Analysis of the ACT plantation forests value chain

by

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Candidate's Declaration

This thesis contains no material which has been accepted for the award of any other degree or diploma in any university. To the best of the author's knowledge, it contains no material previously published or written by another person, except where due reference is made in the text.

Yumeng Cai   Date: 11/21/2024

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Abstract

Radiata pine is the only softwood plantation species in the ACT, and these plantations and processing industries were once a more important part of the local economy. However, the 2003 bushfires destroyed a large number of plantations, leading to a shortage of raw materials and the closure of most processing facilities – only one sawmill producing tile battens remains. While there are other markets for ACT plantation wood outside the ACT, it is likely that the current value chain is suboptimal in terms of its contribution to the ACT bioeconomy.

The current ACT radiata pine processing value chain faces many challenges, including limited plantation management options, outdated processing facilities, and changing market demand. This study aims to enhance the resilience and value-adding of the local wood processing industry and promote sustainable development by optimizing the ACT radiata pine value chain against the background of the global transition to a forest bioeconomy.

The study used Net Present Value (NPV) analysis to explore multiple improvement options for the plantation growing and wood processing components of the value chain, by comparing the NPV values of existing baseline cases and new scenarios. Sensitivity analyses were used to explore how changes in important parameters such as wood prices affect the selection of growing and processing options, and to provide guidance for value chain actors to respond to future changes and enhance the resilience of the value chain.

This study found that the current plantation management regime and sawmill operations are each the most financially rational for plantation and sawmill managers, respectively, under current operating conditions. However, if markets were available, a more attractive option for plantation managers, operating under a standard discount rate of 5%, is to extend the rotation period and produce more higher quality sawlogs. For sawmill managers, if the price of timber increases by more than 26.5%, it will be better to invest in new equipment to increase the recovery rate of primary wood products to the level typical of contemporary sawmills (50%).

Both sawn timber and plywood production are feasible options for the ACT plantation value chain, under certain assumptions. The establishment of new sawn timber and plywood processing facilities can increase the added value of timber from ACT plantations while also providing motivation for the plantation managers to produce more sawlogs and mill owners to upgrade their equipment.

This study provides a systematic framework improving the ACT radiata pine plantation value chain, as a foundation for both the ACT Government and wood processing enterprises drawing greater value from the ACT's plantation forests.

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Chapter 1: Introduction

1.1 The ACT plantation forests value chain

The bioeconomy is an economic system that reduces dependence on fossil resources by producing energy, food, materials and services sustainably and from renewable biological resources, thereby achieving environmental, economic and social sustainability. The forest bioeconomy focuses on the sustainable use of forests and forest resources as an alternative to fossil fuels and greenhouse gas-intensive materials. It includes both traditional forest products (such as sawn timber, pulp and paper) and innovative products (such as engineered wood products and biofuels). An important part of the forest bioeconomy is innovation, bringing to market new forest products, that are more resource-efficient, circular and environmentally friendly. (Hetemäki et al., 2024). Wood, as the most common forest product, is a key element in achieving renewable energy and materials targets (Sikkema et al., 2016). How forest product value chains can contribute sustainably and efficiently to the goals of the forest bioeconomy is an important area of research.

In Australia, solid wood products such sawnwood derive primarily from softwood plantation forests, predominantly radiata pine (ABARES, 2019). Prior to the 2003 bushfires, the radiata pine plantations in the Australian Capital Territory (ACT) and proximate NSW region supported five processing facilities. The loss of much of the ACT 's radiata pine plantations in the 2003 bushfires meant that the remaining plantations could not produce enough wood to satisfy the demand of these facilities, and many closed down due to lack of supply of raw material (Poyry, 2003). The processing facilities in Capital Region produce tile battens, wood chips and sawdust. Different levels and forms of processing technology are used in ACT and region processing facilities; these range from modern (eg the Visy pulp and paper mill at Tumut) to quite dated (eg the Capital Battens plant in Canberra). Further, the market for wood products from the ACT is changing as housing and other markets and technologies change. As a consequence, the radiata pine industry in the ACT faces many challenges.

Value chain analysis is a tool used in the process of achieving collaborative allocation and management of resources within and between businesses in a chain, the purpose of which is to improve the competitiveness of the chain as a whole. It improves existing product/service processes within and between companies in the chain and improves existing or develops new (value-added) proposals for customers and target consumers (Collins et al., 2015). This study uses a value chain analysis approach to investigate options for improving value recovery from the ACT's softwood plantation forests. In turn, this could improve the resilience of the ACT radiata pine industry, increase local value adding, and ultimately promote sustainable development of the forest bioeconomy in ACT and region.

1.2 Research purpose and questions

1.2.1 Research purpose

The purpose of this study is to conduct a value chain analysis of the radiata pine plantation industry in the ACT, with a focus on identifying and addressing challenges in the local plantation value chain. The study aims to improve the resilience and value recovery of the ACT radiata pine value chain.

1.2.2 Research questions

This research aims to address the following research questions:

1. What are the opportunities and constraints faced by each part of ACT's radiata pine plantation value chain?
2. What options are there for processing facilities in ACT to improve value recovery?
3. What impacts would implement these options have for the radiata pine plantation value chain in the ACT?

Chapter 2: Literature Review

2.1 The bioeconomy

The bioeconomy refers to the production, use and conservation of biological resources, including related knowledge, science, technology and innovation, to provide information, products, processes and services to achieve sustainable economic development (Juvenal and Bouillon, 2018). The bioeconomy is seen as contributing to a transition away from the current fossil-based economy, which is based on the use of fossil resources such as coal, oil and gas (Hetemäki et al., 2024). Strengthening the bioeconomy is one of the goals the Sustainable Development Goals (SDGs) and a means to help realise the Paris Climate Agreement (FAO, 2018).

As a pioneer in the development of the bioeconomy, Europe emphasised smart and green growth through investment in research, innovation, skills, policy interaction and stakeholder engagement, aimed at reducing greenhouse gas emissions, reducing dependence on fossil resources and managing natural resources wisely. At the same time, they emphasise the critical importance of technological innovations in biotechnology, biorefineries and biofuels, which are expected to bring economic benefits (McCormick and Kautto, 2013). In addition, European studies have focused on the importance of public understanding and participatory governance for the successful development of the bioeconomy (Mustalahti, 2017).

In many countries, forests are an important source of renewable biomass and central to sustaining ecological processes that are closely linked to human well-being (e.g., climate mitigation and adaptation, water and soil conservation, biodiversity conservation, recreation and cultural ecosystem services). The forest-based sector has been identified as one of the main pillars of the bioeconomy strategy (Lovrić et al., 2020). Therefore, study of forest bioeconomy is important.

2.1.1 The forest-based bioeconomy

The concept of the forest bioeconomy is based on the sustainable use of renewable and sustainably managed forest resources. An important part of the forest bioeconomy is innovation, bringing to market new forest products, that are more resource-efficient, circular and environmentally friendly. (Hetemäki et al., 2024). Wood, as the most common forest product, is a key element in achieving renewable energy and materials targets (Sikkema et al., 2016).

Much of the scientific research on the forest bioeconomy has addressed two aspects: the first is policy research, which has highlighted the need for a multi-level policy framework for the forest bioeconomy that takes into account regional differences in biophysical conditions, socio-economic factors and institutional settings. In addition, cross-sectoral connections and inclusiveness in policymaking are essential to realising the full potential of the forest bioeconomy and ensuring its social legitimacy (Hetemäki et al., 2024; Winkel, 2017).

The second aspect is land management, where these studies reveal that sustainable land management and rational allocation of harvesting activities are critical to balancing biomass production and biodiversity conservation (Winkel, 2017).

In addition, wood, as the most common forest product, has been the focus of many studies on the role of wood products in the forestry bioeconomy, emphasising that wood products are at the heart of the forestry bioeconomy because of their multifunctionality and environmental benefits. Wood is a sustainable alternative to fossil materials and contributes to the reduction of greenhouse gas emissions through carbon storage and substitution effects. However, research on the wood bioeconomy has mainly focussed on assessing the environmental benefits of wood production processes. The core is a life-cycle assessment of carbon and other pollutant emissions of wood from the time it is grown to the time it becomes a product (Verkerk et al., 2022; Garvie et al., 2024). These studies are based on existing wood-processing production systems, and few articles have explored how the technologically altered timber industry affects the local forest bioeconomy.

2.1.2 The Australian forest-based bioeconomy

In 2021, woody bioenergy contributed 83.2 gigajoules (PJ) to Australia's energy consumption, accounting for a significant portion of the country's bioenergy production. Despite this, renewable energy will only account for 8 per cent of Australia's final energy consumption in 2021, of which 18% was wood-based energy, compared to 22 per cent in the EU. (Garvie, 2023).

A key feature of the Australian forest bioeconomy is the underutilization of resources. Australia has large amounts of forest residues that are potential feedstocks for biomass production, yet these resources are significantly underutilized. The main reasons for this include limited knowledge of feedstock supply costs and the lack of a fully developed forest bioeconomy infrastructure (Garvie et al., 2024).

Most research on the Australian forest bioeconomy has focused on the transformation of forest residues into bioenergy (Garvie et al., 2021; Holsbeeck et al., 2020). It also explores how to improve the existing supply chain system for bioenergy. However, wood residues are only a small part of forest products, particularly from plantations, with the major component being sawn wood. There has been little research into other potential aspects of the Australian forest bioeconomy.

2.2 Global wood product markets and trade

Between 1990 and 2019, global trade in wood products increased by 143%, reaching a value of US$244 billion. This substantial growth has been primarily fuelled by economic expansion and heightened demand from China, whose imports of wood products surged by 760% to US$49 billion during the same period. The increased demand for wood products, particularly in Asia, has significantly reoriented global production and trade patterns (ABARES, 2021).

The global trade of wood products is predominantly in the form of manufactured final products. In 2019, 91% of all wood product trade comprised manufactured goods, while only 9% was from roundwood and woodchips. This indicates a high level of processing and value addition before wood products enter the international market (ABARES, 2021).

Wood fibre trade is almost evenly split between interregional and intraregional trade. In 2017, 41% of global roundwood trade and 52% of woodchip trade were intraregional. Oceania, particularly Australia and New Zealand, is the largest interregional exporter of roundwood and woodchips, largely supplying the Asian market (ABARES, 2021).

Global consumption of roundwood and woodchips is projected to continue growing. ABARES projects a 9.4% increase in roundwood consumption, reaching 2.2 billion m^3 annually by 2030. Woodchip consumption is expected to grow even more significantly, by 39% to 348 million m^3. This growth will be primarily driven by economic and population growth, particularly in Asia (ABARES, 2021).

2.3 The Australian forestry sector

2.3.1 Forest Resources

2.3.1.1 Native Forests

Australia has approximately 134.0 million hectares of forest, covering 17% of its land area. Native forests constitute all but 1.8 million hectares of this, with the dominant types being eucalyptus forests, which cover around 92.4 million hectares, or about 77% of the native forest area. These forests are spread across various tenures, including leasehold, multiple-use public forests, nature conservation reserves, other private forests, and areas with unresolved tenure (MPIG and NFISC, 2018).

However, the area of native forest available and suitable for wood harvesting has decreased to 28.1 million hectares, representing 29% of the total native forest area. This reduction is primarily due to increased reservation and protection efforts, along with reclassification of certain forest areas as non-commercial (MPIG AND NFISC, 2018).

2.3.1.2 Plantation Forests

Plantation forests in Australia have seen significant growth in the past 3 decades, with the area expanding from 1.04 million hectares in 1994 to 2.02 million hectares by 2009, but then contracting to 1.72 million hectares by 2022 (ABARES 2023). Just over 1 M ha of these plantations are softwoods, mostly radiata pine, grown on longer rotation cycles primarily for solid wood production; and 0.69 M ha are eucalypts, grown mostly on shorter rotation cycles for pulpwood (ABARES 2023). The plantation industry has been a vital part of Australia's forestry sector, contributing to both the domestic economy and export markets. However, the expansion of plantation forests has faced review due to environmental and social concerns, such as impacts on water resources, soil health, and local communities (MPIG AND NFISC, 2018).

On average, plantation-produced logs account for about 87 per cent of Australia's total harvest, with the remainder produced by native forestry. Breaking this down further, in 2021-22, softwood plantations produce more than 99 per cent of Australia's total softwood logs, while hardwood plantations produce 70 per cent of Australia's total hardwood logs. However, the area of Australian plantations has declined consistently since 2008, mainly because of a reduction in hardwood plantations, while the area of softwood plantations has remained stable (ABARES,2023).

The main reason for the reduction in eucalypt plantations is that they are not the most profitable form of land use. At the same time, plantations only require a large number of labours when they start planting trees, which does not provide a stable supply of local employment, and thus does not lead to the development of subsidiary industries in the entire region. This ultimately leads to an outflow of labour and a downturn in the regional economy (Miller and Buys, 2014). However, a thriving local timber industry can help to create more stable and diverse employment opportunities, enhance the resilience of communities to risks, and promote economic development, thereby mitigating employment fluctuations. In addition, efforts such as developing carbon sinks can increase the value of plantation land, bringing the benefits of both environmental sustainability and economic motivation (Binks et al., 2014).

2.3.2 Forest Products Markets

2.3.2.1 Domestic markets

Australia's domestic forest products market is robust, driven by demand for construction materials, paper products and furniture. Softwood plantations, particularly radiata pine, are a major source of timber for the construction industry, which remains the main consumer market for domestically produced timber. This market supports a number of industries including construction, furniture manufacturing and paper. The domestic market also benefits from a variety of value-added products, including engineered wood products. The domestic market is characterized by a mix of small and large enterprises, including sawmills, pulp and paper mills and manufacturers of wood-based products (MPIG AND NFISC, 2018; Woods and Houghton, 2022).

Between 2020 and 2025, the demand for new housing is expected to be reduced by 286,000 units below pre-COVID-19 levels. This is mainly due to a sharp fall in net overseas migration. From 2023 onwards, as net migration grows and the economy strengthens, the new housing requirement is return to near pre-COVID levels in 2024, at around 179,000 dwellings (NHFIC, 2020). The housing market is going to have a lot of uncertainty in these years due to pandemics and immigration policies.

However, the need for new housing is extremely sensitive to changes in population growth. Overall Australia's population is trending upwards (Australian Bureau of Statistics, 2024), and the number of new homes will continue to rise in the future. According to the State of the Housing System 2024 report by the National Housing Supply and Affordability Council, the outlook for Australia's housing market indicates that from the 2024-25 financial year, demand is expected to stabilize at around 174,000 new households forming per year. This is due to normalized population growth rates (NHSAC, 2024).

In summary, while the domestic forest products market in Australia has faced short-term challenges due to the pandemic and immigration policies, the long-term outlook remains positive. The market is supported by strong demand from the construction industry and a growing population, ensuring continued growth and resilience.

2.3.2.2 Export markets

Australia's export market for forest products is characterised by a heavy reliance on the Asian market, particularly China. In 2018, Australia exported approximately 4.5 million cubic meters of roundwood. With China accounting for 87% of these exports, this equates to about 3.9 million cubic meters. Similarly, Australia exported around 7.3 million tons of woodchips in 2019. With China receiving 53% of these exports, this amounts to approximately 3.9 tons (ABARES, 2019).

In addition, the Russian export tariffs imposed in 2007 significantly reduced the volume of its roundwood exports. After the Russia-Ukraine War, Russia's timber exports were subject to economic sanctions. Australia and New Zealand capture a larger share of the market. However, due to good growing conditions and competitive prices, Vietnam has become a strong competitor in the woodchip market, overtaking Australia in recent years (ABARES, 2021).

Global roundwood consumption is expected to grow by 13.5 per cent to 2.2 billion cubic meters by 2030, driven by economic and population growth in Asia. Despite this increase in global consumption, Australia's roundwood exports are expected to decline by around 75 per cent from 2020 to 2030. This decline is due to a shift in strategy towards meeting growing domestic demand (ABARES, 2021).

2.3.3 Wood processing industries

2.3.3.1 Domestic industries

In 2015-16, the value added by these industries was $8.6 billion, representing 0.52% of Australia's GDP. This sector includes various activities, from logging to the manufacturing of wood products such as sawnwood, wood-based panels, and paper products (MPIG AND NFISC, 2018).

Australia's domestic production of sawn softwood has seen fluctuations over the years. In 2020-21, the production was reported at 3.619 million cubic meters, slightly below the record of 3.746 million cubic meters in 2017-18 (Woods and Houghton, 2022).

In the financial year 2015-16, the total volume of wood-based panel production was 1.70 million cubic meters. This represented a 2% decrease from the 1.73 million cubic meters produced in 2010-11. The breakdown of this production volume includes:

- Particleboard: 0.95 million cubic meters, which is 56% of the total production.
- Medium-Density Fiberboard (MDF): 0.57 million cubic meters, accounting for 34% of the total production.
- Plywood: 0.17 million cubic meters, making up 10% of the total production (MPIG AND NFISC, 2018).

In conclusion, the domestic wood processing industry in Australia includes a variety of operations such as sawmilling, veneer and plywood production, particleboard and fiberboard manufacturing, and pulp and paper production. These industries add significant value to raw timber, creating a wide array of products for both domestic use and export. Innovations in processing technologies and sustainable practices have been increasingly adopted to enhance efficiency and environmental performance. However, challenges facing the industry include high operating costs, technological barriers and environmental regulatory constraints (EPA, 2018).

2.3.3.2 Export industries

Australia's wood product exports have experienced significant growth over the past decade. In 2015-16, the total value of wood product exports was $3.1 billion, up from $2.5 billion in 2010-11. Major export products include roundwood, woodchips, and paper and paperboard (MPIG AND NFISC, 2018).

Woodchips:

The largest category of Australian wood product exports (by value) is woodchips, which increased to $1.3 billion in 2017–18 (up 6% from the previous year) and accounted for 37% of the total value of Australian wood product exports.

Total wood chip exports have been growing strongly since 2012-13. Hardwood wood chips account for most total wood chip exports (92% in 2017-18). Total wood chip exports increased to 7.3 million tons in 2017-18 (up 3% on 2016-17) (ABARES, 2019).

Paper and paperboard:

The second largest category of Australian wood product exports (by value) is paper and paperboard products. The total value of paper and paperboard exports increased to $963 million in 2017–18 (up 6% on 2016–17), accounting for 27% of the total value of Australian wood product exports.

The total volume of paper and paperboard exports decreased to around 1.2 million tons in 2017–18 (down 7% on the previous year). This decline was due to a decrease in the export volume of packaging and industrial products to 872,000 tons (7% lower than the previous year), which accounted for the majority (76%) of paper and paperboard exports. The export volume of newsprints also decreased by 7% to 178,000 tons (ABARES, 2019).

Roundwood:

Roundwood is the third largest category of Australian wood products exports (by value). Most of Australia's roundwood exports come from softwood plantations. The total value of roundwood exports increased to $644 million in 2017-18 (up 8% on 2016-17), accounting for 18% of the total value of Australian wood products exports.

Total log exports have been growing strongly since 2012-13 and increased to 4.5 million cubic meters in 2017-18 (up 4% on the previous year) (ABARES, 2019).

2.4 Constraints and Risks

2.4.1 Constraints on overseas exports

Australian log exports are too dependent on a single market, with China previously accounting for 87 per cent of log exports (Lock et al., 2021). Following China's ban on timber imports from Australia in 2020, India became the largest importer of logs, accounting for more than 90 per cent of the share. Although China is now resuming imports of Australian timber, China is facing issues such as a slowing property market and an overall economic downturn, which is also affecting demand and prices for timber (IndustryEdge, 2023). This over-reliance on a single-market export model makes it easy for prices to change in response to economic conditions in the major trading countries.

In addition, increasing competitive pressures in international markets from other regions and countries, such as Vietnam and countries in South America, which have the advantage of geographic location or low production costs, are expected to exert greater pressure on Australian log exporters (Lock et al., 2021).

2.4.2 Constraints on research input and investment

The Australian sawmill industry is now undergoing further structural adjustment and consolidation. The domestic softwood sawmill industry has become significantly more capital-intensive and larger from 1999 to 2016. Between 2012 and 2017, capital investment in processing facilities in the sawmilling industry is estimated at $938 million. Much of this new investment is targeted at increasing productivity, recovery rates, and grade production in the sawtimber industry, as well as increasing productivity and developing new products in the timber and plywood industries (ABARES, 2018).

Industry is also looking forward to industry transformation, with the Forest Industry Advisory Council (FIAC), in its industry transformation recommendations to the government, pointing out that Australia has the forest resources to contribute to the emerging bioeconomy but lacks investment in research and development and co-operation between research organizations and industry. Australia's focus should be on transforming its industry from one that produces traditional timber and sawn products to one that produces a wide range of innovative products and processes (FIAC, 2016).

Despite the increased intensity of capital investment in the sawmill industry, there has been a decline in capacity related to research and development for forestry and forest products. This includes a decline in expenditures on forestry and forest products research and development and in the number of full-time forestry-related researchers (ABARES, 2018).

2.4.3 Risks

The wood-processing industry operates in an increasingly complex environment with a range of risks to its sustainability and international competitiveness. Clancy and Jeyasingham (2012) show that 66 per cent of the risks to the Australian timber industry are economic. These risks are distributed throughout the timber industry from plantation production to final wood product consumption. Widely recognized solutions to reduce risk are market and economic analysis and forecasting, and the adoption of innovative technologies (Clancy and Jeyasingham, 2012). This means that analyzing the whole industry as a whole and giving models for economic forecasting and options for technological innovation can help significantly in the wood processing industry.

2.5 Value chain and value chain analysis:

2.5.1 Value chain

The Global Supply Chain Forum defines supply chains as: the integration of key business processes from end user through original suppliers that provide products, services, and information that add value for customers and other (Lambert et al., 1998). Value chains build on the supply chain to deliver what consumers want in a more efficient way, and the focus shifts from what can be delivered to what is valuable. Value chains involve co-operation; understanding what is upstream and downstream of each business and understanding consumers' value and willingness to pay (Collins et al., 2015). Exploring the forestry value chain can help us to understand more fully the functions of each sector of the forest industry and to assess how forestry activities contribute to the forestry bioeconomy.

Most current research on forest value chains is about analyzing national-level macro data on forest value chains, analyzing the economic returns from forest industry activities, or analyzing the social and economic factors affecting forest value chains (e.g. Gc et al., 2024; Zhang et al., 2024). Other research areas are the assessment of the sustainability of the entire forest value chain as a whole (e.g. von Geibler et al., 2010) and the calculation of the overall cost of wood processing based on sawmill data (e.g. Stjepan., 2022). There is almost no literature that examines the interactions between the various sectors in the forestry value chain, analyses the impact that changes would have on the chain, or studies on how to increase the resilience of the forestry value chain.

2.5.2 Value chain analysis

Value chain analysis is a tool used in the process of achieving collaborative allocation and management of resources within and between businesses in a chain, the purpose of which is to improve the competitiveness of the chain as a whole. It improves existing product/service processes within and between companies in the chain and improves existing or develops new (value-added) proposals for customers and target consumers (Collins et al., 2015). Applying a value chain analysis approach to explore the ACT radiata pine processing industry can effectively help me to form a framework for my perceptions about the industry as a whole.

2.6 Research methodology:

The combination of value chain analysis and cost-benefit analysis is well suited to assessing the economic efficiency of business models in the wood processing industry. By estimating the different costs, benefits and added value of different business models, the economic returns of different business models can be compared, thus providing recommendations for business models in the wood processing industry (Tham et al., 2021).

The harvesting of timber from plantations is a long-term process, discounting the returns from the plantation according to the planting period and calculating the NPV is an effective way to compare different management options for plantations. By investigating different discount rates and timber prices, the differences in the expected land values under different forest management methods can be explored to find the most suitable plantation management regime (Biblis et al., 1998).

Chapter 3: Wood Processing Technologies

3.1 Wood products processing technology

Plywood and sawn timber are two new products that ACT mills may produce. In this chapter, I will review the production processes and technologies of these two products, as well as the new technologies for sawn wood processing.

3.1.1 Plywood processing technology

3.1.1.1 Production process:

Plywood is made of wood sections rotary cut into veneer or by the wood planning into thin wood, and then glued with adhesive from the three or more layers of plate material. It is usually made of an odd number of layers of veneer, and adjacent layers of veneer fiber direction perpendicular to each other and glued together. The production process of plywood is shown in Figure 3.1.

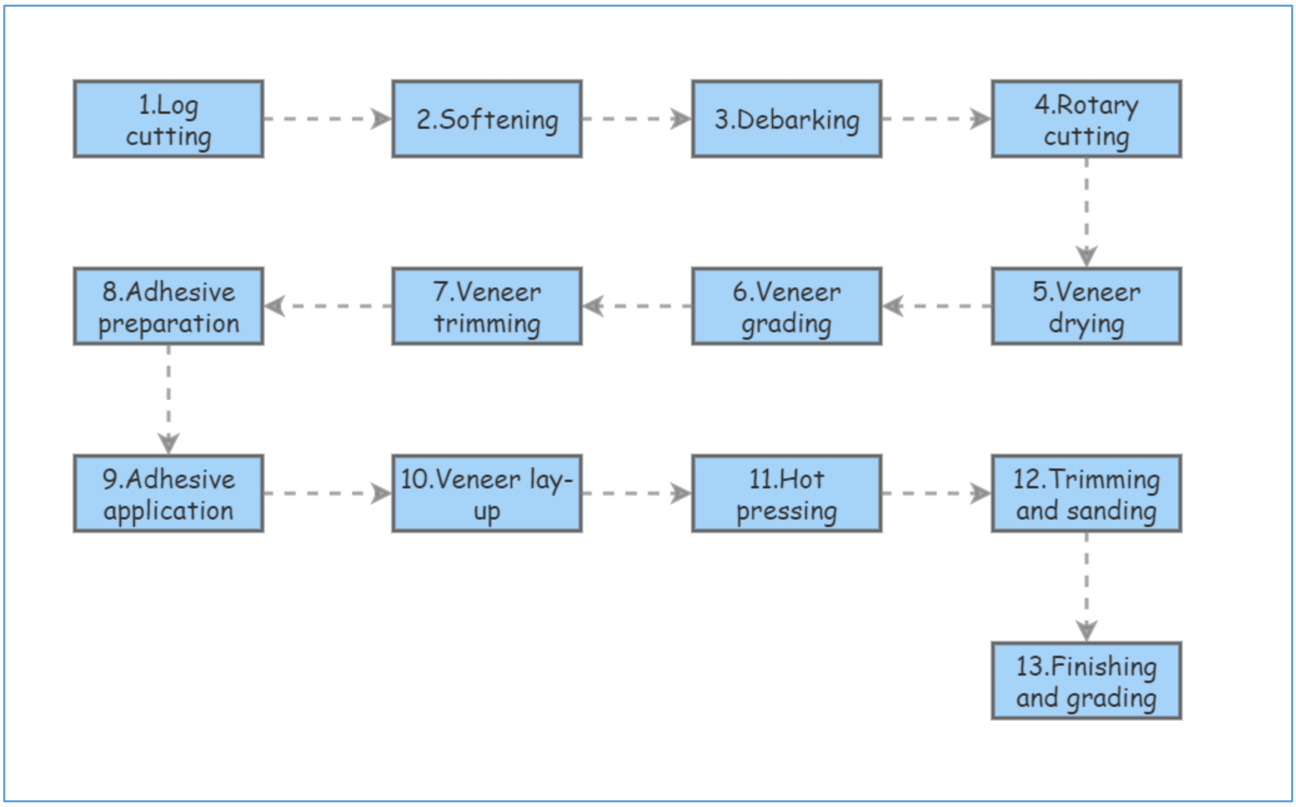

Figure 3.1: Plywood production process

3.1.1.2 Essential stages

Although the plywood production process varies from region to region, the core process is similar. A description of each step is given in Figure 3.2.

1. **Log cutting**: Cutting logs into lengths to meet subsequent processing requirements.
2. **Wood softening**: Softening the wood by boiling, steaming or adding softening agents to improve the efficiency and quality of the subsequent debarking.
3. **Debarking**: Removing the bark by using a debarker.
4. **Wood rotary cutting**: Rotary cutting the wood into veneers using a rotary cutting machine.
5. **Veneer Drying**: Drying the wet veneer to a specific moisture content using large industrial dryers.
6. **Veneer grading**: Grading the dried veneer according to the number of defects.
7. **Veneer trimming**: Trimming the veneer to meet the requirements of plywood production.
8. **Adhesive Preparation**: Preparing the adhesive required for plywood production. Common adhesives are phenolic resin and urea-formaldehyde resin.
9. **Adhesive application**: Applying adhesives to veneer.
10. **Veneer lay-up**: Stacking the veneers in an alternating grain direction.
11. **Hot pressing**: Pressing the veneers under heat and pressure to bond the veneers together.
12. **Trimming and sanding**: After pressing, the plywood is trimmed to the required dimensions and sanded to a smooth surface.
13. **Finishing and grading**: The finished plywood is checked for quality, graded and then finished as required.

Figure 3.2: Plywood process overview

3.1.1.3 Technology Innovation Points

- Application of spindleless lathes for rotary cutting of veneers

Spindleless lathes, also known as chuckless or centerless lathes, are a major innovation in the plywood manufacturing process. Originally designed to process residual peeled cores from traditional spindle lathes, spindleless lathes are now widely used to directly process small diameter and unrounded wood (McGavin et al., 2020).

Traditional rotary cutting machines are generally used to process larger sized timber of around 600mm. Due to the design of the rotary cutting machine's cutter shaft, a core of 130mm in diameter is left over from the wood processed in a traditional rotary cutting machine. This leads to a narrowing of raw material options and waste of raw material (McGavin et al., 2020).

However, the spindleless lathe technology allows for a higher recovery rate. This technological improvement is due to the ability of the spindleless lathe to process smaller log diameters (theoretically up to 100mm, and larger than 800mm) and to produce smaller peeler cores (20-50mm in diameter, much smaller than the 130mm core that would be left over from a traditional rotary cutting machine). This flexibility maximizes the use of existing forest resources, including those previously considered unsuitable for veneer production (McGavin et al., 2020).

In addition, spindleless lathes do not require a spindle to hold the wood, reducing the risk of internal stresses and log splitting. This allows for more efficient processing of lower quality logs and species vulnerable to end splitting, thereby increasing the amount of usable material per log (McGavin et al., 2020).

Utilizing a spindle-less lathe can significantly improve raw material utilization and increase the price per cubic meter log, making it a very promising technology.

- Adhesive Innovations

Plywood adhesives are related to the environmental and mechanical properties of the product, the application of innovative adhesives can also enhance the market competitiveness of the product and economic benefits. Innovation in adhesive technology is mainly reflected in the following:

(1) Environmentally friendly considerations

Traditional plywood adhesives usually contain formaldehyde resins such as urea-formaldehyde resins (UF), phenolic resins (PF) and melamine formaldehyde resins (MF). These resins may release free formaldehyde during production and use, resulting in the release of formaldehyde from plywood.

In order to reduce formaldehyde emissions from plywood, one of the focuses of adhesive research in recent years has been the use of formaldehyde-free raw materials to prepare adhesives. The use of soya proteins to produce adhesives is one such study. In this study, hyperbranched aminated SSPS (A-SSPS) adhesive was prepared from soy soluble polysaccharide (SSPS) and polyamide. This adhesive can meet the mechanical properties of indoor plywood use with zero formaldehyde emission. It also reduces the use of fossil fuels as the raw material is renewable soya bean (Zhang et al., 2018).

As new adhesives are limited by high cost and immature technology, they are not yet able to form a large-scale market. Another research direction is to still use traditional urea-formaldehyde resins but with the effect of reducing formaldehyde emissions by pre-treating the wood. Chemical modification of pine bark with glyoxal improves the compatibility of the veneer with urea-formaldehyde resins and thus allows for better curing of urea-formaldehyde resins. Urea-formaldehyde resin from pine bark modified with glyoxal can significantly reduce formaldehyde emissions, by about 53% (Tian et al., 2024).

(2) Plywood quality improvement

The adhesive is the part that connects the veneer layers. The strength of the adhesive bond as well as its waterproofing properties determine the quality of the plywood.

Some research has been done to improve the performance of adhesives by adding new ingredients. For example, gallic acid (GA) was grafted onto aminated cellulose by covalent modification to obtain gallic acid functionalized cellulose (AC-GA). This modified cellulose-based adhesive has excellent bond strength under boiling water conditions (Huang et al., 2024).

In conclusion, the development of a variety of new adhesives will help to use plywood in a wider range of scenarios and reduce environmental pollution.

- Production process improvement

In the 13-step process described above, the quality of the plywood can be significantly improved by adding additional steps to some of the stages.

(1) Plywood prepressing:

The prepressing process comes before the hot pressing. The prepressing process refers to the initial fixing of the glued veneers together by applying pressure at room temperature.

This process reduces dislocation and stacking irregularities caused by movement of the veneers during hot pressing, thereby improving the flatness and appearance of the finished plywood.

Further, the prepressing process enables the veneer to be shaped in advance before it enters the hot press, thus reducing the pressing time of the hot press and improving production efficiency. This not only increases the output of the production line, but also saves energy and reduces production costs.

In addition, prepressing allows the veneer to gradually set and release internal stresses, reducing deformation and warping problems caused by rapid heating during subsequent hot pressing. This operation also provides sufficient pressure to tighten the glue layer before the adhesive cures, thus improving the strength, stiffness and durability of the plywood to meet higher quality requirements.

(2) Conditioning:

Plywood conditioning occurs after hot pressing. The meaning of conditioning operation is that the plywood is properly handled and stored for a period of time after the plywood has been hot pressed and molded to ensure that the adhesive is fully cured and the internal stresses in the panel are released, thereby improving the performance and stability of the plywood. The conditioning environment should be maintained at the appropriate temperature and humidity, generally recommended to be between 20-25°C and 50-70% humidity. This helps the adhesive to fully cure and the wood to stabilize.

Through the conditioning operation, the stresses inside the plywood can be gradually released, thus reducing the risk of deformation and cracking during use and enhancing service life.

3.2 Wood industry technology

3.2.1 Wood harvesting by stand and tree level optimization

3.2.1.1 Tree level optimization

At harvesting, DBH (diameter at breast height) and log length are the most obvious metrics to use for optimizing value for sawn wood. Estimating the value that can be created by logs of different DBH and length can help loggers develop crosscutting strategies that maximize value. This problem can be solved by applying programming to simulate cutting, and DP (dynamic programming) modeling is one way to do this. It can break down complex log sawing decisions into simpler sub-problems by turning the sawing problem into a horizontal and vertical cutting problem on the saw face circle. By mathematically modeling the horizontal and vertical cuts on the saw face to simulate the size of sawn timber that can be produced from the log with different cuts. The highest value cut is then selected by bringing in the market price of the different sizes of sawn timber to maximize value recovery (Jung et al.,2023). The value of a single tree can be optimized by this method.

This modeling helps forest owners maximize the value of logs in each DBH and height group and helps them make rational logging decisions.

3.2.1.2 Stand level optimization

The value of the wood is also affected by knots, which are related to the growing conditions of the tree. Better logging decisions can be made if the quality of wood harvested within each area of the plantation is known. The internal structure of logs can be examined non-destructively using X-ray computed tomography (CT). This technology provides a detailed understanding of knots, defects and other internal features that affect the quality and value of wood. The use of X-ray CT scanning in timber harvesting is an innovation that improves the accuracy of logging decisions by providing data previously unavailable without destructive testing. By taking random samples of timber with different DBH and stand densities from different areas and then testing their quality by CT, it is possible to find out what the DBH or stand density of the most valuable timber in each area is (Ji et al.,2021).

This technology not only provides a comprehensive check on the quality of the harvested logs, which facilitates sawmills to make the most reasonable processing strategy, but also has a strong significance in guiding the management of plantations, which facilitates managers to maximize the quality of the harvested timber from the plantations.

3.2.2 Sawmill technology

3.2.2.1 Sawn wood manufacturing technology

At present, some sawmills have simple machines, low degree of automation, mostly single manual operation, and the process has not been standardized for production. Some sawmills use manual visual marking to judge sawn wood defects in advance and mark the defective areas with fluorescent pens. A modern and advanced sawmill can utilize intelligent automated production processes, which will significantly improve material utilization and ensure consistent product quality (Ji et al., 2023).

These intelligent automated sawmills combine traditional wood processing with modern technologies such as machine vision, deep learning and optimization algorithms. Machine vision systems are used to check for wood defects, and computers are used to scan logs and simulate various sawing methods. This automated inspection method achieves an average detection accuracy of 89.69% for wood defect type, size and location. Using intelligent automated wood inspection, classification, and optimization production line, the optimized sawn wood comprehensive utilization value is increased by 14.13% compared to manual production of sawn wood (Ji et al., 2023).

In short, the application of intelligent automated production process to replace manual operation for sawn wood production has an important meaning, which can not only reduce labour costs but also significantly improve the quality and efficiency of sawn wood production.

3.2.2.2 Sawmill energy management

Wood processing in sawmills is accompanied by significant energy consumption, which is one of the important operating costs of sawmills. The drying process consumes a significant amount of energy, and drying wood via fossil energy sources is very expensive. Using sawmill waste such as wood chips and sawdust as fuel to power the drying kiln is a very cost-effective way of energy management. In order to increase the energy potential of the wood residues, it is possible to install coupled wood fuel dryers in the sawmill and utilize the heat demand of the kiln as a heat sink. The energy potential of the waste can be increased by about 20% with this treatment (Renstro¨m, 2006).

In summary, this is a new approach to energy management in sawmills that utilizes the energy generated at each step of the wood processing process to reduce the energy costs of the sawmill.

Chapter 4: ACT case study and analysis of value chain options

4.1 ACT plantation forest value chain – key elements

Prior to the 2003 bushfires, the ACT's radiata pine plantations supported five processing facilities. The loss of much of the ACT 's radiata pine plantations in the 2003 bushfires meant that the remaining plantations could not produce enough wood to satisfy the demand of these facilities, and most closed down due to lack of supply of raw material (Poyry, 2003).

4.1.1 ACT radiata pine value chain

The current ACT plantation forest value chain is represented in Figure 4.1.

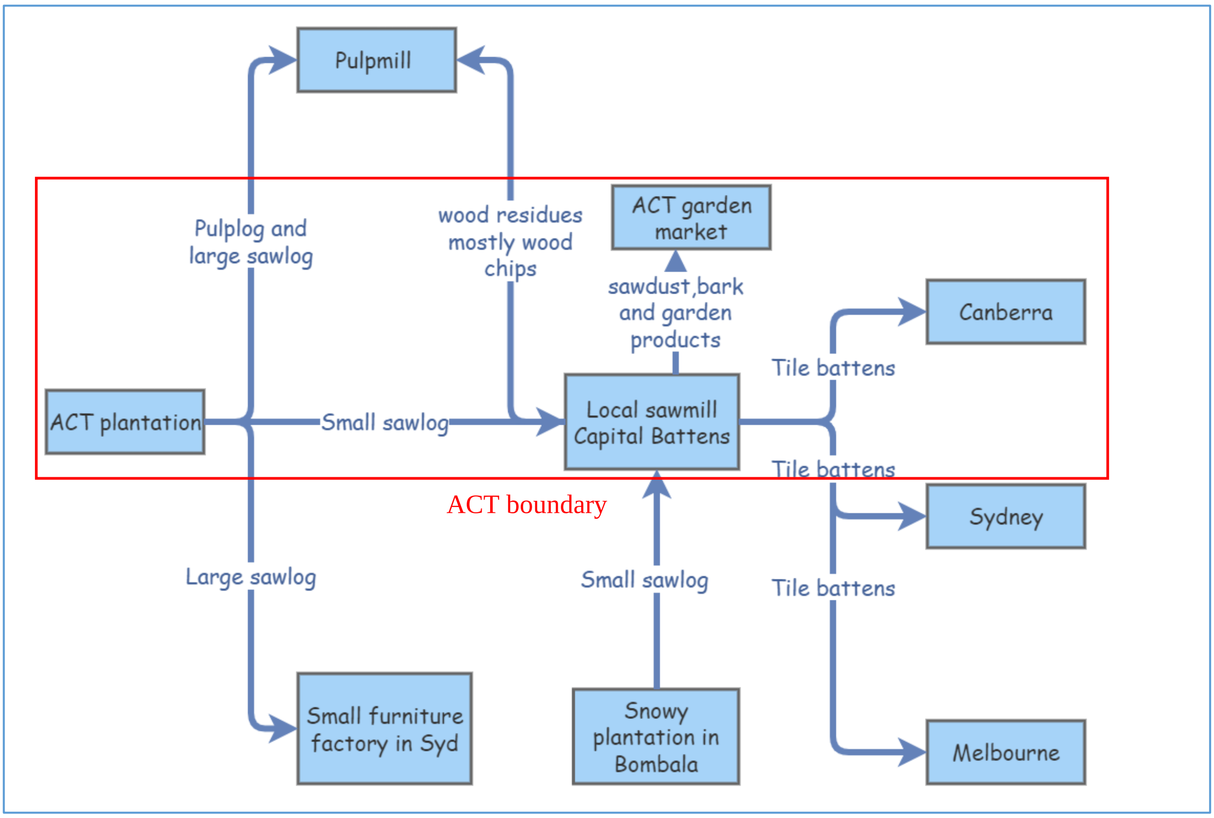

Figure 4.1 ACT radiata pine value chain (Source: interviewees)

As shown in Figure 4.1, the radiata pine processing industry in the ACT begins with ACT plantations, which are owned and managed by an ACT Government agency, which sells the harvested wood of different types to a range of customers: the ACT's local sawmill, Capital Battens; a small furniture factory in Sydney; and the Visy pulp mill in Tumut. The main product produced by Capital Battens is tile battens, is mainly sold to Sydney and Melbourne. Capital Battens also purchases logs from Snowy Plantations, a private plantation owner. The red rectangles in the figure indicate the value chain units in ACT boundary, which are the main objects of my research.

4.1.2 Overview of key value chain elements

ACT plantations:

ACT has a c. 5,000-hectare public radiata pine plantation, which produces sawlogs of different grades and pulp logs. The plantation harvests an average of about 90,000 tonnes of radiata pine per year from 250 hectares of clearfall harvesting, and from thinning operations. The current ACT plantation model is a 32-year rotation, with a single thinning operation in year 19 and clearfall at rotation end. Thinning produces one third of the timber and clearfall produces two thirds. Plantations are managed under a formal Management Plan and and operational Code of Practice (ACT Government undated).

The majority of the wood harvested from ACT plantations now originates from Kowen Forest, east of Canberra city. Due to the low precipitation in this region of ACT, radiata pine at Kowen Forest grows relatively slowly, and the wood is therefore denser than that from faster-growing radiate pine plantations. This means that sawlogs from Kowen Forest are of higher quality for various end uses.

The Forestry Team of the ACT Parks and Conservation agency manage ACT plantations for the ACT Government. They generally sell logs to contracted customers on a delivered mill gate basis, i.e. the customer pays a price on a green tonne basis that includes harvesting and haulage to the mill; these costs are covered within the price paid by the customer.

Local sawmill (Capital Battens):

Capital Battens Pty Ltd is a private company based in Fyshwick, ACT, Australia, established on May 28, 1999. It is the only sawmill in Canberra. The company specializes in the production and supply of timber battens used for roofing and building applications. It also produces simple wooden products such as wooden pallets, but the share of total production is very small, and timber battens are considered to be its only wood product.

Because of the age of its design and equipment, the primary product recovery rate at Capital Battens is consistently very low, at only about 36%. Wood residues, which account for 64%, include wood chips, sawdust and bark, with wood chips accounting for 80% of the wood residue volume. The recovery rate of a standard modern sawmill is at least 50%, and some advanced sawmills can even reach 65% or more. Besides, the factory also lacked the drying equipment that most sawmills have.

The haulage distance to the Capital Battens facility from Kowen Forest averages c. 20 km.

Visy Pulp and Paper Mill

The Visy pulp and paper mill, located near Tumut NSW, is a modern Kraft mill that uses radiata pine and recovered paper to make packaging paper (Visy 2024). The mill has a consumption of 1.9 Green Metric Tonnes annually, and sources wood from as far as the Bombala region in SE NSW (Goldspink, pers[1]. comm.). Since the 2003 ACT bushfires, the Visy mill has sourced pulpwood from the ACT. The haulage distance to the mill from Canberra is c. 200 km.

4.2 Financial analysis of value chain options

Net present value (NPV) is the value of an investment after all future cash flow over its life have been discounted to their present value. Net present value analysis is an internal form of valuation that is widely used in financial and business fields to determine the value of a business, the security of an investment, capital projects, new ventures, cost reduction plans and anything involving cash flow. NPV is important for assessing the economic feasibility of long-term investment projects. Because forestry projects are usually long-term investment projects, the cycle may be as long as 20-40 years. In this case, future benefits and costs must be adjusted according to the time value of money to reflect their true economic benefits. NPV converts the income and costs of the plantation at different stages into current values by discounting future cash flows. This is important for evaluating and comparing different plantation methods.

NPV is calculated as:

$$NPV = \Sigma_{t=0}^{n} \frac{c_t}{(1+r)^t} - C_0$$

Equation 1: NPV equation

Where:

C_0 = initial cost

c_t= the cash flow in year t.

r = the discount rate.

t = time (usually measured in years).

n = the total life of the project (in years).

[1] Goldspink, D. 2024. Supply Manager, Visy Pulp and Paper, Tumut

Sensitivity analysis:

Sensitivity analysis is a technique used to evaluate the response of a model or system output to changes in input variables. Its main purpose is to determine which input variables have the greatest impact on the result, so as to identify and manage risks.

In investment decisions, sensitivity analysis can help analyze the impact of different market conditions on the NPV of an investment project.

In the wood processing value chain, the prices of wood products, the price of wood and other parameters are constantly changing. Changes in these parameters have a huge impact on the NPV of the overall investment project. Therefore, conducting sensitivity analysis can help propose recommendations for investment projects to cope with future changes.

Chapter 5: Results

5.1 *Plantation sector analysis*

Plantations are one of the core segments of the forest industry value chain. As an upstream sector, plantations provide the supply of raw materials for the wood processing industry. The different timber planting and harvesting models in the plantations affect the production of different types of timber resources. This can have a huge impact on the downstream processing industry. Similarly, the processing capacity of the processing industry for different types of timber will also directly affect the demand price of different types of timber, thereby changing the planting model of the plantations. Therefore, exploring different plantation models may have a fundamental impact on the entire radiata pine processing value chain. The analysis of the radiata pine processing value chain should start with the plantation sector.

I will follow up the data analysis by comparing the NPV of other planting models with the NPV under the existing planting model and conduct sensitivity analyses on the parameters affecting the NPV. Ultimately, I will provide recommendations for more economically profitable planting options for the plantation. All calculations are done through Excel's embedded functions.

5.1.1 Plantation baseline study

According to interviews with ACT government staff, the current ACT plantation model is a 32-year rotation, which includes thinning in year 19 and clearfall in year 32. Thinning produces one third of the timber and clearfall produces two thirds.

Calendar Year	Grand Total (tons)
2017	82,631
2018	87,594
2019	86,339
2020	38,971
2021	97,172
2022	94,327
2023	85,889

Table 5.1 Plantation production by year (250 ha)

Table 5.1 shows the timber production from the average clearfall area of 250 hectares of plantations, and other thinning operations, from 2017 to 2023. The data for 2020 is unusually low because in January and February 2020, nearly 90,000 hectares of land (about 40% of the area of the Australian Capital Territory) were destroyed by bushfires in the Beard and Orroral valleys (ACT state of environment, 2024). However, ACT plantation increased its harvest in 2021 and 2022 to make up for the loss of the unharvested part of 2020. Therefore, the data for 2020, 2021 and 2022 have all been affected by fires. I deleted this data when calculating the average annual production and chose to calculate the average of the four normal years of 2017, 2018, 2019, and 2023. The calculated average annual production is 85,613 tons.

S701 Sawlog Gde 1 (Small sawlog)	58.41%
S701 Sawlog Gde 2 (Large sawlog)	0.41%
S701 Sawlog Grd 2	1.00%
S703 Salvage Gde 1	0.99%
S703 Salvage Gde 2	1.00%
S705 Pulp Gde 1	38.02%
S705 Pulp Gde 2	0.15%
Sawlog Grade 6	0.02%

Table 5.2 Proportion of various types of wood from ACT plantations

Table 5.2 shows the percentage of the total production of the eight different types of wood produced by the plantation. S701 Sawlog Gde 1 (Small sawlog) accounts for the largest proportion, reaching 58.41%, followed by S705 Pulplog Gde 2 (Pulplog) with 38.02%. The remaining other types together accounted for 3.88% of production. Therefore, I only considered small sawlog and pulplog in subsequent calculations because they accounted for most of the production. In addition, I also included S701 Sawlog Gde 2 (Large sawlog) because it had the highest price.

In the baseline NPV calculation, I used the previously calculated average annual production of 85613 tonnes. In the baseline study, I assumed that only small sawlogs and pulpwood would be produced, so I need to reallocate the annual average production of small sawlogs and pulpwood based on the relative proportion of the two. Therefore, I allocated the annual average production of small sawlogs and pulpwood to be 85613 tons, resulting in 51859 tons of small sawlogs and 33755 tons of pulpwood.

The baseline rotation is divided into two stages: thinning in year 19 and clearfall in year 32. The thinning process will harvest more pulpwood and less small sawlog, and the clearfall process will harvest more sawlog and less pulpwood. I assume that in the 19-year thinning phase, 30% of the small sawlogs and 70% of the pulpwood were harvested. Then, based on the total amount of small saw logs and pulpwood minus the amount harvested in thinning, it can be finally calculated that in the clearfall in 32 years, 76% of the small sawlogs and 24% of the pulpwood were harvested.

The Ministry of Finance and the Ministry of Finance's technical guide on economic assessment currently recommends the use of a discount rate of 4% or 7% depending on the type of investment (Victorian Government, 2024). I chose a 5% discount rate in the baseline study.

In this section, I assume 3 new plantation management options and apply each with a range of discount rates – a total of 6 scenarios in addition to the base case with a range of discount rate options. I calculate NPV under two different discount rate situations; one where a standard discount rate is used for all scenarios, the other situation where a different discount rate is applied to each scenario. The table below shows all scenarios used.

Discount Rate Situations	Baseline (32 years rotation; one thinning at 19 years)	Option 1 (Higher pulplog option with 32 years rotation)	Option 2 (Higher small log option with 32 years rotation)	Option 3 (Higher large sawlog option with 38 years rotation)
Standard Rate (5%)	Baseline with 5% discount rate	Scenario 1 with 5% discount rate	Scenario 3 with 5% discount rate	Scenario 5 with 5% discount rate
Variable Discount Rate (5%-8%)	Baseline with 5% discount rate	Scenario 2 with 6% discount rate	Scenario 4 with 6% discount rate	Scenario 6 with 8% discount rate

Table 5.3 All plantation management scenarios

Data on log stumpage prices were obtained from industry sources and rounded to the nearest dollar.

Timber class	Price $/tn
Small sawlog	$64.00
Large sawlog	$81.00
Pulplog	$16.00

Table 5.4 Log prices per tn

Since the subsequent unit of wood production is cubic meters, I need to convert the price from per ton to per cubic meter base on density. Green ACT radiata pine has a density of 890 kg/m3 (ACT Forests data).

The results are shown in the table below and rounded to the nearest dollar.

Timber class	Price $/m3
Small sawlog	$57.00
Large sawlog	$72.00
Pulplog	$14.00

Table 5.5 Log prices per m3

Based on interviews with ACT plantation staff, it is known that the costs of management occur mainly in the first two years. The first-year cost was $3,645/ha (including cultivation, planting, weed control and fertilizer program); the second-year cost was $640/ha. Based on the above information and timber prices the baseline NPV results can be calculated as shown in the table below.

Timeline			
Activity	Costs (250 ha)		
Year 0	$911,250		
Year 1	$152,380.95		
Harvesting part	Small sawlog	Pulplog	Large sawlog
Thinning in year 19	30%	70%	N/A
Volume (t)	8561.3	19976.37	N/A
Value	$487,994.10	$279,669.13	N/A
Total value in year 19		$767663.23	N/A
Clearfall in year 32	76%	24%	N/A
Volume (t)	43297	13779	N/A
Value	$2467911.9	$192900.8667	N/A
Total value in year 32		$2660812.767	N/A
PV and NPV			
Present value (PV) in year 19	$303,790.41		
PV in year 32	$558,414.58		
PV for cost in year 1	$152,380.95		
NPV for baseline	-$201,425.97		

Table 5.6 NPV for baseline plantation case

Table 5.6 shows the process of calculating the NPV of the baseline study, which results in an NPV of -$201,425.97 for the existing planting model at ACT plantation. Since the prices of the three wood products are different, changing the production shares of the different products would result in different NPVs. The other planting scenarios that I have proposed subsequently are based on changing the production shares of the three different types of wood.

5.1.2 Option 1 (Higher pulplog option)

Pulpwood is characterized by a short growth cycle and has low requirements for wood quality. The short growing cycle means that harvesting can be done earlier than for sawlogs, thus recovering the capital invested and facilitating the flow of funds. The disadvantage of pulpwood is that it is relatively cheap, but in the ACT plantation pulpwood does not have a significant price disadvantage compared to sawlogs, so planting all pulpwood is an option. In my option 1, I assume that the plantation does a clearfall once every 16 years and the harvested wood is all pulpwood.

5.1.2.1 Standard discount rate situation: Scenario 1

Timeline			
Activity	Planting costs		
Year 0	$911,250		
Year 1	$152,380.95		
Harvesting part 1	Small sawlog	Pulplog	Large sawlog
Clearfall in year 16	N/A	100%	N/A
Volume (t)	N/A	99881.83	N/A
Value	N/A	$1398345.667	N/A
Total value	N/A	$1398345.667	N/A
Planting part 2	Planting costs		
Year 16	$417,454.12		
Year 17	$69,807.47		
Harvesting part 2	Small sawlog	Pulplog	Large sawlog
Clearfall in year 16	N/A	100%	N/A
Volume (t)	N/A	99881.83	N/A
Value	N/A	$1398345.667	N/A
Total value	N/A	$1398345.667	N/A
PV and NPV			
PV in year 16	$640,598.26		
PV in year 32	$293,465.44		
PV for cost in year 1	$152,380.95		
PV for cost in year 16	$417,454.12		
PV for cost in year 17	$69,807.47		
NPV for option 1	-$616,828.84		

Table 5.7 NPV for plantation scenario 1

Table 5.7 shows that the NPV of scenario 1 is -$616,828.84. Although scenario 1 has two clearfalls that harvest a larger volume of timber, the additional timber value is lower than the total cost of the two planting processes, as the harvested timber is low-value pulplog. Therefore, the result of scenario 1 is lower than the baseline (-$0.2M).

5.1.2.2 Variable discount rate situation: Scenario 2

Although the pulpwood-only scenario can generate a greater financial return from harvesting wood earlier than the baseline, this management model only harvests a single type of timber and requires more planting costs. Therefore, the discount rate for this method should be appropriately higher than the baseline. I assume that the current discount rate becomes 6%, and the new NPV results are shown in the table below.

Timeline			
Activity	Planting costs		
Year 0	$911,250		
Year 1	$150,943.40		
Harvesting part 1	Small sawlog	Pulplog	Large sawlog
Clearfall in year 16	N/A	100%	N/A
Volume	N/A	99881.83	N/A
Value	N/A	$1398345.667	N/A
Total value	N/A	$1398345.667	N/A
Planting part 2	Planting costs		
Year 16	$358,710.18		
Year 17	$59,418.31		
Harvesting part 2	Small sawlog	Pulplog	Large sawlog
Clearfall in year 16	N/A	100%	N/A
Volume	N/A	99881.83	N/A
Value	N/A	$1398345.667	N/A
Total value	N/A	$1398345.667	N/A
PV and NPV			
PV in year 16	$550,453.58		
PV in year 32	$216,684.00		
PV for cost in year 1	$150,943.40		
PV for cost in year 16	$358,710.18		
PV for cost in year 17	$59,418.31		
NPV for option 1	-$713,184.30		

Table 5.8 NPV for plantation scenario 2

The NPV of scenario 2 is -$713,184.30, which is lower than that of scenario 1. Increasing the discount rate on the basis of scenario 1 will definitely reduce the final NPV.

5.1.3 Option 2 (Higher small sawlog option)

Sawlogs are high-value wood that can be processed into a wide variety of high value-added wood products. However, sawlogs usually require a longer growing cycle, so in option 2 I try to harvest more small sawlogs because it is slightly less expensive than large sawlog, but due to the shorter growing cycle of large sawlog, it is more economical from a discounting point of view. In option 2, the plantation is thinned in year 13 in hopes of removing the poorly growing trees and leaving enough resources and space for the remaining trees to grow into high quality sawlogs in the future. In year 32, the plantation is clearfelled.

5.1.3.1 Standard discount rate situation: Scenario 3

Timeline			
Activity	Planting costs		
Year 0	$911,250		
Year 1	$152,380.95		
Harvesting part	Small sawlog	Pulplog	Large sawlog
Higher small sawlog option	Small sawlog	Pulplog	Large sawlog
Thinning in year 13	N/A	100%	N/A
Volume (t)	N/A	19525.77	N/A
Value	N/A	$273360.81	N/A
Total value	N/A	$273360.81	N/A
Clearfall in year 32	75%	20%	5%
Volume (t)	49565.42	13217	3304.36
Value	$2825229	$185044	$237914.02
Total value	$3248187		
PV and NPV			
PV in year 13	$144,969.07		
PV in year 32	$681,684.61		
PV for cost in year 1	$152,380.95		
NPV for option 3	-$236,977.27		

Table 5.9 NPV for plantation scenario 3

Table 5.9 gives the NPV result for scenario 3 as -$236,977.27. This result is slightly worse than the baseline result (-$0.2M).

5.1.3.2 Variable discount rate situation: Scenario 4

As this option recovers relatively little money before clearfall. The investment is relatively risky, so I choose a discount rate of 6% for scenario 4. The recalculated NPV results are shown in the table below.

Timeline			
Activity	Planting costs		
Year 0	$911,250		
Year 1	$150,943.40		
Harvesting part	Small sawlog	Pulplog	Large sawlog
Higher small sawlog option	Small sawlog	Pulplog	Large sawlog
Thinning in year 13	N/A	100%	N/A
Volume	N/A	19525.77	N/A
Value	N/A	$170264.73	N/A
Total value	N/A	$170264.73	N/A
Clearfall in year 32	75%	20%	5%
Volume	49565.42	13217	3304.36
Value	$2825229	$185044	$237914.02
Total value	$3248187		
PV and NPV			
PV in year 13	$128,162.21		
PV in year 32	$503,330.64		
PV for cost in year 1	$150,943.40		
NPV for option 3	-$430,700.54		

Table 5.10 NPV for plantation scenario 4

Table 5.10 gives the NPV result for scenario 4 as -$430,700.54. This result is worse than the baseline, which shows that the impact of the discount rate on the final NPV is significant.

5.1.4 Option 3 (Higher large sawlog option)

Large sawlogs contain the most valuable wood and can be used for processing it into many higher value-added wood products such as solid wood furniture or structural wood. Although large sawlog requires a longer growing cycle, a plantation with a large and steady supply of high-quality large sawlogs can make up for these shortcomings. So, in option 3 I expand the production of large sawlog. Similar to option 2, option 3 has a thinning in year 13. In addition, a second thinning was conducted in year 28 to harvest all the small sawlog and pulpwood and give the strongest trees a chance to grow into large sawlogs. Finally, a clearfall was carried out in year 38. I assume that after the second thinning, 30% of the remaining small sawlogs are converted into large sawlogs, and the remaining 80% of pulplogs are converted into small sawlogs.

5.1.4.1 Standard discount rate situation: Scenario 5

Timeline			
Activity	Planting costs		
Year 0	$911,250		
Year 1	$152,380.95		
Harvesting part	Small sawlog	Pulplog	Large sawlog
Thinning in year 13	N/A	100%	N/A
Volume (t)	N/A	19525.77	N/A
Value	N/A	$273360.81	N/A
Total value	N/A	$273360.81	N/A
Second Thinning in year 28	70%	30%	N/A
Volume (t)	38769.92	16616	N/A
Value	$2,209,885.56	$232620	N/A
Total value		$2,442,505.10	N/A
Clearfall in year 38	71.69%	3.38%	24.93%
Volume (t)	19,180.31	905	6668.8
Value	$1,093,277.69	$12669	$480,153.65
Total			$1,586,100.51
PV and NPV			
PV in year 13	$144,969.07		
PV in year 28	$623,067.51		
PV in year 38	$248,391.85		
PV for cost in year 1	$152,380.95		
NPV for option 4	-$47,202.52		

Table 5.11 NPV for plantation scenario 5

Table 5.11 shows that the NPV for scenario 5 is -$47,202.52. This scenario has the highest NPV because it produces the most high-value sawlogs, in a rotation that is six years longer than the current management practice.

5.1.4.1.1 Variable discount rate situation: Scenario 6

This scenario has a longer investment period and will obviously face more risks. Therefore, I am now assuming a discount rate of 8% for this scenario. The recalculated NPV results are shown in the table below.

Timeline			
Activity	Planting costs		
Year 0	$911,250		
Year 1	$148,148.15		
Harvesting part	Small sawlog	Pulplog	Large sawlog
Thinning in year 13	N/A	100%	N/A
Volume	N/A	19525.77	N/A
Value	N/A	$273360.81	N/A
Total value	N/A	$273360.81	N/A
Second Thinning in year 28	70%	30%	N/A
Volume	38769.92	16616	N/A
Value	$2,209,885.56	$232620	N/A
Total value		$2,442,505.10	N/A
Clearfall in year 38	71.69%	3.38%	24.93%
Volume	19,180.31	905	6668.8
Value	$1,093,277.69	$12669	$480,153.65
Total			$1,586,100.51
PV and NPV			
PV in year 13	$100,514.20		
PV in year 28	$283,119.85		
PV in year 38	$85,158.49		
PV for cost in year 1	$148,148.15		
NPV for option 4	-$590,605.60		

Table 5.12 NPV for plantation scenario 6

Table 5.12 shows that the net present value of scenario 6 is -$590,605.60. This result is only slightly better than that of option 1. The main reason for this is the effect of the discount rate.

5.1.5 Sensitivity analysis

Combining these results, if the discount rate varies, maintaining the current situation seems to be the most financially-attractive option, since the baseline has the highest NPV. If the discount rate remains the same, the option of producing more large sawlogs is the most attractive one. It seems that the results are quite robust. However, the price of wood is not stable, changes in the price of different types of wood will affect the final NPV value for different scenarios. So, I will conduct a sensitivity analysis of NPV to the price of different types of wood. The price of timber from ACT plantations differs significantly from the prices in the Australian Radiata Pine Log Index. The stumpage prices in the ACT are approximately $64 for small sawlogs, $81 for large sawlogs and $ 16 for pulpwood.

The Australian log index gives prices of $81.67 for small sawlogs, $111.90 for large sawlogs, and $23.62 for pulpwood. They are 27.6% higher, 38.1% higher, and 47.6% higher (KPMG, 2024). If the timber prices in the ACT are the same as the Australian average, it will affect the final NPV.

5.1.5.1 Pulplog price change:

I adjusted the price of pulpwood from -20% to +40%

5.1.5.1.1 Standard discount rate:

Pulplog	-20%	-10%	0	10%	20%	30%	40%
Baseline	-$231,657.56	-$216,541.76	-$201,425.97	-$186,310.17	-$171,194.38	-$156,078.59	-$140,962.79
Option 1	-$803,641.58	-$710,235.21	-$616,828.84	-$523,422.47	-$430,016.10	-$336,609.73	-$243,203.36
Option 2	-$273,737.99	-$255,357.63	-$236,977.27	-$218,596.91	-$200,216.55	-$181,836.19	-$163,455.83
Option 3	-$88,461.10	-$67,831.81	-$47,202.52	-$26,573.23	-$5,943.94	$14,685.35	$35,314.63

Table 5.13 Pulplog price sensitivity (5% discount rate)

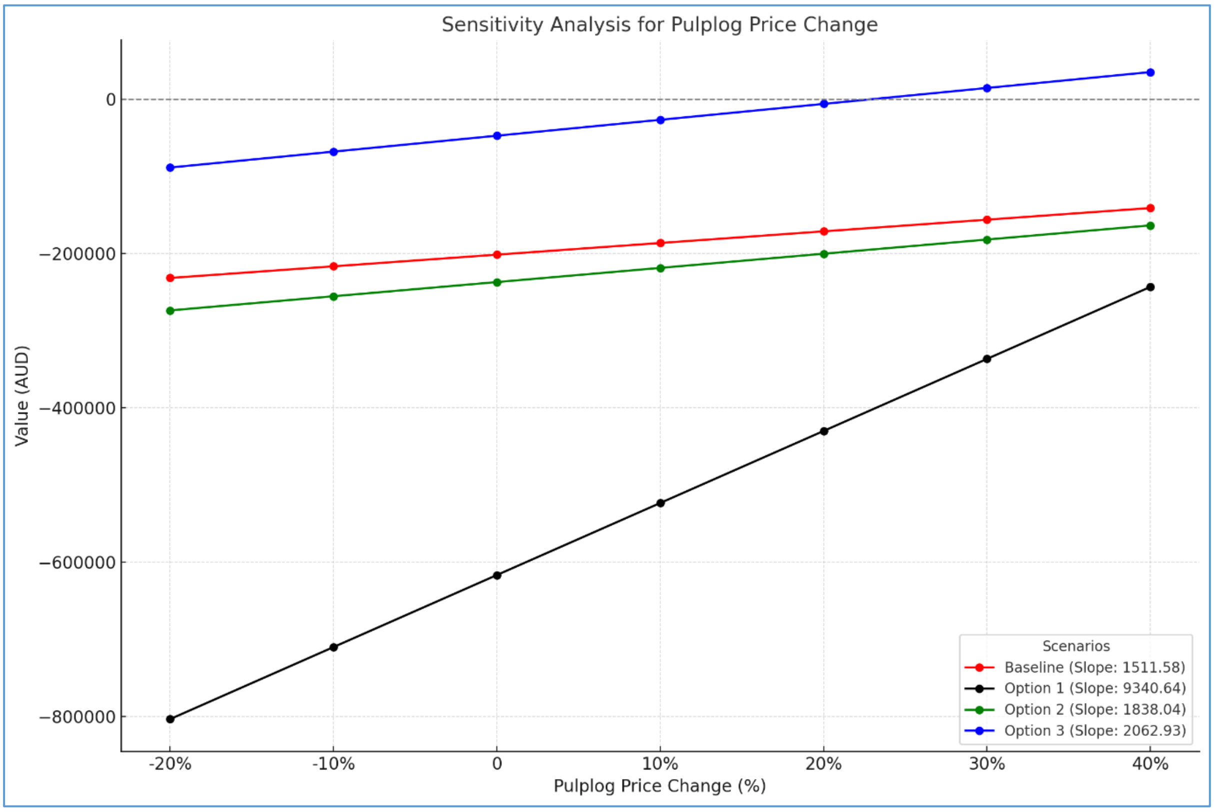

Figure 5.1 Pulplog price sensitivity analysis line chart (5% discount rate)

Table 5.13 shows the NPV resulting from changes in the price of pulpwood, and Figure 5.1 shows a sensitivity analysis graph based on the results of Table 5.13. According to the results shown in Figure 5.1, option 3 maintains a leading position in the range of -20 to 40%, followed by option 2. In addition, option 1 is most sensitive to price changes in pulplog. But unless there is an extremely large increase in pulplog price, the NPV of higher pulplog option is minimal.

5.1.5.1.2 Variable discount rate:

Pulplog	-20%	-10%	0	10%	20%	30%	40%
Baseline (5%)	-$231,657.56	-$216,541.76	-$201,425.97	-$186,310.17	-$171,194.38	-$156,078.59	-$140,962.79
Option 1 (6%)	-$866,611.82	-$789,898.06	-$713,184.30	-$636,470.54	-$559,756.78	-$483,043.03	-$406,329.27
Option 2 (6%)	-$462,067.78	-$446,384.16	-$430,700.54	-$415,016.92	-$399,333.30	-$383,649.68	-$367,966.07
Option 3 (8%)	-$616,237.20	-$603,421.38	-$590,605.55	-$577,789.72	-$564,973.90	-$552,158.07	-$539,342.25

Table 5.14 Pulplog price sensitivity (5%-8% discount rate)

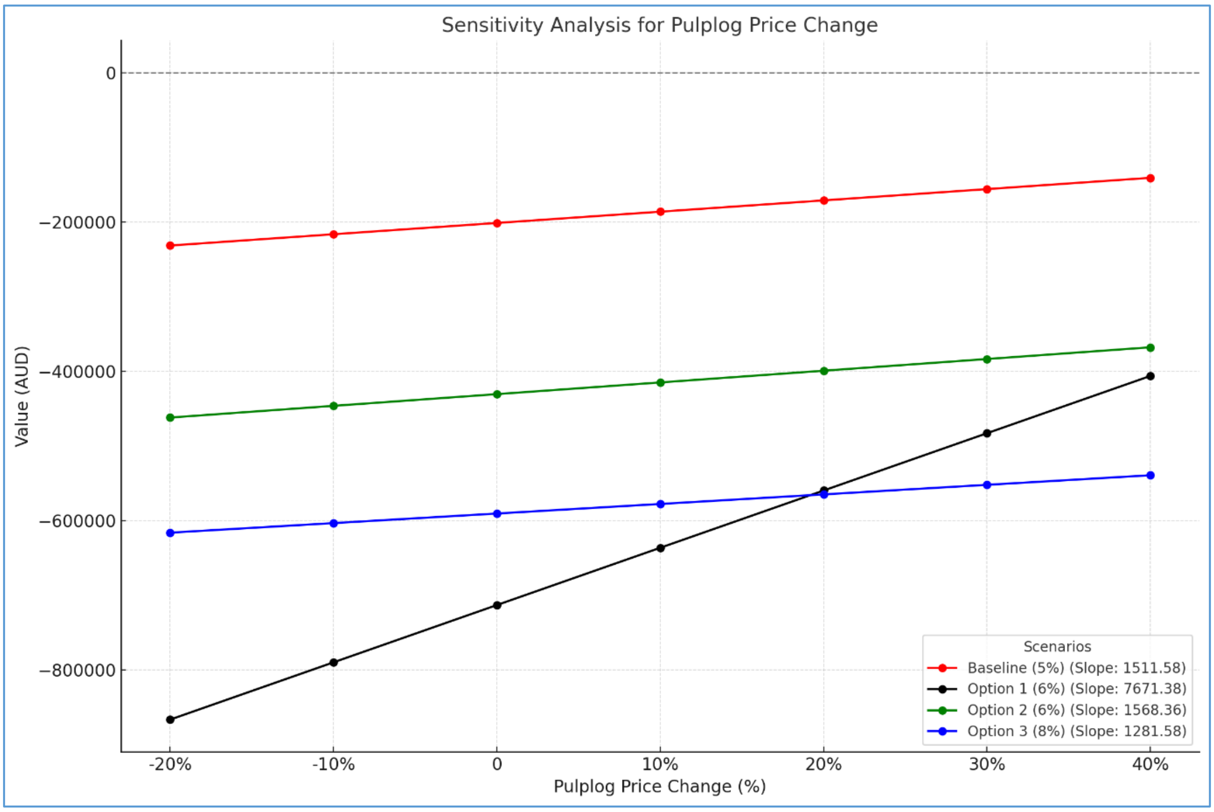

Figure 5.2 Pulplog price sensitivity analysis line chart (5%-8% discount rate)

According to the results in Figure 5.2, it can be found that the change in the discount rate significantly affects the sensitivity of each scenario to the price of pulpwood. Therefore, except for pulplog option, the baseline with the lowest discount rate is more sensitive to the price of pulpwood than sawlog options, which means that the baseline is always the best choice compared with sawlog options, regardless of how the price of pulplog changes. While the high pulplog option has the highest pulplog price sensitivity, the high pulplog option is only higher than the large sawlog option if the price of pulplog increases by more than 19.18%.

5.1.5.2 Small sawlog price change:

I adjusted the price of small sawlog from -20% to +40%.

5.1.5.2.1 Standard discount rate:

Small sawlog	-20%	-10%	0	10%	20%	30%	40%
Baseline	-$343,635.38	-$272,530.67	-$201,425.97	-$130,321.26	-$59,216.56	$11,888.15	$82,992.85
Option 1	-$616,828.84	-$616,828.84	-$616,828.84	-$616,828.84	-$616,828.84	-$616,828.84	-$616,828.84
Option 2	-$355,561.27	-$296,269.27	-$236,977.27	-$177,685.27	-$118,393.28	-$59,101.28	$190.72
Option 3	-$194,190.70	-$120,696.61	-$47,202.52	$26,291.57	$99,785.66	$173,279.75	$246,773.84

Table 5.15 Small sawlog price sensitivity (5% discount rate)

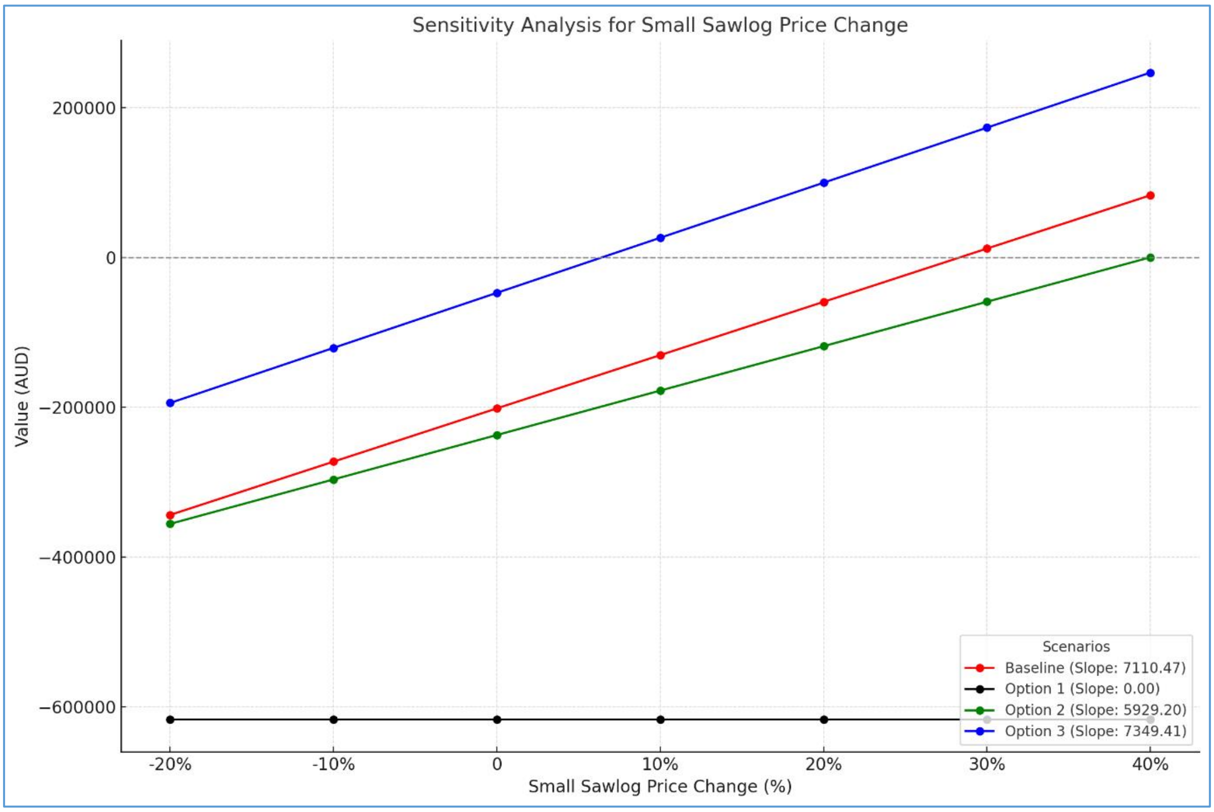

Figure 5.3 Small sawlog price sensitivity analysis line chart (5% discount rate)

In this case, higher large sawlog option is the leader, followed by small sawlog option. However, it is interesting to note that even though small sawlog option produces more small sawlogs and the proportion of small sawlogs is higher, small sawlog option is less price-sensitive than the baseline. A possible reason for this is that despite the baseline produces fewer small sawlogs, the baseline harvests small sawlogs in year 19 during thinning, while small sawlog option harvests small sawlogs in year 32 during clearfall, and the value of small sawlogs is discounted for more years in small sawlog option.

5.1.5.2.2 Variable discount rate:

Small sawlog	-20%	-10%	0	10%	20%	30%	40%
Baseline (5%)	-$343,635.38	-$272,530.67	-$201,425.97	-$130,321.26	-$59,216.56	$11,888.15	$82,992.85
Option 1 (6%)	-$713,184.30	-$713,184.30	-$713,184.30	-$713,184.30	-$713,184.30	-$713,184.30	-$713,184.30
Option 2 (6%)	-$518,258.57	-$474,479.55	-$430,700.54	-$386,921.53	-$343,142.51	-$299,363.50	-$255,584.49
Option 3 (8%)	-$653,576.54	-$622,091.07	-$590,605.60	-$559,120.14	-$527,634.67	-$496,149.21	-$464,663.74

Table 5.16 Small sawlog price sensitivity (5%-8% discount rate)

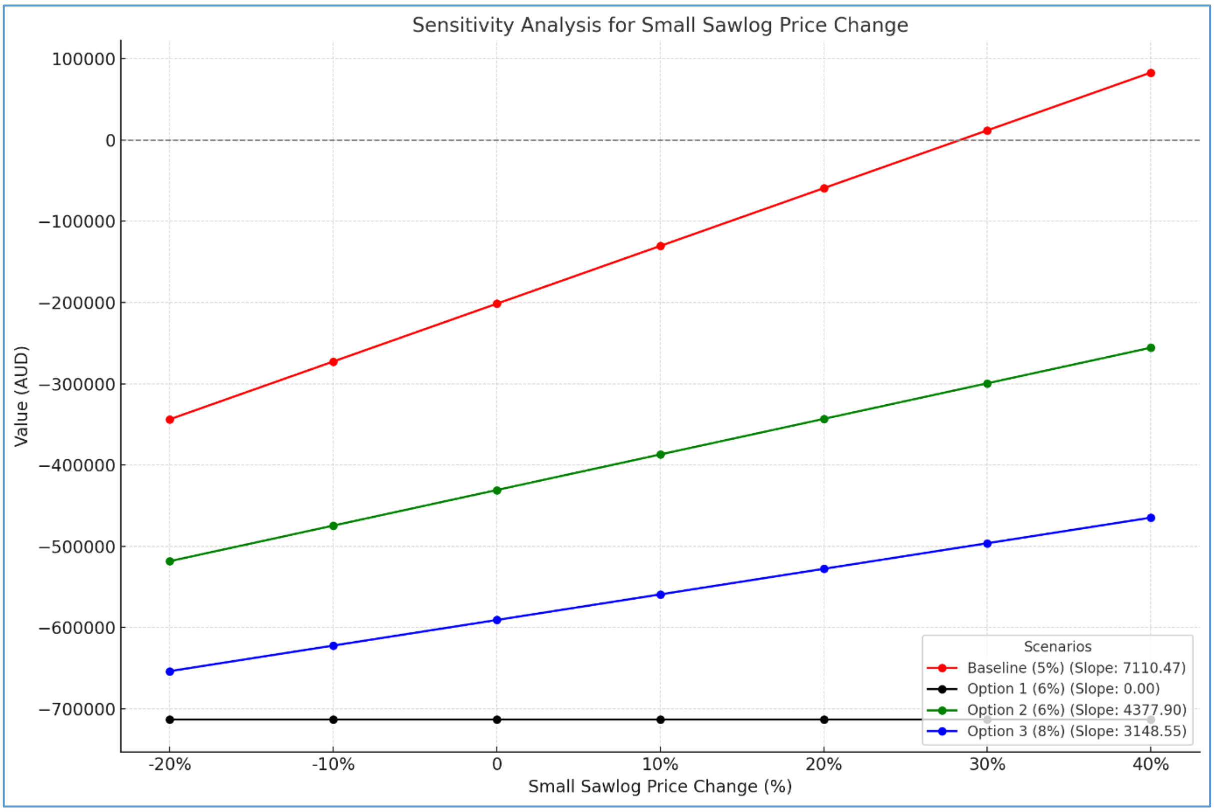

Figure 5.4 Small sawlog price sensitivity analysis line chart (5%-8% discount rate)

Similar to the previous result, a low discount rate gives the baseline a greater sensitivity to small sawlog prices. The baseline always has the highest NPV for any small sawlog price change.

5.1.5.3 Large sawlog price change:

I adjusted the price of large sawlog from -20% to +40%.

5.1.5.3.1 Standard discount rate:

Large sawlog	-20%	-10%	0	10%	20%	30%	40%
Baseline	-$201,425.97	-$201,425.97	-$201,425.97	-$201,425.97	-$201,425.97	-$201,425.97	-$201,425.97
Option 1	-$616,828.84	-$616,828.84	-$616,828.84	-$616,828.84	-$616,828.84	-$616,828.84	-$616,828.84
Option 2	-$246,963.29	-$241,970.28	-$236,977.27	-$231,984.26	-$226,991.25	-$221,998.24	-$217,005.23
Option 3	-$62,241.45	-$54,721.99	-$47,202.52	-$39,683.06	-$32,163.60	-$24,644.13	-$17,124.67

Table 5.17 Large sawlog price sensitivity (5% discount rate)

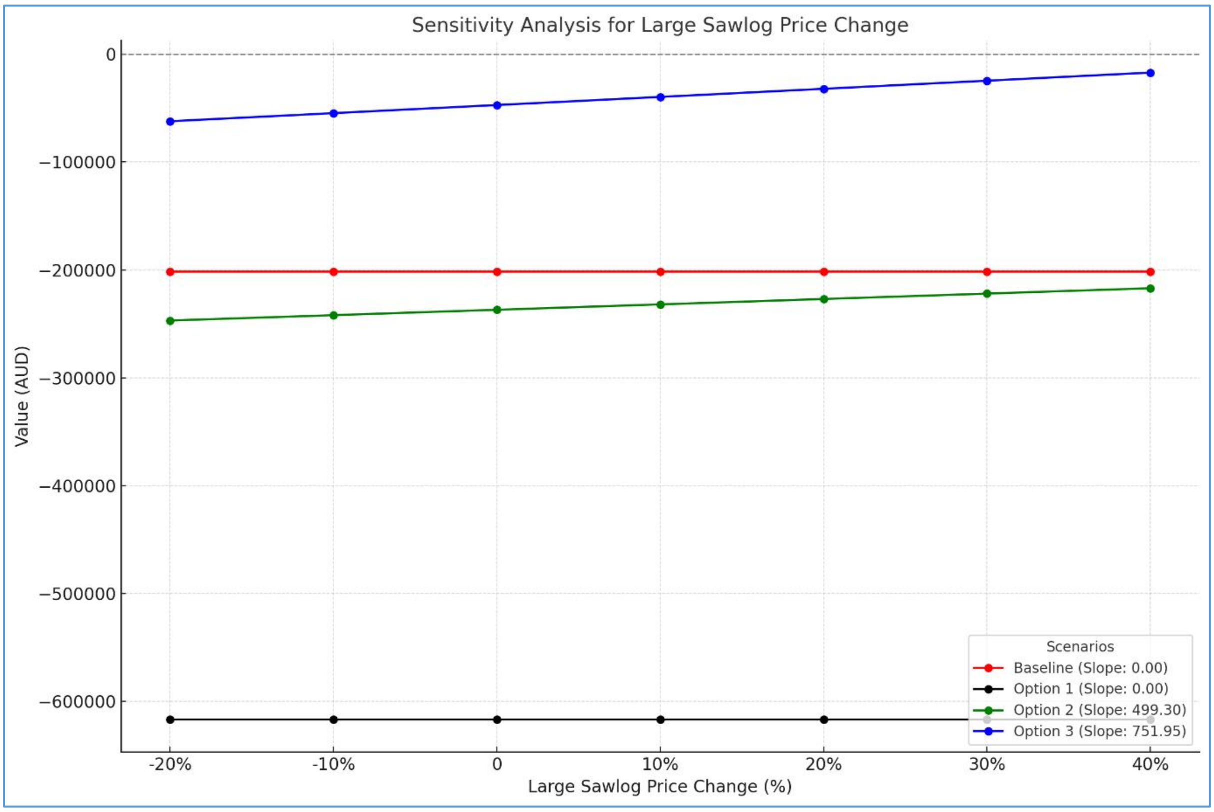

Figure 5.5 Large sawlog price sensitivity analysis line chart (5% discount rate)

The results in Figure 5.5 show that the large sawlog option is always above the baseline in the large sawlog price range of -20% to 40%. The small sawlog option can exceed the baseline when the price of large sawlogs increases by more than 55.8%.

5.1.5.3.2 Variable discount rate:

Large sawlog	-20%	-10%	0	10%	20%	30%	40%
Baseline (5%)	- $201,425.97	- $201,425.97	-$201,425.97	- $201,425.97	- $201,425.97	- $201,425.97	- $201,425.97
Option 1 (6%)	- $713,184.30	- $713,184.30	-$713,184.30	- $713,184.30	- $713,184.30	- $713,184.30	- $713,184.30
Option 2 (6%)	- $438,073.85	- $434,387.19	-$430,700.54	- $427,013.89	- $423,327.23	- $419,640.58	- $415,953.93
Option 3 (8%)	- $595,761.54	- $593,183.57	-$590,605.60	- $588,027.64	- $585,449.67	- $582,871.70	- $580,293.73

Table 5.18 Large sawlog price sensitivity (5%-8% discount rate)

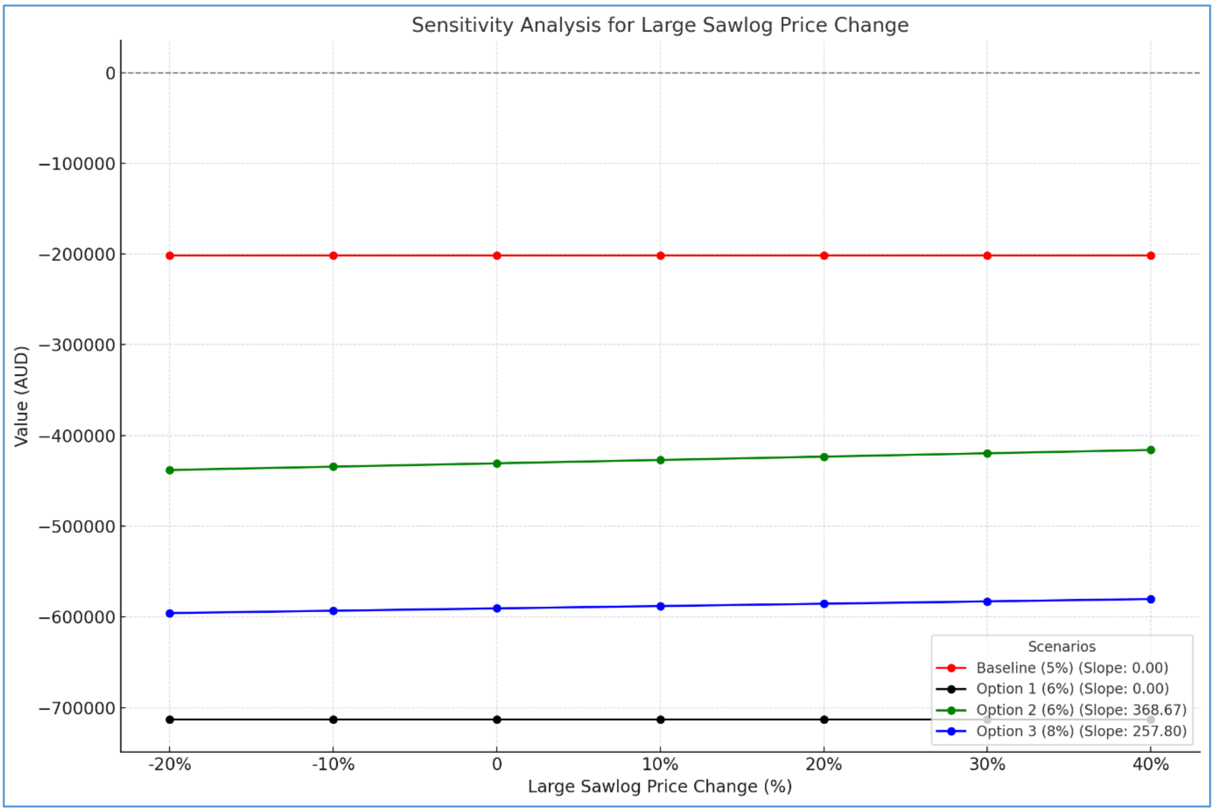

Figure 5.6 Large sawlog price sensitivity analysis line chart (5%-8% discount rate)

According to the results in figure 5.6, it can be seen that the impact of the price change of large sawlog on the overall NPV change is small. There are two main reasons for this. First, the production of large sawlogs is too small a proportion of overall production. Second, if you want to obtain larger sawlog, you need to extend the planting cycle. As the years increase, the impact of the discount rate will be greater than the impact of the price of large sawlog. In this case, the baseline is always the best.

5.2 Local sawmill analysis

The local sawmill sector is a critical component of the forest industry value chain. As a midstream value chain sector, sawmills process raw timber sourced from plantations, transforming them into wood products for various downstream customers. The equipment, processing technology and recovery rate of a sawmill have significant impacts on the type and quantity of raw materials processed into products. Different types of products require different grades of raw materials. This directly reflects the requirements for the type and quality of wood produced in upstream plantations, which in turn affects plantation management. In addition, the operating model of the sawmill directly affects the economic benefits of the sawmill and thus the price of wood products purchased by consumers. The case of local sawmills is fundamental to studying the ACT radiata pine value chain.

Capital Battens Pty Ltd is a private company based in Fyshwick, ACT, Australia, established in 1999. After the 2003 fires, it is the only remaining sawmill in Canberra. The company specializes in the production and supply of timber battens used for roofing and building applications. Capital Battens is known for its versatile, high-strength, and durable battens, which are easy to install and widely used as structural support for roofing tiles. Its products are sold in Canberra, Sydney and Melbourne.

Because of the age of its design and equipment, the primary product recovery rate at Capital Battens is consistently very low, at only about 36%. The lack of scanning equipment and advanced woodworking machinery is the main reason for the low wood recovery rate of Capital Battens. I will explore several scenarios for Capital Battens purchasing new equipment to improve the wood recovery rate and calculate the NPV of each option. The economic feasibility of these Capital Battens upgrade scenarios will be judged by comparing the NPV of different scenarios with the current business model.

5.2.1 Baseline

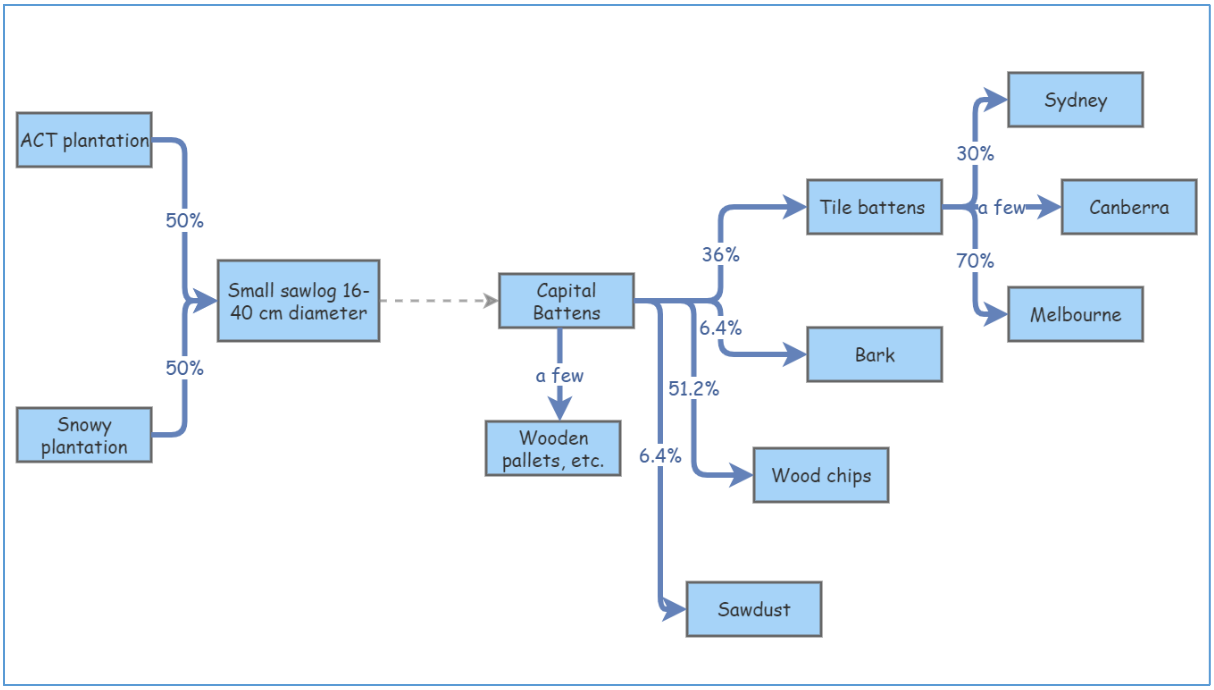

Figure 5.7 Flow chart for Capital Battens

As shown in Figure 5.7, Capital Battens purchases approximately 84,296.6 tons of small sawlog from ACT public plantations and Snowy Plantations, a private company, annually. The main product manufactured from this timber is 38 mm x 38 mm tile battens, which are mostly sold to Melbourne and Sydney. The main wood residues are wood chips, sawdust and bark. It also produces a small number of simple wood products such as wooden pallets.

5.2.1.1 NPV calculation

A. Costs (annual)	
1.Labour	$2,800,000
2.Energy	$360,000
3.Machinery maintenance	$636,000
4.Major business	$318,000
5.Transportation	$1,405,432.36
6.Log inputs	$5,268,537.50
Total costs	$10,787,970
B. Income	
1. Tile battens	$18,426,469.50
2. Wood chips	$4,680,000
3. Sawdust	$1,009,174
4. Bark	$1,743,119
Total income	$25,858,762.50
Annual cash flow	$15,070,792.64
Comparison period	10 years
Discount rate	8%
NPV (10 years)	$101,126,245.36

Table 5.19 NPV for baseline sawmill scenario

All commercial data is from the manager of Capital Battens. To avoid disclosure of trade secrets, the calculation process of specific costs is not listed in this study.

The business loan rate for long-term investments is around 7%. The discount rate is generally slightly higher than the loan rate for that investment because the company's operations are exposed to more risk. So, I assume a baseline discount rate of 8%. In addition, I calculated the cash flow by summing up the costs of the six categories and the revenue of the four products, as shown in Table 5.19 I used a 10-year period for analysis because the comparator scenarios have a 10-year life, as outlined below. The final baseline NPV is $101,126,245.36.

5.2.2 Sawmill upgrade scenario

Pressures on timber pricing and processing costs require that timber manufacturing be carried out in the most efficient manner, extracting maximum value from each log. However, wood is a natural material and each log is different in shape and diameter. In addition, there are many internal defects that are not visible to the human eye. Capital Battens uses visual assessment to develop a cutting plan for the log, which will lead to a lot of waste in wood processing. For a conventional modern sawmill, a typical solution to the challenge of optimizing wood is to use 3D laser scanning to identify internal structural defects, and then use a computer to customize a cutting plan that avoids the defects to maximize wood recovery. Therefore, in this scenario, I simulated Capital Battens purchasing a laser scanner and a companion saw that can recognize the scanner's commands.

5.2.2.1 Machinery selection

The STR 980 high-precision 3D laser wood defect scanner manufactured by Xiamen Strongtech Co., Ltd. is a typical wood scanner. The shape of the machine is shown in the figure below, and some of the parameters of the machine are shown in the table below.

Figure 5.8 STR 980 laser scanner

Machinery	STR 980 laser scanner
Scanning speed	60-120m/min
Whole machine power consumption	22KW
Degree of automation	Fully automatic
Price	$196,503.53
Shipping and installation costs	$752.77
Total cost	$197,256.30

Table 5.20 Parameters of the scanner

In order to ensure that the scanner's signal can be accurately transmitted to the sawing machine, I chose the STR MJY30-50 sawing machine also manufactured by the same company. The detailed information is shown below.

Figure 5.9 STR MT-350 saw

Machinery	STR MT-350 saw
Feeding speed	60m/min
Whole machine power consumption	7.5KW
Price	$40,983.46
Shipping and installation costs	$752.77
Total cost	$41,736.23

Table 5.21 Parameters of the saw

5.2.2.2 NPV calculation

A standard modern sawmill can achieve a primary product recovery rate of at least 50%. Since the price of these two machines is higher than that of similar machines, I assume that the recovery rate can be increased to 50% by using these two machines. In this scenario, I keep the production of tile battens constant, so that increasing the recovery rate reduces the wood intake and associated cost. As the recovery rate increases, the production of wood residue products will decrease. In addition since the new machinery chosen is fully automated, it saves the labour costs of the three workers previously used to sort the wood, so the scenario's labour costs are reduced by the amount of three workers. The service life of the new machinery is about 10 years, which I use as in the basis of my NPV calculations.

A. Costs (annual)	
1.Labour	$2,560,000
2.Energy	$360,000
3.Machinery maintenance	$636,000
4.Major business	$318,000
5.Transportation	$1,405,432.36
6.Log inputs	$3,793,347.00
7.New machinery	$23,899.25
Total costs	$9,096,679
B. Income	
1. Tile battens	$18,426,469.50
2. Wood chips	$3,369,600
3. Sawdust	$726,605
4. Bark	$1,255,046
Total income	$23,777,720.46
Annual cash flow	$14,681,041.85
Comparison period	10 years
Discount rate	8%
NPV (10 years)	$98,510,985.81

Table 5.22 NPV for sawmill upgrading scenario

The final NPV calculation is $98,510,985.81. This result is below the baseline outcome. The main reason is that the cash flow for this scenario is lower than the baseline, for three reasons. Firstly, the increase in the recovery rate leads to a decrease in the production of wood residue products. The reduction in raw material costs due to the reduced intake of wood does not compensate for the reduction in wood residue production. Secondly, since the value of tile battens does not have a significant value advantage over wood residue, the increase in the wood recovery rate is not as economically rewarding as it could be. Thirdly, the relatively low price of wood leads to the fact that using the current high waste model does not result in high raw material costs.

5.2.3 Sensitivity analysis

Changes in the price of timber, the price of tile battens, and the price of timber residuals (primarily wood chips) affect the final NPV results. A modern sawmill needs to make rational business strategy adjustments based on future market changes. Here, I conduct a sensitivity analysis of the sawmill NPV to price changes in the three categories and use the results of the sensitivity analysis to make business recommendations to Capital Battens.

5.2.3.1 Timber price change sensitivity analysis

I assume that timber price fluctuates from -20% to 40%.

Timber Price	-20%	-10%	0	10%	20%	30%	40%
Baseline	$108,196,708.46	$104,661,476.91	$101,126,245.36	$97,591,013.81	$94,055,782.27	$90,520,550.72	$86,985,319.17
Scenario	$103,601,719.24	$101,056,352.53	$98,510,985.81	$95,965,619.10	$93,420,252.39	$90,874,885.67	$88,329,518.96

Table 5.23 Timber price sensitivity

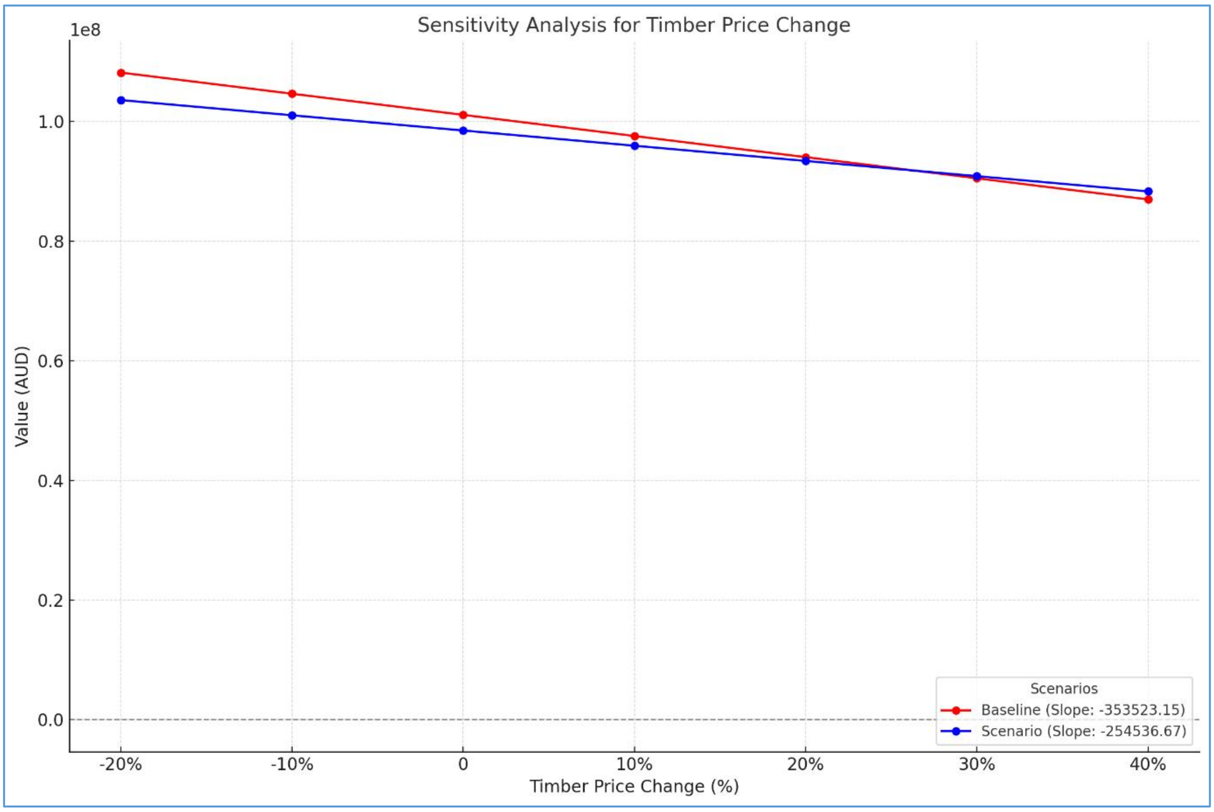

Figure 5.10 Sensitivity analysis for timber price

The NPV of the scenario is greater than the baseline when the price of wood increases by more than 26.5% because the high primary wood product recovery rate from the scenario effectively reduces the volume of wood intake, and this advantage is more obvious in the case of high timber prices.

5.2.3.2 Products price change sensitivity analysis

I assume that tile battens price fluctuates from -20% to 40%.

Tile Battens price	-20%	-10%	0	10%	20%	30%	40%
Baseline	$76,397,623.31	$88,761,934.34	$101,126,245.36	$113,490,556.38	$125,854,867.41	$138,219,178.43	$150,583,489.46
Scenario	$73,782,363.77	$86,146,674.79	$98,510,985.81	$110,875,296.84	$123,239,607.86	$135,603,918.89	$147,968,229.91

Table 5.24 Tile battens price sensitivity

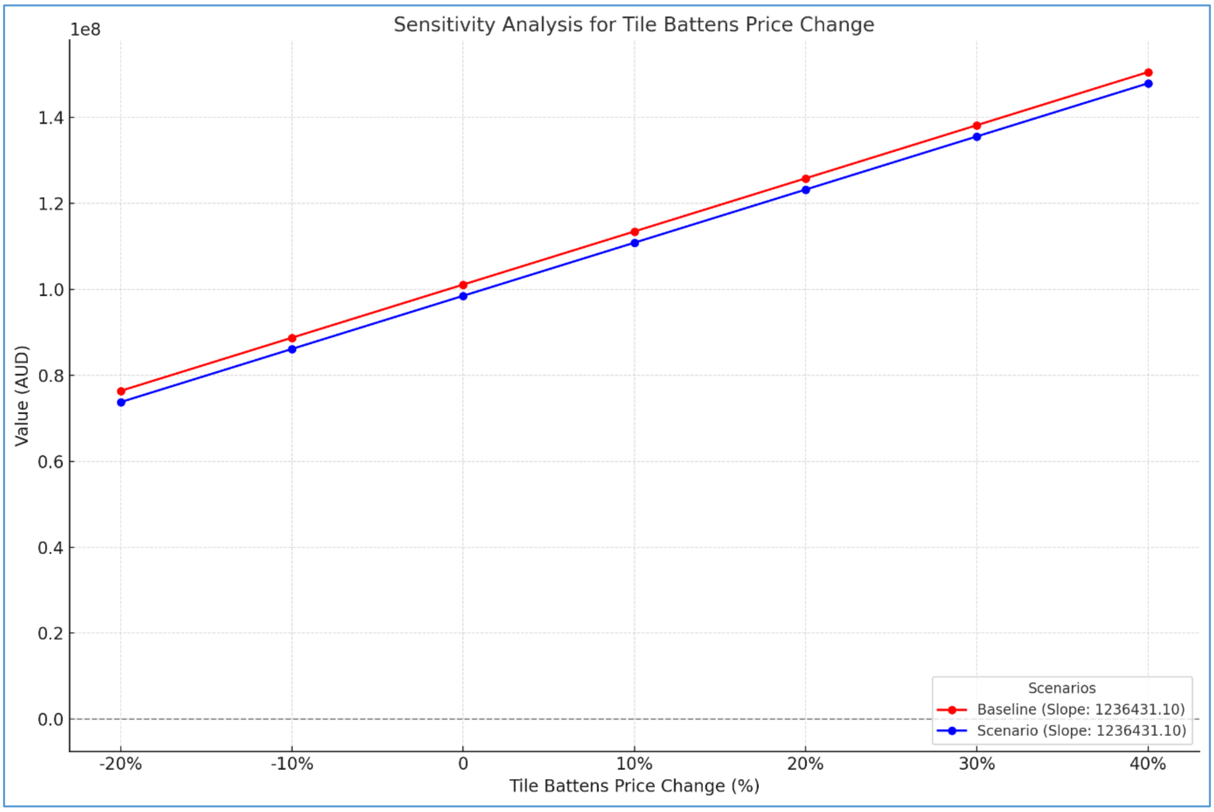

Figure 5.11 Sensitivity analysis for tile battens price

The sensitivity of the NPV of the scenario and the baseline to the price of tile battens is the same. This is because both scenarios produce the same quantity of tile battens. This suggests that the baseline is better regardless of the change in the price of tile battens.

5.2.3.3 Wood residual price change sensitivity analysis

Since wood chips account for 80% of the production of wood residues, the change in the price of wood chips is used in this study to represent the change in the price of wood residues.

I assume that wood chips price fluctuates from -20% to 40%.

Wood chips price	-20%	-10%	0	10%	20%	30%	40%
Baseline	$94,845,609.17	$97,985,927.27	$101,126,245.36	$104,266,563.46	$107,406,881.55	$110,547,199.65	$113,687,517.74
Scenario	$93,988,927.76	$96,249,956.79	$98,510,985.81	$100,772,014.84	$103,033,043.87	$105,294,072.90	$107,555,101.93

Table 5.25 Wood chips price sensitivity

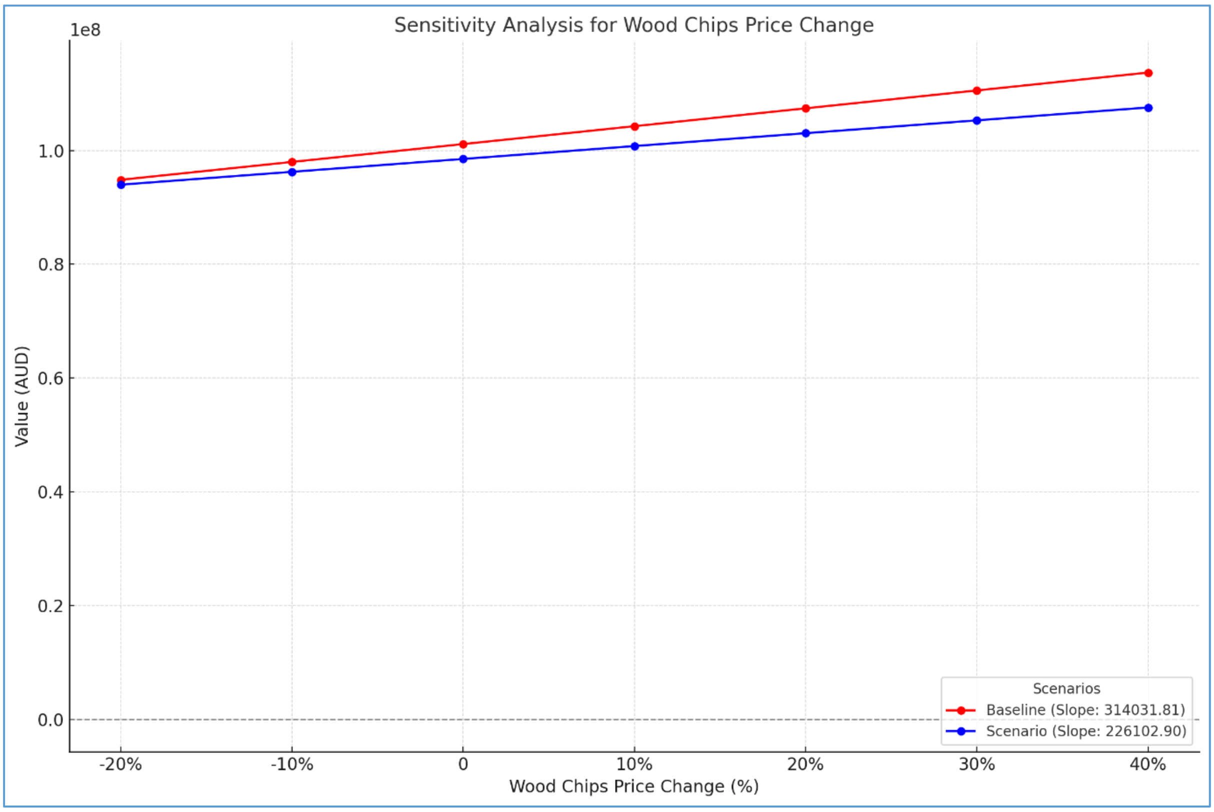

Figure 5.12 Sensitivity analysis for wood chips price

The baseline is more sensitive to changes in wood chip prices. When the wood chip price falls below -29.8%, the scenario results are better than the baseline.

5.3 New wood products analysis

The previous analysis identified challenges and opportunities for both plantations and sawmills, two important sectors in the ACT radiata pine value chain.

From the plantation perspective, the challenge for plantations now is the lack of a nearby market for large sawlogs. Due to the lack of nearby consumers, large sawlogs are forced to be sold to buyers over long distances, however the cost of hauling the timber is high, with the approximate cost of hauling timber to Sydney being $23 per cubic meter. Most consumers are not willing to pay such high haulage costs. This challenge also presents an opportunity, as previous calculations have shown that the sawlog option has a higher NPV, and processing these large sawlogs locally may create sufficient demand for sawlogs to help make management changes on ACT's plantations.

From the perspective of a local sawmill, the analysis shows that even though Capital Battens' current business model is the most economically efficient, the biggest challenge it now faces is its overreliance on a single product. Changes in the demand for and price of tile battens significantly affect Capital Battens' economic recovery. In addition, the manager of Capital Battens mentioned that the market for tile battens is in a downturn and that the steel battens are replacing some of the wood battens. Likewise, such challenges also bring opportunities. If Capital Battens were able to produce a wider variety of more value-added wood products, it would stabilize the company in the face of the fluctuations in the market for tile battens and return more economic benefits.

From the perspective of the ACT Government, it is clear that if local mills can process the sawlogs produced by local plantations into more high value-added wood products, this will lead to more forestry value recovery from limited forest resources, consistent with the Government's sustainability and industry development commitments.

In short, developing more high-value wood product options for the local radiata pine processing industry can increase local forestry value recovery while providing benefits to each of the key sectors of the ACT radiata pine processing value chain. So, I will explore in this section the production possibilities of two new wood products: sawn wood and plywood.

5.3.1 Sawn wood option

Sawn wood is a high value-added wood product. It generally refers to wood processed from logs, which is processed for use in construction, furniture manufacturing, decoration and other high value uses.

As sawn wood is used in the production of structural timber, it usually requires timber of a high quality. Due to the relatively low temperatures and precipitation in the Capital Region, radiata pine grows slowly and has a high timber quality, making it ideal as a raw material for sawn wood production. Sawn wood products also have the advantage of storing carbon, as they have a long service life and can store carbon dioxide for a long time.

In addition, in terms of domestic demand, the import volume of sawn wood has remained stable, reaching a historic high between 2021 and 2022. This shows that domestic demand for sawn wood has been on the rise in recent years. Demand for sawn wood is directly related to demand for new housing. Although demand for new housing is currently lower than in the post-COVID boon, it is expected that demand for sawn wood will expand in the next few years to satisfy Australia's housing shortfall, and ACT's production of sawn wood in the ACT is therefore feasible in terms of market demand.

5.3.1.1 Production line set-up

Since sawn timber is a product with fixed sizes, the sawn timber must first be dried to prevent dimensional changes in the processed sawn timber due to moisture content. Therefore, the timber must first be dried before subsequent processing. Drying needs to be carried out in a drying kiln.

The sawn wood line is relatively simple, requiring a debarker, a wood sorting line (the same machinery selection as in the previous sawmill upgrade scenario) and then adding a finger jointing line including a finger joint shaper, gluer and pressing machine. The entire process is shown in the figure below

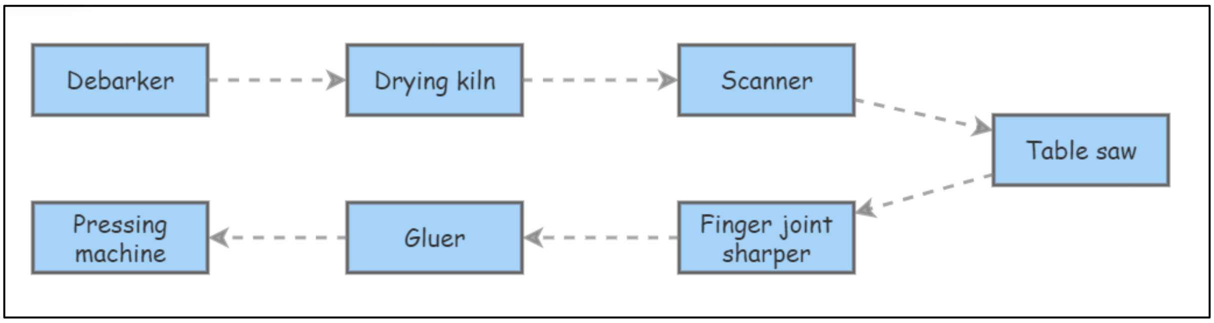

Figure 5.13: Sawn wood processing

Sawn Timber Sizes

Recommended Nominal Timber Sizes (unseasoned)

Width (mm)	Thickness (mm)									
	25	38	50	75	100	125	150	200	250	300
50	25	38	50							
75	25	38	50	75						
100	25	38	50	75	100					
125	25	38	50	75	100	125				
150	25	38	50	75	100	125	150			
175	25	38	50	75	100	125	150			
200	25	38	50	75	100	125	150	200		
225	25	38	50	75	100	125	150	200		
250	25	38	50	75	100	125	150	200	250	
300	25	38	50	75	100	125	150	200	250	300

Figure 5.14: Sawn timber sizes recommendation (Source: Timber & Building Materials Association 2019)

According to the timber specifications provided by the ACT government, the smallest end diameter of a small sawlog produced in ACT is 16 cm, the largest end diameter is 42 cm, and the length is 3.7 meters. The smallest end diameter of a large sawlog is 26 cm, the largest end diameter is 60 cm, and the shortest length is 4.9 m. In order to ensure that more sawlogs can be processed into sawlogs, I assume that the smallest end of a small sawlog is a circle with a diameter of 16 cm. Then the largest sawlog size that can be theoretically processed is the square inscribed in this circle, as shown in Figure 5.15.

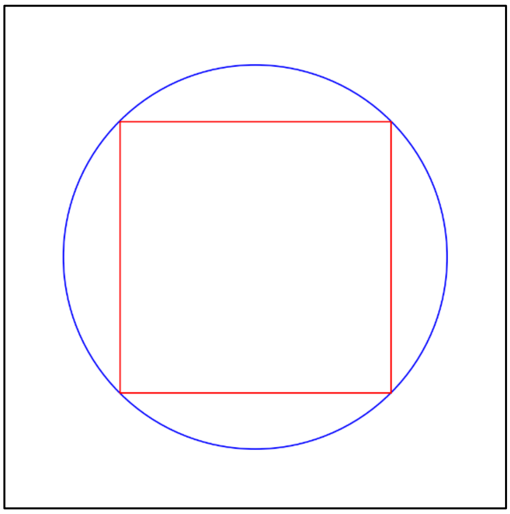

Figure 5.15: Ideal maximum sawn timber

After calculation, the length of the side of this square is 11.31 cm. In practice, due to processes such as peeling, the maximum size of the sawlog must be less than 11.31 cm. Referring to the recommended size of the sawlog in Figure 5.14 and the previous calculation results, the size of the sawlog with a thickness and width of less than or equal to 100 mm can be used as an alternative. For the length, I choose 3.6 m because this is the length of the small sawlog, which can produce the largest size of sawlog without applying finger joints as much as possible. Since the larger the dimension of the sawmill, the higher the value, also according to the recommended size of the sawn timber shown in Figure 5.14, I chose 100mm*100mm*3600mm as the size of my sawn timber production.

5.3.1.2 Baseline

- Demand assumptions

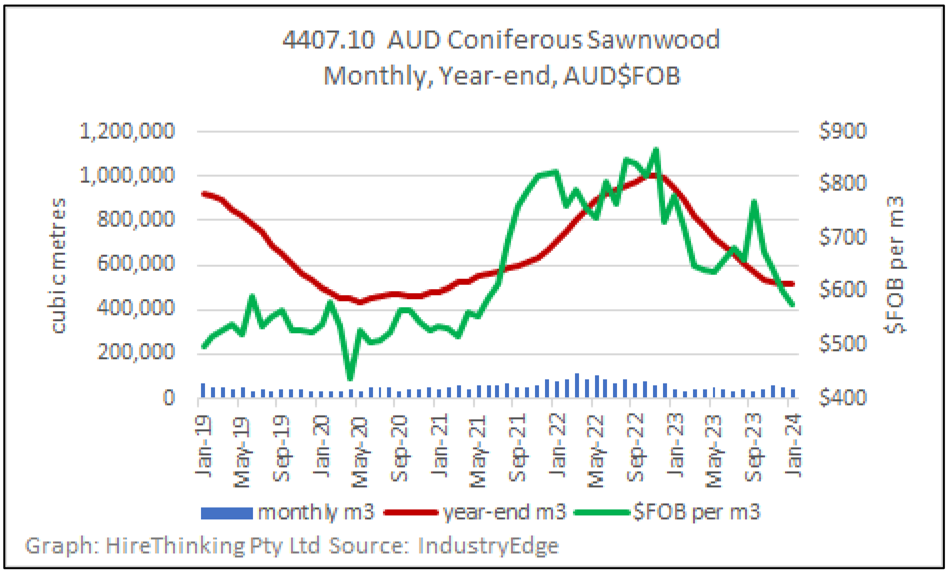

Figure 5.16: Coniferous sawnwood imports (Source: FWPA 2024)

Figure 5.16 shows the imports of coniferous sawn wood. Generally, sawn wood is imported only when domestically produced sawn wood is not able to meet the domestic market demand. Also, since imported sawn wood is not used exclusively for the market, a small portion is used for storage to cover the risk of future timber shortages. So, I assume that 80% of the imports are for market demand that cannot be met by domestic production. As can be seen in Figure 5.16, the demand for radiata pine has continued to fluctuate over the years from 2019 to 2024, and the lowest demand has been over 400,000 cubic meters. I assume that coniferous sawn wood imports 400000 cubic meters of this minimum level; after calculating the market demand in 320000 cubic meters. From recent inventory data: The softwood plantation estate is dominated by radiata pine (772,400 hectares; 74%) and southern pines (156,400 hectares; 15%), both of which are managed for sawlog production (ABARES, 2019). So, I assume that the proportion of radiata pine in the import of sawn timber is also 74%. The nationwide demand for radiata pine sawn timber is 236,800 cubic meters.

Sawmills usually process sawlogs resources produced by nearby plantations. The proportion of softwood plantations in NSW and the ACT is about 29% of the nation's total (ABARES, 2023). So, the maximum demand for sawn timber that this mill could theoretically meet is 68,672 cubic meters.

- Price assumptions

Prices also continue to fluctuate, with the lowest prices still above $400 per cubic meter, as shown in Figure 5.16. Here I have chosen a price of $400 per cubic meter, and if sufficient economic returns are guaranteed despite sawn timber being below the minimum price, then this sawn timber option must be economically feasible.

- Log intake assumptions

I assume that the mill has a sawn timber recovery rate of 50%, and based on the sawn timber demand I can calculate that the required dry sawlogs are 137,344 cubic meters. The green wood has a moisture content of 50% and the moisture content after drying in the drying kiln is 12%. This change in moisture content will result in a volume change of roughly 5%. This would calculate the volume of green sawlog to be 144,573 cubic meters.

- Drying kiln selection

Drying radiata pine from 50% moisture content to 12% moisture content typically takes 5 days. Based on the processing speed of the finger-joining line it can be calculated that a 5-day period can produce 1,680 cubic meters of sawn timber. This would require drying approximately 3,537 cubic meters of green timber. Therefore, the drying capacity of a sawmill's kiln should be greater than or equal to the amount of wood needed for production line processing during the drying cycle time.

I chose the drying kiln manufactured by Harbin Hildebrand Machinery Co., Ltd. as shown below.

Figure 5.17: LFDJ-200 drying kiln

Drying kilns price	$495,000.22
Shipping and installation cost	$10200
Total costs	$505,200.22

Table 5.26: Parameters for drying kiln

- Cutting and sorting machinery selection

Cutting and sorting lines for wood apply the following machine combinations

Figure 5.18 STR 980 laser scanner

Machinery	STR 980 laser scanner
Scanning speed	60-120m/min
Whole machine power consumption	22KW
Degree of automation	Fully automatic
Price	$196,503.53
Shipping and installation costs	$752.77
Total cost	$197,256.30

Table 5.27 Parameters of the scanner

Figure 5.19 STR MT-350 saw

Machinery	STR MT-350 saw
Feeding speed	60m/min
Whole machine power consumption	7.5KW
Price	$40,983.46
Shipping and installation costs	$752.77
Total cost	$41,736.23

Table 5.28 Parameters of the saw

- Finger-joining production machinery selection

I also chose a finger-joining line, including conveyor, finger-joining shaper (including gluing function) and jointing machine, supplied by Xiamen Strongtech Co. Since the finger-joining line and the wood sorting line use machinery from the same company, they can share a computer numerical control system. The entire production line is shown below.

Figure 5.20 STR Automatic Finger Joint production line

Machinery	STR Automatic Finger Joint production line
Feeding speed	70m/min
Whole machine power consumption	65.35kw
Price	$250,584.42
Shipping and installation costs	$2,634.70
Total cost	$253,219.12

Table 5.29 Parameters of the finger joint production line

The production speed of the production line is 70 meters per hour, the sawn timber size produced by the option is 100*100*3600mm, the output is 68,672 cubic meters, it can be calculated that a total of 1,907,556 pieces of sawn timber need to be produced which is equivalent to 6,867,201.6 meters. According to 8 hours of work per day, it takes 204 days to process these sawn timbers. The working time of a year is about 250 days, so the application of one such production line can complete the sawn wood processing of the demanded production.

- Annual costs assumptions

Costs (annual)	
1.Labour	$2,800,000
2.Energy	$1,080,000
3. Machinery maintenance	$1,272,000
4.Major business costs	$318,000
5.Transportation	$1,560,727.27
6.Log inputs	$12,378,340.26
7.New machinery depreciation	$99,741.19
Total costs	$19,508,809

Table 5.30: Annual costs for sawn wood baseline

Table 5.30 shows the annual costs assumptions for the baseline case. All cost assumptions are based on data from Capital Battens. Since the sawn wood line in the baseline case is essentially fully automated the number of workers required is reduced, however, the addition of the extra drying process makes up for these losses so labour costs are assumed to be constant.

Due to the introduction of a large number of drying equipment and high-tech automated production lines, the machinery maintenance costs are twice as high as those of Capital Battens.

The drying process is a huge energy consumer, typically more than 50% of the total energy consumption of a sawmill, while the baseline adds a lot of new woodworking machinery so I'm assuming that the energy consumption has tripled in expansion.

Transportation costs refer to the cost of transporting tile battens by truck from Capital Battens to Sydney.

The price of timber is based on the price of small sawlog sold by ACT to Capital Battens.

New machinery has an average service life of 10 years, so new machinery is depreciated over 10 years.

- NPV calculation

A. Costs (annual)	
1.Labour	$2,800,000
2.Energy	$1,080,000
3.Machinery maintenance	$1,272,000
4.Major business	$318,000
5.Transportation	$1,560,727.27
6.Log inputs	$12,378,340.26
7.New machinery depreciation	$99,741.19
Total costs	$19,508,809
B. Income	
1. Sawn wood	$27,468,800.00
Total income	$27,468,800.00
Annual cash flow	$7,959,991.28
Comparison period (years)	10
Discount rate	7%
NPV	$55,907,647.83

Table 5.31: NPV for sawn wood baseline case

Table 5.31 shows the NPV calculation process for the baseline case, and the baseline NPV result is $55,907,647.83. This is the case when the lowest sawn wood price is used. This result is greater than 0 indicating that the sawn timber production option is economically feasible.

5.3.2 Plywood option

Wood-based panels have long been one of Australia's most important imported wood products, accounting for 15% of Australia's total wood product import value. This category is also growing steadily. Among the wood-based panels Australia mainly imports plywood (accounting for 76% of the import value of wood-based panels in 2022-23), which is commonly used in structural applications in house construction. Besides, the FAO predicts that Australia's future demand for wood-based panels will grow more strongly than other product categories, and that the demand for plywood will double by 2025 (ABARES, 2024). Plywood is considered one of the wood products with the biggest shortfall in local supply in Australia.

In addition, from the perspective of wood recovery, the application of spindle-less lathes as rotary cutting machines can effectively increase the veneer recovery rate to a green recovery rate of about 79%. At the same time, the spindleless machine can theoretically process logs with a minimum diameter of 100mm and a maximum diameter of 800mm (McGavin et al., 2014), which allows both small pulplogs and large sawlogs to be rotary cut into veneer, greatly increasing the range of raw material choices, and thus being able to provide the market demand for almost every type of timber produced by ACT plantation.

Besides, China is the world's largest exporter of plywood, accounting for 56% of Australia's plywood imports by value in 2022-23(ABARES, 2024). The key to China's production success lies in the large number of small enterprises close to forest resources, each using equipment with low capital costs and relying on the supply of low-cost labor (McGavin et al., 2014). Apart from labor costs, producing plywood in the ACT has the remaining keys to success. Therefore, plywood is a possible option for the ACT's new wood products in terms of market demand, wood recovery and geographical features.

5.3.2.1 Production set-up

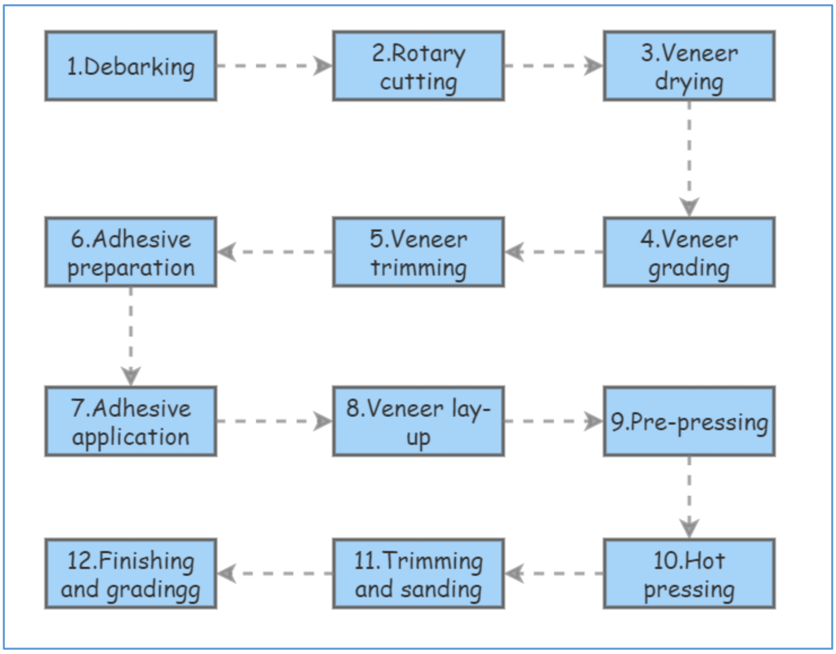

Figure 5.21 Plywood production line

Figure 5.21 shows the plywood production process, which can be simplified into four steps: rotary cutting, drying, gluing and pressing.

5.3.2.2 Baseline

- Demand and price assumptions

Similar to the sawn wood option, this option estimates market demand through plywood imports. In 2023, Australia imported a total of 384,559 cubic meters of plywood with a thickness of <6mm per layer, worth US$255669230 (A$395142675.4). It includes three different outer layer requirements which are tropical species, non-coniferous and no requirements (World Bank, 2024). Since there are entirely softwood plantations in ACT, this option produces plywood with no wood species requirement for an outer layer. Imports of this type of plywood in 2023 were 119,882 cubic meters valued at US$69,300,000.66 (A$107,043,553.02), equivalent to A$893 per cubic meter (World Bank, 2024). Again, this option applies to the same storage and local demand coefficients as sawn wood option. So, the maximum demand for plywood that this mill could theoretically meet is 27812.624 cubic meters. This option assumes a price of $893 per cubic meter.

- Log intake assumptions

Based on the experience of McGavin et al. (2020), this option assumes for sawlogs with the SEDUB of 35 cm, the green veneer conversion rate of 79%, the dried veneer conversion rate of 60%, and the finished plywood conversion rate of 50% after trimming, sanding and other operations (McGavin et al., 2020). Therefore, the required volume of sawlogs is calculated to be 92,708.74 cubic meter. According to information provided by ACT Plantations, the density of radiata pine green sawlog is 890 kg per cubic meter. The calculated required timber weight is 82,511 tons

- Annual costs assumptions

Since the production processes for plywood and LVL are very similar and use the same machinery, the only difference is in the veneer lay-up. Therefore, the average annual cost for this option is based on the assumptions in the report by McGavin et al. (2020) for a plant with an annual veneer production of 30,000 m^3. The report includes all machinery options and machinery costs required to establish a new LVL plant. This study applies the same machinery costs in the report. Maintenance costs are assumed to be only the cost of parts and are set at 5% of the total capital cost. Insurance costs are assumed to be 1.5% of the total capital cost. At the end of the project, the asset is estimated to have a salvage value of 5% (McGavin et al., 2020).

The annual average machinery cost of the green veneer production process is $552,724.

The average annual machinery cost of the veneer drying process is $882,830

The annual average machinery cost of the plywood production process is $1105448. Since production costs for plywood are slightly lower than those for LVL, this option multiplies the production cost of LVL by 80% as the production cost of plywood.

This option has a total of 7 managers and 26 workers, and the assumption of labor costs is changed based on the labour costs of Capital Battens. The final annual average labour cost is $2,920,000.

Annual energy costs are approximately $302096.

This option assumes that the plywood mill is located near Capital Battens. The annual raw material costs are based on the price of sawlogs sold by ACT Plantation to Capital Battens, and the annual haulage costs are based on the cost of Capital Battens transporting tile battens to Sydney. The timber cost is approximately $515,693,7.5 The transportation cost is about $632114. The final total annual cost is shown on the table below.

Costs (annual)	
1.Labour	$2,920,000
2.Energy	$302,096
3. Green veneer production	$552,724
4.Veneer drying	$882,830
5.Plywood production	$1,105,448
6.Transportation	$632,114
7.Log inputs	$515,693,750
Total costs	$522,088,962

Table 5.32 Annual costs for plywood baseline case

- NPV Calculation

This option still uses 10 years as the comparison period and a 7% discount rate, to be consistent with that used for sawn wood option. Transportation costs are still based on the cost of transporting tile battens from Capital Battens to Sydney. Timber prices also use the price of timber sold by ACT Plantation to Capital Battens.

A. Costs (annual)	
1.Labour	$2,920,000
2.Energy	$302,096
3.Green veneer production	$552,724
4.Veneer drying	$882,830
5.Plywood production	$1,105,448
6.Transportation	$632,114
7.Log inputs	$515,693,7.5
Total costs	$6,395,212
B. Income	
1. Plywood (volume)	$24,836,673.23
Total income	$24,836,673.23
Annual cash flow	$18,441,461.23
Comparison period	10
Discount rate	7%
NPV	$129,525,106.70

Table 5.33: NPV for plywood baseline case

The NPV calculation for the baseline case, shown in table 5.33, is $129,525,106.70. This result is not only much greater than 0 but also higher than the sawn timber option and Capital Battens' current model, which demonstrates very promising economic feasibility.

Chapter 6: Discussion

This chapter discusses the results presented in the previous two chapters, and considers the implications for the ACT plantation value chain (Figure 6.1) as a whole.

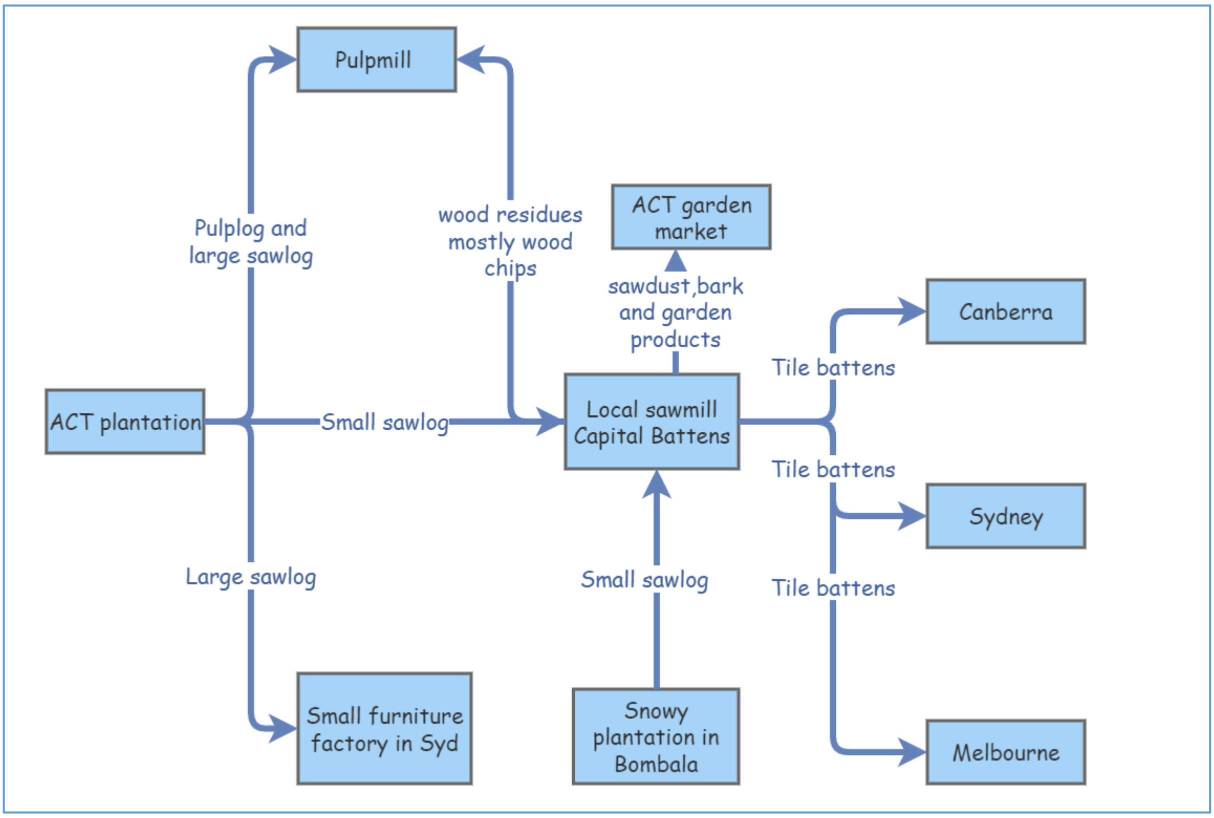

Figure 6.1: ACT plantation value chain

6.1 Review of results

6.1.1 ACT plantation resource

Plantation options	Standard discount rate 5%	Variable discount rate 5-8%
Baseline	-$201,425.97	-$201,425.97 (5%)
Pulplog option	-$616,828.84	-$713,184.30 (6%)
Small sawlog option	-$236,977.27	-$430,700.54 (6%)
Large sawlog option	-$47,202.52	-$590,605.60 (8%)

Table 6.1: NPVs for plantation management options

Table 6.1 shows the NPV results under different plantation management options. The best results among them are highlighted in red.

Under variable discount rates, the baseline case always has the best results with a variable discount rate, which suggests that the plantation maintaining the current management regime is the most appropriate option.

Plantation options	Pulplog percentage
Baseline	39.4%
Pulplog option	100.0%
Small sawlog option	38.2%
Large sawlog option	36.4%

Table 6.2: Pulplog percentage for different options

However, the highest NPV does not necessarily mean that it is the most suitable option. It is also important to pay attention to its product mix. As shown in Table 6.2, the baseline with the highest NPV also produces the highest proportion of pulplog, in addition to the pulpwood option. A high proportion of sawlog is not always a suitable option.

Firstly, the highest revenue does not mean the most suitable management regime. Relying on a single, low-value timber product can lead to increased market risk, especially when pulpwood prices fluctuate or demand declines. At the same time, managing plantations only for pulp has a significant negative impact on the local wood processing industry, as sawmills that need sawlogs must buy them from other plantations at a distance. Further, since the pulp mill is not within the ACT, the pulplog option does not benefit the ACT economy beyond the income to the plantation grower. Therefore, the options with high proportion of pulplog are contrary to the ACT government's goal of revitalizing the ACT timber industry, and less desirable than options that support greater processing in the ACT.

Secondly, the pulp and paper industry is a greater contributor to global greenhouse gas emissions than solid wood products industries. From 1961 to 2019, the net greenhouse gas emissions from paper-related industries accounted for about 4.2% of global anthropogenic greenhouse gas emissions during the same period (Dai et al., 2023). Paper not only emits a large amount of carbon dioxide during the papermaking process, but its short service life and vulnerability to decay also cause it to emit more carbon dioxide during its relatively short life cycle. Compared to pulpwood, sawlogs can store carbon dioxide more effectively. This is because sawlogs are generally processed into wood products, which have a longer service life than paper, and even if these wood products are disposed of, the process of decaying and releasing carbon dioxide is very slow compared to paper. This means that sawlogs can lock carbon dioxide in for a long time (USDA, 2022). Therefore, from the perspective of carbon storage and combating climate change, growing more sawlogs can help combat climate change, and also makes additional income opportunities in the carbon trading market available to plantation managers. The higher pulplog option is not a suitable solution for the sustainable development of plantations in the fullest sense of the concept.

Besides, this is the period of recovery of Australia's population and new housing demand after the end of the global COVID-19 pandemic (NHSAC, 2024). Australia's policymakers are therefore focused on more new houses and building materials, not paper. Sawlogs are the basis of meeting this need. Therefore, the production of sawlogs not only meets the needs of a wider market, but also enhances the market competitiveness of plantations, which is in line with current national demand trends. The higher pulplog option is divorced from the current demand in the Australian timber market.

In summary, from the perspective of wider environmental benefits, market demand and long-term strategy, the financial baseline should not be the primary consideration for the plantation management regime, from wider public policy and value chain perspectives, which governments can be expected to take, continuing to produce sawlogs is desirable.

6.1.1.1 Recommendations for plantation managers

Under the standard discount rate, this study identified a plantation management option better than the baseline, the large sawlog option. This demonstrates that changes can be made in the management of plantations if the standard discount rate can be assumed.

- Try to produce more sawlogs.

When the discount rate remains at the standard level of 5%, option 3, which produces more sawlogs, have a higher NPV than baseline. This means that if plantation management risks can be effectively controlled, growing more sawlogs is a preferred management strategy.

- Increase the proportion of small sawlog in production.

According to the slope of the three sensitivity analysis line figures, the final NPV is very sensitive to price changes in small sawlogs. Increasing the proportion of small sawlogs in production can help to achieve greater economic returns in the future when the price of small sawlogs increases. The price of small sawlogs will be affected by local processing capabilities for small sawlogs. If the future ACT sawmill can process small sawlogs into more value-added wood products, the price of small sawlogs has strong potential to rise in the future.

- Carefully consider the production of large sawlogs.

Large sawlogs have the greatest upward potential if the local sawmill can process them in the future to generate wood products with the highest added value. However, according to the results of the sensitivity analysis, it has a limited impact on the final NPV, and due to its long growth period, it will lead to a weaker ability to deal with future risks. Therefore, the production strategy for large sawlogs needs to be carefully considered.

- Pay more attention to the non-timber values of plantations.

In all cases except the large sawlog option, the final NPV is negative; and even then, the absolute value of the positive option is relatively small, suggesting that the plantation investment is unlikely to generate a sufficient economic return from harvesting timber only. Plantation managers should focus more on generating (or at least demonstrating) income from non-timber values such as carbon sinks and recreation.

6.1.1.2 Plantations in a value chain perspective

The discount rate measures the risk of future returns. If future returns are more stable, this means that the discount rate should be lower. A lower discount rate is the basis for the plantation manager's selection of sawlog options. For the plantation, the future returns of new management options depend on the sawlog market. According to the calculations in this study, there are new sawlog options that can improve the economic returns of the plantation, but the plantation manager lacks the incentive to change the management regime. This incentive does not come from within the plantation, but from the sawmills downstream in the value chain. The future sawlog market determines the demand for sawlogs, and the demand for sawlogs determines the price of sawlogs. If the local sawmill diversifies its wood products and can consume more sawlogs, it is likely to raise the price of sawlogs within the price envelope set by the wider market. Both these factors are incentives for promoting the reform of the plantation management regime. However, changes in plantation management are required to be driven based on other sectors in the value chain.

6.1.2 Processing options

Sawmill options	Current timber prices	Timber prices increased by 26.5%
Current Capital Battens	$101,126,245.36	$91,757,881.76
Updated Capital Battens	$98,510,985.81	$91,765,764.02

Table 6.3: NPVs for sawmill upgrading options

Table 6.3 shows the NPV results before and after sawmill upgrading with constant and 26.5% increase in timber prices. Higher NPV is highlighted in red. The timber price rises by 26.5% is the point at which the updated sawmill scenario starts to exceed the baseline. This means that updating the sawmill is the more economical option once the timber price rises by more than 26.5%.

Capital Battens' apparently outdated low technology, low wood recovery mill is actually the most economically feasible under the current situation. This means that high wood recovery rates do not necessarily represent high economic returns, which is a complex trade-off between investment costs and returns. Based on the results of the sensitivity analyses, final NPV depends mainly on the price of wood and the price of wood residues. If the price of wood is high (more than 22.54% increase) or the price of wood residues are low, a higher primary wood product recovery rate will result in a higher economic return. Therefore, if wood prices remain at these lower levels, Capital Battens' lower recovery rate provides the best operating return to the business.

This creates a contradiction. For Capital Battens, such a low recovery rate brings a higher financial return, and so there is no incentive to spend extra money on upgrading the mill. But from the ACT Government's perspective, the low recovery rate of the local sawmill wastes good quality timber that could be processed into higher value products.

In short, Capital Battens' lack of motivation to upgrade is due to the lower timber prices now, which means that the value of 'wasted' timber is less than the additional costs associated with purchasing new machinery.

6.1.2.1 Recommendations for Capital Battens

- Increasing wood recovery to cope with the risk of changes in wood prices

Based on the standard timber price in the Australian Radiata Pine Log Index (Chapter 6), the current timber price could increase by up to 27.6% to reach the national average. Therefore, it is prudent to increase the timber recovery rate in advance to cope with the possible increase of timber price in the future.

- Diversifying products

NPV has the highest sensitivity to the price and demand of tile battens, which suggests that changes in the price and demand of tile battens can significantly affect Capital Battens' revenue. it would be prudent for Capital Battens to diversify its products to avoid the impact on the company's income due to changes in the price of a single product.

- Pay attention to the price gap between sawlog price and wood residues

The price of wood residues also significantly affects the final NPV. This is because increasing the recovery rate will naturally reduce the volume of wood residues produced. When deciding whether to upgrade the sawmill, it is important to pay attention to the price difference between saw logs and wood residues.

6.1.2.2 Capital Battens operations from a value chain perspective

The driving force behind Capital Battens' upgrading decision is the price of timber, which in turn depends on the demand for sawlog. Plantation managers and Capital Battens are caught in an awkward equilibrium: the plantation manager needs more local sawlog markets to change the plantation management regime; Capital Battens can be expected to seek to maintain its current low timber price, but it also has to tolerate the low resilience of relying on a single wood product.

Increasing timber prices would be beneficial to the entire value chain in terms of results, with plantations earning higher incomes and Capital Battens actively upgrading its mill to improve wood recovery rates. However, Capital Battens' current business model is resistant to such changes, and external incentives are needed to encourage Capital Battens to make changes that will improve the entire value chain.

6.1.3 Wood products processing options

Wood product options	NPV based on current timber prices
Tile Battens option (CB)	$101,126,245.36
Sawn wood option	$139,729,879.37
Plywood option	$129,525,106.70

Table 6.4: NPVs for wood processing options

Table 6.4 shows the NPV results for the three wood product options explored. Both new products generate higher than Capital Battens' existing product.

These two new options are based on many assumptions, and the calculations are fully theoretical estimates with large uncertainties. However, the final NPVs are much greater than zero, so even with the large imprecision, these results suggest that it is economically feasible to develop the sawn timber and plywood options in any case.

6.1.3.1 New wood products from a value chain perspective

Greater production of high-value-added wood products is of great significance to the entire value chain. First, it increases the demand of local sawlogs, which will lead to new plantation regime, thereby incentivizing the plantation manager to choose sawlog options with higher economic returns. Second, it also increases competition for local sawlog resources, leading to higher timber prices, thereby incentivizing Capital Battens to upgrade its mill to improve wood recovery rate and reduce waste. In addition, the production of high-value-added wood products also enables ACT to create more value from its forest resources. So, ACT's new wood product options not only directly increase the value recovery from local plantation forests, but also benefit other parts of the value chain by promoting reform across the entire value chain.

6.2 Applying value chain thinking to the ACT radiata pine processing value chain

6.2.1 Strengthen communication and trust with stakeholders in different sectors

The driving force for change in each sector of the radiata pine processing value chain comes from the other sectors. Maintaining the current situation seems to be the best choice for each actor individually, but this will reduce the forest value recovery overall. The reason for this situation is partly due to the independence of each key actor. Plantation managers do not have certainty about whether the local sawmill will have a long-term demand for sawlogs, so they lack the motivation to switch to sawlog production option. At the same time, the sawmill is waiting and seeing about upgrading because the current model is more economically beneficial in the short term, and they are not actively coordinating future plans with plantation managers. A more coordinated, whole-of-industry development approach would help both the plantation manager and the sawmill, two key sectors in the value chain, understand each other's difficulties and resistance to change, thereby promoting cooperation to solve problems together.

6.2.2 Building a mindset of making the pie bigger

Traditionally, plantations and sawmills are often seen as suppliers and consumers in a linear relationship, with the connection between them being primarily through trading. However, in value chain thinking, each sector of the value chain is not an isolated supplier or consumer, but a partnership that cooperates with each other.

Plantations provide raw materials, but their management regime (such as prioritising the production of sawlog or pulplog) can affect the demand and profitability of downstream processing companies. Besides, the recovery rate and processing technology of the sawmill not only affect its own efficiency, but also directly determine the final value of the plantation timber.

This non-linear relationship means that improvements in a single sector are not enough to improve the overall value chain efficiency. All sectors should work together to increase the overall value recovery of the value chain. Each sector needs to have a mindset to make the pie bigger. Only through collaboration and joint efforts can the ‘pie’ really get bigger, so that each sector can get a bigger share of the pie, instead of a zero-sum game.

6.2.3 External interventions are important

External interventions such as government investment, policy development and technical assistance are important to transform the value chain. The current value chain is in a state of awkward equilibrium, with each sector unwilling to be the first to make changes. This awkward equilibrium comes from the lack of immediate incentives for reform in each sector, as the risks and costs of change outweigh the potential benefits in the short term. External interventions can break this deadlock by providing the necessary boost for collaborative action. For example, government investment in new plywood or sawmill factories can promote reform in plantation management and processing, thereby strengthening the entire value chain.

Chapter 7: Conclusion

This study aimed to analyze the value chain of the ACT plantation forests, with a focus on identifying opportunities and constraints to improving resilience and value recovery. Through value chain analysis and financial modeling, the study examines the economic feasibility of various plantation management options, processing upgrades, and product diversification strategies. The study provides insights into the challenges and opportunities in the value chain of the ACT plantation forests.

The study revealed many challenges in the current value chain:

1. The plantation produces a relatively high proportion of low-value pulplog and a low proportion of high-value sawlogs. There is also a lack of markets for the highest value large sawlogs.
2. The local sawmill, Capital Battens, has outdated equipment, lacks the basic equipment of a contemporary sawmill, and has a low primary wood product recovery rate (36%).
3. Only a lower value-added wood product - timber battens - is produced within the ACT.

Due to the low rainfall in the ACT region, radiata pine in the Kowen Forest grows relatively slowly, resulting in higher timber densities than in the faster-growing radiata pine plantations. This means that the sawlogs from the Kowen Forest are of higher quality and suitable for a variety of higher-value end uses. It is evident that radiata pine in the ACT has a strong potential for added value, and for developing the ACT plantation value chain.

However, the relative independence of the different parts of the value chain often leads to suboptimal results overall. Both plantation and sawmill managers logically choose the management option that is most economical for themselves in the current context, which ensures their maximum profitability but does not unlock the value recovery potential of the ACT radiata pine value chain. If new processing of high value-added wood products could be developed, this would not only directly increase the overall value recovery of the value chain but also optimize the production model in each component.

In addition, this study reveals that if the value of a chain is to be increased, it is not possible to focus only on enhancement within a particular component. Because each part of the value chain interacts with each other, changes in a single component – for example, the plantation or the sawmill – cannot bring the expected benefits without synchronized changes in other sectors. Enhancing communication, building trust, and constructing a community of interest are the prerequisites for improving a value chain, and only by systematically optimizing the chain as a whole will each sector be able to share more of the rewards.

The operation of the value chain is a dynamic process, and changes in some key parameters such as demand and price can significantly affect the overall value chain. Therefore, sensitivity analysis is required to identify the parameters that have the greatest impact on the value chain. Each sector needs to pay close attention to changes in these parameters and actively improve management models to cope with future uncertainties.

However, this study also faced some limitations. First, the establishment of a new factory make many assumptions, each of which can be challenged. For example, in the selection of machinery, only by providing the exact dimensions of the product can machinery sellers provide an accurate quotation. Since the hypothetical new product has not been produced in ACT in recent years, market demand can only be obtained through prediction. The accumulation of these errors can lead to a large difference between the idealized assumption and actual operation. In theoretical analysis, as long as the NPV is greater than zero, it demonstrates that investment is reasonable. However, in the actual investment process, decision-makers consider more than just predicted theoretical values. This study can only be used as a reference for policymakers and investment decision-makers and cannot be used as a guide in any more specifc sense.

Further, this study explores the limited selection of new wood products. Follow-up studies could attempt to develop engineered wood products with the highest added value or attempt to utilize wood residues such as wood chips and sawdust to produce other types of wood-based panels such as particleboard and fibreboard.

In short, this study provides a basis for policy decisions and business investments in the ACT radiata pine value chain. It highlights the potential for change by integrating value chain thinking, adopting advanced technologies and aligning production strategies with market needs. These steps are essential to enhance the resilience and sustainability of the ACT plantation forests and help to prosper the forest bioeconomy.

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