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Forest biomass supply to provide energy for a large-scale industry in Canterbury, New Zealand

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Abstract

As pressure mounts for companies to reduce carbon emissions, demand for renewable energy increases. However, that also raises questions about capacity such as: If a large-scale industrial user were to switch from coal to biomass, how much land would be required to supply these large quantities of biomass, and how economically viable would it be to supply these large quantities of biomass?

This study investigates the logistical and economic viability of three forestry regimes in Canterbury, New Zealand, which aim to supply 500,000m³ of biomass annually required by a large industrial user transitioning multiple processing facilities from coal to biomass. The regimes investigated are as follows, a single-purpose biomass forest, a dual-purpose forest producing both biomass and sawlogs, and lastly a transitional approach that combines the first two regimes. The effects of participation in the New Zealand Emission Trade Scheme, as well as the trade-off between trucking cartage distance and land price, were also considered. Finally, a sensitivity analysis was performed to give insights into how variations in key assumptions can affect returns.

The economic performance was assessed using net present value (NPV), land expectation value (LEV), and the break-even costs of biomass across the different regimes and biomass supply strategies, as well as the effects that participation in the ETS had on the short-rotation biomass crop. Transport costs were investigated based on cartage distance, highlighting trade-offs between land price and transport costs. Sensitivity analysis compares the NPV of each regime as key economic variables change from 75% lower to 75% higher than the initial base value.

Results show that a dual-purpose regime consistently achieved higher NPV and LEV compared to that of the biomass-only forest. Participation in the ETS was found to improve the economic viability of a dedicated short-rotation crop significantly. Transport distance, while having a negative impact on NPV, could easily be offset with lower land prices. The sensitivity analysis highlighted that the level of discount rate impacted the perceived profitability of each regime disproportionately, as regimes over longer time periods were affected more. Apart from these cases, carbon prices and harvesting costs influenced NPV the most. The findings demonstrate the economic trade-offs between an early supply of biomass and waiting for forests to reach maturity.

Under the key assumptions of this study, a large-scale biomass forest in Canterbury is not commercially viable. However, improvement in harvesting efficiency, government incentives, and both biomass and sawlog prices could help reduce the gap.

Acknowledgments

Firstly, I would like to thank both Dr Trevor Best and Dr David Evison for their support, guidance, and suggestions throughout the course of this project. Their encouragement and insights proved extremely valuable and helped shape the course of this study.

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> "*It does not matter how slowly you go as long as you do not stop.*"
>
> -Confucius

Contents

1. Introduction

With New Zealand's commitment to reach net-zero carbon emissions by 2050, a significant investment in renewable energy sources is needed. It is expected that over the next decade, the demand for biomass will increase rapidly as biomass replaces coal. At present, coal and other fossil fuels make up 60% (Energy Resources Aotearoa, n.d.) of New Zealand's total energy production. Fossil fuels are harmful because they introduce additional greenhouse gases into the atmosphere, whereas biomass can be considered a form of carbon recycling, provided replanting occurs.

In 2024, the total consumption of coal in New Zealand was 2,489,106 tonnes (Ministry of Business, Innovation & Employment, 2025), which is down approximately 275,000 tonnes from 2016, when New Zealand consumed 2,765,590 tonnes of coal and was ranked 55th in the world (Worldometer, n.d.). According to the Ministry of Business, Innovation & Employment (2025), dairy manufacturing in New Zealand is one of the largest coal consumers, with 521,699 tonnes of coal consumed in 2024, which is second only to electricity generation with 871,619 tonnes. Dairy manufacturing accounts for 73% of coal consumption within industrial use and 20% of the total coal consumption across all sectors. As dairy production is such a large consumer of coal, finding an alternative fuel would make a significant reduction in coal consumption and, in turn, CO^2 emissions.

More companies want to reduce their carbon footprint, one way of achieving this is switching from fossil fuels to renewable fuels. If a large coal-burning processing plant in Canterbury wanted to change from coal to biofuel, would it be feasible? The wood availability forecast for Canterbury shows that over the next 35 years, the volume of available biomass would not meet the demands of a large user (approx. 500,000 tonnes per annum) wanting to convert multiple processing facilities. Importing biofuel from other regions would be prohibitively expensive (because of transport costs). Trying to utilise existing sources of biomass would cause a strain on the current market, driving up prices and taking the resource away from other consumers. To ensure a sustainable biofuel supply, a purpose-grown forest may be the only viable option for such a large user.

2. Literature review

2.1 Coal vs Biofuel

As many industries rely on fossil fuels for heating and electricity consumption, finding an alternative, more sustainable fuel source will help reduce emissions. One fuel source is biofuel. Biofuel, simply put, refers to any fuel that is derived from biomass such as plants, algae, or animal waste. The primary type of biofuel that will be discussed is woody biomass.

There are multiple ways biofuel can be converted into energy. The most common process globally is combustion. While combustion of biomass is the simplest method, it is suggested that it is also the least environmentally friendly option, releasing pollutants back into the atmosphere.

This has led some articles, such as one by Booth et al. (2020) to criticise others who promote the use of biomass energy. This criticism, however, is based on harvesting established native forests in Europe, with the argument focusing on the significant time difference between the release of emissions from harvesting these trees and the regeneration. Other arguments have been made against biomass in comparison to a fuel such as coal are that it has a lower energy yield, 27443.5 kJ/kg for coal compared to 18710.5 kJ/kg for wood pellets (Saidur et al., 2011), as well as reports of biomass burning power plants emitting 150% the carbon dioxide of the coal counterparts (Partnership for Policy Integrity, n.d.).

While these numbers may seem concerning, the carbon cycle for using biomass for energy is quite different from that of coal. The key factor is that although the combustion of both materials leads to the emission of carbon, biomass sequesters carbon from the atmosphere during its formation, offsetting its emissions. In contrast, the formation of coal is extremely slow, and consumption introduces carbon into atmosphere that has already been sequestered. A simplistic model of this is shown in Figure 1 demonstrating the loop of sequestering and emitting carbon for both biomass and coal. As the atmospheric carbon is being sequestered by forests, the net carbon emissions, not including harvesting, transport, and processing emissions, are effectively zero, assuming all trees are replanted.

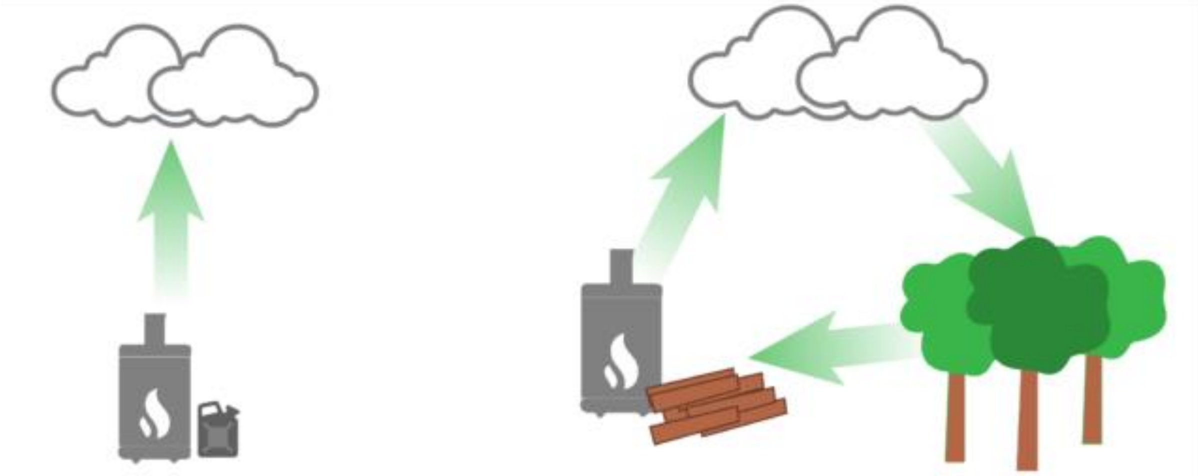

Figure 1: Carbon cycle for both biomass and coal

2.2 Availability of biomass in Canterbury

Canterbury, like many regions of New Zealand, was subject to a planting boom from 1992 to 1995, followed by a quiet period. Due to the planting boom, recently there has been a large area of commercial forest maturing within New Zealand (PF Olsen, 2021) which is also indicated in the Ministry for Primary Industries (2021), Canterbury's wood availability report, the higher area of maturing trees creates an abundance of harvestable wood in the area but due to the lower planting period that followed after the planting boom the volume of mature forest is steadily decreasing until 2036 (Ministry for Primary Industries, 2021).

In August of 2021, a wood availability report was constructed for the Ministry for Primary Industries by Margules Groome Consulting Ltd (2021). The report investigated four main harvesting scenarios and the effect that they had on the availability of wood from 2021 through to 2060. Using the scenarios outlined in this report alongside data retrieved from the Ministry for Primary Industries website for each scenario, the following wood availability estimates were found. These estimates rely heavily on the forests harvested by small-scale owners, who, compared to large-scale owners, are hard to predict. Small-scale owners often harvest based on their own personal goals and situation, causing harvest ages to vary greatly.

One of the greatest limitations of the following scenarios pointed out by Margules Groome is that log prices and market conditions have a large effect on harvest volumes, as lower log prices slow harvest operations and vice versa when log prices increase.

Scenario 1 – large owners harvest based on previous intentions, small-scale owners harvest at age 27

Scenario one looked at the wood availability from large-scale owners based on previously stated harvest intentions over the period 2021 to 2030, after which wood availability from these owners would not decrease. It is assumed that the small-scale owners would harvest their forest at age 27. Figure 2 shows the availability of wood for each year under these harvesting constraints.

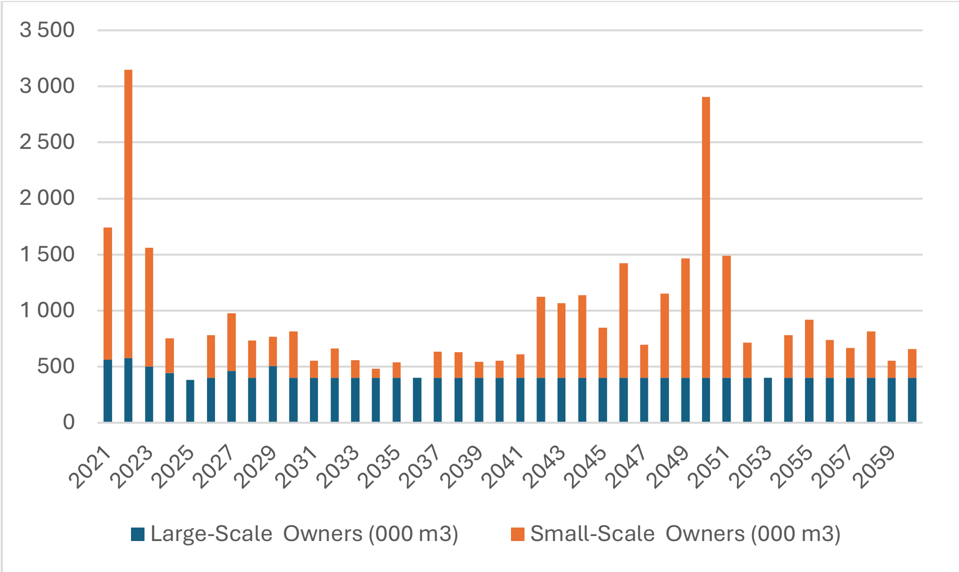

Figure 2: Wood availability under scenario 1, large owners harvest at stated intentions, and small owners harvest at age 27.

As small-scale owners are assumed to harvest at age 27, scenario one showed the availability of mature forests in the Canterbury region from small-scale owners in any given year. While it is unlikely that future harvests would occur this way, including this scenario helps showcase the magnitude of effect that small-scale owners have on the wood availability for the Canterbury region.

Scenario 2 – Non-declining yield, target age of 27

As with scenario 1, scenario 2 assumes all large-scale owners would harvest at previously stated intentions over the period 2021 to 2030, with the wood availability from these owners not decreasing after this period. A constraint of non-declining yield (NDY) was applied to the total wood availability. Figure 3 shows the availability of wood for each year under these harvesting constraints.

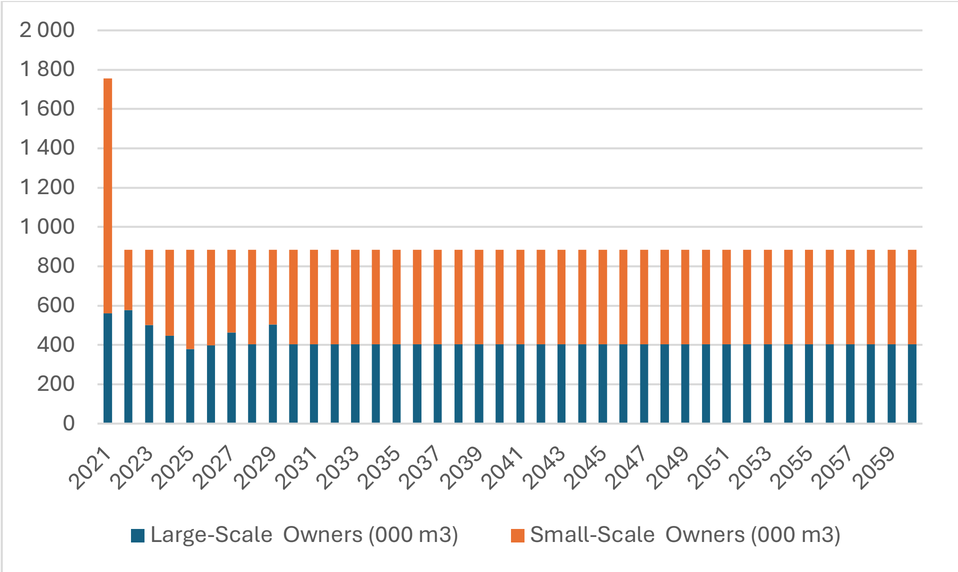

Figure 3: Wood availability under scenario two, NDY.

Applying an NDY constraint to future harvests provided a relatively uniform supply of wood for each year; this uniformity better matches what's possible logistically, as well as the constraints from the market, compared to scenario one. However, adding such a rigid constraint would cause a large change in the average rotation ages, causing forests to be harvested at a non-optimum age and therefore is likely to be an unrealistic option.

Scenario 3 – Split non-declining yield

Scenario three has the same assumptions for large-scale owners as the previous scenarios. The total availability of wood was modelled using the following allowances

year	All
2021 - 2021	NDY, with a max 20% increase/decrease
2022-2024	
2025-2030	20% increase/decrease
2030-2038	20% increase/decrease
2039-2044	NDY, 20% increase/decrease
2044-2055	NDY
2056 - 2056	20% increase/decrease
>2060	NDY

Table 1: Constraints placed on total wood availability.

Figure 4 shows the availability of wood for each year under these harvesting constraints.

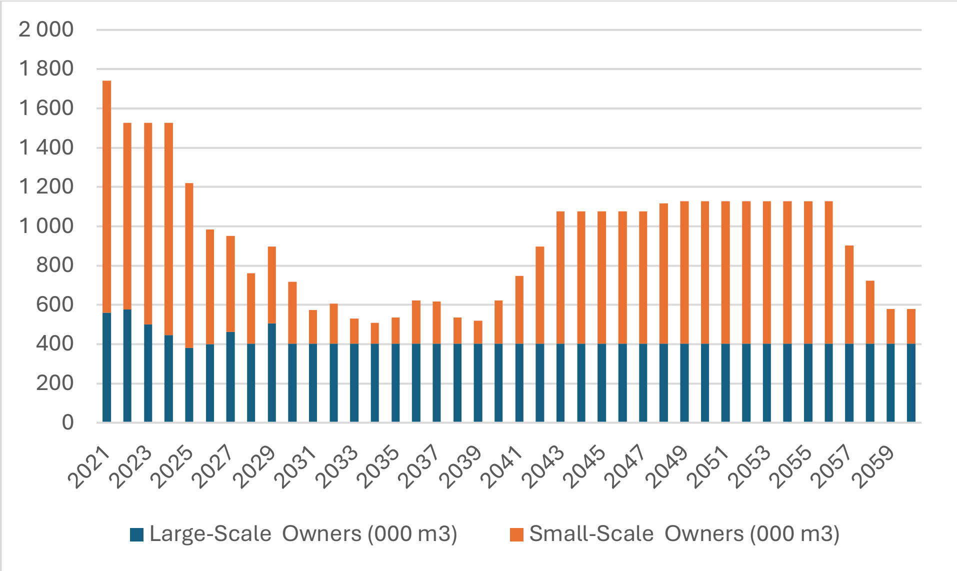

Figure 4: Wood availability under split NDY.

These constraints allowed for some fluctuation of harvest volume, but not to the extent that occurs in scenario one. The fluctuation in harvesting meant that the rotation age was closer to the target rotation age of 27 while still supplying a more realistic volume of wood. The effect that changing the target rotation age by two years had on wood flow can be seen in Figure 5. As this scenario is a compromise between a strict NDY and harvesting everything at the optimal rotation age, this scenario was seen as the most likely of the three scenarios.

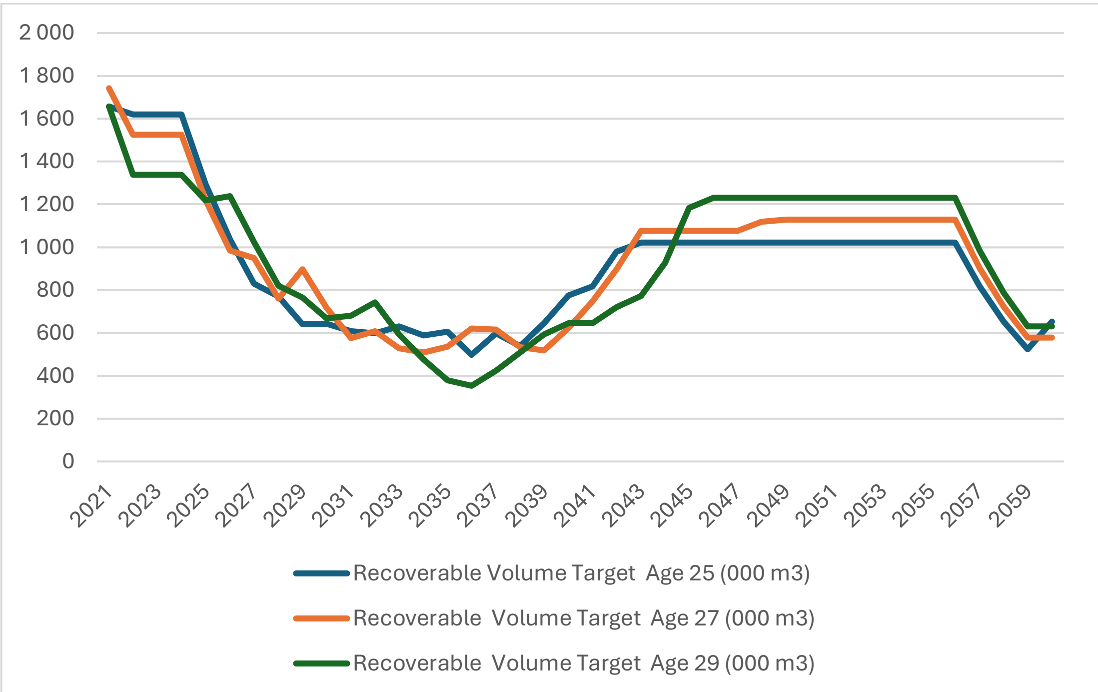

Figure 5: Effect of target rotation age on wood flow for scenario three.

Having an older rotation age caused a sharper decrease in the volume of wood harvested but would give higher yields in later years compared to the younger rotation age.

The availability by log type for the region using scenario three was modelled in Figure 6.

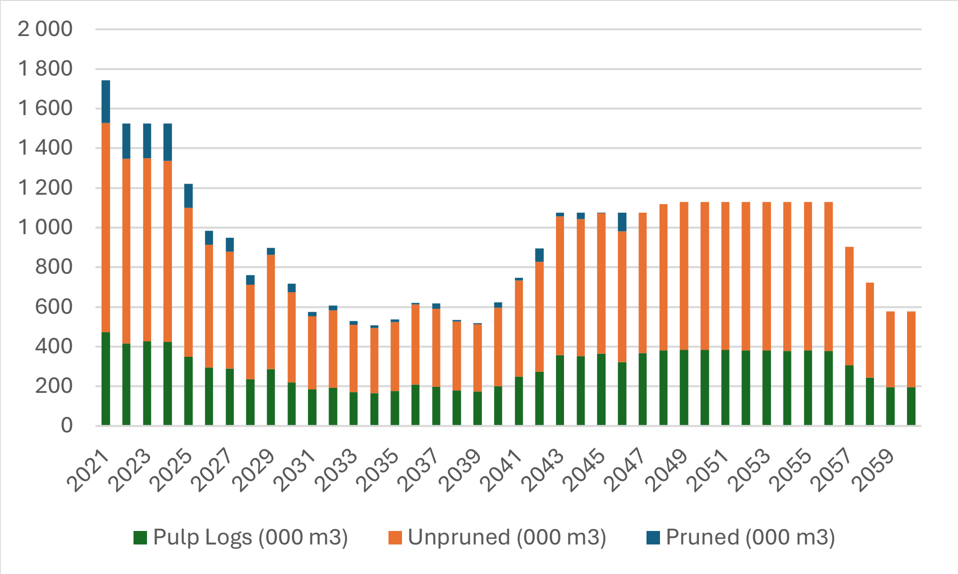

Figure 6: Volume of wood by log grade.

Separating the availability of pulp logs helps illustrate the potential supply of biomass in Canterbury, shown in Figure 7.

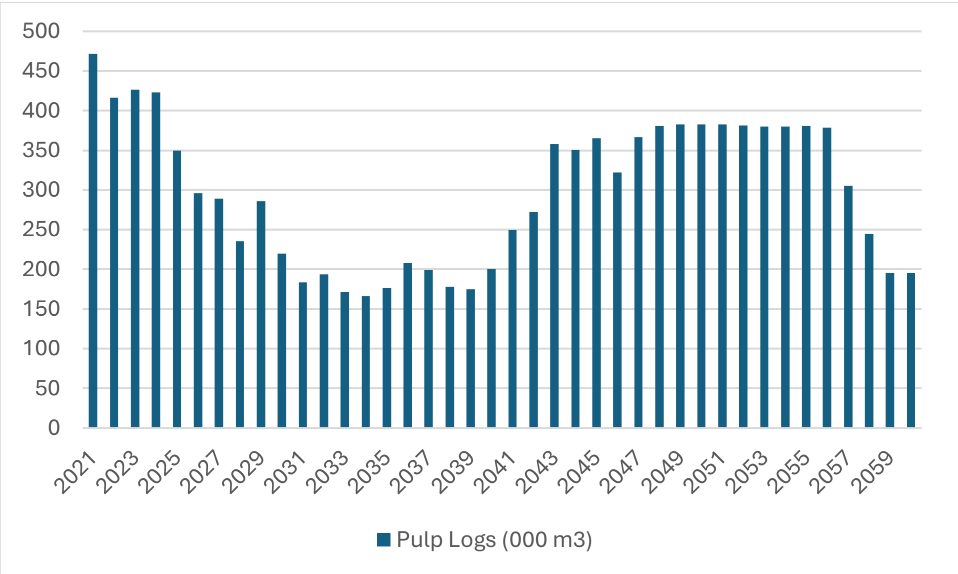

Figure 7: Availability of pulp logs under scenario three.

The supply of pulp logs helps estimate the total biomass supply, as the volume from other log types will be used for sawn timber and sold at a premium. A previous study by Robertson and Manley (2006) estimated that the available biomass for Canterbury was approximately

200,000 tonnes annually. Comparing this with the wood availability study showed that while there is a significant increase in availability, both estimates fall short of the required volume of 500,000 tonnes for a large single user in Canterbury.

2.4 Energy forests

There are three main sources of woody biomass, the first is residues at mills, the second is recoverable forest residues, and the third is purpose-grown forests. The price of woody biomass per tonne is related to how it was sourced. The most inexpensive form of biomass comes from residues at the mill. Approximately 35% - 45% of the total log volume gets left behind when processing logs into sawn timber (Ministry for Primary Industries, n.d.). Sawmills are fortunate in this sense as they end up with a reliable, sustainable fuel source created as a byproduct of normal operations. The second most economical source of woody biomass is forest residues, which are a byproduct of normal logging operations. These residues can be either left on landings or recoverable residues left at the stump between the two types of forest residuals. There can be a large difference in price, as residuals left at the stump will have additional costs to recover them. The price of using these residues as biofuel differs from the price of using the residues at the mill, as both a transport cost and a harvesting cost are involved. Using byproducts of normal operations for biofuel is the most cost-effective approach to biofuel supply, but the volume of residue is determined by the demand for primary products (sawlogs and sawn timber), as the volume of residues produced is linked directly to these products. This causes problems for biofuel supply as it fluctuates as demand for these products changes, and there is limited ability to respond if demand for biofuel increases. Energy production forests, while being less cost-effective, are not bound by this constraint, as biofuel is no longer a byproduct of operations but the primary focus.

Forests grown purposely for biomass are already being utilised internationally, referenced by many studies from China, Italy, Korea, and parts of the European Union. These plantations revolve around using fast-growing species with a short rotation time. The rotation length of these plantations is typically 3-6 years with some being as short as 1-2 years (Mosiej, Karczmarczyk, & Wyporska, 2012, p. 196) For this type of forestry to be successful the plantation needs to be located on higher quality land than standard forestry as well as more intensive land management practises with more attention paid to fertilisation, weeding, and site preparation (Mosiej, Karczmarczyk, & Wyporska, 2012, p. 196). In New Zealand, forestry is restricted on LUCs less than 6, and this higher quality land is used for more lucrative land uses such as agricultural or farming and thus increases the cost of land regardless. The increased costs associated with this type of plantation, alongside the current demand for biofuel being met from forest residues, could explain why energy forests aren't popular in New Zealand at present.

An investigation into short rotation forestry by Scion (2024) highlighted how the current techniques of short rotation forestry could be adapted for New Zealand conditions. Tree species was the main difference, whereas poplar and willow are the species of choice for other countries, the Scion (2024) recommended eucalyptus and radiata pine. Radiata pine was highlighted for multiple reasons, having the greatest potential area to be planted, lower risk from introduced pests and diseases, and economic benefits from entering the ETS.

Radiata pine plantations are generally already planted in lower-quality sites in New Zealand, as the higher-quality rural sites are generally reserved for agriculture and farmland, as these industries can afford the higher land costs. Scion (2024) identified that biomass plantations could be established on areas of lower land value, highlighting marginal grazing land as well-suited. It should be noted that the location of these plantations should be established to minimise transport distance to the processing facilities, as transport costs are a large factor in biomass supply.

As of April 2024, there are 1,623,751 ha of standing radiata pine, which accounts for approximately 91% of all forest plantations (Ministry for Primary Industries, 2024). Due to the large percentage of forested area being radiata pine, there are already well-developed management protocols to fight against introduced pests and diseases. A list of all pests and diseases, along with symptoms, disease development, economic impact, and control, is easily accessible through the New Zealand Farm Forestry Association (n.d). Due to the abundance of information on diseases and pests for radiata in New Zealand, the risk of economic impact from disease or pest is lowered.

The final factor that contributed to radiata pine being highlighted was the additional income generated by entering the emission trade scheme (ETS). The study looked at short rotations compared with standard forest plantations and worked with 16-year rotations. The averaging accounting method was applied, giving revenue for the first 8 years of the stand.

In summary, the literature highlights biofuel as an attractive alternative to coal; however, the residues from current forestry operations in Canterbury are insufficient to meet the biomass demands from a large processing facility. One alternative is to plant dedicated biomass forests; however, the land requirements and economic factors surrounding such an investment are currently unknown.

3. Research objective

The objective of this paper is to investigate the economic viability of three forestry regimes in Canterbury. Each regime is aimed at supplying the volume of biofuel required by a large user that is aiming to convert multiple processing facilities away from coal. This research focuses on the economic and logistical viability of each regime. It analyses the trade-offs between transport distance and land costs, returns from entering the ETS, an estimation of the price of delivered wet wood, and a risk analysis exploring the effects future scenarios may have on returns of both regimes.

1. A single-purpose regime in which all harvest products are exclusively for energy production.
2. A dual-purpose regime involving an additional planting period post-harvest, enabling a portion of the timber to be exported at premium market rates, supplementing biofuel supply with higher-value products.
3. A short-rotation biomass forest that converts to a dual-purpose regime after the first harvest.

This research is targeted at Fonterra, which has three processing sites located in Canterbury. The two main sites are Clandeboye and Darfield, with a smaller processing site in Studholme.

4. Methodology

4.1 Overview

The financial analysis determined the NPV, LEV, and break-even delivered wood price. Each economic factor was compared between the regimes, providing insight into which regime was more economically attractive. Risk analysis was used to explore the effects that future market conditions and policy changes have on the regimes.

4.2 Required Data

The volume of logs was estimated using 2015 yield tables for an unpruned pine crop in Canterbury (Ministry for Primary Industries, n.d.).

Carbon yields were obtained from carbon look-up tables for post-1989 forest land on the MPI website (2023). A conservative price of $40/m3 for carbon was used to calculate carbon revenues. Annual fees for entering the ETS were $15/year, obtained from CarbonCrop (2023)

A baseline land purchase price of $7143 was derived from a Beef+Lamb New Zealand economic service report (Beef + Lamb New Zealand, 2025), looking at the capital value excluding homestead in South Island hill country.

Site preparation and releasing costs were estimated to be $226/ha and $206/ha, respectively (Harrison & Meason, 2015).

Landing costs were estimated using a landing service area of 18.1 ha/landing (Allum, Harvey, Visser, & Hoffmann, 2024). This was used in conjunction with the range of landing prices reported in a comprehensive survey of 142 landings (Visser et al., 2011) to get an average landing price of $235/ha.

Roading costs and cartage costs were obtained from West (2019) and found to be approximately $4/t and $14.4/t respectively.

An average harvesting cost of $43.90/t was used from an updated benchmarking data based on Visser (2017)

No published values for both annual fees and planting costs could be located online. An estimate of $80/year was used for annual fees, and $1,100/ha was used for the planting costs.

All costs were then adjusted to 2025 NZD using the producer price index to account for inflation, as summarised in Table 1.

Year	Activity	Value	Value adjusted for inflation	Units
0	Land purchase price	$7,000	$7,143	/ha
0	Planting	$1,100	$1,100	$/ha
0	Site preparation	$226	$318.97	$/ha
1	Releasing 1	$206	$290.75	$/ha
15 & 29	Roading	$4	$5.16	$/t
15 & 29	Landings	$235	$352.10	$/ha
16 & 30	Harvesting	$43.90	$43.90	$/t
16 & 30	Cartage	$14	$18.58	$/t
1-30	Annual costs	$80	$80	$/ha

Table 1: operational costs adjusted for inflation

A discount rate of 8% was used for the economic analysis, this is slightly higher than the average discount rate of 7.3% from the 2021 discount rate survey (Manley, 2022). This conservative discount rate reflects uncertainty in future market conditions and ensures that the estimates in the economic analysis are not overestimated.

4.3 Data Processing

4.3.1 Regime one – biofuel forest

In regime one, the forest was designed for the sole purpose of supplying biofuel, meaning the total recoverable volume (TRV) of wood was equal to the volume of biofuel, with all logs being priced equally. The benefit of this regime is that it gave the lowest upfront costs required, as the area planted was the minimum area needed to reach the biofuel demand.

To determine the total area of land required, the total volume of biofuel needed (500,000m3) was divided by the TRV (m3/ha) at the age of rotation retrieved from the 2015 yield tables for the unpruned regime in Canterbury, New Zealand (Ministry for Primary Industries, n.d.). This area was planted each year from year 1 through to 17 (the rotation age) to create a sustainable biofuel resource.

Supplying biomass using a short rotation age allows the large user to reduce emissions and start the switch from coal to biofuel for part of the operation sooner. However, harvesting before the optimum rotation age means the log yields for the area harvested early will be lower.

Using the area planted per year, harvest yields for each year are found using the 2015 log yield tables for Canterbury (Ministry for Primary Industries, n.d.). These yields were placed in a spreadsheet at the corresponding year, creating a model of the resource.

To find the total revenue from selling the biofuel, an NPV analysis was performed using a base case price of biomass of $50/m3 delivered for each of the varying volumes supplied in early rotation. An LEV analysis was then performed to show the maximum value the land can be bought for before the project becomes unprofitable. Finally, a breakeven price of biomass was obtained by using what-if analysis on the NPV, setting it to 0 by changing the price of biomass.

4.3.2 Regime two – sawlogs and biofuel

The second regime investigated what further planting would be required if sawlogs were separated from the biofuel and exported, creating additional revenue. This additional planting helped mitigate risks to the forest owner by adding an additional revenue stream separate from biofuel, but also to the large user, as the increased availability of wood creates security, reducing the likelihood of biofuel shortages, which could cause delays at the processing plants.

As the saw logs were now being sold at a premium, they were removed from the total biofuel supply. It was assumed the saw logs were processed locally, with a conservative 30% of the total saw log volume becoming offcuts and being used as biomass. The total volume of biomass supplied was then calculated from both pulp logs and 30% of the saw logs from full-length rotation. The NPV, LEV, and delivered breakeven price of biomass were calculated.

4.3.3 Regime three: short rotation converted full length

The third regime investigated the combination of the first two regimes, an initial short rotation followed by the sawlog regime. This was done to allow for a quicker supply of biomass while still obtaining the long-term profits and reduced market risk associated with the addition of sawlogs.

Initial planting areas for both the short and full rotation were based on the results of the previous two sections. However, as immediate replanting of the short rotation would leave a lag period between the final harvest of the short rotation crop and the first harvest of the long rotation, back planting was used to ensure a smooth transition. The NPV, LEV, and delivered breakeven price of biomass were calculated.

4.3.4 Short rotation only and effects of the addition of the ETS

To find the magnitude of the effect of participation in the ETS, both the revenues and annual costs were removed from the cash flows of each of the three regimes, and the resulting NPV, LEV, and break-even price of biomass were obtained, allowing for comparison.

4.3.5 Increase in transport distance

As the distance increased between the forest and the township where the processing plants were located, so too would the transportation costs. However, as the location of the forest gets further away and the quality of the land decreases, so too would the price of land.

Using a linear structure of y = mx + c, a formula for deriving transport costs was constructed, where:

y = transport costs

M = variable costs (C_v)

X = distance (d)

C = fixed costs (C_f)

The variable costs are all costs that are influenced by the distance, which include operational costs (fuel, tyres, road user charges, etc) and the hourly rate while driving. Fixed costs are associated with the time spent loading and unloading the payload.

The carriage costs formula then becomes:

$$C_v = \frac{Ch*d}{Save} + 2*C_o*d \text{ (\$/round trip)}$$

$$C_f = \frac{Cf}{Th} \text{ (\$/trip)}$$

$$C_c = \frac{Cv + Cf}{Payload} \text{ (\$/t)}$$

Where:

C_h = hourly rate ($/hour)

S_{ave} = average speed (Km/hour)

C_o = operational costs ($/km)

T_h = handling time (hour)

Payload = weight of wood transported (t)

The hourly rate of trucking operations and operational costs used were $92.83/hour and $2.55/km (Transporting New Zealand, 2023). These values were then adjusted for inflation, giving $97.26/hour and $2.55/km.

There is no published data online for both average logging truck speeds or average handling times, so an estimate of 60 km/hour and 0.5 hours was used, respectively.

4.4 Risk analysis

As there is an uncertainty surrounding future market conditions, a set of scenarios was modelled to investigate the magnitude of effect that they could have on the project. Using the range of NPVs calculated for each level of biomass volume supplied in regime two, a sensitivity analysis was performed, illustrating which early biomass supply scenario the investment is most sensitive to, and which scenario causes the lowest decrease in return. The scenarios were as follows:

4.4.1 Change in the price of carbon.

As there is uncertainty around carbon prices, an investigation into the effects that this has on both regimes was performed.

This scenario investigates the effect that low and high carbon prices had on the NPV of each regime.

Using a range of carbon prices (-75%, -50%, -25%, 25%, 50%, 75%), new NPVs were found for each regime and graphed to show the effect carbon pricing has.

4.4.2 Increase in transport price.

As fuel prices increase, so too will the cost of transport. This scenario looked at how a rise in transportation costs affected each regime.

A range of fuel costs was used (-75%, -50%, -25%, 25%, 50%, 75%) to find new NPVs for all different early biomass supply scenarios. These were then graphed together to help illustrate these effects.

4.4.3 Large price change in sawlogs

As sawlog prices can change dramatically, a sensitivity analysis was performed to investigate the effects this has on the NPV of different levels of early biomass supply in regime two and three. Log prices with a price change of -75%, -50%, -25%, 25%, 50% 75% of the current log price were used.

Each of the different levels of early biomass supply was graphed together to illustrate the effect that the change in sawlog price has on each regime.

4.4.4 Change in discount rates

A sensitivity analysis was performed on the discount rate; the rate chosen has a large impact on the NPV of long-term forest investments. The discount rate was increased over a range of -75% to 75% of its initial value of 8% and the NPV was calculated for each 25% increase. This was done for all early supply of biomass scenarios and graphed together, illustrating the effect the discount rate has on each regime.

4.4.5 Harvest costs

Harvesting costs make up a significant part of the total cost for forestry and can vary greatly due to the multiple factors associated. As large areas are harvested at a shorter rotation, the piece size would be below average, which in turn would influence the harvesting costs. Harvesting costs were changed from 75% below the initial value to 75% above the initial value in 25% increments to find the NPV of the project for different volumes of biomass supplied in early rotation. This was then compiled into a single graph to illustrate how the change in harvest costs affected each regime comparatively.

5. Results

This study looked at three regimes, regime one, a short rotation biomass forest, regime two, a full rotation forest that supplies sawlogs as well as biomass, and regime three, a combination of the first two. For each of the three regimes, the land area requirements were found along with key economic factors such as NPV, LEV, and the breakeven price of biomass. Additionally, the effects of participation in the ETS and the location of the forest have on the NPV and LEV of each regime. Finally, a sensitivity analysis was carried out examining the effect of carbon price, transport costs, the price of sawlogs, the discount rate, and harvesting costs on the NPV. The following sections present results for each regime, impacts of the ETS and forest location, followed by the sensitivity analysis.

5.1 Planting and Harvesting Plans

The following section reports the findings of the land requirements for each regime. The planting and harvesting schedules in Appendix A provide more detail on how each regime could be implemented.

Regime one:

Regime one was a short rotation forest with a rotation age of 17. Approximately 2,415 ha of land was planted each year over a 17-year establishment period, with 43,478.26 ha required in total. Harvesting began in year 17, with each area harvested replanted the following year to maintain a stable supply of biomass. This regime had a uniform annual planting from establishment and would have a sustainable supply of biomass from year 17

Regime two:

Regime two allowed the forest to reach maturity, planting 1,967ha annually over a 30-year period, with 60,975.61 ha needed in total. Harvesting started in year 30 with each harvested area replanted in the following year, similar to regime one. Letting the forest mature provided better yields alongside additional saw log product but introduced a longer lag before the first harvest.

Regime three:

Regime three combined both short and full rotations to balance early biomass supply and long-term productivity. An establishment planting period occurred from years 0-17, where 2,415.46 ha was planted for short rotation, and an additional 1601.72 ha was planted for long rotation from years 5 to 17. The first harvest occurred at year 17, and replanting taking place the following year, in 1966.95 ha, which was the required annual planting for long rotation from years 18 to 30. An additional 448.50 ha would be planted for short rotation. Harvesting started in year 17, harvesting exclusively short rotation crops until year 35, where the biomass would come from a proportion of both short and full rotation crops. After age 48, all harvests would come from long rotation crops. To bridge the gap between biomass supplied by short rotation and long rotation, additional area planted in long rotation was favoured over short rotation due to the results illustrated in Figure 8. This graph shows that total NPV declines as a greater portion of biomass is supplied by the short-rotation crop.

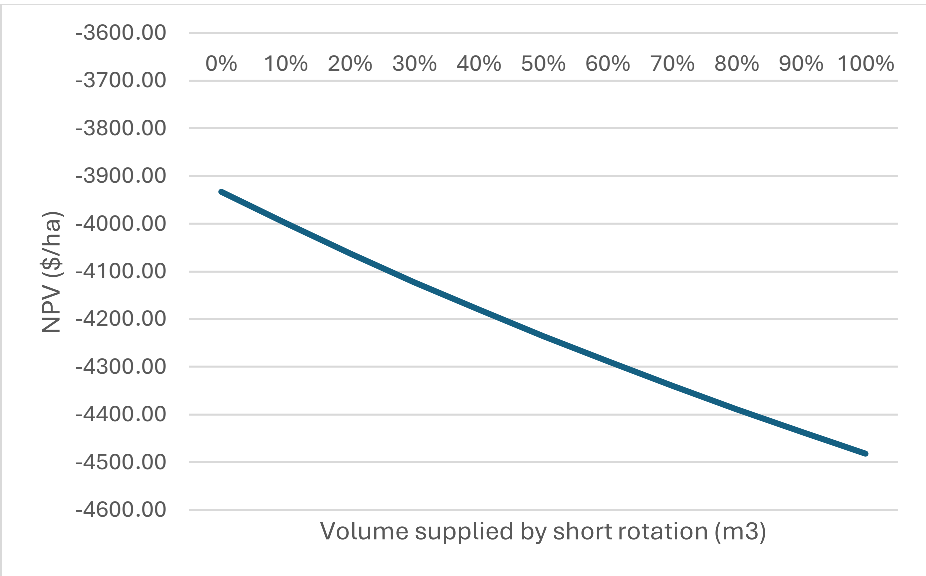

Figure 8: The Effect of supplying higher volumes of biomass in short rotation has on NPV

5.2 Economic analysis regime one

The NPV was -$4975, showing a loss per hectare under the base assumptions. The LEV calculated was $2585.60. The breakeven biomass was found to be $138.93m^{-3}$. The results are summarised in Table 2. Detailed cash flows for the NPV and LEV are provided in Appendix B.

parameter	Value	Units
Net Present Value (NPV)	-4975.20	$/ha
Land Expectation Value (LEV)	2585.60	$/ha
Breakeven Biomass price	138.93	$/m3

Table 2: Key economic factors for regime one

5.3 Economic analysis regime two

The economic analysis produced an NPV of -$3932.93, showing a loss per hectare under the base assumptions. The LEV calculated was $3767.01 ha^{-3}. The breakeven biomass was found to be $302.07m^{-3}. The results are summarised in Table 3. Detailed cash flows for the NPV and LEV are provided in Appendix C.

Parameter	Value	Units
Net Present Value (NPV)	-3932.93	$/ha
Land Expectation Value (LEV)	3767.01	$/ha
Breakeven Biomass price	302.07	$/m3

Table 3: Key economic factors for regime two

5.4 Economic analysis regime three

Under the base assumptions, the NPV was -$6936.72 ha$^{-1,}$ showing a loss per hectare. The LEV calculated was $196.14 ha^{-1}. The breakeven biomass was found to be $165.90m^{-3}. The results are summarised in Table 4, with detailed cash flows for the NPV and LEV provided in Appendix D.

Parameter	Value	Units
Net Present Value (NPV)	-6936.72	$/ha
Land Expectation Value (LEV)	196.14	$/ha
Breakeven Biomass price	165.90	$/m3

Table 4: Key economic factors for regime three

5.5 Comparative analysis

This section compares the land requirements as well as the key economic outcomes for each of the three regimes investigated. These key values include area planted per year, total area planted, NPV, LEV, and breakeven price of biomass.

The land requirements for each of the three regimes are summarised in Table 5. Regimes 1 and 2 maintain a constant area planted with 2415.46 ha and 1966.96 ha, respectively, each year, resulting in total land required for each regime to be 43,478.26ha and 60,975.61ha. Regime three had variation in land planted each year, ranging from 1966.96 - 4017.19ha planted per year, with a total area required of 64,300.75, which was the highest of the three regimes.

	Land is planted each year.	Total land planted
regime one	2415.46	43478.26
Regime two	1966.96	60975.61
regime three	1966.96 - 4017.19*	64300.75

Table 5: Comparative summary of land requirements

*detailed breakdown of yearly planting in Appendix A

Across the three regimes, NPV of -3932.93 and LEV of 3767.01 was the highest in regime two, the dual-purpose forest, and the lowest NPV of -$6936.72 and LEV of $196.14 was found in regime three, the transitional forest. The breakeven price of biomass was lowest in regime one, $138.93 and highest in regime two, reaching $302.07, as summarised in Table 5.

Regime	NPV($/ha)	LEV ($/ha)	Breakeven price of biomass ($/m^3)
Short rotation	-4975.20	2585.60	138.93
Dual purpose	-3932.93	3767.01	302.07
Transitional	-6936.72	196.14	165.90

Table 6: Comparative summary of key economic factors for each regime

Figures 9 – 11 illustrate the difference in key economic factors between the regimes.

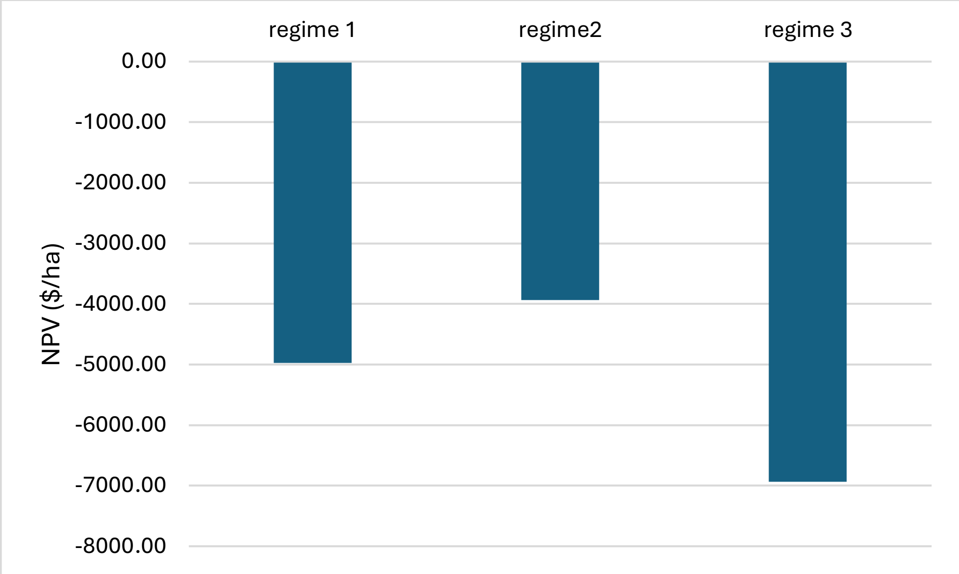

Figure 9: Comparison of NPV across each regime

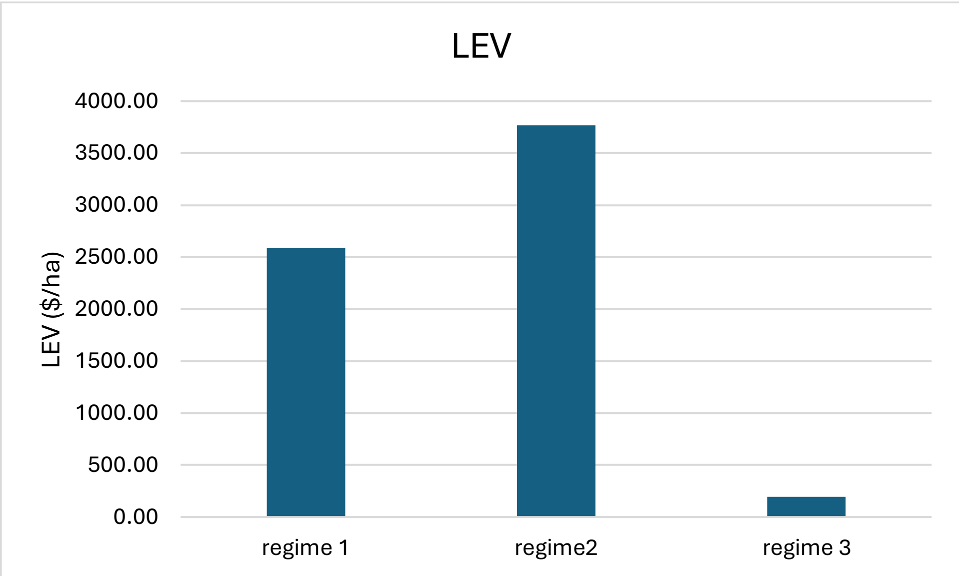

Figure 10: Comparison of LEV between regimes

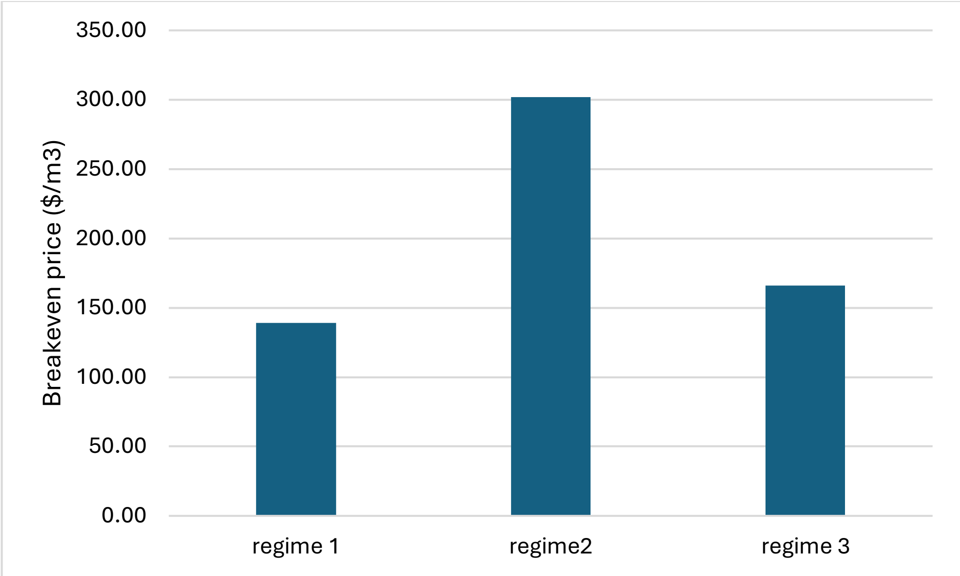

Figure 11: Comparison of the Break-even price of biomass between regimes

5.6 Impacts of carbon and Forest location

This section presents the results of modelling the effects of participation in the ETS and the impact of forest location on the viability of each regime.

5.6.1 The Emission Trade Scheme

For ETS participation, results show a significant improvement in NPV and LEV across all regimes when carbon revenue is included. Regime one increased from -$8,743.73 to -$4,975.20 per hectare, and LEV improved from -$1,269.08 to $2,585.60 per hectare. Regime two had an increase in NPV from -$7669.42 to -$3932.93 per hectare, and LEV increased from -$119.71 to $3,767.01 per hectare. In Regime three, NPV improved from -$10,662.99 to -$6,936.72 per hectare, while LEV rose from -$3,567.31 to $196.14 per hectare. The breakeven price of biomass was also lower under all regimes (Table 6)

		NPV	LEV	Breakeven price of biomass
regime 1	with carbon	-4975.20	2585.60	138.93
	without	-8743.73	-1269.08	206.29
regime2	with carbon	-3932.93	3767.01	302.07
	without	-7669.42	-119.71	541.56
regime 3	with carbon	-6936.72	196.14	165.90
	without	-10662.99	-3567.31	228.16

Table 6: Summary of the effect of entrance into the ETS on NPV.

5.6.2 Cartage Distance

The effect of the location of the forest was also investigated by varying cartage distance from 15km to 115km from the mill. Results show that distance increased, and both NPV and LEV declined gradually for all regimes. At 15km, NPV values were –$4,400.17, –$3,441.62, and –$6,238.75 per hectare for Regimes 1, 2, and 3, respectively. At 115 km, NPVs decreased to –$5,482.47, –$4,366.34, and –$7,552.45 per hectare. The same trend can be seen for LEV, with regime one decreasing from $2,798.57 to $2,397.73 per hectare, regime two from $3,821.23 to $3,719.19, and regime three from $784.73 to -$323.09. A detailed summary of the effect that cartage distance has on the NPV for each of the three regimes is provided in Table 7. Figures 12 and 13 illustrate the reduction in both NPV and LEV as transport distance increases, respectively.

		NPV			LEV		
distance	$/T	1	2	3	1	2	3
15	8.305117	-4400.17	-3441.62	-6238.75	2798.574	3821.226	784.732
20	9.272387	-4454.29	-3487.86	-6304.43	2778.532	3816.124	729.3407
25	10.23966	-4508.4	-3534.09	-6370.12	2758.49	3811.023	673.9494
30	11.20693	-4562.52	-3580.33	-6435.8	2738.448	3805.921	618.5581
35	12.1742	-4616.63	-3626.57	-6501.49	2718.405	3800.819	563.1668
40	13.14147	-4670.75	-3672.8	-6567.17	2698.363	3795.717	507.7755
45	14.10874	-4724.86	-3719.04	-6632.86	2678.321	3790.615	452.3842
50	15.07601	-4778.98	-3765.27	-6698.54	2658.278	3785.514	396.9929
55	16.04328	-4833.09	-3811.51	-6764.23	2638.236	3780.412	341.6016
60	17.01055	-4887.21	-3857.75	-6829.91	2618.194	3775.31	286.2103
65	17.97782	-4941.32	-3903.98	-6895.6	2598.151	3770.208	230.819
70	18.94509	-4995.43	-3950.22	-6961.28	2578.109	3765.106	175.4276
75	19.91236	-5049.55	-3996.45	-7026.97	2558.067	3760.005	120.0363
80	20.87963	-5103.66	-4042.69	-7092.65	2538.025	3754.903	64.64503
85	21.8469	-5157.78	-4088.93	-7158.34	2517.982	3749.801	9.253717
90	22.81417	-5211.89	-4135.16	-7224.02	2497.94	3744.699	-46.1376
95	23.78144	-5266.01	-4181.4	-7289.71	2477.898	3739.597	-101.529
100	24.74871	-5320.12	-4227.63	-7355.39	2457.855	3734.495	-156.92
105	25.71598	-5374.24	-4273.87	-7421.08	2437.813	3729.394	-212.312
110	26.68325	-5428.35	-4320.11	-7486.76	2417.771	3724.292	-267.703
115	27.65052	-5482.47	-4366.34	-7552.45	2397.728	3719.19	-323.094

Table 7: The effect the cartage distance has on NPV.

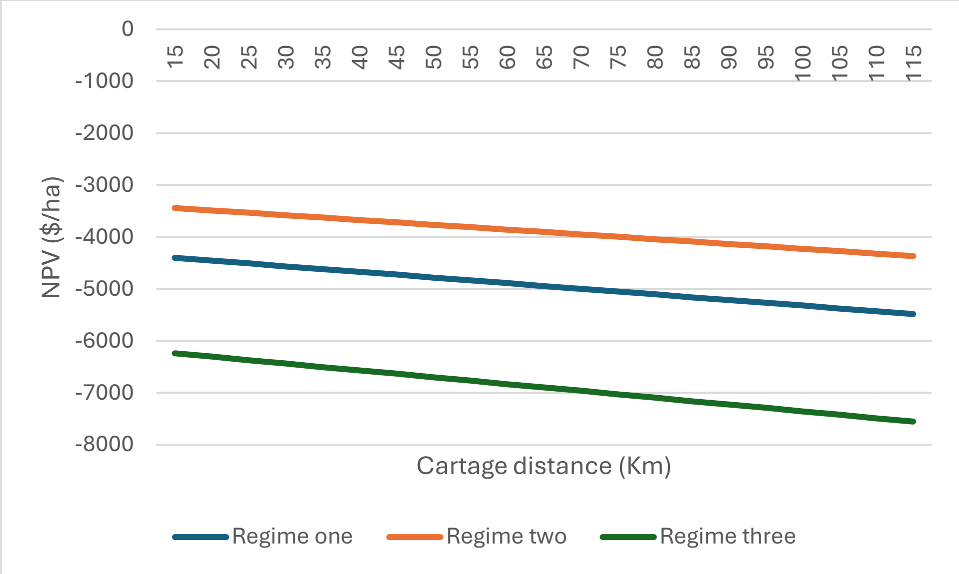

Figure 12: The Effect the cartage distance has on NPV for each of the three regimes

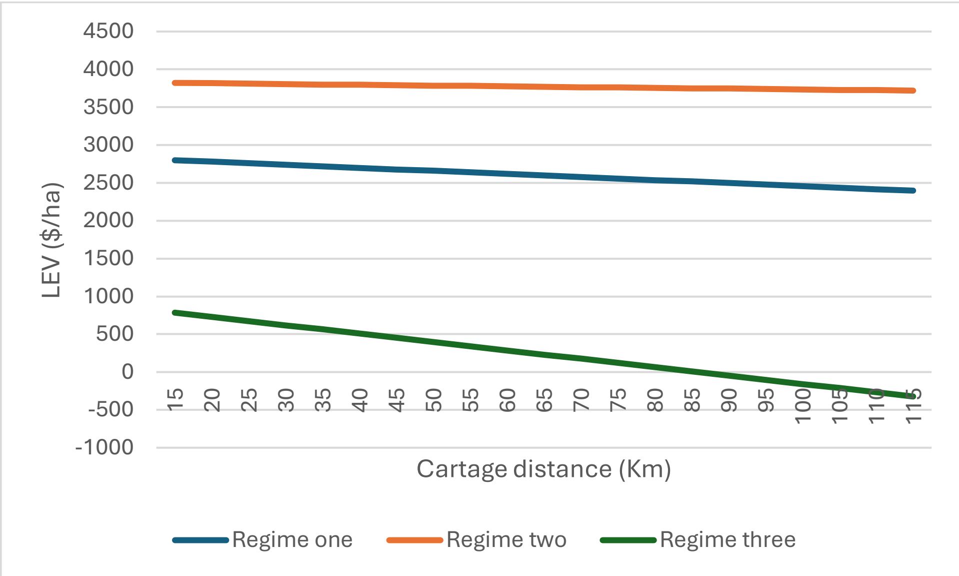

Figure 13: Effect of cartage distance on LEV for each of the three regimes

5.7 Sensitivity analysis

Sensitivity analysis was performed, analysing how varying some of the key base assumptions affected the NPV of each regime. The key assumptions performed in the sensitivity analysis were as follows, carbon price, transport costs, sawlog price, discount rate, and harvest costs. The results are presented in the following sub-sections, with detailed results recorded in tables and figures to help illustrate the trends.

5.7.1 Carbon price

A sensitivity analysis was undertaken to test the effect of varying carbon prices on the NPV across the three forestry regimes. Results summarised in Table 8 show that the NPVs increased linearly with each 25% increase in carbon price NPVs went up by $976.34 regardless of regime. This uniform change in NPV is illustrated in Figure 14 with the parallel lines representing each of the different regimes.

% of initial value	Updated carbon price ($/t)	NPV of Regime one ($)	NPV of Regime two ($)	NPV of Regime three ($)
-75%	10	-7904.21	-6861.94	-9865.7371
-50%	20	-6927.88	-5885.6	-8889.3983
-25%	30	-5951.54	-4909.27	-7913.0595
0%	40	-4975.2	-3932.93	-6936.7207
25%	50	-3998.86	-2956.59	-5960.3819
50%	60	-3022.52	-1980.25	-4984.0432
75%	70	-2046.18	-1003.91	-4007.7044

Table 8: Results of the carbon sensitivity analysis.

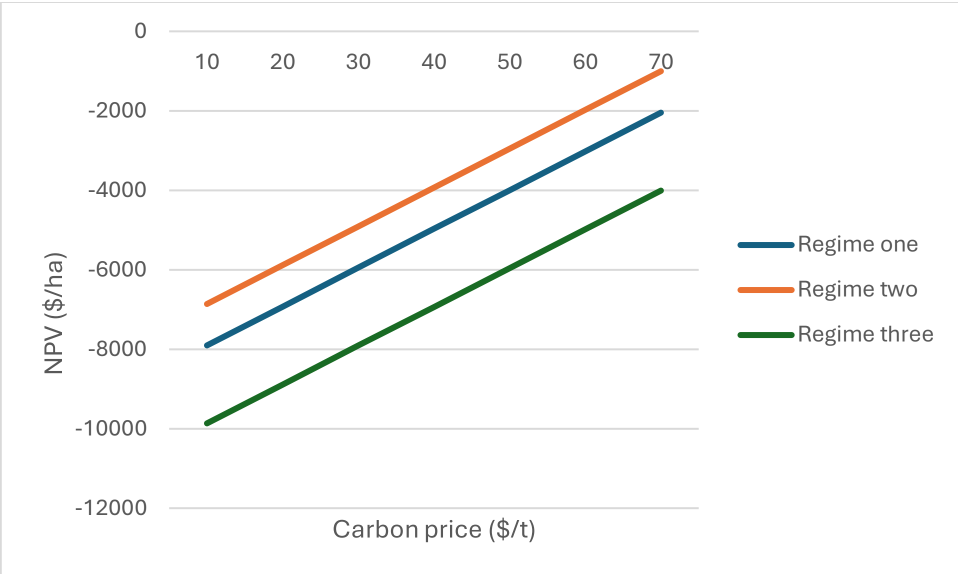

Figure 14: The effect the carbon price has on NPV for each of the three regimes

5.7.2 Transport

A sensitivity analysis was undertaken to test the effect of varying cartage costs on the NPV across the three regimes. NPVs decreased linearly with varying rates. For regimes 1, 2, and 3, the decrease in NPV for each percentage change in cartage costs was -259.92, -222.07, and -315.49, respectively, as shown in Table 9. These changes are illustrated in Figure 15 with the steeper gradient of 500,000m3 contrasting with the flatter gradient of the 100,000m3.

Percentage change	Updated cartage costs	Regime one	Regime two	Regime three
-75%	4.645844	-4195.45	-3266.71	-5990.26
-50%	9.291688	-4455.37	-3488.78	-6305.74
-25%	13.93753	-4715.28	-3710.85	-6621.23
0%	18.58338	-4975.2	-3932.93	-6936.72
25%	23.22922	-5235.11	-4155	-7252.21
5%	27.87506	-5495.03	-4377.07	-7567.7
75%	32.52091	-5754.94	-4599.15	-7883.19

Table 9: Sensitivity analysis of cartage costs

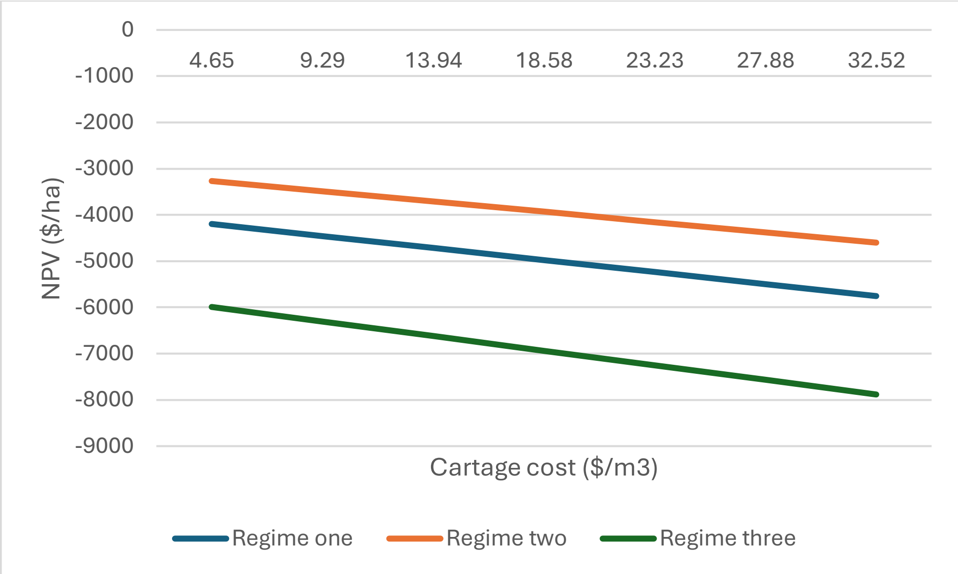

Figure 15: sensitivity analysis of cartage costs

5.7.3 Price of saw log

A sensitivity analysis was undertaken to test the effect of varying sawlog prices on the NPV across the different regimes. Results show that the NPV of regime one remains unchanged while the other two regimes increase linearly with varying rates (Table 10). For each regime one, two and three, the increase in NPV for each 25% percent increase in sawlog price the increase in NPV was 0, 965.95, and 241.73, respectively. These changes are illustrated in Figure 16, with regime one being completely flat and regime two having the steepest gradient.

Percent change	Updated sawlog price	Regime one	Regime two	Regime three
-75%	30	-4975.2	-6830.77	-7661.9
-50%	60	-4975.2	-5864.82	-7420.18
-25%	90	-4975.2	-4898.87	-7178.45
0%	120	-4975.2	-3932.93	-6936.72
25%	150	-4975.2	-2966.98	-6694.99
50%	180	-4975.2	-2001.03	-6453.27
75%	210	-4975.2	-1035.08	-6211.54

Table 10: sensitivity analysis of sawlog prices

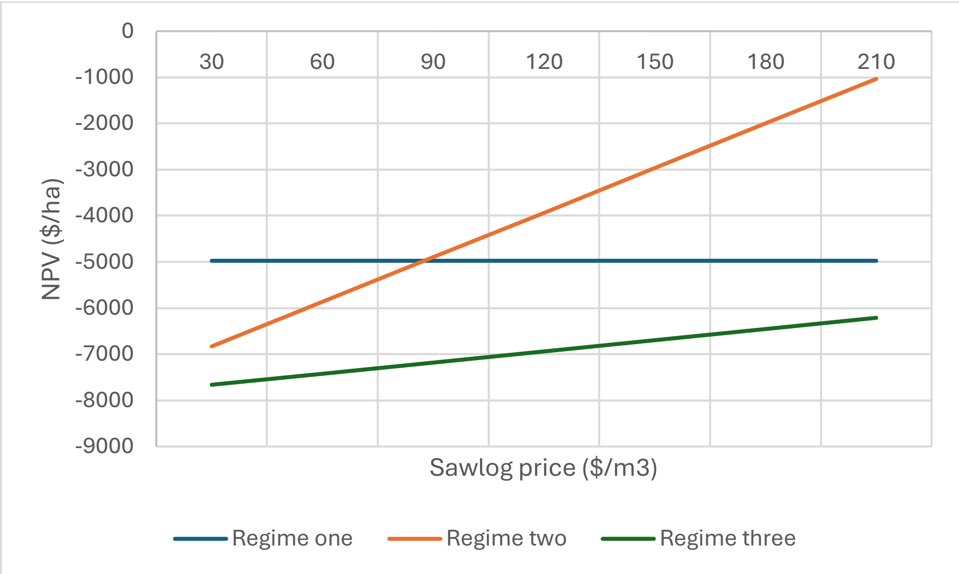

Figure 16: sensitivity analysis on sawlog price

5.7.4 Discount rate

A sensitivity analysis was undertaken to test the effect of varying discount rates on the NPV across the three regimes. Results show the NPVs decreased as discount rates increased from 2% to 14%, with the rate of decline slowing at higher discount levels. The Dual-purpose regime showed the largest variation, with NPV decreasing by $13,976.27 from $7,309/ha at a 2% discount rate to -$6,667/ha at 14%. The short rotation regime and transitional regime decreased by $5441.51 and $6704.82, respectively. These results are summarised in Table 11 and illustrated in Figure 17, which shows the exponential decrease in NPV with increasing discount rate for all the regimes.

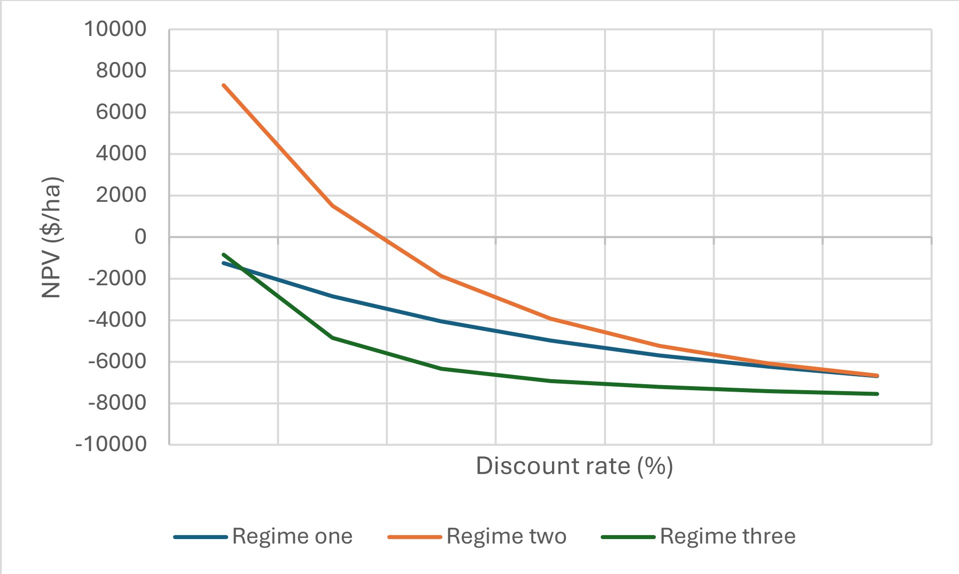

Figure 17: sensitivity analysis of discount rates.

Percent change	Updated discount rates	Regime one	Regime two	Regime three
-75%	2%	-1252.93	7309.162	-848.096
-50%	4%	-2844.34	1521.255	-4843.5
-25%	6%	-4050.66	-1873.04	-6335.05
0%	8%	-4975.2	-3932.93	-6936.72
25%	10%	-5691.33	-5231.4	-7226.59
50%	12%	-6251.7	-6083.84	-7408.81
75%	14%	-6694.43	-6667.11	-7552.91

Table 11: sensitivity analysis of discount rates

5.7.5 Harvest costs

A sensitivity analysis was undertaken to assess the effect of changing harvesting costs on NPV across the three forestry regimes. Results show that NPVs decreased consistently as harvesting costs increased. When harvesting costs were 75% lower than the base case, NPVs were the highest at -$3133.19, -$2359.10, and -$4700.86 per hectare. The rate at which the NPVs decreased was linear across all regimes, with regimes 1, 2, and 3 decreasing by $614.00, $524.61, and $745.29 per hectare for every 25% increase in harvesting costs.

Percent change	Updated harvest costs	Regime one	Regime two	Regime three
-75%	10.975	-3133.19	-2359.1	-4700.86
-50%	21.95	-3747.19	-2883.71	-5446.15
-25%	32.925	-4361.19	-3408.32	-6191.43
0%	43.9	-4975.2	-3932.93	-6936.72
25%	54.875	-5589.2	-4457.54	-7682.01
50%	65.85	-6203.21	-4982.15	-8427.29
75%	76.825	-6817.21	-5506.76	-9172.58

Table 11: sensitivity analysis of harvest costs

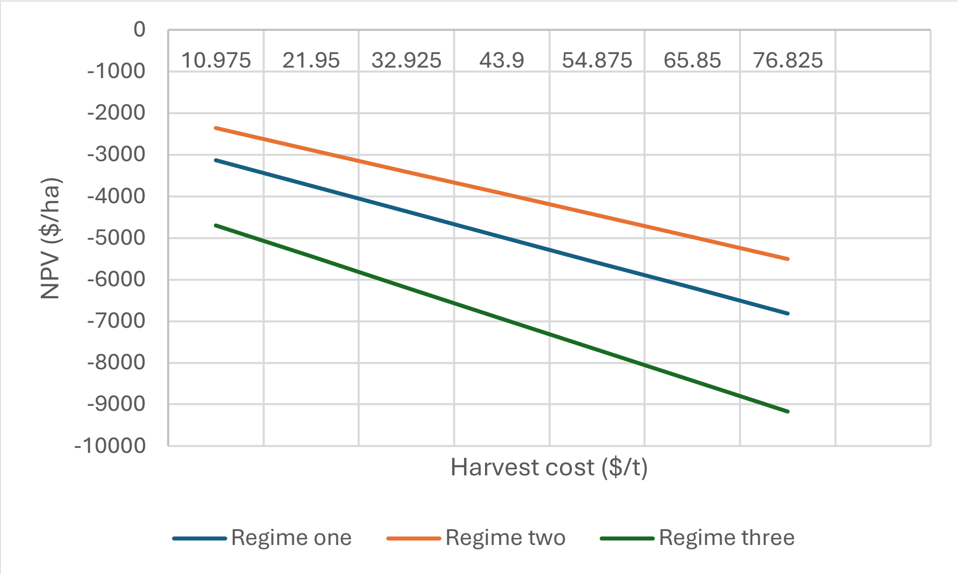

Figure 17 Sensitivity analysis of harvest costs

6. Discussion

This section evaluates the economic results for each of the three biomass regimes and examines how each planting and harvesting strategies influence land requirements, as well as investigating the economic viability through NPV, LEV, and breakeven biomass price comparison. The discussion also examines how factors such as ETS participation and cartage distance affect each regime's outcome. Finally, the results for the sensitivity analysis were discussed, providing insights into which key assumption had the greatest influence on NPV and the reasoning behind this. Together, these analyses provide an understanding of the trade-offs between early supply of biomass and long-term profitability. The following section begins by outlining the planting and harvesting plans for each regime before discussing economic performance.

6.1 Planting and harvesting plans

Regime one

The results for Regime One, a short-rotation biomass forest, demonstrate the feasibility of achieving a sustainable biomass supply within a relatively short timeframe. Establishing 2,415 ha annually enables a sustainable annual harvest of 500,000m^3 from year 17 onward. However, the early supply of biomass has its drawbacks. Due to the trees being harvested before maturity, the TRV of wood is significantly lower compared to a mature biomass forest, thus, more land is required to compensate for this, lowering the efficiency of the land.

Regime two

Regime two is a more conventional forestry regime designed to let trees reach full maturity before harvesting. It was included in the analysis to consider the potential of a regime aimed at reducing the market risk inherent to a single product regime such as regime one. Planting 1,967 ha annually over a 30-year establishment period enables a sustainable annual harvest of the target 500,000m^3 from year 30 onwards. This allows the stand to mature, increasing the TRV and improving log quality. Although higher quality logs were removed from the biomass supply, to achieve the biomass supply target, less land needs to be harvested annually. However, this approach introduces a significant delay before the first harvest, which means that long-term commitment to the project is required well before biomass is supplied. This regime prioritises stand productivity over early supply of biomass, providing a more conventional forestry structure that aligns with current management practices in New Zealand.

Regime three

Regime Three integrates both short and long rotation plantings to balance the need for early biomass supply with the reduced market risk of a more conventional regime. Establishment occurred in two phases, an initial 17-year period of short rotation planting to provide early biomass supply, and an overlapping long rotation planting beginning in year 5 to ensure a continuous supply between the period of time where the final harvest of short rotation crop occurs and first harvest of long rotation crop is harvested. Harvesting began in year 17 from the initial short rotation planting. This was then immediately replanted in long rotation with excess land replanted in a short rotation crop to supplement the initial long rotation crop over the transitional period. Between years 35 and 48, a transitional period occurred where biomass was supplied by both short and long rotation plantings. Over this transitional period, biomass supply was favoured by the long rotation plantings due to the better economic factors of this regime, with NPV of the project improving as higher volumes of biomass were supplied by the long rotation. The combination of the regimes allowed for that crucial early supply of biomass while not compromising market risk. This regime does, however, introduce more complexity in scheduling and land management, both age classes must be managed and harvested simultaneously for the duration of the project.

Overall, the three regimes have different strategies for achieving a continuous biomass supply for a large-scale industry. Regime one prioritises rapid establishment and early supply of biomass through short rotations, regime two focuses on reducing market risk by allowing for sawlogs to be produced separately for greater economic returns, and regime three combines both approaches, attempting to balance an early supply of biomass without increasing market risk and providing better and long-term profits. The scale of land required, especially for regimes two and three, was quite substantial, especially when compared to Canterbury's total forested area, which in 2019 was reported to be 94,782 ha (Canterbury Mayoral Forum, 2019). These regimes form the basis for the following sections evaluating economic performance and financial viability under the base assumptions.

6.2 Economic analysis for regime one

The results for regime one show that a short-rotation biomass forest was not economically viable under the base assumptions. The negative NPV of -$4,975/ha shows that revenue from biomass alone was insufficient to offset the costs associated with a short rotation regime. The LEV of $2,585.60/ha represented the maximum amount that could be paid for the land while still achieving the target rate of return, any land costs higher than this would make the investment uneconomic. The breakeven price of biomass was calculated to be approximately $140/m^3. Comparing this value to current log prices highlights the limitations of this regime, as this price point puts it on par with some of the lower P2 log prices (Ministry for Primary Industries, 2025), far exceeding typical domestic biomass prices.

The poor financial performance was primarily caused by reduced harvest volumes and the low price of biomass. The forest is harvested well before the optimum rotation age, resulting in a significantly lower wood volume per hectare and more land to be purchased to meet biomass demands. Additionally, as all harvest volume was used for biomass, there are no saw logs available to take advantage of the better log prices for higher quality logs.

6.3 Economic analysis for regime two

The results for regime two show that a full rotation forest designed to meet biomass demand while simultaneously producing sawlogs as a bioproduct is still not economically viable under the base assumptions. The NPV of -$3,932.93/ha indicates a loss per hectare of land planted. The LEV of $3,767.01/ha represents the maximum price that could be paid for the land under this regime while still meeting the target rate of return. The breakeven price of biomass was very high; this is a result of the addition of sawlogs for this regime. The forests have two products, biomass and sawlogs, each with separate prices. The breakeven price of biomass is the price biomass must be sold at to achieve a zero NPV, i.e., the point where the project becomes economically viable. Changes in the biomass price do not affect revenues from the sawlog product. However, once the price of biomass exceeds the sawlog price, additional increases in NPV require the biomass revenues to compensate for the now lower-priced sawlogs, causing the breakeven price of biomass to increase further.

Regime two prioritises economic performance and market risk over quicker biomass supply. By allowing the forest to reach maturity, total biomass volumes are increased, and additional revenue is generated from premium sawlog revenues. However, this approach introduces a significant lag between the start of the project and the sustainable supply of biomass. Allocating a portion of the harvest to sawlogs increases the average product price, contributing to improved NPV and LEV. While the NPV of regime two remains negative under the base assumptions, these results demonstrate the effects of allocating higher quality logs to be sold as sawlogs within a biomass forest.

The limitations of the previous regimes highlight the trade-offs between rapid biomass supply and economic performance. Regime one delivers biomass quickly but at low profitability, whereas Regime two improves economic outcomes but delays the supply of biomass. Regime three addresses these challenges by combining elements of both approaches, aiming to provide early biomass supply while maintaining long-term economic viability.

6.4 Economic analysis for regime three

The results for regime three reflect the financial implications of combining an initial short rotation biomass harvest with a long-term sawlog regime. The NPV of -$6936.72/ha reflects the combined effect of short rotation and sawlog regimes. Alone, the biomass and sawlog regimes both have negative NPVs. Due to the delayed start to the sawlog regime, the NPV is discounted further, which is combined with the NPV for the initial short rotation harvest. The total NPV remains substantially negative, highlighting the financial challenges of simultaneously supplying biomass early while maintaining a longer-term sawlog harvest.

The LEV of $196.14/ha was relatively low due to the timing of returns from the sawlog regime. Because regime three starts with a short rotation harvest before transitioning to a sawlog regime, the repeating cycle is delayed. As a result, a larger proportion of future revenues is subject to higher discounting effects, reducing the present value of land returns over multiple rotations.

The breakeven price of biomass was $165.90/$m^3$, which reflects the lowest price biomass required for the regime to be economically viable. Because revenue is generated from two harvest age classes, the timing of returns plays a key role. The short-rotation biomass harvest occurs first in the project timeline, so the breakeven price of biomass is primarily influenced by this stage. Due to the discounting effect, the contribution of the late sawlog harvest plays a less significant role in the project's overall return. As a result, when biomass price exceeds sawlog prices, the impact on the breakeven price becomes minimal.

With the results from each regime individually discussed, the following section presents a comparative analysis of the economic performance. This analysis compares key values such as NPV, LEV, and the breakeven price of biomass, as well as the land requirements. By comparing these outcomes, a clearer understanding of the economic performance of biomass supply can be developed.

6.5 Comparative analysis

The results highlight clear differences in both land requirements and economic performance across the three regimes. The total land area required was far more for regime one and two. This was due to the addition of saw logs as a product. Separating the higher quality sawlogs decreased the yield of biomass which meant more land had to be planted to achieve the target volume. If no sawlogs were removed it would be expected the total land would decrease the longer the rotation length as the total recovered volume would increase. For regime three the initial long rotation crop planted to partially supply biomass over the transitional period caused regime three to have the most volatile planting structure, with area planted ranging significantly.

Economic performance also varied significantly between the three regimes. Regime two achieved the highest NPV and LEV, reflecting the potential of a longer rotations to provide higher value products. However, this improvement in returns comes at the expense of delayed biomass supply. Regime one provides rapid biomass production but at a low economic return, as short rotations reduce yield and allow for no additional wood products. Regime three, which combined elements from both, set out to supply biomass fast and at higher profits, had the lowest NPV and LEV. This is largely due to the overlapping costs and the large discounting effect on the delayed cash flows of the sawlog regime. For every regime the LEV found was far below the original base land price of $7143/ha.

The breakeven price of biomass further demonstrates the effect of harvest timing on project viability. Regime three breakeven price is closer to that of regime one because the initial short-rotation biomass harvest occurs early in the project timeline, meaning it contributes more heavily to the overall cash flow and therefore drives the breakeven biomass price. In comparison, Regime Two has a much higher breakeven price, as the revenue from biomass must offset the lower returns from sawlogs once the biomass price exceeds the sawlog price.

While these comparisons provide useful insights, it is important to recognise that a direct comparison with regime three is challenging. Regime three looked at the initial rotation followed by a repeating long rotation, and therefore, is supplying twice the volume of biomass over the analysis of the NPV. Therefore, modelling two rotations for both regimes 1 and 2 to compare with regime three could be a more balanced approach. This approach could better illustrate the trade-offs between early biomass supply and long-term profitability of the project. This limitation helps explain why regime three appears less economically viable.

Overall, the comparative analysis highlights the trade-offs between rapid biomass supply and long-term profitability. Regime one provides the fastest supply of biomass but has a poor economic performance. Regime two achieves the highest NPV and LEV, demonstrating that longer rotations with additional revenue generated from sawlog production remain the most economically favourable, although this caused a large delay in supply. Regime three, while designed to balance early biomass supply with long-term revenue, shows that integrating both regimes introduces additional complexity and costs, resulting in the lowest NPV and LEV of all regimes. These results emphasise that achieving both early biomass supply and economic viability remains challenging under the base assumptions.

The following section builds on these results by examining the influence of entrance into the ETS, as well as the forest location, on NPV and LEV for each regime.

6.6 Impacts of Carbon and Forest Location

ETS participation

The inclusion of participation in the ETS substantially improved the economic performance of all three regimes. Across all regimes, both NPV and LEV increased, while breakeven biomass prices decreased. The inclusion of ETS revenue provides an early and reliable cash flow during the establishment and growth, which offsets initial investment costs and improves long-term profitability. This highlights the crucial role of carbon revenue in supporting the viability of biomass forests. Furthermore, if future incentives such as grants or clean energy subsidies are introduced, they could further improve the economic viability of these regimes.

It is also important to note that under the averaging accounting method, carbon credits are issued only in the first rotation and up to the average age of that forest type, age 16 for radiata pine. When it comes to early harvesting, if the age of the forest is greater than the average age, all carbon credits can be claimed. If many short-rotation forests were established, taking advantage of this, it is likely that a policy change could occur, lowering the credits accumulated by short-rotation regimes.

Transport distance

Transport distance had a clear inverse relationship with both NPV and LEV, with profitability declining as cartage distances to the mill increased. This relationship reflects the direct link between transport costs and distance, where longer haulage increases the cost of cartage and therefore reduces the overall profitability. Regime three was the most affected, showing the steepest decline in both NPV and LEV as distance increased from 15 km to 115 km. This is due to its two-phase harvest structure, which exposes the regime to increased cartage costs both during short and full rotation harvests. However, it is important to note that land located further from processing facilities often has lower land prices. These savings can partially offset the increased cost of transportation. Therefore, a balance between distance from the mill and lower land costs should be a key consideration when selecting a forest.

These results demonstrate how external and spatial factors can significantly influence the economic viability of each regime. While policy mechanisms such as the ETS can enhance profitability, physical factors like distance to the mill impose economic constraints. To further understand the influence of these and other key assumptions, a sensitivity analysis was conducted to identify which input variables have the greatest impact on the profitability and resilience of each regime.

6.7 Sensitivity analysis

A sensitivity analysis was undertaken to identify which key assumptions have the greatest influence on project viability and create a higher investment risk. This provides insight into which factors are most critical in determining the financial feasibility of each regime under uncertain market and policy conditions.

6.7.1 Carbon price

The sensitivity analysis demonstrates a strong linear relationship between carbon price and NPV across all three forestry regimes. For each 25% increase in carbon price, NPVs increased by approximately $976.34 per hectare, regardless of the regime. This uniform increase occurs because carbon revenues are realised at the start of the regime, meaning carbon revenues are discounted over the same period and therefore have the same present value impact across all regimes. The parallel trend lines in Figure 14 illustrate that while the absolute NPV values differ between regimes, the rate of change with respect to carbon price is identical.

These results further highlight the significant role of carbon revenues in improving the economic viability of a biomass forest. Even modest increases in carbon credits significantly improve profitability under the base assumptions. Conversely, reductions in carbon price make negative NPVs worse, demonstrating the vulnerability of all regimes to fluctuations in carbon markets. These findings underscore the importance of policy certainty and early carbon revenues in supporting long-term investment in biomass forestry.

The sensitivity analysis of carbon price highlights the strong influence of carbon prices on the economic viability of each regime. Other external factors, such as operational costs, can also significantly impact profitability. The next section examines the sensitivity of each regime to transport costs, further exploring how variations in cartage expenses influence NPV and LEV.

6.7.2 Transport costs

The sensitivity analysis examining the effect of varying cartage costs on NPV revealed a clear negative linear relationship across all three regimes. As cartage costs increased, NPV declined proportionally, reflecting the direct impact of higher transportation expenses on overall project profitability. For each 25% increase in cartage costs, the NPV decreased by approximately $259.92, $222.07, and $315.49 per hectare for Regimes 1, 2, and 3, respectively (Table 9).

Rising cartage costs are a realistic future risk for the forestry industry. Increases in fuel prices, driver shortages, and stricter emission standards for heavy vehicles could all lead to elevated transport costs over time. These results emphasise the importance of accounting for long-term volatility in cartage costs when assessing the viability of a biomass forest. Future improvements in transport efficiency, such as increased payload capacity, low-emission fuel technology or even the introduction of self-driving trucks, may help mitigate the risk of fuel price increases, but rising costs remain a significant vulnerability for large-scale biomass supply.

Another major factor influencing the economic performance of each regime is the market value of sawlogs. As saw logs are the premium product within a full rotation forest, fluctuations in price can significantly affect the NPV and LEV of the project. The following section explores how each regime is affected by the change in sawlog markets.

6.7.3 Saw log price

The sensitivity analysis investigating the effect of varying sawlog prices on NPV revealed that only regimes two and three were affected by changes in sawlog value, regime one remained unaffected. This outcome aligns with expectations, as regime one produces no sawlogs and relies solely on biomass revenues. In contrast, Regimes two and three displayed positive linear relationships between sawlog price and NPV. For every 25% increase in sawlog price, the NPV rose by approximately $965.95 and $241.73 per hectare for Regimes 2 and 3, respectively (Table 10)

Regime two was affected the most by fluctuations in saw log price, because a large proportion of the revenue comes from the sale of sawlogs. Regime three showed a lower rate of change, as sawlog revenues are pushed back, creating a higher discounting effect on these revenues. These findings highlight the critical influence of sawlog markets on the profitability of regimes two and three, where revenue stability depends heavily on log market performance. The following section explores how varying discount rates impact the NPV and LEV across all three regimes.

6.7.4 Discount rate

The sensitivity analysis examined the effect of varying discount rates on NPV, which revealed an exponential decay across all three regimes. As discount rates increased from 2% to 14%, NPVs declined substantially, with the rate of decline slowing towards the higher discount rates. This trend shows how the discount rate affects cash flows in later years more heavily than in earlier years.

Between discount rates of 2% and 14%, NPV declined by approximately $14,000/ha in regime two, compared with $5,400/ha and $6,700/ha in regimes one and three. This demonstrates the greater sensitivity of regime two to changes in the discount rate. This greater sensitivity of regime two is due to its main revenue coming from later rotations and thus is more heavily discounted at higher rates.

This highlights the importance of the discount rate, as it directly influences investment attractiveness. When discount rates are high, which often reflects increased market uncertainty or opportunity costs, all regimes become less profitable, especially when large proportions of revenues are realised later. The high sensitivity to discount rate indicates that reducing perceived risk for the investment, through long-term supply agreements, stable policies, and low-interest financing, would help improve biomass supply feasibility.

While discount rate analysis highlights the influence of different discount rates on project viability, operational factors such as harvesting costs also play a major role in determining profitability. As one of the largest ongoing expenses, changes in harvesting costs can significantly affect the economic outcome of each regime. These variations are investigated in the following section.

6.7.5 Harvest costs

The sensitivity analysis showed that harvesting costs have a strong influence on the profitability of all three regimes. As harvesting costs increased, NPVs declined linearly, this demonstrates the direct and proportional relationship between harvesting costs and returns. This result is expected as harvesting costs represent one of the most significant costs for each regime.

Across all regimes, regime three was affected the most by fluctuations in harvesting costs, this is due to the economic analysis including both the short rotation and the long rotation, and therefore two harvest periods, both regime one and three also have a harvest occurs at year 17, the effect discounting has on the harvest cost is lower and therefore causes larger fluctuations in the NPV as a result regime two experienced the lowest change in NPV with each 25% increase in harvest costs.

While the variation in harvesting costs has different effects on the NPV of each regime, regime one decreased by $614.00, while regime two decreased by $524.61 per 25% increase in harvest costs. The difference in declines between regimes one and two is approximately $90. Although regime two has higher per-hectare harvest costs due to larger volume, these are offset by stronger discounting effects, resulting in a lower sensitivity relative to regime one.

Overall, the sensitivity analysis revealed that the economic viability of large-scale biomass supply in Canterbury is highly dependent on external and financial factors. Among the variables tested, the discount rate produced the largest overall change in NPV, followed by harvesting costs and carbon price. The stronger response of NPV to carbon price compared to sawlog highlights how all regimes have a higher dependence on government policy than the log market. Therefore, high carbon prices coupled with lower harvesting costs are essential in improving economic viability.

The results of this study highlight the key economic factors surrounding a large-scale biomass supply in Canterbury, New Zealand. The analysis compared three regimes, a short rotation biomass forest, a mature biomass forest that has additional revenue from sawlogs, and a combination of the two. The study also examined how the location of the forest affected NPV, exploring the trade-off between transport distance and land price. The impact of participation in the ETS under a short-rotation biomass forest was also explored. Additionally, key assumptions were varied to test the effects on profitability under different biomass supply strategies in regime two. The following section brings all these results together to summarise the overall conclusions and practical implications of this study.

7. Conclusion

This study assessed the economic viability of a large-scale radiata pine plantation for biomass production in Canterbury, New Zealand. This was done through three management regimes: a short-rotation biomass forest, a mature biomass forest that also produced sawlogs, and a transitional forest combining the first two regimes. The analysis evaluated each regime's land requirements, as well as the performance of key economic factors such as NPV, LEV, and the breakeven price of biomass. A sensitivity analysis was undertaken to explore how variations in key base assumptions can impact NPVs.

Under the base assumptions, all regimes produced negative NPVs. This indicates that a large-scale supply of biomass is not currently feasible. Regimes one and three both provided biomass early, but as the wood quality is low, all the volume is used to supply biomass, resulting in lower returns.

Sensitivity analysis highlighted the importance of external factors and operational costs in determining project viability. The discount rate had the greatest influence on NPV, reflecting the crucial role offsetting revenue timelines has on profitability. Harvesting costs were the most significant operational cost, while the carbon price had a larger impact on profitability than fluctuations of sawlog price, highlighting the importance of government policy on biomass forest returns.

The lowest breakeven price for biomass was found to be \$140/m^3, significantly higher than the assumed market price of \$50/m^3, highlighting the gap between current conditions and a profitable biomass production. Improvements in harvesting efficiency, policy incentives, or higher log prices could help reduce this gap. Further research investigating how optimising species selection, harvesting systems and silvicultural regimes specifically for biomass production could improve the profitability of supplying large quantities of biomass. Such work could help provide practical insights into the improvement of the economic viability of a large-scale biomass supply in Canterbury, New Zealand.

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9. Appendix A: Planting and harvesting regimes

year	planted	1st harvest	replant	2nd harvest
0	2415.458937			
1	2415.458937			
2	2415.458937			
3	2415.458937			
4	2415.458937			
	2415.458937			
6	2415.458937			
7	2415.458937			
8	2415.458937			
9	2415.458937			
10	2415.458937			
11	2415.458937			
12	2415.458937			
13	2415.458937			
14	2415.458937			
15	2415.458937			
16	2415.458937			
17	2415.458937	2415.458937		
18		2415.458937	2415.458937	
19		2415.458937	2415.458937	
20		2415.458937	2415.458937	
21		2415.458937	2415.458937	
22		2415.458937	2415.458937	
23		2415.458937	2415.458937	
24		2415.458937	2415.458937	
25		2415.458937	2415.458937	
26		2415.458937	2415.458937	
27		2415.458937	2415.458937	
28		2415.458937	2415.458937	
29		2415.458937	2415.458937	
30		2415.458937	2415.458937	
31		2415.458937	2415.458937	
32		2415.458937	2415.458937	
33		2415.458937	2415.458937	
34			2415.458937	2415.458937
35				2415.458937
36				2415.458937
37				2415.458937
38				2415.458937
39				2415.458937
40				2415.458937
41				2415.458937
42				2415.458937

43	2415.458937
44	2415.458937
45	2415.458937
46	2415.458937
47	2415.458937
48	2415.458937
49	2415.458937
50	2415.458937

year	planted	1st harvest	replant
0	1966.955153		
1	1966.955153		
2	1966.955153		
3	1966.955153		
4	1966.955153		
5	1966.955153		
6	1966.955153		
7	1966.955153		
8	1966.955153		
9	1966.955153		
10	1966.955153		
11	1966.955153		
12	1966.955153		
13	1966.955153		
14	1966.955153		
15	1966.955153		
16	1966.955153		
17	1966.955153		
18	1966.955153		
19	1966.955153		
20	1966.955153		
21	1966.955153		
22	1966.955153		
23	1966.955153		
24	1966.955153		
25	1966.955153		
26	1966.955153		
27	1966.955153		
28	1966.955153		
29	1966.955153		
30	1966.955153	1966.955153	
31		1966.955153	1966.955153
32		1966.955153	1966.955153
33		1966.955153	1966.955153
34		1966.955153	1966.955153
35		1966.955153	1966.955153
36		1966.955153	1966.955153
37		1966.955153	1966.955153
38		1966.955153	1966.955153
39		1966.955153	1966.955153
40		1966.955153	1966.955153
41		1966.955153	1966.955153
42		1966.955153	1966.955153
43		1966.955153	1966.955153
44		1966.955153	1966.955153
45		1966.955153	1966.955153
46		1966.955153	1966.955153
47		1966.955153	1966.955153
48		1966.955153	1966.955153
49		1966.955153	1966.955153

50		1966.955153	1966.955153

	Planted	Harvested age 15	Harvested age 30	Replanting of short rotation	Replanting of full rotation	Second harvest of short rotation	second harvest of full rotation
0	2415.458937						
1	2415.458937						
2	2415.458937						
3	2415.458937						
4	2415.458937						
5	4017.188743						
6	4017.188743						
7	4017.188743						
8	4017.188743						
9	4017.188743						
10	4017.188743						
11	4017.188743						
12	4017.188743						
13	4017.188743						
14	4017.188743						
15	4017.188743						
16	4017.188743						
17	4017.188743	2415.458937					
18		2415.458937		448.5037838	1966.955153		
19		2415.458937		448.5037838	1966.955153		
20		2415.458937		448.5037838	1966.955153		
21		2415.458937		448.5037838	1966.955153		
22		2415.458937		448.5037838	1966.955153		
23		2415.458937		448.5037838	1966.955153		
24		2415.458937		448.5037838	1966.955153		
25		2415.458937		448.5037838	1966.955153		
26		2415.458937		448.5037838	1966.955153		
27		2415.458937		448.5037838	1966.955153		
28		2415.458937		448.5037838	1966.955153		
29		2415.458937		448.5037838	1966.955153		
30		2415.458937		448.5037838	1966.955153		
31		2415.458937			1966.955153		
32		2415.458937			1966.955153		
33		2415.458937			1966.955153		
34		2415.458937			1966.955153		
35			1601.729806		1966.955153	448.5037838	
36			1601.729806		1966.955153	448.5037838	
37			1601.729806		1966.955153	448.5037838	
38			1601.729806		1966.955153	448.5037838	
39			1601.729806		1966.955153	448.5037838	
40			1601.729806		1966.955153	448.5037838	
41			1601.729806		1966.955153	448.5037838	
42			1601.729806		1966.955153	448.5037838	
43			1601.729806		1966.955153	448.5037838	
44			1601.729806		1966.955153	448.5037838	
45			1601.729806		1966.955153	448.5037838	
46			1601.729806		1966.955153	448.5037838	

47	1601.729806	1966.955153	448.5037838	
48		1966.955153		1966.955153
49		1966.955153		1966.955153
50		1966.955153		1966.955153

10. Appendix B: Economic analysis of regime one

	17-year rotation			
year	costs	revenues	NET	discounted
0	8562.363	0	-8562.36	-8562.36
1	385.7456	8	-377.746	-349.764
2	95	32	-63	-54.0123
3	95	40	-55	-43.6608
4	95	120	25	18.37575
5	95	400	305	207.5779
6	95	640	545	343.4424
7	95	880	785	458.04
8	95	920	825	445.7218
9	95	1000	905	452.7253
10	95	960	865	400.6624
11	95	560	465	199.4305
12	95	440	345	137.0042
13	95	320	225	82.73203
14	95	480	385	131.0775
15	95	640	545	171.8067
16	1515.639	760	-755.639	-220.564
17	13029.06	17493.39	4464.331	1206.57
			NPV	-4975.2
year	costs	revenues	NET	discounted
0	1418.973		-1418.97	-1418.97
1	385.7456		-385.746	-357.17
2	95		-95	-81.45
3	95		-95	-75.41
4	95		-95	-69.83
5	95		-95	-64.66
6	95		-95	-59.87
7	95		-95	-55.43
8	95		-95	-51.33
9	95		-95	-47.52
10	95		-95	-44.00
11	95		-95	-40.74
12	95		-95	-37.73
13	95		-95	-34.93
14	95		-95	-32.34
15	95		-95	-29.95
16	1157.807		-1157.81	-337.95
17	13029.06	10350	-2679.06	-724.07
			LEV no carbon	-1319.75
			LEV	2585.604

11. Appendix C: Economic analysis of regime two

	costs	revenues	NET	Present value	costs	revenues	NET	Present value
0	8562.363	0	-8562.3634	-8562.36337	1418.973		-1418.97337	-1418.97337
1	385.7456	8	-377.74564	-349.7644798	301		-301	-278.7037037
2	95	32	-63	-54.01234568	95		-95	-81.44718793
3	95	40	-55	-43.66077326	95		-95	-75.4140629
4	95	120	25	18.37574632	95		-95	-69.82783602
5	95	400	305	207.5778751	95		-95	-64.65540372
6	95	640	545	343.4424467	95		-95	-59.86611455
7	95	880	785	458.0399603	95		-95	-55.43158755
8	95	920	825	445.7218297	95		-95	-51.32554403
9	95	1000	905	452.7253153	95		-95	-47.52365188
10	95	960	865	400.6623672	95		-95	-44.00338137
11	95	560	465	199.4305296	95		-95	-40.74387164
12	95	440	345	137.0042467	95		-95	-37.72580707
13	95	320	225	82.73203305	95		-95	-34.93130284
14	95	480	385	131.0775009	95		-95	-32.34379893
15	95	640	545	171.8067292	95		-95	-29.94796197
16	95	760	665	194.1071609	95		-95	-27.72959442
17	95	0	-95	-25.67555039	95		-95	-25.67555039
18	95	0	-95	-23.77365777	95		-95	-23.77365777
19	95	0	-95	-22.01264608	95		-95	-22.01264608
20	95	0	-95	-20.3820797	95		-95	-20.3820797
21	95	0	-95	-18.87229602	95		-95	-18.87229602
22	95	0	-95	-17.47434817	95		-95	-17.47434817
23	95	0	-95	-16.17995201	95		-95	-16.17995201
24	95	0	-95	-14.98143704	95		-95	-14.98143704
25	95	0	-95	-13.87170097	95		-95	-13.87170097
26	95	0	-95	-12.84416756	95		-95	-12.84416756
27	95	0	-95	-11.89274774	95		-95	-11.89274774
28	95	0	-95	-11.01180347	95		-95	-11.01180347
29	2930.041	0	-2930.0408	-314.4740132	2253.807		-2253.80663	-241.8954742
30	30149.5	53873.39	23723.886	2357.616555	30149.5	46730	16580.49647	1647.725512
			Npv	-3932.927073			LEV	3767.01419
							LEV no carbon	-138.3409463

12. Appendix D: Econmic analysis regime three

year	costs initial	revenue initial	NET	disc
0	8562.3634	0	-8562.36	-8562.36337
1	385.74564	8	-377.75	-349.7644798
2	95	32	-63	-54.01234568
3	95	40	-55	-43.66077326
4	95	120	25	18.37574632
5	95	400	305	207.5778751
6	95	640	545	343.4424467
7	95	880	785	458.0399603
8	95	920	825	445.7218297
9	95	1000	905	452.7253153
10	95	960	865	400.6623672
11	95	560	465	199.4305296
12	95	440	345	137.0042467
13	95	320	225	82.73203305
14	95	480	385	131.0775009
15	95	640	545	171.8067292
16	1515.6395	760	-755.63948	-220.5639627
17	13029.059	17493.39	4464.33131	1206.570142
			NPV short	-4975.19821

age	year	costs initial	revenue initial	NET	disc
0	18	8562.363	0	-8562.36	-2142.72
1	19	385.7456	0	-385.746	-89.3819
2	20	95	0	-95	-20.3821
3	21	95	0	-95	-18.8723
4	22	95	0	-95	-17.4743
5	23	95	0	-95	-16.18
6	24	95	0	-95	-14.9814
7	25	95	0	-95	-13.8717
8	26	95	0	-95	-12.8442
9	27	95	0	-95	-11.8927
10	28	95	0	-95	-11.0118
11	29	95	0	-95	-10.1961
12	30	95	0	-95	-9.44085
13	31	95	0	-95	-8.74152
14	32	95	0	-95	-8.094
15	33	95	0	-95	-7.49445
16	34	95	0	-95	-6.9393
17	35	95	0	-95	-6.42528
18	36	95	0	-95	-5.94933
19	37	95	0	-95	-5.50864
20	38	95	0	-95	-5.1006
21	39	95	0	-95	-4.72277
22	40	95	0	-95	-4.37294
23	41	95	0	-95	-4.04902
24	42	95	0	-95	-3.74909
25	43	95	0	-95	-3.47138
26	44	95	0	-95	-3.21424
27	45	95	0	-95	-2.97615
28	46	95	0	-95	-2.75569
29	47	2930.041	0	-2930.04	-78.6968
30	48	30149.5	53873.39	23723.89	589.9913
				NPV long	-1961.52
				NPV TOT	-6936.72

	costs initial	revenue initial	NET	disc
0	1418.9734	0	-1418.97	-1419.0
1	385.74564	8	-377.75	-349.8
2	95	32	-63	-54.0
3	95	40	-55	-43.7
4	95	120	25	18.4
5	95	400	305	207.6
6	95	640	545	343.4
7	95	880	785	458.0
8	95	920	825	445.7
9	95	1000	905	452.7
10	95	960	865	400.7
11	95	560	465	199.4
12	95	440	345	137.0
13	95	320	225	82.7
14	95	480	385	131.1
15	95	640	545	171.8
16	1515.6395	760	-755.64	-220.6
17	13029.059	10350	-2679.06	-724.1
			NPV	237.6

age	year	costs initial	revenue initial	NET	disc
0	18	1513.973		-1513.97	-378.87
1	19	385.7456		-385.746	-89.3819
2	20	95		-95	-20.3821
3	21	95		-95	-18.8723
4	22	95		-95	-17.4743
5	23	95		-95	-16.18
6	24	95		-95	-14.9814
7	25	95		-95	-13.8717
8	26	95		-95	-12.8442
9	27	95		-95	-11.8927
10	28	95		-95	-11.0118
11	29	95		-95	-10.1961
12	30	95		-95	-9.44085
13	31	95		-95	-8.74152
14	32	95		-95	-8.094
15	33	95		-95	-7.49445
16	34	95		-95	-6.9393
17	35	95		-95	-6.42528
18	36	95		-95	-5.94933
19	37	95		-95	-5.50864
20	38	95		-95	-5.1006
21	39	95		-95	-4.72277
22	40	95		-95	-4.37294
23	41	95		-95	-4.04902
24	42	95		-95	-3.74909
25	43	95		-95	-3.47138
26	44	95		-95	-3.21424
27	45	95		-95	-2.97615
28	46	95		-95	-2.75569
29	47	2930.041		-2930.04	-78.6968
30	48	30149.5	46730	16580.5	412.3417
				LEV	196.1414