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造林木生產之成本效益分析

Cost benefit analysis of production for plantation forests

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中文摘要

臺灣森林面積占全島面積 60.71 %，若能好好妥善利用森林除了可以減緩氣候變遷並振興森林產業。然而，長期的觀念導致森林利用相關知識非常式微，甚至反對砍伐森林去做更進一步的利用。因此，為了能夠讓大眾了解永續森林管理需要一個量化的績效去吸引大眾的目光。產量最多的木材分別為柳杉、杉木（即福杉）以及臺灣杉，分別佔總產量的 47.76、17.34 以及 7.82 %。本研究以模擬這三種樹種進行加工成規格材、木顆粒以及萃取抽出物的成本效益評估，觀察臺灣森林產業的發展可行性。

在分析中資料利用文獻、政府統計數據及市場價值等來源進行評估，並藉由淨現值(NPV)、內部報酬率(IRR)、修正後內部報酬率(MIRR)、還本期間(PP)、折現還本期間(DPP)等共 5 種方法評估假設狀況能否進行投資，再透過營業槓桿(OL)評估營業風險，最後藉由生命週期成本(LCC)建議成本改善。

分析表明規格材與精油萃取製程兩者相配合是適合臺灣林業發展的模式，不管收穫量為多少且木材利用率為 33 % - 53 % 時，能創造利潤。精油萃取製程的 OL 相較於規格材小很多，但兩者都能夠穩定獲利。規格材的損益木材利用率為 33 %，最低銷售價格為 NT$ 11,599；精油則是 53 % 以及 NT$ 19。木顆粒製程由於無法透過提高售價去吸引投資者，因此需要調整運送、人力與電力成本。規格材的主要步驟成本為鋸木、乾燥以及加工，而精油萃取製程為包裝、蒸餾以及冷卻和分離，將這些成本改善有助於創造利潤。

關鍵詞：杉木、臺灣杉、日本柳杉、規格材、木顆粒、精油、成本效益分析、生命週期成本

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Abstract

The forest area in Taiwan constitutes 60.71% of the entire island. Properly utilizing these forests can help mitigate climate change and revitalize the forest industry. However, long-standing perceptions have led to a significant decline in knowledge related to forest utilization, and there is even opposition to felling trees for further use. Therefore, to make the public understand sustainable forest management, it is necessary to have a quantified performance metric to attract public attention. The most productive timber species are Japanese cedar, cypress (also known as Chian fir), and Taiwania, accounting for 47.76%, 17.34%, and 7.82% of the total output, respectively. This study simulates the cost-benefit assessment of processing these three tree species into lumber, wood pellets, and extracted products to observe the feasibility of developing Taiwan's forest industry.

In the analysis, data from literature, government statistics, and market values were used for evaluation. The feasibility of investment under hypothetical conditions was assessed using five methods: Net Present Value (NPV), Internal Rate of Return (IRR), Modified Internal Rate of Return (MIRR), Payback Period (PP), and Discounted Payback Period (DPP). Operational risks were then evaluated through Operating Leverage (OL), and finally, Life Cycle Cost (LCC) was used to suggest cost improvements.

doi:10.6342/NTU202403839

The analysis indicates that the combination of lumber and essential oil extraction processes is suitable for the development of Taiwan's forestry industry. Profits can be generated regardless of the harvest volume and when the wood utilization rate is between 33% and 53%. The OL of the essential oil extraction process is much lower than that of lumber, but both can achieve stable profitability. The breakeven wood utilization rate for lumber is 33%, with a minimum selling price of NT$ 11,599; for essential oils, it is 53% and NT$ 19. Due to the inability of the wood pellet process to attract investors through price increases, adjustments in transportation, labor, and electricity costs are necessary. The main cost steps for lumber are sawing, drying, and processing, while for essential oil extraction, they are packaging, distillation, and cooling and separation. Improving these costs can help create profits.

Keywords: *Cunnunghamia lanceolata*, *Cryptomeria japonica*, *Taiwania cryptomerioides*, dimensional lumber, wood pellet, essential oil, cost benefit analysis and life cycle cost

doi:10.6342/NTU202403839

Table of Contents

doi:10.6342/NTU202403839

doi:10.6342/NTU202403839

Lists of Tables

Lists of Figures

doi:10.6342/NTU202403839

Lists of Appendixes

doi:10.6342/NTU202403839

1. Introduction

Since the 2015 Paris Agreement, countries have responded to the United Nations climate agreement by researching and finding ways to replace products that have larger emissions of greenhouse gases (GHG), such as oil, in daily life, with the goal of reducing the global average temperature by 2°C. According to the 2023 Sixth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC), global warming is expected to exceed 1.5°C between 2021 and 2040, even under the scenario of the lowest greenhouse gas emissions, and future warming is difficult to limit to below 2°C. To achieve the goal of keeping the temperature rise below 2°C by 2050, a faster, immediate, and significantly effective approach to reduce greenhouse gas emissions is required.

To achieve the goals of the Paris Agreement and address the severity of the global warming issue, the United Nations Framework Convention on Climate Change (UNFCCC) launched the Climate Neutral Now initiative in 2015. The purpose of this initiative is to strengthen the willingness of governments, companies, and even individuals to take climate action and to promote the use of convention-recognized carbon market mechanisms to achieve climate neutrality by 2050. In addition to the initiative, the UN also established the United Nations Carbon Offset Platform to help

doi:10.6342/NTU202403839

voluntary carbon reducers (including governments, businesses, and individuals) purchase carbon credits to offset GHG emissions or contribute to climate action. The United Nations Carbon Offset Platform is also an educational platform where users can learn about carbon offset certification and access expert teams to address their queries.

To achieve a climate-neutral continent by 2050 and decouple economic growth from resource use, the European Commission formulated the Green Deal in 2020. This is a very long-term goal, and to better implement this policy, phased targets were set for 2030, 2040, and 2050. The EU's target for 2030 is to reduce GHG emissions by at least 55%; for 2040, the goal is to reduce emissions by at least 90%, with a strong focus on the development of carbon capture, storage, and utilization technologies; and by 2050, the aim is to achieve a climate-neutral economy. To achieve these phased targets, sub-goals have been set, such as zero emissions for new cars by 2035, achieving 42.5% renewable energy generation capacity and 11.7% energy efficiency, promoting industrial development through the Green Deal Industrial Plan, providing economic development opportunities, and the 2030 Biodiversity Strategy. Additionally, to prevent carbon leakage (i.e., the production of high-GHG-emission products in countries with weaker climate regulations being imported), the Carbon Border Adjustment Mechanism (CBAM) was established. Furthermore, high-GHG-emission enterprises in the EU, such as those in the oil and electricity sectors, must pay carbon taxes or

doi:10.6342/NTU202403839

purchase allowances to offset carbon taxes for emissions exceeding free quotas. According to Enerdata (2023), the POLES-Enerdata model calculates future projected carbon prices and design issues for the EU ETS. The results indicate that by 2030, the carbon price will be € 70 / tCO_2; by 2040, it will rise to € 130 / tCO_2, and increasing allowances will be necessary to stabilize carbon prices.

In 2018, Japan formulated the Climate Change Adaptation Act and promoted the Climate Change Adaptation Plan, aiming to address the impacts of climate change in seven major areas over the next five years: agriculture, forestry and fisheries, natural disasters, water resources and environment, natural ecosystems, health, economic activities and industries, and urban life and national health. Additionally, Japan integrated the Credit and J-VER systems to form the J-Credit system, which certifies GHG emission reductions and absorption amounts through renewable energy and forest management. This system allows participants to invigorate the economy, reduce tax burdens, and voluntarily respond to energy conservation and carbon reduction, thereby deepening the public's relationship with the global warming crisis.

As of today, the J-Credit system has registered 1,081 projects, with certified GHG emission reductions and absorption amounts reaching as high as 9.36 million t-CO_2. Of these, wood pellets and forest management activities account for 1.479 million and 340,000 t-CO_2, respectively (J-クレジット制度事務局, 2024).

doi:10.6342/NTU202403839

In 2002, the New Zealand government introduced the Climate Change Response Act and in 2019, it proposed the Climate Change Response (Zero Carbon) Amendment Act. This amendment not only intensifies efforts to reduce GHG emissions but also establishes a clear and stable policy framework for addressing climate change. Its aim is to reduce net GHG emissions (excluding biogenic methane) to zero by 2050 and to reduce biogenic methane emissions by 24-27% compared to 2017 levels, to limit global warming to no more than 1.5°C above pre-industrial levels.

Taiwan, not to be outdone, introduced the Greenhouse Gas Reduction and Management Act in 2015 and has since put forward a Climate Change Adaptation Action Plan every five years starting in 2013. Between 2018 and 2022, the Greenhouse Gas Reduction and Management Act was renamed the Climate Change Response Act, and other laws such as the Agricultural Insurance Act and the Coastal Management Act were introduced. In terms of finance and economics, Taiwan encourages the development of green insurance, the issuance of green bonds, and the cultivation of sustainability-related talent. Furthermore, Taiwan continues to research climate change issues and uses technology to analyze and prevent the impacts of climate change. However, the National Climate Change Adaptation Action Plan for 2023-2026 (Ministry of Environment, 2023) points out many shortcomings from past efforts, such as unclear definitions of adaptation issues and critical topics, leading to poor implementation

doi:10.6342/NTU202403839

results. Therefore, in addition to continuing the previous plans, many new initiatives have been added for the 2023-2026 period to better monitor and mitigate the impacts of climate change.

Forest area in Taiwan accounts for 60.71% of the island's total area (Forestry and Nature Conservation Agency, 2020). Proper utilization of forests can mitigate climate change and revitalize the forestry industry (Lin and Ge, 2020). Additionally, it can reduce erosion, prevent forest fires, improve soil, water quality, and air quality, and enhance biodiversity. However, there are drawbacks such as reduced water supply, increased human-wildlife conflicts, and decreased food production (Whitehead, 2011; Ebissa *et al*., 2023). Nevertheless, simply planting trees is not enough to effectively mitigate climate change and boost the industry. It requires a systematic and efficient forest management approach to achieve these benefits. The primary goal of forest management is to maximize carbon benefits (Raymer *et al*., 2011). However, focusing too much on carbon-related issues can hinder the achievement of other goals and lead to an unstable carbon market, low and unfair carbon prices, and non-permanent carbon sequestration (D'amato *et al*., 2011; Todd *et al*., 2020; Ebissa *et al*., 2023).

Afforestation can significantly increase carbon sequestration, and products derived from harvested forests can also help mitigate climate change. If forest products are used to replace energy-intensive products as part of climate action, attention must

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be paid to carbon substitution rates, cross-sectoral carbon leakage, the use of long-lived products, and the utilization of bio-based materials (Harmon, 2019; Yoshimoto *et al*., 2018). Coniferous wood, in particular, can effectively replace energy-intensive products (Lippke *et al*., 2011). However, the long-standing concept of forest conservation has led to a significant decline in knowledge related to forest utilization, with most people even opposing the felling of forests for further use. Therefore, to help more investors and the public understand sustainable forest management, including afforestation and the reuse of harvested wood, there is a need for quantifiable performance metrics and continuous tracking of the carbon impact during the processing stages to attract public attention (Lippke *et al*., 2011).

Liu *et al*. (2023) studied the potential of using forest carbon sequestration and carbon offset market mechanisms in Taiwan to achieve carbon neutrality by 2050. They concluded that relying solely on forest carbon sequestration is insufficient to achieve carbon neutrality. While it can help reduce the wealth gap, there is still a need to increase renewable energy usage and reduce the proportion of high-pollution energy sources. According to forestry statistics from the Forestry Bureau (2023), the most produced types of timber are Japanese cedar, China fir, and Taiwania, accounting for 47.76%, 17.34%, and 7.82% of total production, respectively.

This study conducted a cost-benefit analysis of processing these three tree species into

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dimensional lumber, wood pellets, and extractives, to assess the feasibility of developing Taiwan's forest industry.

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2. Literature Review

2.1 *Cunninghamia lanceolata* (Lamb.) Hook

Cunninghamia lanceolata, also known as China fir, Fuzhou fir, is an evergreen conifer species primarily distributed in China, Taiwan, northern Vietnam, and Laos. In China, the cultivation of China fir has a history of over a thousand years and is one of the country's major economic forest trees. During the former Qing Dynasty period, Taiwan's forest industry development focused on camphor and camphorwood. As a result, high-quality construction materials for temples and luxury residences were imported from Fujian Province, including China fir (Chuko, 2003). In the early Japanese colonial period, the government promoted the planting of China fir to exchange for high-value forest products such as cypress and camphor. However, after the decline of camphor forestry, the planting of China fir grew. After Taiwan's retrocession, there were three significant waves of China fir planting, but its cultivation gradually declined due to competition from other high-value agricultural products like tea (Jen, 1994).

Past planting experiences have led to the belief that China fir cannot be sustainably managed. However, traditional practices such as continuous cultivation, monoculture

doi:10.6342/NTU202403839

planting, and slash-and-burn farming have caused the loss of soil nutrients and organic matter, leading to decreased productivity of China fir with repeated planting (Faroo *et al.*, 2019; Zhang *et al.*, 2004). If other forest management methods more aligned with sustainable forestry are adopted, China fir can demonstrate its characteristic of rapid growth. Additionally, compared to other tree species, China fir can quickly grow and establish vegetation in cadmium-contaminated soil (concentration of 50 mg/kg) (Dai *et al.*, 2024).

Due to its excellent mechanical properties, low shrinkage rate, and durability, China fir is well-suited for use as furniture and structural engineering products (Balboni *et al.*, 2022). Additionally, its low density, low lignin content, high holocellulose content, and excellent papermaking properties make it suitable for pulp and paper production, in addition to traditional uses in furniture and construction (Vivian *et al.*, 2021). Xing *et al.* (2005) conducted decay and field tests on China fir, indicating that it is classified as slightly durable wood (mass loss of 34%) and exhibits moderate resistance to termites. However, China fir grown in New Zealand has a lower basic density compared to those grown in China and Taiwan. Despite its consistent shrinkage rate, inherent dimensional stability, ease of drying, and durability, it is less suitable for use as structural engineering timber (Fung, 1993).

The aromatic components of China fir (Fuzhou fir) include cedrol, α-terpineol, and

doi:10.6342/NTU202403839

camphor (Schmidt *et al*., 2016). However, Wang *et al*. (2006) identified the essential oils of China fir as β-cedrene, α-pinene, and limonene, suggesting that the chemical composition may vary depending on the region where the trees are grown.

Cedrol is a sesquiterpene compound commonly found in cedar and cypress trees, characterized by a distinctive woody and sweet scent. It has relaxing properties (Komori *et al*., 2016; Dayawansa et al., 2003) and shows positive effects on sleep disorders in Alzheimer's patients (Takeda *et al*., 2017). α-terpineol is a monoterpene alcohol found in pine, cypress, and eucalyptus trees. It has a sweet lilac fragrance and offers calming, antihypertensive, and insecticidal properties against Formosan subterranean termites (Khaleel *et al*., 2018). Camphor, a monoterpene ketone, is most commonly found in camphor trees and has a very strong odor. It inhibits various bacteria and fungi, has antiviral activity against herpes simplex virus (HSV-1, etc.), and possesses antitussive, analgesic, and insecticidal properties (Chen *et al*., 2013). However, it is important to note that camphor is biologically toxic, and excessive exposure can lead to coma or even death.

The main component of the heartwood of China fir is cedrol (Su *et al*., 2012; Wang *et al*., 2011; Shieh and Sumimoto, 1992), accounting for about 19.10% to 60.50%. This significant difference might be due to the varying precision levels of the equipment used. The primary component of the leaves and cones is ferruginol, making up 10% to

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15.1% (Hsu *et al*., 2020; Su *et al.*, 2018). Cedrol exhibits cytotoxic and antibacterial activities against lung cancer, liver cancer, oral cancer cells, Gram-positive bacteria, and yeast. Compounds like ι-cadinol, α-cadinol, and ferruginol show excellent resistance against plant pathogenic fungi. Additionally, purified essential oils obtained through steam distillation, particularly α-terpineol, demonstrate strong resistance to European house dust mites, American house dust mites, and tropical house dust mites (Hsieh and Wu, 2007). Qualitative analysis of alcohol plant extract from China fir indicates a rich presence of proteins, flavonoids, and phenols (Jyoti *et al*., 2018). Flavonoids such as sciadopitysin and amentoflavone have anti-inflammatory and analgesic effects, and their mechanism is related to prostaglandin synthesis (Xin *et al.*, 2012).

There is a highly valuable variant of China fir known as red-heart China fir. Wen *et al*. (2018) indicated that its color and mechanical properties improve with the tree's age, making the mechanical performance of red-heart China fir superior to that of ordinary China fir. In China, a famous production area for red-heart China fir is Chenshan, a region known for its iron mines. However, the relationship between the iron mines and the formation of red-heart China fir remains unclear. Future research should delve into the formation, chemical composition, genetic characteristics, and potential environmental factors of red-heart China fir.

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2.2 *Cryptomeria japonica*

Cryptomeria japonica, known as japanese cedar and Sugi (すき) in Japan, is a species native to Japan. During the Japanese colonial period, to export Taiwan's cypress wood to Japan, Japanese cedar was introduced and planted in Taiwan to serve as a local building material. Today, it is mainly distributed in the central and northern mountainous regions in Taiwan, at elevations ranging from 1,000 to 2,500 meters, preferring moist and well-drained environments.

Japanese cedar can grow to over 50 meters tall, exhibiting a reddish-brown color and developing deep fissures with age. It possesses excellent corrosion resistance and durability, making it a popular choice for construction materials. Additionally, its fast growth rate has made it one of Taiwan's important economic forest products. The wood color ranges from pink to rose, but its value significantly decreases under the combined effects of light, oxygen, and exposure to wavelengths above 600 nm (Chang *et al*., 2000).

The aromatic components of Japanese cedar include 3-carene, p-cymene, and limonene (Wang *et al*., 2006). 3-carene is a natural monoterpene commonly found in pine essential oil, characterized by a sweet pine and slight lemony, spicy scent. It exhibits antibacterial activity against Pseudomonas fluorescens, which can delay the

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spoilage of meat (Tang *et al*., 2022). *p*-cymene is also a natural monoterpene found in thyme, rosemary, and peppermint, with a light citrusy and spicy aroma. It has analgesic and antibacterial effects by modulating inflammatory mediators (Balabob *et al*., 2021). Limonene is commonly found in citrus plants, especially lemon peel, and has a fresh, sweet citrus scent. It shows antitumor activity in lung, pancreatic, and breast cancers by upregulating Bax protein, releasing cytochrome c, and activating caspase-3 and caspase-9 to induce apoptosis (Mukhtar *et al*., 2018). Additionally, limonene reduces TRP-2, preventing it from catalyzing the formation of DHICA from dopaquinone, thereby inhibiting melanogenesis (Yang *et al*., 2023).

The main components of Japanese cedar wood are γ-cadinene and δ-cadinene; its branches contain α-eudesmol and δ-cadinene; the bark contains ferruginol and phyllocladanol; and the leaves contain β-elemol and ent-kaur-16-ene (Cheng *et al*., 2006; Chang *et al*., 2005). The ethanol extract of Japanese cedar has antibacterial activity against two Fusarium species and Ralstonia solanacearum. Additionally, five diterpenoid compounds, including ferruginol, exhibit strong antifungal activity, likely due to the cumulative effect of these diterpenoids. The methanol and hot water extracts of Japanese cedar leaves are rich in flavonoids and lignans, providing high antioxidant capacity. Ferruginol can also be used as a natural antioxidant, and its phenolic metabolite, sugiol, can inhibit the formation of reactive oxygen species. Furthermore,

doi:10.6342/NTU202403839

extracts of Japanese cedar have anti-inflammatory activity. Ferruginol and sugiol not only provide antioxidant benefits but also exhibit significant anti-inflammatory properties (Lima *et al*., 2023). Therefore, the essential oil of Japanese cedar can be applied in medicine, cosmetics, and agriculture to create natural, environmentally friendly products that are safe for the environment.

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2.3 *Taiwania cryptomerioides*

Taiwania cryptomerioides, also known as Taiwan fir or Taiwania, is a conifer species endemic to Taiwan and belongs to the Cupressaceae family. It was first described by Japanese botanist Bunzo Hayata in 1906 and named Taiwania cryptomerioides. Taiwania is widely distributed in the central mountain ranges of Taiwan, such as the Central Mountain Range and the Yushan Mountain Range, at altitudes between 1,500 and 2,400 meters. Its distribution is sparse, but it grows well on non-sunny slopes.

Taiwania is an evergreen conifer that can grow up to 60 meters tall with a trunk diameter of up to 3 meters. The bark is reddish-brown and forms deep vertical fissures, turning dark brown with age. The heartwood color ranges from light yellow to reddish-brown with purplish-red streaks. Due to its excellent resistance to decay and durability, it is often used for construction and furniture, but it has become an endangered species with limited natural forests. However, thanks to the efforts of the Forestry Bureau, there are some plantations that can support the development of the national forestry industry.

The main aromatic components of Taiwania are β-cedrene, δ-cadinene, and widdrene (Wang *et al*., 2006). β-cedrene is a sesquiterpene with a rich, slightly sweet, balsamic woody aroma commonly found in conifers. It is a potent inhibitor of human CYP2B6,

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preventing the metabolism of substances like nicotine and aiding in smoking cessation treatments (Jeong *et al*., 2014). δ-cadinene is a bicyclic sesquiterpene present in cinnamon, rose, and chamomile, with a strong spicy, woody, and slightly earthy, smoky scent. It exhibits antiproliferative effects on human ovarian cancer cells (OVCAR-3) by inducing apoptosis (Hui *et al*., 2015) and inhibits Streptococcus pneumoniae, preventing respiratory infections (Ferreira *et al*., 2024). Widdrene, also known as thujopsene, is a sesquiterpene with a unique woody and resinous aroma, found in cedar and other conifers. Although not inherently bioactive against termites and fungi, it can transform through autoxidation to exhibit antifungal and anti-termite properties (Mukai *et al*., 2019). It also inhibits IgE-mediated allergic diseases like asthma (Kim *et al*., 2013).

Research by Cheng *et al*. (2010) on the essential oils from different parts of Taiwania found the main components of the heartwood to be α-cadinol, t-muurolo, cedrol, and t-cadinol; the sapwood contains ferruginol, α-cadinol, and t-muurolol; the bark contains ferruginol and manoyl oxide; and the leaves contain α-pinene, limonene, t-cadinol, and caryophyllene oxide. However, Su *et al*. (2006) indicated that the main components were limonene, α-pinene, and caryophyllene oxide, with limonene comprising up to 44.5%.

The essential oils of Taiwania, containing α-cadinol, ferruginol, sugiol, and cedrol,

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exhibit antifungal activity (Chang *et al*., 2003). Essential oils extracted with n-hexane also show antifungal properties, with α-cadinol, ι-cadinol, and t-muurolol among the active compounds (Wu, 2005). Besides antifungal activity, Taiwania essential oils are toxic to termites and dust mites. Notably, α-cadinol has a termite mortality rate of 100% (Chang *et al*., 2001), and cedrol achieves a 100% dust mite mortality rate within 48 hours (Chang *et al*., 2003). Taiwania essential oil contains a unique lignan, taiwanin A, which has anticancer activity against A-549 lung cancer cells, MCF-7 breast cancer cells, and HT-2 colon cancer cells by inducing apoptosis through disruption of mitochondrial membrane permeability and activation of caspase-9 (Ho, 2007).

doi:10.6342/NTU202403839

2.4 Wood Pellets

Wood pellets, a type of biomass pellet, have gained increasing attention in the context of energy shortages and the growing need for environmental protection. The earliest wood pellets were made from sawdust and other wood processing residues. With the post-war increase in energy demand, the development and technology of wood pellets gradually matured. During the oil crisis, wood pellets, known for their environmental friendliness and renewability, began to be produced and applied on a large scale by various countries, improving their quality and combustion efficiency. Today, countries like Europe, the United States, and Canada are major producers of wood pellets and have developed comprehensive standards such as ENplus, ISO 17225-2, DINplus, and CAN/CSA-ISO 17225-2. These standards regulate the quality, moisture content, ash content, and pellet size. Policies such as the European Union's Renewable Energy Directive (RED II) and Germany's Erneuerbare-Energien-Gesetz (EEG) promote wood pellets as part of renewable energy. However, despite policy promotion, wood pellets have not widely replaced traditional fuels among the general public and businesses. To encourage their use, several countries have implemented incentive measures. Sweden offers tax incentives for residential and industrial renewable energy use. The United States provides additional subsidies and low-interest

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loans alongside tax benefits. Japan guarantees stable electricity prices for wood pellet power generation, providing a more secure market. South Korea has established Renewable Portfolio Standards (RPS), requiring large power companies to use a certain proportion of renewable energy, including wood pellets, and offers financial support to promote renewable energy use. Compared to fossil fuels, wood fuel produces fewer greenhouse gases, promotes local economic development, creates job opportunities, and is considered a carbon-neutral source. However, opponents argue that it could damage forest ecosystems, affect traditional wood markets, and that particulate emissions from burning wood pellets may pose health risks (Mittlefehldt, 2016). Liu (2018) studied the impact of replacing coal with residual biomass. Biomass fuel can reduce environmental impacts by 46-76%, lower SOX concentrations, and significantly reduce social costs, though it may affect ecological quality. Overall, these policies and subsidies have facilitated the development and application of wood pellets worldwide, contributing to mitigating climate change, with benefits far outweighing the drawbacks.

Stele *et al*. (2011) and Castellano *et al*. (2015) studied the strength and quality of pellets made from coniferous and broadleaf tree species as well as herbaceous plants. They found that pellets from coniferous and broadleaf trees exhibit significantly higher mechanical durability compared to those from herbaceous plants. This is due to the presence of a waxy layer and high concentrations of hydrophobic extractives on the

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surface of herbaceous plants, creating a weak chemical boundary layer that limits strong bonds between pellets to van der Waals forces. The thermoplastic behavior of lignin is particularly beneficial for pellet formation, aiding in the establishment of strong bonds and a higher energy absorption destruction mechanism, resulting in greater mechanical durability. Frodeson *et al*. (2018) utilized 21 materials, including cellulose, hemicellulose, lignin, proteins, extractives, and wood, to produce biomass pellets and study the pelleting process. During the pressing process, surfaces rich in hydroxyl groups are compressed together, forming multiple hydrogen bonds and van der Waals forces. Following dehydration and polymerization reactions, these hydroxyl-rich surfaces can form covalent bonds such as esters or acetals, leading to surface crosslinking.

Huang *et al*. (2017) studied the impact of moisture on the bonding mechanisms in pellets made from birch, reed, and spruce, finding that pellet density increases with pressure but reaches a peak as moisture content rises before decreasing. Compression strength, however, increases with moisture content. The primary factor affecting pellet density and compression strength is the moisture content of the raw material (Samuelsson *et al*., 2012). Besides moisture content, pellet size and pelletizing temperature also influence production efficiency and quality (Nielsen et al., 2009; Nguyen *et al*., 2015; Rudolfsson *et al*., 2015; Lisowski *et al*., 2019). However, Nguyen

doi:10.6342/NTU202403839

et al. (2015) and Huang *et al*. (2017) differed slightly, with Nguyen *et al*. (2015) identifying temperature as the main factor affecting compression strength, while Lisowski *et al*. (2019) noted that die thickness also impacts pellet density and strength. The addition of binders can also affect pellet quality, compression work, and the characteristics of the wood pellets. Lignosulfonates can improve durability and strength but increase ash and sulfur content, preventing the pellets from meeting minimum standards (Monedero *et al*., 2015). Muazu and Stegemann (2017) added microalgae and biosolid binders to biomass pellets, finding that microalgae significantly enhance density and strength while improving combustion characteristics. Hosseinizand *et al*. (2018) added spirulina to pine sawdust, noting that protein denaturation and starch gelatinization from spirulina improved pellet bonding strength, creating a more compact structure. Additionally, spirulina reduced energy consumption, improved storage stability, increased pellet calorific value, and enhanced ash content. These studies demonstrate that environmentally friendly and effective additives/adhesive not only enhance biomass pellet properties but also have a significant impact on mitigating climate change.

Crawford *et al*. (2015) studied the mixing characteristics of pure and mixed biomass raw materials and developed a model to assess the pressure required for biomass pelletization, predicting whether a material is suitable for pelletization. The

doi:10.6342/NTU202403839

formula is as follows:

$$P_P = P_C exp\left(\frac{4\mu_\omega \kappa L}{D}\right) \quad \text{equation (1)}$$

P_P is the total granulation pressure, P_C is the pressure required to compress loose biomass to the desired particle density, μ_ω is the wall friction coefficient, κ is the ratio constant of radial to axial stress (usually denoted as λ, L is the length of the granulation mold, and D is the diameter of the granulation mold. This model can assess the granulation suitability of raw materials based on their compressibility, flowability, and wall friction without the need to granulate the materials. The total granulation pressure for pure materials ranges from 50 to 1700 MPa, and for mixed materials, it ranges from 145 to 270 MPa.

In addition to using wood waste, sawdust, and traditional agricultural waste such as straw for making wood pellets, Jiang *et al*. (2016) utilized cedar, camphor, and straw mixed with urban sludge to produce biomass pellets. The study indicated that compared to pure biomass pellets, the pellets mixed with urban sludge had higher hardness, excellent combustion characteristics, stable combustion process, and required significantly less extrusion and compression energy compared to pure biomass pellets. Rivera-Tenorio and Moya (2020) used Canadian construction wood waste to produce wood pellets. Even though the moisture content and ash levels of the resulting wood pellets were much higher than those of standard wood pellets, they still met the standard

doi:10.6342/NTU202403839

specifications and were suitable for use in power plants or drying kilns.

During storage, wood pellets can self-heat, causing fires, further oxidation leading to greenhouse gas emissions, the production of harmful gases to humans, and dust problems, especially in poorly ventilated areas (He *et al.*, 2014). To address these issues, many scholars have explored various methods such as adding additives or extraction. In wood pellets, extractives act as plasticizers and lubricants during the compression process, reducing the energy consumption and friction required for compression and affecting pellet strength (Nielsen *et al*., 2009; Nilsen *et al*., 2010). However, they are also the main cause of spontaneous combustion and the emission of harmful gases. During storage, oxidation and polymerization reactions cause the concentration of low-molecular-weight fatty acids and diterpenes to decrease over time, while the concentration of triterpenes and sterols increases as they migrate from the interior to the exterior of the wood (Nielsen *et al*., 2009). The oxidation of unsaturated fatty acids and other chemically unstable triglycerides in extractives causes carbon oxides to spill during storage, regardless of the presence of oxygen, while methane is produced under anaerobic conditions (Siwale *et al*., 2022). Using raw materials without extractives can reduce the gas emissions from the pellets (Siwale *et al*., 2022). For example, Liu *et al*. (2020) improved pellet density and combustion performance through Soxhlet extraction, and Attard *et al*. (2016) reduced greenhouse gas emissions and improved

doi:10.6342/NTU202403839

storage stability through supercritical extraction methods. There are many types of additives, some of which can increase density, strength, and combustion performance while reducing ash and environmental pollution, such as linear low-density polyethylene (LLDPE) (Emadi *et al*., 2017). Others can enhance pellet durability and combustion efficiency, such as Indulin AT (Stevens and Gardner, 2010). However, to address the issues of spontaneous combustion and emissions, antioxidant additives are required. Antioxidant additives such as acetylsalicylic acid can eliminate free radicals produced by the oxidation of wood pellet extractives, addressing self-heating and the generation of harmful gases (Sedlmayer *et al*., 2020). Waste glycerol can increase pellet value and reduce NOx emissions (Bala-Litwiniak and Radomiak, 2019). Corn starch and molasses can significantly reduce GHG emissions, improve pellet durability, and reduce waste, with corn starch further reducing energy consumption (Ståhl *et al*., 2016). Additionally, adding extracts from waste coffee can lower GHG and VOC emissions (Moreira *et al*., 2014). Although these additives or additional processing steps increase costs, their environmental and social benefits far outweigh the added costs and contribute to the circular economy by reusing waste.

In addition to species such as Japanese cedar, Taiwania, and acacia, bamboo is also an important economic crop in our country. Compared to coniferous and broadleaf species, which require a longer time to grow and sequester carbon, bamboo can be

doi:10.6342/NTU202403839

harvested in just 3-5 years to make a variety of products. Liu *et al*. (2016) used a mixture of moso bamboo and pine to produce biomass pellets. Pure moso bamboo alone did not meet the bulk density standards, but when mixed with pine, the ash content decreased as the proportion of pine increased. The calorific value and combustion characteristics also declined, but when the bamboo-to-pine ratio reached 60%/40%, it improved the bulk density, ash content, net calorific value, and combustion characteristics of pure pine pellets, meeting the standards for biomass pellet production. Stachowicz and Stolarski (2024) mixed short-rotation biomass with wood to produce wood pellets, which increased the energy efficiency of the wood pellets but required more production costs and energy consumption. Therefore, if we aim to enhance the strength and characteristics of our wood pellets, mixing wood with bamboo for pellet production could be an extremely attractive solution.

Heat treatment can improve combustion performance, durability, and energy density, with methods including torrefaction, steam explosion, pyrolysis, and microwave treatment. Torrefied wood pellets are produced by heating wood at 200-300 °C in an oxygen-free environment before pelletizing, while steam explosion involves cooking wood at high temperatures with saturated steam, then compressing it under high pressure to remove excess moisture before pelletizing. Both methods enhance combustion efficiency and durability, with steam-exploded pellets having higher

doi:10.6342/NTU202403839

durability and density, while torrefied pellets have higher combustion efficiency (Arous *et al.*, 2020). Chai and Saffron (2016) studied the differences between mild and severe torrefaction, finding that mild torrefied pellets have higher yield and lower production costs compared to severely torrefied pellets. Severely torrefied pellets are more suitable for humid regions, whereas mildly torrefied pellets are better for dry areas. Peng *et al.* (2015) and Sambeth *et al*. (2022) analyzed the physical properties of biomass torrefied with and without binders, showing that pure biomass torrefaction yields the best pellet characteristics, followed by cellulose-bonded pellets, which have lower energy density. In terms of storage, torrefied, steam-exploded, and untreated wood pellets degrade quickly in high humidity, especially when combined with high temperatures. Among these, steam-exploded pellets still maintain high mechanical performance (Graham *et al*., 2016). Pyrolysis involves decomposing biomass at 400-500 °C in an oxygen-free environment, resulting in biochar, bio-oil, and gas products, and this method increases energy density and durability (Arous *et al*., 2021). Microwave treatment heats wood pellets using microwaves, causing rapid internal temperature changes. Compared to torrefied pellets, microwave-treated pellets are more controllable, faster, and have lower energy costs while also improving calorific value and durability, although they reduce pellet density (Arshanitsa *et al*., 2016).

doi:10.6342/NTU202403839

2.5 Cost Benefit Analysis (CBA) and Life Cycle Costs (LCC)

Cost-benefit analysis (CBA) and life cycle costing (LCC) can be categorized into three types based on the scope of considerations over time. Initially, both focus purely on financial aspects, forming the basic methods: financial cost-benefit analysis (fCBA) and financial life cycle costing (fLCC). As environmental issues have become more critical, methods have evolved to include environmental factors, resulting in environmental cost-benefit analysis (eCBA) and environmental life cycle costing (eLCC). Finally, the most comprehensive approaches incorporate financial, environmental, and social welfare considerations to develop social cost-benefit analysis (sCBA) and social life cycle costing (sLCC), aimed at maximizing contributions to both the environment and society.

In 1902, the United States Congress passed the Rivers and Harbors Act, requiring CBA for projects related to river and harbor improvements. During the 1950s and 1960s, fCBA further developed and standardized, becoming more complex and precise with advancements in technology and economic theory. Today, fCBA combines methods such as net present value (NPV), discounted cash flow (DCF), and internal rate of return (IRR), extending its application from public sector projects to capital budgeting, project evaluation, and financial planning in private enterprises. The fCBA process involves

doi:10.6342/NTU202403839

eight steps: defining objectives and scope, identifying costs and benefits, collecting data, estimating cash flows, discounting cash flows, calculating financial indicators, performing sensitivity analysis, and making conclusions and recommendations (Boadway, 2006). For fCBA, not all costs and benefits can be quantified. For instance, regulatory costs such as legal and compliance costs, changes in market behavior, and innovation hindrances are difficult to quantify successfully (Cochrane, 2014). The challenges in quantifying these costs arise from the low reliability of causal inference, insufficient data quantity and quality, and the controversial nature of estimation models (Coates, 2015). To address these quantification difficulties, combining qualitative and quantitative analysis, using static comparative analysis to simplify market dynamics, employing flexible analytical frameworks, collecting data through historical records and surveys, and comparing different regulatory approaches can be effective solutions (Alfon and Andrews, 1999).

As environmental issues have become increasingly significant, environmental regulations and policies have emerged, leading to the development of environmental cost-benefit analysis (eCBA). In the 1970s, the U.S. Environmental Protection Agency (EPA) and other organizations adopted eCBA to evaluate environmental regulations. By the 1990s, eCBA had further evolved, with the European Union extensively applying it in their environmental policy and regulatory processes. The steps to

doi:10.6342/NTU202403839

formulate eCBA begin with problem definition, followed by identifying and assessing the environmental impacts of each project, discounting costs (including environmental costs) and benefits, and finally selecting projects to implement based on net present value (NPV) and conducting sensitivity analysis (Kuosmanen and Kortelainen, 2007).

However, these environmental impact benefits are not clearly defined regarding the specific time points and conditions for monetization during the evaluation process. Boyd and Banzhaf (2007) emphasized the need for environmental accounts to track the changes in quantity and price separately to avoid double counting and misleading conclusions, and they noted that ecosystem services are the final products of nature. For example, forest products are the final products of deforestation and utilization. Therefore, by using government statistical data or direct data from the forestry industry and monetizing it at market prices, the actual status of environmental benefits can be determined. eCBA employs two modeling methods: Stated Preference (SP) and Revealed Preference (RP). SP involves surveys to investigate the willingness to pay or accept compensation for a certain environmental improvement or protection measure, allowing the estimation of non-market-valued environmental resources. However, it is influenced by the respondents' honesty and the hypothetical scenarios. RP infers the value of environmental resources by observing respondents' behavior in the actual market, providing more practically valuable results. Nonetheless, it cannot estimate

doi:10.6342/NTU202403839

environmental resources not traded in the market or traded in minimal quantities. Hanley *et al*. (2001) compared the Choice Modelling Approaches (CMA) with the Contingent Valuation Method (CVM) within SP and concluded that CMA provides more robust and reliable estimates in multi-attribute situations. However, CMA requires advanced econometric techniques, users with high expertise, and significant costs. Additionally, respondents need the ability to understand and handle the complexity of choice information. Kuosmanen and Kortelainen (2007) proposed using Data Envelopment Analysis (DEA) to evaluate environmental factors, addressing the shortcomings of SP and RP. While DEA uses shadow prices based on observed conditions to assess environmental factors without being influenced by personal preferences or lacking extensive data, further empirical validation is needed to confirm its reliability. In eCBA, the time horizon is crucial. A short time frame can underestimate the true costs of harmful environmental projects and the benefits of environmentally favorable ones. Therefore, for projects with significant and long-term environmental impacts, at least a 100-year perspective should be adopted, using scenario assumptions and sensitivity testing to address forecasting uncertainties (O'Mahony Tadhg, 2021).

sCBA is a tool used to evaluate public projects, policies, and plans. Unlike eCBA, which only considers environmental factors, sCBA also considers social welfare and

doi:10.6342/NTU202403839

other non-market factors. It assesses the socio-economic benefits of a project or policy by comparing the total social costs and benefits, with a particular emphasis on social welfare. In the 1990s, to better reflect long-term impacts, the Social Discount Rate (SDR) was incorporated into sCBA to address the valuation of non-market goods, risk and uncertainty, distributional analysis, and sustainability constraints (Asian Development Bank, 2013). The SDR is determined using the Ramsey formula, as follows:

$$r = \rho + \eta g \qquad \text{equation (2)}$$

where r is the social discount rate, ρ is the pure rate of time preference representing people's preference for current consumption over future consumption, η is the elasticity of marginal utility of income reflecting the rate at which utility or satisfaction changes with income, and g is the growth rate of per capita consumption, indicating the rate of increase in per capita consumption over time. Developing countries typically use a higher SDR (8-15%), while developed countries use 3-7% as the SDR (Asian Development Bank, 2013). In sCBA, determining the discount rate is crucial for evaluating the economic feasibility of projects. A rate that is too low may present long-term social and environmental projects as overly favorable when discounted, while a rate that is too high may favor short-term projects for investment (Brzozowska, 2007). Pekovic *et al*. (2018) found that there is an inverted U-shaped relationship between

doi:10.6342/NTU202403839

environmental investment and economic performance; excessive encouragement of green investment can erode economic performance, while insufficient investment can result in weak and costly economic performance. Therefore, policymaking should carefully balance the relationship between environmental investment and economic performance and conduct further studies for various industries while considering other factors such as market structure to achieve optimal performance and environmental investment. The use of SDR can better reflect the present value of project investments. However, Kurdyukov and Ovcharenko (2023) and Malik (2019) pointed out many issues with using SDR in sCBA. Discounting tends to prioritize short-term benefits over long-term benefits (such as green investments or social welfare), which is ethically unjustifiable for future generations and contrary to sustainable development principles. Moreover, discounting may lead to the undervaluation of environmental capital's true worth. Malik (2019) argued that the capital opportunity cost is an underestimation of future returns, making this valuation method unsuitable for irreplaceable environmental capital. Different types of capital grow at different rates, and failing to classify capital and apply appropriate discount rates can result in biased economic assessments. Kurdyukov and Ovcharenko (2023) suggested using compound interest to evaluate the cumulative benefits of investments. Green investments often involve transaction costs such as R&D and implementation costs. Discounting may fail to carefully consider

doi:10.6342/NTU202403839

these costs, leading to lower economic benefits (Kurdyukov and Ovcharenko, 2023). Malik (2019) mentioned that the assumption of increasing risk over time is unfounded, and that costs and benefits should be directly adjusted instead of the discount rate. Different conceptual bases (such as social opportunity cost, environmental capital) require different discount rates. Additionally, each country and institution have its SDR preferences, so using the same SDR to evaluate all public projects can lead to inaccurate results (Malik, 2019). In summary, sCBA should adopt more comprehensive and multidimensional evaluation methods, such as compound interest and considering different growth rates for various types of capital. This approach will enhance the accuracy and appropriateness of evaluations, creating true sustainable development that balances the interests of present and future generations.

Price (2018) conducted forestry-related research on discount rates, indicating that the adoption of declining discount rates significantly increases the profitability of forestry projects and the social cost of carbon. However, without considering carbon effects, the use of declining discount rates is not economically feasible. Fürtner *et al.* (2022) used sCBA to evaluate short rotation coppice (SRC) with poplar and traditional crops (corn and winter wheat). The analysis showed that, economically, the NPV, payback period, IRR, and benefit-cost ratio of poplar SRC need further enhancement compared to traditional crops. Environmentally, SRC has potential carbon sequestration

doi:10.6342/NTU202403839

benefits, with a 29% increase in soil organic carbon over a 20-year average. Socially, SRC offers employment opportunities, rural development, and biodiversity benefits, but challenges include public awareness, legal restrictions, and long-term commitments from farmers. The regional added value of poplar shows socio-economic benefits but is still lower than that of traditional crops. In summary, applying sCBA to the forestry sector can provide a comprehensive sustainability assessment covering financial, environmental, and social aspects. This ensures the achievement of long-term sustainable development goals, optimizing environmental standards, economic benefits, and social welfare.

fLCC is a method used to evaluate the total cost of a product or system over its entire lifecycle, encompassing initial investment costs, operating costs, and disposal costs of initial investment equipment. It is employed in decision-making processes to consider long-term economic benefits, aiming to minimize costs while achieving performance or maximizing investment returns. Using fLCC during the early design and system operation stages significantly enhances system design and operational efficiency (Norman, 2007). Given the uncertainty of the future, Flanagan *et al.* (1987) suggested that employing risk management systems, including risk identification, risk analysis, risk response, sensitivity analysis, and probability analysis, can effectively mitigate future uncertainties. The concept of this assessment method originated in the

doi:10.6342/NTU202403839

mid-20th century, primarily applied in military and aviation fields. Over time, various industries have adopted fLCC to evaluate the entire lifecycle and analyze which cost components are excessively high and need improvement. Dwaikat and Ali (2018) conducted life cycle cost analysis for green buildings, finding that in a 60-year lifecycle, energy costs accounted for 48% of the total costs, and operating costs exceeded 60%. Therefore, reducing energy consumption costs is crucial for lowering overall life cycle costs. Ong *et al*. (2012) analyzed the life cycle costs of producing biodiesel from palm oil, revealing that raw materials accounted for 79% of the total costs. Sensitivity analysis showed that raw material price fluctuations significantly impacted life cycle costs, with interest rates, initial investment costs, and oil conversion rates also being important variables. However, fLCC only considers economic costs without addressing factors such as risk aversion and profit expectations. To resolve these issues, the Life Profitability Method was developed (Gardoni *et al*., 2016). Gardoni *et al*. (2016) outlined that this model comprises four stages: design information, cost analysis, revenue, and profit analysis. Design information includes structural requirements and capability models; cost analysis considers appreciation/depreciation effects and insurance; revenue considers only appreciation/depreciation effects; and profit analysis maximizes NPV. Life Cycle Assessment (LCA) is similar to LCC, but while LCA mainly evaluates the environmental performance of a product system to achieve the

doi:10.6342/NTU202403839

same end-use function, LCC focuses on the relative cost-effectiveness of investments and business decisions (Norris, 2001). Combining both can lead to more comprehensive decisions regarding economic, environmental, and performance aspects, balancing economic and environmental performance and revealing hidden costs such as accidents and liabilities (Norris, 2001). Schneife-Marin (2022) used the Eco2 framework to integrate LCA and LCC, improving the transparency and comparability of results. However, challenges include data collection difficulty, accuracy, and the lack of standardized methods.

By the 1990s, with the increased awareness of environmental protection and the establishment of international standards such as ISO 14040, traditional LCC began to incorporate environmental impacts, forming eLCC. eLCC assesses the total cost by considering all costs, including environmental costs such as resource use, pollution emissions, and final disposal, throughout the entire life cycle of a product or system, to make more sustainable decisions. eLCC can evaluate the costs of product systems from different roles, including producers, suppliers, and users, and is highly advantageous for identifying and quantifying environmentally friendly products (Klöpffer and Ciroth, 2011). Gluch and Baumann (2004) pointed out that decisions made based on eLCC are uncertain, with some environmental factors often being overlooked, and some irreversible environmental decisions being monetized, leading to idealistic but

doi:10.6342/NTU202403839

unrealistic results. Besides facing issues similar to those in fLCC, such as data accuracy and completeness and methodological standardization, eLCC also encounters challenges like the limited vision of the tools used and the irrelevance of the users' focus and motivation (Rodrigues and Silva, 2024; Abraham *et al*., 1998). Furthermore, Gluch and Baumann (2004) argued that the diversity and definition of LCC confuse many researchers, and eLCC and LCA (Life Cycle Assessment) are the same tool. Kreuze and Newell (1994) mentioned that Activity-Based Costing could be used alongside eLCC to provide a more comprehensive environmental cost assessment; Abraham *et al*. (1998) divided disposal costs (environmental costs) into four main parts using a model—environmental assessment, facility disposal, monitoring, and land remediation; Moreau and Weidema (2015) utilized physical and monetary technical matrices to calculate LCC and coordinate it with LCA to achieve complete harmonization and simplify the avoidance of LCC conceptual errors. Rodrigues and Silva (2024) believed that integrating with LCA could yield a more comprehensive assessment of environmental and economic impacts.

sLCC evaluates the social costs and benefits of a product or system throughout its entire life cycle, similar to Social Cost-Benefit Analysis (sCBA), by adding the dimension of social impact consideration and quantification from an environmental approach. However, unlike eLCC, which has standards like ISO 14040, sLCC currently

doi:10.6342/NTU202403839

lacks a defined framework and standards. Therefore, in various studies, sLCC is often combined with eLCC and other assessment tools to compensate for its inadequacies in social evaluation, such as the development of Life Cycle Sustainability Assessment (LCSA). LCSA integrates Environmental Life Cycle Assessment (eLCA), eLCC, and Social Life Cycle Assessment (sLCA) to provide a comprehensive assessment of the three pillars of sustainability: economic, environmental, and social. Nevertheless, studies by Fauzi *et al*. (2019) and Wood and Hertwich (2013) indicate that combining these tools still presents problems. The static framework of eLCA can result in biases in long-term assessments and fails to consider market mechanisms for indirect impacts. eLCC and sLCA yield different results due to their different perspectives, and both require careful definition and detailed procedural steps to fully assess economic and social impacts. Between sLCA and eLCA, eLCA should consider both positive and negative impacts in sustainability assessments and align its analysis level with sLCA, while sLCA needs clearer definitions of good and bad to increase applicability and lacks a coherent system boundary to capture the physical flow and social impact of product systems.

Orfanidou *et al*. (2023) mentioned that the ReCiPe assessment method evaluates human health, ecosystem quality, resource availability, and climate change, but due to a lack of consensus on monetizing the assessments of human health and ecosystem quality,

doi:10.6342/NTU202403839

this method remains essentially an eLCC unless these issues are resolved. The Sustainability Price, which adds the additional value of minimum social and environmental sustainability values to the market price, can address the inadequacies of eLCC in social evaluation (Hall, 2019). Karatas and El-Rayes (2014) used a MATLAB 2012a model connected to the external building energy simulation engine EnergyPlus, supplemented with a multi-objective genetic algorithm optimization model, to evaluate the sLCC analysis of residential buildings. Zhang *et al*. (2022) used BIM models with carbon emission intensity and LCC to help decision-makers provide low-carbon solutions. Some scholars do not use additional models to aid sLCC assessment. For instance, Walsh *et al*. (2023) analyzed the sLCC of green buildings at Toronto Metropolitan University using ISO 15686 and SFG 20, and calculated energy use intensity based on 2019 energy data. Pattanaik *et al*. (2020) compared natural indigo dye with synthetic indigo, indicating that green products have higher initial costs but can achieve higher sustainability benefits in the long term by reducing operational and maintenance costs and environmental impact. Studies by Siebert *et al*. (2018) and Tam *et al*. (2017) provide important insights for future sLCC analyses of wood products or the use of wood products. The former developed indicators suitable for social assessment of wood products, including health and safety, fair remuneration, adequate working hours, employment, knowledge capital, equal opportunities, and participation.

doi:10.6342/NTU202403839

The latter indicated that non-structural wood has lower costs but requires more consideration in durability and maintenance, external cladding wood has good environmental benefits but higher initial costs, structural wood needs more expertise and technology to ensure safety and stability, and wood applications in flooring and ceilings require comprehensive considerations in cost and maintenance. In summary, sLCC contributes to more comprehensive economic sustainability decision-making. However, due to the lack of standardized methods and frameworks, accuracy of data, and application of alternatives, sLCC cannot yet independently serve as a sustainability assessment tool (Altaf *et al*., 2023; Degieter *et al*., 2022; Franca *et al*., 2021). Overcoming these challenges would improve the comparability and usability of sLCC, enabling its application across various industries to aid users in making more sustainable decisions.

Though the two tools, LCC and CBA, may seem unrelated by definition, their combined use can offer a more comprehensive assessment of sustainability across three dimensions: economic, environmental, and social. Hoohmartens *et al*. (2014) analyzed the differences among LCC, CBA, and LCA as sustainability assessment tools, highlighting that LCC and CBA can complement each other. LCC can utilize CBA's assessment methods, while CBA can use LCC results as input data for evaluating the sustainability of investment plans. Thus, when used together, LCC can address the

doi:10.6342/NTU202403839

challenge of quantifying environmental and social impacts through CBA's technical assessments, and CBA can enhance the accuracy and reliability of data. Future research should focus on integrating these two tools to provide decision-makers with practical and sustainable development-oriented decisions.

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3. Method

3.1 Process Flow Chart

3.1.1 Dimensional Lumber Process

Figure 3.1 shows the process flow diagram to produce dimensional lumber. The production process of dimensional lumber is analyzed based on the actual test results of Chiu (2023). First, the logs enter the sawmilling process. A horizontal bandsaw is used to cut off parts like the outer bark that cannot be made into dimensional lumber. The cut wood is then divided into rough products using a vertical bandsaw. Next, the wood enters the drying process, where drying kilns and wood boilers are used to control the wood's moisture content to between 15 ± 4%. The dried rough products then go through a 4 side moulder to determine their width and thickness and are then cut to the desired length using a cutting machine to produce laminated lumber components. These components are sent to a mechanical stress grading machine for grading to produce dimensional lumber. The quality-approved dimensional lumber is finally transported from the wood processing plant for sale.

doi:10.6342/NTU202403839

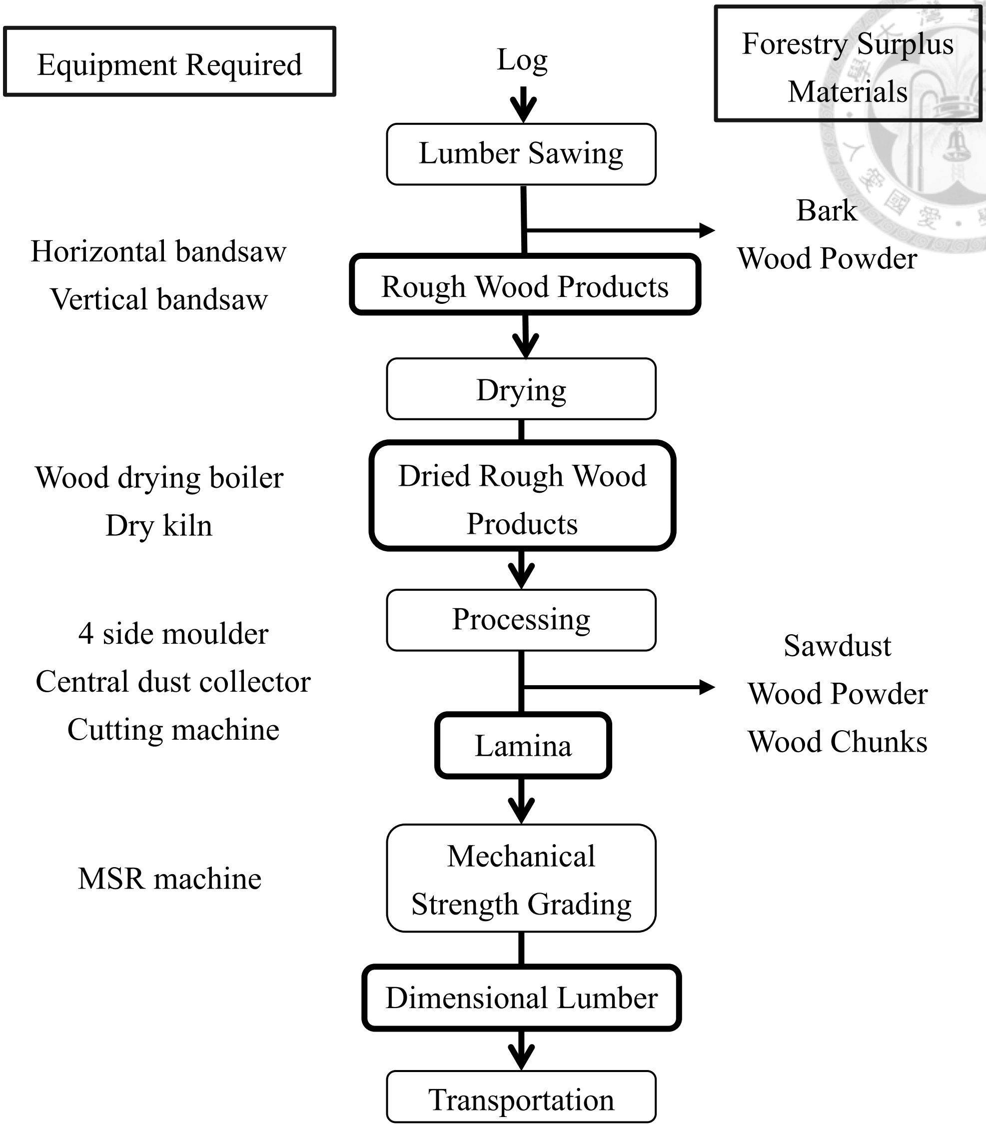

Figure 3.1 The process of dimensional lumber (Chiu, 2023)

doi:10.6342/NTU202403839

3.1.2 Wood Pellets Process

Figure 3.2 shows the process flow diagram to produce wood pellets. The wood pellet production process is also based on the flow described in Chiu's (2023) study. In the production process of dimensional lumber, three types of residual materials are generated: wood dust, sawdust, and residues such as bark and wood chunks. Wood dust is directly sent to the pelletizer for pellet production, while the other two materials require further processing into powder form before being sent to the pelletizer. Residues such as bark and wood chunks are first reduced in size to prevent the crushing machine from overheating due to oversized materials, which could lead to significant repairs or equipment replacement. After being reduced to smaller pieces, these residues still cannot be directly pelletized and must be further processed into chips using a crushing machine. Sawdust also needs to be processed through the crushing machine before palletization can begin. Once the wood pellets are made, they are sent to a packaging machine for sealing, and finally, the packaged wood pellets are transported from the pellet plant for sale.

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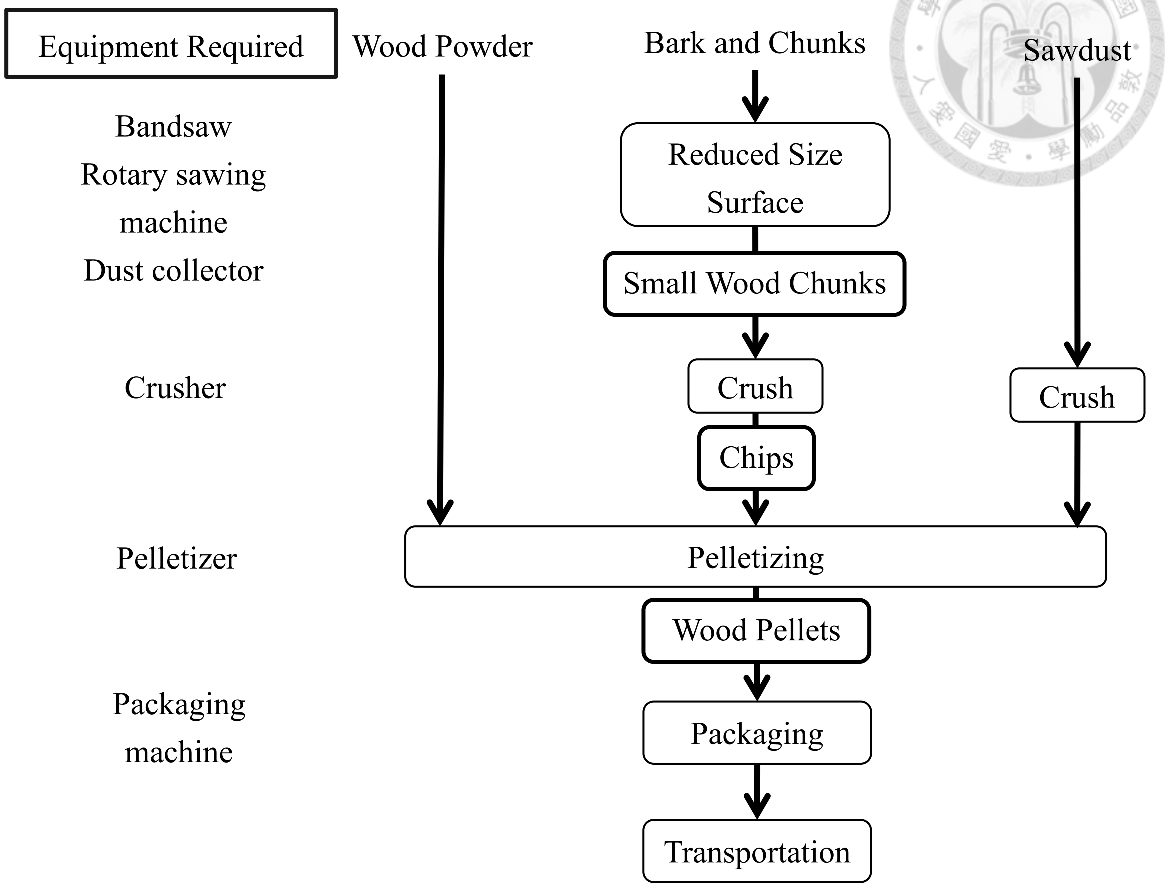

Figure 3.2 The process of wood pellets

doi:10.6342/NTU202403839

3.1.3 Essential Oil Extraction Process

Figure 3.3 shows the process flow diagram for essential oil extraction. In the essential oil extraction process, residues such as bark and wood chunks, as well as sawdust, require further processing similar to the wood pellet production process before essential oil production can begin. After being processed into powder form, the material undergoes a distillation process to obtain a mixture of essential oil and water. At this stage, the mixture is at a high temperature, and some components of the essential oil are in a gaseous state, so the mixture needs to be cooled. After cooling, the mixture is sent to an essential oil separator to obtain pure essential oil, which is then sent to a bottling machine for packaging, ready for shipment and sale.

doi:10.6342/NTU202403839

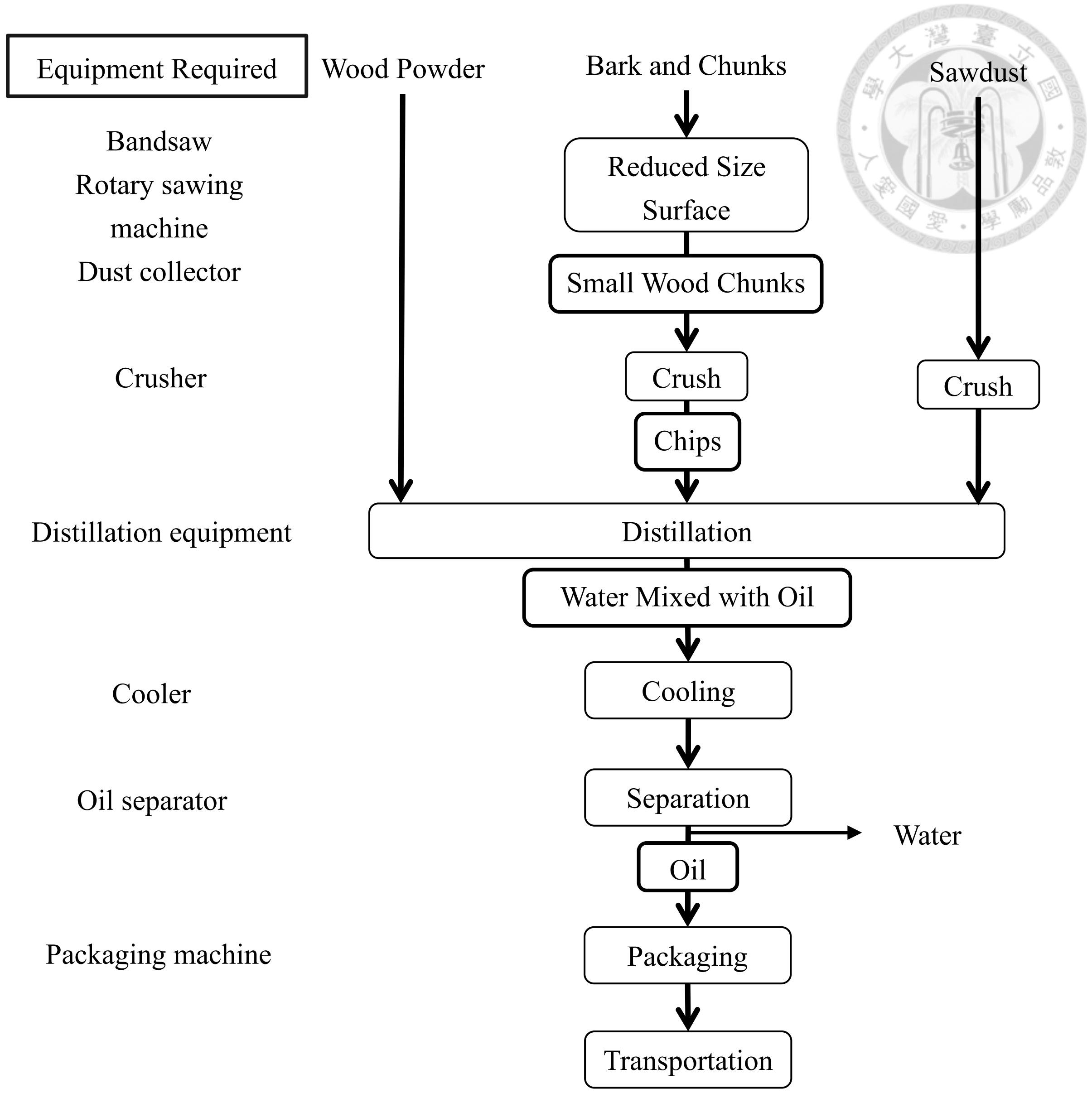

Figure 3.3 The process of essential oil extraction process

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3.2 Sale Price (SP) and Production Volume (PV)

Assuming an annual harvest of 4,000, 8,000, 10,000, 20,000, and 40,000 m^3, with wood utilization rates of 30%, 40%, 50%, and 60%, the plan duration is 20 years, with 220 operating days per year, and 8 hours per day. Additionally, assume that all waste generated during the production process is efficiently recycled (i.e., 100% recovery rate), and products can be sold immediately upon completion.

Residual materials will be managed as follows: 13.15% of the materials (all bark, wood chunks, etc.) will be used as fuel for drying kilns and wood boiler heating equipment, while 86.85% of the residual materials will be processed into other by-products. Thinned wood will be processed at a wood processing plant, with a transportation distance of 233.5 km (the distance from National Taiwan University Experimental Forest to National Taiwan University, which is the same for all transportation distances mentioned).

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3.2.1 SP and PV for Dimensional Lumber

According to the Wood Market Information System established by the Forestry Natural Conservation Agency (2024), the average prices of Japanese cedar (squared timber for construction) and Taiwania in 2023 were NT$20,700 and NT$36,000, respectively. The price of China fir is not transparent and difficult to find, so it is assumed to be calculated using the price of domestically produced cedar (NT$4,256) multiplied by the average ratio of the finished product prices to their respective raw material prices for Japanese cedar and Taiwania, which is 3.605 (i.e., Japanese cedar squared timber NT$20,700 / Japanese cedar raw material NT$3,732, Taiwania NT$36,000 / Taiwania raw material NT$22,273, resulting in 5.55 and 1.66 respectively, then averaging these two ratios), giving a price of NT$15,343.

The selling price of dimensional lumber is then calculated based on the production ratios of the three tree species (65.50% Japanese cedar, 23.78% China fir, and 10.72% Taiwania) multiplied by their respective prices, resulting in an average price of NT$21,066 per cubic meter.

The production volume for the dimensional lumber process is assumed to be the harvest volume multiplied by the wood utilization rate, with a manufacturing yield of 100% (i.e., no normal or extraordinary losses occur during the production process).

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3.2.2 SP and PV for Wood Pellets

Table 3.1 shows the top ten countries exporting wood pellets globally in 2022 and their export volumes. It is evident that the export volumes of the top three countries alone cover more than 50% of the total. To better simulate the domestic wood pellet sale price, the wood pellet prices from these countries serve as crucial reference data in the calculation process.

Table 3.1 Top 10 wood pellets exporting countries and export volume in 2022.

No.	Countries	Export Volume (tons)	Export percentage (%)
1	USA	8,977,160	28.74
2	Vietnam	4,629,704	14.82
3	Canada	3,492,510	11.18
4	Laticia	1,684,798	5.39
5	Rusia	1,377,970	5.37
6	Estonia	790,393	4.41
7	Malaysia	748,723	2.53
8	Austria	683,443	2.40
9	Germany	527,255	2.19
10	Lithuania	523,049	1.69

Resource: FAO STAT (2024)

Table 3.2 shows the 2022 wood pellet prices for countries other than the top ten and neighboring countries of Taiwan. The price range of wood pellets is quite large, from 5.13 to 11.51. Flach and Bolla (2023) reported that the wood pellet sale prices in

doi:10.6342/NTU202403839

the United States and the European Union are 6.51 and 7.03, respectively. According to FAO statistics, the price in the United States is higher by 1.39, while the price in the European Union cannot be directly compared with FAO data due to varying prices across different countries and the fact that the reported value is an average for each country.

If Taiwan aims to produce and sell wood pellets domestically and avoid imports, the price should be the weighted average of the prices in the United States, Vietnam, and Canada. The calculation is (6.51 × 28.74 % + 10.70 × 14.82 % + 7.98 × 11.18 %) / 54.74%), in the analysis, the wood pellet price is 7.95.

Table 3.2 Wood pellet price in 2022

Countries	Sale Price (NT$/kg)	References
USA	5.12	FAO STAT, 2024[1]
Vietnam	10.70	Fu C., 2023
Canada	7.98	
Laticia	6.58	FAO STAT, 2024[1]
Rusia	5.68	
Estonia	6.68	
Malaysia	4.76	
Austria	11.51	
Germany	11.22	
Lithuania	9.37	
Japan	6.14	株式会社 FT カーボン, 2023
South Korea	5.45	INDEXBOX, 2024

[1]: The calculation of sale price is used by export value and export Quantity.

[2]: Equal to USD 183/ton × average exchange rate in 2022 (exclude import rate)

doi:10.6342/NTU202403839

The production volume of wood pellets is determined by the yield rates of the three types of raw materials used, the yield rate of wood powder is 90.56%; bark and chunks are 83.40, 99.34 and 94.09% as the processing progresses; and 99.36 and 97.09% for sawdust.

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3.2.3 SP and PV for Essential Oil

Based on the available information regarding essential oil sales both domestically and internationally, there are 18 records for Japanese cedar (excluding essential oil extracted from branches and leaves), 0 records for China fir, and 5 records for Taiwania. The price range for Japanese cedar essential oil is 17 – 354 NT$ / mL, while for Taiwania, it is 80 – 630 NT$ / mL, showing a significant price difference, as detailed in Appendix Table A. 1. Due to the wide distribution of prices, the mode average is used as the standard for determining the essential oil prices.

For Japanese cedar, 4 records are below 100 NT$ / mL, 10 records are between 101-200 NT$ / mL, 3 records are between 201-300 NT$ / mL, 1 record is above 300 NT$ / mL. Therefore, the price of Japanese cedar essential oil is determined to be 170 NT$ / mL.

For Taiwania, excluding the extreme value of 630 NT$ / mL, the remaining four prices are relatively close. Given the price determination for Japanese cedar essential oil at 170 NT$ / mL, prices below 100 NT$ / mL are considered unreasonable. Thus, the price of Taiwania essential oil is determined to be 128 NT$ / mL.

For China fir, due to its excellent durability and mechanical properties, China fir has long been used as a building material. There is little information or research on

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extracting and selling Fuzhou cedar essential oil. Therefore, the price is determined as the average of the prices for Japanese cedar and Taiwania essential oils, which is 149 NT$ / mL.

Finally, following the pricing model used for dimensional lumber, the average of these prices is calculated and then adjusted for bulk purchase discounts, amounting to one-sixth of the original price. This gives an essential oil sale price of 25 NT$ / mL for analysis purposes.

Table 3.3 shows the extraction yield and extraction time for essential oil obtained via steam distillation from three tree species, focusing on wood (which can be divided into sapwood and heartwood) and bark. The extraction yield of Japanese cedar range from 1.27 – 7.59 mL / kg, 1.8 - 12.6 mL /kg for China fir and 0.17 – 29.34 mL / kg for Taiwania. Considering that using the average or maximum values in the analysis might lead to significant discrepancies between the analysis results and the actual yields, this analysis assumes the lowest yield reported in the literature for each tree species. In essential oil extraction process, Japanese cedar can get 1.27 mL / kg, 1.8 mL / kg for China fir and 0.17 mL / kg for Taiwania. Multiplying the yields of the three tree species by their respective production ratios gives the yield (1.28 mL / kg) used in this analysis and in addition the yield rate is 100%.

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Table 3.3 The yields and extraction time of the essential oil

Tree Species	Parts	Yields (mL/kg)	Yields (%)	Extraction time (hours)	References
Japanese Cedar	Heart	3.8	0.08	6	Cheng *et al*, 2003
	Sap	1.3	0.13		
	Bark	6.3	0.63		
	Wood	7.59 ± 0.81	0.38 ± 0.07	6	Cheng *et al.*, 2006
	Bark	1.58 ± 0.33	0.03 ± 0.01		
	Sap	1.27	0.13	6	Chang *et al.*, 2005
	Heart	3.80	0.38		
	Bark	6.31	0.63		
Chinese Fir	Heart	7.4	0.74	6	Cheng *et al*, 2003
	Sap	1.8	0.18		
	Heart	N/A	1.3 – 2.3	6	Shieh and Wu, 2007
	Heart	10.8 ± 0.2	1.08 ± 0.02	8	Su *et al.*, 2012
	Bark	12.6 ± 0.3	1.26 ± 0.03	3	Su and Ho, 2018
Taiwanese cedar	Heart	2.6	0.26	6	Cheng *et al.*, 2003
	Sap	0.2	0.02		
	Heart	29.34	2.02	6	Cheng *et al.*, 2010
	Sap	0.17	0.02		
	Bark	0.55	0.02		

N/A: not appliable

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3.3 Production Costs

Costs can be categorized into fixed costs (FC) and variable costs (VC) depending on whether they remain constant or change based on the production volume, frequency, and hours of operation. Table 3-4 lists the variable and fixed costs for each process, based on a harvest volume of 4,000 m^3. If the machine and equipment costs exceed this harvest volume, adjustments are made according to equation (3) (Ulrich, 1984). Production costs only consider the actual cash flow, and labor costs are adjusted based on multiples of the harvest volume. Detailed cost descriptions will be provided according to each process.

$$FC_{new} = FC_{origin} \times \left(\frac{Capacity_{new}}{Capacity_{old}}\right)^{x} \qquad \text{equation (3)}$$

FC_{new} is the FC for the projected capacity, FC_{origin} is original FC, $Capacity_{new}$ is projected capacity, $Capacity_{origin}$ is original capacity and x is the adjustment factor, which ranged between 0.4 – 0.8 (Wang *et al.*, 2019；Prabodhan *et al.*, 2019；Jara *et al.*, 2016). In the study, the average value of 0.6 is used.

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3.3.1 Production costs of dimensional lumber

The production costs are shown in Table 3.4. Firstly, for machinery and equipment, the market price for a horizontal bandsaw range from USD 13,000 to 50,000, as detailed in Appendix Table A. 2. Its function is to remove the bark from logs. The average price is USD 31,500, which, when multiplied by the average exchange rate of 29.78 TWD/USD, results in a price of NT$ 938,070. The vertical bandsaw is used to further cut the material into sizes suitable for subsequent processing. Its market price ranges from USD 1,085 to 2,880, as shown in Appendix Table A. 3, with an average price of USD 2,077.21, resulting in a price of NT$ 61,859. The wood boiler heating equipment and drying kiln are provided by NTU Experimental Forestry, priced at NT$ 2,231,000 and NT$ 4,275,676, respectively. The four-side planer, which includes a central dust collection system, has a market price ranging from USD 10,000 to 36,000, with an average of USD 23,000, resulting in a price of NT$ 684,940. The cutting machine is supplied by Po Chuan EnterPrising Co., LTD. (2003), representing the MSS-3000 model from Maushan Machinery, priced at NT$ 231,000, including VAT and non-VAT. The mechanical stress grading machine cost is based on a 1982 study by Woobridge, Reed and Associates LTD., commissioned by the Canadian government, on the potential market value of MSR machines. The cost range is CAD 130,000 to 200,000.

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Using the average value and adjusting for the Canadian Producer Price Index (PPI) from 1982 to 2022, and then multiplying by the 2022 average exchange rate of 22.7966 TWD/CAD, the price is NT$ 6,927,241. The costs of the above machinery are adjusted according to equation (3).

The labor cost per person per month is NT$ 38,269, as disclosed by the Earnings Exploration & Information System established by Directorate General of Budget, Accounting and Statistics, Executive Yuan in 2023 for the wood and bamboo products industry in 2022. In the lumber sawing process, 3 people are required to operate the horizontal bandsaw and vertical bandsaw, totaling 5 people. In the drying step, a total of 3 people are needed. For the processing steps, 2 people are needed to operate the four-side planer and 2 people to operate the cutting machine, totaling 4 people. Additionally, 2 people are needed for mechanical strength grading. Therefore, the entire dimensional lumber production process requires a total of 14 people.

Electricity costs are based on actual operational results from Chu (2023), with each step requiring 12.19, 19.84, 45.22, and 0.51 kWh/m³, respectively. The average electricity price is NT$ 2.7246/kWh (Taiwan Power Company, 2023). During the drying stage, diesel oil is used at a rate of 21.45 L/m³, calculated using the average diesel price of NT$ 27.36 per liter as published by the Petroleum Price Information Management and Analysis System establish by Energy Administration, Ministry of

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Economic Affairs. Transportation costs are based on the 2022 Automotive Freight Survey Report published by the Accounting and Statics Office, Ministry of Transportation and Communications (2023), where the freight rate for forest products (Item No. 009) is NT$ 10.0665 per ton-kilometer. Raw material costs are thinning expenses, provided by NTU Experimental Forest. Thinning expenses include seven items: logging and processing, transportation, collection, cable installation, bamboo removal, forest road repair, and management costs. For this analysis, it is assumed that cable installation, bamboo removal, and forest road repair will not occur over the 20 years. Logging, transportation, and collection costs are NT$ 1,300/m^3. Management costs are divided into personnel costs and miscellaneous expenses. The former includes one manager for every 200 m^3, with a salary of NT$ 46,360 per month (equivalent to a grade 5, level 5 commissioned salary). Miscellaneous expenses are 2% of personnel costs. Maintenance costs are 10% of the machinery and equipment costs annually.

doi:10.6342/NTU202403839

Table 3.4 Variable costs and fixed costs in dimensional lumber for 4,000 m^3

Dimensional Lumber	Fixed Costs		Variable Costs		References
	Value	Unit	Value	Unit	
Lumber Sawing					
Horizontal bandsaw	938,070	NT$			Market Value
Vertical bandsaw	61,859	NT$			Market Value
Raw materials			Note 1	NT$/$m^3$	NTU Experimental Forest
Electricity			12.19	kWh/m^3	Chiu, 2023
Labor	2,296,140	NT$/year			Estimated
Maintenance	99,992	NT$/year			Estimated
Drying					
Wood drying boiler	2,231,000	NT$			NTU Experimental Forest
Dry kiln	4,275,676	NT$			NTU Experimental Forest
Electricity			19.84	kWh/m^3	Chiu (2023)
Labor	1,377,684	NT$/year			Estimated
Maintenance	650,668	NT$/year			Estimated
Processing					
4 side moulder Central dust collector	684,940	NT$			Market Value
Cutting machine	231,000	NT$			Po Chuan EnterPrising Co., LTD., 2023
Electricity			45.22	kWh/m^3	Chiu, 2023
Labor	1,836,912	NT$/year			Estimated
Maintenance	91,594	NT$/year			Estimated
Mechanical Strength grading					
MSR	6,927,241	NT$			Woodbridge, reed and associates LTD., 1982
Electricity			0.51	kWh/m^3	Chiu, 2023
Labor	918,456	NT$/year			Estimated
Maintenance	692,724	NT$/year			Estimated
Transportation					
Freight-out			10.0665	Ton-km	Accounting and Statistics Office, 2023

Note 1: The thinning expenses are divided into logging and processing, collection, and transportation, each with a unit cost of NT$ 1,300/m^3. Additionally, personnel and miscellaneous costs must be accounted for, with the personnel cost being NT$ 46,360 per month for every 200 m^3 produced, and miscellaneous expenses being 2% of the personnel cost.

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3.3.2 Production costs of wood pellets

the production costs, as shown in Table 3.5, include machinery such as circular saws, band saws, and dust collectors, all supplied by Po Chuan EnterPrising Co., LTD., representing Mao Shan Machinery Industrial Co., LTD. models SS-3000, YES-BSM330, and MGD-3100VECK. The individual costs are NT$ 231,000, NT$ 95,550, and NT$ 112,500, respectively. The crusher costs are based on Lot *et al*. (2002), with a rotary crusher of 25 horsepower, purchasing cost USD 13,600, and installation cost USD 18,100. The packaging machine costs are based on Pirraglia *et al*. (2010), with a fixed cost of USD 50,000, adjusted by the U.S. Producer Price Index increase of 101.959%, then converted to NT$. The pelletizer costs NT$ 712,000, with a capacity of 200 kg/hour. Therefore, as the harvest volume increases, the pelletizer cost is calculated based on hourly production capacity rather than using the new harvest volume divided by the baseline harvest volume to the power of 0.6. The required pelletizer capacities for harvest volumes ranging from 4,000 to 40,000 m^3 are 400, 600, 700, 1,000, 2,000, and 4,000 kg/hour, respectively.

In the wood pellet production process, aside from the packaging step where labor is already included in the packaging materials, a total of 4 people are required. Reduced Surface Size requires 1 person, crushing requires 1 person, and pelletizing requires 2

doi:10.6342/NTU202403839

people. Each person's monthly total salary is NT$ 38,269.

Electricity cost in reduced surface size need 0.6 kWh / kg, 0.14 kWh / kg in crush, and the pelletizing cost need to be calculated separately based on the type of forestry surplus materials. Wood powder need 0.25 kWh per kilogram, bark and chunks for 0.2 and sawdust for 0.33. Packaging cost is NT$ 1.1036 per kilogram (Pirraglia *et al.*, 2010), transportation cost is NT$ 10.0665 per ton-kilometer and maintenance cost is 10% of the machinery and equipment costs annually。

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Table 3.5 Variable costs and fixed costs in wood pellets for 4,000 m^3

Wood Pellets	Fixed Costs		Variable Costs		References
	Value	Unit	Value	Unit	
Reduced surface size					
Bandsaw	95,550	NT$			Po Chuan EnterPrising Co., LTD., 2023
Dust collector	112,500	NT$			
Rotary sawing machine	231,000	NT$			
Electricity			1.63476	NT$/kg	Chiu, 2023
Labor	459,228	NT$/year			Estimated
Maintenance	43,905	NT$/year			Estimated
Crush					
Crusher	944,026	NT$			Loh *et al.*, 2002
Electricity			0.38144	NT$/kg	Chiu, 2023
Labor	459,228	NT$/year			Estimated
Maintenance	94,403	NT$/year			Estimated
Pelletizing					
Pelletizer	2,834,523	NT$			NTU Experimental Forest
Electricity			Note 1	NT$/kg	Chiu, 2023
Labor	918,456	NT$/year			Estimated
Maintenance	283,452	NT$/year			Estimated
Packaging					
Packaging machine	3,007,170	NT$			Pirraglia *et al.*, 2010
Packaging materials			1.1036	NT$/kg	
Transportation					
Freight-out			10.0665	Ton-km	Accounting and Statistics Office, 2023

Note 1：The amount of energy required for producing wood pellets from the three types of materials—wood dust, bark and wood chunks, and sawdust—are different, 0.068115, 0.54492 and 0.8991, respectively.

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3.3.3 Production costs of essential oil extraction

As shown in Table 3.6, residual materials such as bark, wood chunks, and sawdust need further processing to increase the reaction surface area to achieve the same yield as reported in the literature. Therefore, the essential oil extraction process requires steps for reducing material size and crushing, with machinery, labor, and electricity costs similar to those in the wood pellet production process. Distillation equipment is NT$ 400,000 with a capacity of 850 liters and is equipped with a cooling machine cost NT$ 200,000 with a capacity of 45 liters. The adjustment of these two equipment is linearly amplified according to the number of units required for the harvest volume and the number of units required in each process are 8, 12, 16, 19, 38 and 76, respectively. The separator ranges from NT$ 22,017 to NT$ 1,456,965 based on market data, with an average NT$ 293,723 and assumes the cost adjustment is as same as distillation equipment and cooler. The market price of essential oil dispensing machine ranges from NT$ 3,880 to 48,000, with an average of NT$ 21,530. Assuming that 4 units required in 4,000 m^3 harvest volume and is adjusted according to equation (3) subsequently.

The essential oil extraction requires a total of 24 peoples, 2 people each for reduced surface size and crush, 1 person for taking care of distillation equipment and 8 people for distillation, 2 people are responsible for feeding and taking care of equipment and

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2 people for sending finished products to next step in cooler and separation and 2 people each for feeding and packing in packaging step.

The electricity costs for size reduction and crushing are the same as in the wood pellet production process. The electricity costs for distillation, cooling, and separation are referenced from the data in Mu'azu *et al*. (2019), assuming that their data for extracting essential oil from lemon eucalyptus leaves is applicable to this analysis. Producing 115.84 mL of lemon eucalyptus essential oil requires 14.82, 4.31, and 0.08 kWh for the distillation, cooling, and separation processes, respectively. Therefore, producing 1 mL of essential oil requires NT$ 0.3486, NT$ 0.1014, and NT$ 0.0019, respectively. The water usage for distillation is assumed to be the same proportion to raw materials as in Mu'azu *et al*. (2019), which is 42.86%, with a daily 6-hour distillation process. The annual water cost for distillation is NT$ 7,015. Cooling water usage is 45 liters per day with two water changes, resulting in an annual water cost of NT$ 1,730, based on the average water cost in Taiwan of NT$ 9.24 per cubic meter. Packaging costs, based on market data, for a 5 mL amber glass bottle with a PE stopper, dropper, or just a screw cap, excluding shipping, range from NT$ 7.44 to NT$ 29.1, with an average cost of NT$ 23. Assuming a bulk order discount of 30% and shipping costs amounting to 5% of the purchase cost, the analysis uses a packaging material cost of NT$ 17 per 5 mL. Maintenance costs are 10% of the machinery and equipment costs

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annually.

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Table 3.6 Variable costs and fixed costs in essential oil extraction for 4,000 m^3

Extraction	Fixed Costs		Variable Costs		References
	Value	Unit	Value	Unit	
Reduced surface size					
Bandsaw	95,550	NT$			Po Chuan EnterPrising Co., LTD., 2023
Dust collector	112,500	NT$			
Rotary sawing machine	231,000	NT$			
Electricity			1.63476	NT$/kg	Chiu, 2023
Labor	459,228	NT$/year			Estimated
Maintenance	43,905	NT$/year			Estimated
Crush					
Crusher	944,026	NT$			Loh *et al.*, 2002
Electricity			0.38144	NT$/kg	Chiu, 2023
Labor	459,228	NT$/year			Estimated
Maintenance	94,403	NT$/year			Estimated
Distillation					
Distillation equipment	3,200,000	NT$			NTU Experimental Forest
Water	7,015	NT$/year			Estimated
Electricity			0.34857193	NT$/mL	Mu'azu *et al.*, 2019
Labor	3,673,824	NT$/year			Estimated
Maintenance	320,000	NT$/year			Estimated
Cooling					
Cooler	1,600,000	NT$			NTU Experimental Forest
Water	1,730	NT$/year			Estimated
Electricity			0.10137281	NT$/mL	Mu'azu *et al.*, 2019
Labor	1,836,912	NT$/year			Estimated
Maintenance	160,000	NT$/year			Estimated
Separation					
Oil separator	2,349,784	NT$			Market Value
Electricity			0.00376326	NT$/mL	Mu'azu *et al.*, 2019
Labor	1,836,912	NT$/year			Estimated
Maintenance	234,978	NT$/year			Estimated
Packaging					
Packaging machine	86,120	NT$			
Packaging materials			17	NT$/5 mL	Market Value
Electricity			0.08952	NT$/5 mL	Estimated
Labor	1,836,912	NT$/year			Estimated
Maintenance	8,612	NT$/year			Estimated
Transportation					
Freight-out			10.0665	Ton-km	Accounting and Statistics Office, 2023

doi:10.6342/NTU202403839

3.3 Net Present Value (NPV)

NPV is calculated by discounting the expected annual net cash flows over the project lifespan using the cost of capital or the required rate of return, and then subtracting the investment cost. If the NPV is greater than 0, the investment project is considered acceptable; otherwise, it is rejected.

The advantages of using this method include considering the time value of money, simplicity of calculation, and the ability to use different discount rates (i.e., cost of capital or required rate of return) for calculation. However, it is difficult to determine the discount rate, compare projects with different time spans, and use NPV for decision-making when funds are limited, which may not effectively utilize capital for investment. In this study, there are no investment cost limitations or differences in project durations.

The calculation of NPV is expressed as in equation (4).

$$NPV = \sum_{i=1}^{n} \frac{C_n}{(1+r)^n} - I_0 \qquad \text{equation (4)}$$

n is project life, C_n is cash flow in year n, r is the capital of cost rate or return rate on investment, I_0 is investment cost. In this study, n is 20 years, I_0 is FC and cost in the beginning of the investment, and required return rate on investment are 8, 10 and 12%.

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3.4 Internal Rate of Return (IRR)

The Present Value Return Method, also known as the Internal Rate of Return (IRR) method, calculates the IRR by discounting each year's net cash flow at the internal rate of return and setting the difference with the investment cost to zero. ◦

This method, like the NPV method, considers the time value of money and the returns over the entire project duration. It is also suitable for comparing projects with different investment amounts. However, it implies that the returns from the investment are reinvested at the IRR and can result in multiple rates of return in cases of frequent cash inflows and outflows. Therefore, NPV is more commonly used in investment decision-making. To avoid multiple rates of return in cases of frequent cash inflows and outflows, the Modified Internal Rate of Return (MIRR) method is used, as detailed in section 335. The IRR calculation is shown in equation (5).

$$I_0 = \sum_{i=1}^{n} \frac{C_n}{(1+r)^n} \qquad \text{equation (5)}$$

doi:10.6342/NTU202403839

3.5 Modified Internal Rate of Return (MIRR)

The Modified Internal Rate of Return (MIRR) is calculated by setting the present value of costs equal to the present value of the terminal value. The calculation is shown in equation (6).

$$\sum_{t=0}^{n} \frac{COF_t}{(1+k)^t} = \frac{\sum_{t=0}^{n} CIF_t (1+k)^{n-t}}{(1+MIRR)^n} \qquad \text{equation (6)}$$

COF represents cash outflows or the cost of the investment plan and *CIF* represents cash inflow. Cash outflows or investment plan costs are discounted using the corporate financing rate, while cash inflows are used to calculate the terminal value using the investment return rate. Since IRR reinvests at the investment return rate and MIRR reinvests at the cost of capital, MIRR is more reasonable for calculation and decision-making. Therefore, MIRR is one of the best indicators for assessing the true profitability of an investment plan. In this study, the corporate financing rate for loans from Taiwanese banks ranges from 2% to 12%. Therefore, the average rate of 7% is used for the financing rate, and the investment return rate is 10%.

doi:10.6342/NTU202403839

3.6 Payback Period method (PP) and Discounted Payback Period method (DPP)

The Payback Period method calculates the payback period by dividing the net investment (i.e., I_0 minus the gain from disposing of old equipment) by the annual net cash inflows. This method is simple to calculate but does not consider the time value of money. The calculation is shown in equation (7).

$$Payback\ Period = \frac{Investment}{Annual\ Cash\ Flow} \qquad \text{equation (7)}$$

The Discounted Payback Period method involves discounting each year's net cash inflows and outflows, then subtracting these discounted values from the net investment. The period when the net investment minus the cumulative discounted cash flows equals zero is the discounted payback period.

doi:10.6342/NTU202403839

3.7 Breakeven Point Analysis (BPA)

Breakeven point analysis can be divided into an analysis of quantity and an analysis of sales. When analyzing quantity, the calculation involves dividing fixed costs by the contribution margin (CM, which is the selling price minus the variable cost). This gives the break-even quantity (BEP(Q)), which is the sales volume at which there is neither profit nor loss (i.e., the minimum sales volume required to break even). When analyzing sales revenue, the calculation involves dividing fixed costs by the contribution margin ratio (CM%, which is the contribution margin divided by the selling price) or calculating BEP(Q) and then multiplying it by the selling price to get the break-even sales amount (BEP(Sales)). The calculation formulas for both are shown in equations (8) and (9) respectively.

$$BEP(Q) = \frac{FC}{Sale\ Price(SP) - VC} \qquad \text{equation (8)}$$

$$BEP(Sales) = \frac{FC}{\frac{SP-VC}{SP}} = \frac{FC}{CM\%} = SP \times BEP(Q) \qquad \text{equation (9)}$$

doi:10.6342/NTU202403839

3.8 Operating Leverage (OL)

Operating leverage is the contribution margin divided by net profit. It indicates the percentage change in net profit when sales change by a certain percentage. The higher the operating leverage, the greater the percentage change in net profit that the company will experience when sales change by 1%, indicating higher business risk for the company. The calculation is shown in equation (10).

$$Operating\ Leverage = \frac{CM}{Net\ Incom(NI)} \qquad \text{equation (10)}$$

3.9 Life Cycle Cost (LCC)

Life cycle cost analysis involves categorizing and analyzing costs at each stage of a product's life cycle (such as applying the value chain or the process) to determine which parts of the costs should be improved. In this study, we analyze the processes of the sawmill and pellet plant over a 20-year period and provide recommendations for improvements based on the quantities in different parts of the processes.

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4. Results

4.1 Results of NPV

Figures 4.1 - 4.3 show the actual results for dimensional lumber (DL), wood pellets (WP), and essential oil extraction (EO). The chart titles are formatted as Process–NPV project life, discount rate, such as dimensional lumber-NPV 20 years, 8%, represented as DL-$NPV_{20,\ 8\%}$. The horizontal axis labels represent Harvest Volume-Wood Utilization Rate, for example, 4,000 harvest volume and 30% wood utilization rate are labeled as 4,000 - 30. Apart from the negative values calculated for various harvest volumes at a 30% wood utilization rate, the other values in Figure 4.1 are positive. The ranges for different discount rates are NT$ 48,563,718 – NT$ 2,199,705,938, NT$ 40,071,229 - NT$ 1,899,300,816, NT$ 33,274,287 - NT$ 1,658,872,373, respectively. From Figure 4.1, it can be understood that with increased scale and higher wood utilization rates, producing dimensional lumber in Taiwan is a viable investment. However, at various harvest volumes with a 30% wood utilization rate, the production of dimensional lumber in Taiwan is not feasible.

In Figure 4.2, the production of wood pellets using residual materials results in negative values across various harvest volumes and wood utilization rates. The calculated results ranges are NT$ (13,120,951) – NT$ (115,716,859), NT$ (12,104,258)

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– NT$ (102,043,088), NT$ (11,290,550) – NT$ (91,099,322), respectively. These results indicate that under the conditions of harvest volumes between 4,000 – 40,000 and wood utilization rates of 30% – 60%, producing wood pellets from residual materials in Taiwan is not suitable for investment.

Figure 4.3 shows a trend opposite to dimensional lumber, with the calculated results decreasing and turning negative as the wood utilization rate increases. However, the graph with a 12% discount rate is unique, showing positive values starting at a harvest volume of 10,000 and increasing with higher volumes. The calculated results ranges (excluding negative values) are NT$ 1,406,875 – NT$ 545,859,170, NT$ 74,692 - NT$ 463,525,856 and NT$ 1,059,596 – NT$ 397,630,606, respectively. Figure 4.3 shows consistent results with 8% and 10% discount rates, indicating that essential oil extraction using residual materials is highly suitable for production in Taiwan across various harvest volumes and wood utilization rates except at 60%. At a 12% discount rate, it suggests that to profitably produce essential oil from residual materials in Taiwan, a minimum harvest volume of 10,000 m^3 and wood utilization rates between 30% - 50% are required. In summary, based on the NPV results, producing dimensional lumber is not feasible at a 30% wood utilization rate, and producing wood pellets is not suitable for Taiwan's forestry industry. Conversely, essential oil extraction is not feasible at a 60% wood utilization rate. For Taiwan's forestry industry, the combination of

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dimensional lumber and essential oil extraction processes is highly suitable. They can generate profits at different harvest volumes and wood utilization rates of 40% and 50%, with maximum profitability achieved between 40% - 50%.

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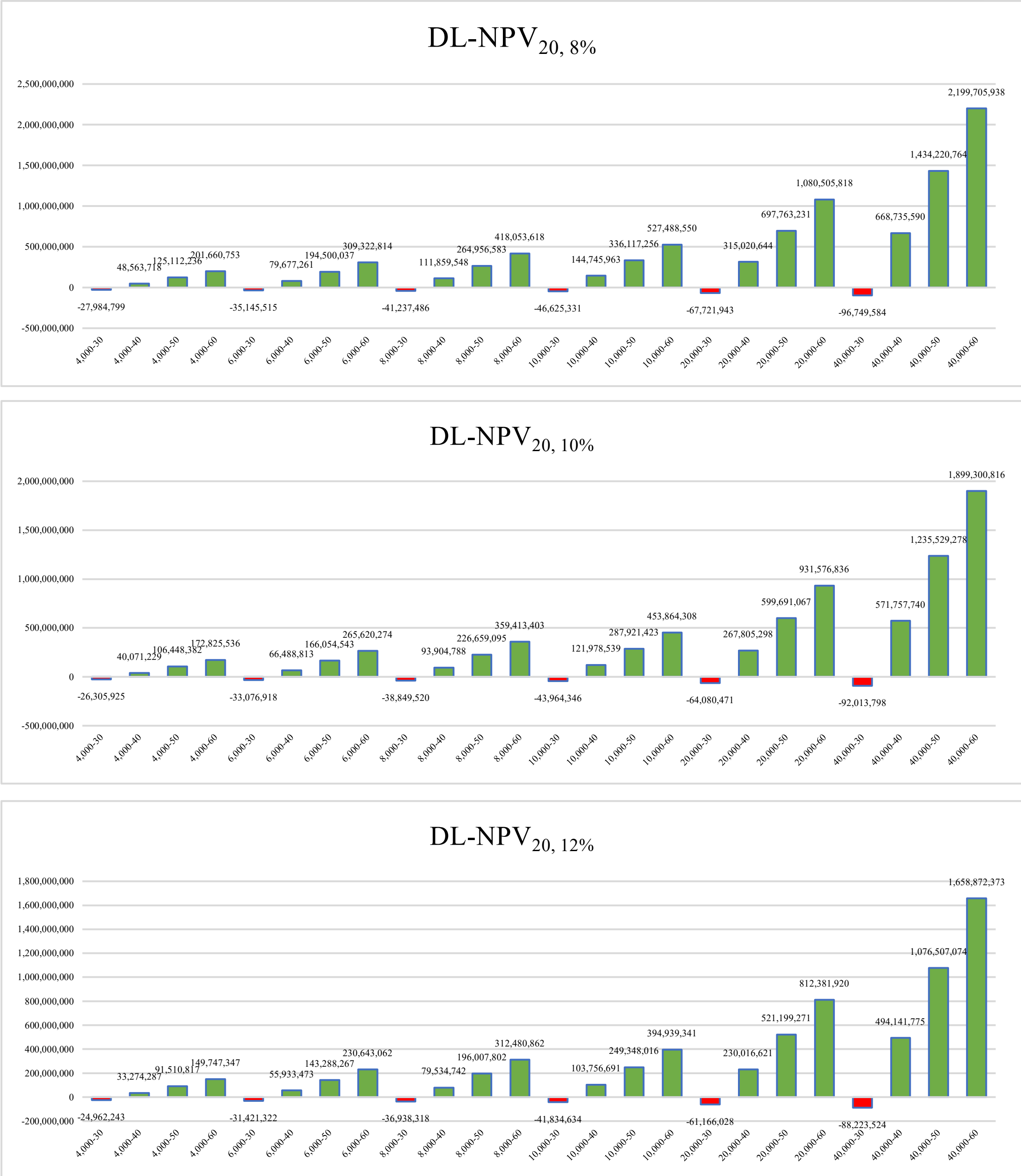

Figure 4.1 The NPV results of Dimensional Lumber (DL).

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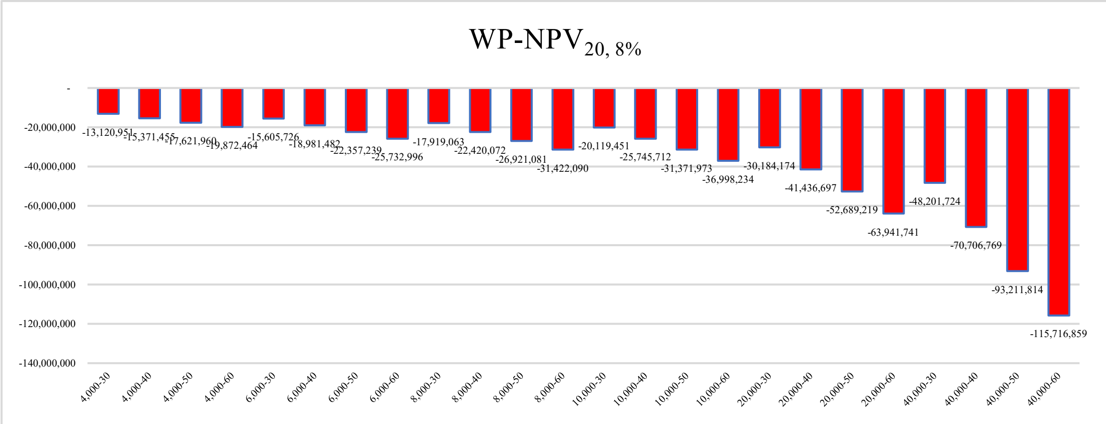

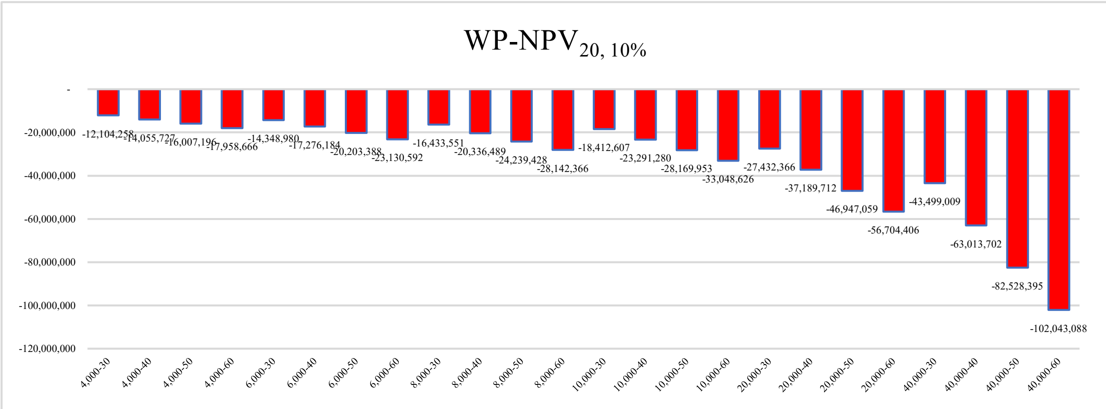

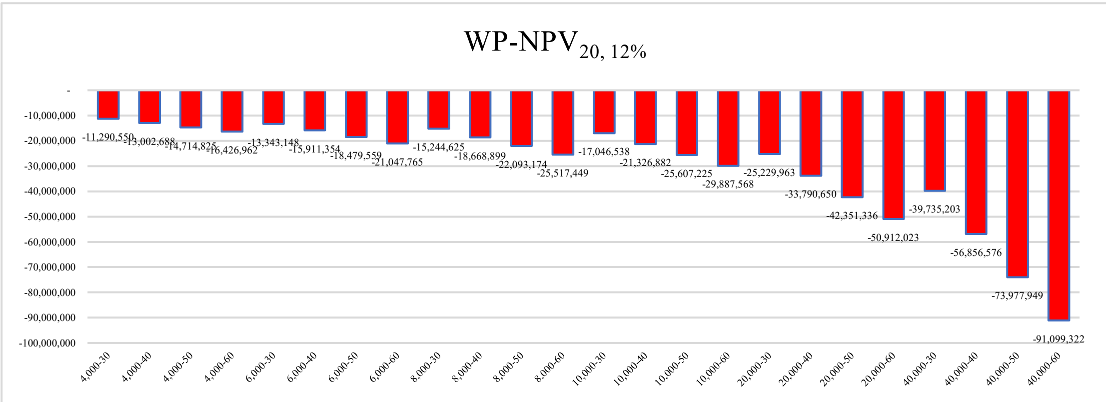

Figure 4.2 The NPV results of Wood Pellets (WP).

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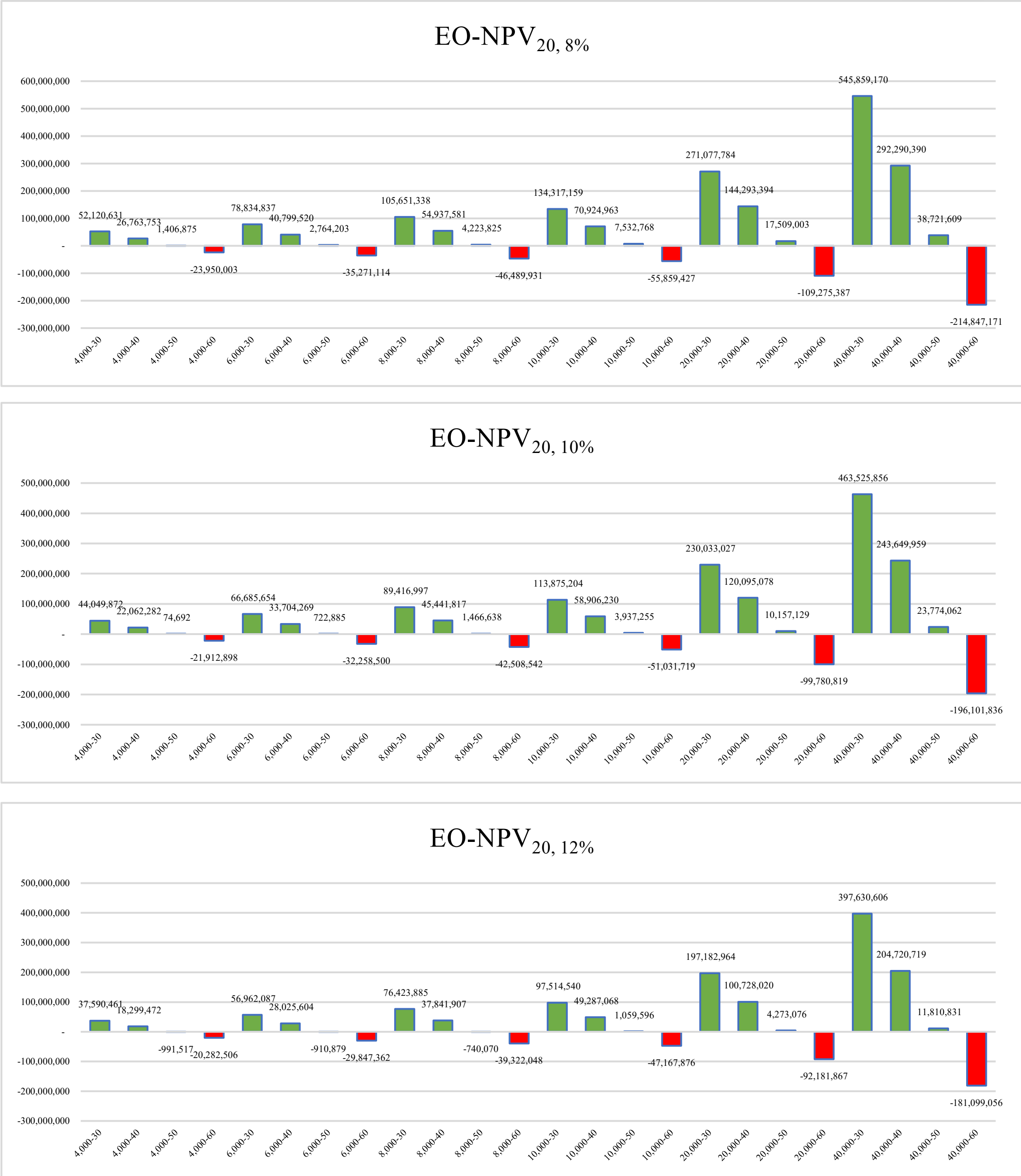

Figure 4.3 The NPV results of Essential Oil (EO).

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4.2 Results of IRR and MIRR

Figure 4.4 shows the internal rate of return (IRR) for each process, and Figure 4.5 shows the modified internal rate of return (MIRR) for each process. Appendix Table A. 6 provides the actual IRR and MIRR for each process. The vertical axis represents the rate of return, and the horizontal axis represents the wood utilization rate. Each line represents a different assumed harvest volume. The internal rate of return (IRR) for dimensional lumber in Figure 4.4 shows linear growth with increasing wood utilization rates and exponential growth with increasing harvest volumes. However, when observing the modified internal rate of return (MIRR), there is rapid growth initially, followed by slower growth that approaches a plateau. For the essential oil extraction process, the IRR shows a linear decline between 30% and 50% wood utilization rates and a slower decline between 50% and 60%. The MIRR declines in a curved shape. This phenomenon may be due to not performing detailed calculations for non-linear trends in wood utilization rates. For example, not calculating for 31%, 32%, 33%, etc., or for more precise decimal points might lead to observed trends in expected return rates that are curved rather than linear. The IRR for dimensional lumber ranges from 42.37% to 376.82%, which is significantly higher compared to the 10.13% to 85.55% for essential oil extraction. After adjustment, the MIRR for dimensional lumber, while

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still very high, indicates that this process is highly suitable for Taiwan's forestry industry under different harvest volumes and wood utilization rates of 40% to 60%. The MIRR for essential oil extraction, after adjustment, ranges from 10.05% to 21.48%, making it suitable for Taiwan's forestry industry, except at a 60% wood utilization rate. Based on the NPV results from Figure 4.1, it can be seen that the wood pellet process in Figures 4.4 and 4.5 shows a 0% return rate across various scales and wood utilization rates, indicating that wood pellet production is not suitable for development.

In summary, based on the IRR and MIRR results, dimensional lumber production is not feasible at a 30% wood utilization rate, essential oil extraction is not feasible at a 60% wood utilization rate, and wood pellet production is not suitable overall. The best combination, consistent with the NPV results from Figure 4.1, is dimensional lumber and essential oil extraction processes, which can maximize returns at wood utilization rates between 40% and 50%.

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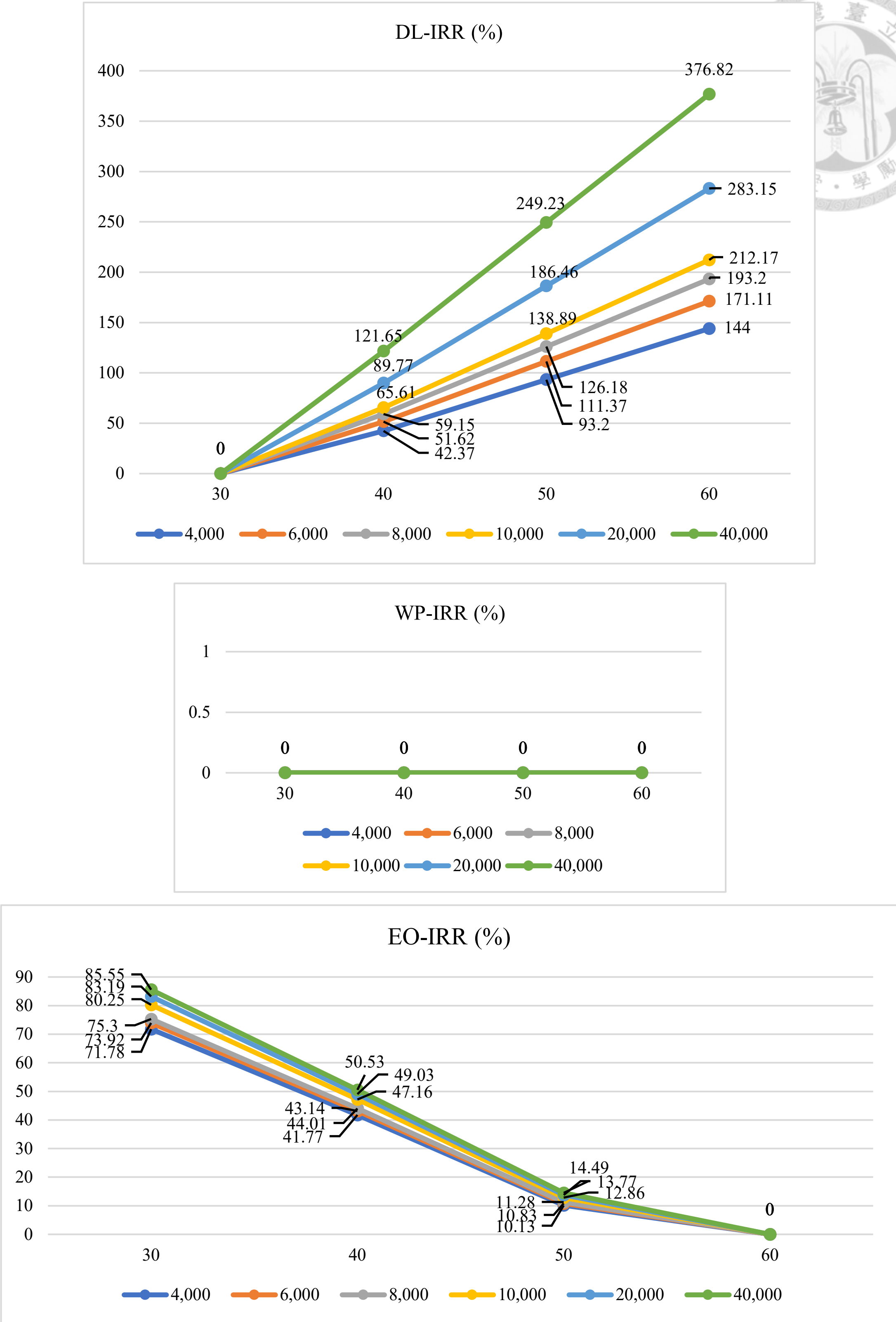

Figure 4.4 The IRR results of each process.

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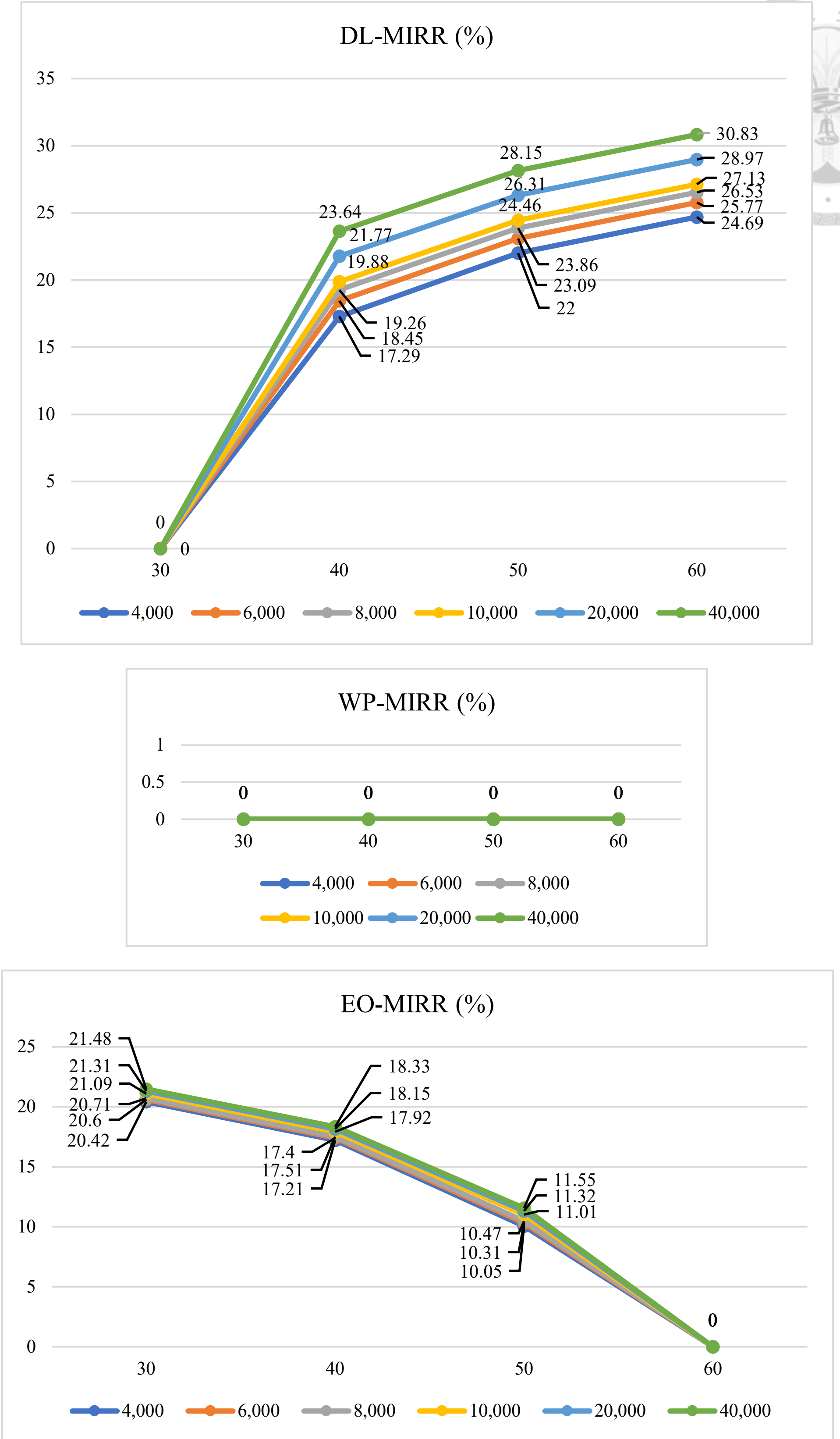

Figure 4.5 The MIRR results of each process.

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4.3 Results of PP and DPP

Figures 4.6 and 4.7 show the payback period (PP) and discounted payback period (DPP) for dimensional lumber and essential oil extraction, respectively. Appendix Table A. 7 provides the actual results for the payback period and discounted payback period. The PP results indicate that, except for the 30% wood utilization rate where dimensional lumber cannot recoup the investment within the project duration, all other scenarios can recoup the investment within 3 years. The payback period decreases with increased scale and wood utilization rate, with the longest being 2.36 years and the shortest being 99 days. For essential oil extraction, the investment can be recouped within 10 years. The payback period increases with scale but shows exponential growth with increased wood utilization rates, with the longest being 8.44 years and the shortest being 1.17 years. When considering the time value of money, the DPP results show the same increasing trend for dimensional lumber and decreasing trend for essential oil extraction as the PP results. Dimensional lumber can still recoup the investment within 3 years after considering the time value of money, with the longest payback period increasing by 172 days to 2.83 years and the shortest increasing by 7 days to 106 days. Essential oil extraction takes longer to recoup the investment after considering the time value of money, with the shortest payback period increasing by 52 days and the longest

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increasing by 11.1 years to 19.51 years. However, it is still possible to recoup the investment within the 20-year project duration, making essential oil extraction an acceptable investment for Taiwan's forestry industry. Appendix Table A. 7 shows that wood pellets cannot recoup the investment within the project duration under any harvest volume or wood utilization rate, making wood pellet production unsuitable for utilizing residual materials in Taiwan's forestry industry.

From this section, it can be understood that dimensional lumber is suitable for production except at a 30% wood utilization rate, and essential oil extraction is suitable except at a 60% wood utilization rate. Wood pellets cannot recoup the investment within the project duration. The combination of dimensional lumber and essential oil extraction can recoup the investment within 20 years, and the profits from dimensional lumber can help recoup the investment for the essential oil extraction process more quickly.

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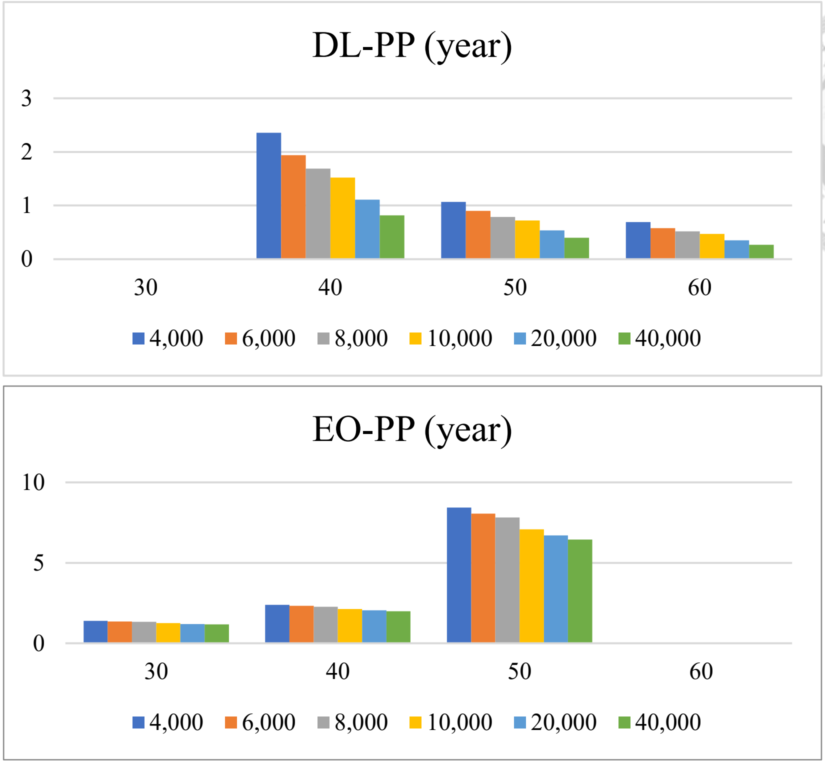

Figure 4.6 The PP results of DL and EO.

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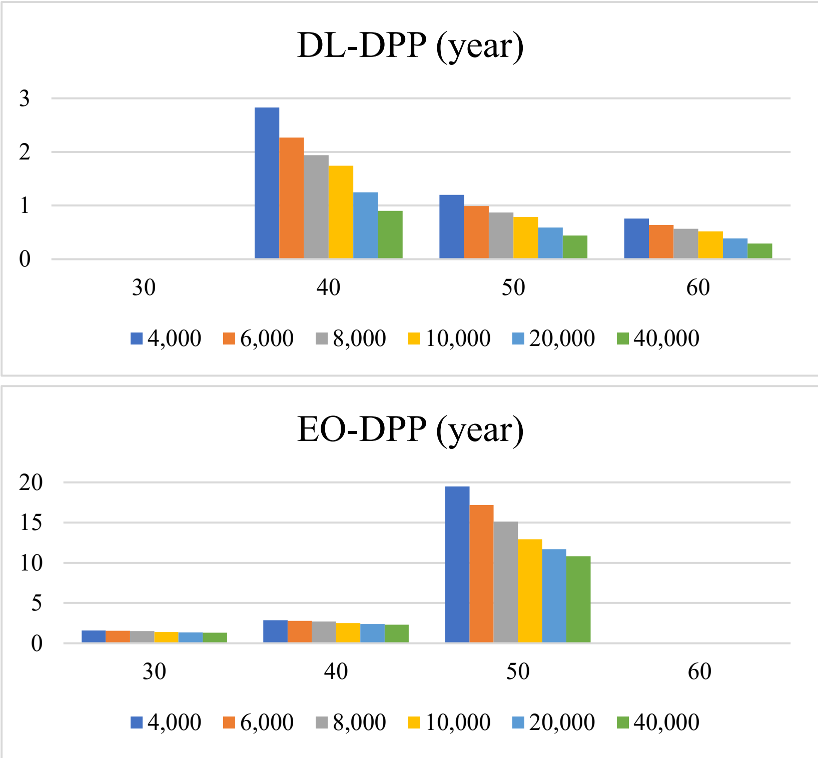

Figure 4.7 The DPP results of DL and EO.

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4.4 Summary of accept the project or not.

Through five methods—NPV, IRR, MIRR, PP, and DPP—it can be concluded that dimensional lumber, excluding the 30% wood utilization rate, can achieve stable profits in Taiwan. The current analysis indicates that developing wood pellets in Taiwan is not suitable for production. The essential oil extraction process is feasible except at a 60% wood utilization rate.

Considering overall benefits, the combination of dimensional lumber and essential oil extraction is highly suitable for production. Both processes can be manufactured at various harvest volumes with wood utilization rates of 40% and 50%. For maximizing profits, when the harvest volume exceeds 10,000 m^3 and the wood utilization rate is 40% or 50%, these conditions serve as the benchmark for investment and development in Taiwan's forestry industry.

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4.5 Results of operating leverage

Appendix Table A. 8 shows the operating leverage for each process. First, the operating leverage for the wood pellet process is negative. Generally, smaller operating leverage indicates lower business risk and stable profits. However, when the operating leverage is negative, it does not mean that the business risk is very low and stable profits can be achieved. Instead, it indicates greater losses. Therefore, the business risk for the wood pellet process is very high in this analysis and is not suitable for Taiwan's forestry development. For the dimensional lumber process, the operating leverage is negative only at a 30% wood utilization rate. In other cases, the operating leverage increases with higher wood utilization rates, following a pattern from 0.4 to 0.6 and then to 0.7. This indicates increasing business risk with higher wood utilization rates. The operating leverage for the essential oil extraction process is very stable. The business risk at different harvest volumes and the same wood utilization rates can be observed as follows: 0.32-0.33, 0.20-0.22, 0.05-0.06, and (0.19) -(0.17). Compared to dimensional lumber, the essential oil extraction process has lower business risk at 40% and 50% wood utilization rates and achieves stable profits under these conditions.

Overall, dimensional lumber and essential oil extraction at 40% and 50% wood utilization rates have acceptable business risks for Taiwan's forestry development and

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will bring stable profits.

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4.6 Breakeven point analysis

Appendix Table A. 9 shows the break-even analysis for each process. Figures 4.8 – 4.10 illustrate the break-even wood utilization rates for different harvest volumes for each process. The breakeven sale volume ranges from1,305 to 12,343 m^3 per year and sales amount ranges from NT$ 27,499,535 to 260,017,560. In the previous investment feasibility analysis for the dimensional lumber process, only the 30% wood utilization rate was not profitable, while other wood utilization rates were profitable. This indicates that the 30% wood utilization rate does not exceed the break-even wood utilization rate. From Figure 4.8, it can be understood that the break-even wood utilization rate for dimensional lumber slightly exceeds 30% by about 0.86% to 2.63% across different harvest volumes. To provide a basic reference for wood utilization in Taiwan's forestry industry, a minimum wood utilization rate applicable to different harvest volumes is needed. Therefore, the rate should be set at 32.63%, or for practical implementation, it can be rounded to 33% (i.e., the highest break-even wood utilization rate in this analysis). Appendix Table A. 9 also provides the minimum selling prices, which decrease with higher wood utilization rates and larger harvest volumes. The minimum selling price ranges from NT$ 11,599 to NT$ 22,778.

In Appendix Table A. 9, for the wood pellet process, the annual break-even sales

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volume is at least over one million kilograms, which translates to needing to harvest nearly 5,500 cubic meters of wood annually. This amount increases with higher harvest volumes and wood utilization rates. Additionally, it can be observed that the annual harvest volume for the wood pellet process exceeds the maximum sustainable harvest limits. Therefore, to improve the wood pellet process, efforts should be focused on cost reduction rather than increasing the harvest scale and wood utilization rate. From Figure 4.9, it can be observed that as the harvest volume increases, the break-even wood utilization rate for the wood pellet process gradually appears, reaching 0.82% at 10,000 m^3, and then the highest wood utilization rate for the next two harvest volumes is about 7%. However, this is clearly unrealistic in terms of actual wood utilization rates. The contribution margin for wood pellets is 30.44%, while for dimensional lumber it is 92.53%. It is illogical to sacrifice the production of high-contribution-margin products for low-contribution-margin ones. Furthermore, to maximize overall profit and achieve higher wood utilization rates for both primary and by-products, more trees would need to be cut, potentially leading to unsustainable forestry management and exacerbating climate change. Therefore, improvements in the wood pellet process can only be considered by reducing costs or increasing selling prices. In Appendix Table A. 9, the minimum selling price, except for the 4,000 m^3 harvest volume, ranges from NT$ 10 to NT$ 13 per kilogram, while the others are in the range of NT$ 9 to NT$ 12 per kilogram.

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Thus, without changing the original cost structure and considering 4,000 m^3 as the baseline production capacity, the minimum selling price for wood pellets should be NT$ 12 per kilogram. Comparing this to the FAO statistics database, the unit export price of wood pellets from Taiwan in 2022 was NT$ 7.76 per kilogram. The minimum selling price calculated from the break-even analysis is still too high, and even in the international market, this is a very high price without considering taxes. Therefore, increasing the price of wood pellets to achieve higher wood utilization rates is not suitable for the production of wood pellets in Taiwan's forestry industry. Cost improvements will be discussed in the next section on life cycle cost analysis.

As shown in Appendix Table 9, the break-even extraction volume for the essential oil extraction process ranges from 700,270 to 6,896,486 mL per year, with sales amounts ranging from NT$ 17,500,402 to NT$ 172,412,159. Compared to the dimensional lumber process, the sales amount is 33.69% to 36.36% less. This is because the contribution margin for essential oil extraction is 22.17% less than that of dimensional lumber, requiring more production and sales to reach the break-even point. Additionally, the selling price of essential oils is only 0.12% of that of dimensional lumber. From Figure 4.10, it can be observed that as the harvest volume increases, the break-even wood utilization rate slowly increases from 52.28% to 53.00%. If the cost structure remains unchanged and only the selling price is adjusted, the minimum selling

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prices for essential oil extraction, as shown in Appendix Table A. 9, are as follows regardless of harvest volume as follow: 30% wood utilization rate for NT$ 19, 40% wood utilization rate for NT$ 21, 50% wood utilization rate: NT$ 24 and 60% wood utilization rate: NT$ 28.

In summary, the minimum wood utilization rate for dimensional lumber is 33%, with the lowest selling price being NT$ 11,599 under conditions of high harvest volume and high wood utilization rate. For the wood pellet process, the break-even wood utilization rate begins at 0.82% at a harvest volume of 10,000 m^3, with the minimum selling price being NT$ 9. However, this price is still too high compared to the FAO statistics database, indicating a need for cost improvements. The essential oil extraction process has a maximum wood utilization rate of up to 53.00%, with a minimum selling price of NT$ 19. Combining the production of dimensional lumber and essential oil extraction, Taiwan's forestry wood utilization rate should be between 33% and 53%. Achieving a wood utilization rate of 53% will yield the maximum profit.

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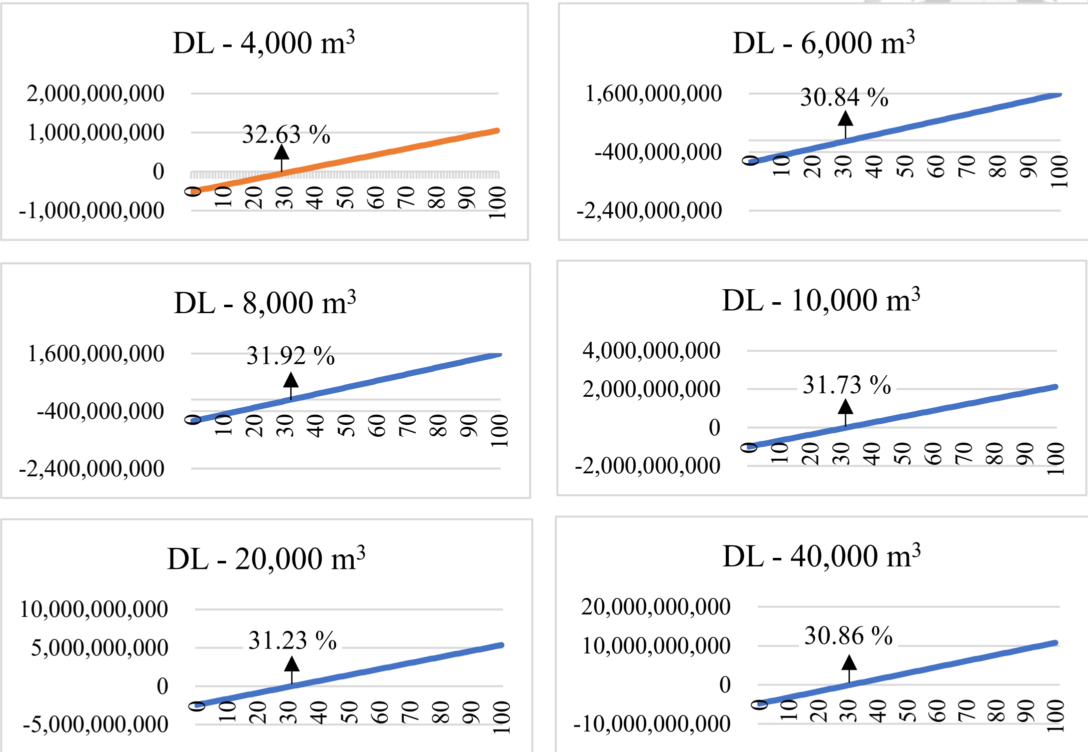

Figure 4.8 Breakeven point of wood utilization percentage for DL.

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Figure 4.9 Breakeven point of wood utilization percentage for WP.

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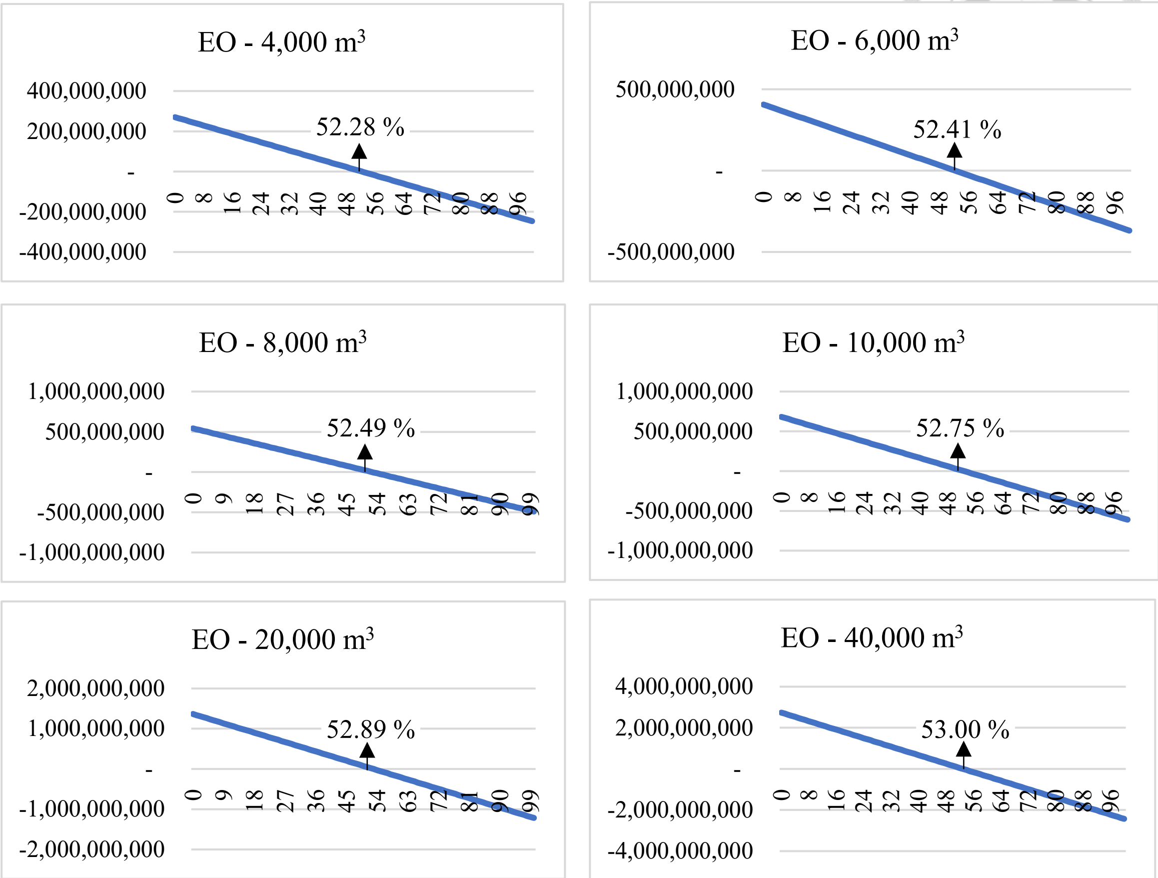

Figure 4.10 Breakeven point of wood utilization percentage for EO.

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4.7 Life cycle costs analysis

Appendix Table A. 10 shows the percentage of life cycle costs relative to sales amounts for each process, and Appendix Table A. 11 provides detailed results of the life cycle costs for each process. The net income for dimensional lumber, when profitable, is at least 17.04% and up to 44.96%, increasing with larger harvest volume and higher wood utilization rates. The highest cost proportion is for lumber sawing. Observing this step in Appendix Table A. 11 reveals that most of the costs come from raw material costs. For the same wood utilization rate (40% – 50%) at different harvest volumes, the proportions are 49.58%, 39.67%, and 33.06%, respectively. The second highest cost proportion is for drying, ranging from 6.54% to 10.03%, followed by processing, which ranges from 4.33% to 6.44%.

In the wood pellet process, the three highest costs are pelletizing, transportation, and reduced surface size costs. Transportation costs account for 29.57% in every scenario. Therefore, it is recommended to either purchase vehicles for transportation or lease them to reduce these costs. Granulation costs are the primary cost in this process, ranging from 26.62% to 43.86% in this analysis. These costs decrease with an increase in harvest volume and wood utilization rate. The cost for surface size reduction ranges from 24.68% to 31.37%, and this cost is only incurred for edge materials. If the edge

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materials and wood chunks are used for other treatments, the results are as shown in Appendix Table A. 12, taking a harvest volume of 4,000 as an example. In this case, the net profit margin changes from -20.00% to -57.85% to -82.04% to -176.07%. This indicates that edge materials and wood chunks are not causing losses in the wood pellet process but are instead providing substantial profits. At this point, the top three costs are pelletizing, packaging and crush. Therefore, to enable the development of the wood pellet process in Taiwan under the assumptions of this analysis, a detailed examination of variable and fixed costs is necessary. Besides implementing the previously mentioned transportation cost recommendations, labor costs account for at least 34.89% to as much as 61.05% of the entire wood pellet process. To reduce labor costs, it is advisable to adopt automated equipment and shift to automated production. Next, the electricity cost consistently accounts for 26.08% in any scenario. The equipment at the NTU Experimental Forest woodworking factory may be outdated, leading to increased power consumption. Thus, it is essential to replace, or upgrade outdated and abnormally power-consuming equipment. Additionally, the heat generated in the drying process of the dimensional lumber production can be utilized for thermoelectric power generation to reduce electricity costs.

Lastly, for the essential oil extraction process, the net profit margin ranges from 3.21% to 23.13%. The top three costs are packaging, distillation and cooling and

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separation (the difference between these two step costs is less than 0.5%). The packaging cost accounts for 20.84% – 26.28%. After subdividing the step costs, packaging materials account for a maximum of 13.60% under any circumstance. This price is based on the market average, assuming a 30% discount and an additional 5% shipping cost. However, the actual purchase cost through a professional factory producing amber glass bottles with lids may be lower. Therefore, this cost is acceptable and does not need improvement, though in actual operations, it may be obtained at a more favorable price. The distillation cost accounts for 17.50% – 29.75%. After subdividing the costs, labor costs account for 14.31% - 25.04%, while other costs are less than 1.5%, and even less than 1%. A possible solution is to reduce labor costs through automation. For example, using automated equipment to accurately monitor distillation conditions and assigning 1 - 2 people to handle any issues that arise during the distillation process. Finally, cooling and separation account for 8.50% - 14.57% and 8.54% – 14.94%, respectively. Upon further breakdown, the high labor cost accounts for 7.15%. For both processes, labor involves 2 people responsible for feeding materials and taking care of the equipment, and 2 people to transport the essential oil to the filling area. Cost-saving methods for these steps could include using tools like pallet trucks to transport large quantities of separated essential oil at once, reducing the labor needed for feeding materials and transporting to the filling area.

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5. Conclusions

Through NPV, IRR, MIRR, PP, and DPP, it can be understood that the development of dimensional timber and essential oil extraction processes in Taiwan is a profitable investment. The conditions are that the timber utilization rate is above 30% and below 60%, while the wood pellet process is not suitable for development under the assumptions in this analysis for Taiwan's forestry. The breakeven timber utilization rate for dimensional timber is at least 33%, with a minimum selling price of NT$11,599 per cubic meter. For essential oil extraction, the breakeven timber utilization rate is a maximum of 53%, with a minimum selling price of NT$19 per milliliter. Combining the two can bring high profits to Taiwan's forestry, with a profitable timber utilization rate of 33% – 53%. Through breakeven analysis, it can also be understood that the wood pellet process will only start to breakeven at a very high yield (10,000 m^3) with a breakeven timber utilization rate of 0.82% and a minimum selling price of NT$9 per kilogram. However, this price is still higher than the 2022 average export price of wood pellets from Taiwan according to the FAO statistical database, indicating that the wood pellet process needs cost improvements. Through lifecycle costing, for dimensional timber, the main step costs are lumber sawing, drying, and processing. For essential oil extraction, the main step costs are distillation, packaging, and cooling and separation. Except for the relatively high cost

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of packaging materials, adjusting labor costs can bring more profits to the process. For wood pellets, the main costs are transportation, labor, and electricity. Transportation costs can be reduced through leasing or owning transport tools for delivery. Labor costs can be reduced by using more automated equipment, such as fully automated wood pellet production equipment from Tsung Chang Machinery Co., LTD. (2024) and RICHi (2024), which can reduce labor and electricity costs. Lastly, electricity costs may need to be addressed by replacing or updating old equipment or by generating electricity through the heat produced in the drying step of the standard timber process. According to this analysis, producing standard timber and extracting essential oils from remaining materials is the best combination for Taiwan. The wood pellet process requires further cost reduction to mass-produce using residual materials. However, this analysis considers only the economic aspects and does not extensively address the other two sustainability dimensions - environmental and social. Therefore, future research should consider environmental issues such as carbon tax, environmental costs, and carbon benefits, as well as social aspects like poverty, which can prevent the purchase of carbon-reducing products.

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Appendixes

Table A.1 The price of essential oil of Japanese Cedar and Taiwan Fir.

Tree Species	Supplier	Capacity (mL)	Currency	Price (NT$)	Unit Price (NT$ / mL)	Reference Link
Japanese Cedar	Fussen	10	NT$	1,400	140	https://www.fussenaroma.com/products/cryptomeria-japonica-leaves-essentail-oil
	OSHADHI	3	NT$	900	300	https://www.canjune.com/oshadhi/product/cryptomeria-japonica
	梵宇健康生活	5	NT$	675	135	https://www.funyu.store/product/sugi/
	Flavor Life	3	NT$	550	183	https://www.decentrossi.com/products/flavorlife-sugi-3ml
	J'Olie et CO	10	€	721	72	https://www.jolieetco.com/essential-oil/japanese-cedar/
	Real Botany	10	$	3,543	354	https://www.realbotany.com/products/sugi-japanese-cedar
	Essentia Azorica	100	€	1,964	20	https://essentiaazorica.com/en/product/japanese-cedar-cryptomeria-japonica/
	WMS & CO.	8	NT$	1,052	132	https://wmscoshop.com/products/japanese-essential-oil-yoshino-cedar
	Perfect Potion	10	$	1,487	149	https://www.perfectpotion.com.au/products/sugi-wood-pure-essential-oil
	Aso Oguni-Sugi Lab	5	¥	747	149	https://waseiyulife.com/en/products/ogunisugi_eo?variant=45622629531932
	Aroma Vera	100	£	13,411	134	https://www.amazon.co.uk/Aroma-Vera-Professional-Essential-Cedarwood/dp/B01DEV533K
	Ninjaroma	5	¥	673	135	https://ninjaroma.jp/en/products/essentialoil5sugi

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Table A.1 The price of essential oil of Japanese Cedar and Taiwan Fir (countinued).

Tree Species	Supplier	Capacity (mL)	Currency	Price (NT$)	Unit Price (NT$ / mL)	Reference Link
Japanese Cedar	Aisu	10	$	2,233	223	https://aisuessence.com/product/kitayama-sugi-essential-oil/
	Mantra Aroma Therapy	10	₤	1,835	183	https://www.ebay.co.uk/itm/144944123771
	N/A	1,000	NT$	17,367	17	https://shopee.tw/100-%E5%A4%A9%E7%84%B6%E6%A4%8D%E7%89%A9%E7%B2%BE%E6%B2%B9-%E5%A4%A7-%E6%97%A5%E6%9C%AC%E6%9F%B3%E6%9D%89%E7%B2%BE%E6%B2%B9-%E5%B1%8B%E4%B9%85%E6%9D%89-i.323715376.24015101526?sp_atk=95d0ba64-391d-4668-9b6f-54af9dca8de9&xptdk=95d0ba64-391d-4668-9b6f-54af9dca8de9
	Plant Therapy	5	NT$	823	165	https://www.mamashopping.com/products/plant-therapy-sugi-essential-oil---5ml
	美杜莎	15	NT$	646	43	https://shopee.tw/%E8%91%A1%E8%90%84%E7%89%99%E7%B2%BE%E6%B2%B95ML-10ML-15ML%E3%80%90%E7%8F%BE%E8%B2%A8%EF%BC%8F%E5%96%AE%E6%96%B9%EF%BC%8F%E8%B6%85%E5%80%BC%EF%BC%8F100-
	森林邦	10	NT$	2,000	200	https://foutw.waca.ec/product/detail/1324125

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Table A.1 The price of essential oil of Japanese Cedar and Taiwan Fir (countinued).

Tree Species	Supplier	Capacity (mL)	Currency	Price (NT$)	Unit Price (NT$ / mL)	Reference Link
Taiwan Fir	Fussen	10	NT$	1,400	140	https://www.fussenaroma.com/products/taiwania-cryptomerioides-essentail-oil
	Formosa	10	NT$	800	80	https://shop.toastliving.com/shop/sensitude/essential-oil-and-roll-on-oil/essential-oil-taiwan-fir/
	MUZEN	5	NT$	3,150	630	https://www.dhyana.store/zh-TW/products/taiwania-fir
	Pinkoi	5	NT$	440	88	https://en.pinkoi.com/product/QjZQAuGB
	TOAST	10	$	1,161	116	https://theobjectroom.com/products/tolse03031

$:Unite State of America dollar；NT$: New Taiwan dollar；¥: Yen；₤: the pound；€: Euro

Exchange rate in 2022: $ to NT$: 29.777；¥ to NT$: 0.226441；₤ to NT$: 36.70313；€ to NT$: 31.35518

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Table A.2 The market price of horizontal bandsaw.

Name	Model	Price (USD)	References
Factory Supply Industrial Carbide Blades Vertical Band Saw Machine For Wood Working		27,000	https://www.alibaba.com/product-detail/Factory-Supply-Industrial-Carbide-Blades-Vertical_1600974383048.html?spm=a2700.galleryofferlist.normal_offer.d_title.53c465cacXmWDZ
Wood Cutting Vertical Band Sawmill with Log Carriage for sale	MJ3210	50,000	https://www.alibaba.com/product-detail/MJ3210-Wood-Cutting-Vertical-Band-Sawmill_60752715203.html?spm=a2700.galleryofferlist.normal_offer.d_title.2dca65caO0yWZp
Automatic Vertical Band Saw Mills For Timber Sawing	MJ3215B	15,200	https://www.alibaba.com/product-detail/MJ3215B-Automatic-Vertical-Band-Saw-Mills_1600448030716.html?spm=a2700.galleryofferlist.normal_offer.d_title.421665caXO7iQ5
Vertical band saw machine for wood cutting		13,000	https://www.alibaba.com/product-detail/Vertical-band-saw-machine-for-wood_1600974184257.html?spm=a2700.galleryofferlist.normal_offer.d_title.dce165ca4NqgWN
Log Cutting Band Sawmill Twin Vertical Band Saw Machine Twin Bandsaw Sawmill Line		50,000	https://www.alibaba.com/product-detail/Log-Cutting-Band-Sawmill-Twin-Vertical_1600785644092.html?spm=a2700.galleryofferlist.normal_offer.d_title.dce165ca4NqgWN
Hydraulic Portable Saw mill for wood chainsaw sawmill vertical sawmill machine bandsaw sawmill rima	MJH1000D	19,600	https://www.alibaba.com/product-detail/Hydraulic-Portable-Saw-mill-for-wood_1600434186371.html?spm=a2700.galleryofferlist.normal_offer.d_title.dce165ca4NqgWN

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Table A.3 The market price of vertical bandsaw.

Name	Model	Price (USD)	References
NEWEEK band saw machine for long wood cutting wood cutting band wood cutting vertical band saw machine		2,880	https://www.alibaba.com/product-detail/NEWEEK-band-saw-machine-for-long_1600473832655.html
sawmill wood machine vertical log bandsaw timber band saw machine wood cutting		2,300	https://www.alibaba.com/product-detail/sawmill-wood-machine-vertical-log-bandsaw_1600892196844.html
14" Woodworking Band Saw Electric Vertical Wood Cutting Machine		1,800	https://www.alibaba.com/product-detail/High-quality-automatic-wood-cutting-vertical_1600473739909.html
Band saw machine RMJ347E Vertical wood cutting band saw machines	BMJ347E	1,500	https://www.alibaba.com/product-detail/Band-saw-machine-RMJ347E-Vertical-wood_62019205053.html
Woodworking Band Saw Machine MJ396 Bandsaw For Log Wood Cutting	MJ396	1,800	https://www.alibaba.com/product-detail/Woodworking-Band-Saw-Machine-MJ396-Bandsaw_1600092079728.html
Golden promise vertical band saw machine for wood working horizontal metal cutting band saw machine	MJG396V	1,786	https://www.alibaba.com/product-detail/Golden-promise-vertical-band-saw-machine_1601002620437.html
woodworking vertical timber cutting band wood saw machine		1,085	https://www.alibaba.com/product-detail/woodworking-vertical-timber-cutting-band-wood_62378059304.html
Band Saw Wood Cutting Machine Saw Woodworking Automatic Vertical Furniture Manufacturing Machinery Band Saw	MJG396U	2,550	https://www.alibaba.com/product-detail/Band-Saw-Wood-Cutting-Machine-Saw_1600720410336.html
2021 Hot selling Fully automatic Woodworking		1,800	https://www.alibaba.com/product-detail/2021-Hot-selling-

doi:10.6342/NTU202403839

Machine Auto Feed Vertical Band Saw Wood Cutting Machine			Fully-automatic-Woodworking_1600391908729.html
Heavy duty woodworking large wood cutting band saw machine vertical resaw band saw	MJ650	2,500	https://www.alibaba.com/product-detail/MJ650-Heavy-duty-woodworking-large-wood_60819014832.html
Wood Saw, Vertical Style Cutting Saw with Tilt Table, Wood Cut Saw Machine	TBS-457	2,390	https://www.alibaba.com/product-detail/TBS-457-TTMC-Wood-Saw-Vertical_238370623.html
Woodworking Vertical Band Saw Machine Wood Cutting Machine With Band Saw Woodworking	MJG396	2,620	https://www.alibaba.com/product-detail/MJG396woodworking-automatic-vertical-bandsaw-cutting-machine_1600491157996.html
NEWEEK woodworking vertical wood cutting band saw machine		2,500	https://www.alibaba.com/product-detail/NEWEEK-woodworking-vertical-wood-cutting-band_60718517615.html
		1,570	https://www.alibaba.com/product-detail/High-Efficient-Portable-Vertical-Wood-Band_289147900.html

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Table A.4 The market price of 4 side moulder.

Name	Model	Price (USD)	References
4 Side Molder Machinelegno Planer, Macchina Pialla Machine Four Side Moulder 4 Sided Planer Moulders for Railway Sleeper	KFSM521	10000-22000	https://kingmarks.en.made-in-china.com/product/twafygqTAskj/China-4-Side-Molder-Machinelegno-Planer-Macchina-Pialla-Machine-Four-Side-Moulder-4-Sided-Planer-Moulders-for-Railway-Sleeper.html
Germany Quality Four Sided Moulder with Multiple Rip Saw Machine	M621ZS	23000-25000	https://3059dcdc1e5fc08e.en.made-in-china.com/product/lwOtEjRCLcrX/China-Germany-Quality-Four-Sided-Moulder-with-Multiple-Rip-Saw-Machine.html
Hicas High Speed Floor Wood Planer Machine 4 Sided Moulder for Sale	MB620	20000	https://hicasmachinery.en.made-in-china.com/product/KFmaCikvkVhe/China-Hicas-High-Speed-Floor-Wood-Planer-Machine-4-Sided-Moulder-for-Sale.html
Hicas Solid Wood Door Six Spindle Four Sided Planer Moulder for Sale	MB523/623/520/620	32600-36600	https://hicasmachinery.en.made-in-china.com/product/QwCTeWVGAihK/China-Hicas-Solid-Wood-Door-Six-Spindle-Four-Sided-Planer-Moulder-for-Sale.html
Hicas 3600kg Wood Foor 4 Sided Planer Moulder for Sale	MB520A	17000-18000	https://hicasmachinery.en.made-in-china.com/product/vdCapfLEaHVG/China-Hicas-3600kg-Wood-Foor-4-Sided-Planer-Moulder-for-Sale.html
	MB4023DR	10000-15000	https://sosnmachinery.en.made-in-china.com/product/zZVTbPwJHIrR/China-Wood-Four-Side-

doi:10.6342/NTU202403839

			Planer-Moulder-4-Side-Moulder.html
Wood Planer Machine Wood Four Side Moulder Cutting Machine	VH623V	25000-26000	https://vhold123.en.made-in-china.com/product/CnsRrHwvnckm/China-Wood-Planer-Machine-Wood-Four-Side-Moulder-Cutting-Machine.html
Planer For Woodworking Double Side Planer Thicknesser Surface Planer ML9321	ML9321	12108	https://jayamac.en.made-in-china.com/product/DvNxqBbAljUS/China-Planer-For-Woodworking-Double-Side-Planer-Thicknesser-Surface-Planer-ML9321.html
Mmlti Functional Combined Woodworking Machine Four-Sided Planer Moulding Machine		13980	https://elasn2022.en.made-in-china.com/product/OwiaVWcKQspX/China-Mmlti-Functional-Combined-Woodworking-Machine-Four-Sided-Planer-Moulding-Machine.html
Wood Photo Frame Automatic Four Side Planer Moulder	MB415	19980	https://elasn2022.en.made-in-china.com/product/NZYasILCljrg/China-Wood-Photo-Frame-Automatic-Four-Side-Planer-Moulder.html
Wood Working Machinery Four Side Planer with Saw	VH621HS	19000-20000	https://vhold123.en.made-in-china.com/product/lxjRsEJcOMkf/China-Wood-Working-Machinery-Four-Side-Planer-with-Saw.html
210mm Woodworking Moulder Machine Four Side Wood Planer Moulder	M421A	13000	https://jayamac.en.made-in-china.com/product/sdXAGCHYburt/China-210mm-Woodworking-Moulder-Machine-Four-Side-Wood-Planer-Moulder.html

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Table A.5 Actual results of net present value of each process.

Unit: NT$ 1,000,000

HV (m^3/year)	4,000				6,000				8,000			
WU (%)	30	40	50	60	30	40	50	60	30	40	50	60
Dimensional Lumber												
$NPV_{8\%, 20}$	27.985	28.563	125.112	201.661	35.146	79.677	194.500	309.323	41.238	111.860	264.957	418.054
$NPV_{10\%, 20}$	36.305	40.071	106.448	172.826	33.077	66.489	166.054	265.620	38.850	93.905	226.659	359.413
$NPV_{12\%, 20}$	24.962	33.274	91.511	149.747	31.421	55.934	143.288	230.643	36.938	79.535	196.008	312.481
Process Wood Pellets Process												
$NPV_{8\%, 20}$	13.121	15.372	17.622	19.873	15.606	18.982	22.357	25.733	17.919	22.420	26.921	31.422
$NPV_{10\%, 20}$	12.104	14.056	16.007	17.959	14.349	17.276	23.131	23.131	16.434	20.337	24.239	28.142
$NPV_{12\%, 20}$	11.291	13.003	14.715	16.427	13.343	15.911	21.048	21.048	15.245	18.669	22.093	25.518
Essential Oil Process												
$NPV_{8\%, 20}$	52.121	26.764	1.407	23.850	78.834	40.800	2.764	35.271	105.651	54.938	4.224	46.490
$NPV_{10\%, 20}$	44.050	22.062	0.075	21.913	66.686	33.704	0.723	32.259	89.417	45.442	1.467	42.509
$NPV_{12\%, 20}$	37.590	18.300	0.992	20.283	56.962	28.025	0.911	29.847	76.424	37.842	0.740	39.322

HV: Harvest Volume；WU: Wood Utilization

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Table A.5 Actual results of net present value of each process (continued).

Unit: NT$ 1,000,000												
HV (m^3/year)	10,000				20,000				40,000			
WU (%)	30	40	50	60	30	40	50	60	30	40	50	60
Dimensional Lumber Process												
$NPV_{8\%, 20}$	46.625	144.746	336.117	527.489	67.722	315.021	697.763	1,080.506	93.750	668.736	1,434.221	2,199.706
$NPV_{10\%, 20}$	43.934	121.979	287.921	453.864	64.081	267.806	599.691	931.577	92.014	571.758	1,235.529	1,899.301
$NPV_{12\%, 20}$	41.835	103.757	249.348	394.939	61.166	230.017	521.199	812.392	88.224	494.142	1,076.507	1,658.872
Wood Pellets Process												
$NPV_{8\%, 20}$	20.120	25.746	31.372	36.998	30.184	41.437	52.689	63.942	48.202	70.707	93.212	115.717
$NPV_{10\%, 20}$	18.413	23.291	28.170	33.049	27.432	37.190	46.947	56.704	43.499	63.014	82.528	102.043
$NPV_{12\%, 20}$	17.047	21.327	25.607	29.888	25.230	33.791	42.351	50.912	39.735	56.857	73.978	91.099
Essential Oil Process												
$NPV_{8\%, 20}$	134.317	70.925	7.533	55.859	271.078	144.293	17.509	109.275	545.859	292.290	38.722	214.847
$NPV_{10\%, 20}$	113.875	58.906	3.937	51.032	230.033	120.095	10.157	99.781	463.526	243.650	23.774	196.102
$NPV_{12\%, 20}$	97.515	49.287	1.060	47.168	197.183	100.728	4.273	92.182	397.631	204.721	11.811	181.099

HV: Harvest Volume；WU: Wood Utilization

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Table A.6 Actual results of internal return rate and modified internal return rate of each process.

Unit: %

HV (m^3/year)	4,000				6,000				8,000			
WU (%)	30	40	50	60	30	40	50	60	30	40	50	60
Dimensional Lumber												
IRR	0	42.37	93.20	144.00	0	51.62	111.37	171.11	0	59.15	126.18	193.20
MIRR	0	17.29	22.00	24.69	0	18.45	23.09	25.77	0	19.26	23.86	26.53
Process Wood Pellets Process												
IRR	0	0	0	0	0	0	0	0	0	0	0	0
MIRR	0	0	0	0	0	0	0	0	0	0	0	0
Essential Oil Process												
IRR	71.78	41.77	10.13	0	73.92	43.14	10.83	0	75.30	44.01	11.28	0
MIRR	20.42	17.21	10.05	0	20.60	17.40	10.31	0	20.71	17.51	10.47	0

HV: Harvest Volume；WU: Wood Utilization

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Table A.6 Actual results of internal return rate and modified internal return rate of each process (continued).

Unit: %												
HV (m^3/year)	10,000				20,000				40,000			
WU (%)	30	40	50	60	30	40	50	60	30	40	50	60
Dimensional Lumber Process												
IRR	0	65.61	138.89	212.17	0	89.77	186.46	283.15	0	121.65	249.23	376.82
MIRR	0	19.88	24.46	27.13	0	21.77	26.31	28.97	0	23.64	28.15	30.83
Wood Pellets Process												
IRR	0	0	0	0	0	0	0	0	0	0	0	0
MIRR	0	0	0	0	0	0	0	0	0	0	0	0
Essential Oil Process												
IRR	80.25	47.16	12.86	0	83.19	49.03	13.77	0	85.55	50.53	14.49	0
MIRR	21.09	17.92	11.01	0	21.31	18.15	11.32	0	21.48	18.33	11.55	0

HV: Harvest Volume；WU: Wood Utilization

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Table A.7 Actual results of payback period and discounted payback period of each process.

Unit: year

HV (m^3/year)	4,000				6,000				8,000			
WU (%)	30	40	50	60	30	40	50	60	30	40	50	60
Dimensional Lumber												
PP	0	2.36	1.07	0.69	0	1.94	0.90	0.58	0	1.69	0.79	0.52
DPP	0	2.83	1.20	0.76	0	2.27	0.99	0.64	0	1.94	0.87	0.57
Process Wood Pellets Process												
PP	0	0	0	0	0	0	0	0	0	0	0	0
DPP	0	0	0	0	0	0	0	0	0	0	0	0
Essential Oil Process												
PP	1.39	41.77	10.13	0	1.35	2.32	8.05	0	1.33	2.27	7.82	0
DPP	1.59	2.87	19.51	0	1.54	2.77	17.17	0	1.51	2.71	15.11	0

HV: Harvest Volume；WU: Wood Utilization

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Table A.7. Actual results of payback period and discounted payback period of each process (continued).

Unit: year												
HV (m^3/year)	10,000				20,000				40,000			
WU (%)	30	40	50	60	30	40	50	60	30	40	50	60
Dimensional Lumber Process												
PP	0	1.52	0.72	0.47	0	1.11	0.54	0.35	0	0.82	0.40	0.27
DPP	0	1.74	0.79	0.52	0	1.25	0.59	0.39	0	0.90	0.44	0.29
Wood Pellets Process												
PP	0	0	0	0	0	0	0	0	0	0	0	0
DPP	0	0	0	0	0	0	0	0	0	0	0	0
Essential Oil Process												
PP	1.25	2.12	7..08	0	1.20	2.04	6.71	0	1.17	1.98	6.44	0
DPP	1.41	2.51	12.94	0	1.35	2.40	11.68	0	1.31	2.32	10.84	0

HV: Harvest Volume；WU: Wood Utilization

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Table A.8 Operating leverage results of each process.

HV (m^3/year)	4,000				6,000				8,000				10,000				20,000				40,000			
WU (%)	30	40	50	60	30	40	50	60	30	40	50	60	30	40	50	60	30	40	50	60	30	40	50	60
Dimensional Lumber Process																								
OL	0.31	0.40	0.61	0.71	0.26	0.42	0.62	0.72	0.22	0.44	0.63	0.73	0.20	0.45	0.64	0.73	0.14	0.47	0.66	0.75	0.10	0.49	0.67	0.76
Wood Pellets Process																								
OL	0.66	0.93	1.32	1.90	0.53	0.78	1.14	1.67	0.46	0.70	1.04	1.55	0.42	0.65	0.98	1.48	0.32	0.54	0.85	1.31	0.26	0.48	0.77	1.21
Essential Oil Extraction Process																								
OL	0.32	0.20	0.05	0.19	0.32	0.21	0.05	0.19	0.33	0.21	0.06	0.19	0.33	0.21	0.06	0.18	0.33	0.22	0.06	0.18	0.33	0.22	0.06	0.17

HV: Harvest Volume；WU: Wood Utilization

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Table A.9 Breakeven point analysis of each process

HV (m³/year)	Unit	4,000				6,000				8,000			
WU (%)		30	40	50	60	30	40	50	60	30	40	50	60
Dimensional Lumber Process													
BEP(Q)	m^3/y	1,305				1,850				2,554			
BEP(Sale)	NT$	27,499,535				38,976878				53,793,955			
HV	m^3/y	4,351	3,263	2,611	2,176	6,167	4,626	3,700	3,084	8,512	6,384	5,107	4,256
BEP(%)	%	32.63				30.84				31.92			
MSP	NT$	22,778	17,477	14,297	12,176	22,176	21,610	16,610	16,601	22,313	17,129	14,018	11,944
Wood Pellets Process													
BEP(Q)	kg/y	1,096,861				1,517,959				1,933,701			
BEP(Sale)	NT$	8,676,167				12,007,056				15,295,579			
HV	m^3/y	5,467	6,378	7,654	9,568	7,566	8,827	10,593	13,241	9,638	11,425	13,494	16,867
BEP(%)	%	N/A				N/A				N/A			
MSP	NT$	10	10	11	13	9	10	11	12	9	10	10	12
Essential Oil Extraction Process													
BEP(Q)	mL/y	700,270				1,047,591				1,394,471			
BEP(Sale)	NT$	17,506,756				26,189774				34,861,784			
HV	m^3/y	2,726	3,181	3,817	4,772	4,078	4,758	5,710	7,139	5,428	6,333	7,601	9,503
BEP(%)	%	52.28				52.41				52.49			
MSP	NT$	19	21	24	28	19	21	24	28	19	21	24	28

HV: Harvest Volume，y: year，MSP: Minimum Sale Price，N/A: Not Applicable

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Table A.9 Breakeven point analysis of each process (continued)

HV (m³/year)	Unit	10,000				20,000				40,000			
WU (%)		30	40	50	60	30	40	50	60	30	40	50	60
Dimensional Lumber Process													
BEP(Q)	m^3/y	3,173				6,247				12,343			
BEP(Sale)	NT$	66,839,854				131,591,412				260,017,560			
HV	m^3/y	10,576	7,932	6,346	5,288	20,822	15,617	12,493	10,411	41,143	30,857	24,686	20,572
BEP(%)	%	31.73				31.23				30.86			
MSP	NT$	22,189	17,036	13,943	11,882	21,867	16,794	13,750	11,721	21,623	16,611	13,604	11,599
Wood Pellets Process													
BEP(Q)	kg/y	2,345,915				4,377,704				8,375,302			
BEP(Sale)	NT$	18,556,190				34,627,637				66,248,637			
HV	m^3/y	11,693	13,642	16,370	20,463	21,820	25,457	30,549	38,186	41,746	48,704	58,445	73,056
BEP(%)	%	0.82				7.46				7.11			
MSP	NT$	9	10	10	12	9	9	10	11	9	9	10	11
Essential Oil Extraction Process													
BEP(Q)	mL/y	1,733,086				3,456,213				6,896,486			
BEP(Sale)	NT$	43,327,147				86,405,330				172,412,159			
HV	m^3/y	6,748	7,873	9,448	11,812	13,454	15,698	18,839	23,553	26,846	31,323	37,592	46,997
BEP(%)	%	52.75				52.89				53.00			
MSP	NT$	19	21	24	28	19	21	24	28	19	21	24	28

HV: Harvest Volume，y: year，MSP: Minimum Sale Price

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Table A.10 Life cycle costs analysis of each process expressed as proportion of sale.

HV (m^3/y)	4,000				6,000				8,000			
WU (%)	30	40	50	60	30	40	50	60	30	40	50	60
Dimensional Lumber Process												
Sales	100	100	100	100	100	100	100	100	100	100	100	100
Costs												
Lumber Sawing	75.95	57.00	45.63	38.05	75.86	56.93	45.58	38.01	75.80	56.89	45.54	37.98
Drying	12.35	10.03	8.63	7.70	11.78	9.59	8.28	7.41	11.42	9.23	8.07	7.23
Processing	8.39	6.44	5.27	4.49	8.29	6.36	5.21	4.44	8.23	6.32	5.17	4.41
Mechanical Strength Grading	7.75	5.81	4.65	3.88	7.13	5.35	4.28	3.57	6.75	5.07	4.06	3.38
Transportation	3.68	3.68	3.68	3.68	3.68	3.68	3.68	3.68	3.68	3.68	3.68	3.68
Total Costs	108.13	82.96	67.87	57.80	106.74	81.92	67.23	57.11	105.89	81.28	66.52	56.68
Net Income	8.13	17.04	32.13	42.20	6.74	18.08	32.97	42.89	5.89	18.72	33.48	43.32
Wood Pellets												
Sales	100	100	100	100	100	100	100	100	100	100	100	100
Costs												
Reduced Surface Size	23.89	25.56	27.88	31.37	23.71	25.34	27.62	31.05	23.59	25.20	27.46	30.84
Crush	15.61	17.52	20.18	24.17	13.91	15.52	17.79	21.18	12.85	14.29	16.31	19.34
Pelletizing	28.47	31.89	36.68	43.86	28.01	31.35	36.03	43.05	27.73	31.02	35.64	42.56
Packaging	22.45	23.88	25.88	28.87	19.59	20.54	21.88	23.88	18.17	18.88	19.88	21.38
Transportation	29.57	29.57	29.57	29.57	29.57	29.57	29.57	29.57	29.57	29.57	29.57	29.57
Total Costs	120.00	128.41	140.18	157.85	114.78	122.33	132.89	148.73	111.90	118.96	128.85	143.68

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Net Income	20.00	28.41	40.18	57.85	14.78	22.33	32.89	48.73	11.90	18.96	28.85	43.68
	Essential Oil Extraction											
Sales	100	100	100	100	100	100	100	100	100	100	100	100
Costs												
Reduced Surface Size	7.49	8.13	9.03	10.37	7.46	8.09	8.97	10.30	7.43	8.06	8.94	10.26
Crush	5.19	5.87	6.84	8.28	5.10	5.78	6.72	8.14	5.05	5.72	6.65	8.05
Distillation	17.60	20.30	24.08	29.75	17.60	20.30	24.08	29.75	17.60	20.30	24.08	29.75
Cooling	8.50	9.85	11.74	14.57	8.50	9.85	11.74	14.57	8.50	9.85	11.74	14.57
Separation	8.54	9.96	11.95	14.94	8.54	9.96	11.95	14.94	8.54	9.96	11.95	14.94
Packaging	20.88	22.08	23.76	26.28	20.87	22.07	23.75	26.26	20.86	22.06	23.74	26.26
Transportation	9.40	9.40	9.40	9.40	9.40	9.40	9.40	9.40	9.40	9.40	9.40	9.40
Total Costs	77.59	85.59	96.79	113.59	77.47	85.44	96.61	113.36	77.39	85.35	96.50	113.22
Net Income	22.41	14.41	3.21	-13.59	22.53	14.56	3.39	-13.36	22.61	14.65	3.50	-13.22

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Table A.10 Life cycle costs analysis of each process expressed as proportion of sale (continued)

HV (m^3/y)	10,000				20,000				40,000			
WU (%)	30	40	50	60	30	40	50	60	30	40	50	60
Dimensional Lumber Process												
Sales	100	100	100	100	100	100	100	100	100	100	100	100
Costs												
Lumber Sawing	75.76	56.86	45.52	37.96	75.66	56.79	45.46	37.91	75.59	56.73	45.42	37.87
Drying	11.17	9.14	7.92	7.11	10.52	8.65	7.53	6.78	10.03	8.28	7.23	6.54
Processing	8.19	6.29	5.15	4.39	8.09	6.22	5.09	4.34	8.03	6.17	5.05	4.31
Mechanical Strength Grading	6.49	4.87	3.90	3.25	5.80	4.35	3.48	2.90	5.28	3.96	3.17	2.64
Transportation	3.68	3.68	3.68	3.68	3.68	3.68	3.68	3.68	3.68	3.68	3.68	3.68
Total Costs	105.29	80.84	66.16	56.38	103.76	79.69	65.24	55.62	102.60	78.82	64.55	55.04
Net Income	5.29	19.16	33.84	43.68	3.76	2031	34.76	44.38	2.60	21.18	35.45	44.96
Wood Pellets Process												
Sales	100	100	100	100	100	100	100	100	100	100	100	100
Costs												
Reduced Surface Size	23.51	25.11	27.35	30.70	23.30	24.86	27.05	30.33	23.14	24.68	26.83	30.06
Crush	12.11	13.43	15.28	18.05	10.20	11.20	12.60	14.69	14.00	15.63	17.91	21.34
Pelletizing	27.53	30.79	35.36	42.21	27.01	30.19	34.64	41.31	26.62	29.73	34.09	40.62
Packaging	17.31	17.88	18.68	19.88	15.60	15.88	16.28	16.88	14.74	14.88	15.08	15.38
Transportation	29.57	29.57	29.57	29.57	29.57	29.57	29.57	29.57	29.57	29.57	29.57	29.57
Total Costs	110.03	116.78	126.23	140.40	105.67	111.70	120.13	132.78	108.06	114.49	123.48	136.97

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Net Income	10.03	16.78	26.23	40.40	5.67	11.70	20.13	32.78	8.06	14.49	23.48	36.97
	Essential Oil Extraction Process											
Sales	100	100	100	100	100	100	100	100	100	100	100	100
Costs												
Reduced Surface Size	7.42	8.04	8.92	10.23	7.37	7.99	8.86	10.16	7.34	7.95	8.81	10.10
Crush	5.02	5.68	6.60	7.99	4.92	5.57	6.47	7.82	4.85	5.49	6.37	7.70
Distillation	17.50	20.19	23.95	29.58	17.50	20.19	23.95	29.58	17.50	20.19	23.95	29.58
Cooling	8.45	9.79	11.67	14.49	8.45	9.79	11.67	14.49	8.45	9.79	11.67	14.49
Separation	8.47	9.88	11.85	14.81	8.47	9.88	11.85	14.81	8.47	9.88	11.85	14.81
Packaging	20.86	22.06	23.73	26.25	20.85	22.05	23.72	26.24	20.84	22.04	23.71	26.22
Transportation	9.40	9.40	9.40	9.40	9.40	9.40	9.40	9.40	9.40	9.40	9.40	9.40
Total Costs	77.12	85.04	96.13	112.76	76.98	84.87	95.92	112.50	76.87	84.74	95.77	112.31
Net Income	22.88	14.96	3.87	-12.76	23.02	15.13	4.08	-12.50	23.13	15.26	4.23	-12.31

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Table A.11 Life cycle costs of each process.

HV (m^3/y)	4,000				6,000				8,000			
WD (%)	30	40	50	60	30	40	50	60	30	40	50	60
Dimensional Lumber Process (Unit: NT$ 1,000)												
Sales	505,584	674,112	842,640	1,011	758,376	1,011,168	1,263,960	1,516,752	1,011,168	1,348,224	1,685,280	2,022,336
Costs												
Lumber Sawing												
Horizontal bandsaw	938	938	938	938	1,196	1,196	1,196	1,196	1,422	1,422	1,422	1,422
Vertical bandsaw	62	62	62	62	79	79	79	79	94	94	94	94
Raw materials	334,253	334,253	334,253	334,253	501,379	501,379	501,379	501,379	668,506	668,506	668,506	668,506
Electricity	797	1,063	1,329	1,594	1,196	1,594	1,993	2,391	1,594	2,126	2,657	3,188
Labor	45,923	45,923	45,923	45,923	68,884	68,884	68,884	68,884	91,846	91,846	91,846	91,846
Maintenance	2,000	2,000	2,000	2,000	2,551	2,551	2,551	2,551	3,031	3,031	3,031	3,031
Total	383,973	384,238	384,504	384,770	575,285	575,684	576,082	576,481	766,492	767,024	767,555	768,087
Drying												
Wood drying boiler	2,231	2,231	2,231	2,231	2,845	2,845	2,845	2,845	3,382	3,382	3,382	3,382
Dry kiln	4,276	4,276	4,276	4,276	5,453	5,453	5,453	5,453	6,481	6,481	6,481	6,481
Electricity	1,297	1,730	2,162	2,595	1,946	2,595	3,243	3,892	2,595	2,595	2,595	2,595
Diesel oil	14,085	18,780	23,475	28,170	21,127	28,170	35,212	42,255	28,170	37,560	46,950	56,340
Labor	27,554	27,554	27,554	27,554	41,331	41,331	41,331	41,331	55,107	55,107	55,107	55,107
Maintenance	13,013	13,013	13,013	13,013	16,598	16,598	16,598	16,598	19,725	19,725	19,725	19,725
Total	62,456	67,583	72,711	77,838	89,300	96,991	104,683	112,374	115,459	125,714	135,968	146,223

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Processing												
4 side moulder	685	685	685	685	874	874	874	874	1,038	1,038	1,038	1,038
Central dust collector												
Cutting machine	231	231	231	231	295	295	295	295	350	350	350	350
Electricity	2,957	3,943	4,928	5,914	4,435	5,914	7,392	8,871	5,914	7,885	9,857	11,828
Labor	36,738	36,738	36,738	36,738	55,107	55,107	55,107	55,107	73,477	73,477	73,477	73,477
Maintenance	1,832	1,832	1,832	1,832	2,336	2,336	2,336	2,336	2,777	2,777	2,777	2,777
Total	42,443	43,429	44,414	45,400	63,047	64,526	66,004	67,483	83,555	85,527	87,498	89,469
Mechanical Strength Grading												
MSR	6,927	6,927	6,927	6,927	8,835	8,835	8,835	8,835	10,500	10,500	10,500	10,500
Electricity	33	45	56	67	50	67	83	100	67	89	111	133
Labor	18,369	18,369	18,369	18,369	27,554	27,554	27,554	27,554	36,738	36,738	36,738	36,738
Maintenance	13,854	13,854	13,854	13,854	17,670	17,670	17,670	17,670	21,000	21,000	21,000	21,000
Total	39,184	39,195	39,206	39,218	54,109	54,126	54,143	54,159	68,304	68,326	68,349	68,371
Transportation												
Freight-out	18,616	24,822	31,027	37,232	27,924	37,232	46,541	55,849	37,232	49,643	62,.54	74,465
Total Costs	546,672	559,267	571,862	584,458	809,666	828,559	847,452	866,345	1,071,043	1,096,233	1,121,424	1,146,645
Net Income	41,088	114,845	270,778	426,710	51,290	182,609	416,508	650,407	59,875	251,991	563,856	875,722

Wood Pellets Process (Unit: NT$ 1,000)

Sales	105,306	90,262	75,218	60,175	157,958	135,393	112,828	90,262	210,611	180,524	150,437	120,349
Costs												
Reduced Surface Size												
Bandsaw	96	96	96	96	122	122	122	122	145	145	145	145

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Rotary sawing machine	231	231	231	231	295	295	295	295	350	350	350	350
Dust collector	113	113	113	113	144	144	144	144	171	171	171	171
Electricity	14,660	12,566	10,471	8,377	21,990	18,848	15,707	12,566	29,320	25,131	20,943	16,754
Labor	9,185	9,185	9,185	9,185	13,777	13,777	13,777	13,777	18,369	18,369	18,369	18,369
Maintenance	878	878	878	878	1,120	1,120	1,120	1,120	1,331	1,331	1,331	1,331
Total	25,162	23,067	20,973	18,879	37,447	34,305	31,164	28,022	49,685	45,497	41,308	37,120
Crush												
Crusher	944	944	944	944	1,204	1,204	1,204	1,204	1,431	1,431	1,431	1,431
Electricity	4,426	3,794	3,162	2,529	6,640	5,691	4,743	3,794	8,853	7,588	6,323	5,059
Labor	9,185	9,185	9,185	9,185	11,714	11,714	11,714	11,714	13,921	13,921	13,921	13,921
Maintenance	1,888	1,888	1,888	1,888	2,408	2,408	2,408	2,408	2,862	2,862	2,862	2,862
Total	16,443	15,811	15,178	14,546	21,966	21,017	20,069	19,12	27,067	25,802	24,537	23,273
Pelletizing												
Pelletizer	1,079	1,079	1,079	1,079	1,376	1,376	1,376	1,376	1,636	1,636	1,636	1,636
Electricity	8,376	7,179	5,983	4,786	12,563	10,769	8,974	7,179	16,751	14,358	11,965	9,572
Labor	18,369	18,369	18,369	18,369	27,554	27,554	27,554	27,554	36,738	36,738	36,738	36,738
Maintenance	2,158	2,158	2,158	2,158	2,753	2,753	2,753	2,753	3,272	3,272	3,272	3,272
Total	29,982	28,786	27,589	26,393	44,246	42,452	40,657	38,862	58,397	56,004	53,611	51,218
Packaging												
Packaging machine	3,007	3,007	3,007	3,007	3,007	3,007	3,007	3,007	3,007	3,007	3,007	3,007
Packaging materials	14,618	12,530	10,442	8,353	21,927	18,795	15,663	12,530	29,237	25,060	20,883	16,707
Maintenance	6,014	6,014	6,014	6,014	6,014	6,014	6,014	6,014	6,014	6,014	6,014	6,014
Total	23,640	21,552	19,463	17,375	30,949	27,817	24,684	21,552	38,258	34,081	29,905	25,728

doi:10.6342/NTU202403839

Transportation												
Freight-out	31,135	26,687	22,239	17,792	46,703	40,031	33,359	26,687	62,270	53,374	44,479	35,583
Total Costs	126,362	115,902	105,443	94,984	181,310	165,621	149,932	134,243	235,677	214,758	193,839	172,921
Net Income	21,056	25,640	30,225	34,809	23,352	30,228	37,105	43,981	25,065	34,234	43,403	52,571
Essential Oil Extraction Process (Unit: NT$ 1,000)												
Sales	513,596	440,225	366,854	293,484	770,394	660,338	550,282	440,225	1,027,193	880,451	733,709	586,967
Costs												
Reduced Surface Size												
Bandsaw	96	96	96	96	122	122	122	122	145	145	145	145
Rotary sawing machine	231	231	231	231	294	294	294	294	350	350	350	350
Dust collector	113	113	113	113	144	144	144	144	171	171	171	171
Electricity	18,806	16,119	13,433	10,746	28,209	24,179	20,149	16,119	37,612	32,239	26,866	21,493
Labor	18,369	18,369	18,369	18,369	27,554	27,554	27,554	27,554	36,738	36,738	36,738	36,738
Maintenance	878	878	878	878	1,120	1,120	1,120	1,120	1,331	1,331	1,331	1,331
Total	38,492	35,806	33,119	30,433	57,443	53,413	49,383	45,353	76,347	70,973	65,600	60,227
Crush												
Crusher	944	944	944	944	1,204	1,204	1,204	1,204	1,431	1,431	1,431	1,431
Electricity	5,431	16,119	13,433	10,746	8,146	6,982	5,819	4,655	10,861	9,310	7,758	6,206
Labor	18,369	18,369	18,369	18,369	27,554	27,554	27,554	27,554	36,738	36,738	36,738	36,738
Maintenance	1,888	1,888	1,888	1,888	2,408	2,408	2,408	2,408	2,862	2,862	2,862	2,862
Total	26,632	25,856	25,080	24,304	39,312	38,148	36,984	35,821	51,892	50,340	48,789	47,237
Distillation												
Distillation equipment	3,200	3,200	3,200	3,200	4,800	4,800	4,800	4,800	6,400	6,400	6,400	6,400

doi:10.6342/NTU202403839

Water	140	140	140	140	211	211	211	211	281	281	281	281
Electricity	7,161	6,138	5,115	4,092	10,742	,9207	,7673	6,138	14,322	12,276	10,230	8,184
Labor	73,477	73,477	73,477	73,477	110,215	110,215	110,215	110,215	146,953	146,953	146,953	146,953
Maintenance	6,400	6,400	6,400	6,400	9,600	9,600	9,600	9,600	12,800	12,800	12,800	12,800
Total	90,378	89,355	88,332	87,309	135,567	134,032	132,498	130,963	180,756	178,710	176,664	174,618
Cooling												
Cooler	1,600	1,600	1,600	1,600	2,400	2,400	2,400	2,400	3,200	3,200	3,200	3,200
Water	34	34	34	34	52	52	52	52	69	69	69	69
Electricity	2,083	1,785	1,488	1,190	3,124	2,678	2,231	1,785	4,165	3,570	2,975	2,380
Labor	36,738	36,738	36,738	36,738	55,107	55,107	55,107	55,107	73,477	73,477	73,477	73,477
Maintenance	3,200	3,200	3,200	3,200	4,800	4,800	4,800	4,800	6,400	6,400	6,400	6,400
Total	43,655	43,358	43,060	42,763	65,483	65,037	64,591	64,144	87,311	86,716	86,121	85,526
Separation												
Oil separator	2,350	2,350	2,350	2,350	3,525	3,525	3,525	3,525	4,700	4,700	4,700	4,700
Electricity	77	66	55	44	116	99	82	66	155	133	111	88
Labor	36,738	36,738	36,738	36,738	55,107	55,107	55,107	55,107	73,477	73,477	73,477	73,477
Maintenance	4,700	4,700	4,700	4,700	7,049	7,049	7,049	7,049	9,399	9,399	9,399	9,399
Total	43,865	43,854	43,843	43,832	65,797	65,781	65,764	65,748	87,730	87,708	87,686	87,664
Packaging												
Packaging machine	86	86	86	86	110	110	110	110	131	131	131	131
Packaging materials	69,849	59,871	49,892	39,914	104,774	89,806	74,838	59,871	139,698	119,741	99,784	79,828
Electricity	368	315	263	210	552	473	394	315	736	631	525	420
Labor	36,738	36,738	36,738	36,738	55,107	55,107	55,107	55,107	73,477	73,477	73,477	73,477

doi:10.6342/NTU202403839

Maintenance	172	172	172	172	220	220	220	220	261	261	261	261
Total	107,214	97,183	87,152	7,121	160,762	145,716	130,669	115,623	214,302	194,240	174,178	154,116
Transportation												
Freight-out	48,288	41,391	34,492	27,594	72,433	62,086	51,738	41,391	96,578	82,781	68,984	55,187
Total Costs	398,525	376,801	355,078	333,355	596,797	564,212	531,627	499,042	794,915	751,498	708,021	664,575
Net Income	115,072	63,424	11,777	-39,871	173,597	96,126	18,655	-58,817	232,278	128,983	25,688	-77,608

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Table. A.11: Life cycle costs of each process (continued)

HV (m^3/y)	10,000				20,000				40,000			
WD (%)	30	40	50	60	30	40	50	60	30	40	50	60
Dimensional Lumber Process (Unit: NT$ 1,000)												
Sales	1,263,960	1,685,280	2,106,600	2,527,920	2,527,920	3,370,560	4,213,200	5,055,840	5,055,840	6,741,120	8,426,400	10,111,680
Costs												
Lumber Sawing												
Horizontal bandsaw	1,626	1,626	1,626	1,626	2,464	2,464	2,464	2,464	3,735	3,735	3,735	3,735
Vertical bandsaw	107	107	107	107	162	162	162	162	246	246	246	246
Raw materials	835,632	835,632	835,632	835,632	1,671,264	1,671,264	1,671,264	1,671,264	3,342,528	3,342,528	3,342,528	3,342,528
Electricity	1,993	2,657	3,321	3,986	3,986	5,314	6,643	7,971	7,971	10,628	13,285	15,942
Labor	114,807	114,807	114,807	114,807	229,614	229,614	229,614	229,614	459,228	459,228	459,228	459,228
Maintenance	3,466	3,466	3,466	3,466	5,253	5,253	5,253	5,253	7,962	7,962	7,962	7,962
Total	957,630	958,294	958,956	959,623	1,912,743	1,914,071	1,915,400	1,916,728	3,821,670	3,824,327	3,826,984	3,829,641
Drying												
Wood drying boiler	3,866	3,866	3,866	3,866	5,860	5,860	5,860	5,860	2,727	2,727	2,727	2,727
Dry kiln	7,409	7,409	7,409	7,409	11,230	11,230	11,230	11,230	920	920	920	920
Electricity	3,243	4,325	5,406	6,487	6,487	8,649	10,811	12,974	12,974	17,298	21,622	25,947
Diesel oil	35,212	46,950	58,687	70,425	70,425	83,900	117,374	140,949	140,849	187,799	234,749	281,699
Labor	68,884	68,884	68,884	68,884	137,768	137,768	137,768	137,768	275,537	275,537	275,537	275,537
Maintenance	22,550	22,550	22,550	22,550	34,180	34,180	34,180	34,180	51,807	51,807	51,807	51,807
Total	141,165	153,984	166,803	179,621	265,950	291,587	317,224	342,861	507,070	558,344	609,619	660,830

doi:10.6342/NTU202403839

Processing												
4 side moulder	1,187	1,187	1,187	1,187	1,799	1,799	1,799	1,799	2,727	2,727	2,727	2,727
Central dust collector												
Cutting machine	400	400	400	400	607	607	607	607	920	920	920	920
Electricity	7,392	9,857	12,321	14,785	14,785	19,713	24,641	29,570	29,570	39,426	49,283	59,139
Labor	91,846	91,846	91,846	91,846	183,691	183,691	183,691	183,691	367,382	367,382	367,382	367,382
Maintenance	3,174	3,174	3,174	3,174	4,812	4,812	4,812	4,812	7,293	7,293	7,293	7,293
Total	104,000	106,464	108,928	111,392	205,693	210,622	215,550	220,478	407,891	417,748	427,604	437,461
Mechanical Strength Grading												
MSR	12,004	12,004	12,004	12,004	18,195	18,195	18,195	18,195	25,578	25,578	25,578	25,578
Electricity	83	111	139	167	167	222	278	334	333	445	556	667
Labor	45,923	45,923	45,923	45,923	91,846	91,846	91,846	91,846	183,691	183,691	183,691	183,691
Maintenance	24,008	24,008	24,008	24,008	36,389	36,389	36,389	36,389	55,156	55,156	55,156	55,156
Total	82,018	82,046	82,074	82,101	145,596	146,652	146,707	146,763	266,758	266,869	266,981	267,092
Transportation												
Freight-out	46,541	62,054	77,567	93,081	93,081	124,108	155,135	186,162	186,162	248,216	310,270	372,324
Total Costs	1,331,354	1,362,842	1,394,330	1,425,818	2,624,063	2,687,039	2,750,015	2,812,992	5,189,551	5,315,504	5,441,457	5,567,410
Net Income	67,394	322,438	712,270	1,102,102	96,143	683,521	1,463,185	2,242,848	133,711	1,425,616	2,984,943	4,544,270

Wood Pellets Process (Unit: NT$ 1,000)

Sales	263,264	225,655	188,046	150,437	526,529	451,310	376,092	300,873	1,053,057	902,620	752,184	1601,747
Costs												
Reduced Surface Size												

doi:10.6342/NTU202403839

Bandsaw	166	166	166	166	251	251	251	251	380	380	380	380
Rotary sawing machine	400	400	400	400	607	607	607	607	920	920	920	920
Dust collector	195	195	195	195	296	296	296	296	448	448	448	448
Electricity	36,650	31,414	26,178	20,943	73,299	62,828	52,357	41,885	146,598	125,656	104,713	83,771
Labor	22,961	22,961	22,961	22,961	45,923	45,923	45,923	45,923	91,846	91,846	91,846	91,846
Maintenance	1,522	1,522	1,522	1,522	2,306	2,306	2,306	2,306	3,496	3,496	3,496	3,496
Total	61,893	56,658	51,422	46,187	122,681	112,210	101,739	91,268	243,688	222,745	201,802	180,860
Crush												
Crusher	1,636	1,636	1,636	1,636	2,480	2,480	2,480	2,480	3,758	3,758	3,758	3,758
Electricity	11,066	9,485	7,904	6,323	22,132	18,970	15,809	12,647	44,264	37,940	31,617	25,294
Labor	15,916	15,916	15,916	15,916	24,124	24,124	24,124	24,124	91,846	91,846	91,846	91,846
Maintenance	3,272	3,272	3,272	3,272	4,959	4,959	4,959	4,959	7,517	7,517	7,517	7,517
Total	31,889	30,308	28,727	27,147	53,694	50,532	47,371	44,209	147,384	141,061	134,737	128,414
Pelletizing												
Pelletizer	1,870	1,870	1,870	1,870	2,855	2,855	2,855	2,855	4,296	4,296	4,296	4,296
Electricity	20,939	17,948	14,956	11,965	41,878	35,895	29,913	23,930	83,755	71,790	59,825	47,860
Labor	45,923	45,923	45,923	45,923	91,846	91,846	91,846	91,846	183,691	183,691	183,691	183,691
Maintenance	3,740	3,740	3,740	3,740	5,669	5,669	5,669	5,669	8,593	8,593	8,593	8,593
Total	72,472	69,481	66489	63,498	142,227	136,244	130,262	124,279	280,335	268,370	256,405	244,440
Packaging												
Packaging machine	3,007	3,007	3,007	3,007	3,007	3,007	3,007	3,007	3,007	3,007	3,007	3,007
Packaging materials	36,546	31,325	26,104	20,883	73,091	62,650	52,208	41,767	146,183	125,300	104,416	83,533

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Maintenance	6,014	6,014	6,014	6,014	6,014	6,014	6,014	6,014	6,014	6,014	6,014	6,014
Total	45,567	40,346	35,126	29,905	82,113	71,671	61,230	50,788	155,204	134,321	113,438	92,555
Transportation												
Freight-out	77,838	66,718	55,598	44,479	155,675	133,436	111,197	88,957	311,351	266,872	222,394	177,915
Total Costs	289,659	263,511	237,363	211,215	556,391	504,094	451,798	399,501	1,137,962	1,033,369	928,776	824,183
Net Income	26,395	37,856	49,317	60,778	29,862	52,784	75,706	98,628	84,905	130,749	176,593	222,437
Essential Oil Extraction Process (Unit: NT$ 1,000)												
Sales	1,283,990	1,100,563	917,136	733,709	2,567,981	2,201,126	1,834,272	1,467,418	5,135,962	4,402,253	3,668,544	2,934,835
Costs												
Reduced Surface Size												
Bandsaw	166	166	166	166	251	251	251	251	380	380	380	380
Rotary sawing machine	400	400	400	400	607	607	607	607	920	920	920	920
Dust collector	195	195	195	195	296	296	296	296	448	448	448	448
Electricity	47,015	40,299	33,582	26,865	94,030	80,597	67,164	53,731	188,060	161,194	134,328	107,463
Labor	45,923	45,923	45,923	45,923	91,846	91,846	91,846	91,846	183,691	183,691	183,691	183,691
Maintenance	1,522	1,522	1,522	1,522	2,306	2,306	2,306	2,306	3,496	3,496	3,496	3,496
Total	95,220	88,504	81,787	75,071	189,335	175,902	162,469	149,036	376,994	350,129	323,263	296,398
Crush												
Crusher	1,636	1,636	1,636	1,636	2,480	2,480	2,480	2,480	3,758	3,758	3,758	3,758
Electricity	13,577	11,637	9,698	7,758	27,153	23,274	19,395	15,516	54,306	46,548	38,790	31,032
Labor	45,923	45,923	45,923	45,923	91,846	91,846	91,846	91,846	183,691	183,691	183,691	183,691
Maintenance	3,272	3,272	3,272	3,272	4,959	4,959	4,959	4,959	7,517	7,517	7,517	7,517

doi:10.6342/NTU202403839

Total	64,407	62,467	60,528	58,588	126,437	122,558	118,679	114,800	249,272	241,514	233,756	225,998
Distillation												
Distillation equipment	7,600	7,600	7,600	7,600	15,200	15,200	15,200	15,200	30,400	30,400	30,400	30,400
Water	333	333	333	333	666	666	666	666	1,333	1,333	1,333	1,333
Electricity	17,903	15,345	12,788	10,230	35,805	30,690	25,575	20,460	71,610	61,380	51,150	40,920
Labor	183,691	183,691	183,691	183,691	367,382	367,382	367,382	367,382	734,765	734,765	734,765	734,765
Maintenance	15,200	15,200	15,200	15,200	30,400	30,400	30,400	30,400	60,800	60,800	60,800	60,800
Total	224,727	222,169	219,612	217,054	449,454	449,454	444,339	434,109	898,908	888,678	818,448	868,218
Cooling												
Cooler	3,800	3,800	3,800	3,800	7,600	7,600	7,600	7,600	15,200	15,200	15,200	15,200
Water	82	82	82	82	164	164	164	164	329	329	329	329
Electricity	5,207	4,463	3,719	2,975	10,413	8,925	7,438	5,950	20,826	17,851	14,876	11,901
Labor	91,846	91,846	91,846	91,846	183,691	183,691	183,691	183,691	367,382	367,382	367,382	367,382
Maintenance	7,600	7,600	7,600	7,600	15,200	15,200	15,200	15,200	30,400	30,400	30,400	30,400
Total	108,534	107,791	107,047	106,303	217,068	215,581	214,083	212,606	434,137	431,162	428,187	425,212
Separation												
Oil separator	5,581	5,581	5,581	5,581	11,162	11,162	11,162	11,162	22,323	22,323	22,323	22,323
Electricity	193	166	138	111	387	331	276	221	773	663	552	442
Labor	91,846	91,846	91,846	91,846	183,691	183,691	183,691	183,691	367,382	367,382	367,382	367,382
Maintenance	11,162	11,162	11,162	11,162	22,323	22,323	22,323	22,323	44,646	44,646	44,646	44,646
Total	108,781	108,754	108,726	108,692	217,562	217,507	217,452	217,397	435,124	435,014	434,904	434,793
Packaging												

doi:10.6342/NTU202403839

Packaging machine	149	149	149	149	226	226	226	226	343	343	343	343
Packaging materials	174,623	149,677	124,731	99,784	349,245	299,353	249,461	199,569	698,491	598,706	498,922	399,138
Electricity	920	788	657	526	1,839	1,576	1,314	1,051	3,678	3,153	2,627	2,102
Labor	91,846	91,846	91,846	91,846	183,691	183,691	183,691	183,691	367,382	367,382	367,382	367,382
Maintenance	299	299	299	299	452	452	452	452	686	686	686	686
Total	267,836	242,758	217,681	192,603	535,454	485,299	435,144	384,990	1,070,580	970,270	869,960	769,650
Transportation												
Freight-out	120,722	103,476	86,230	68,984	241,444	206,952	172,460	137,968	482,889	413,905	344,921	275,936
Total Costs	990,227	935,919	881,610	827,302	1,976,755	1,868,139	1,759,522	1,650,906	3,947,904	3,730,671	3,513,438	3,296,205
Net Income	293,763	164,644	35,526	-93,593	591,226	332,988	74,750	-183,488	1,188,057	671,582	155,106	-361,369

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Table A.12 Life cycle costs analysis of wood pellets without bark and chunks expressed as proportion of sale.

HV (m^3/y)	4,000			
WU (%)	30	40	50	60
	Wood Pellets			
Sales	100	100	100	100
Costs				
Reduced Surface Size	0	0	0	0
Crush	38.29	44.17	52.42	64.78
Pelletizing	73.78	84.37	99.19	121.42
Packaging	40.41	44.83	51.01	60.30
Transportation	29.57	29.57	29.57	29.57
Total Costs	182.04	202.93	232.19	276.07
Net Income	82.04	102.93	132.19	176.07

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