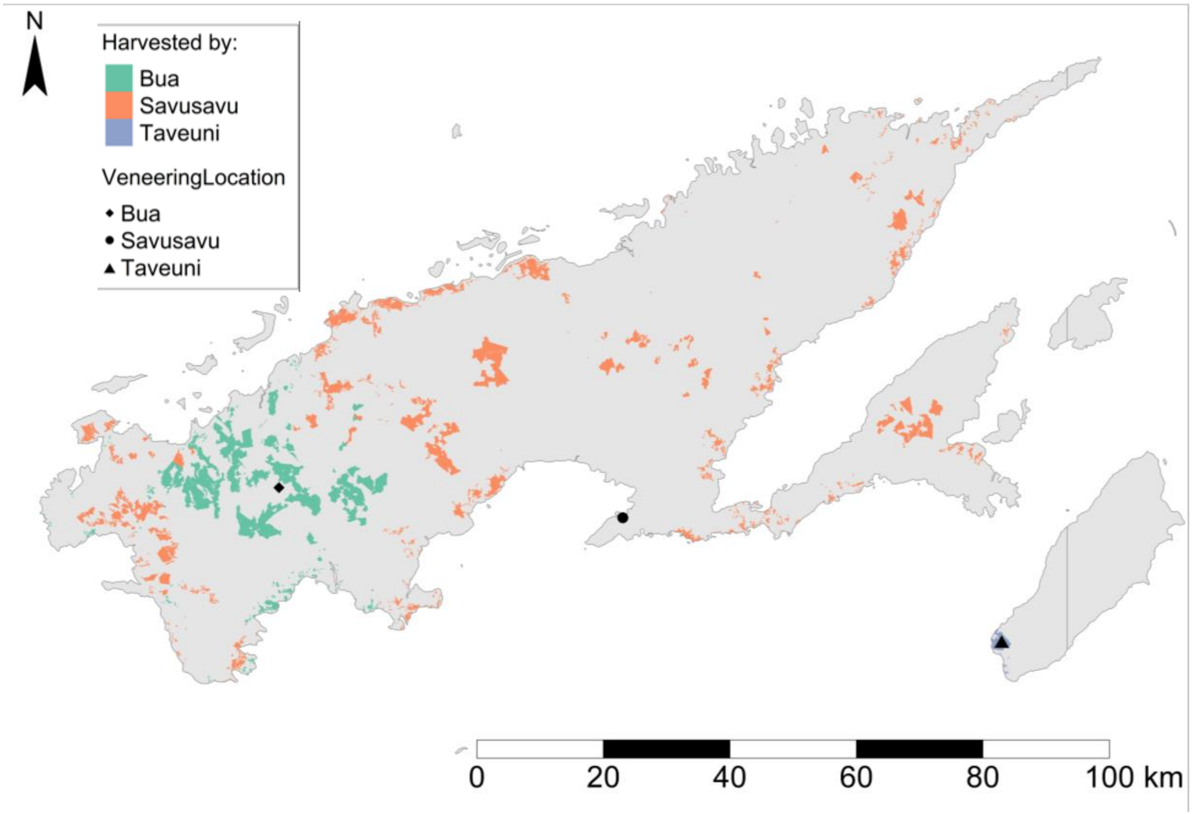


Figure 7. Average return haul distances by scenario and milling location

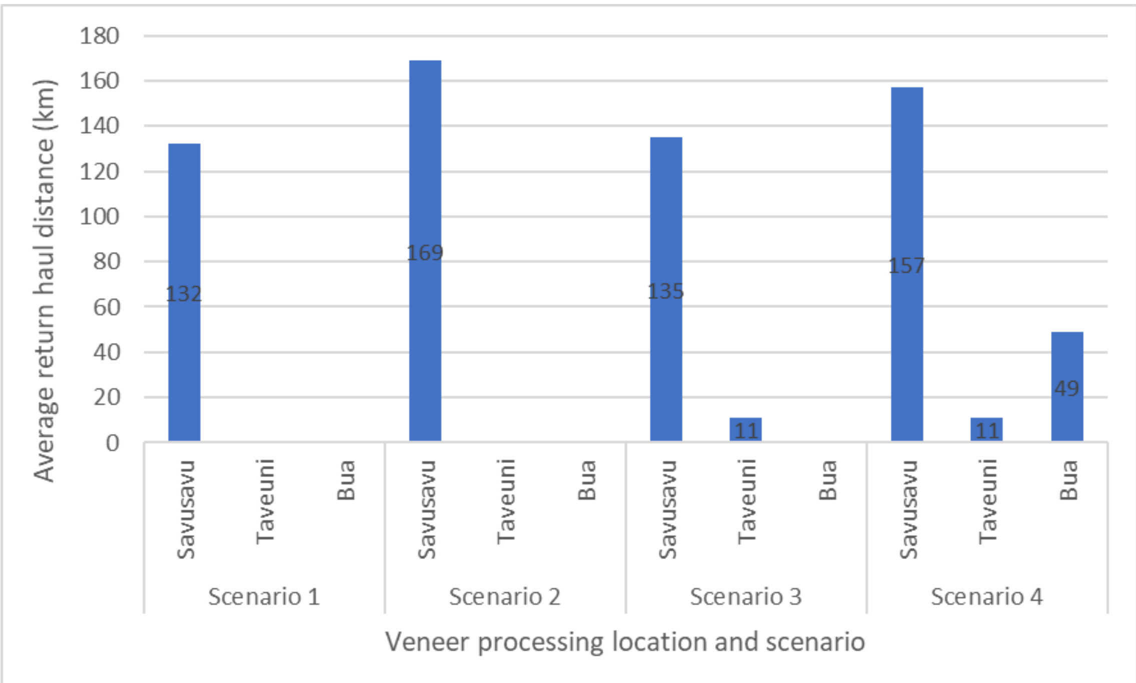
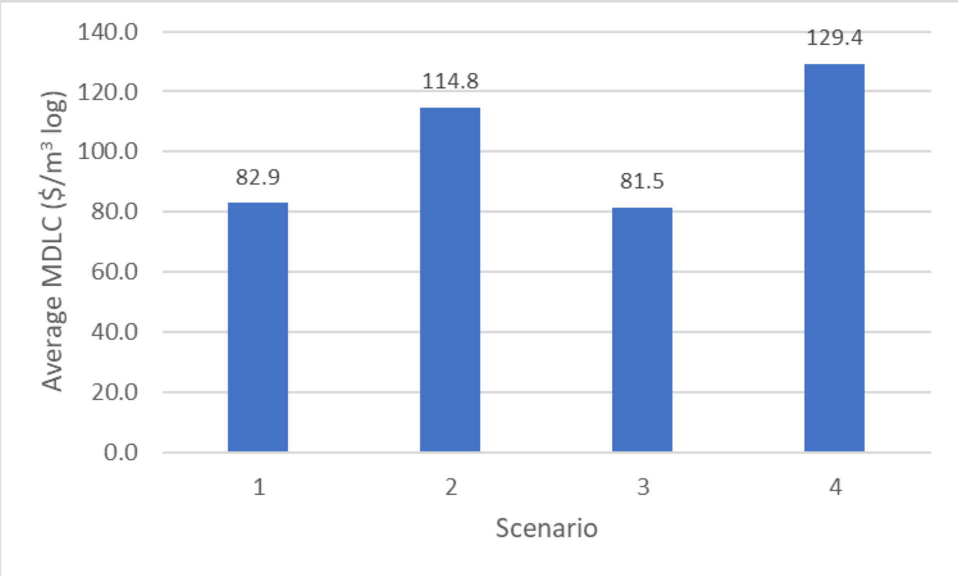


Figure 8 reports estimated mill-delivered log costs for each scenario. Scenarios 1 and 3 have similar low mill-delivered log costs because: (a) effectively only coconut logs were harvested (which has low stumpage and harvest costs); and (b) there was not enough log volume on Taveuni in this analysis for distributed production in scenario 3 to have a meaningful impact on costs. Mill-delivered logs costs for scenarios 2 and 4 are much higher than scenarios 1 and 3 because they also procure the higher cost pine and mahogany logs. Although the average haul distances for scenario 4 are lower than for scenario 2 (Figure 7), the mill-delivered log costs are higher, because a higher proportion of the logs processed in scenario 4 are pine and mahogany, which have higher stumpage and harvest costs than coconut.

Figure 8. Mill-delivered log costs by scenario



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 9 outlines the average annual labour hours employed at each stage of production. The labour hours reported for the Taveuni mill do not represent actual operations at the mill, which was full-time production over a short period in the first few years of the simulation before the mill shut down. There are two instances in Table 9 where the entire 3800 hours of labour were utilised: the manufacturing of one-stage and two-stage LVL in Scenario 4. This labour constraint at Savusavu restricts potential output of final product and therefore caps the annual demand for logs at 43,000 m^3, even though there are four spindleless lathes in operation in this scenario which are each capable of processing 15,000 m^3/y.

These binding labour constraints could have altered the optimal log procurement mix relative to if this constraint had not been reached. When processing constraints are less binding or non-binding, NPV can be maximised through greater emphasis on maximising the volume of marketable product, which can be achieved by processing logs with higher final product recovery. Processing 'bottlenecks' indicate opportunities for NPV to be maximised through greater emphasis on minimising mill-delivered log costs per cubic metre of LVL (Venn et al. 2023). Further research is necessary to investigate the effects of constraints in processing capacity on optimal log procurement.

Table 9. Average annual labour hours by mill location and processing stage

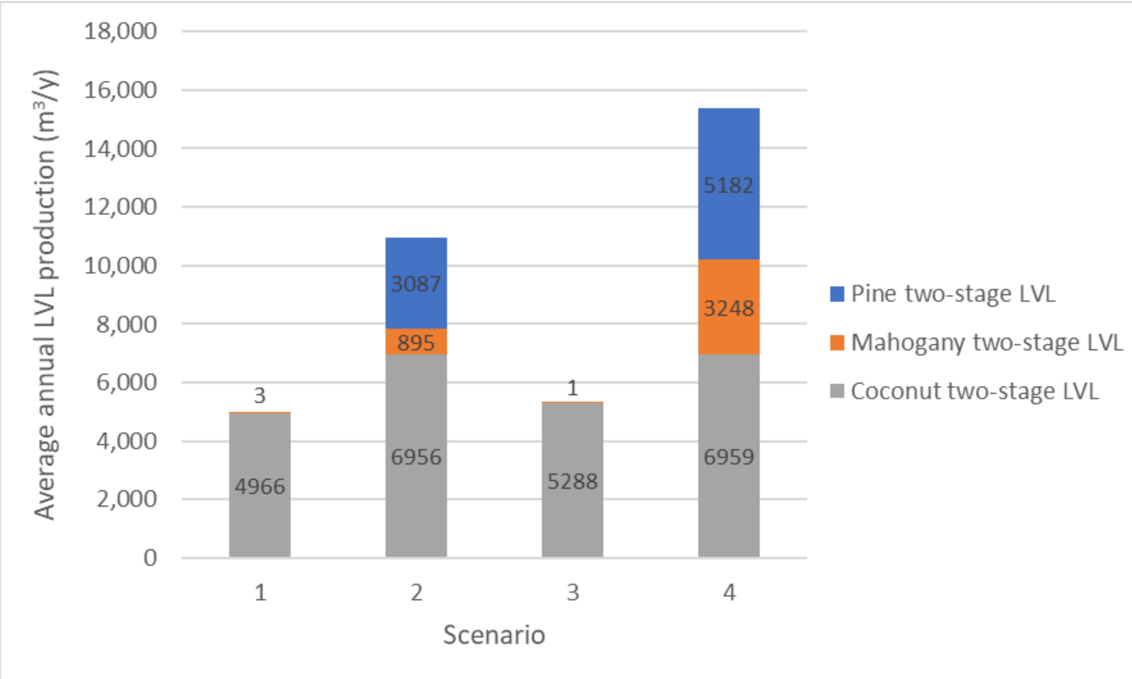
Scenario	Average annual labour hours											
	Savusavu				Taveuni				Bua			
	GV	DV	LVL1	LVL2	GV	DV	LVL1	LVL2	GV	DV	LVL1	LVL2
1	1668	2005	2454	2454								
2	1615	3027	2701	2701								
3	1668	2004	2612	2612	108	130						
4	1437	2640	3800	3800	108	130			1522	2230		

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

3.4 Average annual LVL production

The average annual final product volumes for each scenario that maximised NPV are outlined in Figure 9. In this case study, coconut logs were preferentially utilised in all scenarios, because two-stage coconut LVL was the most profitable product type. Despite the price of mahogany LVL being $700/m^3 higher than pine, the much larger volumes of pine harvested in Scenario 2 (given that supply of mahogany logs was not a constraint) confirms that pine was the second most profitable product type in this case study. The relatively high mill-delivered log costs for mahogany and low recovery of product from log volume made this species the least profitable. The much greater processing capacity in Scenario 4 resulted in similar pine and mahogany log volumes being utilised (Figure 5), although LVL output remained skewed towards pine because of the greater recovery from log volume.

Figure 9. Average annual product volume being sold to market by scenario and product type



3.5 Net present value

Net present values (NPVs) are presented in Figure 10, with all scenarios being financially viable with NPVs ranging from $75 to $316 million. The relative magnitudes of the NPVs are useful for decision-making in this case study, not the absolute values. This is because product manufacturing costs, final product market prices and technical coefficients in the model have not yet been adjusted to reflect Fijian conditions and have put upward bias on NPV estimates. This will be addressed in Project Report 8.

The small-scale LVL Scenarios 1 and 3 have similar NPVs. Therefore, the additional investment required for distributed production at Taveuni in Scenario 3 was not efficient. There were problems with the R model not fully accounting for the coconut resource on Taveuni, so this will need to be rectified and opportunities on Taveuni investigated further.

Scenarios 1 and 2 in Figure 10 highlight economies of scale in two-stage LVL manufacture. Investment costs for Scenario 2 were 65 % higher than scenario 1, but the NPV of Scenario 2 was 109 % greater than scenario 1. Figure 10 also reveals a large return to investment in distributed production. Relative to Scenario 2, Scenario 4 also had facilities producing dry veneer at Bua and Taveuni, which represented a 79 % increase in investment costs, but achieved a 95 % increase in NPV.

Figure 10. Net present value (NPV) of each processing scenario

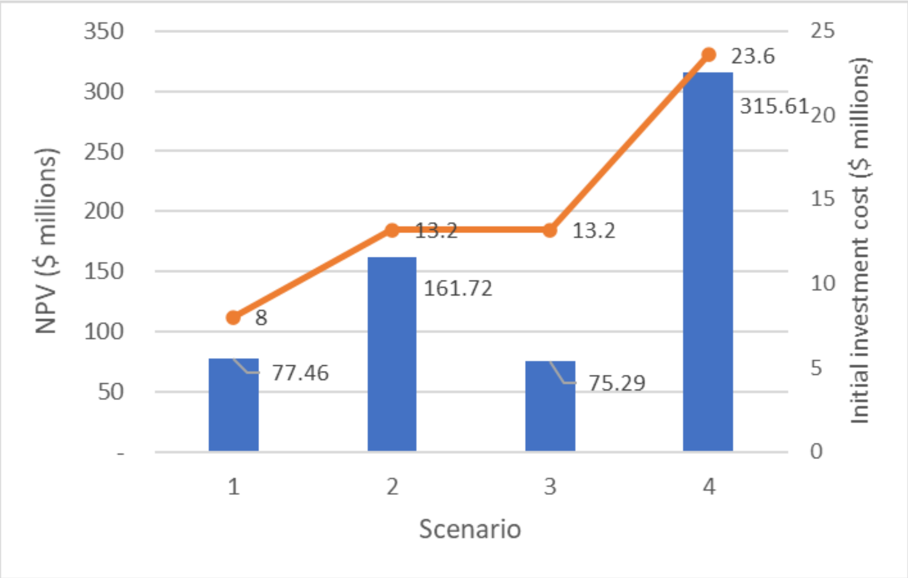


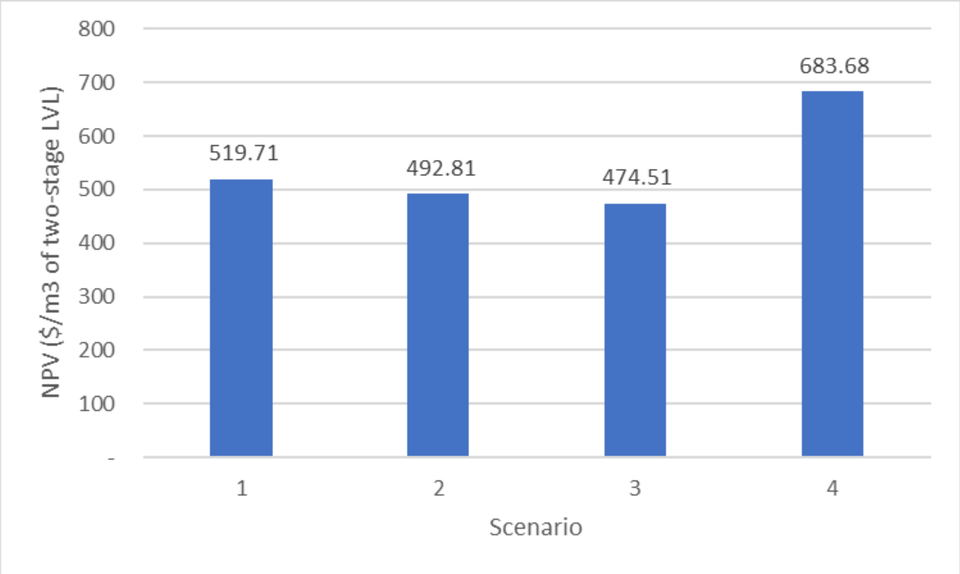
Figure 11 reports NPV per cubic metre of two-stage LVL, which was maximised by Scenario 4. The second highest NPV/m^3 was generated by Scenario 1. This is because all effort in that scenario was focussed on producing the highest value coconut LVL product. Scenario 3 was the worst because of the inefficient investment on Taveuni. The NPV/m^3 for Scenario 2 was lower than Scenario 1 because 30 % of log volume processed and 36 % of final product volume was the less profitable pine and mahogany LVL. There are two explanations for Scenario 4 having the highest NPV/m^3 of two-stage LVL. First, distributed processing at Bua dramatically reduced the cost of dry veneer at Savusavu relative to Scenarios 1 and 2. Second, the fixed costs at Savusavu, such as in the buildings and equipment, can be distributed over substantially greater volume of final product in Scenario 4 compared to Scenarios 1 and 2.

4. Conclusions

The analyses performed indicate on Vanua Levu and Taveuni, there is sufficient log resource to supply at least about 43,000 m^3/y for 30 years for LVL manufacture. This includes at least 21,000 m^3/y of coconut. The model successfully optimised log procurement in Fiji, accounting for the spatial and temporal heterogeneity in log availability, as well as the processing characteristics of different log types. Coconut was found to be the most profitable species and mahogany the least profitable species. With pine and mahogany, higher quality log types were preferentially procured over lower quality log types. The scenarios analysed revealed large financial benefits of distributed production on Vanua Levu.

The milestone highlighted several areas where further research is necessary, including better representation of the full extent of the coconut resource on Taveuni. The research team also need to devise better ways to summarise production when facilities do not operate for the full 30 years (as in the case of the Taveuni mill in scenarios 3 and 4). The next milestone in which Fijian components of the model will be improved will be Project Report 8, where the mill to market module will also be adjusted to represent the Fijian context.

Figure 11. Net present value (NPV) per cubic metre of final product by processing scenario



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