ACIAR PROJECT FST/2019/128

Financial and Economic Modelling Report 2:

Utilising senile coconut palms for the manufacture of veneer and engineered wood product manufacture in Fiji: A comprehensive review of published literature

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

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Utilising senile coconut palms for the manufacture of veneer and engineered wood product manufacture in Fiji: A comprehensive review of published literature

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Executive Summary

The coconut palm has often been labelled the 'tree of life' for the wide variety of products that can provide local communities with essential nutrition and income. However, in the Asian-Pacific region, many coconut plantations are characterised by the presence of unproductive, senile trees over the age of 60. The long-term effectiveness of programs aimed at encouraging senile coconut replacement, such as seedling and subsidy provisions have been limited. In Fiji in particular, approximately 60% of all coconut palms are senile which has resulted in the average coconut yields being significantly lower than neighbouring countries such as Solomon Islands and Samoa. Creating a market for senile coconut palms may have the potential to create long-term incentives for replacement with little to no cost to society. Potential markets for senile coconut palms could be facilitated by the manufacture of veneer and veneer-based engineered wood products (EWPs). Previous research has demonstrated that coconut wood veneer and EWPs can constitute a feasible alternative to typical construction materials with significant social and environmental benefits. The purpose of this project report is to evaluate existing knowledge of coconut wood processing and highlight gaps within the literature in which future reports will fill. The comprehensive literature review revealed information relevant to the coconut and forest products industry in Fiji, such as:

- There are a myriad of benefits that coconuts provide to Fijian communities, including essential food, drink, oil and timber. Standing palms provide coastal stabilisation and protects infrastructure from strong winds and tides;
- Coconut farming in Fiji is a low-income generating activity and is often supplemented by integrating additional crops or livestock underneath the canopies of the palms;
- There are approximately 17,000 to 20,000 ha of coconut plantations in Fiji, mainly situated in the Northern and Eastern Divisions;
- Fiji's coconut industry has been declining in size for decades
- Approximately 60% of coconut palms in Fiji are comprised of low-productivity, senile palms over the age of 60 which contribute to the industry's decline;
- Previous coconut replacement programs have been ineffective due to lack of funding and long-term incentives and poor infrastructure and logistics;
- Processing of senile coconut palms for manufacture of veneer and engineered wood products (EWPs) is technically feasible and spindleless lathe technologies are particularly efficient at processing small-diameter logs such as coconut; and
- Although there is no coconut veneer processing occurring in Fiji, there is one furniture manufacturer processing coconut wood and two veneer processing facilities who are processing other hardwood and softwood species.

The critical literature review also revealed several gaps in literature in which future economic research activities will address, including:

1. The costs of harvesting and transporting logs to potential mills throughout Fiji;
2. The financial performance of coconut veneer and EWP manufacture in Fiji; and
3. The regional and national socio-economic impacts from coconut wood manufacture.

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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. This paper describes important background information and current knowledge about the economic performance of veneer and EWP manufacture in Fiji, with a focus on utilising senile coconut palms in the manufacture of these products. Peer-reviewed scientific literature, grey literature and government documents have been reviewed. Where appropriate, international literature has been reviewed before focusing on Fiji. The review commences with an overview of coconut morphology productivity of coconut palms over their lifetime. The importance of coconut to countries throughout Asia and the Pacific are then presented, followed by an overview of the Fijian agricultural sector and coconut industry and its decline in recent decades. A summary of the coconut replacement programs trialled in Fiji are then presented. The review concludes by reviewing literature that evaluate the suitability of utilising senile coconut palms for timber manufacture, including the potential benefit to the forestry sector, the mechanical properties and its potential applications, and the economic performance of coconut wood manufacture. The review addresses current knowledge gaps that motivate the need for further research.

All financial figures presented in this document have been adjusted to reflect Fijian dollars in 2022. Historic costs have been converted into 2022 equivalent values using consumer price index (CPI) adjustment from the country of origin and then exchanged into Fijian dollars.

2. Coconut morphology

Coconut palms (*Cocos nucifera*) are a monocotyledon and belong to the family *Arecaceae* and the subfamily *Cocoidae* (Perera, 2014). Subfamily *Cocoidae* includes 27 genera and 600 species and coconut is currently the sole species of the genus *Cocos* (Perera, 2014). Coconuts are native to coastal areas of Southeast Asia (Malaysia, Indonesia and Philippines) and Melanesia (Fiji, Papua New Guinea, Solomon Islands and Vanuatu) and thrive in year-round warm tropical climates (between 21°C and 30°C and relative humidity above 60%) with high levels of sunlight and moderate rainfall (Chan & Elevitch, 2006) (Chan & Elevitch, 2006; Gunn et al., 2011). Coconut yields are substantially depressed during dry seasons that contain less than 40 mm of monthly rainfall and annual rainfall above 2500 mm can lead to diseases (Chan & Elevitch, 2006). Coconuts can adapt to a wide range of light, medium and heavy types of soil with yields being maximised when grown on deep soils with good physical and chemical properties such as loams and well drained clays (Chan & Elevitch, 2006). For optimal nut production, coconuts are typically planted between 7 m and 10 m from one another (Chan & Elevitch, 2006; Bourdeix & Batugal, 2018).

There are three distinct types of coconut varieties - Talls, Dwarves and Hybrids. As described in Table 1, Tall varieties of coconut are characterised by their taller height, larger nut size and longer productive life than Dwarves. Likewise, Dwarves bear fruit earlier and yield more nuts than Talls. Hybrids are produced by cross-breeding Tall and Dwarf varieties and can produce higher yields and an earlier fruiting than Talls and have a longer productive life and produce larger nuts than Dwarves. Tall varieties of coconut account for approximately 90% to 95% of all existing coconut palms worldwide (Bourdeix & Batugal, 2018), therefore, this review focuses predominantly on Tall varieties.

Table 1. Characteristics of Tall, Dwarf and Hybrid coconut varieties

Characteristic	Talls	Dwarves	Hybrids
Maximum height (m) [a]	20-30	10-15	15-20
Trunk diameter of mature tree (mm) [b]	300-350	200-250	200-300
Annual rate of height growth (cm/y) [c]	30-50	15-30	20-40
Average annual nut yield per tree [a]	40-60	80-100	70-130
Age of palm at first fruiting (years) [a]	8-10	3-5	4-6
Nut size [b]	Medium-large	Small-medium	Medium-large
Harvesting frequency (months) [d]	2-3	2-3	2-3
Productive life (years) [d]	60-80	30-40	40-50

Sources: a. Perera (2014)
b. Foale et al. (2020)
c. Bourdeix and Batugal (2018)
d. Magat (2014)

The productivity of coconut palms is greatly dependent on the palm's age, variety, soil type, climatic conditions, level of irrigation and land management practices (Magat, 2014). Table 2 outlines the average annual production of a Tall coconut palm throughout various stages in its life. Young palms typically begin to bear fruit at eight to ten years of age and reach maximum production between 20 and 40 years of age (Mwinjaka et al., 1999; Chan & Elevitch, 2006; Bourdeix & Batugal, 2018). From about age 40, yield levels begin to decline and at about 60 years of age, nut production diminishes substantially and the palm is classed as senile (Nelliat et al., 1974; Mwinjaka et al., 1999). As highlighted in Table 2, once a palm reaches senility, the yield of coconuts is less than 20% of maximum production.

Table 2. Yields of coconut over a Tall palm lifetime (Tanzania)

Age of palm (years)	Annual nut production per palm
0-8	0
8-10	11
11-20	30
21-30	45
31-40	50
41-50	38
51-60	19
61-70	9
71-80	7

Note: Due to a lack of reliable coconut yield data in the Asia-Pacific region, this paper reports coconut yields in Tanzania.
Source: Mwinjaka et al. (1999)

3. Significance of coconuts to Asian-Pacific economies

Coconuts are a considerable contribution to the welfare of 11 million farmers throughout the Asia-Pacific region and play a pivotal role in the culture and identity of many of these countries (Quirke & Longmore, 2007; Spurrier, 2008; Morgan, 2013). Due to its many uses, low initial and ongoing costs and resilience to adverse weather conditions, coconuts are particularly favoured among smallholder farmers. According to Prades et al. (2016), 96% of the global coconut palms are managed by smallholders who own, tenant or lease less than four hectares of farmland. Often labelled as the "tree of life", coconut palms provide almost all the necessities of life such as food, drink, oil, medicine, timber, fuel and domestic utensils for many Pacific Island countries (Chan & Elevitch, 2006). Copra (dried coconut flesh), coconut oil, desiccated coconut, coconut milk and coconut water are the main coconut products traded internationally (Chan & Elevitch, 2006; Cloin, 2007). Wood for low-cost domestic construction and household tools are produced from the stems of fallen or over-mature (senile) palms, and remaining wood residues can be used for mulching, charcoaling and composting (Arancon, 1997; Enie, 2002; Van Dam et al., 2004; Chan & Elevitch, 2006; Arancon, 2009).

Due to their low fruit yields, large spatial requirements and low labour requirements, coconuts are generally regarded as low-income, low-maintenance crops (Reynolds, 1995; Arancon, 2009; Leslie, 2013). However, coconut's desirability is due to its consistent supply of fruit, resilience to adverse weather conditions, diverse range of uses and low labour requirements. A study conducted by Macchia and Whillans (2019) revealed that 38% of individuals in Pacific Island countries valued leisure time over the income from work, which was found to be substantially higher than individuals in regions such as North America (29%), Europe (21%), Asia (10%), Middle East (9%), Latin America (8%) and Africa (7%).

Additionally, coconuts also offer other external benefits to farmers and farming communities. They are often incorporated with additional fruit, vegetable and spice crops and livestock on small farms to increase and diversify household income and food security (Ginigaddara et al., 2016; Harrison & Karim, 2016; Nuwarapaksha et al., 2022). According to Thomas et al. (2010), coconut root systems cover a diameter of 2 m, which at a spacing of 10 m, suggests that only 20% of the available land area is effectively utilised and allows for additional farming opportunities under the palms. Incorporation of additional crops can improve the productivity of coconut palms due to improved surface runoff and soil erosion properties, nutrient recycling, mitigation of weeds and indirect fertilising of coconut trees (Nampoothiri et al., 2019). Additionally, the integration of pasture and cattle in coconut plantations has also been found to increase the productivity of the land due to decreased weed control costs and efficient nutrient recycling as the manure produced can be directly recycled as fertilizer (Macfarlane & Shelton, 1986; Food and Agriculture Organization of the United Nations, 2014; Seresinhe et al., 2018). Additionally, coconut trees along coastlines provide coastal stabilisation and protect infrastructure and inland resources from extreme winds and tides, which are expected to become more frequent with climate change (Chan & Elevitch, 2006; Small, 2017). The small canopy of the trees and distance between the palms also provide opportunities to rear livestock and grow other crops, such as cinnamon and coffee, underneath the coconut palms (Plucknett, 1979; Batugal et al., 1998; Chan & Elevitch, 2006).

The global area under coconut and its production has steadily been increasing since the 1960s since which, they have more than doubled (Rethinam, 2019). There are approximately 12 million hectares of coconut plantations in the world, of which, about 90% are located in the Asia-Pacific region (Quirke & Longmore, 2007; Batugal et al., 2009; Rethinam, 2019). Table 3 reports the plantation area and value of coconut exports of the top ten growers of coconuts globally, and several Pacific Island countries. Although coconuts are grown in 94 countries (Nampoothiri et al., 2019), Indonesia, Philippines and India are, by far, the largest producers of coconut, constituting 70% of global coconut production. In 2018, the global coconut products market was valued at F$23.0 billion and is estimated to reach F$62.1 billion by 2026, mainly due to greater demand as a result of increased health consciousness in consumers (Bhandalkar & Deshmukh, 2019). Although more than 50 coconut products are traded globally, only several are traded on a larger scale, including coconut oil, copra, fresh coconut, desiccated coconut and coconut milk, cream and powder, and as illustrated in Table 3, their exportation is a significant contributor to the economies of many Asian-Pacific countries (Nampoothiri et al., 2019). The United States of America, China, Netherlands, and Germany are the largest importers of coconut products and collectively make up 55% of international coconut product imports (OEC, 2021).

Table 3. Coconut plantation areas and value of exports for various Asian-Pacific countries (2021)

Country or region	Area of coconut plantations ('000 ha) [1]	Total export value (F$ millions) [2]
Top 10 producers		
Indonesia	3400	1992.7
Philippines	3500	2530.0
India	2100	757.7
Sri Lanka	440	308.5
Brazil	251	2.8
Papua New Guinea	221	108.8
Vietnam	159	232.9
Mexico	169	27.9
Thailand	206	440.0
Malaysia	88	418.8
Other Pacific countries		
Vanuatu	96	12.3
Samoa	93	7.2
Solomon Islands	59	16.5
Tonga	31	0.3
Kiribati	25	5.7
Fiji	18	3.3
Federated States of Micronesia	17	-
World	12,000	8318.4

Notes: 1. Coconut plantation area are average plantation areas reported by Arancon (2009), Quirke and Longmore (2007), Jayasekhar et al. (2017), and Nampoothiri et al. (2019)
2. The value of coconut product exports are official trade figures reported by the Food and Agriculture Organization of the United Nations (FAO) (FAOSTAT, 2021)

4. The Fijian agricultural sector

Fiji's agricultural sector is a critical component to its economy, contributing approximately 13% (F$1.28 B) to its gross domestic product (GDP) and employing 190,000 farmers (Fiji Bureau of Statistics, 2022a). The 2020 Fijian Agricultural Census estimated there to be about 195,000 ha of agricultural land in Fiji which accounts for approximately 11% of the country's total land area (Fiji Ministry of Agriculture & Food and Agriculture Organisation, 2021). According to the census, 65% of farmland in Fiji is less than one hectare in area, 21% range between one and three hectares and a further 11% between three and ten hectares. Only 3% of farms in Fiji are larger than ten hectares (Fiji Ministry of Agriculture & Food and Agriculture Organisation, 2021).

The majority of cropland in Fiji is characterised by sugarcane, coconut, cassava and taro/dalo.
Table 4 reports the total area of coconut and other commonly grown crops in Fiji by division, as outlined in the 2009 Fijian Agricultural Census.

Table 4. Area of the ten most grown crops in Fiji by division (2009)

Crop	Area by division (ha)				Total area (ha)
	Central	Western	Northern	Eastern	
Sugarcane	0	39,941	17,236	0	57,176
Coconut	903	804	14,052	1,998	17,757
Cassava	5564	5203	4112	567	15,446
Taro/Dalo	7259	2118	4934	881	15,192
Kava/Yaqona	1314	1728	4552	1289	8883
Rice	20	53	3549	0	3622
Banana	321	739	22	3	1085
Yam	18	472	249	110	849
Watermelon	250	507	75	9	841
Tomatoes	131	367	121	1	620

Source: Fiji Ministry of Agriculture (2009)

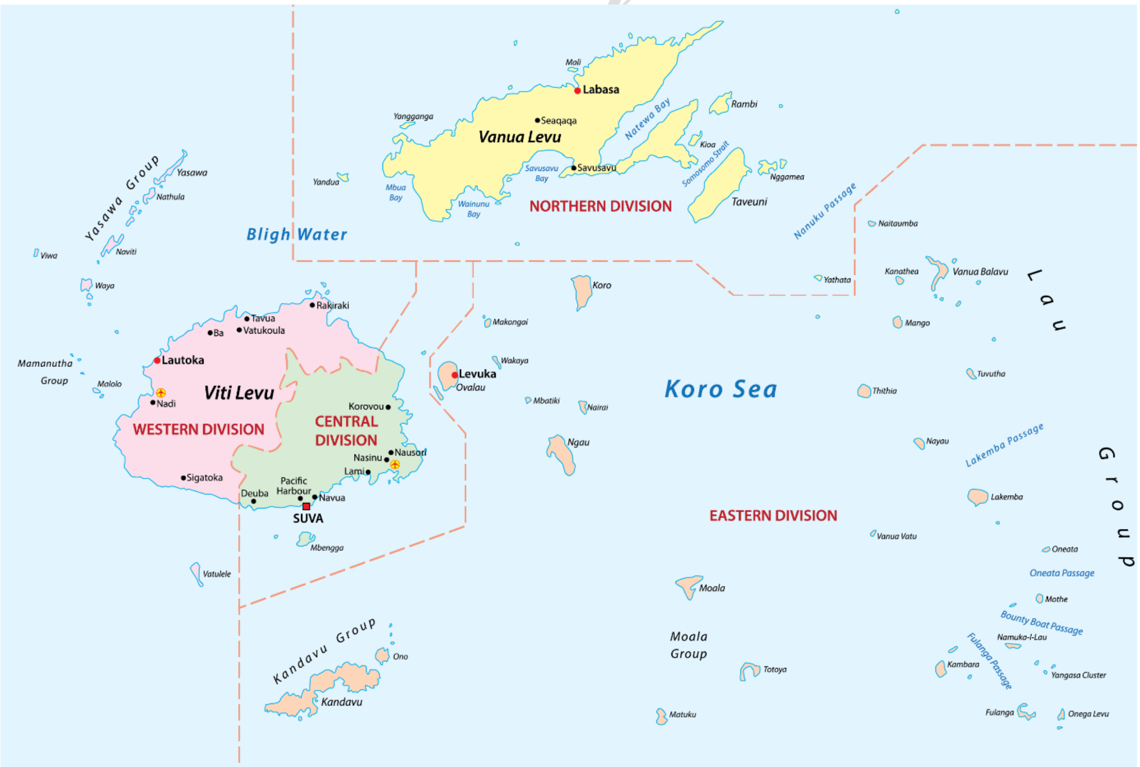

Figure 1. Fiji and its divisions

One of the key constraints on land use in Fiji is the steep-sloped nature of many of the islands. These areas are often not suitable for cropping due to high levels of surface erosion (Harrison & Karim, 2016). Only about 16% (about 300,000 ha) of the land is suitable, and used, for mechanised agriculture, and much of this land is diverted to other purposes, including residential development, tourism and other urban investments (Tabaiwalu, 2010). In Fiji, land is divided into eight land use classifications (LUC) which represent the land's suitability for various agricultural activities. LUCs are determined based on several criteria, including slope, drainage, soil depth, water-holding capacity, extent of erosion, fertility, stoniness, rainfall and altitude (Ben, 2015; Harrison & Karim, 2016). Classes I to III are considered suitable for ploughing and cropping, IV for low intensity cropping, V to VII for pastoral and forestry use and VIII only for conservation purposes (Ben, 2015; Harrison & Karim, 2016). Table 5 outlines the proportion of land by LUC on Viti Levu and Vanua Levu, the two largest islands in Fiji.

Table 5. Slope and LUC classes on Viti Levu and Vanua Levu

Slope group	LUC class	Proportion of land on Viti Levu (%)	Proportion of land on Vanua Levu (%)
Flat (0-3°)	I	16	15
Undulating to rolling (4-15°)	II-IV	17	13
Steep land (16°+)	V-VIII	67	72

Source: Ben (2015)

In Fiji, the majority of the land in Fiji is managed under customary land tenures, where land is communally owned by indigenous Fijians (*iTaukei*) through *mataqali* (clan) land owning units and is able to be leased to non-native Fijians and other non-land owning iTaukei (Rakai et al., 1995; Powell, 1998; Ben, 2015). All legal dealings relating to Native Lands, such as the issuing of leases, agricultural licenses, timber concessions and land subdivisions are handled by the iTaukei Land Trust Board (iTLTB) (Powell, 1998). Leases are typically limited to under five hectares for agricultural purposes and permit the leaseholder use of the land for between 30 to 50 years (Rakai et al., 1995; Batugal et al., 1998; Powell, 1998). The areas that are leased are generally more accessible to the main urban centres and are better suited to agriculture (Kareback & Nilsson, 2005). Out of the 195,000 ha of agricultural land, 77% of land (or 137,000 ha) is managed under customary land tenure arrangements (of which, 30% of this area is leased), whilst the remaining 23% is comprised of freehold ownership (14%), State-owned (6%) and other formal/informal arrangements (3%) (Fiji Ministry of Agriculture & Food and Agriculture Organisation, 2021).

Over the last few decades, widespread urbanisation and declining interest in agriculture has had negative consequences on the livelihoods (human health, food security, rural employment opportunities and poverty) and the Fijian economy. Other issues that have constrained agricultural development in Fiji include lack of economies of size, population fragmentation, vulnerability to natural disasters, market access difficulties, land ownership and tenure issues, availability of financial credit, policy, regulatory and government environments (Duncan, 2007; Food and Agriculture Organization, 2010; Barnett, 2011; Singh-Peterson & Iranacolaivalu, 2018). As a result of the country's declining agricultural sector, locally-grown food crops only account for about 40% of the Fijian population's food energy requirements (Food and Agriculture Organization, 2003; Secretariat of the Pacific Community, 2011; World Health Organization, 2011; Shah et al., 2018; Palanivel & Shah, 2021). Furthermore, Fijian diets have trended away from traditional root crops, green leafy vegetables and fresh meats, towards imported foods, especially highly processed packaged foods, fatty foods, flour-based food products, rice and sugar. These dietary changes have brought with them substantial public health and productivity costs, including increasingly prevalent non-communicable diseases such as increased hypertension and cardiovascular disease, type 2 diabetes, obesity and associated micronutrient deficiencies (Food and Agriculture Organization, 2003; Secretariat of the Pacific Community, 2011; Shah et al., 2018). The transition from locally-grown crops to imported foods has resulted in large trade debts for Fiji. The nation's trade deficit in crop and livestock products was F$250.1 million in 2020, whilst the total food import bill to Fiji averaged F$781.7 million between 2016 to 2020 (Fiji Agriculture and Rural Statistics Unit, 2021; Fiji Ministry of Agriculture, 2021).

Expanding the Fijian agricultural sector has been widely promoted as an approach to reduce rural poverty, improve food security and substantially reduce net imports while also contributing to rural development objectives set in the strategic plans of the Ministry of Agriculture (2019) and Ministry of Forestry (2019) (Singh-Peterson & Iranacolaivalu, 2018). Since the availability of suitable agricultural land in Fiji is scarce, since much of the available land is steep or mountainous and not conducive to mechanised agriculture, improving the productivity of existing farmland should be considered as a primary objective (Ben & Gounder, 2019; Xing & Gounder, 2021). Fiji's coconut plantations are one major component of its agricultural sector that could be improved to enhance the livelihoods of many farming communities since (i) coconut palms cover a significant area of farmland; and (ii) a large proportion of coconut plantations are low-productive and offer the opportunity for largescale improvement (Fiji Ministry of Agriculture, 2009; Lin, 2020).

5. The Fijian coconut industry

have relied on coconuts for food, water, building materials and ingredients for local medicines (Labouisse, 2004; Chan & Elevitch, 2006; Pilgrim, 2011; Bourdeix & Batugal, 2018) and according to Food and Agriculture Organization of the United Nations (2014), 100,000 rural farmers in Fiji still rely on coconut as part of their livelihood. Approximately 80% of all coconuts that are harvested in Fiji are consumed domestically, whilst the remaining 20% is exported, mainly in the form of coconut oil, to Malaysia, Australia and New Zealand (Food and Agriculture Organization of the United Nations, 2014).

The coconut industry in Fiji is deeply rooted in Fiji's colonial history. Commercialisation of Fiji's coconut industry began in the late 19th century when the islands were a colony under the British monarchy (Lin, 2020). Throughout the late 1800s to early 1900s, large quantities of copra were exported, primarily to Europe, for production of coconut oil which was mainly used in the soap, cooking oils and animal feedstuff industries (Brookfield et al., 1985). Between 1885 and 1920, the price of copra increased by 400% and accounted for 20% of Fiji's total export income (McHarg, 1968). In response, production of coconuts rapidly increased and large coconut estates up to 200 hectares often replaced other crops such as cotton, tea, coffee and sugar (Brookfield et al., 1985). However, in the 1930s, the expansion of Fiji's coconut industry was halted by The Great Depression, which dramatically reduced the global demand for coconut. This was compounded by World War II (O'Loughlin, 1956; Brookfield et al., 1985). These events, in addition to the increasing number of senile coconut palms and the gradual decline in the international price of coconut products throughout the remainder of the 20th century, led to many large estates becoming unprofitable and ceasing production. As such, the contribution of smallholder farmers to the country's total coconut production increased from 7% in 1907, to 25% in 1940 and then to 70% in 1980 (Fiji Ministry of Agriculture, 1965; McHarg, 1968; Brookfield et al., 1985). Currently, smallholders produce 80% of all coconuts grown in Fiji (Fiji Ministry of Agriculture, 2009).

In Fiji, coconuts are generally considered a low-income resource, compared to other commonly grown crops. Table 6 outlines the planting densities, labour requirements, average annual revenues, costs and gross margins of coconuts and several other commonly grown crops in Fiji, as reported by Leslie (2013). Due to their long juvenile period (Table 1) and low planting densities (usually between 120 and 200 palms per ha), coconut farming is not become profitable until the age of 16 and even then, is generally less profitable than alternative crops. Given their low productivity and profitability, it is therefore important for growers of coconut to ensure that their palms are well maintained and productive. As explained in the next section, this is rarely the case in Fiji.

Table 6. Annual labour days, annual revenues, annual costs, and annual profits of growing various crops in Fiji (Leslie, 2013)

Crop type	Crops per ha	Annual labour days per ha	Annual revenues (F$/ha)	Annual costs (F$/ha)	Annual gross margin (F$/ha)
Coconuts					
Year 0-3	200	31	-	3,389	-3,389
Year 4-10	200	15	849	1,703	-852
Year 11-15	200	16	1,700	1,705	-5
Year 16-44	200	27	3,833	2,263	1,571
Year 45-60	200	10	849	989	-140
Coconut average	200	20.35	2,320	1,869	451
Sugarcane	5550	27.5	6,611	4,315	2,296
Cassava	6800	110	24,107	6,963	17,144
Taro/Dalo	10,000	97	24,107	9,517	14,589
Kava/Yaqona	2500	73	32,544	28,561	3,983
Rice	50,000	30	9,040	3,783	5,257
Banana	1650	65	52,733	37,816	14,917

Note: Costs include capital, operating and labour. The daily labour wage was assumed to be F$20 per day

There is uncertainty regarding the current area of coconut plantations in Fiji. The most recently published estimate (the 2009 Fijian Agricultural Census) indicates a coconut plantation area of 17,800 ha (Fiji Ministry of Agriculture, 2009). A value chain study undertaken for the project this PhD has contributed to (Young et al., 2022) reported there to be approximately 10,3000 ha of coconut plantations within the Cakaudrove Province, which covers the island of Taveuni and southern parts of Vanua Levu and is the largest coconut-growing region in Fiji. According to the report, this equates to approximately 17,000 to 20,000 ha of coconut plantations nationally, given the assumption that the Cakaudrove Province accounts for 50% to 60% of coconut farmland nationally. The distribution of the 17,800 ha of coconut plantations, as determined in the 2009 Census, are outlined previously in Table 4.

5.2 The decline of Fiji's coconut industry

In Fiji, the production, exportation and planted area of coconut has declined substantially since the mid-twentieth century. From 1970 to 2019, the production of coconut oil in Fiji declined from 17,000 tonnes to 5000 tonnes (Fiji Bureau of Statistics, 2022b). While global coconut exports have increased by over 400% since the 1960s, the production and export of coconut has declined by 90% during the same time period (FAOSTAT, 2021). An underlying contributor to this is the declining productivity on many coconut farms.

Table 7 reports the average yield of coconut per hectare for various coconut-producing countries in the Asia-Pacific region. As shown, the productivity of coconut farms in Fiji is only 65% of the global average.

Table 7. Average coconut yield levels per hectare in various countries (2019)

Country	Yield of coconut (tonnes/ha)	Proportion of global average (%)
Brazil	11.81	236
Vietnam	10.16	203
Solomon Islands	7.24	144
Samoa	6.58	131
Kiribati	6.52	130
Mexico	6.24	124
Papua New Guinea	5.96	119
Sri Lanka	5.77	115
Indonesia	5.71	114
India	5.58	111
World	**5**	**100**
Myanmar	4.91	98
Thailand	4.56	91
Vanuatu	4.17	83
Philippines	4.06	81
Fiji	3.25	65
Federated States of Micronesia	2.33	46

Source: FAOSTAT (2021)

There are several factors that contribute to Fiji's low coconut productivity. First, due to Fiji's location in the Pacific, it is highly susceptible to natural disasters, such as cyclones and floods, which are expected to increase in their occurrence and severity due to global warming (World Trade Organization, 2019). It was estimated that in 2018, almost half of the 281 natural disaster events worldwide occurred in the Asia-Pacific region, including eight of the ten deadliest (Economic and Social Commission for Asia and the Pacific, 2019). As reported by Young et al. (2022), for each severe (Category 4-5) cyclone faced, approximately 10% of coconut palms are destroyed. In 2003, Cyclone Ami ravaged Fiji's coconut plantation areas and the overall copra supply in Fiji dropped by approximately 50% (Arancon, 2009). In 2016, Cyclone Winston directly hit the main coconut growing areas of Vanua Levu, southern Taveuni and Lau, destroying 15% of the commercial coconut palms in these areas (McGregor & Sheehy, 2017). Events such as these can quickly destroy large areas of coconuts, simultaneously increasing the potential risk of diseases and pests (Arancon, 2009). Since the majority of coconuts are grown on low-income, smallholder farms and because newly planted coconut palms take between eight and ten years to reach maturity, natural disasters can take a very long time to recover from (FAO, 2014b).

Second, coconut palms are often subject to various diseases and pests which can reduce yields, and premature death in some cases. Pests that threaten the health of coconut palms include the palm weevil (e.g., *Rhynchophorus bilineatus*, *R. ferrugineus)*, nutfall bug (e.g., *Amblypelta cocophaga* and *Amblypelta lutescens*), coconut leaf beetle (*Brontispa longissimi)*, and coconut leaf miner (*Promecotheca papuana)*

(Domberg, 2015; CABI, 2021). Coconut bud rot (*Phytophthora palmivora*) is a fatal disease which has been recorded in Cook Islands, Fiji, Papua New Guinea, Samoa, Tonga and Vanuatu. Bud rot is characterised by the rotting of the terminal bud and surrounding tissues (CABI, 2021). The disease affects palms of all ages, however, young palms in low lying and humid conditions are particularly susceptible. Bud rot can cause premature nut fall and in severe cases, may rot the entire crown and destroy the palm in only a few months (Joseph & Radha, 1975). The coconut rhinoceros beetle (*Oryctes rhinoceros*) is a prominent pest to coconut plantations in Fiji and throughout the Asia-Pacific areas (Domberg, 2015). Adult female rhinoceros beetles burrow into the crown of juvenile or old palms to deposit their eggs which can stunt plant development and production of coconuts (ACIAR, 2017). Adults also spend most of their time feeding on healthy leaves which may cause physical damage and can lead to secondary infections from bacteria, fungi, or other pests (Hinckley, 1973; Bedford, 1980; Domberg, 2015). Since coconuts are typically grown in favourable conditions where there is no cold season and a minimal dry season, beetles can be active and reproduce throughout the year. Damage is greater when there is a high presence of dying, diseased or dead trees where beetles can reproduce quickly (ACIAR, 2017). Losses from rhinoceros beetle damage can be substantial. Rhinoceros beetles can cause more than 15% reduction in canopy size which can often result in reduced photosynthetic activity, delayed plant maturity, reduced fruit bunch size and an approximately 25% crop loss in mature trees (Manjeri et al., 2014).

Third, prices for coconut products are volatile, which can cause long periods of economic instability during downtrends, leading to neglect and poor condition of the palms and further contribute to low yields (Reynolds, 1995). Figure 2 displays the world price of coconut oil, the largest coconut commodity commercially exported from Fiji, and highlights the volatile nature of the international coconut market. Due to their low coconut exports and distance from large coconut buyers, Fijian growers are generally considered as price-takers are thus, particularly vulnerable to price fluctuations. Prices are determined by a number of factors outside the control of Fiji and other small-scale producers, such as the availability of substitute oils (such as avocado, olive, and peanut oil), supply of coconut oil from large producer countries such as Indonesia, Philippines and India, and external economic conditions (McGregor & Sheehy, 2017). According to Food and Agriculture Organization of the United Nations (2014) and Lin (2020), price fluctuations can reduce incentives to invest in the land and participate in the upkeep of the palms.

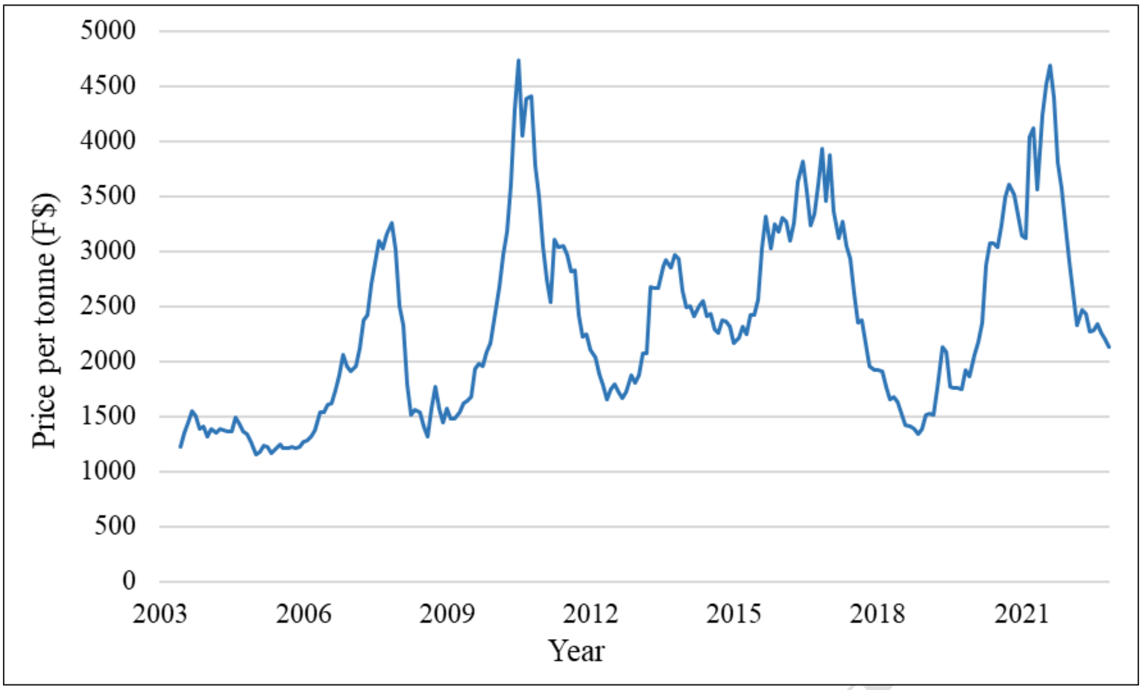

Figure 2. Inflation-adjusted coconut oil world prices (F$/tonne, 2003-2023)
Source: Index Mundi (2021)

Fourth, approximately 60% of Fiji's coconut palms are low-productive senile palms which substantially reduce coconut yield levels (Arancon, 2009; Nolan et al., 2019). As outlined in Table 2, coconut yields fall by about 80% once a palm reaches the age of 60. The Fijian Ministry of Agriculture has also identified widespread senility as the largest contributor to low coconut productivity, and have expressed the need to replace these palms (Lin, 2020). Additionally, Bourdeix (2018) reported that coconut processing facilities in Fiji were facing reduced supply of coconuts due to poor yields within the major coconut growing areas as a result of high levels of senile coconut palms. Section 2.5 further describes the issue and causes of coconut senility in Fiji.

6. Impact and causes of senile coconut palms

The impact of senile coconut palms on a country's coconut production can be substantial. Table 8 reports the average yields of coconuts per hectare for various Asian-Pacific countries and the proportion of senile palms in each corresponding country. Figure 3 graphically displays the information reported in Table 8, illustrating the strong correlation between a country's average coconut senility rate and average yield of coconuts per hectare. The chart also indicates that 75% of variability in yield can be explained by level of senility. Table 8 and Figure 3 illustrate that countries with high rates of senility, typically have low average yields of coconuts.

Table 8. Coconut yield levels and proportion of senile coconut palms in Asian-Pacific countries (2019)

Country	Coconut yield (t/ha) [a]	Average proportion senile palms (%)
Vietnam	10.16	10 [b]
Indonesia	5.71	12 [c]
Sri Lanka	5.77	15 [b]
Samoa	6.58	16 [b]
Solomon Islands	7.24	20 [b]
India	5.58	20 [b]
Kiribati	6.52	24 [c]
Papua New Guinea	5.96	25 [b]
World	**5**	-
Myanmar	4.91	30 [b]
Thailand	4.56	35 [b]
Vanuatu	4.17	50 [b]
Philippines	4.06	50 [b]
Fiji	3.25	60 [b]
Federated States of Micronesia	2.33	60 [b]

Sources: a. FAOSTAT (2021)
b. Alouw and Wulandari (2020)
c. Arancon (2009)

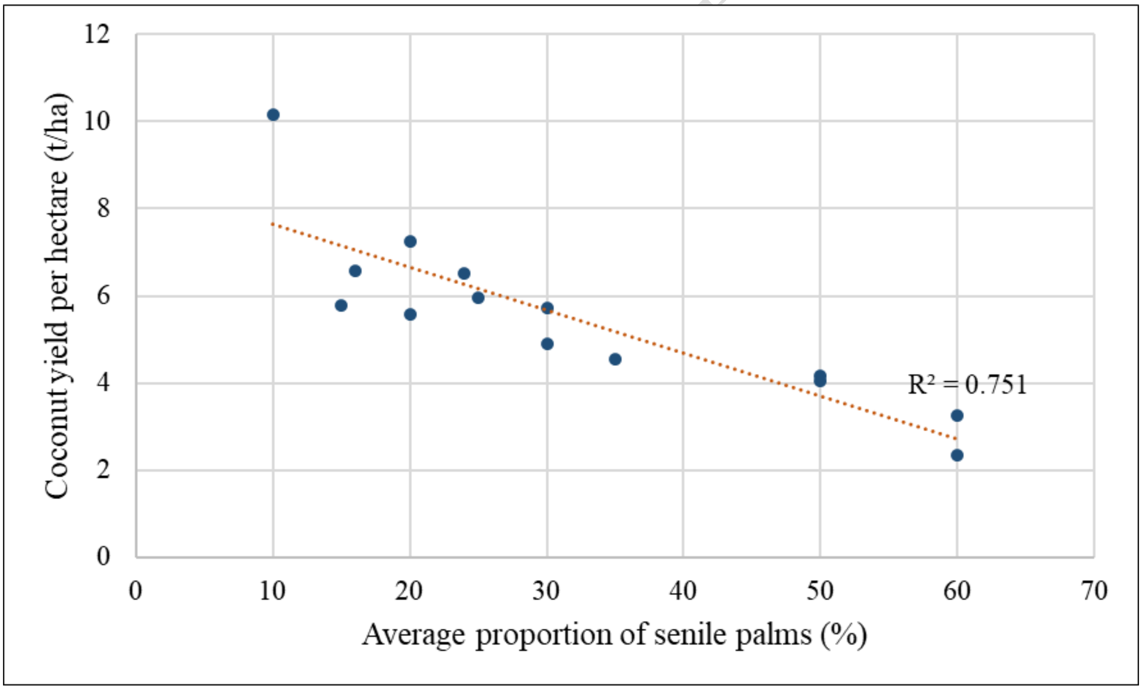

Figure 3. Relationship between the proportion of senile palms and the yield of coconuts per hectare

Senile palms represent a large opportunity cost in countries with high proportions of coconut senility, such as Fiji, with respect to foregone income and employment, food security and foreign exchange. Despite the financial burden of senile palms, landowners have been reluctant about replacing these low-yielding palms (Nolan et al., 2019; Lin, 2020). There are three main reasons for the high level of senile coconut palms throughout the Asian-Pacific region that have been commonly cited by existing literature.

First, the costs of replacement (removal of senile palms and the planting of new palms) are substantial. A study conducted in the Philippines by Perkins and Cahn (1999) revealed the costs of senile palm removal to be about F$1833/ha, as well as an additional cost of F$1549/ha to replant the area with new coconut palms. Once old palms are cut down, effective disposal of tree waste is critical due to potential outbreaks of rhinoceros beetle which can severely affect the health of young and productive palms (Domberg, 2015). In addition to these costs, landholders must also wait until the palms reach between seven to ten years of age before any income is received and fifteen years until the palms become profitable (Table 6) (Mwinjaka et al., 1999; Perkins & Cahn, 1999). If a particular coconut plantation has a high proportion of senile palms, then it also may not be feasible to remove palms that, whilst they have low production, may be providing the bulk of the landholder's income.

Second, the customary land arrangements that account for the vast majority of coconut plantation areas limit the incentive for coconut farmers to replace large areas of senile palms. Kurer (2001) asserted that communal tenures inhibit agricultural growth through three main factors. First, the relatively short leases reduce the attractiveness of coconut replacement, since many landholders will not receive the full benefits of the new palms before the lease ends (Rutz, 1978; Rakai et al., 1995; Lin, 2020). Additionally, as the end of tenure approaches, it is generally cost-efficient to avoid expenditures on replacing long-term crops, such as coconuts, and to rely instead on the output of existing crops (Kurer, 2001). Second, since banks only loan to individual landholders in Fiji (owners of freehold land), *iTaukei* landholders and leaseholders have limited access to funds for investment (Rakai et al., 1995; Powell, 1998; Kareback & Nilsson, 2005; Ostrom & Hess, 2011). This reduces the ability for their land to be developed through capital (irrigation systems, tractors, farming equipment), crop replacement or new land use systems which limit the potential productivity of the land (Rakai et al., 1995). Lastly, leaseholders are unlikely to be compensated for their investment in fixed capital stock after the lease ends as the mataqali who own land are not required to repay leaseholders for investments and do not generally have access to the funds necessary to compensate the tenants for improvements (Powell, 1998; Ben & Gounder, 2019).

Third, market uncertainty and risk aversion of coconut landholders in Fiji reduce the incentives for replacing senile palms. Since farmers in the Pacific region are generally risk-averse, their land-use decisions are highly dependent on expected future market prices and projected crop output which are not known at the time the decisions are made (Hardaker & Fleming, 1994; Pattanayak et al., 2003; Aimin, 2010; Kahan, 2013; Versteeg et al., 2017; Liu et al., 2018). These factors are particularly volatile in Pacific countries such as Fiji as they are (i) generally price-takers due to their relatively small agricultural export volumes and geographic isolation from major international markets; and (ii) experience a high frequency of natural disasters such as intense cyclones and flooding (Fleming, 1993; Malua, 2003; Becker, 2012; Economic and Social Commission for Asia and the Pacific, 2019; Sleet, 2019; World Trade Organization, 2019). Landholders may be hesitant to renew coconut palms due to the volatile nature of its prices (Figure 2) and low financial returns compared to alternative agricultural land uses. Alternatively, farmers are often reluctant to adopt new land management systems in place of coconut farming, even if the potential returns are higher, due to status-quo bias and anticipated learning curves associated with managing new land-use systems (Vanclay & Lawrence, 1994; Ashraf et al., 2015; Hermann et al., 2016; Liu et al., 2018; Okumu et al., 2022).

7. Coconut replacement programs

To encourage senile palm replacement, many government and international aid programs have been trialled throughout the Asia-Pacific region, however, many of these programs have been ineffective at reducing the high population of senile coconut palms due to lack of funding and long-term incentives and poor infrastructure and logistics. In Fiji, coconut replacement programs have been recommended and implemented since as early as the 1940s, however, they have been largely unsuccessful (O'Loughlin, 1956; Brookfield et al., 1985). In 1960, after recognising the increasing proportion of senile coconut palms, an independent commission prescribed a five-year replacement scheme targeted at replacing 1620 ha/y of old, unproductive coconuts through the provision of subsidies (Spate, 1960). The Fiji Government undertook the subsidy scheme which was comprised of three parts (Brookfield et al., 1985). These subsidies provided financial support to farmers on private land for the clearing of senile palms, replanting of harvested areas and all other new coconut plantings over several years. According to Brookfield et al. (1985), this program had a small effect on mitigating the impact of senile coconut palms as only a small fraction of senile palms were removed, whilst many new palms that were planted under this program were neglected following the payment of the subsidy to the farmers.

In the 1970s, a revision of the scheme emphasised replacing senile palms and included subsidies to farmers on mataqali land. The majority of the subsidies were distributed in the Northern Division, where 500 hectares of senile palms were replaced and 436 hectares of new plantings were carried out during 1971 and 1972 (Davidson, 1972; Dickson Commission, 1983). Various collapses in the market price of coconut throughout the late 1970s reduced the incentives to replace coconuts. The subsidy program was ultimately stopped a few years later (Dickson Commission, 1983).

More recently, the Fijian Government has taken various approaches to incentivise the planting of new coconuts but has not emphasised the importance of replacing the existing senile palms. In the 2014 Agriculture Sector Policy Agenda, the Ministry of Agriculture set a benchmark for coconut production to reach 1977 level by 2020 (Bacolod et al., 2014). To achieve this, the Fijian Ministry of Agriculture established the One Million Coconut Trees program designed to provide free seeds to coconut landholders to improve the increase the number of productive coconut palms and revitalise the coconut oil and copra industries. However, observations by Bourdeix (2018) indicated that less than 40% of seedlings released by the Ministry of Agriculture had been planted and remained as living palms, with very few seedlings having been used to replace senile palms, and were instead, planted alongside the senile palms. Furthermore, the majority of these seedlings were provided to coconut landholders who were not selling coconuts to oil and copra markets but were instead, using coconuts for their own household consumption. Bourdeix (2018) asserted that “the development plan seem[ed] to have had no effect on the coconut industry [and only] assisted in self-consumption”. Following interviews with coconut farmers in Fiji, Lin (2020) asserted that most farmers claimed to have either not heard of the program or had not received any seedlings from the Ministry.

In 2018, the Fiji Government launched another coconut development program, centred around stimulating new coconut plantings with the aim of planting 30,000 palms within the first year but with no incentives for farmers to replace their senile palms (Turagaiviu, 2019). Coconut landholders who engaged in the program were provided free seedlings and received payments for every successfully grown coconut seedling after six months (Turagaiviu, 2019). It is not clear how successful the program has been, however, the Ministry of Agriculture indicated that the planting subsidy may be removed, as some farmers are taking advantage of the initiative and planting the maximum number of trees in a small plot just to receive the funds (Turagaiviu, 2019).

Despite these programs, the proportion of senile palms in Fiji is still around 60%, indicating that short-term public sector and international aid funded projects are ineffective at addressing the dominance of senile coconut palms and other approaches should be considered. One alternative method to encourage the removal of senile coconut palms and the establishment of new, productive agricultural systems in Fiji could be to create a market for senile coconut palms that would minimise costs to taxpayers and international aid agencies The forest products market could be such a market, whereby senile coconut palms are purchased by log processing facilities to provide feedstock for the manufacture of veneer and veneer-based engineered wood products (EWPs). Demand for old palms could provide landholders an immediate income from this previously low-value resource, whilst transforming unproductive coconut farms into productive agricultural areas could support rural development goals throughout the region (Bedford, 1980; Enie, 2002; Nolan et al., 2019). In particular, this could increase rural employment and incomes through improving the productivity and output of crops; support food security by expanding the availability and accessibility of affordable and nutritious food; encourage adoption of sustainable agricultural practices; and preserve important cultural assets through preserving traditional knowledge and practices (Harrison & Karim, 2016; Oduol et al., 2017; Singh-Peterson & Iranacolaivalu, 2018). Fiji also has an active veneer processing industry, which is likely to benefit from utilising senile coconut palms for timber manufacture since wood processors have encountered problems securing a regular supply of traditional forest sawlogs due to decreasing availability and increasing harvest regulations (McGregor & Tawake, 2018; McGavin et al., 2019; Nolan et al., 2019).

Designing profitable upstream products that utilise unproductive agroecological resources is part of a growing body of research aimed at to encouraging agricultural revitalisation, whilst also increasing income and employment for farmers. Research from countries such as Laos, Papua New Guinea and Ethiopia, has underlined the importance of upstream value-adding to renew farms that are characterised by underutilised and unproductive agricultural resources.

8. The Fijian forestry sector

Forestry is an important contributor to the Fijian economy and accounts for F$160 million (1.4%) of Fiji’s gross domestic product (GDP) (Fiji Ministry of Forestry, 2021). The 2020 Fiji Agriculture Census revealed that a total of 14,094 farmers identified forestry as primary or secondary occupation, whilst a further 900 people are employed in cultivation, logging and milling occupations (Fiji Ministry of Agriculture, 2020). There is approximately 1.1 M ha of forests in Fiji, which account for 56% of the total land area (FAO, 2014a). This includes 526,000 ha of native forest, 76,000 ha of *Pinus caribaea* var. *hondurensis* (pine) forest and 54,000 ha of *Swietenia macrophylla* (mahogany) forest (FAO, 2014a). As of 2021, 42 licensed sawmills were operating, comprising 21 static and 21 portable sawmills. The annual log volume harvested by the three main forest types between 2000 and 2020 is illustrated in Figure 4. During this period, the average total log production per year was 465,000 m^3, consisting of 64,000 m^3 of native timber, 39,000 m^3 of plantation mahogany and 362,000 m^3 of plantation pine logs were harvested per annum. Although the harvested volume of pine sometimes varied substantially between years, the pine log production in 2020 are about the same as they were in 2000. By 2020, harvested volumes for native forest and mahogany logs had both declined by 80% relative to their peak volume over the period 2002 to 2020.

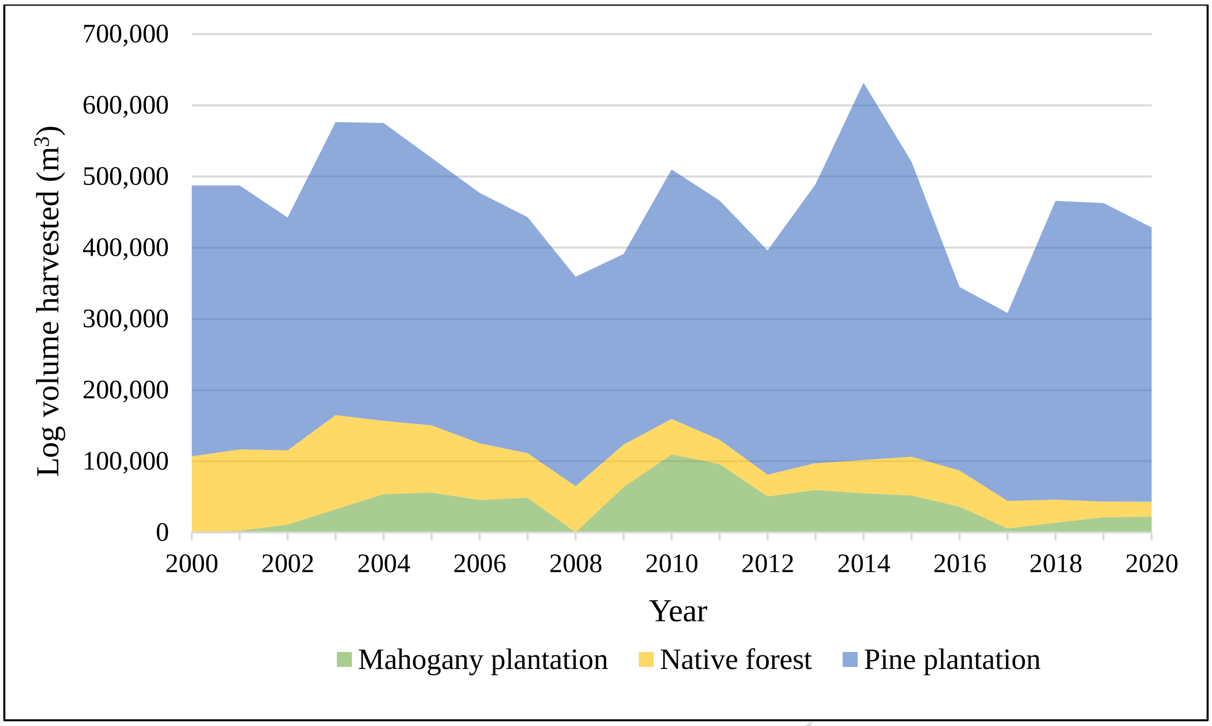

Figure 4. Log volume harvested in Fiji between 2000 and 2020 (Fiji Bureau of Statistics, 2021)

Fiji is a net importer of timber products. Over the period 2013 to 2020, Fiji had an average annual trade deficit in timber and paper products of F$67.5 million (Fiji Ministry of Forestry, 2021). Additionally, in 2021, the trade deficit for veneer-based wood products was F$9.4 million (Fiji Ministry of Forestry, 2022b). Due to the diminishing native timber resource in Fiji, the Fiji Government has set regulations to enforced close monitoring of native forest logging operations and increased the minimum size requirements for native logs to be harvested (McGregor & Tawake, 2018). As a result, the average volume of native forest harvested decreased from 107,000 m^3 in 2000, to just 21,000 m^3 in 2020, representing an annual decrease of 4% per year. Additionally, over the last decade, harvesting costs for native logs in Fiji have increased by a factor between two and three as a result of decreased supply and increased government regulation (McGregor & Tawake, 2018). The Fijian Government has expressed a desire for an increase in the area of forest conservation as part of its National Development Plan (Fiji Ministry of Economy, 2017). According to McGregor and Tawake (2018), the Fijian Ministry of Forestry is considering a bill which proposes the closing of all native logging concessions by 2030. As a result, log processing facilities in Fiji are now facing difficulties in securing sufficient supply of native logs to meet their requirements (Pordesimo & Noble, 1990; Ernst & Young, 2016).

This presents a problem for veneer processors in Fiji as the veneering industry sources approximately 75% of its log processing volume from native forests which consist of kaudamu (*Myristica castaneifolia*.), vusavusa (Gonystylus punctatus) and kauvula (*Endospermum macrophyllum*) (Fiji Ministry of Forestry, 2022a). As a result of the proposed native harvesting shutdown, the veneering industry will become increasingly reliant on plantations, resulting in increased competition for Fiji's plantation timbers. Pine accounts for the remaining 25% of veneering input in Fiji (Fiji Ministry of Forestry, 2022a). The mahogany plantations on Vanua Levu, where all Fijian veneer is currently produced, have only recently opened for harvesting and thus only account for a small fraction of the country's current veneer production. Coconut timber could complement the country's supply of plantation pine and mahogany by offering critical timber supplies to mills running under capacity and reducing Fiji's dependency on veneer imports. Increased coconut wood research has also been called for in the Ministry of Forestry 2022-2023 Annual Operational Plan, which promoted increased research of lesser-known tree species, such as coconut, for use of timber manufacture (Fiji Ministry of Forestry, 2022a). The following sections review the potential for utilising senile coconut palms for the manufacture of veneer and engineered wood products (EWPs), based on its mechanical, resource supply and economic suitability.

9. Potential for manufacturing veneer and engineered wood products from senile coconut palms

Unlike conventional timbers (dicotyledon plants), the coconut palm belongs to the monocotyledon plant group and is more closely related to grasses and bamboos (Butterfield et al., 1997). As a monocot, coconut stems have neither heartwood, branches, knots, or annual growth rings, which allows for a significant portion of the stem to be used (Anoop et al., 2012; Peters et al., 2014; McGavin et al., 2019). The stem of a coconut palm is comprised of two anatomical components, the cortex and the central cylinder. The cortex is a fibrous tissue, typically 1 to 1.5 cm thick, that covers the entire outer circumference of the stem and plays a similar function to the protective bark layer on trees but also anchors the palm frond bases (McGavin et al., 2019). In contrast to conventional timbers, the central cylinder contains fibrovascular bundles which increase in concentration radially from the centre to the stem periphery corresponding with increasing density (Mosuera, 2015). These fibrovascular bundles are characterised by long and dense fibres that run up the stem longitudinally (Gibson, 2012). As such, coconut wood densities vary greatly throughout the palm, with densities increasing radially from the core to the stem periphery and decreasing with palm height (Killmann, 1983; Butterfield et al., 1997; Mosuera, 2015). Coconut wood can be classified into three density categories: (i) high (≥ 600 kg/m3); (ii) medium (400 to 600 kg/m3); and (iii) low (< 400 kg/m3) (Killmann, 1983). Figure 5 displays a cross sectional diagram of a coconut log which demonstrates the variation in density levels throughout timber.

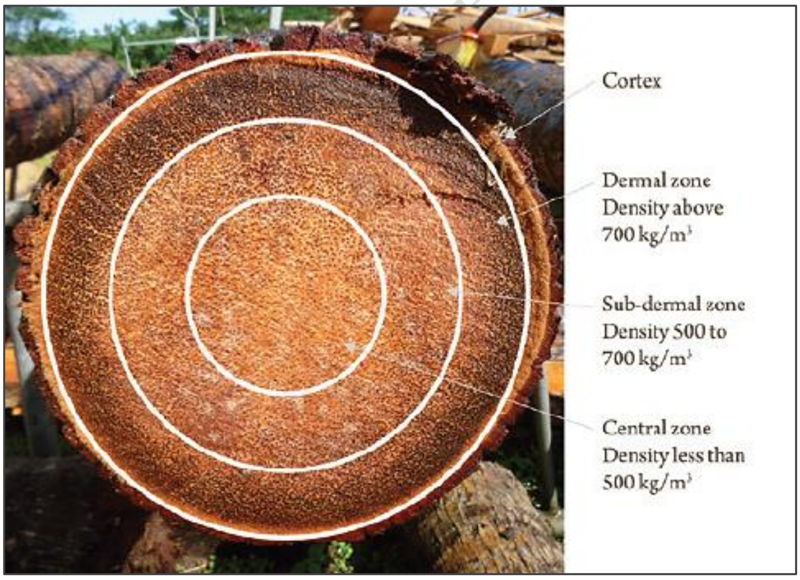

Figure 5. Cross sectional diagram of a coconut log
Source: McGavin et al. (2019)

Market appraisals performed by Anoop et al. (2012) and Peters et al. (2014) have indicated that the visual defect-free, unique attractive appearance of coconut wood, in addition to its favourable elasticity and hardness properties and sustainable plantation origins, can stimulate high levels of consumer demand. However, high-density coconut wood is also characterised by its relatively low structural and durability properties which limits its ability to effectively substitute for conventional wood in structural applications (Anoop et al., 2012; Nolan et al., 2019). McGavin et al. (2019) revealed that for dry densities of coconut between 500 and 1200 kg/m3, the modulus of elasticity (MoE) range from 5000 to 18,000 MPa and the modulus of rupture (MoR) between 30 and 160 MPa. For the same density range, typical commercial hardwoods exhibit an MoE of between 8000 and 24,000 MPa and an MoR of between 70 and 170 MPa. Coconut wood's relatively lower structural properties are a consequence of its density variation throughout the stem, the high grain angle deviation and its low shear properties (Killmann & Fink, 1996; McGavin et al., 2019; Nolan et al., 2019).

To account for its limitations, coconut EWPs must be designed in a manner to ensure its structural properties are suitable for a given application. Table 9 indicates the likely utility of producing various coconut wood EWPs and the veneer densities required for effective manufacture as assessed by Nolan et al. (2019). In the analysis, utility was defined as an estimate of likely profitable production, supply to the target market and degree of suitability for the desired use. Coconut wood EWPs used in applications where aesthetic finishes are highly desired (e.g., flooring, lining and benchtops) were considered more likely to generate higher utility than those in structural applications (e.g., structural plywood and laminated veneer lumber (LVL)).

Table 9. Likely utility of coconut wood veneer in applications

Application	Density level required (HD, MD, LD) [1]	Likely utility [2]
Flooring (plywood)	HD and MD	High
Lining (plywood or LVL)	HD, MD and LD	High
Joinery surfaces (plywood or LVL)	HD and MD	High
Bench tops (plywood or LVL)	HD and MD	High
Light joinery plywood	LD core with HD face veneer	High
Joinery sides (plywood)	HD and MD and LD	Medium
Architectural structures (LVL)	HD and MD	Medium
Structural plywood (core material)	HD, MD and LD	Medium
Formwork plywood	HD and MD	Low
Structural plywood (face material)	HD and MD	Low
Structural LVL	HD and MD	Low

Notes: 1. HD: high-density, MD: medium-density and LD: low-density.
2. In this analysis, utility was an estimate of likely profitable production and supply to the target market. The categories were High, Medium and Low.

Source: Nolan et al. (2019)

Coconut logs are particularly suitable for spindleless rotary veneer processing due to its relatively small diameter and the unique structural characteristics and recent literature has demonstrated its advantages over traditional sawing methods for small diameter logs, including coconut logs (Leggate et al., 2017; Belleville et al., 2018; McGavin & Leggate, 2019; McGavin et al., 2019; Nolan et al., 2019; McGavin et al., 2020a; McGavin et al., 2020b). As shown in Figure 6, spindleless lathes use drive rollers to grip, spin and push the log against a blade to produce a continuous ribbon of veneer from the log periphery and, because the system does not require spindles to grip the log, veneer can be recovered down to a residual core of 60 mm or less (McGavin et al., 2019; Nolan et al., 2019). The veneer ribbons can then be cut to length, dried and glued together to produce valuable veneer-based EWPs such as plywood or laminated veneer lumber (LVL). Based on the commercial coconut veneer trials by Nolan et al. (2019), an eight-foot spindleless lathe can produce about 100 m^3 of green veneer in eight hours or 12.5 m^3 per hour.

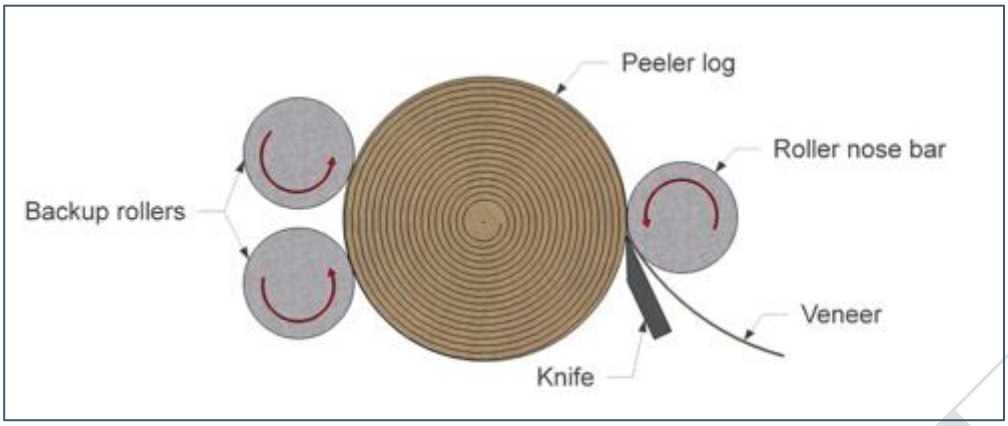

Figure 6. A standard spindleless lathe peeling set-up
Source: McGavin et al. (2019)

In comparison to rotary veneering, sawing of small diameter logs is largely inefficient because the squared-up sawing pattern leads to a high proportion of the log volume being converted to waste during processing (Leggate et al., 2017; McGavin & Leggate, 2019; McGavin et al., 2020a). A processing study by McGavin and Leggate (2019) assessed the difference in the volume of saleable product recovered from spindleless rotary veneering versus traditional sawing. The analysis used Queensland spotted gum logs that ranged in diameter from 20 cm to 28 cm. It was found that processing the logs through rotary veneering recovered twice the volume of saleable product when compared to traditional sawing (43% to 46% versus 12% to 22%).

Spindleless rotary veneering is also able to recovery a much greater portion of the high-density wood from the periphery of the coconut log, which is the most attractive for high-value wood products (Nolan et al., 2019). Hass and Wilson (1985) reported that 14% of sawn boards milled from a senile coconut log exceeded a density of 500 kg/m^3, compared to a processing study by Nolan et al. (2019) that found that 68% of the coconut veneer recovered had a density of 500 kg/m3 or more. High variance in density throughout the stem (Figure 5) also results in sawn boards usually including a mixture of hard and soft material which further decreases its quality and value (Nolan et al., 2019). Because a veneer sheet contains less density variation than sawn boards, veneer sheets can be assembled in a particular manner to either separate sheets into similar densities or combine veneers with varying densities together to produce EWPs with a more consistent density distribution than could be accomplished through conventional sawing (McGavin & Leggate, 2019; Nolan et al., 2019; McGavin et al., 2020b).

Nolan et al. (2019) found that due to the size of the fibrovascular bundles, the minimum peelable veneer thickness is around 2 mm. Veneers with thicknesses below 2 mm resulted in checks, fragmentation and surface roughness that were deemed unacceptable. Heating the logs above 70 °C was necessary to significantly reduce the cutting forces observed, improve surface quality and limit premature knife damage. Even with this heating, the cutting forces were still high compared to usual hardwood cutting forces.

9.1 Potential supply of coconut wood to wood processing facilities in Fiji

According to Young et al. (2022), six 2.5 m logs can be produced from each senile coconut palm. Assuming an average coconut log diameter of 30 cm, a planting density of between 120 and 200 stems, and 60% of the 17,000 ha to 20,000 ha of coconut palms are senile, there is potential to harvest at least 1.3 M m^3 to 2.5 M m^3 of coconut wood feedstock from Fiji's coconut plantations. Venn and McGavin (2021) estimated that 15,000 m^3 of log throughput can be achieved annually with one full-time spindleless rotary veneering line. Therefore, assuming a single spindleless lathe processing facility in Fiji processing 15,000 m^3 of senile palms each year, there are approximately between 86 and 170 years of coconut log supply, excluding palms that are expected to become senile in the future.

9.2 Economics of veneer and engineered wood product manufacture in Fiji

This section evaluates findings from prior research into the economics of veneer and EWP manufacture from coconut and other wood resources in Fiji. It should be noted that there are research gaps within this field, particularly around the financial performance of hardwood and softwood veneer production and the manufacture of coconut and conventional wood-based EWPs. A lot of the detail regarding the input costs of coconut veneer production (e.g., labour, electricity, capital etc.) have not been published.

9.2.1 Costs of harvesting and transporting logs throughout Fiji

McGregor and Tawake (2018) assessed the costs of harvesting and hauling coconut logs in Fiji. According to their research, Fijian coconut landholders are currently being paid around F$10 for each senile coconut palm harvested. They also estimated that the average cut, snig and load cost for coconut logs is around F$100/$m^3$. Transport costs from the coconut resource to the veneering mills in Vanua Levu was estimated to be between F$20/$m^3$ and F$40/$m^3$, and an additional F$50/m^3 if shipping from one of the other islands is required. In Indonesia, Killmann and Fink (1996) noted that the average MDLC of coconut logs in Indonesia was around F$110/$m^3$, whilst in the Philippines, Arancon (2009) estimated the MDLC to be F$180/$m^3$. There does not appear to be any available literature that estimates the MDLCs for plantation-grown pine or mahogany logs in Fiji.

9.2.2 Financial performance of coconut veneer and engineered wood product manufacture

If the private sector is to finance the removal of senile coconut palms, coconut wood manufacture needs to be profitable; however, information regarding the financial performance of coconut veneer and EWP manufacture in Fiji is scarce. One study by Blackburn and Nolan (2016) estimated the net present value (NPV) and veneer prices that would achieve a 12% internal rate of return (IRR) for five potential coconut veneer processing scenarios in Fiji. Table 10 describes the five scenarios and presents the start-up capital investment, NPV and aspirational veneer prices for each scenario. All scenarios were evaluated over a 15-year period and discount rate at a 10% net of inflation.

Table 10. Start-up capital, NPV and suggested product prices of various coconut veneer scenarios

Scenario	Log throughput per annum (m^3/y)	Start-up capital (F$ million)	NPV (F$ million)	Price required to achieve 12% IRR (F$ m^{-3} product)
Scenario 1. One low-cost 8-foot veneer line at an existing sawmill	15,000 m^3	0.40	1.09	247 (green veneer)
Scenario 2. One high-cost 8-foot and one 4-foot veneering line at an existing sawmill	50,000 m^3	2.57	5.20	249 (green veneer)
Scenario 3. Veneer drying line at an existing peeling facility with a continuous veneer dryer and upgraded heat plant	35,000 m^3	8.71	16.17	501 (dry veneer)
Scenario 4. Three shifts at an existing peeler mill. Costs have been included for staff night shift loadings and upgrading of the heat plant and buildings	35,000 m^3	1.97	6.04	410 (dry veneer)
Scenario 5. New integrated mill installed at a greenfield site with one high-cost 8-foot and a 4-foot veneering line, a new heat plant and one new quality build continuous dryer	50,000 m^3	21.19	33.07	560 (dry veneer) with a new boiler and heat plant. 463 (dry veneer) with a refurbished boiler and heat plant.

Source: Blackburn and Nolan (2016)
Note: A discount rate of 10% was adopted in the analysis

Although the returns from coconut veneer manufacture appear to be favourable (Table 10), the applicability of the investigation may be limited, as the scenarios adopted in the financial assessment are unlikely to be feasible in reality. Specifically, the log processing scales adopted in the analysis are much higher than would be expected for veneer production Fiji. The analyses adopted annual throughput levels between 15,000 m^3 and 50,000 m^3. However, it is likely that since coconut wood is currently not being harvested, and that the total output of Fiji's existing plywood mills is about 11,000 m^3/y, log processing facilities are unlikely to process close to 15,000 m^3 of coconut wood per year. Additionally, the investigation by Nolan et al. (2019) reported aspirational prices of coconut veneer and did not conclude whether these prices were likely to be achieved in reality.

The financial performance of coconut EWPs has not been evaluated in Fiji or elsewhere. There also does not appear to be any literature estimating the financial performance of utilising plantation pine and mahogany for the manufacture of veneer or EWPs. Findings by Venn et al. (2021), who assessed the financial performance of manufacturing LVL from hardwood native forest logs in Australia, found that the largest contributors to the financial performance of EWP manufacture was: (1) value-adding; (2) log processing scale; and (3) log procurement decision. In Fiji, EWP prices are capped by the Fijian Competition and Consumer Commission (FCCC). Table 11 reports the maximum wholesale and retail prices various plywood products in Fiji as set by the FCCC.

Table 11. Maximum wholesale and retail prices for conventional plywood in Fiji

Product Type	Length (m)	Width (m)	Thickness (mm)	Maximum wholesale price (F$/m³)	Maximum retail price (F$/m³)
Exterior plywood	2.4	1.2	6	1933	2056
	2.4	1.2	9	2323	2475
	2.4	1.2	12	2081	2217
Interior plywood	2.4	1.2	6	1844	1964
	2.4	1.2	9	1973	2103
	2.4	1.2	12	2007	2132
Marine plywood	2.44	1.22	6	1259	1340
	2.44	1.22	9	1132	1203
	2.44	1.22	12	1072	1141

Source: Fijian Competition and Consumer Commission (2021)

9.2.3 Benefits of a senile coconut wood value chain

The establishment of a market for senile coconut palms is likely to benefit many actors throughout the value chain. Coconut landholders who supply senile coconut logs to processing facilities can receive immediate income for their senile palms which are removed at no extra charge to landholders. Since stumpage prices for senile coconut palms in Fiji are estimated to be about F$10 per tree (McGregor & Tawake, 2018), and given there is approximately between 1.22 M and 2.4 M senile palms in Fiji[1] (Nolan et al., 2019), additional coconut wood income to farmers may be F$13.26 M to F$26 M. This equates to between F$720 and F$1200 per hectare of senile coconuts (given a planting density of 120 to 200 trees/ha and 17,000 to 20,000 ha of senile coconuts in Fiji). In addition to coconut landholders, other actors such as manufacturers, sellers and transport contractors are likely to benefit from coconut log harvesting and manufacturing. Blackburn and Nolan (2016) estimated the percentage of the final veneer and EWP price each actor is likely to receive as income. These levels are displayed in Table 12.

Table 12. Estimated share of income from coconut wood manufacturing by value chain actor

Actor	Share of the final price to the consumer (%)
Coconut landholder	**7%** (high value niche export markets) to **20%** (domestic markets under present price control arrangements)
Coconut veneer processor	**20%** (high grade coconut veneer sold on export markets) to **60%** (price controlled domestic markets)
Wholesaler/Retailer	**10%** (price controlled domestic market) to **30%** (high value niche markets
Input supplier (loggers, truckers, shippers)	**15%** to **30%** (depending on the final product market and the regulatory controls in place)

Source: Blackburn and Nolan (2016)

[1] Assuming a total coconut plantation area of between 17,000 and 20,000 ha, between 120 and 200 stems/ha and a 60% senile probability.

Commercial coconut veneer production is also likely to generate many new full-time equivalent (FTE) jobs. Blackburn and Nolan (2016) estimated the employment requirements for the coconut veneering scenarios listed in Table 10. Depending on the scenario, coconut veneer processing could generate between 9.5 and 33.5 FTE new positions. Table 13 does not account for additional harvest, haul or freight FTEs generated through coconut wood veneering. Greater investment in coconut EWP manufacture would also generate additional FTE positions in addition to veneering.

Table 13. The staffing levels required for coconut veneering scenarios as stated in Nolan et al. (2019)

	Number of FTE employees by scenario				
Position	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5
Log docking	0.5	2	0	0	2
Loader operator	0.5	1.5	0	0	1.5
Line operators/forklift drivers	6	10	13	13	23
Supervisors	1	2	1	1	2
Maintenance/control room	0.5	1	1	1	2
Administration	0.5	1.5	2	2	2
General manager	0.5	1	1	1	1
Total	9.5	19	18	18	33.5

Source: Blackburn and Nolan (2016)
Note: Scenarios from this case study have been previously described in Table 23

Demand for EWPs as construction material is likely to rise as consumers are increasingly preferring sustainable and low-embodied-energy products (Venn et al., 2021). It appears that no available literature has estimated the embodied energy in coconut wood, however, assuming coconut wood has similar embodied energy levels as standard wood types, then if coconut EWPs were to be substituted for regular building products such as brick, concrete and steel, carbon sequestration benefits may be present (Lawson, 1996). Table 14 outlines the embodied energy in various floor and wall construction assemblies.

Table 14. Embodied energy for assembled floor and wall constructions

Construction and materials	Embodied energy (MJ m^{-2})
Flooring	
Elevated timber floor	293
110mm concrete slab-on-ground	645
200mm precast concrete, T beam/infill	644
Walls	
Steel frame, compressed fibre cement clad wall	385
Timber frame, reconstituted timber weatherboard wall	377
Timber frame, fibre cement weatherboard wall	169
Cavity clay brick wall	860
Cavity clay brick wall with plasterboard internal lining	906
Cavity concrete block wall	465

Source: Lawson (1996)

10. Gaps in literature

The review of published research on senile coconut palms has revealed four gaps in the literature that this research will fill.

1. It appears that although there are some estimations on the mill-delivered log cost of coconut and other species (albeit rather dated), no studies have thoroughly assessed the cost of harvesting and hauling coconut logs (or other log resources) from various locations in Fiji to potential locations for veneering mills using spatial mapping data.
2. There is limited information that has been published financial performance of veneer or engineered-wood product manufacture (coconut or other) such as plywood or LVL in Fiji. A lack of financial support may be a contributing reason as to why Fijian wood processing mills have not invested in coconut wood processing despite evidence from previous research that it is technically feasible (FST/2004/054; FST/2009/062).
3. There is seemingly no literature that has thoroughly investigated market-based solutions to the high stocking of senile coconut palms in Fiji (such as the sale of senile coconuts for the manufacture of EWPs) and estimated the financial and socio-economic benefits that may arise if the problem is addressed such as employment benefits throughout the value chain, improved productivity of farms and GDP and Government tax revenue increases.

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