BIOENERGY OPTIONS FOR NEW ZEALAND

ANALYSIS OF LARGE-SCALE BIOENERGY FROM FORESTRY

Productivity, Land use and Environmental & Economic Implications

New Zealands EnergyScape

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This report is the 4th output from the Bioenergy Options for New Zealand project. It builds on previous studies described in the *Situation Analysis, Pathways Analysis* and *Bioenergy Research Strategy*.

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Bioenergy Options for New Zealand
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Executive Summary

Background

Bioenergy Options for New Zealand studies (Situation and Pathways analyses) identified a significant opportunity for New Zealand to develop a purpose-grown forestry-based biomass resource that could meet national-scale demands for consumer energy. Such forests could utilise low productivity grazing land on steep terrain with low current financial returns. The biomass arising from these forests could be used to provide heat, electricity and transport fuels for New Zealand whilst mitigating some environmental issues (carbon, water quality and erosion).

Purpose

This study (Large-scale Bioenergy from Forestry) considers the potential nation-wide impacts of growing forests for energy through a preliminary assessment of the environmental, economic and land-use implications. This information can assist in determining whether large-scale forests for bioenergy is a strategic direction worth pursuing, and what particular scenarios maximise the long-term benefits. The principal focus of this study is on the production of liquid fuels, since finding renewable options for transportation is recognised as one of the greatest challenges facing New Zealand.

Study methodology

Four large-scale afforestation scenarios were developed and analysed. The land area selected for these scenarios specifically targeted low productivity grazing land on rolling to steep terrain. The current plantation forest estate is ~1.7 – 1.8 million ha, and there is 9.2 million ha of hill country that is either marginal land or low to moderate productivity hill country grazing. The benefits of using this marginal hill-country for afforestation are that competition with food production is minimised and environmental benefits are maximised. Forest (radiata pine) biomass productivity and costs were estimated for these land area scenarios and this data was used as the basis for assessing the environmental, land use competition and economic impacts of each of the scenarios.

Afforestation scenarios

Afforestation scenarios of 0.8, 1.8, 3.3 and 4.9 million ha of purpose-grown forest were considered. Location of afforestation area was dependent on the scenario; with lower afforestation area scenarios biased towards the southern part of New Zealand and higher area scenarios more evenly spread across all the regions. Recoverable forest biomass production of 640 to 900 m^3 per ha was estimated to be possible from a 25-year rotation, biomass-focused forest management regime. A significant percentage of the crop could also be used to produce saw logs for traditional markets.

Environmental impacts

All of the afforestation scenarios considered provided significant environmental benefits, contributing to large volumes of stored carbon, reductions in erosion, improvements in water quality and positive impacts on biodiversity. The limiting environmental factor was water availability, especially in regions with low rainfall, and/or high levels of existing water allocation.

Land-use competition

The land-use competition analysis showed that forestry for biofuels could be competitive if petrol prices reached $2.75 per litre (excluding taxes). At this price, the low-end estimate of afforestation that would be viable for biofuels ranged from 0.2 to 4 million ha. The high-end estimation assumes that biofuels are not regarded as a high-risk option, and that an emissions trading scheme could significantly affect the profitability of sheep/beef farming. There are currently large areas (~2.5 million ha) of hill country grazing that are earning less than $200 per ha per annum. The cost estimates for forestry production gave returns to the forest grower equivalent to $185 per ha per annum. At this level, much of the land in the 1.8 million ha scenario would earn as much from biofuels as it currently does from sheep and beef farming.

Economic impacts

A general equilibrium model of the New Zealand economy was used to investigate the economy-wide effects of using local resources to produce biofuels instead of producing other goods and services that are exported in exchange for oil. A number of biofuel scenarios were compared with a business-as-usual (BAU) picture of the economy in 2050. The analysis focused on the impact of biofuels on private consumption and real gross national disposable income, two measures of economic welfare (or standard of living). The broad conclusions from the study were:

- There is likely to be a loss in national production efficiency reflected in a decline in GDP as long as biofuels cost more to produce than importing fossil fuels. This has a negative effect on gross national disposable income. Efficiency gains in production which lead to lower cost biofuels and rising oil prices will offset this effect.

- The production and use of biofuels reduces CO_2 emissions, so if there is a price on carbon, New Zealand's liability to purchase offshore emission units is reduced. This will generate a gain in real gross national disposable income.

- As oil prices are assumed to increase faster than the price of other goods, there are likely to be gains in terms of trade from domestic production of biofuels from forestry. There will also be increases in wage rates (or employment rates) from the creation of a new biofuels industry. The improved terms of trade and reduced carbon emissions liability effects lead to significant increases in private consumption, especially for high oil prices.

- Lower afforestation scenarios are more likely to improve economic welfare as they utilise low-productivity land first and therefore have a lower impact on agricultural production per hectare. In the higher afforestation scenarios, larger reductions in agriculture production per hectare of afforestation occur, making gains in economic welfare less likely.

- Results were sensitive to oil and carbon prices but not sensitive to the price of agricultural goods.

- Efficiency gains in the forest/feedstock/processing chain had a positive impact on the future viability of biofuels

Overall, the results showed that biofuels could significantly decrease the exposure of the New Zealand economy to increasing oil and carbon prices.

Economic analysis of the environmental benefits was not attempted is this study. Whilst there is clearly a value (public benefit) to improved water quality, reduced erosion and increased biodiversity, these factors are difficult to quantify.

The tree crops from the scenarios have an energy insurance value (stored energy), but the extent of this value is also difficult to determine.

Future work

Further analysis is required on:

- the potential of existing forests to provide bioenergy as a transition supply whilst a larger resource is developed;
- the option of using new forests to provide a range of log products (sawlog, energy chip) and the cost reductions this may enable in the price of energy feedstock;
- understanding the potential of bioenergy to alleviate the volatility of oil prices;
- understanding the social aspects of land use change.

Work on some of these (bullet points 1-3) is under way in the next phase of the Bioenergy Options for New Zealand project.

Potential scenario

This study estimates that a level of new afforestation in the range of 1.0 to 2.0 million ha could be viable under future conditions where oil reaches ~US$200 per barrel. This scenario would provide good environmental outcomes and minimise impacts on existing land uses. In conjunction with use of lower value (chip log) volumes available from the existing forestry estate, these new forests could be a significant contributor to New Zealand's energy supply. Further detailed analysis is underway in the next stage of the Bioenergy Options for New Zealand project.

The basis of the decision to plant forests for energy rests on the investor's view of where the price of oil, carbon, and exchange rate will be in 30 years time. Predicting the future is fraught with difficulties, but it is highly likely that oil and carbon prices will rise over time due to resource depletion, increasing energy demands from developing countries and the growing international momentum for governments to implement climate policies. The IEA Energy Outlook 2008 predicts US$200 per barrel by 2030.

Bioenergy from forestry, especially for liquid fuels, represents an opportunity for New Zealand to minimise the impacts of rising and fluctuating global oil prices and move to a more secure, stable and sustainable state whilst minimising our carbon liabilities. At the same time we would be enhancing our environment by: reducing erosion and nutrient run-off; improving water quality; and enhancing biodiversity, thus protecting our access to valuable markets and the associated business opportunities.

This analysis started with forestry as an energy proposition. Results from the analysis suggest a traditional forestry proposition with a significant energy component is likely to be the best option, as this may reduce the cost of the log harvest portion delivered to the energy system.

“Creating a new energy economy isn’t just a challenge – it’s an opportunity to seize.”
Barack Obama, 2008

"*The country that harnesses the power of clean, renewable energy will lead the 21st century.*"
President Obama, 2009

“The world’s energy system is at a crossroads. Current global trends in supply and consumption are patently unsustainable – environmentally, economically, socially. But can – and must- be altered; there is still time to change the path we are on.”
International Energy Agency
World Energy Outlook, 2008.

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General Introduction and Overview

Introduction

Energy is a fundamental driver of economic prosperity and social well-being, as the cost of energy is reflected in the cost of all consumer goods and services. Energy from fossil fuels provides around 70% to 75% of New Zealand's consumer energy and almost 100% of transport fuels. This fossil fuel is a major contributor to the nation's greenhouse gas emissions.

New Zealand's energy policies (which are under review) aim to achieve an energy supply that is affordable, secure, sustainable and moving towards being carbon neutral. Some of the goals are; improved fleet efficiency limiting demand growth; significant changes to fuels in the light vehicle fleet (including electric cars); significant volumes of biodiesel (120PJ pa in 2050); low carbon urban fleets and reducing transport GHG emissions.

Scion and its partners (Landcare, CRL Energy, NIWA, Waste Solutions, NZCEE and Fuel Technology Ltd) have conducted a series of studies in the Bioenergy Options for New Zealand project. This previous work was aimed at determining current and future potential for bioenergy to contribute to New Zealand's energy supply in line with government policy. These studies have been summarised in two previous reports:

1. Situation Analysis – biomass resources and conversion technologies.
2. Pathways Analysis – lifecycle analysis of biomass resource to consumer energy, pathways evaluation, energy demand, economics of purpose-grown energy forests.

From these studies and other information, a Bioenergy Research Strategy for New Zealand was developed, based on knowledge gaps identified in these studies. Key findings in this previous work were:

- Residual biomass resources and biomass wastes are diverse, distributed and could make a small but significant contribution to New Zealand's energy demand. The extent of this contribution varies depending on the energy product made from the resource, but with a maximum of 10% to 12% of current national consumer energy. The environmental benefits of waste to energy are significant.
- There is a wide range of technology options for conversion of biomass to consumer energy, including liquid fuels.
- The most problematic area for renewable energy supply in New Zealand is likely to be liquid fuels.
- Over 60% (9,288,000 ha) of New Zealand's available productive land is hill country which is unsuitable for cropping and 23% (3,600,000 ha) is unsuitable for pasture. Given New Zealand's economic drivers (agricultural exports) and land resources, the use of steeper lands to grow biomass via forests is a potentially large-scale solution to carbon neutral energy supply, including liquid fuels.
- Biofuels from arable crops have low yields in terms of litres per ha (land-use efficiency). For example, canola could yield 1360l/ha/pa of biodiesel, whereas forests could potentially produce the equivalent of 2400 l/ha/pa of liquid biofuels (diesel equivalent).
- Liquid fuels from woody biomass:
    - are technically possible;
    - give significant GHG benefits over fossil fuels;
    - are almost cost effective under some conditions (residual biomass or low-cost logs and oil at US$180/barrel).
- Forest establishment investment risk can be mitigated by having alternative markets for the wood (carbon, logs, and reconstituted wood products) as well as a variety of energy end uses: heat, electricity and transport or solid, gas and liquid fuels.

The current study has also contributed to the Bioenergy Research Strategy for New Zealand.

Purpose of this study

Large-scale bioenergy production from new plantation forests has been identified as the most promising route to meeting a large percentage of energy supply from renewable resources in New Zealand. However, the concept of large-scale bioenergy from forests has impacts across a number of areas including the environment, land use and the national economy. The current study was initiated to investigate whether large-scale bioenergy from forests was an avenue that New Zealand should pursue based on a holistic approach that takes these different impacts into account.

This report (Analysis of Large-scale Bioenergy from Forestry) builds on the previous work and is intended to determine the value of the largee-scale forestry to energy proposition, by examining in detail the following aspects of large-scale forestry for bioenergy:

- land use, land-use change, potential biomass production, and cost of biomass production;
- environmental impacts;
- land-use competition and agricultural production impacts;
- economic impacts.

The Bioenergy Research Strategy for New Zealand proposed a broad strategic direction for bioenergy in New Zealand with a focus on biomass feedstocks from forests for national-scale supply of solid, gas, and liquid fuels. This document is focused mainly on the production of liquid fuels. The potential of woody biomass to meet heat and electricity demands will be addressed in future work (Bioenergy Options for New Zealand – Transition Analysis).

Structure of the study

To determine the impacts of the energy forest concept at different scales we examined four possible scenarios of land area for conversion to new bioenergy forests. We then developed estimates of biomass production and cost from this land. Scion commissioned three studies to investigate the impacts of these scenarios on the environment, existing land use and macro-economic effects. Reports from these studies are included as chapters in the current document. An outline of the report and project structure is given in Figure. 1.

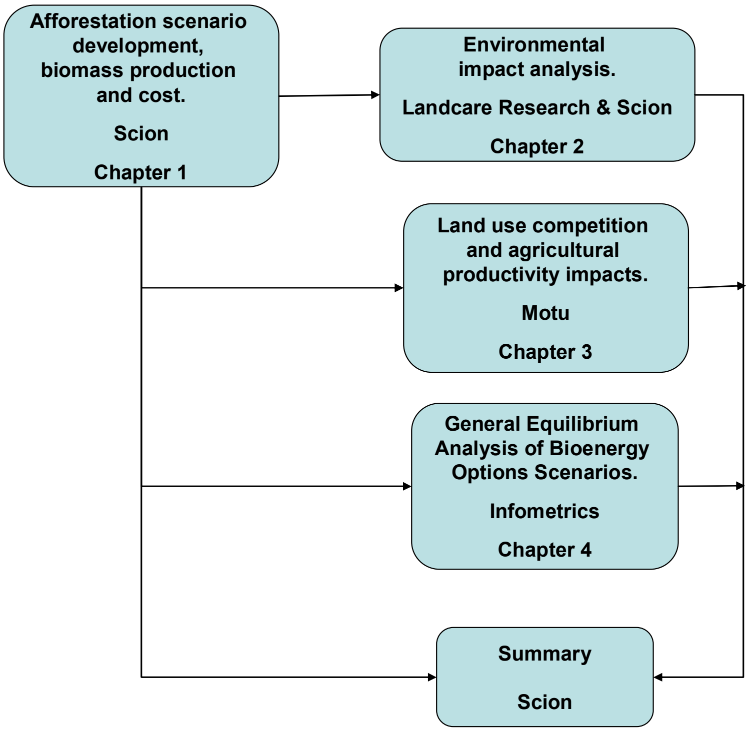


Figure 1: Diagram of information flow within this report

The land-use scenarios developed for the study are outlined in Table 1.

Table 1: New afforestation / land-use change scenarios

	Descriptive area, Millions of hectares	Actual area, hectares
Scenario 1	0.8	765,181
Scenario 2	1.8	1,855,669
Scenario 3	3.3	3,386,648
Scenario 4	4.9	4,927,040

In the land-use chapter of the report (Chapter 1) we describe how these scenarios were developed and what land-use changes are implied by each one. We also provide analysis of productivity and growth for the selected areas and provide cost estimates for forest establishment, management, roading, harvest and transport. Estimates of potential productivity gains from various parts of the supply chain are provided, along with their impact on delivered cost.

The environmental impact analysis (Chapter 2) uses the area scenarios as the basis for assessing the impacts of afforestation and land-use change on a variety of factors including water quality and yield, carbon storage, erosion and biodiversity for the area scenarios.

The land area, production and cost data from Chapter 1 are used as the base information for the land-use competition, agricultural production impacts and macro-economic analysis (Chapters 3 and 4).

The major findings from the chapters are summarised in the General Introduction and Overview section at the beginning of this document (pages 4 -20).

Underlying assumptions
Discount rate 6%

1 cubic metre (m3) of wood = ~ 1 tonne of wood (green, 59% moisture content)
= 6.5 gigajoules (GJ) per tonne, green
= 140 litres of ethanol = 94 litres of petrol equivalent
= 95 litres of biodiesel = 100 litres of petrol equivalent

No production of, or value for co-products from biomass to liquid fuel conversion plants was included in this analysis.

Acknowledgements
Scion acknowledges the input to this report of the many contributing authors and organisations. We also acknowledge the valuable review provided by these organisations and individuals on the summary section, and the review comments provided by EECA, MED and MAF.

Land use, forest productivity, and production costs: Summary

This section summarises the key results from Chapter 1.

Forest biomass scenarios

This analysis develops four scenarios that involve different levels of new afforestation and considers the land-use change impacts and potential biomass production and cost of each one. The four scenarios are outlined in Table 2.

These scenarios were based on a Geographic Information Systems (GIS) analysis using land-use capability ratings and site selection criteria (including slope, altitude and current land use). The scenarios assume the use of scrub, idle, marginal and low-to-moderate productivity grazing lands as the resource area (see Chapter 1 for details).

The four scenarios correspond to the utilisation of land with increasing value. Maps of these scenarios are shown in Figure 1. Otago and South Canterbury had large areas of land identified for afforestation in all scenarios. Manawatu/Wanganui and Gisborne and Southern Hawke's Bay also had large areas of land potentially suitable for afforestation Scenarios 2, 3 and 4. If the land selection had been based on clustering of forest to meet energy demand, the maps would be different. The selection here was based on obtaining low productivity land that did not compete with high value food production.

Table 2: Area scenario summary, hectares (area from minor contributing land uses not shown)

Scenario	Total Area	North Island area	South Island area	Area from scrubland	Area from sheep and beef	Regions with significant area*
1	831,158	86,793	744,365	0	532,790	C, O
2	1,855,669	917,208	938,460	51,475	1,617,804	C, O, M/W, G, HB
3	3,474,550	1,948,892	1,525,657	69,443	3,159,984	C, O, M/W, G, HB, Wai
4	4,927,040	2,505,421	2,421,619	198,077	4,411,545	C, O, M/W, G, HB, Wai, Wtt, S

* C = Canterbury O = Otago M/W = Manawatu/Wanganui Wtt = Wellington
G = Gisborne HB = Hawke's Bay Wai = Waikato S = Southland

Productivity and site quality surface models, together with biomass productivity models, were used to develop predictions of potential growth for the different land-area scenarios. Modelling included volume growth and wood density, to provide biomass predictions including stem, bark and crown material.

Radiata pine was used as the model species, as it is the only plantation forest species with a comprehensive nationwide data set that currently allows accurate, national level modelling of site productivity and variability. The use of radiata pine as the crop does not presuppose that this will ultimately be the crop that is used, it is simply the species that has the most information currently available in terms of growth and management. For this reason it can be modelled more accurately and in more detail than any other plantation forest species. Productivity surfaces for other species are limited, with one other available (*Cupressus lusitanica*). However, a productivity surface for Douglas fir will be released soon and several are under development for *Eucalyptus* species, which are expected to be available later in 2009.

The forest management regime (833) chosen for the current analysis had an initial stocking of 833 stems per ha, with no thinning or pruning to reduce costs. This regime assumes a final crop stocking at age 25 of ~670 stems per ha, which produces the high volumes of biomass required for liquid biofuel production. Assuming a 25-year rotation, the mean annual biomass increment is ~ 37 m^3/ha, giving a total volume at harvest of up to ~ 900 m^3/ha for three of the scenarios.

Scenario 1 has a lower yield (640 m^3/ha) due to a large proportion of the land selected being low productivity land in South Canterbury and Otago (Figure 1a). This regime could also produce significant quantities of sawlog grade material if the end use is optimal. Table 3 provides a summary of the biomass and liquid fuel production for each scenario using the regime and productivity described above. The yields generated for the various scenarios may appear high. They are based on a regime focussed on developing maximum biomass from a stand (833 stems per ha, initial stocking, ~ 670 stems per ha at harvest, with no thinning) as opposed to more common regimes where thinning is applied, which are focussed on producing less volume whilst maximising the volume of high grade sawlogs. It should also be noted that the volume figures are for total recoverable biomass (including some of the bark, branches and upper stem) which are excluded from traditional total recoverable volume (of logs) figures.

Scenario maps

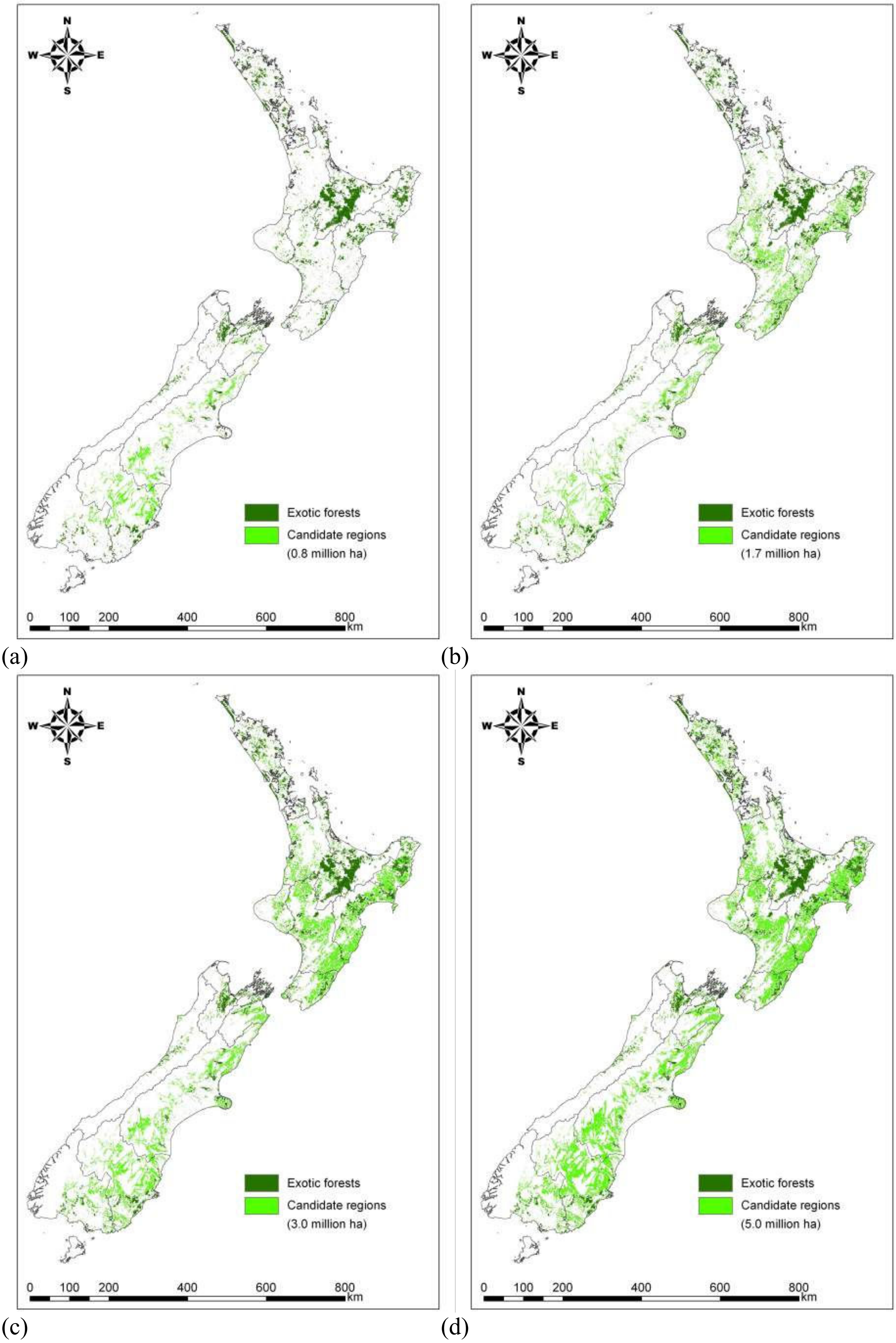


Figure 1: Land area converted to forestry in (a) Scenario 1 (0.8 M ha), (b) Scenario 2 (1.8 M ha), (c) Scenario 3 (3.4 M ha) and (d) Scenario 4 (4.9 M ha).

Table 3: Summary of potential biomass and liquid fuel production (assumes sustained yield harvest on 25-year rotation)

	Scenario 1 / 0.8		Scenario 2 / 1.8		Scenario 3 / 3.3		Scenario 4 / 4.9	
Region	**TEB p.a. m^3 millions**	**LPe, p.a. millions**	**TEB p.a. m^3 millions**	**LPe, p.a. millions**	**TEB p.a. m^3 millions**	**LPe, p.a. millions**	**TEB p.a. m^3 millions**	**LPe, p.a. millions**
Northland	0.29	25.2	1.08	94.2	3.07	267.1	8.38	728.8
Auckland	0.01	0.9	0.51	44.3	1.15	100.6	2.47	214.8
Waikato	0.23	20.4	4.39	382.0	11.35	987.4	16.88	1,468.3
Bay of Plenty	0.02	2.3	0.44	39.4	1.24	107.8	2.29	199.2
Gisborne	0.26	22.9	6.26	544.8	10.93	950.7	13.26	1153.6
Hawke's Bay	0.51	44.9	8.47	736.8	16.86	1,466.3	20.12	1,750.1
New Plymouth	0.52	45.4	2.60	226.5	3.83	333.6	4.84	421.5
Manawatu-Wanganui	1.35	117.7	16.08	1,389.2	25.93	2,252.2	29.80	2,591.4
Wellington	0.36	31.4	5.73	499.0	7.97	693.2	9.76	849.4
Tasman	0.10	8.8	0.81	710.4	1.24	108.3	1.70	148.4
Nelson	0.00	0.1	0.11	9.3	0.13	11.7	0.14	12.9
Marlborough	0.88	77.2	3.24	288.1	4.16	362.0	5.58	485.7
West Coast	0.14	12.5	0.34	30.1	0.94	81.9	1.29	112.5
Canterbury	9.90	861.2	12.14	1055.7	18.86	1,640.2	27.16	2,361.7
Otago	6.47	563.4	8.27	714.3	13.12	1,141.5	17.54	1,525.4
Southland	1.49	129.9	3.00	261.0	5.79	503.7	7.39	642.9
Total*	**22.59**	**1964.2**	**73.55**	**7,039.1**	**126.63**	**11,011.2**	**168.67**	**14,666.1**

- LPe = litres of petrol equivalent
- TEB = total extractable biomass = total recoverable stem volume + bark + branches x 0.8 +upper stem x 0.8 of the estimated 15% of the above ground biomass in unmerchantable stem breakage

Although the management regime assumed in this analysis is focused on producing biomass in large volumes, it would also produce material that fits into current log markets (sawlog and pulp/chip). Up to 84% of the harvested volume would fit into these log markets (up to 55% being suitable for sawlogs). This feature gives rise to substantial risk mitigation via alternative sales opportunities for much of the material produced. It also means that returns for the investment may be higher if the crop is planned and managed to have a mixed-log output. The impact of selling more logs or wood products into the export market was not assessed. However, New Zealand's current share of world log trade is small (<6%) and its share of wood product trade (such as sawn lumber) is even smaller. Given that the world market for certified sustainably produced wood products is expected to grow, the prospects for being able to sell more wood from sustainable plantations are good.

The use of genetic modification and molecular biology has the potential to improve yields from forestry crops. Gains could be made from a range of sources, from increased growth rates, increased density and resistance to pests and diseases. Gains can also be made in the conversion process by growing a crop that has wood properties which lend themselves to the conversion process. Finally, there is potential to extend the range of land on which a particular species can be planted by improving its tolerance of some limiting site factors (e.g. temperature and frost).

Potential contribution to energy supply

Marginal land can be used to grow trees, enabling the capture and storage of solar energy. This energy can then be converted into consumer energies as and when required, meaning that forests offer a highly manageable energy store.

The scale of the energy storage associated with each scenario can be compared to current national energy demand - 740 PJ of primary energy and 560 PJ of consumer energy (where the difference between the two figures are conversion and transmission losses). See Tables 4 and 5.

Table 4: Stored primary energy by scenario

Scenario	* Gross standing biomass volume, 2035	* Biomass Harvest, per annum, post 2035	Gross Primary energy, PJ, in standing volume	Primary energy in annual harvest, PJ	Annual harvest as % of current primary energy consumption	Stored energy increment, PJ, pa
1 / 0.8	283	19.588	2,094	144	19.5	83.76
2 / 1.8	828	69.030	6,129	510	69.0	245.16
3 / 3.3	1,511	125.983	11,188	932	125.9	447.52
4 / 4.9	2,594	178.950	19,200	1,324	178.8	768.00

* Millions of tonnes

Given that woody biomass can be used for a variety of energy end uses, it is useful to consider what proportion of the three consumer energy demands (heat, electricity, liquid fuels) could be produced from the four scenarios (Table 5), using the following assumptions:

- heat demand 180 PJ, conversion efficiency 85% (biomass to heat);
- liquid fuel demand 245 PJ, conversion efficiency 35% (biomass to liquid fuels);
- electricity demand 145 PJ, conversion efficiency 30% (biomass to electricity).

Table 5: Indicative energy potential of biomass scenarios to meet consumer energy demand (100% to energy)

Scenario	Percentage of current consumer energy demand
1 / 0.8	68% of heat or 20% of liquid fuel
2 / 1.8	100% of heat and 42% of liquid fuel or 72% of liquid fuel or 73% of electricity
3 / 3.3	100% of heat and 100% of liquid fuel
4 / 4.9	100% of heat and 100% of liquid fuel and 85% of electricity

* Priority is given to making heat and liquid fuels as these are a more efficient use of the biomass

Scenario 3 has the potential to produce ~11 billion litres per annum of liquid fuels. This exceeds current demand (~8.1 billion litres). However, if demand grows in line with historical levels, demand for liquid fuels in New Zealand could be in the order of 11 billion litres by 2030.

Multiple-product forests

Forests can produce multiple products (both energy and non-energy) so there is potential for give and take between energy production and other end uses. If 56% of the crop could be used for sawlogs, then the volume available for energy would be substantially reduced, but the return to the grower may be enhanced. Table 6 presents the energy production possible if all the potential sawlog material is sold as sawlogs.

The flexibility offered by multi-product options is an important factor in risk mitigation. If the bioenergy markets fail to develop as predicted, there is a fall-back position of being able to sell the logs into the traditional solid wood and export log or chip markets. Furthermore, the high total standing volume of the 833 regime also fits well with the other option of selling the carbon credits from the stand if the decision is made not to harvest at all.

Table 6: Indicative energy potential of biomass scenarios to meet consumer energy demand (44% to energy, 56% to sawlogs)

Scenario	Bioenergy Harvest volume m^3 pa	PJ pa from Bioenergy harvest	Harvest as % of primary energy	% Heat	And Or	% Liquid fuels
1 / 0.8	8.61	63	8.5	30	or	9
2 / 1.8	30.37	224	30.2	100	and	1.4
2 / 1.8	30.37	224	30.2	0	and	32
3 / 3.3	55.43	410	55.4	100	and	27
3 / 3.3	55.43	410	55.4	0	and	58
4 / 4.9	78.73	582	78.6	100	and	53
4 / 4.9	78.73	582	78.6	0	and	83

The biomass regime assumed here gives the market options:

- 56% sawlog and 30% chip, or a proportion to logs/energy
- High volumes of carbon
- Energy end-use options
  - Solid fuel for heat and/or cogeneration of heat and power
  - Liquid fuel
  - Feedstock for gas production

For a given estate area, some of the land could be retained as carbon forests, some logged, and there are a range of options for marketing the material produced.

Biomass production costs

Approximate costs for the production of biomass from energy forests are presented in Table 7.

Table 7: Costs to establish, grow, harvest and deliver, by scenario ($/m^3), biomass regime

Scenario	Yield, m3 per ha	Growing *	Road	Harvest	Transport (75km)	Total
1 / 0.7	640	28.06	5.87	38	15	86.93
2 / 1.8	940	19.10	3.99	38	15	76.10
3 / 3.3	940	19.10	3.99	38	15	76.10
4 / 4.9	908	19.78	4.14	38	15	76.91

* This includes land rental, land preparation, planting, weed control and forest maintenance (discount rate, 6%).

The delivered biomass costs for Scenarios 2, 3 and 4 are all very similar, and are lower than that for Scenario 1. This reflects the low productivity land used in Scenario 1. Harvesting and transport make up 61% to 70% of delivered cost and growing costs are 25% to 32%. Growing has a greater proportion of the cost when productivity is lower.

Costs can be reduced by improving yield and by increasing the efficiency of harvesting and transport operations. Gains in transport are the most readily attainable, by moving to heavier (52 tonne) and longer (24 m) trucks which have a significant gain in payload and therefore reduced costs. The gains in transport could be as much as $2.25 per tonne, or 3% to 4% of total delivered cost.

There are also significant potential gains in cost from yield improvement due to alternative species, breeding or genetic modification. For example, a growth gain of 32% (growth and density gains combined) results in a delivered cost reduction of 8% to 9%. The impact of improved yield, transport and harvesting on delivered cost is shown in Table 8. If a particular volume of wood was a production target, increased yield would reduce the land area required to produce this volume, and also reduce land-use competition issues.

Harvesting has high costs on steep terrain, and it has been a target of much research both in New Zealand and overseas for many years. Gains in this area would be particularly valuable as small changes to this large cost component make a substantial change to total delivered cost (Table 8). However large harvesting productivity gains may be difficult to achieve unless there are major improvements in technology.

Table 8: Costs ($/m^3), to establish, grow, harvest and deliver, by scenario, with improved supply chain and improved yields

Scenario	Yield, m^3 per ha	Growing	Road	Harvest	Transport (75km)	Total
1 / 0.8	845	21.25	4.44	34	12.75	72.44
2 / 1.8	1240	14.48	3.03	34	12.75	64.26
3 / 3.3	1240	14.48	3.03	34	12.75	64.26
4 / 4.9	1198	14.99	3.13	34	12.75	64.87

By taking the potential for gains in growth and in the supply chain, it is possible to reduce delivered cost by $12 to $14 per m^3 or, 15% to 17%, from those in the original scenarios.

These scenarios have costs which are typically lower than current costs, due to the high per ha yields from the biomass focused regimes.

Environmental impacts: Summary

The environmental impacts of the four afforestation scenarios presented in Table 2 were assessed (see Chapter 2 for details). The key environmental impacts were determined to be:

- greenhouse gas (GHG) reductions and carbon stocks
- sustainable land use (water quality, erosion and sedimentation)
- biodiversity
- water availability

Greenhouse gases and carbon stocks

Analysis showed that the large-scale bioenergy scenarios result in substantial reductions in GHGs, both by reducing fossil fuel use in transport and by removing land from agricultural production. The combined impacts of these two factors result in emissions reduction of 5, 15, 29 and 37 million tonnes of CO_2-e per year from 2035 onwards for Scenarios 1 to 4 respectively. These figures correspond to approximately 6%, 20%, 37% and 48% respectively of New Zealand's total GHG emissions in 2006.

Of the reduction in GHGs from these changes, 10%, 15%, 19% and 19% came from reduced agricultural emissions in Scenarios 1 to 4 respectively. The lower percentages in Scenarios 1 and 2 are due to the lower intensity land use being displaced in these scenarios.

Once plantation forests are fully established they will store substantial amounts of carbon, as long as they remain sustainably harvested. This stored carbon is equivalent to an additional 208, 647, 1183 and 2034 net million t CO_2-e removed from the atmosphere and stored for Scenarios 1 - 4, respectively. These estimates assume an even rate of establishment and harvest on a 25-year rotation and the subsequent age-class distribution for the afforested area.

Sustainable land use

Converting land from low-productivity pastoral grazing to forestry has a number of additional environmental benefits, including reduced erosion and reduced nutrient leaching into waterways. Analysis showed that the total erosion would be reduced by 1.1%, 8.0%, 16.6% and 20.2% for Scenarios 1 - 4, respectively (Table 9). The erosion reductions are particularly significant in the eastern, central and lower North Island regions for Scenarios 2 - 4. These are regions where a combination of highly erodable soils, grazing for land use and heavy rainfall events are currently a cause for concern.

If Scenario 2 is used as a benchmark, the reductions in erosion in the eastern and southern North Island show reductions in erosion of 15% to 24%. Given the scale of erosion in these regions, the actual amounts of erosion mitigated are estimated to be millions of tonnes per annum. Specifically, the Manawatu-Wanganui and Gisborne regions had 340,000 ha and 117,000 ha of afforestation with reductions in erosion of 3.1 and 8.9 million tonnes per annum respectively. The use of these and other data (water yield, nutrient run-off impacts etc.) can be used to prioritise regional establishment areas.

Table 9 - Reduction in erosion and sedimentation relative to current levels for each of the bioenergy scenarios, percentage change from current levels.

Region	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Northland	0.5	1.3	5.7	14.4
Auckland	0.1	2.5	7.0	13.0
Waikato	0.5	6.4	21.2	29.0
Bay of Plenty	0.1	0.6	1.9	3.2
Gisborne	0.7	15.4	32.4	37.2
Hawke's Bay	1.5	18.1	42.6	47.4
Taranaki	4.4	19.6	29.5	32.3
Manawatu-Wanganui	2.6	24.8	45.7	49.8
Wellington	1.9	23.4	37.4	43.2
North Island total	**1.1**	**14.2**	**29.5**	**34.9**
West Coast	0.1	0.01	0.3	0.4
Canterbury	3.2	2.7	5.1	8.7
Otago	2.4	2.2	3.7	7.9
Southland	1.6	2.4	4.0	5.0
Tasman	0.8	3.6	7.0	8.7
Nelson	0.1	4.9	8.0	8.6
Marlborough	3.0	8.8	10.9	16.8
South Island total	**1.2**	**1.3**	**2.4**	**4.0**
Total New Zealand	**1.1**	**8.0**	**16.6**	**20.2**

Analysis also showed that in the long term, nitrogen leaching from afforestation of grazed pastures could be reduced by 0.3%, 3.4%, 8.4% and 12% in Scenarios 1 - 4 at a national level. Regions that would have significant benefits in terms of reduced nitrogen leaching from afforestation were in the east and south of the North Island. Leaching rates can remain high for several years if the soil already contains a large amount of surplus nitrogen, but in the long term, afforestation will reduce nitrogen leaching.

Biodiversity

Analysis of biodiversity impacts based on the scenarios are largely positive, however afforestation of land that has historically never been forested (e.g. native grasslands in Central Otago) is not desirable from a biodiversity perspective.

Plantations established on marginal pastoral land and exotic scrub pasture would improve the species richness of insects, plants and native birds. They will also benefit native species by improving connectivity between currently fragmented native forest remnants (this is especially so for Canterbury). Where afforestation reduces erosion and sedimentation, improved water quality will lead to greater aquatic biodiversity and improved native fish habitat. The higher the afforestation area, the greater the benefits in terms of connectivity of forest area and gains from water quality improvement

On the negative side, there could be a risk of spreading wilding pines or other weeds in some regions. However, careful species selection, management of boundaries and monitoring of at-risk areas would avoid the development of wilding issues, as they develop slowly over many years and early intervention will control any spread. Some areas currently in scrub might revert to native forest if left undisturbed; in which case planting exotic forest would not produce a long-term biodiversity benefit. However, this process is likely to be very slow.

Overall, bioenergy forests present a major opportunity to return forest cover to areas of formerly forested land. If managed appropriately they have the potential to significantly increase both terrestrial biodiversity and aquatic water quality and biodiversity at a landscape level. Research on biodiversity aspects of new bioenergy forests is required to guide planning and afforestation scenarios. Early consideration of biodiversity issues will ensure maximum future biodiversity benefits from new forests.

Water availability

Afforestation is likely to have important impacts on water availability. Planting forests results in greater water interception and subsequently less water being available for other purposes (Table 10). In particular, Canterbury and Otago already have high levels of water allocation (mainly for irrigation) and large areas targeted for afforestation in all scenarios. Therefore, even in Scenario 1 there could be water availability issues in these regions. In developing a large-scale afforestation plan, water availability would be a key consideration, and would affect the decision on how much forest to establish within some regions.

Table 10 – Reduction (%) in available water by region and scenario

	Reduction in available water as % of annual water balance			
Region	**Scenario 1**	*** Scenario 2**	**Scenario 3**	**Scenario 4**
Northland	0.0%	0.8%	2.7%	7.0%
Auckland	0.1%	1.3%	3.7%	8.7%
Waikato	0.1%	1.1%	3.6%	5.3%
Bay of Plenty	0.0%	0.2%	0.7%	1.2%
Gisborne	0.4%	5.8%	12.1%	14.4%
Hawke's Bay	0.6%	6.0%	14.3%	16.1%
Taranaki	1.0%	2.5%	4.2%	5.1%
Manawatu-Wanganui	0.9%	5.7%	10.8%	12.1%
Wellington	0.5%	5.6%	8.8%	10.7%
North Island (average)	**0.4%**	**3.2%**	**6.8%**	**9.0%**
Tasman	0.1%	0.5%	0.9%	1.2%
Nelson	0.0%	1.2%	1.8%	2.5%
Marlborough	1.0%	2.6%	3.4%	5.6%
West Coast	0.1%	0.0%	0.4%	0.6%
Canterbury	2.8%	2.5%	4.2%	7.6%
Otago	6.2%	5.4%	9.1%	14.6%
Southland	0.6%	0.8%	1.5%	2.1%
South Island (average)	**1.5%**	**1.9%**	**3.0%**	**4.9%**
New Zealand (average)_	**0.9%**	**2.6%**	**5.1%**	**7.2%**

* Interpolated based on Scenario 3 data

Impact on water availability needs to be assessed at catchment scale to determine the impacts on specific rivers and aquifers.

Competition for land: Summary

Economics is an important driver for land-use change. An analysis was carried out to determine how economically viable the scenarios presented in Table 2 are likely to be from a competing land-use perspective.

This section summarises the results of Chapter 3.

Land-use economics

Table 11 shows the (average 2000-2008) return on the land from its current (pre-afforestation) land use in each of the bioenergy scenarios, with and without a price on carbon ($25/t CO2-e).

With the least restrictive criteria, Scenario 4 includes more than 2.5 million ha of land that are earning less than $200 per ha in sheep and beef farming. Average returns for all land in this scenario are $160 per ha without the Emissions Trading Scheme (ETS). With the ETS applied to agricultural land, the value of displaced profit falls even further – to only $108 per ha on average. Around 2.5 million ha are earning less than $100 per ha. The cost estimates for forestry production gave returns to the forest grower equivalent to $185 per ha per annum.

Table 11: Current annual profit (EBIT) on pasture and scrub land selected to be converted to biofuels for all four scenarios (average 2000–08, 2007$)

	Total value for all land converted		Average value per ha	
	Without ETS	**with ETS**	**without ETS**	**with ETS**
Scenario 1 (0.8 mill)				
North Island	$16,313,425	$10,915,650	$190	$127
South Island	$61,663,575	$39,062,875	$83	$52
New Zealand	$77,977,000	$49,978,525	$94	$60
Scenario 2 (1.8 mill)				
North Island	$174,179,150	$120,302,100	$190	$131
South Island	$92,254,600	$64,341,225	$98	$69
New Zealand	$266,433,750	$184,643,325	$144	$100
Scenario 3 (3.4 mill)				
North Island	$400,333,100	$280,034,875	$205	$144
South Island	$163,879,775	$116,439,950	$107	$76
New Zealand	$564,212,875	$396,474,825	$162	$114
Scenario 4 (4.9 mill)				
North Island	$526,213,650	$338,200,850	$210	$135
South Island	$260,644,050	$191,614,125	$108	$79
New Zealand	$786,857,700	$529,814,975	$160	$108

Figure 2 shows the profit per ha to the landowner from biofuel as a function of petrol price (based on biofuel production, see Chapter 3 for assumptions). Assuming the low biofuel productivity of Scenario 1, biofuel production becomes more profitable than the lowest value sheep and beef farming in the $2.70 to $2.80 range. At $2.75, if the higher average productivity land is converted to biofuels, the figure suggests that Scenario 4 would also be viable, as the average profitability displaced in this scenario is only $210 per ha even in the North Island. Thus, at high but not impossible petrol prices, we might expect more than half (~1.5 million ha) the sheep/beef land to be converted to biofuels. A petrol price of $2.75 per litre would be the equivalent to oil at US$180 a barrel and the foreign exchange rate being 0.5, or oil at US$215 a barrel and the foreign exchange rate at 0.60. In 2008 oil reached a peak of US ~ $147 a barrel when the NZ$ to US$ exchange rate was at ~ 0.75. If the exchange rate had been low, say 0.55 at the time of the 2008 oil price peak, petrol prices could have been ~ $2.90 per litre including taxes (or $2.38 excluding taxes).

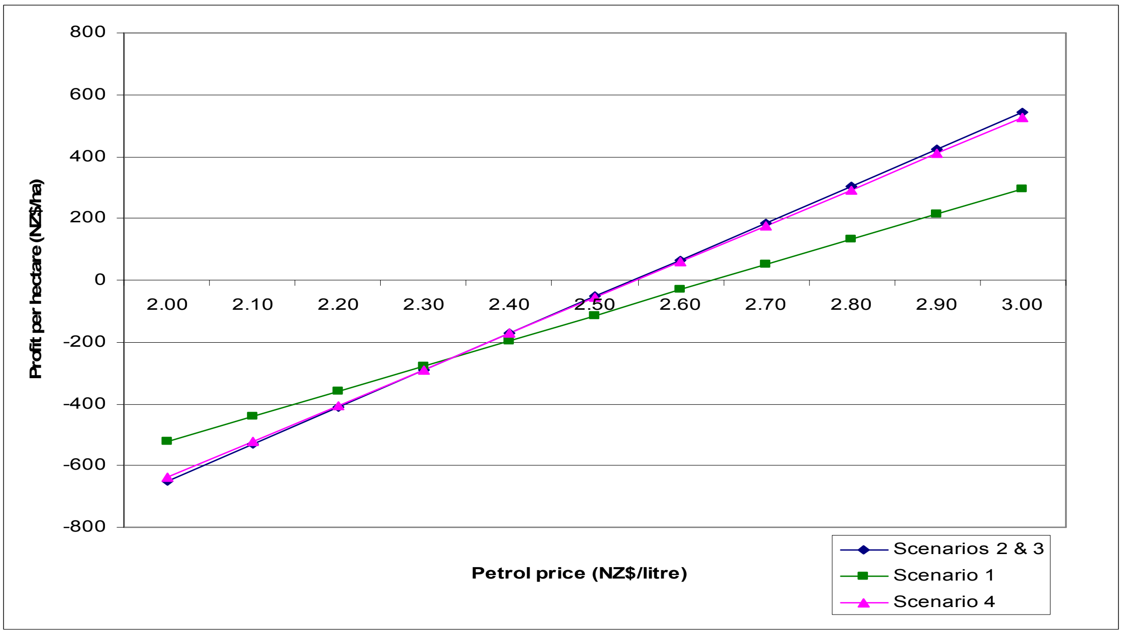


Figure 2: Profitability of ethanol production from PGF by petrol price

These results should only be considered as an indication of the economic value of biofuels as a new land use.

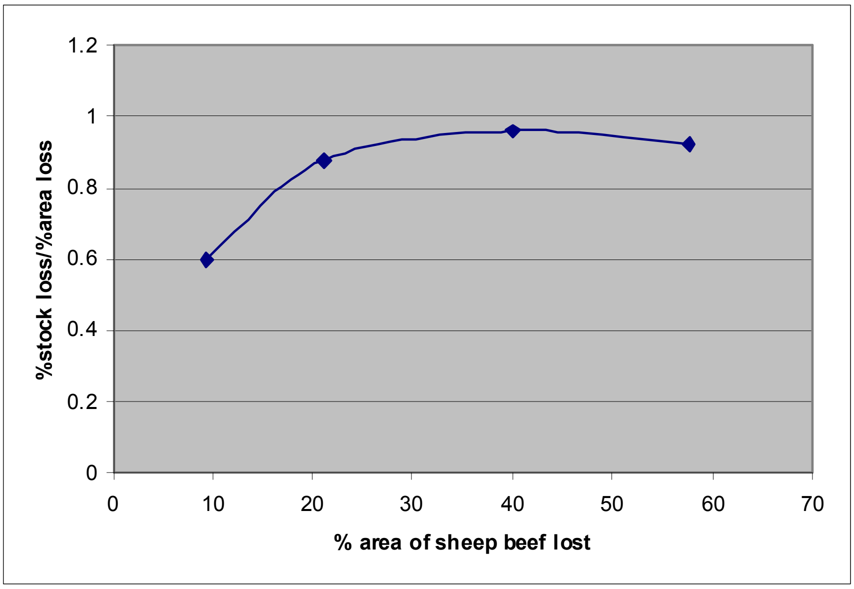
Implications for agricultural production

Table 12 shows the loss of stock (units and %) by scenario for the North and South Islands. The effect of expanding forest area on stock losses is non-linear. Initial losses would be relatively low because land converted is relatively unproductive (Figure 3). In Scenario 1 large areas of comparatively unproductive land was used, in Scenarios 2 and 3 the land used is more productive than Scenario 1. In Scenario 4 the average productivity of the afforested land drops slightly (leading to a drop in the line graphed in Figure 3) as this scenario is large (4.9 million ha) and it is taking land that is on average slightly lower in productivity than Scenarios 2 and 3.

Table 12: Impact on livestock numbers from conversion of farmland to biofuels

Scenario	Location	Total stock units lost	% stock lost
1 (0.8 mill)	North Island	778,400	2.34
	South Island	2,833,575	9.23
	New Zealand	3,611,975	5.65
2 (1.8 mill)	North Island	7,868,625	23.69
	South Island	4,011,100	13.06
	New Zealand	11,879,725	18.59
3 (3.4 mill)	North Island	17,520,300	52.75
	South Island	7,012,175	22.84
	New Zealand	24,532,475	38.38
4 (4.9 mill)	North Island	22,924,175	69.03
	South Island	11,098,450	36.15
	New Zealand	34,022,625	53.23

Figure 3: Percentage loss of stock relative to percentage area converted across scenarios



Social aspects of land-use change

An analysis was also carried out to answer the question of whether economic drivers would be sufficient to lead land-use change. Historically farmers have tended to stay in sheep and beef farming for very long periods even when profitability is low. We can speculate that because conversion to forestry is relatively difficult to reverse, uncertainty makes it less attractive. Other possibilities are that farmers enjoy the livestock raising lifestyle, or that many people find the pastoral land attractive, which results in a higher perceived market value. More research is required to understand these social drivers.

Economic impacts: Summary

This section summarises the methodology and results of Chapter 4. The economic analysis applies a number of future economic scenarios to the forest area/bioenergy supply scenarios.

Introduction

A general equilibrium model (GEM) of the New Zealand economy was used to investigate the economy-wide effects of using the nation's resources to produce biofuels instead of producing other goods and services that are exported in exchange for oil (see Chapter 4 for more details). Thirteen scenarios were considered ranging from 0.8 M ha to 3.5 M ha of biofuels and with a number of different production efficiency, oil price and carbon price assumptions.

A business-as-usual (BAU) picture of the economy in 2050 was used as a comparison for the different biofuel scenarios. Inputs to the model were population, capital stock, labour, productivity, carbon price, oil price and balance of payments. Some of the critical assumptions of the BAU are:

- oil price $US200/bbl.
- carbon price: $100/tonne.
- unemployment rate: 3%
- oil consumption 430 PJ (currently approximately 245PJ)

This oil price in 2050 is equivalent to a 2.5% rate of real price increase, which is the rate of increase over the last 50 years (with much volatility). This is a reasonably conservative estimate given the potential impact of peak oil and increasing demand from developing countries. The above price of carbon is also quite conservative. The scenarios consider the sensitivity of the results to these assumptions.

Four closure rules were applied to the scenarios, such that total employment, capital stock, balance of payments and fiscal surplus were held constant at the BAU levels. The closure rules allow the analysis of the various bioenergy scenarios on allocative efficiency, terms of trade, real exchange rate etc., and through these the effect on welfare measures such as private consumption.

This analysis does not include any value being derived from the manufacture of co-products which could be made along with the production of biofuels. This is an area that is under investigation, and may provide significant revenue to a biorefinery, producing a range of fuel and chemical products derived from biomass.

Efficient use of resources

In most of the scenarios considered in this work, biofuels were more costly to produce than petrol and diesel from imported oil. Therefore, the (mandated) use of biofuels on a large scale corresponds to a reduction in productive efficiency of the economy. That is, instead of resources being used in exporting industries to earn foreign exchange to import oil, resources are diverted out of these industries into biofuel manufacture. Increases in oil price lead to a decrease in the price ratio between biofuels and imported petrol and diesel, (see Table 13 for example) and increase the productive efficiency of the economy.

Table 13: Ratios of producer price of purpose-grown-forest ethanol to producer price of oil for various oil prices (assumes a exchange rate of $US 0.75=$NZ 1.00)

Oil price (US$/bbl)	Price Ratio
100	3.0
200	1.6
300	1.1

Substituting biofuels for fossil fuel alternatives reduces GHG emissions, so a price on carbon reduces the productive efficiency penalty. This is because a carbon price effectively internalises an externality produced by other industries, particularly transport and agricultural methane emissions. Increasing the efficiency of production of biofuels reduces the cost of producing biofuels and therefore offsets the productive efficiency penalty. The base-line cost of biofuel production in this work was based on conservative estimates and current (2008) technology. Technology improvements are likely to increase the production efficiency, but estimating the effects of this is speculative.

In most of the scenarios considered, these effects were not sufficient to offset the loss in productive efficiency due to the unfavourable price ratio. This was reflected in the reduction in GDP which ranges from -0.4% to -2% relative to BAU for the 0.8 M ha and 3.5 M ha biofuel scenarios, respectively.

Under a scenario of high oil prices ($US 300/bbl), high carbon prices (US$150/tonne CO2-e) and greater production efficiency, (30% reduction in costs) the price of producing biofuels drops below that of petrol and diesel from imported oil. In this case, mandates are unnecessary as biofuel production becomes economically viable and their use leads to an increase in productive efficiency of the economy. This was reflected in a rise in the GDP in comparison to other scenarios.

GDP is a useful way to assess changes in standard of living over time. However, as a means for comparing alternative options at some given point in time with fixed total input use, changes in GDP are of limited value. We are better served by looking at welfare measures such as private consumption and real gross national disposable income (see below).

Allocation of resources / terms of trade

In this study, the price of oil is assumed to rise faster than the price of other traded goods. Therefore, reducing imports of oil through biofuels will increase (improve) the terms of trade. The terms of trade is an index of export prices divided by an index of import prices. In a stylised sense, the terms of trade measures the number of kilograms of milk solids that must be exported in order to import a car. Increases (improvements) in the terms of trade represent a gain in allocative efficiency: the allocation of resources to where they are most valued.

All the biofuel scenarios considered in this work led to an increase in the terms of trade. This increase ranged from ~0.8% for 0.8 M ha scenarios and ~3.5% for the 3.5 M ha scenarios or about 1% for every million ha of biofuel crops. The effects of biofuels on the terms of trade were also sensitive to oil prices, ranging from increases of 0.74% for oil at US$100 and 0.96% for US$200 in comparison to BAU for the 0.8 M ha scenarios.

There was a significant drop in the terms of trade benefits from biofuels when more sheep and beef land was converted to biofuels. This is due to a loss in export earnings from this land. It was found that the relative increases in terms of trade were insensitive to changes in prices for agriculture and food, as when biofuels are introduced the amount of oil saved is about the same as the higher agricultural prices. Hence the change in the terms of trade is about the same.

More efficient production tends to decrease the terms of trade benefits. Effectively, more efficient production means that resources are freed up for use in other industries. Therefore, exporters regain some lost international competitiveness and are able to sell more product – effectively transferring some of the benefit from greater productivity in New Zealand to foreign consumers.

Employment

Due to the new industry required for biofuel production and the new jobs created, there is an increase in the real wage rate in most of the biofuel scenarios. The increase in the real wage rate ranges from 0.13% to 0.52% above BAU. The real wage rate increases with oil price and biofuel production volume.

The closure rules behind the modelling assumed that total employment was held constant at the BAU level. In the case of biodiesel production instead of ethanol, the wage rate does not show an increase. This is due to the fact that the increased price of diesel has a negative effect on New Zealand's most productive industries, which are diesel dependent.

Land-use change

Table 14 shows the change in land use predicted by the model under the 0.8 M ha scenario. All changes are less than 2% and all agricultural industries display a greater reduction in land use than in output, implying a (small) shift to more intensive farming. In absolute terms, the largest agricultural land-use change occurs in sheep and beef farming, where 0.11 million ha is no longer farmed.

Table 14: Scenario 1: Changes in agricultural output

	Output (% Δ on BAU)	Land use (% Δ on BAU)	Land use (Δ million ha on BAU)
Horticulture and fruit growing	-1.7	-1.9	-0.01
Sheep, beef and mixed cropping	-1.1	-1.2	-0.11
Dairy cattle farming	-0.9	-1.2	-0.02
Other farming	-1.6	-1.8	-0.01
			-0.16
Regular forestry (to PGF biofuels)			-0.22
Land previously in scrub			-0.46
Total land converted to PGF			-0.83

There is also some contribution from 'regular' forestry to the production of biofuels (equivalent to 0.22 million ha).

Table 15 shows the estimated impacts on agricultural production, agricultural land use, under the 3.5 million ha scenario.

Table 15: Scenario 5 - Changes in agricultural output

	Output (% Δ on BAU)	Land use (% Δ on BAU)	Land use (Δ million ha on BAU)
Horticulture and fruit growing	-6.8	-7.5	-0.04
Sheep, beef and mixed cropping	-4.2	-4.6	-0.42
Dairy cattle farming	-3.5	-4.4	-0.08
Other farming	-6.4	-7.2	-0.06
			-0.59
Regular forestry (to PGF biofuels)			-0.98
Land previously in scrub			-1.92
Total land converted to PGF			-3.48

As discussed with regard to Scenario 1, there is some re-direction of the BAU forest harvest out of traditional uses and into biofuels. This makes a sizable contribution to the assumed 3.5 million ha in PGF, and could be as much as half of the production from the existing forest estate. To put this in perspective, in the model's base year (2005/06) an estimated 1.85 million ha was in exotic plantation forestry. In the BAU this rises to about 2.2 million ha – without any specific allowance for increased planting that might be induced by the possibility of securing carbon credits.

Also as in Scenario 1 some land comes out of agriculture. Total land used in agriculture falls by 0.59 million ha, most of which is removed from sheep and beef farming.

A different approach to land-use change is given in Chapter 3. This work showed that more research into the social side of land-use change is required.

Economic welfare

One of the most important questions is: what effect do the above macro economic effects have on economic welfare, such as standard of living? In this analysis two measures of economic welfare are presented: real private consumption (spending on goods and services by private individuals and households) and real gross national disposable income (RGNDI). RGNDI is equal to the GDP adjusted for payments to foreigners and for changes in the terms of trade.

In most of the scenarios considered, biofuels lead to a decrease in productive efficiency which implies a reduction in economic welfare. However, the production and use of biofuels reduces CO_2 emissions, so if there is a price on carbon, New Zealand's liability to purchase offshore emission units is ameliorated. This generates a gain in RGNDI. In addition, the increase in allocative efficiency, reflected in increases in the terms of trade for high oil prices, also leads to increases in economic welfare.

Due to these effects, most of the biofuel scenarios gave rise to increases in private consumption. The increases ranged from 0.1%-0.8% relative to BAU in the high oil price and high carbon price scenarios (see Figure 1). These increases in private consumption are equivalent to about $100 to $440 per capita.

Private consumption decreased relative to the BAU in the case of biodiesel and when large areas of sheep and beef land were converted to biofuels. In these cases the effect of carbon price and terms of trade were not able to compensate for lost exports. However, the cost data for biodiesel production available to this study were less robust than that for ethanol production. In reality the difference may not be large.

In the majority of cases the RGNDI ranged from 0% to -1.0% below BAU (see Figure 2) due to the unfavourable ratio of biofuel to oil costs. Scenarios with increases in production efficiency (30% reduction in cost of production) increased RGNDI from -0.33% to -0.04% in comparison to BAU in the 3.5 M ha scenario. This change is equivalent to an increase in real gross national disposable income of $240 per capita.

Under a scenario of high oil prices ($US 300/bbl), high carbon prices (US$150/tonne CO2-e) and greater production efficiency, (30% decrease in cost of production) the price of biofuel drops below that of petrol and diesel at the pump. This gives rise to an enhancement of consumer welfare under both measures (private consumption and RGNDI) of 0.8% and 0.3% above BAU, respectively. This is equivalent to private consumption of $440 per capita and real gross disposable income of $240 per capita. Both consumer welfare measures change in the same direction in this scenario as the initial high cost of biofuels is mitigated by enhanced productivity in biofuels production; a higher price of oil; and by a greater value on the reduction in carbon emissions from using biofuels rather than imported oil. Note that this scenario avoids the need for regulatory intervention such as mandatory biofuels requirements which are less likely to enhance consumer welfare.

To give some international perspective on price the IEA World Energy Outlook 2008 projects oil prices averaging $US100 per barrel for 2008 to 2015 and rising to $US200 per barrel in 2030.

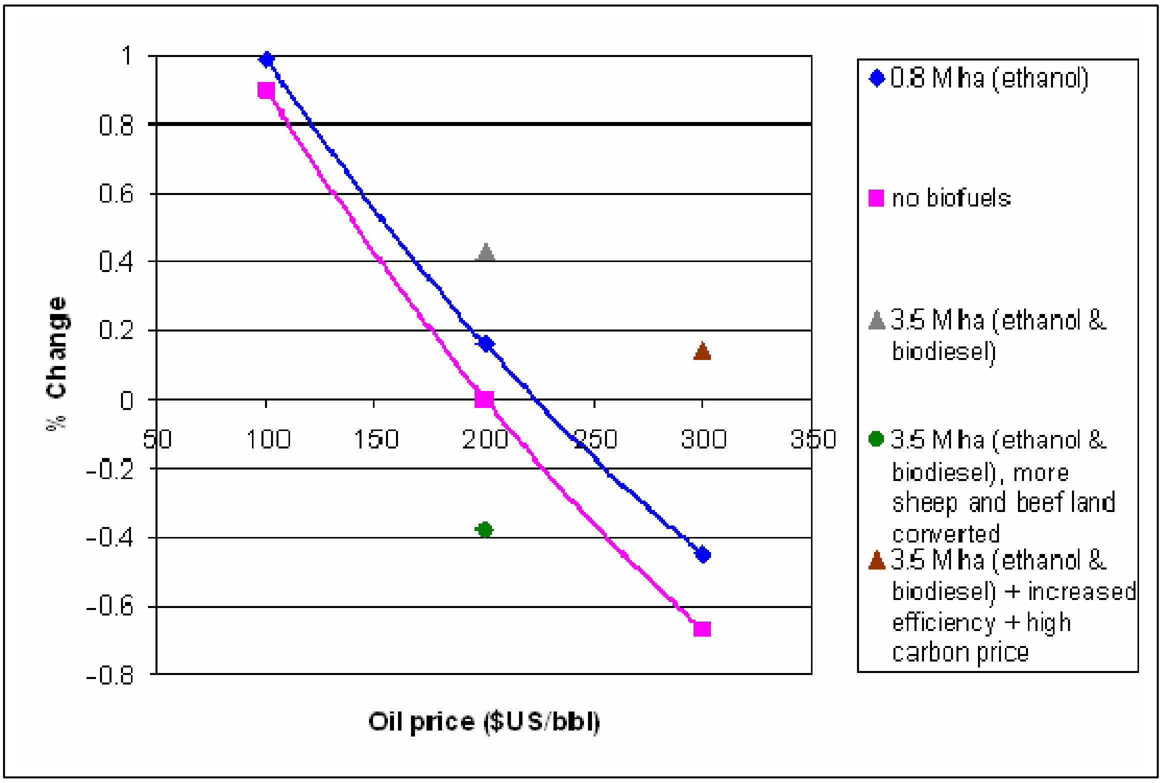
Energy security

Due to the importance of transportation in the New Zealand economy and the fact that our export industries are mainly focused on low-cost production of goods, we are very sensitive to changes in oil prices. Figure 4 shows a graph of the percentage change in private consumption with respect to the BAU with $US200/bbl (equivalent graph for RGNDI is shown in Figure 5). Assumptions in the model mean that the price of oil has very little impact on GDP but it has a large influence on terms of trade. Reductions in the terms of trade mean that we have to produce more in order to buy the fuel that we need, and as a result, are worse off. This is reflected in the reduction in economic welfare for high oil prices shown in Figures 4 and 5. Private consumption is reduced by about 0.7% (or $380 per capita) when oil prices increase to $US300/bbl from $US200/bbl.

As New Zealand is heavily exposed to international oil prices, (93% of oil-based fuel consumption is imported) the volatility of oil prices, such as the recent (2008) oil price spike also have an important impact on the economy. The general equilibrium model used here cannot provide us with information on the impact of these short-term price fluctuations; this will be a topic of future research.

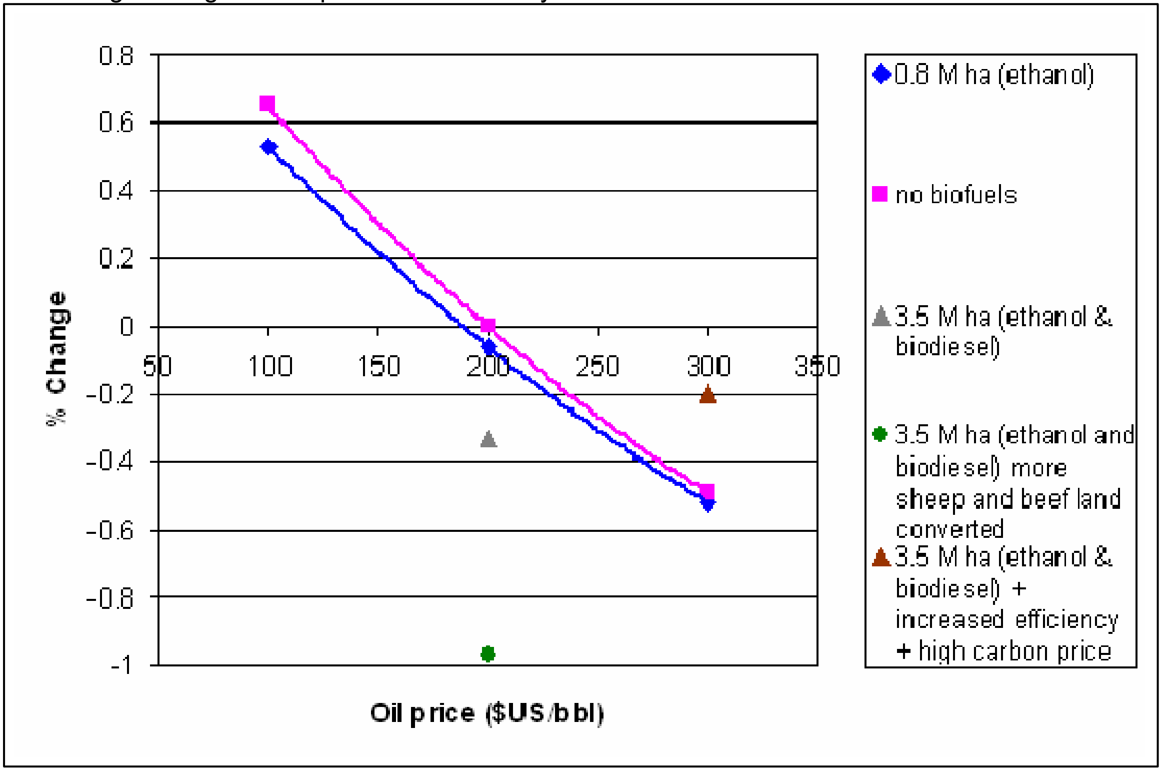
One of the important questions of this study is: can biofuels play a role in reducing this dependence on oil prices and enhancing energy security? Figures 4 and 5 show that a scenario of 0.8 M ha land for the production of ethanol (which reduces oil imports by 15%) is able to alleviate some of the negative effects of high oil prices in terms of lifting economic welfare. A scenario with 3.5 M ha for biofuel (which, under the assumptions of the model, reduces oil imports by 63%) can largely offset the negative impacts of high oil prices, in combination with production gains and a high carbon price.

Figure 4: Impact of oil prices on private consumption with and without biofuels. Percentage change in comparison to economy with $US200/bbl



* In Figures 4 and 5 the legends refer to economic analysis Scenarios 1, BAU, 5, 7 and 10 respectively (Infometrics, Chapter 4)

Figure 5: Impact of oil prices on real gross national disposable income with and without biofuels. Percentage change in comparison to economy with $US200/bbl



Future high prices for oil, carbon and gains in biofuel production efficiency over time can lead to biofuels being competitive at the pump with petrol and diesel, as well as enhancing consumer welfare as measured by private consumption and real gross national disposable income.

The oil price ($US/barrel) at which domestically produced biofuels from forest derived biomass become competitive with fossil fuels from imported oil is highly dependant on the exchange rate ($US:$NZ). The exchange rate is endogenous to the GE model, and is a product of other factors (including relative inflation rates of New Zealand versus its trading partners).

In the Infometrics analysis, the real exchange rate is projected to rise over time from an estimated current equilibrium of around $0.60 to $0.65 $US:$NZ. If New Zealand has the same rate of inflation as our trading partners then our exchange rate will rise. Specifically the $US:$NZ rate would go from $0.70 to $0.75 by 2050 under the equal inflation assumption. Consequently, around $US300 per barrel is needed to get to a domestic price equal to the cost of producing domestic bioethanol from forests. If a lower exchange rate ($0.50) eventuates, the price oil needs to get to (in US dollars) to make biofuels viable is lower (~ $US180).

In the analysis by Scion and Motu, a lower exchange rate ($0.60) was used as the basis for the calculations and hence the apparent discrepancy between Motu and Infometrics in the cost of oil required to make biofuels viable. The numbers here give some of the range of oil prices and foreign exchange rates that could occur, and what their impacts would be. An estimate of petrol price by oil and exchange rate is given in Appendix 6, Chapter 1.

Given the long-term nature of the analysis, (over 40 years) it is difficult to be precise on the likely impacts, as predicting the future is fraught with uncertainty. However, it is worth reiterating that a forest has many values and potential end uses. Wood from an energy forest could be used for traditional purposes if timber markets are favourable.

Conclusions

The aim of this study was to consider whether the large-scale bioenergy forest concept was worth pursuing, based on the productivity, cost, economic, environmental and land-use impacts.

Key findings:

- There are significant areas of low productivity hill country in New Zealand that are suitable for forestry activities, and which could be highly productive in this use. Potential production from the four scenarios' analyses were;
    - Scenario 1 = 8.25 M odt pa, 1964 M lPe pa, costs $71 - $87 per m3, 2094 PJ of stored energy
    - Scenario 2 = 26.85 M odt pa, 6385 M lPe pa, costs $64 - $76 per m3, 6129 PJ of stored energy
    - Scenario 3 = 46.25 M odt pa, 11,011 M lPe pa, costs $64 - $76 per m3, 11,188 PJ of stored energy
    - Scenario 4 = 61.60 M odt pa, 14,666 M lPe pa, costs $64 - $77 per m3, 19,200 PJ of stored energy.
- *Environmental benefits* - In general, forestry is seen as an excellent land-use option from an environmental perspective when compared with other intensively-farmed energy crops from arable land or animal grazing on steep hill country. Arable crops have higher energy and fertiliser inputs than forests and comparatively low yields in terms of litres per ha. In the case of animal grazing, erosion, sedimentation and nutrient run-off are reduced if they are replaced by afforestation. It should be noted however, that parts of Otago and South Canterbury, which have never been forested or where water availability is an issue, should be given careful consideration before large-scale afforestation is implemented.
- *Land-use impacts* - Larger land-use scenarios will have a significant impact on sheep and beef farming and meat production. However, if the price of oil is high, this could be a more profitable land use than sheep or beef farming. Historical trends suggest that land-use change will be slow to occur, despite potential for increased profit.
- *Economic impacts* - If domestically produced biofuels are cheaper to produce than imported oil, then all measures of national welfare and macro economic indicators are positive. In this case, biofuels from forestry could significantly decrease the exposure of the New Zealand economy to increasing oil prices. If, on the other hand, domestically produced biofuels are more expensive to produce, then the situation is mixed, with benefits in some areas and negative impacts in others.

In a future scenario assuming high oil prices and appropriate technological advances, these results suggest that the overall concept of large-scale bioenergy from forests is a promising option for New Zealand.

Remaining questions

A number of areas were identified for further work:

- Investigation of transitional issues such as: the potential for existing forests to contribute to bioenergy while an energy-focussed forest estate is established; and the impact that this would have on log supply to existing industries, and export log volumes.
- More detailed analysis of the multiple-product option (i.e. energy and timber).
- Investigation of the ability of domestically produced biofuels to mitigate the impacts of fluctuating oil prices or potential shortages.
- Investigation of the benefits to New Zealand of widespread bioenergy use in industrial production that leads to a reduced GHG footprint of export products via substitution for gas and coal.
- Understanding the social aspects of land-use change.

A revised scenario

A revised scenario based on the results of this study would help to determine whether large-scale bioenergy from forestry is an avenue worth pursuing for New Zealand.

This alternative scenario could consist of using approximately ~30%-40% of the existing harvest in 2030/2050 and a new afforestation area of approximately 1.1 to 1.3 million ha. This would yield the volumes of wood and fuel presented in Table 16. This scenario shows how an existing resource can be used as a transition stage while a larger biofuel supply resource is developed.

Table 16: Possible future option, use of existing forest and moving to a new biomass-focussed estate (1.1 million ha) with a larger proportion of production focussed on energy

		30% of cut from existing estate (A)	**1.1 million ha energy forest (B) ***	**1.1 million ha new forest, 44% to energy (C) ***	**Possible option (A+B)**	**Most likely scenario (A + C)**
2030	Biomass volume	12.9 M m^3	0	0	12.9 M m^3	12.9 M m^3
	Fuel production	1.21 B l Peq	0	0	1.21 B l Peq	1.21 B l Peq
	% of current petrol and diesel demand	19 %	0	0	19 %	19 %
2050	Biomass volume	17.3 M m^3	39.6 M m^3	17.4 M m^3	56.9 M m^3	34.7 M m^3
	Fuel production	1.62 B l Peq	3.71 B l Peq	1.63 B l Peq	5.33 B l Peq	3.25 B l Peq
	% of current petrol and diesel demand	27%	58%	27%	84%	51%

Note - current petrol and diesel demand = ~ 6.3 billion litres per annum
* Assumes no production available from new plantings in 2030 as they would mature in ~2035

Table 16 shows that using a proportion of the existing forest estate for energy supply could make a significant contribution to New Zealand's energy supply, potentially contributing as much as ~10% of current petrol and diesel use in 2030 and ~25% in 2050. This difference is due to the age class distribution of the forest and assumes that area harvested is replanted.

If 1.1 million ha of new forest is established and a proportion (44%) of this harvest is used for producing liquid fuels, it would represent the equivalent of 26% of the petrol and diesel demand in 2050. The establishment of this new forest would be at a rate of 44,000 ha per annum, to achieve a sustainable harvest off a 25-year rotation.

The New Zealand forest industry has the capacity to achieve new establishment rates of this magnitude, as it has been done in the past. By combining reduced consumption, energy efficiency gains and the deployment of electric vehicles in urban settings, this scenario suggests that a 50% reduction in per capita GHG emissions from transport by 2050 is possible.

Chapter 1

Evaluation of potential land-use change and recoverable biomass for four afforestation scenarios for large-scale bioenergy

Peter Hall, David Palmer, Barbara Höck, Mark O. Kimberley, Christian Walter, Phil Wilcox

Background and Introduction

Background

This work was funded by FRST, through the Bioenergy Options for New Zealand project, which was part of the EnergyScape programme. It builds on the findings of two previous reports, Bioenergy Options for New Zealand:

1. Situation Analysis – Biomass resources and conversion technologies
2. Pathways Analysis – Life cycle analysis of biomass resources to consumer energy

These previous reports found that biomass residues and wastes were insufficient to meet more than a small percentage of New Zealand's energy demand (Scion, 2008, a). It was also found that wood residues are the largest residue resource, and that due to New Zealand's land resource, biomass from forestry has significant potential to contribute towards meeting national energy demand. Conversion of wood to heat and electricity use mature technologies and making liquid fuels from wood by a variety of techniques is possible, and several (gasification, pyrolysis enzymatic hydrolysis, supercritical water, Scion, 2008, a) are being developed further.

There are significant environmental benefits from the use of biofuels through reduced GHG emissions (Scion, 2008, b) and it was hypothesised that there would be other significant gains in environmental terms from afforestation through carbon stock increase, erosion reduction and water quality improvement. Moreover woody-biomass can be grown on marginal land that cannot be used for food crops, bypassing the food versus fuels debate.

In the Bioenergy Options Situation Analysis (Hall & Gifford, 2008) it was estimated that around 3.2 million ha of forest could meet 100% of New Zealand's current heat and road transport fuel demand on a sustained yield basis, given current forest practice and productivity.

Introduction

This analysis is step one in a four-part analysis of the impacts of large scale bioenergy from forestry in New Zealand. The data from this analysis are used in the three subsequent sets of analysis; environmental impacts, land-use competition and economic impacts of large-scale bioenergy from forestry.

In this project the four afforestation for bioenergy area scenarios were developed using geographic information systems (GIS), the land cover database and various land selection criteria (Chapter 1), with the aim of getting a range of afforestation levels that were physically achievable, and represented a range of increases in plantation forest area (Table 1).

Table 1: Four area scenarios used in this study

Number	Descriptive area, Millions of hectares	Actual area, Hectares
1	0.8	765,181
2	1.8	1,855,669
3	3.3	3,386,648
4	4.9	4,927,040

Once the land was identified it was then subject to a productivity analysis, using a GIS based site productivity model. From these, volumes of biomass potentially available at a regional level were derived. The regionalised area scenarios were then used in an analysis of the environmental impacts (Chapter 2) of the four scenarios.

The area and productivity data from Chapter 1 was combined with forest crop information derived from a forest productivity model and cost information, to derive estimates of delivered cost, which fed into the economic assessment (Chapters 3 and 4). Future productivity gains from molecular biology and supply chain efficiency were also considered in terms of their impact on growth and biomass yield, as well as growing and delivered costs.

The volume information was also used to derive potential liquid biofuels volumes (litres of petrol equivalent) and the subsequent displacement of GHG emissions and amounts of CO_2 equivalent added to national carbon stocks (Chapter 2).

Identifying candidate areas

Barbara Hock

The selection of candidate area for afforestation was undertaken using GIS analysis and a range of datasets. The NZ Land Resource Inventory (NZLRI, 2003) is a national level spatial database covering soil and climate data. These data include a land-use capability (LUC) rating. There are eight LUC classes, with 1 being high-value land suitable for arable and other uses and 8 being land that has a limited range of uses (Ministry of Works, 1962). The LUC classes take into account soil, climate, altitude and slope and can be broadly used to categorise the suitability of land for cropping, pastoral and forestry uses.

Land area in NZ suitable for biofuel plantations was identified using the selection process and criteria presented in Figure 1, and Tables 2 and 3. Suitability included slope and elevation criteria. Highly productive lands (based on LUC and land use), developed areas (e.g. cities), and existing plantations were excluded. Also excluded were indigenous forest area and other areas such as wetlands, and the Department of Conservation's (DOC) estate. Four criteria sets were used to develop four candidate areas as described below. The codes referred to in the scenarios are listed in Tables 1 and 2.

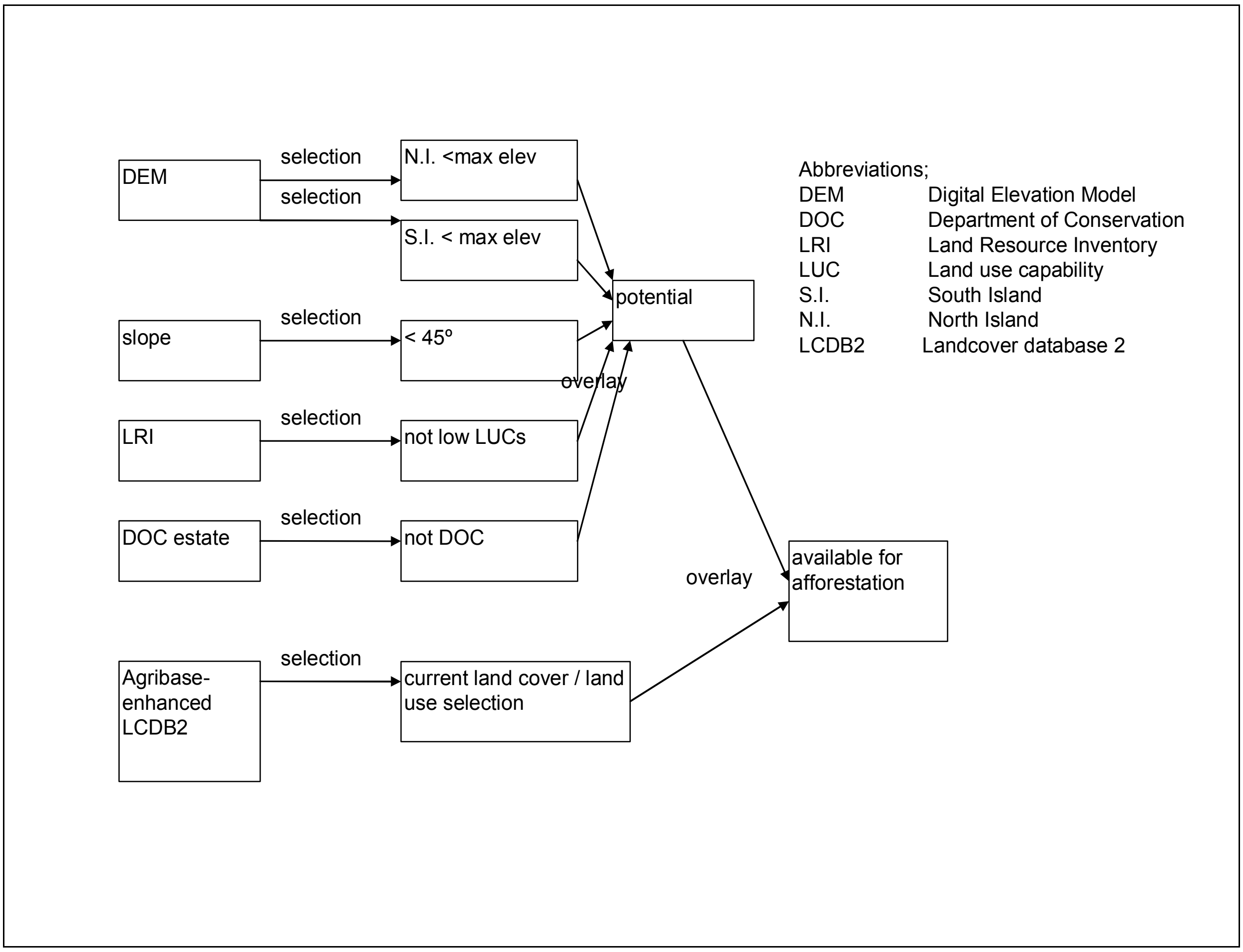


Figure 1: GIS overlays to identify potentially available land

Table 2: Potentially available lands based on Land Cover Database 2, where '-' indicates land excluded for all scenarios

Class type	LCDB2 CLASS	LCDB2NAME	Inclusion
artificial	1	Built-up Area	-
surfaces	2	Urban Parkland/ Open Space	-
	3	Surface Mine	-
	4	Dump	-
	5	Transport Infrastructure	-
bare or	10	Coastal Sand and Gravel	-
lightly	11	River and Lakeshore Gravel & Rock	-
vegetated	12	Landslide	-
surfaces	13	Alpine Gravel and Rock	-
	14	Permanent Snow and Ice	-
	15	Alpine Grass-/Herbfield	-
water	20	Lake and Pond	-
bodies	21	River	-
	22	Estuarine Open Water	-
primarily	30	Short-rotation Cropland	-
horticulture	31	Vineyard	-
	32	Orchard and Other Perennial Crops	-
grassland	40	High Producing Exotic Grassland	possible
	41	Low Producing Grassland	possible
	43	Tall Tussock Grassland	-
	44	Depleted Grassland	possible
(wetlands)	45	Herbaceous Freshwater Vegetation	-
	46	Herbaceous Saline Vegetation	-
	47	Flaxland	-
scrub and	50	Fernland	-
shrubland	51	Gorse and Broom	possible
	52	Manuka and or Kanuka	-
	53	Matagouri	-
	54	Broadleave Indigenous Hardwoods	-
	55	Sub alpine shrubland	-
	56	Mixed Exotic Shrubland	possible
	57	Grey Scrub	-
forest	61	Major Shelterbelts	-
	62	Afforestation (not imaged)	-
	63	Afforestation (imaged, post LCDB1)	-
	64	Forest Harvested	-
	65	Pine Forest - Open Canopy	-
	66	Pine Forest - Closed Canopy	-
	67	Other Exotic Forest	-
	68	Deciduous Hardwoods	-
	69	Indigenous Forest	-
	70	Mangrove	-

Table 3: Potential available land based on the additional information in the Agribase-enhanced Land Cover Database 2, where '-' indicates land excluded for all scenarios

FTYPE01 code	Description	Inclusion
API	Honey production / processing	-
ARA	Arable cropping	-
AVOC	Avocados	-
BEF	Beef cattle farming	possible
BERR	Berryfruit production	-
CITR	Citrus	-
DAI	Dairy milk production	-
DEE	Deer farming	possible
DOG	Kennels / catteries	-
DRY	Dairy drystock rearing	-
EMU	Emu	-
FIS	Aquaculture / fish hatcheries	-
FLO	Cut flower growing	-
FOR	Forestry	-
FRU	Orchards of unspecified type	-
GOA	Goat farming	-
GRA	Grazing other peoples' stock	possible
HAYF	Hay fodder production	-
HERB	Herbs	-
HOR	Horses (equine)	-
KIWF	Kiwifruit orchards	-
LIF	Lifestyle blocks	-
MAIZ	Maize growing	-
NAT	Native forest blocks	-
NOF	Not farmed – idle	possible
NUR	Plant nursery	-
NUTS	Nut trees	-
OAN	Miscellaneous animal types	-
OFRU	Other fruits e.g. Cherimoyas	-
OLAN	Other land use e.g. Quarries	-
OPL	Other plant types e.g. Meadowfoam	-
OST	Ostrich farming	-
OTH	Other land use not covered elsewhere	-
PIG	Piggeries	-
PIPF	Pip fruit	-
POU	Poultry or egg layers	-
SEED	Seed crops e.g. Clover, lucerne	-
SHP	Sheep farming	possible
SNB	Mixed sheep and beef farming	possible
SQUA	Squash	-
STON	Stone fruit	-
TOU	Tourism e.g. Home stays	-
UNS	Unspecified	possible
VEG	Vegetables / market gardening	-
VIT	Viticulture	-
ZOO	Zoological gardens	-

Area scenarios

Barbara Hock and Peter Hall

Scenario 1 – Low afforestation area: Strictest criteria – "0.8 million hectare scenario"

After excluding by elevation, slope and conservation and other unavailability criteria, the focus is on lower value land and land cover, and land area with potentially lower value land use. LUC's included are the higher-number classes, land cover is the lower value grasslands, and from Agribase only the lower intensity pastoral land uses are included (Table 4). Hectares matching these criteria are in Tables 5 and 6. No gorse or shrub lands were included as this scenario is a base case.

Table 4: Criteria to determine availability of land to change to biofuel production - Scenario 1

GIS layer	Criterion
DEM	North Island < 800m South Island < 700m
Slope	< 45º
LRI	LUC 5, 6, 7
DOC (2001)	not DOC estate
LCDB2 (summer 2001/02)	Low Producing Grassland (41) Depleted Grassland (44) Gorse and Broom (51) Mixed Exotic Shrubland (56)
Agribase farm type (LCDB2) (summer 2001/02)	BEF, DEE, GRA, NOF, SHP, SNB, UNS

Table 5: Land potentially available for conversion – Scenario 1

Land available	Hectares	%
North Island	86,793	10
South Island	744,365	90
Total	**831,158**	**100**

Table 6: Land by districts and displaced land use – Scenario 1 / 0.8

Region	Beef cattle farming	Deer farming	Grazing other peoples' stock	Not farmed - idle	Sheep farming	Mixed sheep/beef farming	Unspecified in Agribase	Region Total
Northland	3,716	5	196	0	9	2,501	231	**6,658**
Auckland	166	2	1	0	9	67	2	**246**
Waikato	1,099	7	39	0	10	4,300	86	**5,541**
Bay of Plenty	296	76	2	32	0	225	12	**643**
Gisborne	885	2	1	0	515	4,297	63	**5,763**
Hawke's Bay	2,442	16	4	0	3,147	5,935	35	**11,578**
Taranaki	1,395	1	32	15	4,773	6,455	94	**12,765**
Manawatu -Wanganui	4,097	1,865	181	35	10,279	18,074	216	**34,747**
Wellington	2,824	102	151	0	2,378	3,370	28	**8,852**
Nelson	0	0	0	0	25	3	6	**35**
Tasman	811	268	12	9	812	908	40	**2,861**
Marlborough	3,949	338	0	16	14,179	7,593	86	**26,161**
West Coast	1,395	1,247	87	0	76	1,619	73	**4,497**
Canterbury	10,471	1,846	796	16	125,338	201,054	2,503	**342,023**
Otago	12,817	2,967	137	402	138,011	160,788	3,024	**318,145**
Southland	469	3,173	42	0	8,305	37,984	671	**50,644**
Total	***46,831***	***11,915***	***1,680***	***525***	***307,866***	***455,173***	***7,168***	***831,158***

Key features, Scenario 1 / 0.8 (Table 6):

- 55% of area is from mixed sheep and beef farming
- 37% of area is from sheep farming

Scenario 2 – Medium afforestation area: Mid-range scenario – "1.8 million hectares scenario"

The scenarios are in order of least-to-most potential land. In this scenario (2), LCDB2 class 40 has been added to the land classes allowed to be included, but restricted to land that is over 7^0 slope and excluding land identified as being used for beef farming. This eliminates very high value flat land and high value grazing land (Table 7). It is identical to the next one (described in 2.3 – see additional comments there) except for one criteria: the areas must exceed a minimum slope angle.

Table 7: Criteria to determine availability of land to change to biofuel production – Scenario 2 / 1.8

GIS layer	Criterion
DEM	North Island < 800m South Island < 700m
Slope	Slope >= 7° and < 45°
LRI	LUC 5, 6, 7
DOC (2001)	not DOC estate
LCDB2 (summer 2001/02)	40 High Producing Grassland (excluding farm=BEF) 41 Low Producing Grassland 44 Depleted Grassland 51 Gorse and Broom (regardless of farm type) 56 Mixed Exotic Shrubland (regardless of farm type)
Agribase farm type (LCDB2) (summer 2001/02)	BEF, DEE, GRA, NOF, SHP, SNB, UNS

Table 8: Land potentially available for conversion – Scenario 2 / 1.8

Land available	Hectares	%
South Island	836,263	48
North Island	917,208	52
Total	**1,753,471**	**100**

In Scenario 1 / 0.8, the area available for afforestation was mostly (90%) in the South Island, with around 80% of that area in Canterbury and Otago (Table 4).

In Scenario 2 / 1.8 the North Island / South Island split was near to 50/50 (Table 8), with 36% of the national total in Canterbury and Otago. In this scenario there are also large areas in Manawatu/Wanganui (18%) and Gisborne/Hawke's Bay (15%) and Southland (5%) (Table 9).

Table 9: Land by districts and displaced land use – Scenario 2 / 1.8

Region	Gorse and broom	Mixed exotic shrubland	Beef cattle farming	Deer farming	Grazing other people's stock	Not farmed - idle	Sheep farming	Mixed sheep/beef farming	Unspecified in Agribase	Region Total
Northland	3,134	268	2,396	491	2,369	146	1,418	8,901	867	19,989
Auckland	577	182	119	822	889	7	1,614	4,841	331	9,381
Waikato	7,244	212	872	6,397	4,799	23	8,318	50,648	4,158	82,671
Bay of Plenty	1,116	97	191	2,332	1,171	169	299	2,735	136	8,246
Gisborne	3,056		805	1,922	247	1	9,316	100,648	1,281	117,275
Hawke's Bay	3,927	134	2,144	3,021	706	6	73,723	78,501	1,144	163,306
Taranaki	2,318	35	997	595	2,534	171	21,072	23,747	248	51,716
Manawatu - Wanganui	10,221	127	2,865	7,626	1,059	53	155,242	160,697	2,602	340,492
Wellington	18,806	23	2,603	1,433	304		67,684	32,729	550	124,132
Nelson					63		321	775	41	1,201
Tasman			704	1,729	263	26	5,883	5,696	144	14,445
Marlborough			3,283	1,577	173	19	52,926	28,074	181	86,233
West Coast			32	163	43		52	149	42	480
Canterbury			9,212	6,591	1,521	11	122,911	192,941	3,146	336,333
Otago			8,821	4,518	395	450	146,232	147,115	3,190	310,721
Southland			262	7,593	182		26,908	50,384	1,521	86,850
Total	50,398	1,077	35,307	46,810	16,716	1,084	693,918	888,579	19,582	1,753,470

Key features, Scenario 2 /1.8 (Table 9):

- 48% of area from mixed sheep and beef farming
- 37% of area from sheep farming
- 8% of area from gorse/broom and exotic shrubland

Scenario 3 – High afforestation area: High range scenario – "3 million hectare scenario"

This scenario keeps the criteria of the strictest scenario, but assumes LUC is the more robust indicator of less productive lands than the land cover classes. The high producing grasslands (in the land cover classes as identified on satellite imagery) on LUC 5-7 are included (Table 10), except for farm type "beef". Hectares matching these criteria are in Tables 11 and 12.

Table 10: Criteria to determine availability of land to change to biofuel production – Scenario 3 / 3.3

GIS layer	Criterion
DEM	North Island < 800m South Island < 700m
Slope	< 45º
LRI	LUC 5, 6, 7
DOC (2001)	not DOC estate
LCDB2 (summer 2001/02)	40 High Producing Grassland (excluding farm=BEF) 41 Low Producing Grassland 44 Depleted Grassland 51 Gorse and Broom (regardless of farm type) 56 Mixed Exotic Shrubland (regardless of farm type)
Agribase farm type (LCDB2) (summer 2001/02)	BEF, DEE, GRA, NOF, SHP, SNB, UNS

Table 11: Land potentially available for conversion – Scenario 3

Land available	Hectares	%
South Island	1,423459	42
North Island	1,948,892	58
Total	**3,373,351**	**100**

In Scenario 3 / 3.3 the North Island / South Island split was 42/58 (Table 11) and there are large areas from the following regions; Canterbury (17%), Otago (16%), Manawatu/Wanganui (18%), Gisborne (7%), Hawke's Bay (11%), Waikato (8%), Wellington (5%), Southland (5%) (Table 12).

Table 12: Land by districts and displaced land use – Scenario 3 / 3.3

Region	Gorse and broom	Mixed exotic shrubland	Beef cattle farming	Deer farming	Grazing other people's stock	Not farmed - idle	Sheep farming	Mixed sheep/beef farming	Unspecified in Agribase	Region Total
Northland	4,336	555	3,716	851	3,827	27	2,163	50,548	1,536	**67,759**
Auckland	737	257	166	1,271	1,410	3	2,329	19,583	532	**26,297**
Waikato	10,109	1,224	1,099	11,664	7,864	26	12,446	215,909	6,432	**266,872**
Bay of Plenty	1,778	257	296	4,920	2,249	16	521	17,822	247	**28,506**
Gisborne	3,513	0	885	2,533	289	1	11,035	224,441	1,684	**244,381**
Hawke's Bay	5,006	177	2,442	5,021	986	0	107,918	268,737	1,748	**392,044**
Taranaki	2,694	50	1,395	984	5,490	05	27,986	48,288	390	**87,483**
Manawatu -Wanganui	12,602	5,162	4,097	10,721	2,322	69	209,052	393,727	3,331	**641,184**
Wellington	20,938	49	2,824	1,932	584	6	86,762	80,228	1,043	**194,366**
Nelson			-	-	73	0	354	1,284	47	**1,758**
Tasman			811	2,415	524	34	7,168	15,336	227	**26,515**
Marlborough			3,949	1,974	246	23	60,761	46,254	280	**113,486**
West Coast			1,395	6,564	537	0	629	8,804	843	**18,773**
Canterbury			10,471	11,387	2,127	79	200,081	344,286	4,029	**572,459**
Otago			12,817	6,927	589	707	221,788	273,382	4,966	**521,176**
Southland			469	12,313	688	-	45,188	108,342	2,291	**169,292**
Total	**61,713**	**7,730**	**46,831**	**81,476**	**29,806**	2,017	**996,183**	**2,116,970**	**29,625**	3,372,351

Key features, Scenario 3 / 3.3 (Table 12):

- 61% of area from sheep and beef farming
- 29% of area from sheep farming
- 5% of area from gorse/broom and exotic shrublands

Scenario 4 – Very high afforestation area: Most lenient criteria – “5 million hectare scenario”

In this scenario maximum elevations are set higher than for the previous scenarios. LUC 4 is included. Table 13 shows criteria and Tables 14 and 15 show hectares.

Table 13: Criteria to determine availability of land to change to biofuel production - Scenario 4 / 4.9

GIS layer	Criterium
DEM	North Island < 1000m South Island < 1000m
Slope	< 45º
LRI	LUC 4, 5, 6, 7
DOC (2001)	not DOC estate
LCDB2 (summer 2001/02)	40 High Producing Grassland 41 Low Producing Grassland 44 Depleted Grassland 51 Gorse and Broom 56 Mixed Exotic Shrubland
Agribase farm type (LCDB2) (summer 2001/02)	BEF, DEE, GRA, NOF, SHP, SNB, UNS and 20% of unknown farms (blank farm type) (*1)
Composite	Excluded slope < 15º and LUC=4 and LCDB2=40 (i.e. where all three criteria hold)

(*1) This is not a spatial criterion. It was first used when the resulting areas were presented in tabular format only. To implement it, the blank farms that matched all the other criteria were subjected to further criteria, e.g., slopes < 15º, LCDB2=40, or LUC=4 were excluded.

Table 14: Land potentially available for conversion – Scenario 4 / 4.9

Land available	Hectares	%
South Island	2,421,619	49
North Island	2,505,421	51
Total	**4,927,040**	**100**

In Scenario 4 / 4.9 the North Island / South Island split is near 50/50 (Table 14).

Regions with significant afforestation area are; Canterbury (21%), Otago (18%), Manawatu/Wanganui (15%), Gisborne (6%), Hawke’s Bay (9%), Waikato (8%), Wellington (5%), Southland (5%) (Table 15).

Consistent across the scenarios, regardless of the total area, are that there is a large conversion from mixed sheep and beef farming and sheep farming. Shrublands make a small contribution.

Except for Scenario 1 / 0.8 the area is evenly split between the North and South Islands. Large areas come from Canterbury and Otago in all scenarios, and for Scenarios 2 / 1.8, 3 / 3.3 and 4 / 4.9 Manawatu/Wanganui, Gisborne, Hawke’s Bay, Waikato, Wellington and Southland all make a significant contribution to the total area of afforestation.

Table 15: Land by districts and displaced land use – scenario 4 / 4.9

	Low producing grassland	Depleted grassland	Gorse and broom	Mixed exotic shrubland	Beef cattle farming	Deer farming	Grazing other people's stock	Not Farmed - idle	Sheep farming	Mixed sheep and beef farming	Un specified in Agribase	**Region Total**
Northland	7,706	5	5,530	760	96,977	1,081	4,676	255	2,651	57,380	1,706	**178,729**
Auckland	641	-	830	335	22,886	1,626	1,992	14	2,803	22,238	619	**53,984**
Waikato	1,707	0	10,525	929	105,838	12,767	8,799	46	13,591	227,713	7,035	**388,949**
Bay of Plenty	1,222	-	2,187	330	20,506	5,338	2,399	413	551	18,767	263	**51,974**
Gisborne	2,347	-	3,573	18	45,524	2,650	289	1	11,310	227,625	1,690	**295,028**
Hawke's Bay	2,030	-	5,338	181	58,718	5,259	995	10	112,377	276,237	1,751	**462,896**
Taranaki	1,164	-	2,764	52	16,893	1,021	5,790	202	29,516	50,285	394	**108,081**
Manawatu -Wanganui	4,850	6	13,034	716	73,123	11,022	2,371	121	215,913	404,468	3,510	**729,136**
Wellington	2,088	-	21,368	50	38,042	2,104	606	6	88,965	82,329	1,086	**236,644**
Nelson	64	-	1,640	28	250	-	73	0	354	1,284	47	**3,738**
Tasman	965	-	7,432	1,330	6,971	2,821	654	67	8,790	17,826	313	**47,169**
Marlborough	2,257	11	5,299	1,583	34,648	2,098	262	23	83,178	57,625	384	**187,368**
West Coast	924	-	12,765	23	7,383	6,806	558	0	675	9,382	857	**39,373**
Canterbury	45,931	17,320	38,342	7,524	54,021	26,759	2,650	80	297,073	524,482	6,220	**1,020,403**
Southland	4,117	0	7,212	1,788	5,426	15,000	825	1	56,277	144,240	2,906	**237,791**
Otago	36,667	5,579	16,324	28,270	31,834	9,769	826	971	342,371	404,230	8,939	**885,778**
Total	**114,681**	**22,922**	**154,161**	**43,916**	**619,041**	**106,121**	**33,765**	**2,210**	**1,266,395**	**2,526,109**	**37,720**	**4,927,040**

Key features, Scenario 4 / 4.9 (Table 15):

- 51% of area from mixed sheep and beef farming
- 26% of area from sheep farming
- 4% of area from gorse/broom and exotic shrublands
- 3% of area from depleted and low productivity grasslands

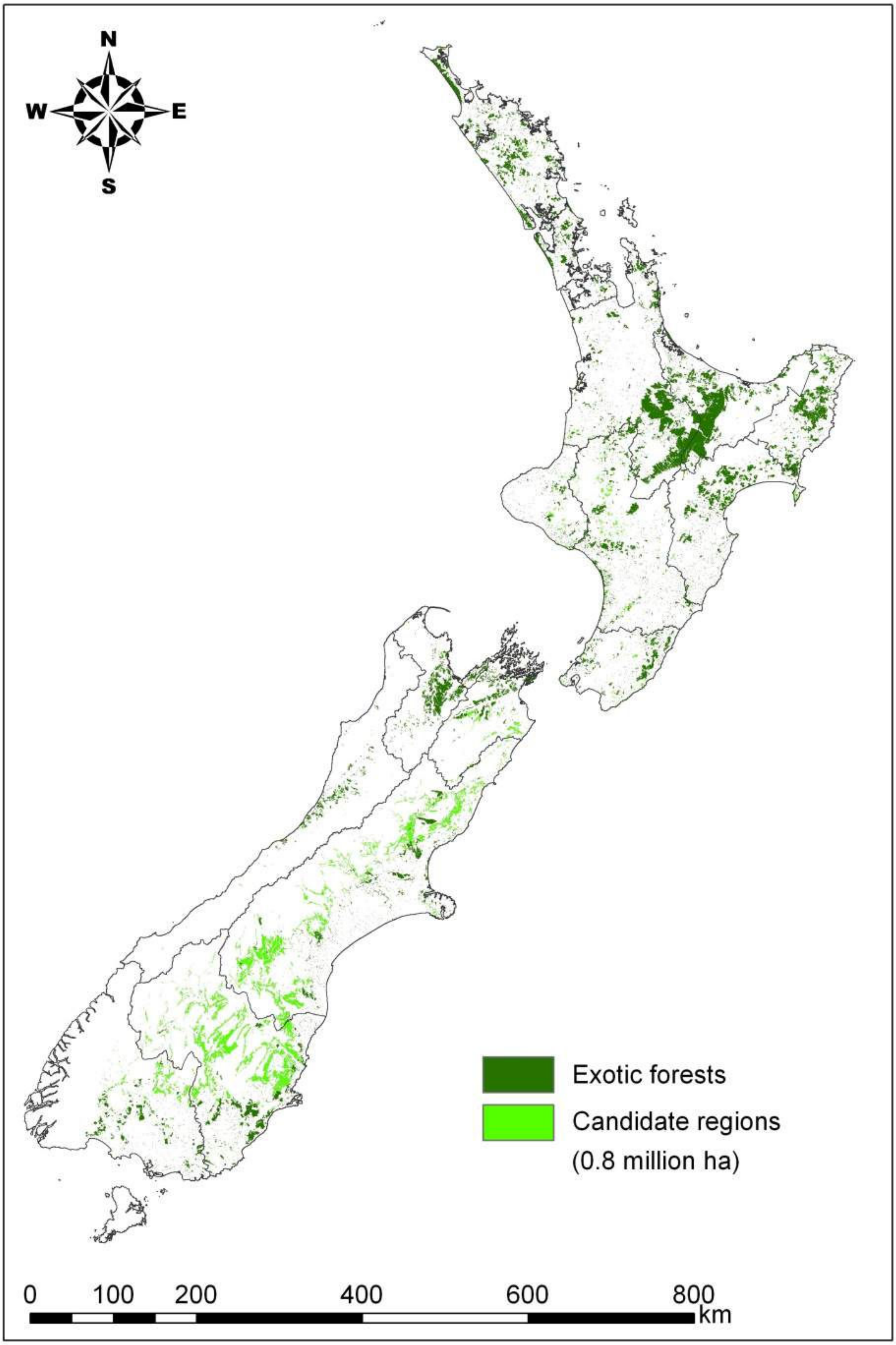


Figure 2: Map of Area Scenario 1, 0.8 million ha, showing existing plantations and scenario candidate areas

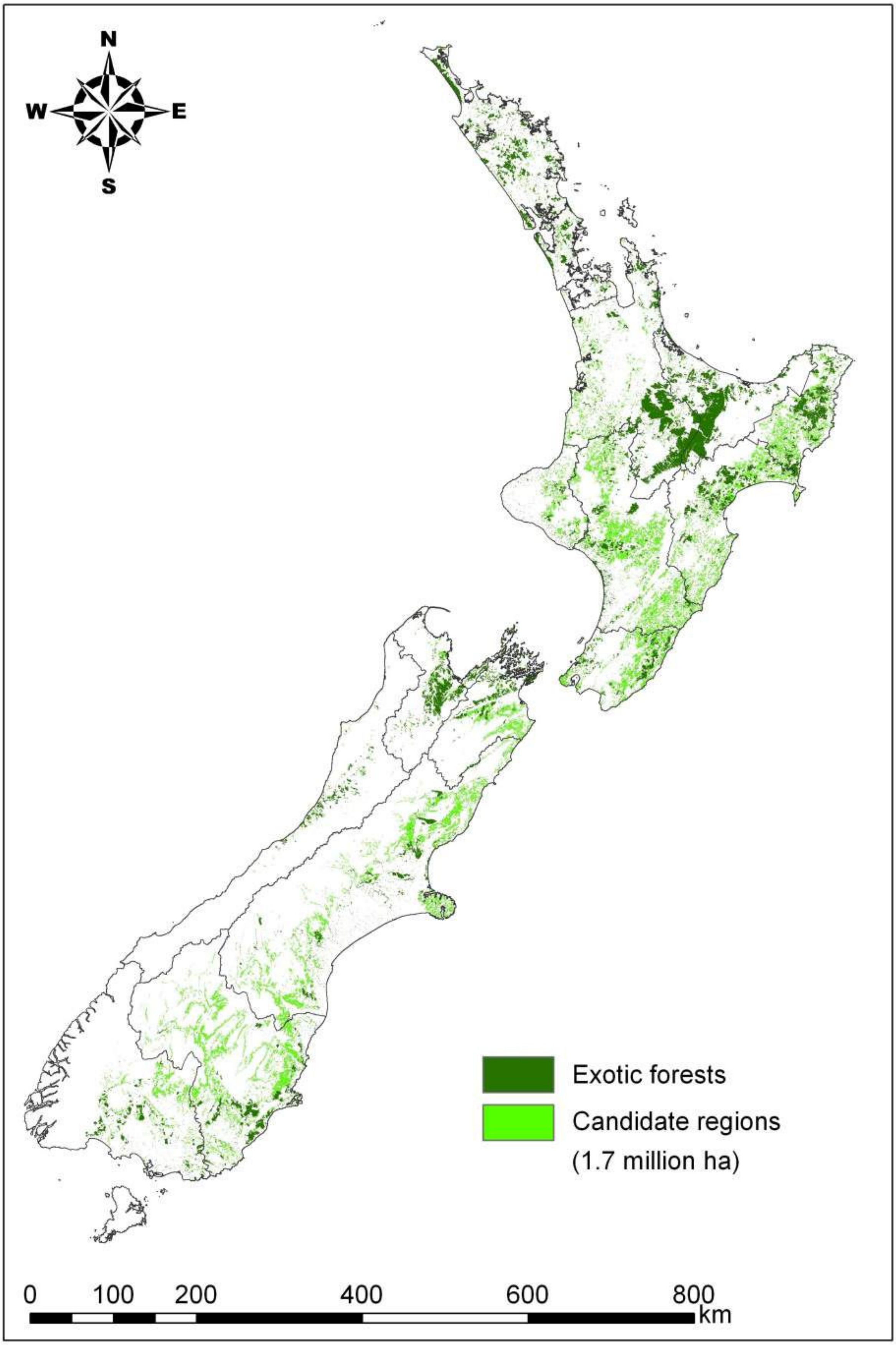


Figure 3: Map of Area Scenario 2, 1.8 million ha showing existing plantations and scenario candidate areas

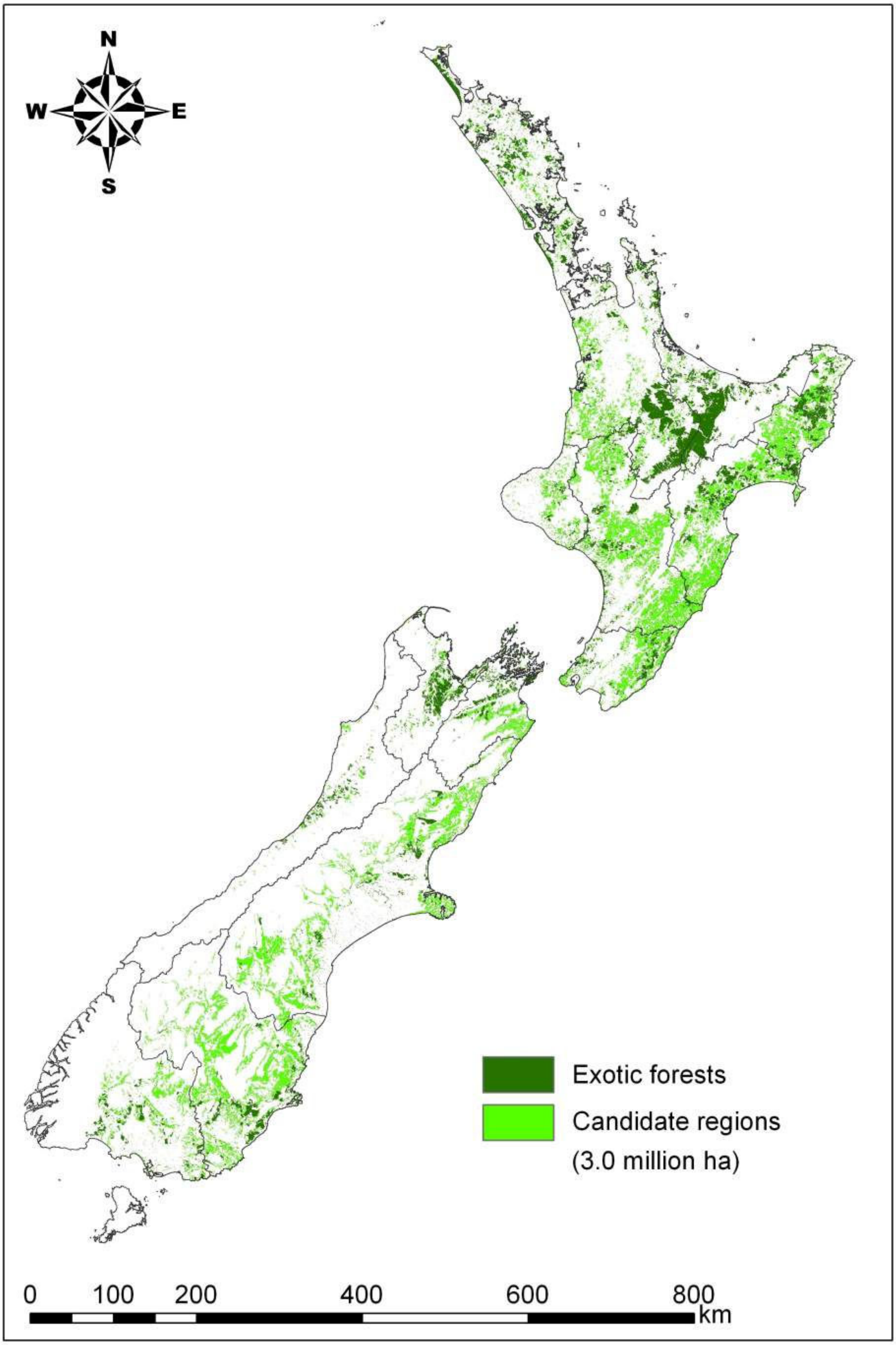


Figure 4: Map of Area Scenario 3, 3.3 million ha showing existing plantations and scenario candidate areas

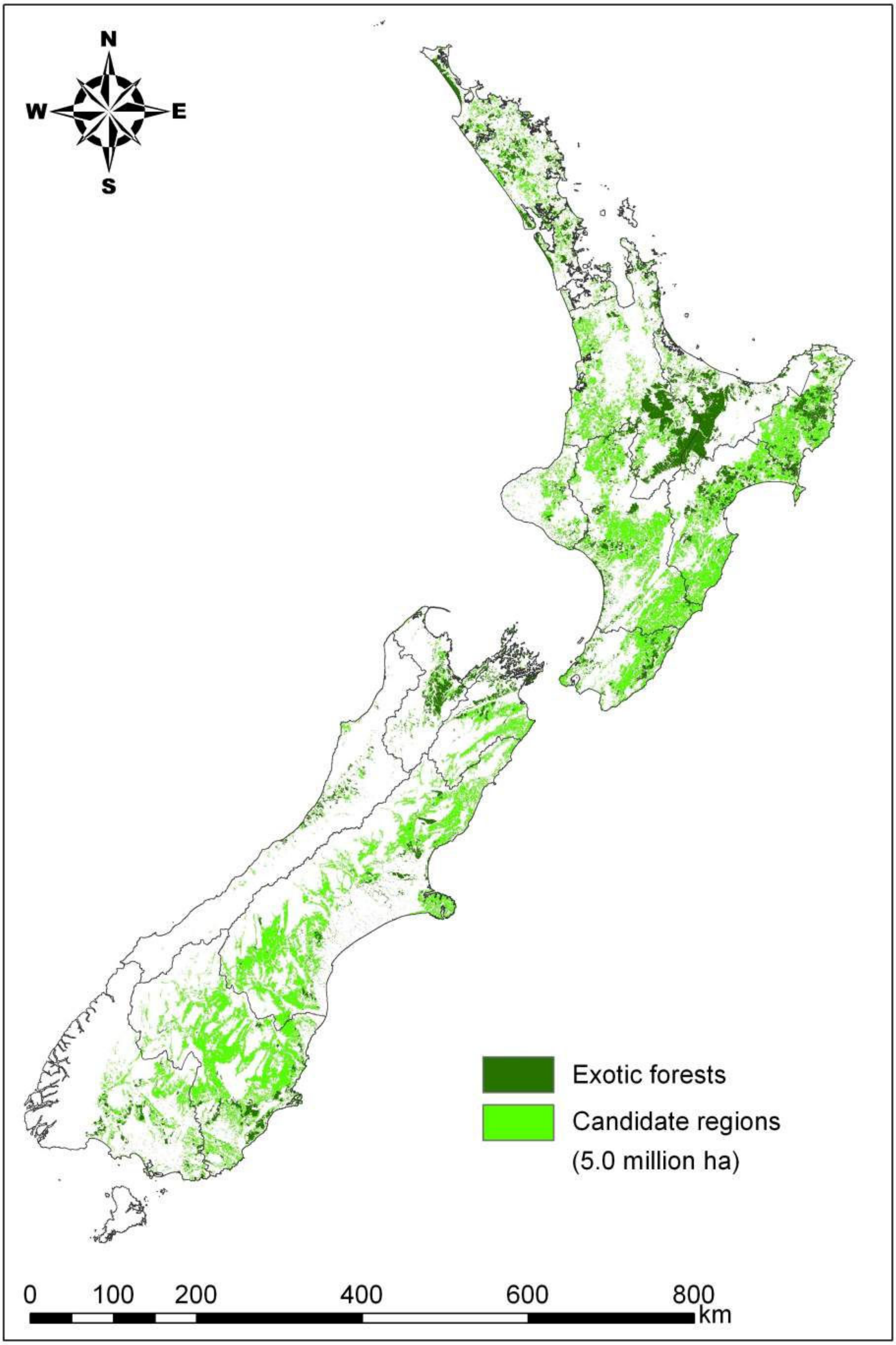


Figure 5: Map of Area Scenario 4, 4.9 million ha showing existing plantations and scenario candidate areas

The evaluation of total recoverable biomass from Pinus radiata using three growth regimes at three different growth period scenarios across four sets of potential candidate areas for the production of bioenergy

Dave Palmer

Materials and methods

Overall modelling approach

When modelling the potentially available biomass for New Zealand, strict modelling scenarios were defined. Four candidate areas were chosen to represent conservative to extensive usage of land areas from ~800,000, ~1,800,000, ~3,300,000, and ~4,900,000 ha, respectively. Growth regimes were chosen to provide estimates at low and high initial stockings: 555 and 833 stems per ha. An alternative regime of 833 stems per ha thinned to 450 stems per ha at age seven was provided as an alternative to focusing solely on bioenergy as a crop. Finally, growth periods were applied to the above candidate areas and regimes providing recoverable biomass at age 20, 25, and 30 years.

Productivity and site quality model surfaces

The modelling of total recoverable biomass potentially available for New Zealand required base estimations for *Pinus radiata* productivity and site index. The foundation models and surfaces, 300 Index and Site Index were calculated using partial least squares (PLS) regression in association with ancillary data, including climate, environmental, terrain, and land-use variables (Figure 6). Regression transfer functions were used to populate productivity and site index maps for New Zealand. For development details refer to Palmer *et al* (in prep).

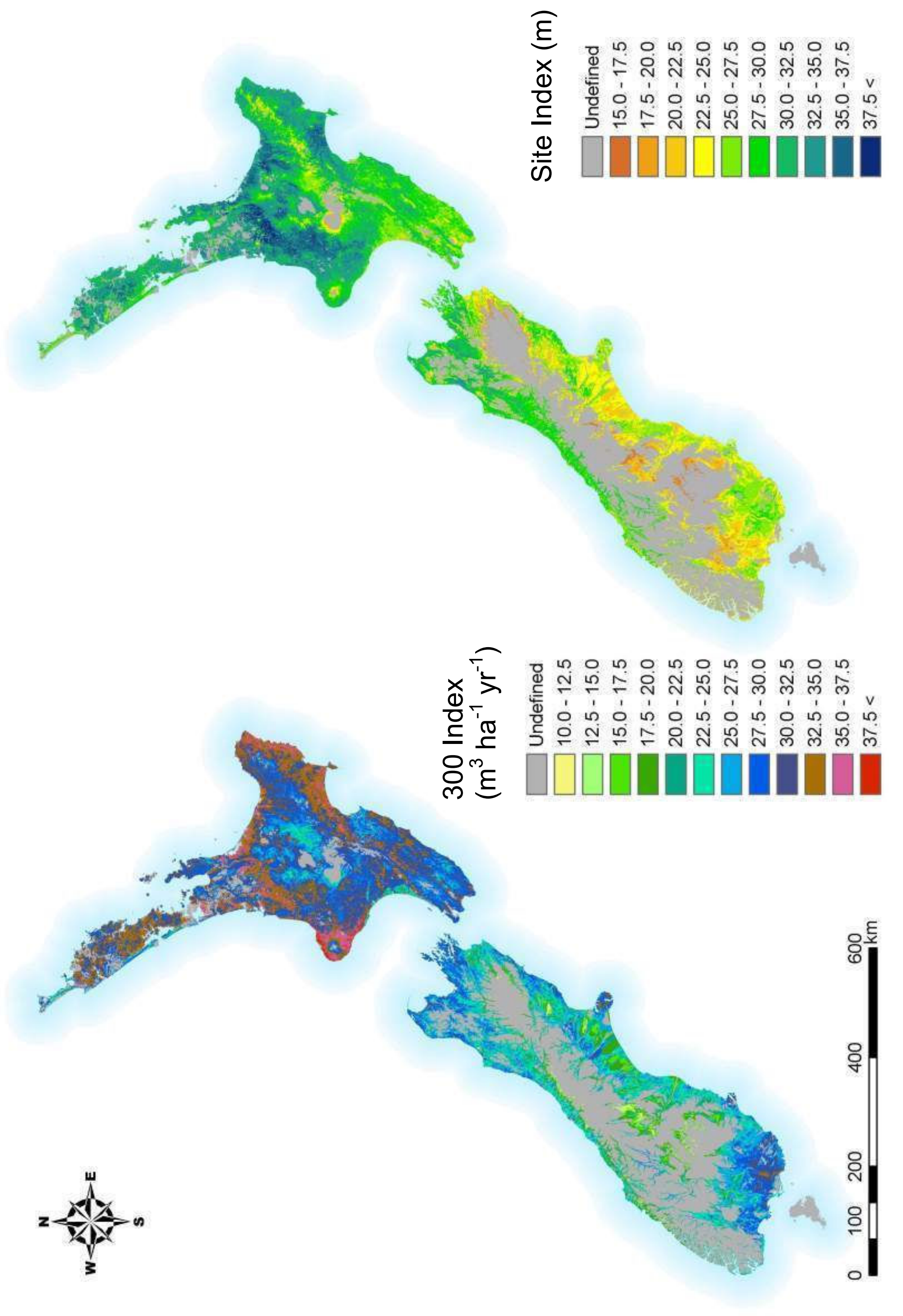


Figure 6: Distribution of the 300 Index and Site Index across New Zealand developed using partial least squares (Palmer *et al* (in prep)).

Methods of predicting biomass in radiata pine plantations

Mark Kimberley

The amount of biomass produced by a radiata pine plantation is influenced by a variety of site and management factors. Predicting biomass is therefore complex. However, a number of models which have been developed at Scion in recent years make realistic prediction of biomass possible. Many of these models were developed for predicting carbon sequestration, but are equally useful for predicting biomass. In this project, the following models were used to predict biomass for several management regimes for a range of rotation lengths and site productivity levels. The following models were used:

- The 300 Index Growth Model
- A radiata pine stand-level volume function
- A radiata pine wood density model
- C-Change, a model for predicting forest biomass
- A regression model for predicting biomass in several specific regimes developed for this project

The required inputs to the modelling system are two site productivity indices (Site Index and 300 Index), mean annual temperature, and the management regime (i.e., initial stocking, timing and intensity of thinning, and rotation length). The productivity indices and temperature were obtained from N.Z. productivity surfaces or maps, and the three regimes used in the study are described in the productivity and regimes section. A brief discussion of how the inputs are used by these models to predict biomass, and of the model linkages, is given as follows.

The productivity indices and regime information are used as inputs into the 300 Index Growth Model (Kimberley *et al*, 2005) which provides annual predictions of basal area (BA), mean top height (MTH) and stocking. This national-level radiata pine growth model has been developed and validated using a large database of permanent sample plots, and has been found to provide reliable estimates for a wide range of site productivity levels, management regimes, and rotation lengths.

The estimates of BA, MTH and stocking produced by the growth model are converted into under-bark total stem volume estimates using a general-purpose stand-level volume function (Kimberley & Beets, 2007) which provides good estimates for radiata pine plantations of any age and site type in New Zealand.

A radiata pine wood density model (Beets *et al*, 2007) is then used to predict the mean basic wood density of the stem wood of these trees. This model takes account of the strong increase in wood density with age that occurs in radiata pine. It also adjusts for the influence of stocking and mean annual temperature on wood density for the species. Soil C/N ratio can also be utilised by this model, but in this study, an average of 15 was assumed for all sites.

The forest biomass model C-Change (Beets *et al*, 1999) is then used to determine the development of various biomass pools in annual steps, using the predicted stem volume increments and wood densities. C-Change keeps track of the effects of thinning operations. Its output consists of annual biomass and litter predictions for each component of the stand. For the purposes of this study, it was assumed that the utilisable biomass consisted of 85% of the stem wood biomass and 80% of the stem bark biomass. Other components (e.g., the remainder of the stem, and all branches, foliage, roots etc.,) were assumed not to be harvested.

For each of the three regimes used in the study, predictions of biomass using the above steps were obtained for all combinations of the following input levels:

- Age: 20, 25, and 30 years
- Site Index: 20, 30, and 40 m
- 300 Index: 15, 27.5, and 40 m3/ha/yr
- Mean Annual Temperature: 8, 12, and 16 °C

These input ranges cover the site conditions likely to be found anywhere in New Zealand.

The above steps provided biomass predictions for the particular input levels given above. To provide general predictions for any combination of model inputs within the general range of these inputs, a series of quadratic response-surface regression models were developed specifically for this project. These models can be used for predicting biomass for any combination of input variables. Separate regressions were derived for each of the three regimes, and each of the three rotation ages (20, 25 and 30 years) and for stem wood and stem bark. Because the model predictions used as independent variable in these regression models vary in a very regular way with the model inputs, these regression equations explain most of the variation in the original model predictions, with R^2 values in excess of 0.99 for all models.

The models are based on data from fully stocked forest with no canopy gaps. In reality there are often stocking losses due to storm damage, rock outcrops, wet areas and establishment losses. An accurate figure was not available (range from 10% to 25%), so the 100% stocking was used.

Calculation of total biomass national surfaces

Dave Palmer and Barbara Hock

Determination of candidate areas potentially available for bioenergy production

New Zealand land area potentially available for bioenergy production was derived by overlaying LCDB2, slope class, elevation and excluding unsuitable or unavailable areas (DOC estate, urban areas and waterways) and limiting the selection of other land by land use class. Figure 7 provides a flow chart describing the development of candidate areas potentially available for bioenergy production.

Scenario modelling of biomass growth regimes across growth periods

Biomass national surfaces were calculated using model equations discussed in section on modelling of total biomass. The grid module from the GIS platform ArcInfo™ was used in association with Arc Macro Language (AML) to undertake model calculations. A purpose written routine calculates biomass in oven dried tons ha^{-1} (ODT) from the 300 Index and Site Index surfaces in association with model coefficients for the 20, 25, and 30 year growth period scenarios as described in Figure 7. All surface values were reclassified into 25 ton class intervals.

When calculating regional estimates of biomass some regions, especially Otago, were impacted by residual no data cells from the original 300 Index and Site Index surfaces. To overcome this issue a second AML was developed that populates no data cells with the nearest adjacent value using the *eucallocation* command in the ArcInfo™ grid module. These values were multiplied by 0.8; ensuring biomass predictions would not unduly influence the extrapolated values. The biomass values from the calculated and populated surfaces were merged together into one comprehensive national surface. Because productivity of *Pinus radiata* is known to taper off in cooler regions, we removed all biomass values below a mean annual temperature of 7.9 °C. This threshold was determined by assessing the actual PSP dataset in relation to temperature and elevation in association with expert knowledge.

This process altered the total area available from that generated from the initial GIS area analysis (Table 16).

Table 16: GIS area variation, initial analysis and variation due to productivity overlay

Scenario	GIS Area	Productivity overlay area	Variation, Hectares	Variation, %
1 / 0.8	821,158	765,181	-65,977	-8.0
2 / 1.8	1,753,470	1,855,669	+102,199	+6.0
3 / 3.3	3,372,351	3,386,648	+14,297	+0.4
4 / 4.9	5,169,076	4,927,040	-242,036	+4.6

The productivity overlay areas were used in the subsequent analysis.

The *Pinus radiata* productivity data was used as it is the only dataset with a comprehensive widespread national level coverage of a wide range of sites. It is used to represent expected forest productivity. It does not infer that *Pinus radiata* is the only species that will be used, or is the species of choice. It is however the only dataset that allows national level modelling of site productivity and variability.

Regional descriptors were incorporated into the surfaces by creating a regional surface with identifying values two orders of magnitude greater (1000 to 16,000) than the biomass categories. The summation of the regional and biomass surfaces allows the determination of biomass classes for each of New Zealand's 16 regions. The value and count fields were extracted from each of the surfaces associated ArcInfo™

tables and saved to a spreadsheet. The extracted data provided for each region the number of cells associated with each class. Each cell represents 100 by 100 m, or 10,000 m^2 (1 ha).

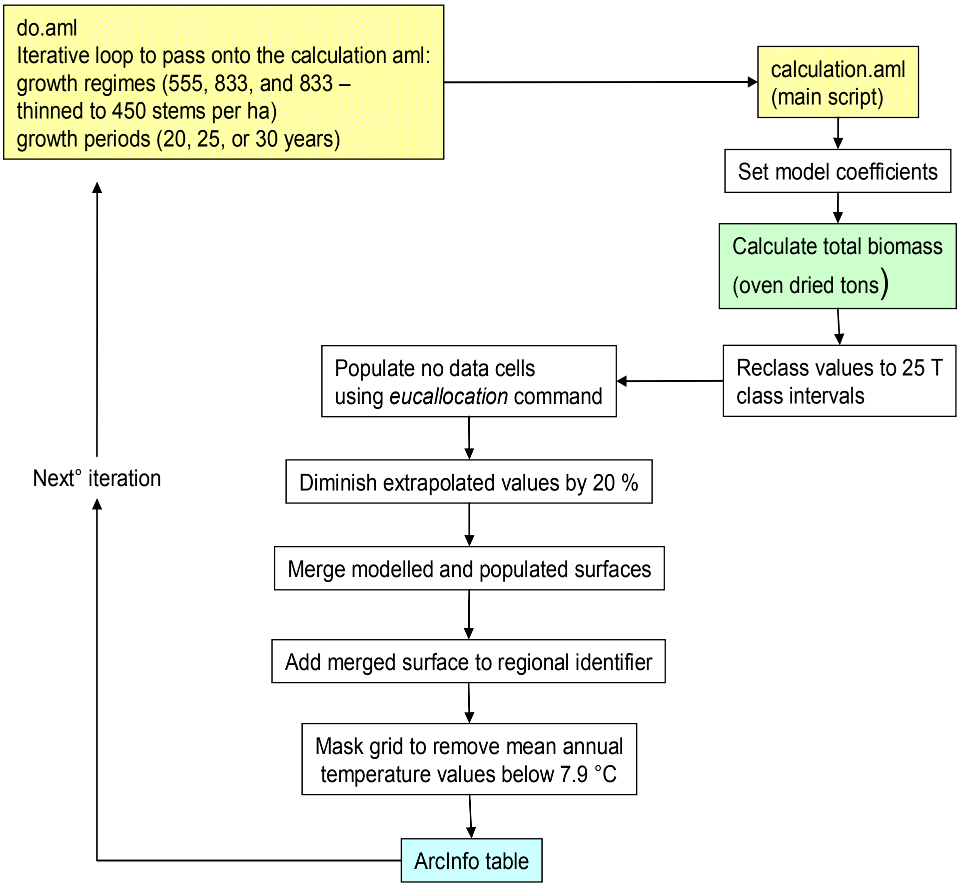


Figure 7: Flow chart illustrating architecture of the iterative routines modelling the potential biomass available in each region for each growth regime (stems ha^{-1}), growth period (yr), and for each candidate region (ha) using arc macro language (AML).

Productivity and regime outputs

Peter Hall

In order to conduct the environmental and economic impacts analysis we had to provide not only area scenarios but productivity data and establishment time frames. In order to simplify the subsequent analysis the number of regimes and rotation lengths was narrowed. The scenarios used in the subsequent analyses were based on the 833 regime (no thinning) and a 25-year rotation. This results in a final crop stocking of 630-660 stems per ha.

Modelling of these regimes (*Pinus radiata* Calculator V3.1) found that the 833 regime (no thinning) over a 25-year rotation had the best compromise of high biomass volume production (Table 17), potential for traditional log production (Table 18) and availability at a reasonable time frame (by 2035). The selection of a 25-year rotation is based on; the land being used, which has up to 30% over 20^o slope and optimising the mean annual biomass increment. The use of hill country with sloping terrain infers use of cable logging systems being used for the harvest, where harvest volumes and individual piece size impact on logging cost. The 25-year rotation also allows for multiple end-use options due to the age effect on the wood density in radiata pine.

The 833 regime produced more volume than the 555 or 833 and thin to 450 regimes. The 25-year-old regime produces more volume than the 20-year rotation and less than the 30-year rotation, and is a compromise between maximum volume and future availability. The PradCalc model was run for mid-range sites, with moderate altitude (400 m), site index (29.5) and latitude (39). Costs and revenues for the different regimes vary, but the gross return for the regimes were all very similar, at around $20,000 per ha ($20,055 - $20,326).

The significance of the log product mix is the risk mitigation that it offers. That is, if the bioenergy market fails to develop as predicted, there is a fall-back position of being able to sell some of the logs into the traditional solid wood log market. Further, the high total standing volume of the 833 regime also fits well with the other option of selling the carbon credits from the stand if the decision is made to not harvest at all.

The use of *Pinus radiata* as the crop does not presuppose that this will ultimately be the crop that is used, it is simply that this is the species that has the most information available on it in terms of growth and management, and so it can be modelled more accurately and in more detail than any other exotic plantation species. The existing New Zealand plantation forest estate is ~90% *Pinus radiata (MAF, 2007),* suggesting that it has proven to be a productive, robust, manageable and adaptable option across a range of soils and climates. In any establishment of energy forests *Pinus radiata* will inevitably be part of the species mix, but by no means the sole species. Its use here is to allow the development of a baseline, based on best available knowledge. Use of other species would be dependant on having, or developing, productivity and suitability data on a site-by-site basis.

Table 17: Biomass production by regime, 25-year rotation

Regime, Stems/ha	Total volume, m^3/ha	Mean Annual *Biomass Increment m^3/ha/pa
555	830	33.2
833	940	37.6
833/450	780	31.2

*tree biomass not stem or merchantable log volume

These yields are very high compared to some current forest yields. Factors that have influenced these yields are:

- volumes are for net stocked area (all native forest, waterways and very steep slopes (>45°) were mapped out of the candidate area;
- stands are assumed to be 100% stocked. Mature stands often have canopy gaps due to stem damage and small areas which are unplantable (rock outcrops, swamps, establishment failures). An exact figure for this potential productivity loss was difficult to obtain and so was applied. It could be 10% to 25%, depending on site and management;
- biomass includes branches, bark and logs which traditionally would be unmerchantable;
- a biomass-focussed regime was used, with a final crop stocking of ~630 to 660 stems per ha.

Table 18: Log product (m^3/ha) mix by regime

Log Grade	555 regime	833 regime	833/450 regime
S1	42	24	64
S2	176	165	170
S3	183	253	159
L1	13	5	15
L2	58	29	60
L3	75	53	66
Pulp/chip	162	278	134
Waste	125	142	118
Total	**833**	**949**	**787**
Volume of sawlog grade	547	529	534
% Potential sawlogs	**66%**	**56%**	**68%**

The 833 regime (Table 18) has the greatest total volume, and a volume of saw logs that is similar to the other regimes.

Annual biomass increment

The biomass calculations presented use mean annual biomass increment (MABI), in order to determine biomass yield at harvest (Figure 8).

Use of mean annual increment (MAI) is a common procedure in forestry; the MABI differs from MAI in that it is based on stand biomass, not recoverable log volume. The MABI's here are based on rotation ages that are 25 years. These MABI figures should not be applied to short or medium rotation forests, as the actual annual increment in the first five years of the crop's life is quite low (Figures 8 and 9). If the MABI of a long rotation is applied to a shorter rotation, over estimation of the biomass yield will occur (Figure 8). In the later years of the crop's life, when the trees are large, the annual volume increments are very high. The mean annual biomass increment is used for the convenience of the calculations and comparison purposes.

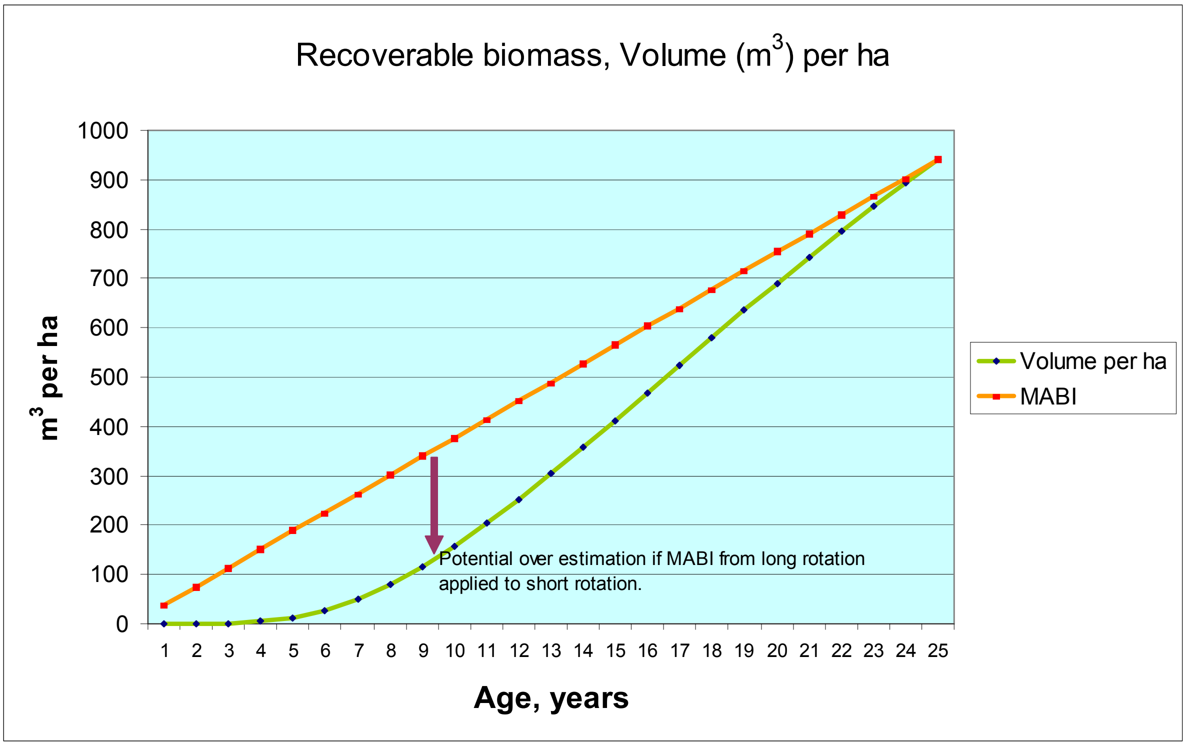


Figure 8: Recoverable biomass, m^3 per ha over time (833 regime, 25-year rotation)

The justification for the rotation age being set at 25 is partly seen in Figure 9, where the actual annual biomass increment (AABI) although high, is dropping after age 18. If the rotation was continued beyond age 25 or 26, the MABI would begin to decrease. Other factors, including; sawlog production, wood density as well as maximising biomass volume production were also considered.

If the current (actual) annual increment line in Figure 9 is considered to be equivalent to a marginal cost curve then the optimum harvest point may be less than 25 and could be 18 to 19. If a discount rate of 6% is applied the optimum harvest age could drop to 15 to 18 on a purely volume basis. This would result in less volume being produced, but potentially at a lower cost. This takes no account of the wood density difference between the less mature wood from a young stand and that from a more mature stand, which could be in the order of 10% (with 18-year-old trees less dense than 25-year-old trees.) This issue may be important to both the energy yield of the bioenergy crop and the value of any sawlogs intended to be cut. More detailed cost/revenue analysis would be required to determine optimum rotation age on a site-by-site basis.

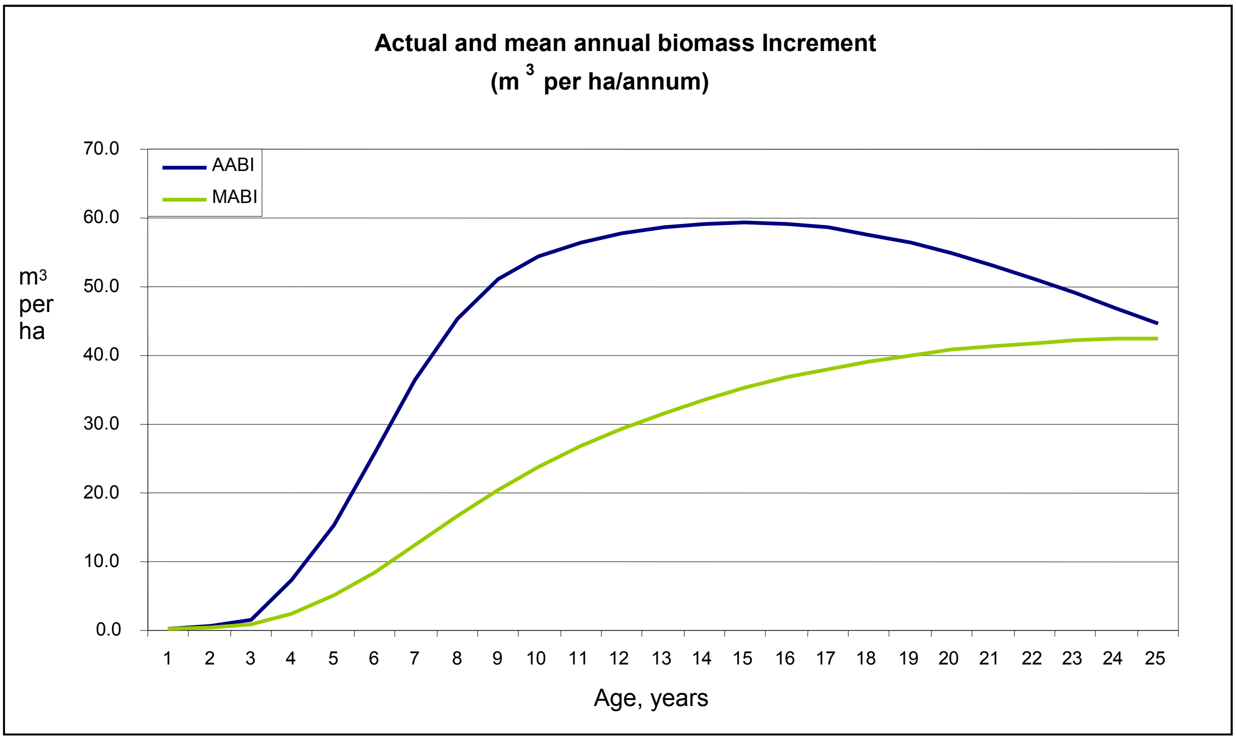


Figure 9: Actual and mean annual biomass increment, m^3 per ha per annum

Other options for determining when to harvest could be considered (Gerard Horgan pers comm.), and these could be determined by developing an analysis of the marginal cost and marginal revenue (Samuelson, 1995), an example of this approach is given in Figure 10. Where the marginal revenue line is above the marginal cost line, harvesting should be considered, and ideally harvesting would occur where the lines are parallel (on the same slope). The example here would suggest harvest no later than 25 and maybe as early as 21, depending on the discount rate chosen. This kind of analysis needs to be done on a site specific basis to be accurate; the figures in this analysis are highly sensitive to the discount rate.

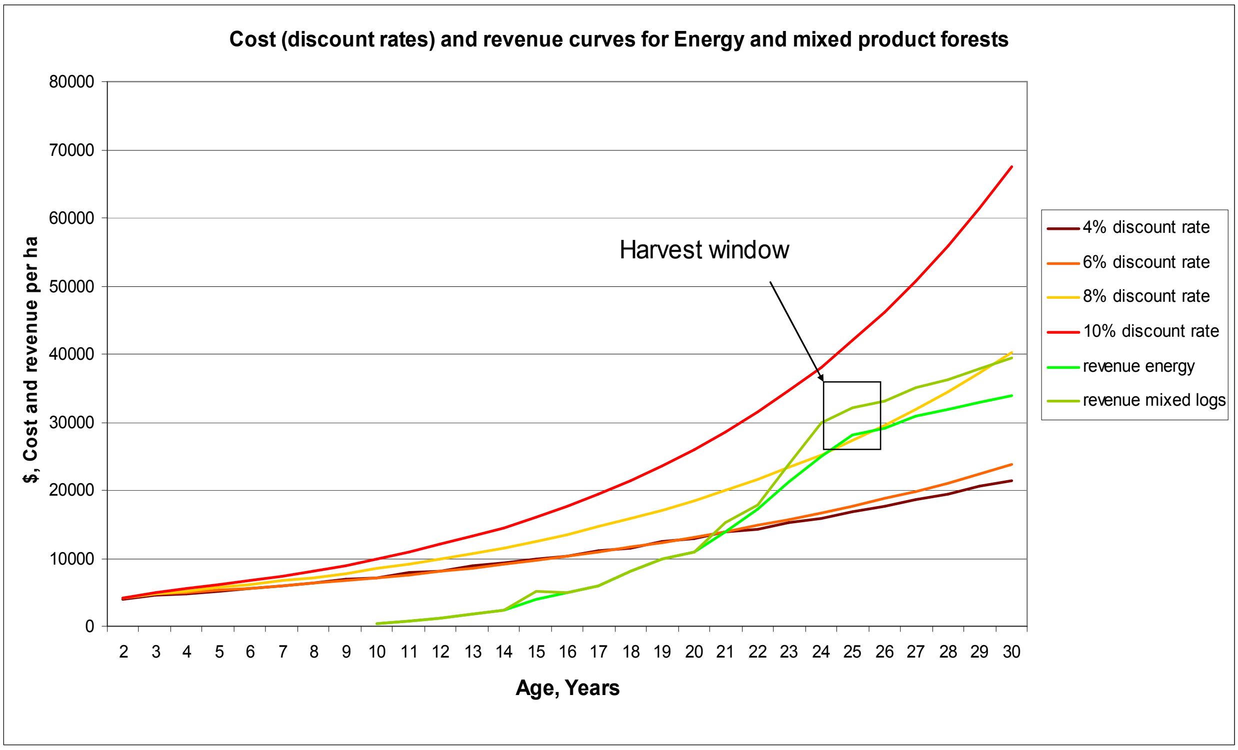


Figure 10: Example marginal cost and revenue analysis

More commonly this might be represented by using land expectation value (LEV). Figures 11 and 12 show indicative LEV from two possible scenarios;

- Figure 11; harvesting as energy logs only (value relative to density), with optimum rotation age being indicated by the peak LEV, as 20 to 21years
- Figure 12; harvesting as mixed products, with 50% sawlogs and 50% energy logs at differing prices, optimum harvesting is shown as 25 years by the peak LEV.

These figures are indicative only, and are highly sensitive to log price assumptions. The unevenness of individual lines is due to price changes which are assumed to take place based on log quality related on age and density (for both sawlogs and energy logs).

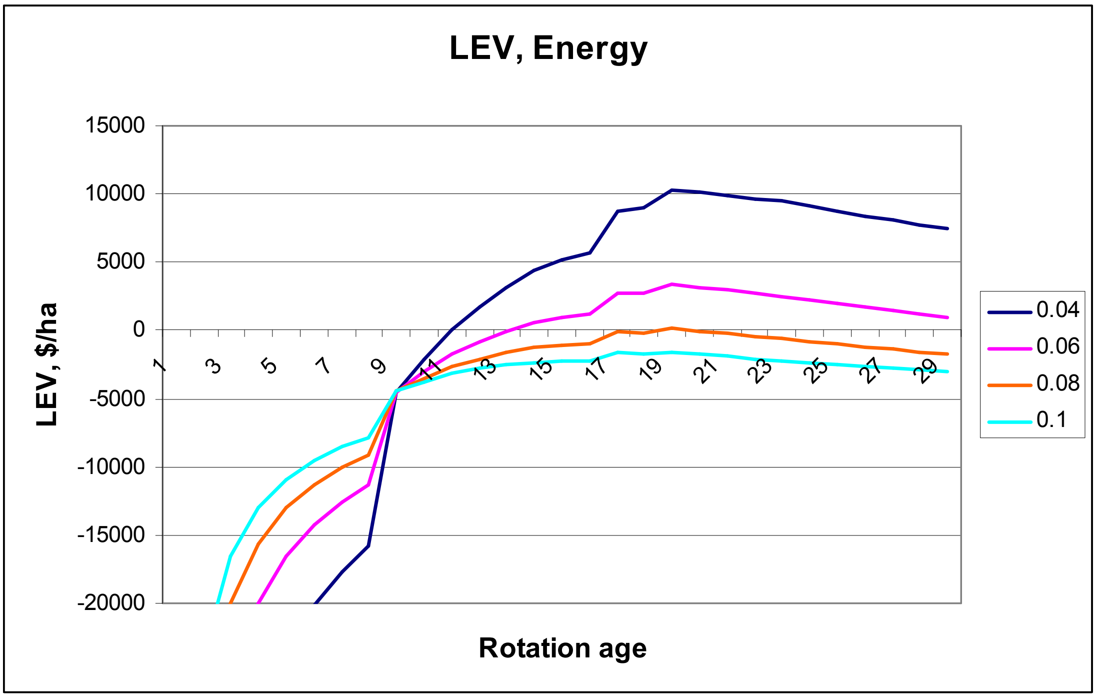


Figure 11 – LEV of crop as energy logs, by discount rate

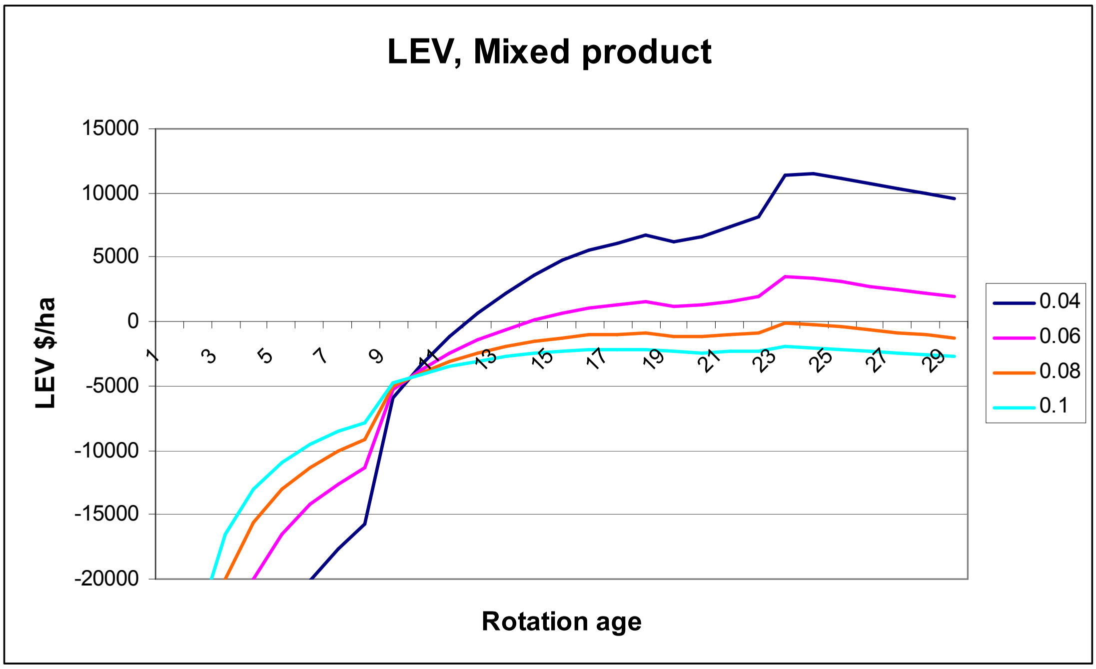


Figure 12 - LEV of crop as mixed saw logs and energy logs, by discount rate

By going to a shorter rotation in the energy only option (Figure 11) the volume at harvest is reduced, but the effect that this has on the area required to grow a particular volume of wood (or energy) is offset by the shorter rotation. The net impact of the reduced volume and shorter rotations would be a reduction in production of approximately 4%.

The mean annual increments (MAI) of stem volume of some alternative species, and their respective rotation lengths are presented in Table 19. The growth rate of the modelled scenarios is greater than any of the alternative species on which data is available, and represents an optimum volume from a biomass production oriented regime. The species is not critical at this level of analysis, but the potential volumes from the growth of a well planned and managed forest estate is. A bioenergy forest estate may contain a variety of species which are selected for site suitability on a case-by-case basis. These species should have similar or better productivity than the scenarios presented here. A concerted research effort on species and molecular biology will yield improvements in tree growth and yield.

Table 19: MAI's of other species trialled in New Zealand (Nicholas *et al*, 2005)

Species	MAI, m3/ha/pa	Rotation, years
Poplar	20	20
Willow (Salix)*	24	3 to 5
Acacia melanoxylon	15	30 to 35
Acacia dealbata	25-30	20 to 25
Eucalyptus nitens	25	12 to 15
Eucalyptus regnans	30	30 to 35
Eucalyptus saligna	30	30 to 35
Eucalyptus fastigata	30	30 to 35
Eucalyptus maidenii	28	15+
Cupressus Macrocarpa	21-22	30 to 40
Redwood	27	25 +
Douglas Fir	18+	40 to 50

* biomass volume

For some of the species with high MAI's (Table 19), the MABI figures would be similar to that for *Pinus radiata* and these species would be suitable candidates for bioenergy from plantation forests on some sites. However, the species with these high yields tend to Eucalyptus, which tend to have greater sensitivity to and growth variation with local site factors – and we do not have New Zealand wide data to model these species at this stage.

The next step was to analyse the area figures and the data developed from the productivity overlay at a regional level and convert this into volumes of biomass that could potentially be produced if the scenario area was harvested at a sustainable rate (1/25th of the area harvested every year). Average productivity and biomass yield figures derived from this analysis are presented in Tables 20 to 23 for area Scenarios 1 to 4 respectively.

Table 20: Area Scenario 1, 0.8 million ha, harvest from 2035 (assumes planting begins 2010)

Region	Odt ha	TRV ha	TEB ha	Odt annum	Gross TEB	TEB annum	TRV annum	LPe, pa millions
Northland	396	944	1,086	106,204	7,269,919	290,797	252,867	25.2
Auckland	391	932	1,072	4,057	277,683	11,107	9,659	0.9
Waikato	384	916	1,053	85,768	5,871,032	234,841	204,210	20.4
Bay of Plenty	384	915	1,052	9,842	673,722	26,949	23,434	2.3
Gisborne	418	997	1,146	96,543	6,608,617	264,345	229,865	22.9
Hawke's Bay	406	968	1,114	188,613	12,911,036	516,441	449,080	44.9
New Plymouth	371	884	1,017	190,736	13,056,366	522,255	454,134	45.4
Manawatu-Wanganui	354	844	971	494,549	33,853,058	1,354,122	1,177,498	117.7
Wellington	372	885	1,018	132,150	9,045,955	361,838	314,642	31.4
Tasman	326	778	895	37,187	2,545,569	101,823	88,542	8.8
Nelson	362	862	991	536	36,695	1,468	1,276	0.1
Marlborough	310	738	849	324,421	22,207,365	888,295	772,430	77.2
West Coast	295	702	808	52,811	3,615,015	144,601	125,740	12.5
Canterbury	265	631	726	3,617,222	247,607,475	9,904,299	8,612,434	861.2
Otago	228	543	625	2,366,289	161,978,138	6,479,126	5,634,022	563.4
Southland	304	726	834	545,511	37,341,517	1,493,661	1,298,835	129.9
Total	**269**	**641**	**738**	**8,252,435**	**564,898,790**	**22,595,952**	**19,648,654**	**1964.2**

*Note: Totals for the first three columns are a weighted average (by area) not a simple average of the data in the table, the figures in this scenario are heavily influenced by large areas with lower productivity in Canterbury and Otago.

Abbreviations:

Odt / ha = Oven dry tonnes per ha
Odt / annum = Oven dry tonnes pa
TRV / ha = Total recoverable log volume/ha
TRV / annum = Total recoverable log volume pa
TEB / ha = Total extractable biomass per ha
TEB / annum = Total extractable biomass pa
Gross TEB = Gross total extractable biomass
LPe = litres of petrol equivalent

For Scenario 1 / 0.8, the total extractable biomass per annum would be 22.5 million m^3 per annum (Table 20) from 2035, with a sustained yield at this level possible, assuming restocking of harvested area. This estimate equates to 1.96 million litres per annum of liquid biofuels (litres of petrol equivalent).

It has been estimated (NZLBI, 2008) that with current technology a liquid biofuels plant needs to be in the order of 800,000 to 1,000,000 tonnes per annum of in-feed biomass, for 80 to 100 million litres of fuel output to be of commercially viable scale. Based on this there is the potential for biofuels plants in Manawatu–Wanganui (1), Canterbury (6 to 8), Otago (4 to 5) and Southland (1)

Table 21: Area Scenario 2, 1.8 million ha, harvest from 2035 (assumes planting begins 2010)

Region	Odt/ ha	TRV/ m^3 / ha	TEB/ m^3 / a	Odt, annum	Gross TEB	TEB annum	TRV annum	LPe, pa millions
Northland	405	966	1,111	395,799	27,093,387	1,083,735	942,379	94.2
Auckland	399	952	1,094	186,218	12,747,071	509,883	443,376	44.3
Waikato	389	926	1,065	1,604,648	109,841,984	4,393,679	3,820,591	382.0
Bay of Plenty	399	950	1,093	163,974	11,224,424	448,977	390,415	39.4
Gisborne	408	971	1,117	2,288,287	156,638,713	6,265,549	5,448,303	544.8
Hawke's Bay	396	943	1,085	3,094,755	211,843,376	8,473,735	7,368,465	736.8
New Plymouth	395	940	1,082	951,691	65,145,548	2,605,822	2,265,932	226.5
Manawatu-Wanganui	368	877	1,008	5,872,833	402,009,369	16,080,375	13,982,935	1,389.2
Wellington	374	890	1,024	2,095,961	143,473,493	5,738,940	4,990,382	499.0
Tasman	334	796	915	298,405	20,426,563	817,063	710,489	71.0
Nelson	363	865	995	41,740	2,857,172	114,287	99,380	9.3
Marlborough	319	760	874	1,182,983	80,977,978	3,239,119	2,816,625	288.1
West Coast	299	712	819	126,443	8,655,301	346,212	301,054	30.1
Canterbury	299	712	819	4,433,909	303,511,644	12,140,466	10,556,927	1055.7
Otago	254	605	696	3,021,623	206,837,311	8,273,492	7,194,341	714.3
Southland	314	748	860	1,096,430	75,053,234	3,002,129	2,610,547	261.0
Tota	**341**	**812**	**934**	**26,855,694**	**1,838,336,196**	**73,533,448**	**63,942,129**	**6,385.70**

In Scenario 2 / 1.8 only Auckland, Bay of Plenty, Nelson and the West Coast do not have sufficient material to supply a liquid fuels plant of viable scale, Tasman is also marginal. Of the four regions where it appears that a biomass liquid fuels plant is not viable in this scenario, two regions are essentially urban areas (Auckland and Nelson) and one (West Coast) has a large area in conservation use. Bay of Plenty already has a large plantation forestry estate. A map of regional boundaries is attached in Appendix 1.

Table 22: Area Scenario 3, 3.3 million ha, harvest from 2035 (assumes planting begins 2010)

Region	Odt ha	TRV ha	TEB ha	Odt annum	Gross TEB	TEB annum	TRV annum	LPe, pa millions
Northland	413	984	1,131	1,121,954	76,800,425	3,072,017	2,671,319	267.1
Auckland	399	951	1,094	422,589	28,927,194	1,157,088	1,006,163	100.6
Waikato	388	924	1,063	4,147,473	283,904,410	11,356,176	9,874,936	987.4
Bay of Plenty	397	945	1,087	453,085	31,014,726	1,240,589	1,078,773	107.8
Gisborne	408	971	1,116	3,993,341	273,353,684	10,934,147	9,507,954	950.7
Hawke's Bay	392	934	1,074	6,158,580	421,569,492	16,862,780	14,663,287	1,466.3
New Plymouth	400	952	1,095	1,401,222	95,917,015	3,836,681	3,336,244	333.6
Manawatu-Wanganui	369	879	1,011	9,472,104	648,388,073	25,935,523	22,552,629	2,252.2
Wellington	374	890	1,024	2,911,457	199,296,136	7,971,845	6,932,040	693.2
Tasman	332	791	910	455,232	31,161,744	1,246,470	1,083,887	108.3
Nelson	364	867	997	49,340	3,377,445	135,098	117,476	11.7
Marlborough	316	753	866	1,520,659	104,092,705	4,163,708	3,620,616	362.0
West Coast	299	711	818	344,342	23,571,006	942,840	819,861	81.9
Canterbury	284	676	777	6,889,057	471,572,371	18,862,895	16,402,517	1,640.2
Otago	253	602	692	4,794,308	328,181,785	13,127,271	11,415,019	1,141.5
Southland	315	750	863	2,115,919	144,839,684	5,793,587	5,037,902	503.7
Total	**341**	**813**	**935**	**46,250,656**	**3,165,967,524**	**126,638,701**	**110,120,610**	**11,011.2**

For Scenarios 2 /1.8 and 3 / 3.3, the total extractable biomass volumes are 73.5 and 126.6 million m^3 per annum (sustained yield) (Tables 21 and 22). The LPe per annum in Scenario 3 / 3.3 is over 11 billion litres. This exceeds the current demand, indicating that this scenario could potentially provide sawlogs as well as fuel, or heat and liquid fuel feedstock. New Zealand liquid fuel demand may exceed 11 billion litres by 2035, depending on demand growth.

Table 23: Area Scenario 4, 4.9 million ha, harvest from 2035 (assumes planting begins 2010)

Region	Odt ha	TRV ha	TEB ha	Odt annum	Gross TEB	TEB annum	TRV annum	LPe, pa millions
Northland	412	980	1,127	3,061,114	209,540,544	8,381,622	7,288,367	728.8
Auckland	399	949	1,092	902,200	61,757,744	2,470,310	2,148,095	214.8
Waikato	388	925	1,063	6,166,913	422,139,886	16,885,595	14,683,126	1,468.3
Bay of Plenty	395	941	1,083	836,804	57,281,206	2,291,248	1,992,390	199.2
Gisborne	407	970	1,115	4,845,213	331,666,351	13,266,654	11,536,221	1153.6
Hawke's Bay	392	934	1,074	7,350,502	503,159,390	20,126,376	17,501,196	1,750.1
New Plymouth	404	961	1,106	1,770,302	121,181,420	4,847,257	4,215,006	421.5
Manawatu-Wanganui	370	880	1,013	10,884,256	745,053,239	29,802,130	25,914,895	2,591.4
Wellington	374	890	1,024	3,567,536	244,206,306	9,768,252	8,494,132	849.4
Tasman	331	788	906	623,640	42,689,673	1,707,587	1,484,858	148.4
Nelson	363	864	994	54,290	3,716,284	148,651	129,262	12.9
Marlborough	301	717	825	2,040,068	139,647,521	5,585,901	4,857,305	485.7
West Coast	299	712	819	472,503	32,343,932	1,293,757	1,125,006	112.5
Canterbury	278	662	761	9,919,441	679,009,336	27,160,373	23,617,716	2,361.7
Otago	254	604	695	6,406,943	438,570,525	17,542,821	15,254,627	1,525.4
Southland	315	749	861	2,700,487	184,854,755	7,394,190	6,429,731	642.9
Total*	**339**	**808**	**929**	**61,602,207**	**4,216,817,741**	**168,672,710**	**146,671,921**	**14,666.1**

In Scenario 4 / 4.9, the total extractable biomass volume is 168.7 million m^3 per annum (Table 23). This is a very ambitious scenario, considering NZ currently harvests 19.3 million m^3 per annum. There is potential for the harvest from existing plantation forests to grow to ~40 million m^3 per annum by 2025, based on the current forest estate and its age class distribution.

Potential impact of molecular biotechnology on tree growth and biomass yield

Christian Walter and Phillip Wilcox

Modern biotechnology techniques such as molecular breeding and genetic engineering are being increasingly used to achieve genetic gain for agricultural crops. For example, one of the most successful crop engineering techniques has developed agricultural plants that are resistant to insects, reducing the application of harmful pesticides and thereby providing both environmental and economic benefits (James, 2008). Similarly, molecular breeding has enabled rapid 'pyramiding' of disease-resistance genes thus increasing productivity and sustainability of important agricultural crops (e.g., Richardson *et al*, 2006).

In plantation forestry, genetic gain has traditionally been achieved by conventional breeding and selection, and today's planted forests show significant genetic gain over those planted using unimproved genotypes. However, compared to agricultural crops, trees are relatively undomesticated, thus further significant improvements can confidently be expected. Molecular techniques such as genetic engineering and molecular breeding can be used to achieve this goal and further accelerate delivery of genetic gain.

Although achieving genetic gains from new biotechnologies has been slow in forest tree species, the following examples of applications are at the research stage and should be available for commercial plantations within a ten year time frame, or potentially faster.

1. Acceleration of carbon fixation and faster accumulation of components that can be converted to bioenergy. This can be achieved via several routes:
    - Molecular breeding can be used to increase carbon fixation. For example, specific genotypes that have enhanced growth rates, or increased density can be identified at seedling stage. These

improvements can increase ability to capture and sequester carbon and are beneficial for commercial products. For example, increased density translates into an increase in carbon capture and also improved raw material for energy and sawn timber.

- Genetic engineering technology could be used to increase root mass and make the roots more resistant to rapid decay. This could increase the above-ground biomass and thereby bioenergy potential, as well as limiting rapid decay of underground masses, which in turn prolongs carbon storage.
- Genetic engineering technology can also be used to modify the biochemical makeup of wood, in particular increasing the amounts per cubic meter of those substances that are required in a bioenergy conversion process. Alternatively, the chemistry can be modified to make the bioconversion process more economic.

2. An example of an indirect benefit is development of trees that resist adverse biotic or abiotic environmental stressors such as pathogens and insects, drought or wind forces. This is an enabling intervention that will improve the conversion of carbon from atmospheric to components that store carbon permanently or for a long time period in the soil or other organic matter. As examples, molecular forestry research worldwide has developed trees that are resistant to pathogens, herbicides and insects, or have modified wood characteristics or growth rates (Wagner *et al,* 2007; Grace *et al,* 2005, Bishop-Hurley *et al,* 2001).

There are many cases where tree growth is limited by adverse conditions such as the presence of weeds, pathogens or insects, or abiotic environmental factors. Further, a situation could arise in New Zealand with the arrival of a serious pest or disease which has a serious negative effect on plantation forest growth. Weed competition is already a problem in New Zealand plantation forests and in particular during the first two to three years of tree crop establishment. The use of improved tree breeds could improve the growth of tree crops on a range of sites, and extend the range of sites on which tree crops are economically viable.

The impacts of using modern biotechnology could be significant. Increasing the average density of wood in a plantation forest by 10% over and above the achievements of traditional breeding is possible and would translate into an additional 10% of carbon fixed. Furthermore, combined improvements of 20% extra growth and 10% higher density will lead to approximately 75% increase in net present value for a standard radiata pine plantation grown for both timber production and carbon sequestration (Turner *et al,* 2008).

The application of molecular technologies could improve the economics and carbon fixation potential of plantation forests. Since these would almost certainly include marginal land, direct competition with the cultivation of food crops can be avoided.

Timelines: Research in both molecular breeding and genetic engineering is reaching a mature stage and direct application to commercial forestry is expected within the next five to ten years. Compliance barriers need to be overcome with regard to the application of genetically engineered trees, however this field is moving fast internationally. To date environmental impact studies world-wide and in New Zealand have found no scientifically substantiated net negative impact of genetically engineered trees on the environment or human health.

Internationally, a range of biotechnology research programmes are driven by carbon sequestration and bioenergy outcomes. This research aims to replace petrochemical use with biomaterials, improve carbon capture and sequestration, and reverse global warming. Furthermore, commercial plantations of genetically modified insect resistant poplar have successfully been established in China. Plantations are expected in Brazil in the near future.

In summary, implications of molecular biotechnology for biofuels production from New Zealand forests in the longer term are:

- improved biomass yield via greater wood density and/or improved growth rate;
- wood composition which allows greater yields of liquid biofuels (more cellulose);
- improved resistance to pathogens and insects which would both reduce management cost and improve crop yield.

For example – *dothistroma pini*, which is arguably the widest spread pathogen affecting New Zealand forestry, costs an estimated $25 million per annum in terms of lost growth ($24 million) and spraying treatment ($1 million). Rough estimates would put this in the order of 1% of the mean annual increment or 1.6 % of current harvest.

Whilst the gains from molecular breeding and genetic engineering have yet to be determined for a New Zealand specific situation, the potential is for gains in the order of 10% from a combination of crop yields and reduced cost.

The yield gain of 6% from higher density wood could reduce growing costs by 5% to 6% and delivered log costs of 2% to 3%.

Production cost estimates

Peter Hall

The costs of biomass (logs and other material) production from the four afforestation scenarios were estimated and are presented in Tables 24 and 25.

Costing assumptions

Land	$3000 per ha	Roading	$5.47 per m^3
Interest	8%	Logging	$38 per m^3
Transport	$0.20 per t/km (75 km)	Establishment	$1425 per ha
Profit margin	6%		

Table 24: Costs to establish, grow, harvest and deliver, by scenario ($/$m^3$), biomass regime

Scenario	Yield, m3 per ha	Growing	Road	Harvest	Transport (75km)	Total
1 / 0.7	640	28.06	5.87	38	15	86.93
2 / 1.8	940	19.10	3.99	38	15	76.10
3 / 3.3	940	19.10	3.99	38	15	76.10
4 / 4.9	908	19.78	4.14	38	15	76.91

Table 25: Costs as a proportion of total delivered cost, by scenario (%), biomass regime

Scenario	Yield, m3 per ha	Growing	Road	Harvest	Transport (75km)	Total
1 / 0.7	640	32	7	44	17	100
2 / 1.8	940	25	5	50	20	100
3 / 3.3	940	25	5	50	20	100
4 / 4.9	908	26	5	49	20	100

The delivered biomass costs for Scenarios 2, 3 and 4 are all very similar, and are lower than that for Scenario 1. This reflects the low productivity land used in Scenario 1. Harvesting and transport make up 61% to 70% of delivered cost and growing costs are 25% to 32%. Growing costs have a greater proportion of the cost when the per ha productivity is lower.

From the section on molecular biotechnology it can be seen that there is further room to improve productivity. If the goals of a 20% growth increase and a 10% gain in wood density were achieved, then in terms of the bioenergy yield, the gain would be in the order of 32%. The impacts of this gain on delivered cost are presented in Tables 26 and 27. The potential increased yields from molecular biology and genetic engineering are also shown.

Table 26: Costs to establish, grow, harvest and deliver, by scenario, ($/$m^3$), improved yields

Scenario	Yield, m3 per ha	Growing	Road	Harvest	Transport (75km)	Total
1 / 0.7	845	21.25	4.44	37	15	77.69
2 / 1.8	1240	14.48	3.03	36	15	68.51
3 / 3.3	1240	14.48	3.03	36	15	68.51
4 / 4.9	1198	14.99	3.13	36	15	68.12

Table 27: Costs as a proportion of total delivered cost, by scenario (%), improved yields

Scenario	Yield, m3 per ha	Growing	Road	Harvest	Transport (75km)	Total
1 / 0.7	845	27	6	48	19	100
2 / 1.8	1240	21	4	53	22	100
3 / 3.3	1240	21	4	53	22	100
4 / 4.9	1198	22	5	53	22	100

The gain in yield has reduced the growing costs ($5 to $7 per m^3) and roading costs by around $1 per m^3. A small reduction in harvest costs has been included to adjust for the greater volume per ha. The 32% gain in crop productivity has resulted in a reduction in growing cost of 24% and in delivered cost of 8% to 9% for Scenarios 2, 3 and 4 and 23% and 10% for Scenario 1.

It is possible (and should be a major research target) to improve both harvesting and transport efficiency. There is significant potential to improve transport efficiency by moving to trucks that are similar to the existing fleet but are slightly longer and permitted to carry heavier loads. An example would be a 4 axle truck and 4 axle trailer being allowed to have a gross combination mass (GCM) of 52 tonnes and a length of 24 metres, as opposed to the current 44 tonnes and 22 metres (NZFOA, 2007). The bulk (6.5 tonnes) of the 8 tonnes increased GCM would be payload (an increase of 18% in the GCM but a 23% increase in payload). It is estimated that this would result in costs being lowered by 15% to 16%. This would reduce transport costs by around $2.25 per tonne (or 2%-3% of total cost per delivered tonne).

It has long been a goal of the forest industry to develop steep terrain harvesting systems that are more productive and cheaper, as high harvesting costs are a significant issue for the New Zealand forest industry. If an increased effort in harvesting research was to yield a 10% reduction in costs, then delivered cost could drop by $3.80 to $4.00 per tonne, a 5% to 6% reduction in delivered cost. The impact of these potential gains in transport and logging cost are presented in Tables 28 and 29. The reduction of harvesting costs will be a significant challenge, but it is essential to improve harvesting productivity to enhance the viability of current forests as well as any future scenario areas.

The impact of improving yield and reducing growing costs as a proportion of delivered costs raises the proportion of delivered costs attributable to harvesting and transport.

Table 28: Costs to establish, grow, harvest and deliver, by scenario, ($/m^3), improved supply chain

Scenario	Yield, m3 per ha	Growing	Road	Harvest	Transport (75km)	Total
1 / 0.7	845	21.25	4.44	34	12.75	72.44
2 / 1.8	1240	14.48	3.03	34	12.75	64.26
3 / 3.3	1240	14.48	3.03	34	12.75	64.26
4 / 4.9	1198	14.99	3.13	34	12.75	64.87

Table 29: Costs as a proportion of total delivered cost, by scenario (%), improved supply chain

Scenario	Yield, m3 per ha	Growing	Road	Harvest	Transport (75km)	Total
1 / 0.7	845	29	6	47	18	100
2 / 1.8	1240	23	5	53	20	100
3 / 3.3	1240	23	5	53	20	100
4 / 4.9	1198	23	5	52	20	100

By taking the potential for gains in growth and in the supply chain it is potentially possible to reduce delivered cost by $12 to $15 per m^3 or, 15% to 17%, from those in the original scenarios.

These scenarios have costs which are typically lower than current costs, due to the high per ha yields from the biomass focussed regimes.

Areas of harvest by harvest type (ground based or hauler) and region are provided in Appendix 2, and a summary is presented in Table 30. This analysis was done to determine the amount of harvesting from steep terrain, the cut-off-point (slope) for the two different harvesting systems was a slope of 20° on an area greater than 5 ha (100 m up slope and 500 m across). This analysis suggests that a greater than anticipated amount of ground-based logging may be possible. This would reduce the logging costs used in the economic analysis significantly (by ~$10 per tonne (25%) approximately).

Table 30: Area and proportion of hauler and ground-based harvesting by scenario

	Hauler		Ground-based	
Scenario	Area, 000's ha	%	Area, 000's ha	%
1 / 0.8	601	72	229	28
2 / 1.8	1403	76	452	24
3 / 3.3	2953	85	521	15
4 / 4.9	4114	84	812	16

Amount of roading (kilometres) required by region is provided in Appendix 3, a summary is provided in Table 31.

Table 31: Estimated amount of roading required to harvest the four scenarios

Scenario	New Road, km
1 / 0.8	14,668
2 / 1.8	38,043
3 / 3.3	31,107
4 / 4.9	39,632

Cost of roading (regional totals) is provided in Appendix 4, a summary is provided in Table 32.

Table 32: Estimated roading cost ($) by region and scenario

Region	Scenario 1 / 0.8	Scenario 2 / 1.8	Scenario 3 / 3.3	Scenario 4 / 4.9
Northland	10,958,500	44,952,500	43,004,000	84,308,500
Auckland	973,500	14,086,000	13,241,500	19,945,000
Waikato	10,858,500	140,592,000	97,124,000	113,339,500
Bay of Plenty	3,170,000	22,743,000	20,743,000	37,740,500
Gisborne	17,403,000	144,021,000	114,814,500	130,085,000
Hawke's Bay	17,647,000	144,685,000	94,925,500	102,238,500
Taranaki	21,130,500	66,120,500	61,421,500	65,741,500
Manawatu-Wanganui	66,857,500	263,419,500	219,074,500	232,248,500
Wellington	25,141,500	103,931,500	90,101,000	95,266,500
Tasman	8,292,000	31,632,500	30,705,500	37,122,500
Nelson	164,000	3,523,000	3,333,500	3,339,000
Marlborough	65,913,500	122,587,500	118,055,500	174,852,500
West Coast	3,995,500	14,366,500	16,909,500	29,083,000
Canterbury	303,515,000	414,651,000	374,811,000	527,327,500
Otago	171,292,500	279,471,500	222,032,500	295,144,000
Southland	61,188,000	112,335,000	98,352,500	126,126,000
NZ Total	**788,500,500**	**1,923,118,000**	**1,618,649,500**	**2,073,908,000**

The cost of building these roads is incorporated in the costs to grow and harvest the forests provided in Tables 24 to 29. They are provided here to show the level of expenditure required. The expenditure would be spread over a period of 20 to 25 years, beginning in approximately 2033, as the roading would not be required at this level of intensity or quality until harvest. Some of this roading would be public road, and some would be private. The split has not been determined as this level of analysis is not possible. These figures are indicative of the level of total investment required.

Summary and interpretation

The four area scenarios developed for large-scale plantation forests for energy represent a range of afforestation levels, from low (0.8 million ha) to high (4.9 million ha). The 0.8 million ha scenario is realistically achievable, the 4.9 million ha scenario would be a very challenging target for a variety of reasons and the biomass produced would potentially exceed the national demand for liquid fuels if it was used solely for that purpose.

These data were required to perform the environmental impacts, land-use competition and economic impact analyses, which are presented in Chapters 2, 3 and 4 respectively.

The land selected was chosen using a set of criteria which focussed on selecting land which is scrub, marginal or low productivity grazing land. Only in the higher area scenarios (3/3.3 and 4/4.9) were the higher value land-use classes included, and this was restricted by slope. This approach was used in order to avoid two issues;

- encroaching on high productivity grazing (e.g. dairy) and arable land
- high land costs.

As can be seen in Tables 4 to 15, the bulk of the land in all four scenarios is coming from sheep, and mixed sheep and beef farming. These are uses that are currently suffering from low returns and high costs, although costs are fluctuating widely due to the volatility in fuel and fertiliser costs, as well as commodity export prices (wool).

This land selection approach pushes the afforestation onto rolling to steep land that is often highly erodable and has high roading and harvesting costs. It was done deliberately, with the basis for this decision being that trees are the only biomass crop which has an established methodology (cable logging) and existing expertise (~45% of NZ's existing harvest comes from steep terrain) for harvesting off steep land. As yet there is no system available for harvesting annual or short rotation crops off land that is over 15^{o} to 18^{o} slope.

The forestry approach allows the use of a marginal land resource to grow trees which in essence is the capture and storage of solar energy. This energy can then be converted into a range of consumer energies as and when required.

The scale of the energy storage associated with each scenario can be looked at in comparison with the national energy demand (740 PJ of primary energy and 560 PJ of consumer energy, where the difference between the two figures is conversion and transmission losses). (Tables 33 and 34).

Table 33: Stored primary energy by scenario

Scenario	*Gross standing biomass volume, 2035	*Biomass Harvest, per annum, post 2035	Gross Primary energy, PJ, in standing volume	Primary energy in annual harvest, PJ	Annual harvest as % of current primary energy consumption
1 / 0.8	283	19.588	2,094	144	19.5
2 / 1.8	828	69.030	6,129	510	69.0
3 / 3.3	1,511	125.983	11,188	932	125.9
4 / 4.9	2,594	178.950	19,200	1,324	178.8

* Millions of tonnes

Table 34: Stored energy increment, PJ per annum (stored solar energy)

Scenario	Stored energy increment, PJ, pa
1 / 0.8	83.76
2 / 1.8	245.16
3 / 3.3	447.52
4 / 4.9	768.00

Given that the woody biomass can be used for a variety of energy end uses, it is useful to consider what proportion of the three consumer energy demands (heat, electricity, liquid fuels) the four scenarios could produce (Table 35), given the following assumptions:

- heat demand 180 PJ, conversion efficiency 85% (biomass to heat)
- liquid fuel demand 245 PJ, conversion efficiency 35% (biomass to liquid fuels)
- electricity demand 145 PJ, conversion efficiency 30% (biomass to electricity).

Table 35: Indicative energy potential of biomass scenarios to meet consumer energy demand (100% to energy)

Scenario	% of heat	and or	% of liquid fuel	and or	% of electricity
1 / 0.8	68%	or	20%	-	-
2 / 1.8	100%	and	42%	or	73%
2 / 1.8	0%	and	72%	-	-
3 / 3.3	100%	and	100%	-	-
4 / 4.9	100%	and	100%	and	85%

* Priority is given to making heat and liquid fuels as these are a more efficient use of the biomass

It would also be useful to consider the idea of multiple (energy and non-energy) end uses. In Table 17 it was suggested that 56% of the crop could be used for sawlogs (typically ~80% from current forest harvest). If this was the case then the volume available for energy would be substantially reduced, but the return to the grower may be enhanced. Table 36 presents this option by scenario.

Table 36: Indicative energy potential of biomass scenarios to meet consumer energy demand (44% to energy, 56% to sawlogs)

Scenario	Bioenergy harvest volume, m³ p. a.	PJ pa from bioenergy harvest	Harvest as % of primary energy	% of heat	and or	% of liquid fuels
1 / 0.8	8.61	63	8.5	30	or	9
2 / 1.8	30.37	224	30.2	100	and	1.4
2 / 1.8	30.37	224	30.2	0	and	32
3 / 3.3	55.43	410	55.4	100	and	27
3 / 3.3	55.43	410	55.4	0	and	58
4 / 4.9	78.73	582	78.6	100	and	53
4 / 4.9	78.73	582	78.6	0	and	83

Obviously there is huge potential for a variety of options for end-use percentages of both sawlog and biomass for energy, and within the biomass, and range of percentages that could go to the three main energy end-uses. The figures presented in Table 35 are provided to give a feel for the possible scale of the contributions. The actual end use would be dictated by the value of the various end uses.

Significance of gains from molecular biology and genetic modification

If we were to assume that a given target for energy production from biomass was set, then GM and molecular biology has the potential to reduce the area of land required to produce the energy required. The gain in efficiency may have a double benefit, not only is it more efficient it its own right, it has less collateral effect on other land uses, and would displace less of the other activity, altering the macro economic impacts.

For example, Scenario 3 / 3.3, which could theoretically produce 100% of New Zealand's current liquid fuel and heat demand from 3.386 million ha. If GM and molecular biology were to increase yields from that which was modelled in our study to a level that was 30% higher, then the area required to grow the biomass to meet the energy demand would be reduced by 1,016 million ha to 2.370 million ha. This would suggest that there is significant value in pursuing productivity gains from this means.

The Otago region contributes significant area to all scenarios (1 / 0.8 = 38%, and 15% to 18% in the other scenarios). This area has some of the lowest productivity (due to low temperatures, low rainfalls and high altitudes) and has some area with no history of forest cover. It is likely that this region would not contribute as much area as the initial analysis has suggested due to its low productivity and potential catchment water yield issues and that subsequently total production from each scenario would be reduced. Some afforestation would occur however, and the amount of land that might not be afforested would only be a proportion of Otago's total area in each scenario.

Other considerations

Biofuels from forestry derived biomass have a higher land-use efficiency in terms of litres per ha (or km per ha) than biofuels from arable crops.

Canola crops in New Zealand could be expected to produce around 1350 litres per ha per annum of biodiesel. It is anticipated that forestry to biodiesel via gasification of wood, followed by Fischer-Tropsch processing to biodiesel would yield the equivalent of 2400 to 2500 litres per ha per annum.

The reason for the difference being that in the canola crop only part of the plant (~30%), the seeds, are used for making fuel. In the case of the forest biomass scenario a large proportion (85%+) of the above ground biomass (mostly the very large stem) is used.

The focus of this study has been on the production of liquid fuels, which are seen as the most vulnerable energy supply, as it is mostly imported and internationally reserves are expected to be diminishing in the period 2020-2030. However, wood is a versatile resource and it can be used as a solid fuel on a small and large scale. The use of torrefaction of wood may enhance its ability to be co-fired with coal and lignite and this is recommended as an area of further research. Torrefaction is also a means of improving energy density and its use may be beneficial in terms of transport efficiency of feedstock for further processing or use as a heat fuel. Wood can also be gasified and the product used in gas-fired applications including heat, electricity generation and as a transport fuel. This versatility underpins the concept of forestry for energy.

Because of its end-use versatility and because of the ability of a hectare of forest to store large volumes of solar energy (captured as wood and conveniently stored in vertical stacks) wood can be seen as an alternative fuel for coal and gas-fired power stations in the longer term. This concept would see the use of wood as an energy store (both green and processed to solid or gas fuels) and thus available for use in base load or fast-start peaking electricity generation.

The question of gas supply in New Zealand beyond 2015 was raised by NIWA in their EnergyScape asset review. The continued large-scale use of gas in New Zealand is dependant on;

- finding /developing new gas fields
- building a gas import facility
- finding an alternative source for gas production (wood).

Conclusions

There is a range of afforestation scenarios that could make a significant contribution to New Zealand's energy supply. Subsequent analysis of the environmental and economic inputs will indicate which scenarios show the most promise.

Good growth and yield rates are possible, with the selected biomass production oriented regime giving yields which are significantly better than those achieved currently, which are focussed on maximising high value logs for solid wood processing. Total production would likely be lower than estimated due to stand gaps and some land area initially selected for afforestation being unsuitable (for example in Otago).

Estimates of delivered biomass costs range from \$76 to \$87 per m^3 for a biomass production oriented regime. Estimates of possible improvements due to increased yield and supply chain efficiency could potentially reduce these costs to ~\$65 to \$72 per m^3. The impact of land prices on total cost can also be significant.

The focus on forestry as a source for biofuels on a large scale is supported by the brief analysis of arable land use and production in Appendix 5, with the area of arable land available being limited by competing demands and high returns from these alternative uses.

National level sustained yield (millions of cubic metres per annum) possible to give long-term bioenergy supply is shown in Table 37.

Table 37: Log and biomass yield by area scenario

Scenario	Total recoverable log volume, m^3 millions	Total recoverable biomass volume, m^3 millions
1 / 0.8	19.6	22.5
2 / 1.8	63.9	73.5
3 / 3.3	110.1	126.6
4 / 4.9	146.6	168.7

The biomass regime gives market options, which mitigates the investment risk as bioenergy is just one option for the end use of the forest. These options include;

- 56 % sawlog and 30% chip
- High volumes of carbon in carbon forest which are not harvested
- Energy end-use options
  - Solid fuel for heat and or cogeneration of heat and power
  - Liquid fuel
  - Feedstock for gas production.

There is also the option to have a mix of these end uses from a given estate.

This chapter (1) outlines what is theoretically possible in terms of forestry biomass production. The next steps in utilising this information are:

- determine the environmental value to New Zealand of these options (Chapter 2)
- determine the land-use competition and impact on agricultural production for each of the forest area scenarios (Chapter 3)
- determine their economic viability (Chapter 4).

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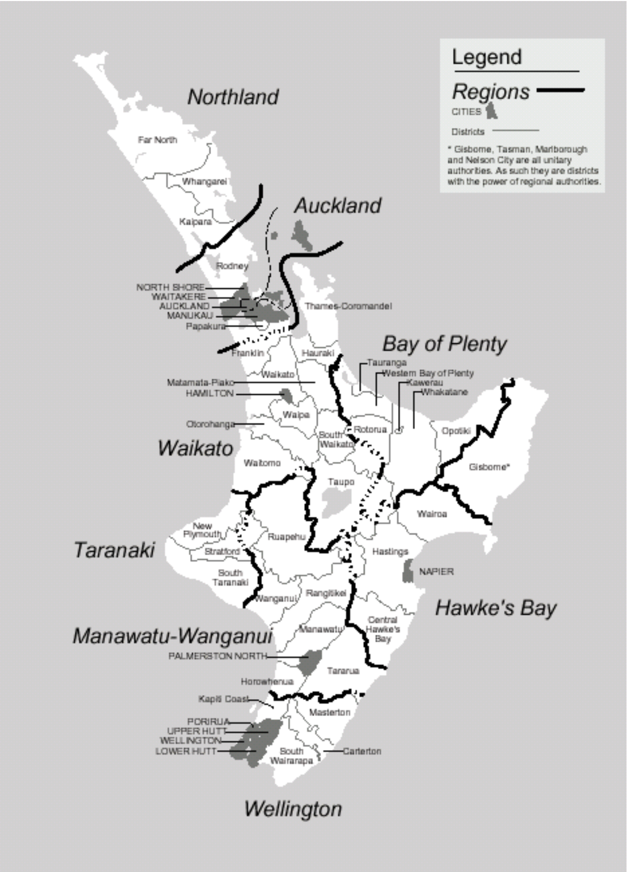
Glossary

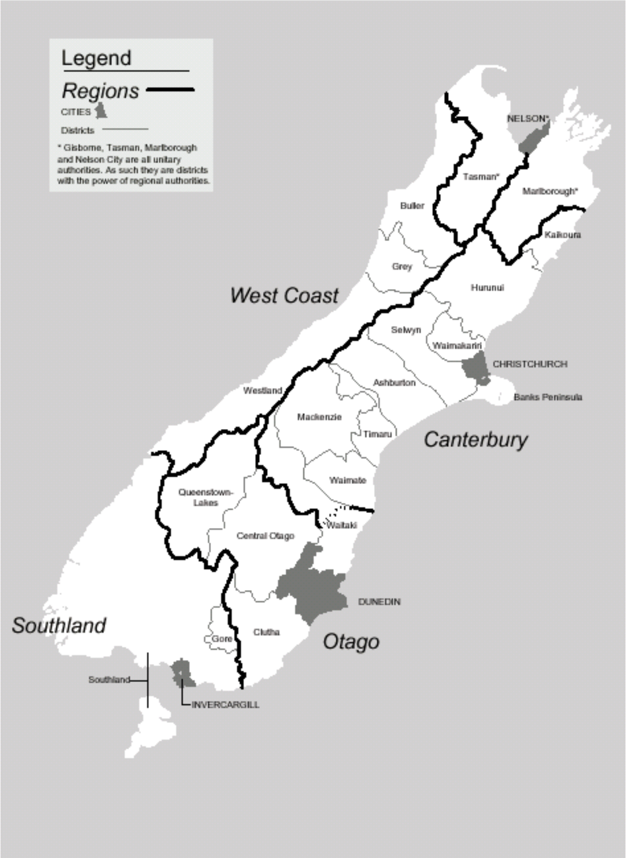
FRST	Foundation for Research Science and Technology
GHG	Greenhouse gas
GIS	Geographic Information System
Gross TEB	Gross total extractable biomass
Ha	Hectare
Odt / ha	Oven dry tonnes per hectare
Odt / annum	Oven dry tonnes per annum
PJ	petajoules = $1*10^{15}$ Joules
TEB / ha	Total extractable biomass per hectare
TEB / annum	Total extractable biomass per annum
TRV / ha	Total recoverable log volume per hectare
TRV / annum	Total recoverable log volume per annum

Appendix 1

Regional Boundary Maps

http://www.stats.govt.nz/analytical-reports/agriculture-statistics-2002/regional-Councils-by-territorial-local-authority.htm





Appendix 2

Area by harvesting class by scenario

	Scenario 1 / 0.8		Scenario 2 / 1.8		Scenario 3 / 3.3		Scenario 4 / 4.9	
Region	**Ground-based**	**Hauler**	**Ground-based**	**Hauler**	**Ground-based**	**Hauler**	**Ground-based**	**Hauler**
Northland	213	405	20,442	1,925	65,631	2,185	180,162	4,232
Auckland	4,290	29	10,132	550	25,762	654	55,189	925
Waikato	402	903	87,063	7,557	257,628	9,217	382,262	11,587
Bay of Plenty	3,802	195	8,447	974	27,343	1,165	50,618	1,873
Gisborne	8,285	1,569	95,740	32,892	203,809	40,822	244,772	50,179
Hawke's Bay	9,545	2,516	159,462	19,662	368,417	23,716	437,037	27,599
Taranaki	24,054	2,414	45,248	9,992	76,144	11,369	96,550	12,175
Manawatu-Wanganui	5,246	8,429	316,911	48,753	583,114	58,069	666,041	63,915
Wellington	61,670	3,031	107,036	21,485	170,234	24,242	208,431	28,195
Tasman	1,737	913	13,950	1,493	26,657	1,700	37,647	9,337
Nelson	11	23	1,140	41,575	1,685	47,549	1,915	1,795
Marlborough	10,543	13,837	43,410	93	72,512	109	104,960	81,617
West Coast	4,169	-	9,595	136,107	28,680	155,417	39,074	117
Canterbury	224,087	95,110	205,217	96,261	452,629	107,706	725,512	287,888
Otago	217,911	78,673	220,374	26,362	447,309	29,820	690,069	189,194
Southland	25,856	21,288	59,297	6,524	145,716	7,541	194,469	41,707
Total	**601,822**	**229,336**	**1,403,466**	**452,202**	**2,953,268**	**521,281**	**4,114,705**	**812,335**

Appendix 3

Kilometres of harvest road required for each scenario

Region	**Scenario 1 / 0.8**	**Scenario 2 / 1.8**	**Scenario 3 / 3.3**	**Scenario 4 / 4.9**
Northland	255	1,144	1,095	2,159
Auckland	25	352	336	512
Waikato	236	3,285	2,239	2,641
Bay of Plenty	57	512	467	832
Gisborne	354	2,943	2,317	2,614
Hawke's Bay	359	3,183	1,999	2,156
Taranaki	395	1,286	1,191	1,280
Manawatu-Wanganui	1,302	5,501	4,490	4,795
Wellington	496	2,181	1,874	1,971
Tasman	158	615	597	741
Nelson	3	60	56	57
Marlborough	1,117	2,155	2,055	2,992
West Coast	117	383	458	780
Canterbury	6,200	8,587	7,695	10,783
Otago	3,636	6,257	4,828	6,306
Southland	1,237	2,428	2,119	2,803
NZ total	**14,668**	**38,043**	**31,107**	**39,632**

Appendix 4

Roading cost by cost class and region

Cost class	1	2	3	4	5	6	7	8	9	
Cost, $/km	$30,000	$35,000	$40,000	$45,000	$55,000	$60,000	$65,000	$70,000	$80,000	
Scenario 1 / 0.8	Cost class									
Region	1	2	3	4	5	6	7	8	9	Total
Northland	594,000	3,832,500	1,532,000	211,500	2,337,500	2,172,000	-	7,000	272,000	10,958,500
Auckland	12,000	427,000	28,000		368,500	138,000	-		-	973,500
Waikato	588,000	1,589,000	2,184,000	252,000	2,678,500	3,336,000	-	119,000	112,000	10,858,500
Bay of Plenty	24,000	-	656,000	-	-	1,914,000	-	-	576,000	3,170,000
Gisborne	72,000	2,201,500	2,684,000	58,500	9,273,000	2,244,000	-	742,000	128,000	17,403,000
Hawke's Bay	147,000	1,788,500	3,784,000	18,000	5,186,500	6,252,000	-	231,000	240,000	17,647,000
Taranaki	342,000	322,000	2,840,000	157,500	2,706,000	14,460,000	-	119,000	184,000	21,130,500
Manawatu-Wanganui	807,000	5,222,000	9,460,000	229,500	18,106,000	31,488,000	-	553,000	992,000	66,857,500
Wellington	237,000	2,194,500	3,712,000	81,000	7,799,000	8,748,000	-	770,000	1,600,000	25,141,500
Tasman	33,000	336,000	2,072,000	22,500	1,215,500	2,814,000	-	735,000	1,064,000	8,292,000
Nelson	-	-	-	-	22,000	102,000	-	-	40,000	164,000
Marlborough	54,000	1,316,000	5,836,000	58,500	1,023,000	37,914,000	-	-	19,712,000	65,913,500
West Coast	234,000	924,000	2,548,000	4,500	11,000	258,000	-	-	16,000	3,995,500
Canterbury	2,382,000	21,682,500	67,264,000	112,500	18,315,000	146,550,000	-	441,000	46,768,000	303,515,000
Otago	807,000	36,046,500	17,140,000	130,500	58,701,500	27,414,000	-	18,277,000	12,776,000	171,292,500
Southland	915,000	6,709,500	12,360,000	40,500	16,874,000	15,084,000	-	6,013,000	3,192,000	61,188,000
NZ Total	**7,248,000**	**84,591,500**	**134,100,000**	**1,377,000**	**144,617,000**	**300,888,000**	**-**	**28,007,000**	**87,672,000**	**788,500,500**

Scenario 2 / 1.8	Cost class									
Region	1	2	3	4	5	6	7	8	9	Total
Northland	4,587,000	21,455,000	5,324,000	958,500	7,755,000	4,434,000	-	7,000	432,000	44,952,500
Auckland	471,000	7,255,500	1,512,000	148,500	3,465,000	1,218,000	-	-	16,000	14,086,000
Waikato	4,365,000	32,564,000	50,128,000	1,836,000	27,263,500	23,508,000	6,500	385,000	536,000	140,592,000
Bay of Plenty	324,000	332,500	14,376,000	18,000	445,500	6,330,000	-	77,000	840,000	22,743,000
Gisborne	1,275,000	21,962,500	18,108,000	535,500	72,072,000	24,630,000	-	4,438,000	1,000,000	144,021,000
Hawke's Bay	2,451,000	27,006,000	42,272,000	189,000	24,354,000	46,626,000	-	651,000	1,136,000	144,685,000
Taranaki	1,200,000	525,000	16,780,000	580,500	4,972,000	41,316,000	-	203,000	544,000	66,120,500
Manawatu-Wanganui	4,917,000	38,853,500	54,168,000	1,444,500	62,573,500	97,758,000	-	1,169,000	2,536,000	263,419,500
Wellington	3,480,000	15,333,500	16,988,000	522,000	32,923,000	30,054,000	-	2,415,000	2,216,000	103,931,500
Tasman	444,000	1,946,000	7,744,000	112,500	2,717,000	14,040,000	-	1,253,000	3,376,000	31,632,500
Nelson	12,000	108,500	304,000	-	137,500	2,130,000	-	7,000	824,000	3,523,000
Marlborough	183,000	6,121,500	13,912,000	67,500	2,997,500	67,242,000	-	-	32,064,000	122,587,500
West Coast	2,226,000	1,725,500	6,956,000	18,000	275,000	2,880,000	-	70,000	216,000	14,366,500
Canterbury	2,829,000	46,634,000	90,472,000	162,000	37,224,000	181,152,000	-	994,000	55,184,000	414,651,000
Otago	2,307,000	79,236,500	43,812,000	306,000	78,298,000	40,026,000	-	21,126,000	14,360,000	279,471,500
Southland	2,226,000	19,246,500	30,924,000	90,000	23,039,500	26,988,000	-			112,335,000
NZ Total	**33,297,000**	**320,306,000**	**413,780,000**	**6,988,500**	**380,512,000**	**610,332,000**	**6,500**	**38,976,000**	**118,920,000**	**923,118,000**

Scenario 3 /3.3	Cost class									
Region	1	2	3	4	5	6	7	8	9	Total
Northland	4,320,000	20,107,500	6,144,000	661,500	6,908,000	4,416,000	-	7,000	440,000	43,004,000
Auckland	501,000	6,989,500	1,712,000	121,500	2,755,500	1,146,000	-	-	16,000	13,241,500
Waikato	3,765,000	18,665,500	33,944,000	1,336,500	20,933,000	17,556,000	-	420,000	504,000	97,124,000
Bay of Plenty	363,000	416,500	12,712,000	18,000	423,500	5,844,000	-	70,000	896,000	20,743,000
Gisborne	984,000	16,033,500	12,780,000	454,500	59,867,500	19,392,000	-	4,319,000	984,000	114,814,500
Hawke's Bay	1,314,000	12,589,500	24,624,000	148,500	18,254,500	35,994,000	-	721,000	1,280,000	94,925,500
Taranaki	1,131,000	780,500	14,576,000	594,000	4,895,000	38,610,000	-	203,000	632,000	61,421,500
Manawatu-Wanganui	5,358,000	23,789,500	43,632,000	1,197,000	54,186,000	87,216,000	-	1,232,000	2,464,000	219,074,500
Wellington	3,423,000	11,403,000	14,432,000	472,500	28,792,500	26,964,000	-	2,422,000	2,192,000	90,101,000
Tasman	384,000	1,855,000	7,640,000	99,000	2,590,500	13,524,000	-	1,253,000	3,360,000	30,705,500
Nelson	12,000	94,500	280,000	-	132,000	2,016,000	-	7,000	792,000	3,333,500
Marlborough	276,000	4,270,000	13,240,000	63,000	2,656,500	65,526,000	-	-	32,024,000	118,055,500
West Coast	2,295,000	2,485,000	8,480,000	22,500	330,000	3,024,000	-	49,000	224,000	16,909,500
Canterbury	2,703,000	34,695,500	78,356,00	148,500	31,669,000	172,404,000	-	987,000	53,848,000	374,811,000
Otago	1,866,000	53,389,000	25,116,000	279,000	70,680,500	36,036,000	-	20,706,000	13,960,000	222,032,500
Southland	2,997,000	14,626,500	26,684,000	76,500	20,443,500	23,856,000	-	6,069,000	3,600,000	98,352,500
NZ Total	**31,692,000**	**222,190,500**	**324,352,000**	**5,692,500**	**325,517,500**	**553,524,000**	**-**	**38,465,000**	**117,216,000**	**1,618,649,500**

Scenario 4 / 4.9	Cost class									
Region	1	2	3	4	5	6	7	8	9	Total
Northland	8,136,000	38,241,000	15,424,000	1,075,500	12,375,000	8,178,000	-	7,000	872,000	84,308,500
Auckland	897,000	10,843,000	2,856,000	139,500	3,195,500	1,998,000	-	-	16,000	19,945,000
Waikato	5,388,000	20,842,500	41,392,000	1,431,000	23,204,500	19,902,000	6,500	469,000	704,000	113,339,500
Bay of Plenty	627,000	756,000	21,228,000	58,500	605,000	11,586,000	-	112,000	2,768,000	37,740,500
Gisborne	1,077,000	17,657,500	13,836,000	468,000	69,052,500	21,864,000	-	4,858,000	1,272,000	130,085,000
Hawke's Bay	1,401,000	13,765,500	26,852,000	153,000	18,656,000	39,102,000	-	805,000	1,504,000	102,238,500
Taranaki	1,200,000	1,004,500	16,032,000	589,500	5,219,500	40,794,000	-	238,000	664,000	65,741,500
Manawatu-Wanganui	6,663,000	26,341,000	46,796,000	1,390,500	56,804,000	90,390,000	-	1,288,000	2,576,000	232,248,500
Wellington	3,603,000	11,637,500	14,588,000	499,500	31,256,500	28,182,000	-	2,940,000	2,560,000	95,266,500
Tasman	654,000	2,702,000	9,528,000	166,500	2,849,000	15,774,000	-	1,449,000	4,000,000	37,122,500
Nelson	24,000	94,500	288,000	-	137,500	2,004,000	-	7,000	784,000	3,339,000
Marlborough	417,000	4,546,500	20,072,000	81,000	2,750,000	90,114,000	-	-	56,872,000	174,852,500
West Coast	3,069,000	5,092,500	13,964,000	27,000	555,500	5,238,000	-	161,000	976,000	29,083,000
Canterbury	3,159,000	42,899,500	115,628,000	135,000	32,406,000	231,330,000	-	1,498,000	100,272,000	527,327,500
Otago	2,487,000	70,633,500	29,588,000	409,500	84,854,000	49,524,000	-	31,304,000	26,344,000	295,144,000
Southland	4,395,000	21,157,500	37,328,000	81,000	23,490,500	27,624,000	-	6,874,000	5,176,000	126,126,000
NZ Total	**43,197,000**	**288,214,500**	**425,400,000**	**6,705,000**	**367,411,000**	**683,604,000**	**6,500**	**52,010,000**	**207,360,000**	**2,073,908,000**

Appendix 5

Arable land – area, current use and implications for large-scale production of biofuels

Peter Hall, Scion, 2008

Introduction

This report is intended to briefly outline the scale of the opportunity to use arable land for biofuels production in New Zealand.

It is acknowledged that some biofuels will be grown on arable land, but in terms of a large-scale bioenergy production system, New Zealand is hampered by its limited areas of arable quality land and the other priority demands on this land.

Methods

Data on land areas has been derived from a number of sources (LCDB2, MAF, Saggar *et al*). This has then been used along with productivity data to give an estimate of the amount of biomass or biofuel that could be produced from this land.

Results

Current New Zealand land area by land-use class (LUC) (Saggar *et al* 2007) shows that New Zealand's land area is ~26,724,500 ha. Of this 11,385,600 ha is unavailable for farming, plantation forestry or other commercial use, as it is either under native forest cover or unsuitable for use. This leaves 15,338,900 ha available for productive purposes. Table 1 shows the categories used to classify the land suitability and how these relate to the LUC class and areas of land within the LUCs.

Table 1: New Zealand land area suitable for different energy crop types

Category	LUC class	Total area (ha)	Total area, excluding slopes >15° (ha)	Description
A	I, II	1 336 900	1 336 900	Highly versatile land. Suitable for cropping or pasture.
B	IIIs, IIIc	1 038 700	1 038 600	Some cropping possible, but with limitations. Also suitable for pasture.
C	IIIe, IIIw, IV	3 675 100	3 331 000	More suitable to pasture. Some cropping in rotation possible.
D	V	180 400	36 700	Unsuitable for cropping. Suitable for pasture.
E	VI	5 432 900	726 100	Unsuitable for cropping. Moderate limitations under perennial pasture.
F	VII, VIII	3 674 900		Unsuitable for cropping or pasture.
Unavailable	Urban areas and areas still under natural landcover	11 385 600		Land not available for farming (e.g. urban, indigenous forest).
All		26 724 500		Total land area

From this table it can be ascertained that there are 2,375,500 ha of land that is suitable for, or potentially useable for cropping. There is a further 3.3 million ha that is possibly useable for cropping, with limitations.

Data from MAF and Landcare Research shows that some of this land is used for arable and other purposes and some is used for grazing (Table 2).

Table 2: Estimates of current use of arable quality lands

Land-use type	Area, ha	% of Categories A and B (2.375 million ha)
Grain crops	166,000	7.0
Orchards and vineyards	62,000	2.6
Vegetables	56,000	2.4
Sub-Total	***284,000***	***12.0***
Dairy	832,000	35.0
Beef	190,000	8.0
Sheep	380,000	16.0
Sheep and Beef	475,000	20.0
Forestry	23,000	1.0
Deer	71,000	3.0
Lifestyle	47,000	2.0
Other*	73,000	3.1
Total	**2,375,000**	**100**

* Includes uses such as horse rearing/grazing

If we are to assume that we do not wish to compete with land that is used for high value intensive grazing (dairying) or staple food production (grains, vegetables), then we cannot consider the use of land currently used for grains, orchards, vegetables and dairy. Furthermore, some of the land used for other purposes (lifestyle) may be difficult to convert back to arable uses. Some of the land used for animal grazing will be required to be kept in grazing land. If half of the grazing land has to stay as grazing, then we are left with an area of 600,000 ha potentially available to grow energy crops.

If all of this land (600 k ha) was used for canola oil production, the yield would be in the order of 700 to 750 million litres of biodiesel, or ~9% of the total liquid fuel demand. However, the Government's sustainability principles, as they relate to biofuels, limits the use of land for biofuel production to 12 out of 24 months, effectively halving the potential production to around 360 million litres or 4% to 5% of liquid fuel demand.

This indicates broadly that the use of arable land to produce biofuels, whilst it can make a useful contribution towards meeting the national liquid fuel demand (8.1 billion litres per annum), will inevitably be limited in its scale. Even if all the high quality arable land was used, with no sustainability principles limiting its use, we would still only be able to grow about 35% of the total fuel demand.

If we were to consider the growing of biomass crops (for example, miscanthus) with yields of 20 to 25 tonnes of dry matter per ha per annum (yet to be proven in New Zealand as no growth trial data is available) and then converting this material into liquid fuels (ethanol), we again run into limitations from land area availability (Table 3).

Table 3: Miscanthus area, yield and % of liquid fuel demand

Area, ha	Yield 10 Odt, billions of litres (ethanol)	% of liquid fuel demand	Yield 20 Odt, billions of litres (ethanol)	% of liquid fuel demand
600,000	1.8	15	3.96	30
1,200,000	3.6	30	7.92	60
2,375,000	7.1	59	15.67	118
3,000,000	9.0	74	19.80	149

Whilst miscanthus has high growth rates and dry matter yield, and may be an option for biomass and liquid fuel production, it is still limited in scale. This is especially so if the Government's sustainability principles (currently specified as applying to oil seed crops) are applied to all forms of biomass for energy from arable land.

Forest suitable land

As a way of comparing the potential scale, we can look at forest suitable land in terms of availability and use. There are 9,288,200 ha of land that is unsuitable for cropping (arable use) but suitable for forestry. Of this 3,674,900 ha is unsuitable for grazing. By any set of criteria, there are millions of hectares that are suitable for forestry use that are currently in scrub, gorse or low-to-moderate productivity grazing. One analysis has estimated that there are 3.37 million ha that could be used for forestry. If the areas were established in forests and harvested sustainably, it would yield sufficient wood to create 6.8 to 7.3 billion litres of liquid fuel, or all of the current demand for petrol and diesel (6.3 billion litres), with some material available to use for other purposes.

Table 4: Earnings by farm type (MAF, 2008)

Farm type	Year	Gross	Farm surplus	Net
Arable	06/07	$2,313.82	$ 487.94	$ 290.42
Grazing beef / sheep	05/06	$ 676.37	$ 195.10	$ 146.40
Dairy	06/07	$4,027.00	$ 995.75	$ 712.30
Kiwi fruit	01/02	$37,673.00	$6,220.00	$4,120.00
Forestry logs	06/07	$2,265.00	$ 561.00	$ 375.00

From the figures in Table 4 it can be seen that forestry to logs competes well with grazing, or even cropping use in terms of dollars per ha. Energy forestry would have to earn at similar levels to traditional log supply for the product to end up in an energy end use. (Discount rate used in MAFs calculations was not available).

Interpretation

There is considerable scope to use more land area for food production (as opposed to animal feed production or grazing).

High quality grazing land for dairy has earnings that are too high for forestry use to compete with.

There is a lot of sheep and beef grazing land and forestry is competitive in terms of earnings from it.

Conclusions

The pursuit of large-scale bioenergy from forestry of low quality lands makes sense in terms of the potential scale and ability to compete for the land on an earnings basis.

References

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Appendix 6

Estimated petrol prices ($NZ/litre, pump), by oil price ($US per barrel) and $NZ vs. $US exchange rate

	Exchange Rate		
Oil Price	**0.5**	**0.6**	**0.7**
40	1.34	1.23	1.15
50	1.51	1.37	1.27
60	1.67	1.50	1.39
70	1.84	1.64	1.51
80	2.00	1.78	1.62
90	2.17	1.92	1.74
100	2.33	2.06	1.86
110	2.50	2.19	1.98
120	2.67	2.33	2.10
130	2.83	2.47	2.21
140	3.00	2.61	2.33
150	3.16	2.75	2.45
160	3.33	2.87	2.57
170	3.49	3.02	2.69
180	3.66	3.16	2.81
190	3.83	3.30	2.91
200	4.00	3.44	3.04

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Chapter 2

Environmental impacts of large-scale forestry for bioenergy

Donna Giltrap[1], Anne-Gaelle Ausseil[1], Jagath Ekanayake[1], Steve M. Pawson[2], Peter Hall[2], Peter Newsome[1], John Dymond[1]

Summary

In this report, we investigated the potential environmental impacts of four scenarios for afforestation for bioenergy production identified in earlier studies as a part of this FRST-funded Bioenergy Options project. The four scenarios were:

- Scenario 1 0.8 million ha of new plantation forest
- Scenario 2 1.9 million ha of new plantation forest
- Scenario 3 3.5 million ha of new plantation forest
- Scenario 4 4.9 million ha of new plantation forest

These bioenergy scenarios result in substantial reductions in greenhouse gas (GHG) emissions both by reducing fossil fuel use in transport and by removing land from agricultural production. The combined impacts of these two factors result in emissions reductions of 5, 15, 29 and 37 Mt CO_2e/y from 2035 onwards for scenarios 1-4 respectively. This corresponds to approximately 6%, 20%, 37% and 48% of New Zealand's total GHG emissions in 2006.

Once the plantation forests are fully established and for as long as they remain sustainably harvested, the bioenergy forests will store carbon. This stored carbon is equivalent to an additional 208, 647, 1183 and 2034 net Mt CO_2e removed from the atmosphere for scenarios 1–4.

The new plantations were planted on low-productivity pasture and scrubland. Removing land from pastoral grazing has several additional environmental benefits. Total erosion would be reduced by 1.1%, 8.0% 16.6% and 20.2% for scenarios 1 to 4 respectively. These erosion reductions are particularly significant in the central and lower North Island regions for scenarios 2–4.

Reduction in pastoral farming can potentially reduce nutrient leaching into waterways. Unlike erosion, nutrient leaching tends to be a bigger problem on more intensive farms. In the long term N-leaching from afforestation of grazed pastures could be reduced by 0.3%, 3.4%, 8.4% and 12% in scenarios 1–4. However, leaching rates can remain high for many years if the soil already contains a large amount of surplus N.

The impacts of afforestation on biodiversity are largely positive. There could be a risk of spreading wilding pines or other weeds in some regions. Some areas currently in scrub might revert to native forest if left undisturbed; in which case planting exotic forest would not produce a long-term biodiversity benefit. Afforestation of land that has never historically been forested (e.g., native grasslands in Otago) is not desirable from a biodiversity perspective.

The impacts of afforestation on water availability are likely to be the biggest issue. Planting forests results in less water being available for other purposes. In particular, Canterbury and Otago already have high levels of water allocation (mainly for irrigation) and large areas targeted for afforestation in all scenarios. Therefore, even in scenario 1 there could be water availability issues in these regions. Impact on water availability needs to be assessed at catchment scale to determine the impacts on specific rivers and aquifers.

Introduction

By international standards, New Zealand has a high rate of renewable electricity generation. However, when it comes to transport, New Zealand is almost completely dependent on fossil fuels. One of the goals of the New Zealand Energy Strategy is to halve per capita greenhouse gas emissions from transport by 2040 (MED 2007). While there is some scope to reduce transport emissions by improving the efficiency of the transport fleet and/or reducing demand there are currently few renewable options commercially available for transport fuel.

One possible future source of renewable transport fuels is biofuels produced from purpose grown forests. Hall and Jack (2008) identified land potentially available for afforestation for energy forests. It was found that New Zealand's current liquid fuel consumption could be produced from 42% of the low to medium productivity land. Scenarios were developed based on different degrees of land conversion.

Hall *et al.* (in prep.) established four forest establishment scenarios to provide a bioenergy resource:

- Scenario 1 0.8 million ha of new plantation forest
- Scenario 2 1.9 million ha of new plantation forest
- Scenario 3 3.5 million ha of new plantation forest
- Scenario 4 4.9 million ha of new plantation forest

Appendix 1 contains maps showing the energy forest areas in each of these scenarios. These scenarios involve major changes in land use; targeted land areas for conversion are currently in low productivity livestock farming or exotic scrub. Changes in land use on this scale will have major environmental and economic impacts. In this report we shall look at the potential environment consequences. The economic impacts will be assessed elsewhere.

Afforestation can have both positive and negative environmental consequences. As much of the afforested land area is currently in pastoral production, many of the positive environmental consequences will be due to reduced levels of pastoral production. Table 1 shows the percentage reduction in livestock numbers expected under each scenario.

Table 1: Percentage reduction in livestock numbers in each scenario

Animal	Scenario 1 (0.8 Mha)	Scenario 2 (1.9 Mha)	Scenario 3 (3.5 Mha)	Scenario 4 (4.9 Mha)
Beef Cattle	3.0%	15.0%	33.3%	46.8%
Dairy Cattle	0.1%	0.8%	2.0%	3.5%
Deer	2.0%	11.1%	14.9%	27.2%
Sheep	2.8%	15.1%	32.1%	42.0%

Dairy farming tends to occur on the more productive land, so these scenarios have little impact on total dairy production. However, in the most extreme scenario, beef and sheep production are reduced by over 40%.

Major environmental concerns for New Zealander's include water pollution, other pollution and climate change (MfE 2007). In this report we examine the effects of afforestation on greenhouse gas emissions, carbon sequestration, nitrate leaching, erosion/sedimentation, water availability, and biodiversity. Two of these chapters impact on climate change while another two have relevance for water quality. In most cases afforestation produces positive environmental impacts.

However, afforestation tends to reduce water availability and could have some negative (as well as positive) impacts on biodiversity.

The environmental impacts of plantation forestry have largely been determined from studies of current *Pinus radiata* forests where the primary product is timber. Different species and management practices that might be adopted to optimise energy production could alter the results.

These analyses have been performed as first-order static comparisons between the current farming systems and the bioenergy forest systems, assuming no other land-use change. No attempt has been made to account for changes that might occur in response to the scenario (e.g., the removal of some land from agricultural production might lead to intensification of remaining farms or to land clearance for agriculture in other countries). Similarly we have not attempted to model the impact on downstream processes (e.g., closure of meat processing plants due to reduced animal production).

This study does not include the impacts of the biofuel production system. Previous studies (Hall & Jack 2008) have looked at the life-cycle energy return on energy investment and greenhouse gas emissions of bioenergy production from purpose grown forests. Similar life-cycle assessments could be performed for other environmental aspects.

Agricultural Greenhouse Gas Emissions

Anne-Gaëlle Ausseil, Donna Giltrap

Pastoral agriculture produces a significant amount of New Zealand's total greenhouse gas emissions. The gases methane (CH_4) and nitrous oxide (N_2O) are the major greenhouse gases produced by agriculture. In this section we calculated the changes in greenhouse gas emissions resulting from the land use changes occurring in each of the bioenergy scenarios. Beef, dairy, deer and sheep were the grazing animals considered. The spatial distribution of these animals was found using data from the Land Use New Zealand database (LUNZ) and the Land Resource Inventory (LRI). The process used to calculate the spatial distribution of animals is described in Appendix 2.

Figure 1 illustrates the process used to calculate the greenhouse gas emissions. We used the IPCC methodologies currently used for the National Inventory Report (MfE 2008) to calculate N_2O and CH_4 emissions. These methods involve using average "emission factors" that are applied to the number of animals or the amount of synthetic fertiliser used. In reality, agricultural greenhouse gas emissions are highly complex and depend upon a number of factors such as animal type and age, feed quality and quantity, climate and soil conditions, and other management practices.

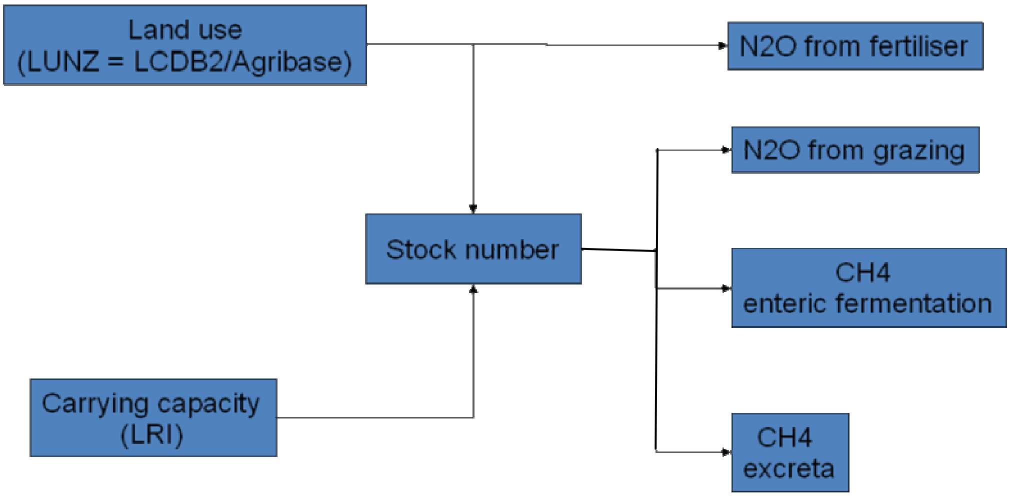

Figure 1: Data used in greenhouse gas emissions calculations

Greenhouse gas emissions are frequently quoted in terms of mass of carbon dioxide equivalent (CO_2e). That is, the mass of CO_2 that would produce the same amount of radiative forcing (warming) over a 100-year time frame. In this chapter we use the following conversion factors as recommended by the UNFCCC[1]:

- 1 kg CH_4 = 21 kg CO_2e
- 1 kg N_2O = 310 kg CO_2e

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[1] http://unfccc.int/ghg_data/items/3825.php

The bioenergy scenarios involved converting some low-productivity pastoral land into forestry. The reduction in grazed animal numbers led to a reduction in agricultural greenhouse gas emissions (but at a cost of reduced animal production). Table 1 shows the reduction in total animal numbers for each of the scenarios.

In addition to the change in annual greenhouse gas emissions resulting from reduced animal numbers there will also be changes in the total carbon stored in soil and biomass. This change is a one-off benefit that lasts only as long as the change in land use (although it takes years for the carbon stocks to reach their new equilibrium). The changes in carbon stocks under each of the bioenergy scenarios are considered in Section 3.

Methane (CH_4)

CH_4 is a by-product of the ruminant digestive system. The amount of CH_4 emitted depends upon the type and age of the animal as well as the quantity and quality of food consumed. Table 2 shows the emission factors per animal for enteric CH_4 production. These emission factors take into account the average population structure, productivity and feed intake of New Zealand animals. However, there is significant variation between animals of the same species and therefore the emission factor has a high degree of uncertainty.

Table 2: Annual per capita enteric CH_4 emissions for New Zealand animals in 2006 (MfE 2008)

Species	CH_4 emission (kg animal^{-1} y^{-1})	CO_2e (kg animal^{-1} y^{-1})
Beef Cattle	58.0	1,218.0
Dairy Cattle	79.4	1,667.4
Deer	22.2	466.2
Sheep	11.0	231.0

There is also methane produced from manure management systems. Table 3 shows the annual CH_4 emitted per animal based on the animal production model.

Table 3: Annual CH_4 emission from animal waste on pastures (MfE 2008)

Species	CH_4 emission (kg animal^{-1} y^{-1})	CO_2e (kg animal^{-1} y^{-1})
Beef Cattle	0.705	14.805
Dairy Cattle	3.400	71.400
Deer	0.203	4.263
Sheep	0.109	2.289

In addition, soil has some capacity to oxidise CH_4 to CO_2 via microbial action. However, this effect has not been included in our overall estimate of greenhouse gas emission changes due to the limited number of studies that have been published to date. Saggar et al. (2008) reviewed measurements of soil CH_4 uptake in New Zealand and found that for sheep-grazed pasture the annual CH_4 consumption was 0.8–1.3 kg CH_4 ha^{-1}, while for pine forest the annual uptake was 5.6–8.5 kg CH_4 ha^{-1}. This suggests switching from sheep-grazed pasture to pine forest could potentially produce an additional reduction of CH_4 by increased soil consumption. However, Tate et al. (2006) found that forest soil CH_4 oxidation was reduced following harvest so the mean annual CH_4 consumption over the planting-harvest cycle would need to be considered.

Table 4 shows the avoided agricultural CH_4 emissions for the bioenergy scenarios.

Table 4: Current CH_4 emissions from enteric fermentation and manure in farms switching from pasture to forestry

Region	**Scenario 1 (0.8 Mha)**		**Scenario 2 (1.9 Mha)**		**Scenario 3 (3.5 Mha)**		**Scenario 4 (4.9 Mha)**	
	Total CH_4 (tCH_4/y)	**Total CH_4 (tCO_2e/y)**	**Total CH_4 (tCH_4/y)**	**Total CH_4 (t CO_2e/y)**	**Total CH_4 (t CH_4/y)**	**Total CH_4 (t CO_2e/y)**	**Total CH_4 (t CH_4/y)**	**Total CH_4 (t CO_2e/y)**
Northland	335	7037	936	19 662	3970	83 371	11 335	238 035
Auckland	12	245	404	8493	1130	23 729	2767	58 110
Waikato	508	10 677	7867	165 211	27 531	578 156	41 805	877 911
Bay of Plenty	37	783	706	14 821	2426	50 953	5434	114 107
Gisborne	588	12 358	11 690	245 491	25 114	527 394	29 825	626 332
Hawke's Bay	1117	23 449	17 348	364 299	43 673	917 137	52 388	1 100 151
Taranaki	928	19 478	3928	82 491	7316	153 630	9503	199 553
Manawatu-Wanganui	2702	56 732	29 738	624 506	57 770	1 213 160	67 515	1 417 824
Wellington	630	13 225	8532	179 170	15 757	330 891	19 513	409 769
North Island Total	**6856**	**143 986**	**81 150**	**1 704 144**	**184 687**	**3 878 421**	**240 085**	**5 041 792**
West Coast	275	5765	23	487	158	24 324	1700	35 706
Canterbury	7961	167 184	12 828	269 379	22 206	466 324	36 214	760 496
Otago	7269	152 639	10 219	214 594	19 475	408 982	31 365	658 665
Southland	1883	39 552	4555	95 646	9592	201 429	14 631	307 260
Tasman	194	4084	1007	21 156	1955	41 064	3041	63 858
Nelson	1	15	81	1708	140	2939	164	3439
Marlborough	966	20 284	3518	73 879	4730	99 327	6289	132 075
South Island Total	**18 549**	**389 523**	**32 231**	**676 850**	**59 257**	**1 244 389**	**93 405**	**1 961 498**
Total New Zealand	**25 405**	**533 509**	**113 381**	**2 380 994**	**243 943**	**5 122 810**	**333 490**	**7 003 290**

Nitrous oxide (N_2O)

Nitrous oxide is produced by microbial processes in agricultural soils. In New Zealand's grazed pasture systems nitrogen is added to the soils in the form of fertiliser and animal excreta[2]. This added nitrogen, in the form of ammonium (NH_4^+) or nitrate (NO_3^-), is processed by soil microbes and N_2O is a by-product of these processes.

The actual amount of N_2O produced in a given system depends on many interacting factors such as soil properties, weather conditions and farm management practices. However, for the National Inventory New Zealand uses a simplified calculation based on "average" emission factors. Figures 2(a) and (b) illustrate this methodology. Both the direct emission of N_2O and the indirect emissions of downstream processes on leached nitrate and volatilised ammonia are calculated. Note that for dairy cattle the national inventory report assumes that 5% of the nitrogen excreted is treated in anaerobic lagoons. However, as there was very little dairy land in the scenarios considered we treated the nitrogen excreted as if it was all applied directly to pasture.

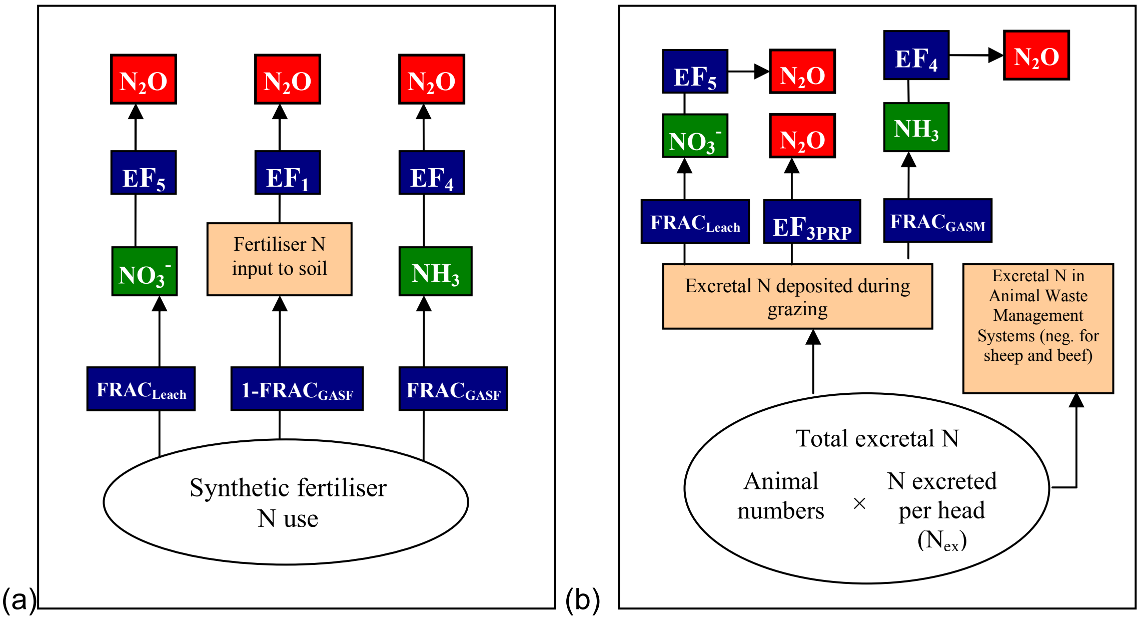

Figure 2: Methodology used to calculate N_2O emissions from (a) fertiliser addition and (b) excretal N in the New Zealand inventory.

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[2] There is also nitrogen fixation from legumes in the pasture but this is assumed to eventually form part of the N in the animal excreta.

Table 5 gives the New Zealand specific emission factors used to calculate N_2O emissions.

Table 5: New Zealand emission factors (MfE 2008)

Factor	Value	Units
EF_1	0.01	kg N_2O-N/kg N
EF_{3PRP}	0.01	kg N_2O-N/kg N
EF_4	0.01	kg N_2O-N/kg N
EF_5	0.025	kg N_2O-N/kg N
$FRAC_{Leach}$	0.07	kg leached N/kg N
$FRAC_{GASF}$	0.1	kg volatilised N/kg N
$FRAC_{GASM}$	0.2	kg volatilised N/kg N
N_{ex} (non-dairy cattle, 2006)	74.98	kg N/head/year
N_{ex} (dairy cattle, 2006)	116.59	kg N/head/year
N_{ex} (deer, 2006)	29.48	kg N/head/year
N_{ex} (sheep, 2006)	15.12	kg N/head/year

The N_2O emissions from animal excreta are easy to calculate once the number of animals is known. The emissions from synthetic fertiliser N are more difficult. Although data on fertiliser use are collected at the national and regional level such information is not available on a spatial basis. In these bioenergy scenarios it is the more marginal pasture lands that will be converted to forests. These pastures are likely to use less than the average amount of fertiliser per hectare. We used the following guidelines as a reasonable approximation of fertiliser N inputs into sheep and beef systems (Surinder Saggar, pers. com.):

Stocking rate < 12 stock units/ha	No applied fertiliser N
Stocking rate 12–18 stock units/ha	15 kg N/ha
Stocking rate >18 stock units/ha	30 kg N/ha

A stock unit is a “ewe equivalent”. We used the following stock unit values:

- 1 Beef Cattle = 5.3 su
- 1 Dairy Cattle = 6.65 su
- 1 Deer = 1.9 su
- 1 Sheep = 1 su

Table 6 shows the calculated regional N_2O emissions from fertiliser N and animal excreta in the land that could switch to energy forestry in the bioenergy scenarios.

Table 6. N_2O emissions from agricultural soils in farms switching from pasture to forestry (includes direct and indirect emissions)

Region	Scenario 1 (0.8 Mha)				Scenario 2 (1.9 Mha)				Scenario 3 (3.5 Mha)				Scenario 4 (4.9 Mha)			
	Fert. N (t N)	Animal N (t N)	Total N_2O (tN_2O/y)	Total N_2O (tCO_2e/y)	Fert. N (t N)	Animal N (t N)	Total N_2O (tN_2O/y)	Total N_2O ($t\ CO_2e/y$)	Fert. N (t N)	Animal N (t N)	Total N_2O (tN_2O/y)	Total N_2O ($tCO_2e\ /y$)	Fert. N (t N)	Animal N (t N)	Total N_2O (tN_2O/y)	Total N_2O ($t\ CO_2e/y$)
Northland	2	436	9	2937	11	1226	27	8274	91	5163	113	35 102	562	14 757	329	102 061
Auckland	0	15	0	101	4	530	12	3573	8	1476	32	9932	134	3620	81	25 015
Waikato	17	673	15	4606	313	10 495	233	72 091	1298	36 631	815	252 786	2131	55 658	1242	385 003
Bay of Plenty	2	49	1	338	54	935	21	6577	243	3219	74	22 952	428	7191	163	50 617
Gisborne	0	776	17	5200	19	15 451	334	103 605	38	33 238	719	222 853	40	39 274	849	263 064
Hawke's Bay	2	1485	32	9955	69	23 060	500	154 857	198	58 054	1258	389 994	257	69 638	1509	467 923
Taranaki	4	1234	27	8289	44	5217	114	35 200	130	9734	213	65 949	246	12 648	278	86 127
Manawatu-Wanganui	4	3599	78	24 130	268	39 622	861	266 929	489	77 007	1673	518 608	725	90 012	1958	607 071
Wellington	2	839	18	5633	9	11 368	246	76 198	14	21 050	455	141 077	30	26 072	564	174 809
North Island Total	**33**	**9107**	**197**	**61 188**	**792**	**107 905**	**2346**	**727 303**	**2509**	**245 571**	**5352**	**1 659 253**	**4553**	**318 870**	**6973**	**2 161 691**
West Coast	4	360	8	2435	0	31	1	208	6	1532	33	10 298	23	2249	49	15 194
Canterbury	7	10 641	230	71 318	11	17 142	371	114 883	42	29 702	643	199 192	46	48 420	1047	324 587
Otago	0	9736	210	65 215	4	13 703	296	91 811	9	26 116	564	174 981	22	42 110	910	282 187
Southland	1	2525	55	16 921	9	6111	132	40 986	26	12 903	279	86 577	78	19 667	426	132 181
Tasman	0	259	6	1733	0	1340	29	8977	2	2601	56	17 433	11	4035	87	27 088
Nelson	0	1	0	6	0	108	2	725	0	188	4	1261	0	219	5	1470
Marlborough	0	1287	28	8622	1	4689	101	31 411	2	6306	136	42 247	2	8375	181	56 108
South Island Total	**13**	**24 809**	**536**	**166 250**	**26**	**43 123**	**932**	**289 000**	**88**	**79 348**	**1716**	**531 989**	**182**	**125 074**	**2706**	**838 817**
Total New Zealand	**46**	**33 916**	**734**	**227,438**	**818**	**151 028**	**3278**	**1 016 303**	**2597**	**324 919**	**7069**	**2 191 241**	**4695**	**443 944**	**9679**	**3 000 508**

Summary

The greenhouse gas emissions from farms that could switch to bioenergy production were calculated using the methodology currently used to compile New Zealand's national greenhouse gas inventory. This methodology uses average New Zealand emission factors and does not take into account regional or management factors that may affect emissions. In addition, if other mitigation technologies (e.g., nitrification inhibitors) to reduce greenhouse gas emissions from pastoral farming are discovered and adopted, then the avoided emissions in these scenarios would be reduced.

Table 7 shows the combined effect of avoided N_2O and CH_4 emissions. Note that this analysis has considered only the direct effects of land use change on greenhouse gas emissions. There could be other second-order effects as the proposed land changes cause changes in other parts of the economy (e.g., less meat processing and fertiliser manufacture). However, we have not attempted to account for these effects on greenhouse gas emissions.

In 2006 New Zealand's total greenhouse gas emissions (before LULUCF[3]) were 77 868 kt CO_2e with the agricultural sector accounting for 37 668 kt CO_2e (MfE 2008). The proposed land-use change scenarios would make a significant reduction in agricultural greenhouse gas emissions by converting land from pastoral production to forestry. The four scenarios correspond to reductions in agricultural greenhouse gas emissions of 2, 9, 19, and 27% respectively. In terms of New Zealand's total emissions these correspond to reductions of 1, 4, 9 and 13%.

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[3] Land use, land-use change and forestry.

Table 7: Summary of changes in greenhouse gas emissions due to land-use change

Region	Scenario 1 (0.8 Mha)			Scenario 2 (1.9 Mha)			Scenario 3 (3.5 Mha)			Scenario 4 (4.9 Mha)		
	N_2O (tonnes CO_2e/y)	CH_4 (tonnes CO_2e/y)	Total (tonnes CO_2e/y)	N_2O (tonnes CO_2e/y)	CH_4 (tonnes CO_2e/y)	Total (tonnes CO_2e/y)	N_2O (tonnes CO_2e/y)	CH_4 (tonnes CO_2e/y)	Total (tonnes CO_2e/y)	N_2O (tonnes CO_2e/y)	CH_4 (tonnes CO_2e/y)	Total (tonnes CO_2e/y)
Northland	2937	7037	9974	8274	19 662	27 935	35 102	83 371	118 473	102 061	238 035	340 096
Auckland	101	245	346	3573	8493	12 067	9932	23 729	33 661	25 015	58 110	83 125
Waikato	4606	10 677	15 282	72 091	165 211	237 301	252 786	578 156	830 942	385 003	877 911	1 262 914
Bay of Plenty	338	783	1122	6577	14 821	21 398	22 952	50 953	73 905	50 617	114 107	164 724
Gisborne	5200	12 358	17 558	103 605	245 491	349 096	222 853	527 394	750 247	263 064	626 332	889 396
Hawke's Bay	9955	23 449	33 404	154 857	364 299	519 156	389 994	917 137	1 307 131	467 923	1 100 151	1 568 074
Taranaki	8289	19 478	27 767	35 200	82 491	117 691	65 949	153 630	219 579	86 127	199 553	285 681
Manawatu-Wanganui	24 130	56 732	80 863	266 929	624 506	891 435	518 608	1 213 160	1 731 767	607 071	1 417 824	2 024 895
Wellington	5633	13 225	18 858	76 198	179 170	255 368	141 077	330 891	471 969	174 809	409 769	584 578
North Island Total	**61 188**	**143 986**	**205 174**	**727 303**	**1 704 144**	**2 431 447**	**1 659 253**	**3 878 421**	**5 537 674**	**2 161 691**	**5 041 792**	**7 203 483**
West Coast	2435	5765	8200	208	487	695	10 298	24 324	34 622	15 194	35 706	50 900
Canterbury	71 318	167 184	238 502	114 883	269 379	384 262	199 192	466 324	665 515	324 587	760 496	1 085 084
Otago	65 215	152 639	217 854	91 811	214 594	306 404	174 981	408 982	583 964	282 187	658 665	940 852
Southland	16 921	39 552	56 473	40 986	95 646	136 632	86 577	201 429	288 005	132 181	307 260	439 441
Tasman	1733	4084	5818	8977	21 156	30 134	17 433	41 064	58 497	27 088	63 858	90 946
Nelson	6	15	21	725	1708	2433	1261	2939	4201	1470	3439	4910
Marlborough	8622	20 284	28 906	31 411	73 879	105 290	42 247	99 327	141 574	56 108	132 075	188 183
South Island Total	**166 250**	**389 523**	**555 773**	**289 000**	**676 850**	**965 850**	**531 989**	**1 244 389**	**1 776 378**	**838 817**	**1 961 498**	**2 800 315**
Total New Zealand	**227 438**	**533 509**	**760 948**	**1 016 303**	**2 380 994**	**3 397 297**	**2 191 241**	**5 122 810**	**7 314 052**	**3 000 508**	**7 003 290**	**10 003 798**

Carbon Storage

Peter Hall - Scion

One of the consequences of establishing a large-scale forest resource, even if it is for energy end-use and will be harvested and consumed, is that carbon is absorbed as the forest expands in area and the trees grow. The carbon in an energy forest should be regarded as being in stock. In the scenarios being considered here, a planting programme is implemented over a period of 20, 25, or 30 years depending on the scale of the new forest area. The goal is to establish a large forest estate that can then be harvested at a sustainable rate. In any scenario, in any year, only a proportion (around 1/25th) of the area of established forest would be harvested. Hence the rest is in stock, and has an age class distribution that reflects the planting programme. It is assumed here that establishment is carried out evenly over the establishment period, and that harvesting is done on a sustained yield basis.

The carbon held in stock is increased over that which was in place when the planting programme began. If the harvest of the forest is held to sustainable levels this increase in carbon stock is permanent. The area of the increase in forest holding carbon in stock is equivalent to 24 years of the 25 years of establishment (one year's planting has been harvested and will be restocked in the next year). The amount of carbon and CO_2 equivalent held in the forest can be calculated using the mean annual increment (MAI), and the age class distribution of the forest.

In addition to the increases in carbon stock, converting land from grazed pasture to forestry removes a source of agricultural greenhouse gas emissions. If the biofuel is substituted for fossil fuels it also reduces the emissions from fossil fuel combustion.

Afforestation scenarios

In this study we investigate four forest establishment scenarios, to provide a bioenergy resource. The details of these scenarios are presented in Table 8. The MAIs presented are a national average derived from the area weighted regional yields presented in Tables 19–22 in section 1 of Hall et al. (2008). They are higher than currently derived from plantation forests, but it should be remembered that the figures are for:

- net stocked area (assumes all scenario area is 100% stocked with no stand gaps)
- biomass, which includes bark, branches, needles and felling breakage, not just merchantable logs
- a regime that is intended to grow large volumes of biomass rather than large diameter logs for solid wood processing.

Table 8: Establishment scenario assumptions

Scenario name	Total Area, Hectares	Establishment period, Years & (ha per annum)	Rotation length, years	Mean Annual Increment, m^3/ha/pa	Yield, m^3/ ha of Harvest	Total annual harvest, millions, m^3
1	765 181	20 (38 259)	25	25.6	640	19.58
2	1 855 669	25 (74 266)	25	37.2	930	69.03
3	3 386 648	25 (135 465)	25	37.2	930	125.98
4	4 927 040	30 (164 234)	25	36.3	908	178.95

Maps of these scenarios are presented in Appendix 1.

The MAI and yield are averages for each scenario, derived from a detailed productivity analysis provided in Scions report on the land-use change and site productivity of these scenarios (Palmer et al 2008).

Methods

The area, age class distribution, volume and yield figures were used to estimate the carbon being stored in the forest as they developed over the establishment period. Once the forested area for each scenario was fully established, the figures were then adjusted down by one year's harvest, to allow for the fact that each year, one age class (the 25-year-old trees) were harvested, and then replanted. The volume of the woody biomass was adjusted up from the harvested volume by a factor of 15% to allow for the branches, stump and non-merchantable logs within the stand. This figure is not precise and will vary with stand, site and regime but was considered to be a conservative but realistic estimate. The harvested volume was derived from the data modelled in the land use/forest productivity section of this report.

The CO_2 equivalence of the woody biomass was calculated using:

Woody Biomass	Oven dry tonnes	Carbon	CO_2	CO_2 equivalent
$1m^3$	x 0.420	x 0.5	x 3.67	= 0.77 t

The carbon stock figures based on this equation are a conservative estimate, and are presented to give an indicative level of potential carbon stock for each scenario. The oven dry tonnes in a cubic metre of wood will vary from site to site, and by species, with many hardwood species being more dense (e.g., *Eucalyptus nitens* 520 kg/m^3 and *Eucalyptus fastigata* 500 kg/m^3).

In addition to the carbon stored in living biomass, there is also carbon stored in the soil and in forest litter. In order to account for the net change in atmospheric CO_2 it is necessary to consider the change in carbon across all pools. Guo and Gifford (2002) performed a meta-analysis on published soil carbon changes with land use and found that soil carbon stocks declined when pasture was converted to plantation forestry. This effect was significant for coniferous, but not for broadleaf forests. However, some of this “lost” carbon may in fact be stored in the litter layer. In this study we omit the changes in soil and litter carbon as the carbon stored in living biomass represents the largest carbon pool.

Assuming afforestation takes place on grazing land, then some GHG emissions from agricultural lands will be displaced by planting forests. These emission reductions may not occur immediately, as it is still possible to graze some animals during the early stages of forest establishment. As the forest is established over time an increasing area that had grazing use is moved into forest cover. Table 9 shows the displaced emissions per hectare, per annum and total emissions displaced per annum for each scenario using the data from Table 7. The displaced emission rates vary for the different scenarios as the proportions of the different land use types displaced varies.

Table 9: Displaced emissions due to land use change

Scenario	Emissions per ha ($t\ CO_2e/ha/y$)	Total emissions displaced, 2035 ($t\ CO_2e/y$)
1	0.99	760 948
2	1.83	3 397 297
3	2.16	7 314 052
4	2.03	10 004 026

Results

Carbon stocks and displaced emissions

The carbon stocks of the afforestation scenarios and the displaced greenhouse gas emissions in CO_2 equivalents are presented in Figures 3, 4, 5 and 6. Tables of the data are presented in Appendix 3.

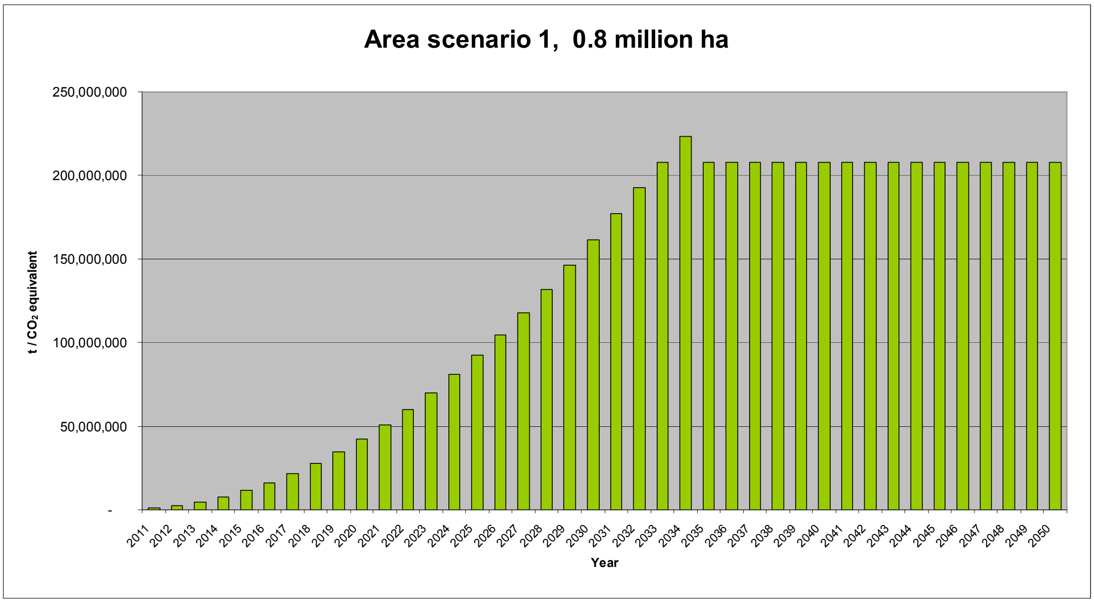

Figure 3: CO_2 equivalent of carbon stock increase for forest area Scenario 1

For Scenario 1, the net gain in carbon stock in 2050 versus 2005 was 207.8 million tonnes of CO_2 equivalent (Figure 3). Potential displaced emissions were 0.8 million tonnes of CO_2 equivalent per annum by 2035 (Figure 7).

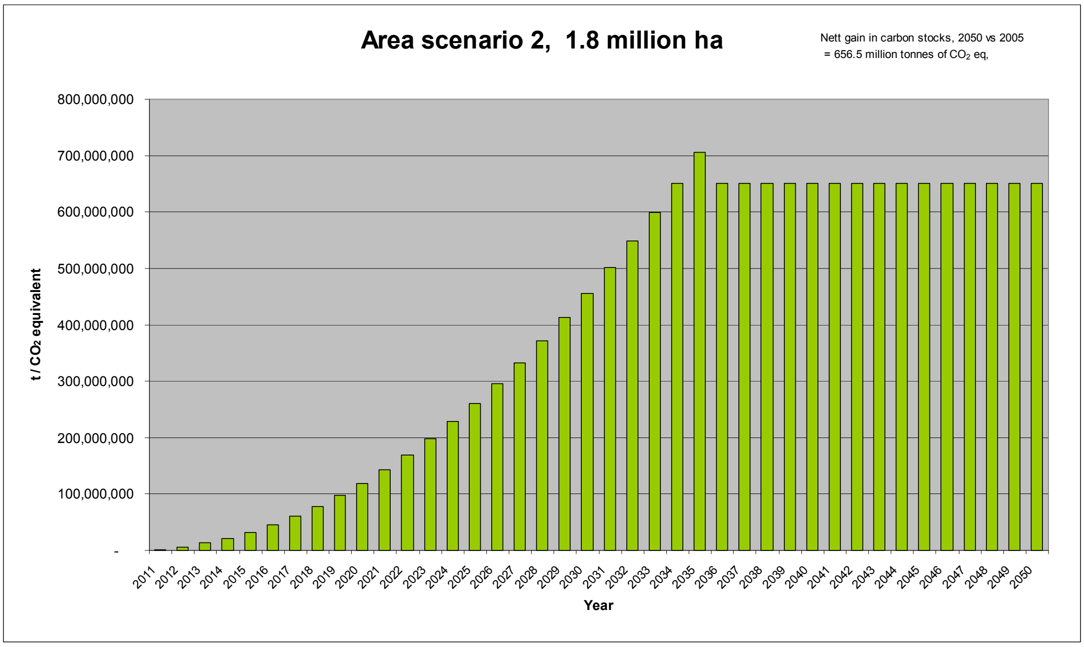

Figure 4: CO_2 equivalent of carbon stock increase for forest area Scenario 2

For Scenario 2 the net gain in carbon stock, in 2050 versus 2005, was 651.1 million tonnes of CO_2 equivalent (Figure 4). Potential displaced emissions were 3.4 million tonnes of CO_2 equivalent per annum by 2035 (Figure 7).

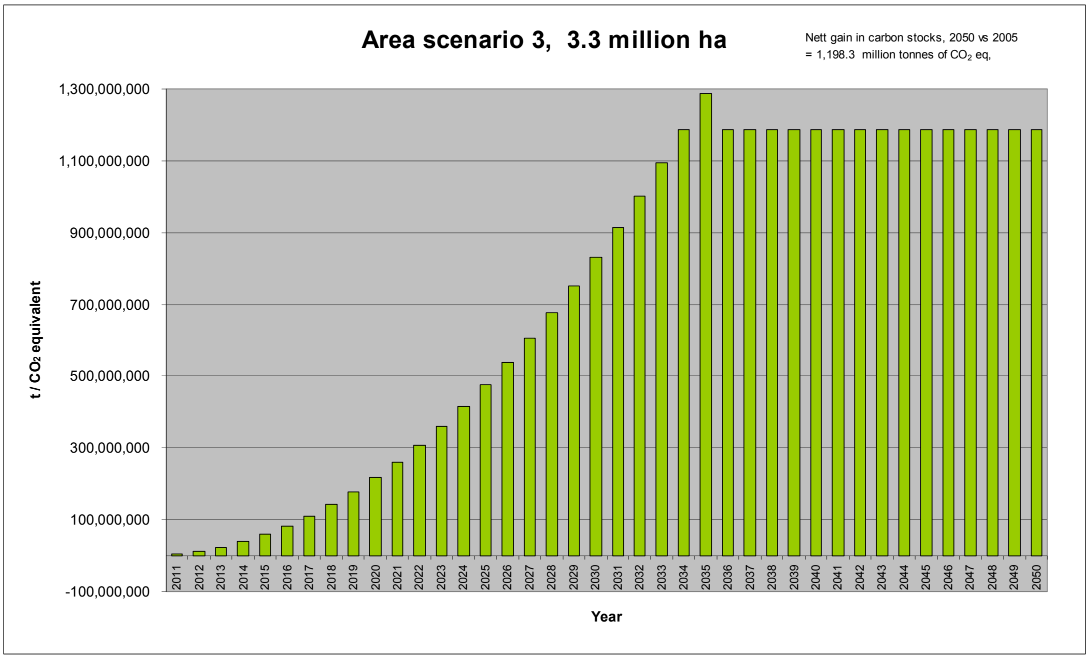

Figure 5: CO_2 equivalent of carbon stock increase for forest area Scenario 3

For Scenario 3 the net gain in carbon stock, in 2050 versus 2005, was 1188.5 million tonnes of CO_2 equivalent (Figure 5). Potential displaced emissions were 7.3 million tonnes of CO_2 equivalent per annum by 2035 (Figure 7).

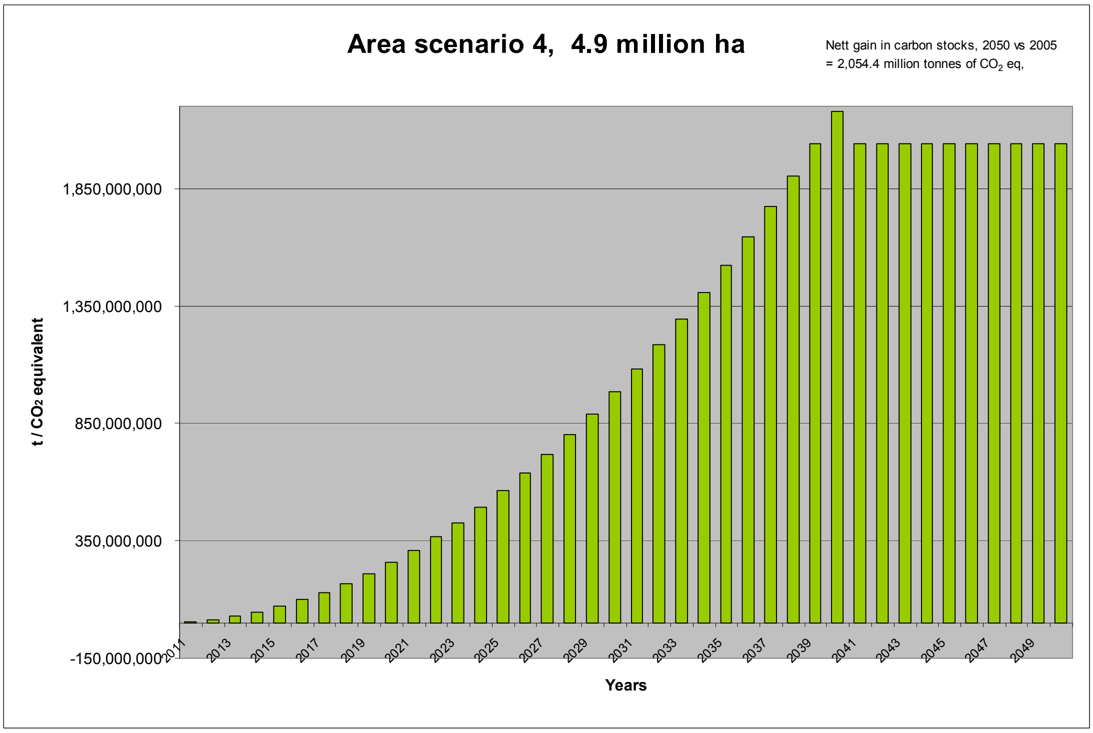

Figure 6: CO_2 equivalent of carbon stock increase for forest area Scenario 4

For Scenario 4 the net gain in carbon stocks, in 2050 versus 2005, was 2039.7 million tonnes of CO_2 equivalent (Figure 6). Potential displaced emissions were 10.0 million tonnes of CO_2 equivalent per annum by 2035 (Figure 7).

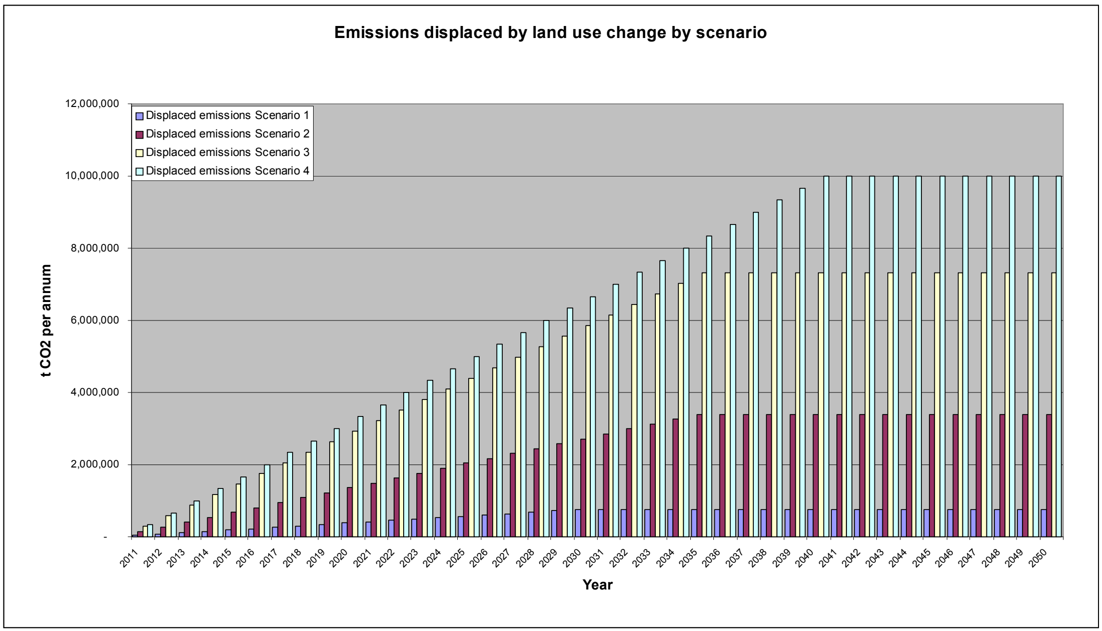

Figure 7: Emissions displaced by land use change, by scenario over time.

The agricultural emissions that are displaced by converting to forestry from grazing use are somewhat off-set by the loss of scrub cover on some of the land area. In scenarios 2, 3, and 4 there are areas of land (Table 10) that were under gorse, broom and other exotic scrub species.

When these are removed to create a forest the average loss of carbon stock is 29 t CO$_2$ equivalent per hectare.

Table 10: Carbon stock losses due to scrub area loss by scenario

Scenario	Scrub area, ha, converted	Years	Scrub area per annum (average)	tCO$_2$ equivalent per annum	tCO$_2$ Equivalent Total
1	0	20	0	0	0
2	153 673	25	647	178 263	4 456 575
3	171 641	25	6866	199 103	4 977 589
4	198 077	30	6602	191 474	5 744 233

Reduction in transport emissions

The intended use of the forest is for bioenergy, principally liquid biofuels. As the liquid biofuel is produced from a renewable source, the GHG emissions of using the fuel are substantially reduced, with reductions estimated to be 80% (Sandilands *et al.* 2008) when the full lifecycle of the fuels are compared.

For the sustained yield volume that would be expected from these scenarios the future amount of GHG emissions potentially displaced can be calculated, assuming that fossil sourced petrol is being displaced (Table 11). These reductions are not achieved until after 2035, as the forest is assumed to take 25 years from establishment (which begins in 2010) to mature.

Table 11: Estimated reductions in transport GHG emissions (millions tonnes / CO2 equivalent per annum) for sustainable levels of liquid biofuel production for each area scenario

Scenario	Avoided transport emissions 2035 onwards (Mt CO$_2$e/y)
1	4.26
2	12.10
3	29.90
4	27.29

These reductions are significant and would make a large contribution towards getting New Zealand's future GHG emissions down to 1990 levels, especially at the larger scale afforestation scenarios. The GHG emissions reductions from displaced agricultural activity and displaced petrol used are added together in Table 12.

Table 12: Combined emissions reductions, displaced agricultural activity and displaced petrol (millions tonnes /CO2 equivalent per annum)

Scenario	Total avoided emissions 2035 onwards (Mt CO_2e/y)
1	5.02
2	15.49
3	29.21
4	37.29

Conclusions

All the afforestation scenarios provide increased carbon stocks. The two mid-range scenarios (2 and 3) increase carbon stocks by 650 million tonnes and 1188 million tonnes respectively (Appendix 3). At the lower scale of planting scenario 1 increases CO_2 equivalent stocks by 207 million tonnes and at the higher end scenario 4 increases CO_2 equivalent stocks by 2039 million tonnes.

These two mid-range scenarios might also provide reductions in agricultural GHG emissions of around 3.3 and 7.3 million tonnes of CO_2 equivalent per annum, and transport GHG emissions of 12.1 and 21.9 million tonnes of CO_2 equivalent per annum.

New Zealand's net GHG emissions in 1990 were 41.299 million tonnes of CO_2 equivalent and in 2006 were 54.951 million tonnes (MED 2008), an increase of 13.655 million tonnes of CO_2 equivalent. The increase in carbon stocks is substantial. For example, the increase in carbon stocks for Scenario 2 is 651 million tonnes of CO_2 equivalent (about 11 years of net emissions) or 47 years of the 1990–2006 difference in net emissions.

The various scenarios have differing rates of forest establishment, and varying growth rates. These can be used to determine the increase in carbon stock on an annual basis. The mean CO_2 equivalent stock increases over the first 25 years are:

- Scenario 1 8.3 million tonnes per annum
- Scenario 2 26.0 million tonnes per annum
- Scenario 3 47.5 million tonnes per annum
- Scenario 4 67.9 million tonnes per annum

Afforestation of marginal farmland, with bioenergy as the end use of a sustained yield harvest could give substantial benefits in terms of increased carbon stocks and GHG emissions reductions.

Water Quality

Donna Giltrap, Peter Newsome - Landcare Research

In recent years the impact of agriculture on water quality has increased due to increased stocking rates and use of nitrogen fertilisers (MfE 2007). As a result of this intensification, higher levels of nutrients, sediment and animal effluent make their way into New Zealand's waterways. In this section we shall focus on the effects of the proposed bioenergy scenarios on nitrogen leaching. Sedimentation is covered in Section 5. Animal effluent in waterways and phosphorous leaching can also affect water quality. Both of these impacts are likely to be reduced by reducing the area of grazing land, but we have not quantified these effects.

Grazed pastures receive nitrogen (N) both from synthetic fertilisers and animal excreta. This nitrogen aids plant growth, but in heavy rainfall surplus nitrogen can leach through the soil (mainly in the form of nitrate) or run-off the soil surface into waterways.

Leached N degrades water quality by encouraging algal blooms. In addition, high nitrate levels in drinking water poses a health risk for infants. According to MfE (2007), 5% of the 1000 monitored groundwaters had nitrate levels deemed unsafe for infants to drink.

The regional N leaching rates for farmed areas were estimated using AgResearch's OVERSEER® nutrient model. For each region two scenarios were run, one for flat/rolling land and one for hill country using typical soil and climate data. Stocking rates and production values were taken from MAF farm monitoring reports (MAF 2006). It was assumed that all the farmland in the bioenergy scenarios was equivalent to sheep and beef farming in terms of N-leaching (Table 1 shows that even in the high scenarios there was only a small reduction in dairy numbers). However, leaching rates for dairying were calculated in order to compare the scenarios with the present situation. The fertiliser N application rates given in section 2 were used for the sheep and beef farms, while dairying was assumed to use 150 kg N/ha/y of urea fertiliser. Table 13 shows the estimated regional N-leaching rates from sheep and beef farms. Flat/rolling land was defined as land with slope ≤15° and hill country as land of slope > 15°.

Table 13: Regional N-leaching and runoff from sheep and beef and dairy farms based on MAF monitoring farms

Region	N-leaching and runoff (kg N/ha)		
	Flat/Rolling Sheep and Beef	Hill Sheep and Beef	Flat/Rolling Dairy
Northland	11	12	30
Auckland	12	12	31
Waikato	15	15	32
Bay of Plenty	16	15	47
Gisborne	10	10	36
Hawke's Bay	9	9	32
Taranaki	10	14	32
Manawatu-Wanganui	9	8	27
Wellington	7	9	34
West Coast	15	7	48
Canterbury	8	6	30
Otago	6	5	25
Southland	7	7	31
Tasman	9	7	45
Nelson	9	6	33
Marlborough	7	5	44

It should be noted that OVERSEER® predicts long-term average N-losses and that the actual N-leached in any given year will vary depending upon rainfall. The leaching and run-off predicted by OVERSEER® was not only sensitive to the total stocking rate, but to the proportion of the stocking units that were sheep rather than beef. For some regions there was up to 75% difference in the leaching rate predicted using the same number of beef stock units compared to sheep, so there is a high degree of uncertainty in these N-leaching figures. The values in Table 13 were calculated using the sheep/beef ratios in Appendix 2.

For each scenario the amount of pasture land on flat and hill country was calculated from the LCDB2 and LENZ databases. The areas were then scaled so that total number of stock units in the region implied by the stocking rates used in OVERSEER® matched the regional animal numbers calculated in Appendix 2.

Table 14 shows the mean annual N-leached/ha for the targeted pasture areas in each scenario. It should be noted that these mean leaching rates are substantially lower than those calculated using the MAF Monitoring Farm data (see Table 13) as the targeted grazed areas tend to have lower stocking rates. However, it should be noted that the average N-leached from pastures tends to increase from scenario 1 to scenario 4 as higher productivity land is included in the higher scenarios. Also the targeted North Island pastures tend to have higher leaching rates than the South Island.

Table 14: Regional land area and average N-leaching rates for bioenergy scenarios

Region	Scenario 1 (0.8 Mha)*				Scenario 2 (1.9 Mha)*				Scenario 3 (3.5 Mha)*				Scenario 4 (4.9 Mha)*			
	Flat pasture (ha)	Hill pasture (ha)	Scrub (ha)	Average pasture N-leaching (kg N/ha/y)	Flat pasture (ha)	Hill pasture (ha)	Scrub (ha)	Average pasture N-leaching (kg N/ha/y)	Flat pasture (ha)	Hill pasture (ha)	Scrub (ha)	Average pasture N-leaching (kg N/ha/y)	Flat pasture (ha)	Hill pasture (ha)	Scrub (ha)	Average pasture N-leaching (kg N/ha/y)
Northland	6223	0	0	5.3	15 509	0	3402	5.8	61 045	0	4893	6.3	156 416	-	6292	7.1
Auckland	238	0	0	5.2	8317	0	759	5.1	24 860	0	992	4.8	48 261	0	1165	6.1
Waikato	5421	3	0	9.8	71 373	1,75	7456	11.1	249 627	1912	11 329	11.3	354 080	2468	11 451	12.1
Bay of Plenty	250	189	0	10.0	5633	586	1212	12.4	24 196	716	2036	10.7	41 225	1422	2516	14.0
Gisborne	4789	132	0	12.1	109 326	2587	3056	10.6	234 176	3343	3512	10.7	270 117	3866	3591	11.0
Hawke's Bay	11 099	347	0	7.7	149 481	7602	4061	8.7	372 008	11 632	5192	8.9	421 860	11 389	5524	9.5
Taranaki	12 529	0	0	6.4	48 220	4	2352	7.1	83 123	4	2740	7.6	95 132	4	2814	8.6
Manawatu-Wanganui	34 305	238	0	5.3	326 061	1027	10 348	6.1	618 046	1808	17 768	6.3	683 412	1814	13 753	6.6
Wellington	8011	528	0	4.6	101 894	1593	18 828	5.1	169 579	1733	20 979	5.6	200 531	1814	21 425	5.9
North Island total	**82 865**	**1437**	**0**	**6.4**	**835 813**	**14 974**	**51 474**	**7.6**	**1 836 660**	**21 147**	**69 440**	**8.1**	**2 271 034**	**22 776**	**68 531**	**8.7**
West Coast	4315	54	0	6.9	290	116	10 019	5.7	17 804	317	10 018	6.9	22 010	396	12 795	8.2
Canterbury	314 679	25 233	0	1.5	308 652	25 092	35 545	2.4	522 847	46 145	35 547	2.5	832 518	84 714	45 864	2.5
Otago	298 698	16 500	0	0.9	294 743	12 876	34 338	1.3	492 914	23 450	34 353	1.5	697 552	100 968	44 593	1.6
Southland	27 760	22 583	0	2.1	57 922	28 232	6476	2.8	129 472	38 790	6478	2.9	164 195	50 356	9000	3.4
Tasman	614	2188	0	6.7	3340	10 583	7647	6.9	9228	16 374	7644	6.8	13 092	18 982	8760	8.3
Nelson	2	27	0	2.3	76	1075	1644	6.5	270	1408	1641	7.2	339	1426	1665	7.9
Marlborough	12 528	13 507	0	2.4	51 745	32 891	6530	2.5	74 615	36 496	6531	2.5	113 727	53 312	6872	2.2
South Island total	**658 596**	**80 092**	**0**	**1.4**	**716 768**	**110 865**	**102 198**	**2.2**	**1 247 149**	**162 978**	**102 212**	**2.3**	**1 843 434**	**310 154**	**129 548**	**2.4**
Total New Zealand	**741 461**	**81 528**	**0**	**1.9**	**1 552 581**	**125 838**	**153 673**	**4.9**	**3 083 809**	**184 126**	**171 652**	**5.6**	**4 114 468**	**332 930**	**198 079**	**5.7**

* Land classed as "unspecified" not included

N-leaching changes with land use in the order pristine forest < plantation forest < grazed pasture, so it would be expected that afforestation of pasture land would lead to a reduction in N-leaching to reduced N inputs. However, if the soil already has a large surplus of N, then leaching rates may remain high for a long time after afforestation. For example, Parfitt et al. (2003a) examined leaching from three adjacent sites, one of which had remained in indigenous forest, one that had been converted to pasture 70 years ago and one that had been converted to pasture for 50 years and then been converted to *Pinus radiata* for 22 years. The N-leaching rates measured were: 5 kg N/ha/y for the indigenous forest (close to the rate of N deposition); 20 kg N/ha/y for the pasture; and 21 kg N/ha/y for the pine forest. Recent calculations done for the Lake Taupo variation show the average N loss from pine over two rotations at this site was 8 kg N/ha/y (R. Parfitt, pers. comm.). For the Lake Taupo catchment, a long-term leaching rate of 3 kg N/ha/y is to be used for pine planted into pasture.

Table 15 shows the long-term reduction in N-leaching from afforestation of grazed pastures assuming that the forests have obtained a long-term equilibrium leaching rate of 3 kg N/ha/y. For regions where the leaching from targeted pasture was already less than 3 kg N/ha/y it was assumed that afforestation made no difference to leaching.

Table 15: N-leaching from pastures targeted for conversion to forestry in the bioenergy scenarios in tonnes N/y and as a percentage of the total N-leaching from agricultural lands

Region	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Northland	14 (0.2%)	44 (0.5%)	204 (2.5%)	634 (7.7%)
Auckland	1 (0.02%)	18 (0.7%)	46 (1.8%)	149 (5.8%)
Waikato	37 (0.1%)	590 (2.1%)	2086 (7.4%)	3235 (12%)
Bay of Plenty	3 (0.05%)	59 (0.9%)	193 (3.0%)	470 (7.4%)
Gisborne	45 (1.1%)	847 (21%)	1828 (45%)	2196 (54%)
Hawke's Bay	53 (0.7%)	891 (12%)	2281 (32%)	2812 (39%)
Taranaki	43 (0.5%)	195 (2.2%)	382 (4.4%)	534 (6.1%)
Manawatu-Wanganui	78 (0.6%)	1023 (8.4%)	2036 (17%)	2492 (21%)
Wellington	13 (0.4%)	213 (5.8%)	452 (12%)	588 (16%)
North Island total	**287 (0.4%)**	3880 (4.8%)	9507 (12%)	13 112 (16%)
West Coast	17 (0.5%)	1 (0.03%)	71 (2.0%)	117 (3.3%)
Canterbury	0	0	0	0
Otago	0	0	0	0
Southland	0	0	0	95 (1.2%)
Tasman	10 (0.6%)	54 (3.2%)	98 (6%)	169 (10%)
Nelson	0	4 (9.8%)	7 (17%)	9 (21%)
Marlborough	0	0	0	0
South Island total	27 (0.1%)	59 (0.2%)	176 (0.5%)	389 (1.1%)
Total New Zealand	314 (0.3%)	3939 (3.4%)	9683 (8.4%)	13 502 (12%)

N-leaching from plantation forests will also vary with the age of the trees and management practices. In some cases there may even be a short term increase in N-leaching. For example, Parfitt *et al.* (2003b) found N-leaching increased over a 6 month period in which *Pinus Radiata* was planted into an herbicide treated pasture, due to reduced plant uptake of N.

In addition to pasture lands, the bioenergy scenarios also include some land that is currently in mixed exotic scrubland or gorse and broom. Table 16 shows these areas for each scenario. Both broom and gorse cause biological N-fixation and would therefore be expected to leach more N. A study by Magesan *et al.* (2008) found significant differences in N-leaching from gorse stands compared to neighbouring *Pinus radiata* stands. However, the impact of afforestation of gorse and broom on N-leaching is likely to be small compared to afforestation of pasture land. As with afforestation of pasture land, any reduction in N-leaching from gorse and broom could take a long time to become apparent.

Table 16: Mixed exotic shrub land and gorse and broom area targeted for afforestation under scenarios 1–4

	Mixed exotic shrubland (ha)	Gorse and broom (ha)
Scenario 1	0	0
Scenario 2	30 882	122 791
Scenario 3	37 535	134 106
Scenario 4	43 916	154 161

The reduction in N-leaching from the targeted grazed pasture areas represent 0.3%, 3.4%, 8.4% and 12% of the total N-leaching from grazed pastures for scenarios 1–4 respectively. Although there are large areas of grazing land targeted for afforestation in Canterbury and Otago, they already have low N-leaching rates. Leaching reductions occur mostly in the North Island. The Manawatu-Wanganui region sees the largest absolute reduction in N-leaching in scenarios 1 and 2 while in scenarios 3 and 4 the Hawke's Bay and Waikato regions experience the largest reductions in N-leaching. In all scenarios Gisborne has the greatest reduction of N-leaching relative to current N-leaching from grazed pastures.

Some of the most nutrient enriched rivers are in Southland, Taranaki, Waikato and the Manawatu. Regions with monitored lakes with high levels of nutrients include the Waikato, Northland and the coastal lagoons in Canterbury (MfE, 2007). More detailed catchment-scale analysis would be needed to assess the impacts of the proposed bioenergy scenarios on specific lakes and rivers. However, it is worth noting that the biggest reductions in N-leaching are not necessarily occurring in the regions with the biggest water quality problems. This is because the bioenergy scenarios are primarily targeting less intensive farm types that contribute less to the problem of nutrient leaching. The targeted pasture lands in Waikato, Bay of Plenty and Gisborne produce the highest rates of leaching per hectare in all scenarios.

Erosion and Sedimentation

Anne-Gaëlle Ausseil, John Dymond, Donna Giltrap - Landcare Research

Erosion is the removal of soil through the action of wind or water. Erosion can lead to the loss of soil productivity and increased sedimentation and nutrient loading in waterways leading to degraded water quality and increased flood risk. Due to the shallower root systems of pastures, land under pasture (particularly in hill country) tends to be more prone to erosion than land under forestry.

The New Zealand Empirical Erosion model (NZEEM) is a spatial model of erosion rates under current land use (Dymond *et al.* 2008). This map was used to estimate the change in erosion (and hence sedimentation) that could be expected under the different bioenergy scenarios. Each region was divided by land use (forest, pasture and other) and slope classes (flat, rolling, hill or steep) and the average erosion rate found. Erosion rates were divided by a factor of 10 for areas where the land cover changed from non-woody to woody. For each bioenergy scenario, the difference between the annual erosion under the original land-cover and the new land-cover was calculated. It was also assumed that all the mass lost via erosion was eventually deposited as sediment.

Table 17 shows the reduction in the regional erosion/sedimentation rates for each of the bioenergy scenarios compared with the current land use.

Table 1: Reduction in erosion/sedimentation relative to current levels for each of the bioenergy scenarios (kt/y). Numbers in parentheses represent percentage change from current levels

Region	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Northland	94 (0.5%)	226 (1.3%)	988 (5.7%)	2510 (14.4%)
Auckland	0.5 (0.1%)	15 (2.5%)	41 (7.0%)	76 (13.0%)
Waikato	38 (0.5%)	464 (6.4%)	1 541 (21.2%)	2102 (29.0%)
Bay of Plenty	2 (0.1%)	16 (0.6%)	50 (1.9%)	85 (3.2%)
Gisborne	396 (0.7%)	8991 (15.4%)	18 995 (32.4%)	21 773 (37.2%)
Hawke's Bay	148 (1.5%)	1819 (18.1%)	4268 (42.6%)	4752 (47.4%)
Taranaki	148 (4.4%)	656 (19.6%)	988 (29.5%)	1083 (32.3%)
Manawatu-Wanganui	330 (2.6%)	3190 (24.8%)	5892 (45.7%)	6410 (49.8%)
Wellington	124 (1.9%)	1499 (23.4%)	2395 (37.4%)	2761 (43.2%)
North Island total	**1280 (1.1%)**	**16 877(14.2%)**	**35 158 (29.5%)**	**41 552 (34.9%)**
West Coast	42 (0.1%)	4 (0.01%)	175 (0.3%)	221 (0.4%)
Canterbury	627 (3.2%)	532 (2.7%)	1005 (5.1%)	1707 (8.7%)
Otago	437 (2.4%)	410 (2.2%)	677 (3.7%)	1445 (7.9%)
Southland	124 (1.6%)	184 (2.4%)	310 (4.0%)	390 (5.0%)
Tasman	24 (0.8%)	103 (3.6%)	201 (7.0%)	250 (8.7%)
Nelson	0.04 (0.1%)	2 (4.9%)	3 (8.0%)	3 (8.6%)
Marlborough	56 (3.0%)	166 (8.8%)	205 (10.9%)	317 (16.8%)
South Island total	**1311 (1.2%)**	**1401 (1.3%)**	**2576 (2.4%)**	**4334 (4.0%)**
Total New Zealand	**2592 (1.1%)**	**18 278 (8.0%)**	**37 735 (16.6%)**	**45 885 (20.2%)**

The bioenergy scenarios could produce reductions in annual erosion of 2.6, 18, 38, and 46 Mt/y respectively corresponding to reductions of 1.1%, 8.0%, 16.6% and 20.2% relative to current erosion rates. In scenario 1 the erosion reductions are reasonably evenly split between the North and South Islands. In the other scenarios there is a proportionately higher reduction in the North Island. In scenarios 2–4, Gisborne has the highest absolute reduction in erosion losses while the Hawke's Bay, Taranaki, Manawatu-Wanganui, and Wellington regions all have proportional reductions in erosion similar to Gisborne.

Water Quantity

Jagath Ekanayake, Donna Giltrap - Landcare Research

New Zealand has a very high amount of freshwater per capita due to high rainfalls and low population density. However, demand for water is increasing and between 1996 and 2006 there has been a 50% increase in water allocation (MfE 2007). Irrigation is the major use for allocated water. Other uses include electricity generation (which doesn't consume the water), town water supply, and industrial processing as well the need to maintain sufficient water in the rivers to maintain their cultural, recreational and ecological value.

Large changes in land cover can lead to changes in the amount of water received by rivers and aquifers. Afforestation could potentially reduce the availability of freshwater for other purposes. Many eastern regions (Hawke's Bay, Wairarapa, Marlborough, Tasman, Canterbury and Otago) have surface water catchments that are highly allocated (20–50% of low flow river flow) (MfE 2007).

Landcare Research has developed a model (WATYIELD) to predict the hydrological effects of land cover change (Fahey *et al.* 2004). The model requires data on land cover, soil types and physical properties, evaporation and rainfall. The soil information was extracted from Landcare Research's Fundamental Soil Layers database. Evaporation and rainfall time series data was taken from NIWA's climate database (CliFLO). Regional values were used for evaporation, but for rainfall the data for the Glendhu catchment were used for all regions. However, the results are quoted in terms of change in water availability per mm of annual rainfall. The reduction in available water for each scenario was calculated by comparing the WATYIELD predictions for the targeted land area under current land cover with the predictions when the land is afforested. The model was run for a 10-year time period (1980–1989) and the average reduction in water availability found.

Preparing the model data was computationally intensive, so the model was only run for scenarios 1, 3 and 4.

Table 18 shows the reduction in available water predicted for each region (in $10^3 m^3$/mm rainfall) compared to the 2006 water allocation and water balance. Note that the water allocation is based on consents issued by councils while water balance is the current water outflow to sea. Not all this water is available for use, as a certain amount will be needed to maintain river flows.

Table 18: Change in water availability by region for three afforestation scenarios. Mean annual rainfall figure from NIWA (2007)[*]. Water allocation and water balance from MfE 2006. The water balance was determined as a mean annual value (10^6m^3/y) over the period 1995–2001 from the national water accounts and was calculated as the outflow to the sea

Region	Reduction in available water (10^3m^3/mm rainfall)			Mean annual rainfall 1971-2000 (mm)	Water allocated 2006 (10^6m^3/y)	Annual water balance (10^6m^3/y)
	Scenario 1 (0.8Mha)	Scenario 3 (3.5Mha)	Scenario 4 (4.9Mha)			
Northland	0.007	181	477	1412	114.0	9557
Auckland	1	67	159	1240	152.3	2258
Waikato	20	676	979	1146	668.0	21 311
Bay of Plenty	2	75	133	1300	438.7	14 160
Gisborne	21	601	719	1050	296.4	5233
Hawke's Bay	44	1035	1164	803	443.1	5816
Taranaki	49	211	256	1432	105.6	7201
Manawatu-Wanganui	132	1623	1833	924	198.0	13 946
Wellington	32	516	624	1114	830.1	6515
North Island total					**3246.2**	**85 997**
West Coast	23	96	130	2274	272.9	51 511
Canterbury	1151	1726	3135	688	4015.8	28 320
Otago	1188	1734	2794	695	1749.9	13 310
Southland	186	505	694	1112	166.5	37 022
Tasman	10	89	124	970	148.9	10 124
Nelson	0	8	11	970	29.2	428
Marlborough	94	325	536	655	186.2	6226
South Island total					**6569.4**	**146 941**
Total New Zealand					**9815.6**	**232 938**

[*] The following climate stations were used to represent each region: Northland (Kaitaia and Whangarei), Auckland (Auckland), Waikato (Hamilton and Taupo), Bay of Plenty (Tauranga and Rotorua), Gisborne (Gisborne), Hawke's Bay (Napier), Taranaki (New Plymouth), Manawatu-Wanganui (Palmerston North and Wanganui), Wellington (Masterton and Wellington), West Coast (Westport), Canterbury (Christchurch, Kaikoura and Timaru), Otago (Queenstown, Alexandra, Dunedin), Southland (Invercargill), Tasman (Nelson), Nelson (Nelson), Marlborough (Blenheim)

Figures 8 and 9 show the regional reduction in water in 10^6m^3/y and relative to the annual water balance respectively.

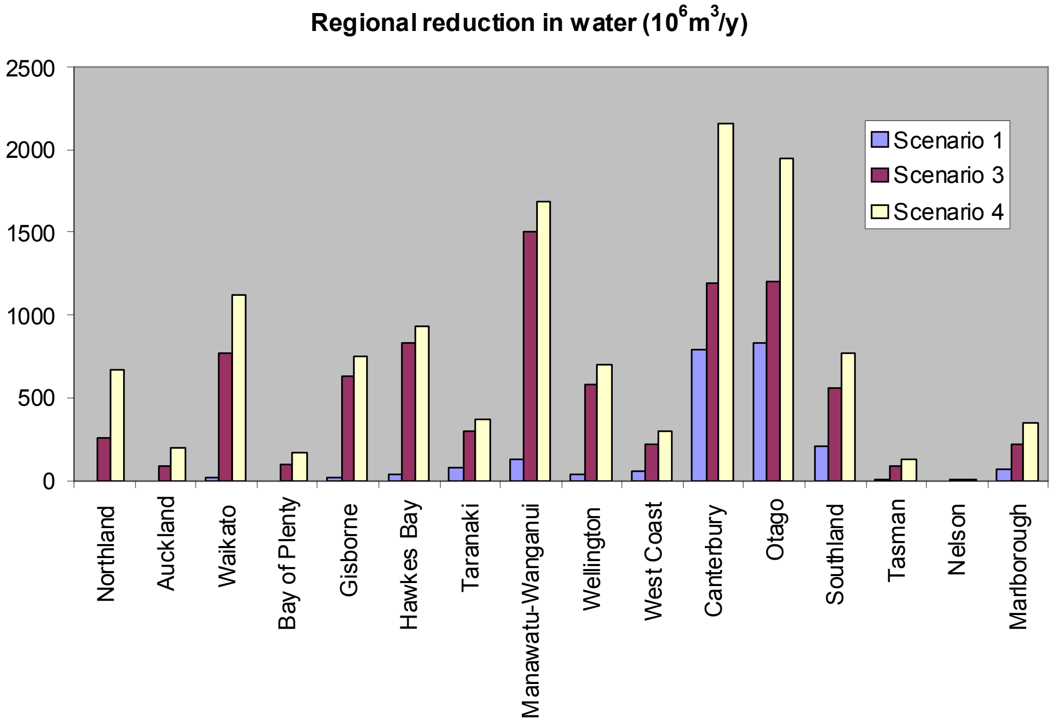

Figure 8: Predicted reduction in regional water availability ($10^6m^3/y$)

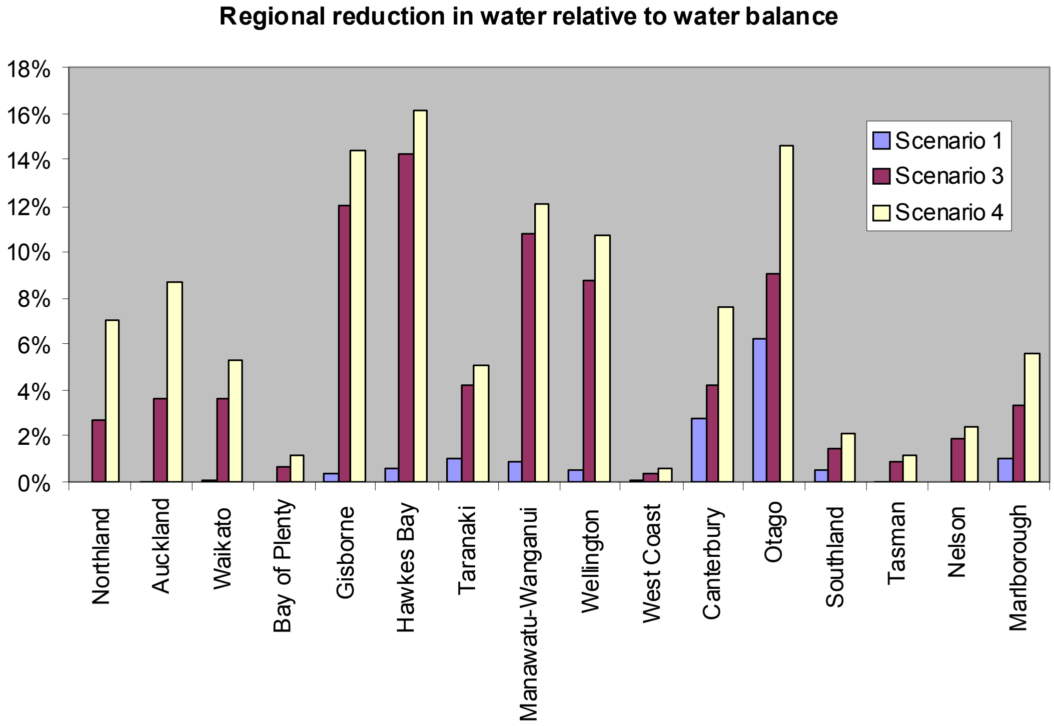

Figure 9: Predicted reduction in regional water as percentage of current regional water balance

Scenario 1 represents a fairly minor decrease in available water at a national scale (2260 × 10^6 m^3/y or about 1% of currently available water). However, in this scenario most of the afforestation occurs in Canterbury and Otago. Taking into account the typical annual rainfalls in these regions the available water would be reduced by 790 × 10^6 and 830 × 10^6 m^3/y in Canterbury and Otago respectively. This is equivalent to 3% and 6% of the current regional water balances. Canterbury and Otago already have high rates of water allocation making it more difficult to accommodate additional water reductions.

In the higher scenarios (3 and 4) the total water availability is reduced by 8530 × 10^6 and 12 260 × 10^6 m^3/y (4% and 5% of current water balance) respectively. In scenario 4 the total reduction in water is greater than the current amount of water allocated by councils. Canterbury, Otago and Manawatu–Wanganui have the largest areas of afforestation in absolute terms while Manawatu–Wanganui, Hawke's Bay, Gisborne and Wellington have the most afforestation as a proportion of total land area. Canterbury and Otago remain the regions with the largest reductions of available water, both in absolute and relative terms. The Manawatu–Wanganui region sees the largest absolute reduction in water available in the North Island (1500 × 10^6 and 1690 × 10^6 m^3/y in scenarios 3 and 4 respectively), while Gisborne sees the largest reduction relative to current water availability (14% and 16% for scenarios 3 and 4).

Summary

Afforestation can have substantial impacts on regional water balances. In the smallest scenario (scenario 1 with 0.8 Mha afforested) there are still significant reductions in the available water in the Canterbury and Otago regions (3 and 6% of current water balance). In the higher scenarios (3 and 4) other regions also see significant reductions in water balance. The highest percentage reduction in water balance occurs in Hawke's Bay under scenario 4 (16% reduction). This reduction in water balance means there is less water available for other uses such as irrigation, town supply and maintaining river flows.

Biodiversity

Steve Pawson - Scion

Despite annual decreases in the global forest cover, the area of plantation forests is currently increasing at 2–3 million ha per year. Plantations cannot provide the same biodiversity values as pristine native habitat; however they are increasingly recognised for their contribution to the regional and national conservation of native species. These biodiversity values of plantations are maximised when new forests are established on degraded agricultural land in highly modified landscapes. In New Zealand the current plantation estate (ca 1.7 million ha) is known to provide habitat to a range of terrestrial and freshwater species, including: native understorey plants, birds, insects, Herpetofauna (frogs and lizards) and fish. This is discussed in more detail in Appendix 4.

Scion has recently derived four scenarios for establishing new bioenergy forests in New Zealand to meet future liquid and solid fuel requirements. To meet the afforestation targets of between 0.8 and 5 million ha significant areas of non-forest land will require conversion to new bioenergy forests. It is anticipated that this land will be steep, in some cases erosion prone, marginal pastoral land. This report analyses the potential biodiversity impacts of converting marginal farmland and exotic (or native) scrubland to new bioenergy forests.

The limited available research in New Zealand suggests that a shift from marginal pastoral land and exotic scrub to exotic plantation forest will result in an overall increase in native forest species. Areas of exotic scrub could in the long-term revert back to a native forest cover by natural succession pathways. Therefore some areas should be left undisturbed to allow for the regeneration of secondary native forests within the landscape.

Future bioenergy forests have clear benefits for some native species and will increase connectivity between currently fragmented native forest remnants. However, large-scale planting concurrently increases the risks of invasive wilding pines. Care needs to be taken in species selection to prevent further wilding pine infestations. In addition, during the forest establishment phase extra care is required to prevent young stands acting as a conduit for the dispersal of exotic weed species into adjacent native remnants.

The key determinant of the overall net biodiversity gain from new bioenergy forest is the biogeographic and landscape context of new plantings. New Zealand was a largely forested country; however, significant areas of Otago are not thought to have been forested. New bioenergy forests should be placed in areas that were historically forested. Planting areas of native grasslands that were not historically forested is not desirable.

Proximity of native forest habitat is a key landscape determinant of native species diversity in plantation forests. As such, sufficient areas of native reserve should be maintained (or restored) within the landscape to allow movement of native species around the landscape. Appropriate restoration targets for native habitat can be achieved by retaining regenerating native shrublands and restoring exotic shrublands, e.g., gorse that can act as a cover for emergent native species.

Overall, bioenergy forests present an exciting opportunity to return forest cover to areas of formerly forested land. If managed appropriately they have the potential to increase significantly both terrestrial biodiversity and aquatic water quality at a landscape level. Research on the biodiversity benefits and pitfalls of new bioenergy forests is urgently required to guide planning and afforestation scenarios. Early consideration of biodiversity issues will ensure maximum future biodiversity benefits from new bioenergy forests.

Exotic plantation forests and biodiversity a global overview

Land-use change, associated deforestation, and subsequent fragmentation of habitat, are the most significant global drivers of biodiversity loss (Sala et al. 2000). However, on isolated island ecosystems such as New Zealand the impacts of introduced invasive species (e.g., mammalian predators) can also have catastrophic consequences (Duncan & Blackburn 2007). Rapid global deforestation continues, FAO (2006a) estimates that ~13 million ha of natural or semi-natural forests were destroyed on average each year between 2000 and 2005. In contrast, plantation forests, though small by comparison (ca 140 million ha), are increasing by ca 2–3 million ha annually (FAO 2006a 2007). The principle objective of plantation forests is the production of timber; however, they provide many additional environmental services, including soil conservation, carbon sequestration, maintenance of water quality and protection of indigenous flora and fauna (Carnus et al. 2006). The adoption of management practices to conserve biodiversity and maintain environmental services is implicit in guidelines prepared by the FAO, Montreal Process and forest certification schemes, e.g., Forest Stewardship Council (Anon 1996, 2007; FAO 2006b). Some plantation owners in New Zealand have voluntarily adopted such policies, however others have not.

The ability of plantations to provide such environmental services (particularly biodiversity) was the focus of two recent global reviews (Brockerhoff et al. 2008; Carnus et al. 2006). Both papers acknowledged the significant trade-offs that are made between management for timber production and the provision of ecological services. Future purpose grown bioenergy forests proposed for New Zealand may be somewhat different to current plantations (Hall & Gifford 2008), and different trade-offs will apply. Some new forests are likely to utilise different species (including mixtures) to those currently used in our exotic plantation forests, be planted at different stocking rates and have different rotation times. However, some will be very similar in species composition and rotation length to current NZ plantation forests. Irrespective of these differences purpose grown bioenergy forests provide a significant new opportunity to restore forest cover to the landscape. How this and the tradeoffs between productivity and the management of environmental services will ultimately determine the net biodiversity gains of future bioenergy forests.

Comparisons in the biodiversity value of different land-use types

Comparisons between the diversity of different land-use classes are fraught by a lack of consensus in the application of suitable reference points. Plantations are forests, although a direct comparison with native forests from the conservation estate is inappropriate as plantations are a productive land use, whereas native forests are largely managed for conservation purposes. A more constructive approach is to compare plantations with other productive land use classes, e.g., arable or pastoral farming (Stephens & Wagner 2007). Few direct comparisons have been made between plantations and other land-use types in New Zealand and further research in this area is urgently required. We have attempted to synthesise information currently available and have drawn comparisons (where appropriate) between different land-use classes.

Plantation versus agricultural pasture

Species richness

Pinus radiata stands tend to have higher species richness of beetles (Berndt et al. 2008; McLean & Jones 2006; Pawson et al. 2008), plants (Ecroyd & Brockerhoff 2005; Schipper 1996), and native forest birds (Brockerhoff et al. 2007) than does adjacent pasture. This relationship is not absolute as high variation in trap catch (particularly for insects) and a lack of standardised trapping methodologies make it difficult to compare between studies. For example, Berndt et al. (2008) and Pawson et al. (2008) found a greater diversity of native beetles in young and mature pine compared to adjacent pasture. However, if total species richness was considered (including exotic species), the relationship was less clear and in the case of Berndt *et al.* (2008) total species richness was highest in pasture, due to the presence of exotic species. Neumegen (2006) recorded greater abundance and species richness of beetles in *P. radiata* stands compared to adjacent pasture. However, when the confounding effects of sample size (due to lower abundance of beetles in pasture traps) were taken into account by rarefaction the relationship was no longer apparent. Neumegen's analysis was conducted on total species richness, restricting the analysis to native beetles may have revealed a more consistent trend between studies. These studies also serve to highlight the importance of defining target taxa, native species richness should be given a much higher weighting in analyses compared to exotic species.

Presence of exotic species

Species diversity and abundance of exotic birds (Brockerhoff *et al.* 2007), insects (Pawson *et al.* 2008) and plants (Ecroyd & Brockerhoff 2005) were higher in pasture compared with mature plantation forest. In fact, improved pastoral land was shown in two independent studies to have an entirely exotic plant species composition (Ecroyd & Brockerhoff 2005; Harris & Burns 2000b). This contrasts sharply with the high abundance of native plants recorded in plantation stands (Allen et al. 1995; Brockerhoff et al. 2003; Ecroyd & Brockerhoff 2005).

The abundance of exotic species (both insects and plants) in plantations is known to change throughout a rotation. Exotic insects (Pawson et al. 2008) and plants (Allen et al. 1995; Brockerhoff *et al.* 2003) are more abundant in clearfells and recently regenerating stands; whereas older stands have a greater proportion of native species. It is important to have an understanding of the proportion of exotic species in a given habitat as it may provide a conduit allowing dispersal of these species into adjacent native forest remnants. For example exotic pasture and young plantation stands have a high number of exotic plant species and may present a source of propagules that could disperse into adjacent native forest (Sullivan *et al.* 2006). Older plantation stands, however, present less exotic pest pressure adjacent to native forests and may in fact buffer these remnants from exotic species present in agricultural habitats (Pawson *et al.*, 2008)

Comparisons between exotic shrubs and plantation forest

No comprehensive nationwide studies have compared the native fauna and flora present in large areas of gorse shrublands with exotic plantation forests. A single study of carabid beetles in mid-Canterbury showed that small areas of gorse had the lowest species richness (5 species) of all surrounding land use types, including pasture (12 species), plantation forest (young stands 13 species, old stands 7 species), and kanuka remnants (12 species) (Berndt *et al.* 2008). Other studies have compared the fauna of gorse with that of native kanuka shrublands (Harris *et al.* 2004; Williams & Karl 2002). While drawing conclusions on the basis of these studies (and others) that were undertaken in different geographic locations using different sampling methods is not ideal, it does provide some measure of the relative diversity of native taxa in different habitat types. Harris et al. (2004) record 84 recognisable beetle taxa from gorse plots collected by combined pitfall and Malaise trapping. In contrast, Pawson (2006), in a more comprehensive study of mature plantation forest and recent clearfells, recorded over 350 beetle species. In addition, a second pitfall trap study of three selected beetle taxa (Carabidae, Scarabaeidae and Scolytinae) in recent clearfells and mature *P. radiata* stands recorded a total of 40 species (Pawson *et al.* 2008) and a Malaise trap study of plantation stands by Hutcheson and Jones (1999) recorded 131 recognisable taxonomic units. These comparisons suggest a shift from exotic gorse dominated shrubland to plantation forests would increase the number of native beetle species. This conclusion, however, should be treated with caution as more detailed replicated studies are urgently required.

Comparisons between native shrub cover and plantation forest

As with exotic shrubland, Berndt et al. (2008) published the only known study comparing insects in a native shrubland (kanuka) with exotic plantation stands at Eyrewell Forest, mid-Canterbury.

Although there were no statistically significant differences in species richness between habitat types (due to high variability in trap catch), kanuka had the greatest species richness of all habitat types (pasture, young and old pine) at the largest comparable sample size. In addition, a study of kanuka shrublands near Gisborne highlighted their importance as a repository of native insects. Species richness of insects in old (60 yr) kanuka stands at this site was greater than adjacent mature native forest (Dugdale & Hutcheson 1997).

In addition to the insect work at Eyrewell forest, Ecroyd and Brockerhoff (2005) surveyed the understorey plant diversity in plantation forests and adjacent kanuka remnants. Their results showed no significant difference in the abundance of native understorey plants between kanuka remnants and different aged plantation stands. In contrast, adjacent pastoral grassland had significantly fewer native species present than either kanuka or plantation sites.

Potential negatives impacts of bioenergy forests

Unwanted ‘wilding’ pines were first identified in New Zealand in the late 1800s. The problem has been growing steadily and recent estimates suggest 150 000 ha and more than 300 000 ha of land are affected in the North and South Islands respectively (Ledgard 2004). The worst wilding species (*Pinus contorta* and *Pinus nigra*) are no longer planted for commercial purposes on a large scale; however, continued concern surrounds the use of Douglas-fir (Pseudotsuga *menziesii*) because of its shade tolerant seedlings that have been observed colonising native forest remnants. Consideration should be given to the known wilding potential of species before widespread planting of new bioenergy forests.

A second potential impact of bioenergy forests is the transfer of weed propagules into adjacent native remnants. Denyer (2000) advanced the hypothesis that mature pine plantations have the ability to buffer native reserves from weed invasions. However, Sullivan et al. (2006) provide further information as they studied the potential of plantations to act as a source of exotic weed propagules throughout an entire plantation rotation. Sullivan et al. (2006) showed that young stands of pines are more likely to act as a conduit for the transfer of weedy species into adjacent native reserves than older stands. As such, special care must be taken to prevent unwanted weed invasions when converting marginal agricultural land adjacent to native reserves for bioenergy forests.

Impacts of potential bioenergy scenarios

Scion has identified four national scenarios for the establishment of biofuel forests. These advocate large scale planting of purpose grown bioenergy forests of 0.8, 1.8, 3.0 and 5.0 million ha respectively (Fig 10). At this stage the conversion technology required to convert this biomass to liquid fuels has not yet been adopted in NZ on a commercial scale. As such, the species composition and key silvicultural parameters that determine the resulting feed stock, e.g., stocking and rotation times, have yet to be finalised. International trends suggest that purpose grown bioenergy forests are of higher stocking and shorter rotation times than plantations optimised to produce timber. However, due to the nature of the terrain being considered in the New Zealand scenarios (steep lands), rotations of ~25 years are considered to be the base case. This is similar to current (27–28 years) average rotation lengths. The key difference would be the stocking, which would be higher in bioenergy stands due to there being no early or mid-rotation thinning as the crop is aimed at maximum biomass production rather producing large diameter saw logs. Based on these characteristics what impacts would such afforestation plans have on terrestrial biodiversity?

Densely stocked forests may not have the equivalent biodiversity value of current plantation forests (see above, plantations as habitats for plants, insects and birds). However, even short-rotation forests will create a generalised forest microclimate that presents an opportunity for some forest species that would otherwise be absent if the land remained in agricultural pasture.

Therefore, conversion of marginal agricultural land to bioenergy forests will be a net benefit for native species. However, the size of this benefit will reflect stocking, rotation length, climatic variables (particularly average rainfall) and the retention and expansion of remnant native habitat within the landscape.

A key determinant of the net biodiversity gains from new bioenergy forests is the historical land-use context. New Zealand was largely forested (Fig. 10), as such returning forest cover (in what ever form) to the landscape will be beneficial for forest-adapted native species. However, there are important biogeographic considerations, for example, large areas of Otago are not thought to have been forested (Fig. 10). In such cases, conversion of tussock grasslands to bioenergy forests will have negative regional impacts on biodiversity. From a biodiversity perspective bioenergy forests should therefore be restricted to areas that were historically forested.

A second caveat is the land-use class chosen for conversion to bioenergy forests. Conversion of native forest is neither legal (in NZ) nor desirable as it represents a net loss in biodiversity. There is international concern at the on-going conversion of native forest habitats for high producing bioenergy crops (Groom *et al.* 2008). Successful NZ based bioenergy projects should clearly separate themselves from such practices.

Conversion of other marginal land uses may in some cases result in an unanticipated long-term net biodiversity loss. For example, Hinewai Reserve (Banks Peninsula) is now famous for its restoration of native forest, facilitated by an unnatural succession process where gorse acts as a cover crop for emergent native species (Wilson 1994). The conversion of large areas of gorse scrubland to bioenergy forests may interrupt a pathway that would otherwise have led to the growth of secondary native forest. Similar caveats apply to other areas of degraded agricultural land that are currently reverting to native land cover types.

Conversion Scenarios

0.8 Million ha

The stand out feature of the smallest afforestation scenario is the large increases in forest area in Otago and Canterbury, 103.3 and 84.4 %, respectively, relative to current native and exotic forest cover (Table 18). Both regions are relatively dry, and historically large areas of Otago were not forested (Fig 8); however, the predominantly forested Canterbury has since lost most of its original vegetative cover (Leathwick et al. 2003). Botanical studies in Canterbury have shown that plantation forests support a large number of indigenous species still present in the small native remnants (Ecroyd & Brockerhoff 2005). Furthermore, the critically endangered ground beetle *Holcaspis brevicula* only survives in a plantation forest on the Canterbury plains and is no longer present in its ever diminishing native habitat, kanuka (Brockerhoff *et al.* 2005b). Expansion of bioenergy forests in Canterbury will have a net benefit for these and other dry forest species. In addition to the basic provision of habitat, bioenergy forests will increase connectivity between remaining forest areas. A significant proportion of the land identified for bioenergy forests in Canterbury is on Banks Peninsula. Although, this will have significant benefits for forest biodiversity there is strong public opposition (largely on aesthetic grounds) to the afforestation of the Peninsula with exotic species.

In Otago conversion of land for bioenergy could have negative consequences as this land was historically not forested. Conversion of Otago's dry native grasslands and mixed shrublands is not beneficial from a biodiversity perspective. In addition, conversion of tussock grasslands to bioenergy forests will significantly reduce already scarce available water in the region (Mark & Dickinson 2008), affecting aquatic fauna and flora.

1.8 Million ha

As with the 0.8 million ha scenario Canterbury and Otago show the greatest increases in regional forest cover, 91.8 and 112.1% respectively. In addition to the comments on these regions (see above) this scenario also shows significant planting in the Wellington, Manawatu – Wanganui and Gisborne regions. Afforestation of erosion prone surfaces in these latter regions will have significant benefits for water quality, thus improving aquatic biodiversity and native fish habitat. In addition these regions have little native forest remaining, particularly at lower altitudes.

Afforestation for bioenergy in these regions could provide supplementary forest habitat for some native species and increase connectivity between remnant native forest patches. Significant care should be taken in these East Coast regions to avoid afforestation of seral scrub habitat (manuka and kanuka) that are important habitats for native species (Dugdale & Hutcheson, 1997; Harris *et al.*, 2004; Williams & Karl, 2002).

3.3 Million ha

Again the same regions as the previous 1.8 million ha scenario are projected to have a > 50% increase in total forest area. In addition to these regions, Hawke's Bay will also gain 88.8 % forest area (Table 19).

4.9 Million ha

The final afforestation scenario suggested a >250% increase in forest area in Canterbury and Otago. Significant benefits from increased connectivity and available forest area could accrue in these regions. However, as already mentioned, afforestation of non-forested lands in Otago would result in a net biodiversity deficit. Another four regions will have a >100% increase in forest area (Wellington, Manawatu–Wanganui, Hawke's Bay and Gisborne), while Marlborough increases by 64.8%, and Waikato almost gains an additional 47.7%. Lack of connectivity between isolated native forest remnants is a significant problem in the Waikato region, which is presently dominated by pasture (Harris & Burns 2000a). Afforestation for bioenergy may improve regional connectivity between remnant native forest patches.

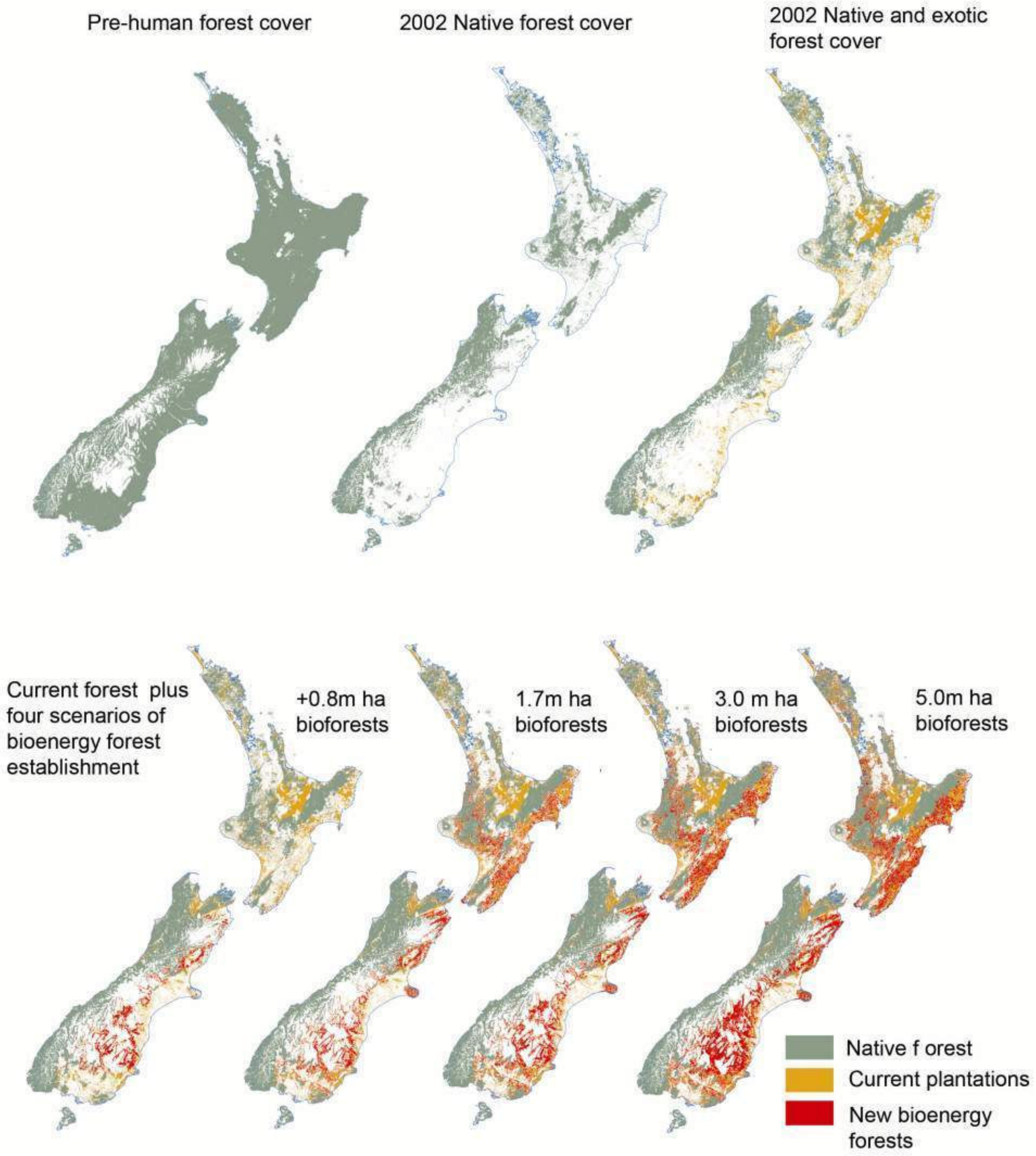

Figure 10: Projected historical forest cover (Hall & McGlone, 2006), current native forest cover, current total forest cover including plantation forests, and current forest cover with additional purpose -grown bioenergy forests

Table 19: Historical, current and future forest cover of native and exotic species. Historical projected forest cover is based on (Hall & McGlone 2006), current forest cover is based on LCDB2, native forest (Class 69) and exotic forest (Classes 62–68). Future forest cover is based on a series of purpose grown bioenergy forest scenarios (Hall & Gifford 2008)

					2002 native and plantation forest cover + Biofuel Scenario (% increase)			
Region	**Pre-human predicted forest cover (ha, %)**	**2002 Native Forest Cover (ha, %)**	**2002 Plantation Forest Cover**	**2002 Native & Plantation Forest Cover**	**0.8 m ha**	**1.8 m ha**	**3.0 m ha**	**5.0 m ha**
Northland	1 102 954	255 960	181 928	437 887	444 545 (1.5)	457 877 (4.6)	505 647 (15.5)	616 616 (40.8)
Auckland	451 734	68 425	52 192	120 617	120 862 (0.2)	129 998 (7.8)	146 914 (21.8)	174 601 (44.8)
Waikato	2 191 077	473 552	341 100	814 651	820 193 (0.7)	897 322 (10.1)	1 081 524 (32.8)	1 203 601 (47.7)
Bay of Plenty	1 175 ,214	540 703	283 243	823 946	824 588 (0.1)	832 192 (1)	852 452 (3.5)	875 920 (6.3)
Gisborne	827 618	132 239	153 587	285 826	291 589 (2)	403 102 (41)	530 207 (85.5)	580 854 (103.2)
Taranaki	1 376 171	225 230	26 906	252 136	264 902 (5.1)	303 853 (20.5)	339 619 (34.7)	360 218 (42.9)
Hawke's Bay	705 786	290 276	151 238	441 514	453 092 (2.6)	604 820 (37)	833 558 (88.8)	904 410 (104.8)
Manawatu–Wanganui	2 129 460	443 213	138 510	581 723	616 471 (6)	922 216 (58.5)	1 222 907 (110.2)	1 310 859 (125.3)
Wellington	779 402	159 653	68 581	228 235	237 087 (3.9)	352 367 (54.4)	422 601 (85.2)	464 879 (103.7)
Tasman	1 704 279	533 122	104 531	637 653	640 513 (0.4)	659 744 (3.5)	671 815 (5.4)	684 822 (7.4)
Nelson	3 078 396	12 930	11 549	24 479	24 514 (0.1)	27 323 (11.6)	27 880 (13.9)	28 217 (15.3)
Marlborough	1 793 453	214 985	74 328	289 313	31 5473 (9)	382 076 (32.1)	409 329 (41.5)	476 680 (64.8)
Canterbury	2 388 580	284 551	120 713	405 264	747 287 (84.4)	777 141 (91.8)	1 013 267 (150)	1 425 667 (251.8)
West Coast	809 047	1 438 468	42 515	1 480 984	148 5481 (0.3)	1 491 483 (0.7)	1 509 776 (1.9)	1 520 357 (2.7)
Otago	40 628	182 806	125 084	307 890	62 6034 (103.3)	652 949 (112.1)	863 404 (180.4)	1 193 668 (287.7)
Southland	756 103	1 200 651	81 003	1 281 654	1 332 298 (4)	1 374 980 (7.3)	1 457 421 (13.7)	1 519 445 (18.6)
North Island	**10 739 416**	**2 589 251**	**1 397 286**	**3 986 536**	**4 073 329 (2)**	**4 903 747 (23)**	**5 935 429 (49)**	**6 491 958 (63)**
South Island	**10 570 486**	**3 867 513**	**559 723**	**4 427 236**	**5 171 600 (17)**	**5 365 696 (21)**	**5 952 892 (34)**	**6 848 856 (55)**
New Zealand	**21 309 902**	**6 456 763**	**1 957 009**	**8 413 772**	**9 244 929 (10)**	**10 269 443 (22)**	**11,888,321 (41)**	**13 340 814 (59)**

Recommendations

Stand level initiatives to improve biodiversity in newly created bioenergy forests, though important will have less impact on the final net biodiversity benefits of such plantations compared to landscape scale issues. The diversity of species, final stocking, and length of rotation are all factors that require urgent research to ensure the future potential biodiversity values from new energy forests are maximised.

The most important consideration to increase biodiversity values of new plantings is to integrate these forests within the existing landscape (including native remnants). Ensuring connectivity with what native forest remains, and if necessary setting aside regions that can naturally (or with assistance) regenerate into native forest cover, will be essential. One critical determinant of biodiversity in plantation stands is the proximity to native habitat (Pawson *et al.* 2008). As such, a network of smaller native habitat areas throughout a bioenergy plantation could facilitate increased use of stands by native species.

The reservation of native habitat (often scrub species) is a common feature of many plantation forests, and will also occur in bioenergy forests for much the same reasons. Existing native remnants in plantations are frequently found in deep/steep) gully bottoms (which are typically wet and shady and where *Pinus radiata* performs poorly). In addition, the NZ forest industry has (due to agreements (NZ Forest Accord, FSC certification) and legislation (Resource Management Act, Regional Council By-laws)) been stepping its plantations back from waterways to create riparian buffers, which are frequently colonised by native species. New bioenergy plantings should establish riparian protection as forests are created and set aside reasonable areas for restoration to native forest cover.

Research Requirements

- Comparison of the biodiversity value of different land-use types, including purpose grown bioenergy forests (of different species), agricultural pasture, traditional plantation forestry, native forest and exotic and native shrublands.
- Influence of stocking, rotation length and species selection on the biodiversity values associated with different types of bioenergy forests.
- The potential benefits of bioenergy forests providing connectivity between existing native remnants within the landscape.
- Impact of different harvesting scenarios for bioenergy forests on biodiversity, how to maximise habitat heterogeneity in the landscape; a factor largely determined by how forests are initially planted.

Conclusions

The four bioenergy scenarios require large-scale changes in land use. The areas selected for afforestation in these scenarios are currently in low productivity pasture or scrub. These afforestation scenarios result in major greenhouse gas benefits from increased carbon storage in forest biomass, displaced agricultural emissions and displaced emissions from substituting fossil fuels with biofuels. By 2035 the net CO_2 removed by new forests will be 208, 647, 1183 and 2032 Mt for scenarios 1–4 respectively. The corresponding reductions in GHG emissions from displaced agriculture and transport emissions post 2035 are 5.0, 15.5, 29.2 and 37.3 Mt CO_2e/y. These displaced emissions represent a sizeable proportion of New Zealand's 77.9 MtCO_2e total GHG emissions for 2006.

There are some negative environmental impacts associated with agriculture (such as nutrient leaching and erosion) that could be reduced by afforestation. In the long-term N-leaching could be reduced by 314, 3940, 9680 and 13500 t N/y (equivalent to 0.3%, 3.4%, 8.4% and 12% of current leaching from grazed pastures) for scenarios 1–4 respectively. However, soils with large reserves of surplus N can continue to leach high levels of N for a long time. Erosion and sedimentation rates could be reduced by 1.1, 8.0, 16.6 and 20.2% in scenarios 1–4.

Exotic forests can provide biodiversity benefits as they can provide habitats for many native species. Wilding pines and other weeds may be an issue in some areas. Some scrubland could be in the process of reverting to native forest, in which case the biodiversity benefit of converting it to exotic forestry is questionable. Similarly, there is little biodiversity benefit to afforestation in areas (such as parts of Otago) that have never historically been under forest cover.

The effects of afforestation on water availability could be a serious issue in some regions. This may cause afforestation to conflict with other water uses such as irrigation, town supply and maintaining river flows. The change in the national water balance ranges from 2260×10^6 m^3/y for scenario 1 to $12\,260 \times 10^6$ m^3/y for Scenario 4. In all scenarios, Canterbury and Otago have high reductions in water availability. In Scenario 4 the largest absolute reduction in available water occurs in Canterbury while the largest reduction relative to current water balance occurs in Hawke's Bay.

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Appendix 1: Scenario Maps

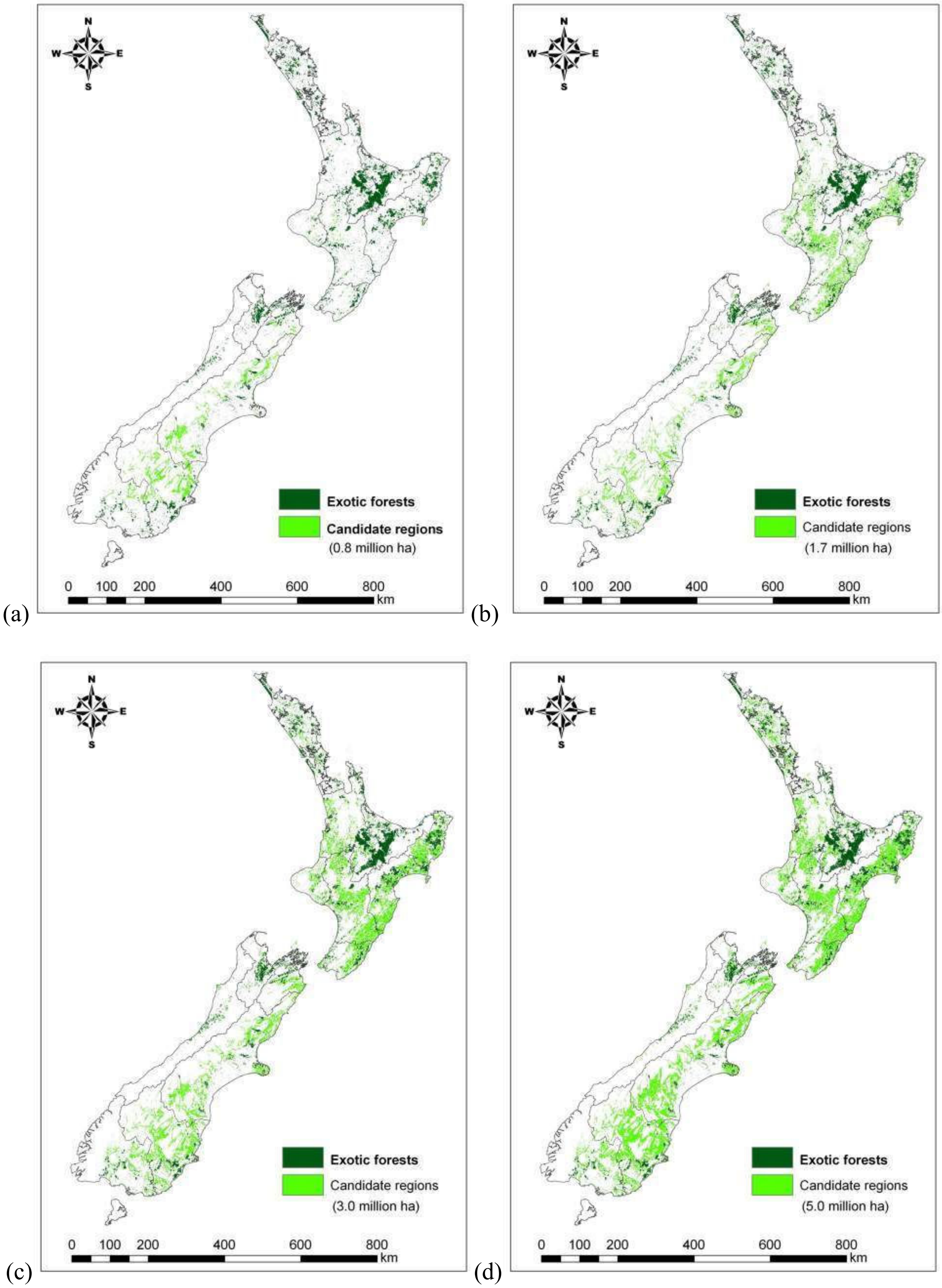

Figure A1: Land area converted to forestry in (a) Scenario 1 (0.8 Mha), (b) Scenario 2 (1.8 Mha), (c) Scenario 3 (3.4 Mha) and (d) Scenario 4 (4.9 Mha).

Appendix 2: Animal stocking rates

We derived a stocking rate layer for four animal types: dairy, beef, sheep, and deer.

The inputs used for the model were:

- Land Use of New Zealand (LUNZ): developed as part of the CLUES project (Woods et al. 2006), this layer is a combination of Agribase 2003 and LCDB2, and provides information on the spatial distribution of farm enterprises, especially for dairy (DAI), dry stock (DRY), beef (BEF), sheep (SHP), sheep and beef intensive (SBI), sheep and beef hill country (SBH), and deer (DEE).
- Land Resource Inventory (LRI): the LRI comprises two attributes describing the stock carrying capacity related to the soil and landform potential. CCAV is the average carrying capacity for all farmers, and CCTO is the estimated stocking rate for the top farmer.
- MAF Farm monitoring reports for sheep and beef (MAF 2006): the MAF monitoring reports were used to estimate the proportion of sheep and beef in various parts of the country.

The rules used to create a spatial layer of stocking rate for each animal type are described in table A1.

Table A1: Rules used for stocking rate estimation of dairy cattle, beef, sheep and deer

Animal type	LUNZ	LRI carrying capacity (SU/ha)	Stocking rate (animal/ha)
Dairy	DAI or DRY	CCTO	CCTO / 6.65
Sheep	SHP or SBH or SBI	CCAV	CCAV * *r*
Beef	BEF or SBH or SBI	CCAV	CCAV / 5.3 * (1- *r*)
Deer	DEE	CCTO	CCTO / 1.9

r is the ratio of sheep stock units over the total stock units. It is equal 1 for SHP, 0 for BEF, and depends on the region and the monitoring farm model from MAF (intensive: SBI or hill country: SBH) (Table A2).

Table A2: Ratio of sheep versus beef per region.

		Sheep and Beef intensive		Sheep and beef hill country	
	Regional Council	**MAF monitoring farm model name**	***r***	**MAF monitoring farm model name**	***r***
1	Northland RC	Northland	0.24	Central North Island Hill Country	0.62
2	Auckland RC	Northland	0.24	Central North Island Hill Country	0.62
3	Env. Waikato	Waikato/Bay of Plenty	0.42	Central North Island hill country	0.62
4	Env. Bay of Plenty	Waikato/Bay of Plenty	0.42	Central North Island hill country	0.62
5	Gisborne	Waikato/Bay of Plenty	0.42	Gisborne hill country	0.53
6	Hawke's Bay	Manawatu/Rangitikei intensive	0.62	Hawke's Bay/Wairarapa hill country	0.65
7	Taranaki	Manawatu/Rangitikei intensive	0.62	Central North Island hill country	0.62
8	Manawatu / Wanganui	Manawatu/Rangitikei intensive	0.62	Central North Island hill country	0.62
9	Wellington	Manawatu/Rangitikei intensive	0.62	Hawke's Bay/Wairarapa hill country	0.65
10	Marlborough	Canterbury/Marlborough breeding and finishing sheep and beef	0.81	Canterbury/Marlborough hill country	0.73
11	Tasman	Canterbury/Marlborough breeding and finishing sheep and beef	0.81	Canterbury/Marlborough hill country	0.73
12	West Coast	Southland/South Otago intensive sheep and beef	0.95	Southland/South Otago hill country	0.85
13	Canterbury	Canterbury/Marlborough breeding and finishing sheep and beef	0.81	Canterbury/Marlborough hill country	0.73
14	Otago	Southland/South Otago intensive sheep and beef	0.95	Otago hill country	0.85
15	Southland	Southland/South Otago intensive sheep and beef	0.95	Southland/South Otago hill country	0.85

The animal numbers from the stocking rate layer were then multiplied by appropriate scaling factors so that the total animal number in each region match the regional totals in the Agricultural production survey (Statistics New Zealand 2007) for the year ended 30 June 2006.

LRI carrying capacity values were not available for the entire Gisborne region. So for Gisborne, the animal numbers under each bioenergy scenario were assumed to be proportional to the areas under the appropriate farm types.

Appendix 3: Tree growth and carbon storage

Scenario 1: 0.8 million hectares

		Total ha	Established	Rotation, years	MAI, m^3 / ha / pa	Yeild, m^3 / ha			
Scen 1, 0.8 million hectares		765,181	over years	25	25.6	640			
Area Established per annum		38,259	20						
							Carbon stock	t / CO_2 yr, Displaced	t / $CO_{2\ yr,}$ Reduced
Year	Year	Area, ha	MAI, m3/pa	Volume, m3	Wood, odt	Carbon, t	t / CO_2 eq	emissions	transport emissions
1	2011	38,259	979,432	979,432	411,361	209,794	769,945	- 37,876	-
2	2012	76,518	1,958,863	2,938,295	1,234,084	629,383	2,309,835	- 75,753	-
3	2013	114,777	2,938,295	5,876,590	2,468,168	1,258,766	4,619,670	- 113,629	-
4	2014	153,036	3,917,727	9,794,317	4,113,613	2,097,943	7,699,450	- 151,506	-
5	2015	191,295	4,897,158	14,691,476	6,170,420	3,146,914	11,549,175	- 189,382	-
6	2016	229,554	5,876,590	20,568,066	8,638,588	4,405,680	16,168,844	- 227,259	-
7	2017	267,813	6,856,022	27,424,087	11,518,117	5,874,240	21,558,459	- 265,135	-
8	2018	306,072	7,835,453	35,259,541	14,809,007	7,552,594	27,718,019	- 303,012	-
9	2019	344,331	8,814,885	44,074,426	18,511,259	9,440,742	34,647,523	- 340,888	-
10	2020	382,591	9,794,317	53,868,743	22,624,872	11,538,685	42,346,973	- 378,765	-
11	2021	420,850	10,773,748	64,642,491	27,149,846	13,846,422	50,816,367	- 416,641	-
12	2022	459,109	11,753,180	76,395,671	32,086,182	16,363,953	60,055,707	- 454,518	-
13	2023	497,368	12,732,612	89,128,283	37,433,879	19,091,278	70,064,991	- 492,394	-
14	2024	535,627	13,712,044	102,840,327	43,192,937	22,028,398	80,844,221	- 530,270	-
15	2025	573,886	14,691,475	117,531,802	49,363,357	25,175,312	92,393,395	- 568,147	-
16	2026	612,145	15,670,907	133,202,709	55,945,138	28,532,020	104,712,514	- 606,023	-
17	2027	650,404	16,650,339	149,853,047	62,938,280	32,098,523	117,801,578	- 643,900	-
18	2028	688,663	17,629,770	167,482,818	70,342,783	35,874,820	131,660,588	- 681,776	-
19	2029	726,922	18,609,202	186,092,020	78,158,648	39,860,911	146,289,542	- 719,653	-
20	2030	765,181	19,588,634	205,680,653	86,385,874	44,056,796	161,688,441	- 757,529	-
21	2031	765,181	19,588,634	225,269,287	94,613,100	48,252,681	177,087,340	- 757,529	-
22	2032	765,181	19,588,634	244,857,920	102,840,327	52,448,567	192,486,239	- 757,529	-
23	2033	765,181	19,588,634	264,446,554	111,067,553	56,644,452	207,885,138	- 757,529	-
24	2034	765,181	19,588,634	284,035,188	119,294,779	60,840,337	223,284,037	- 757,529	-
25	2035	765,181	19,588,634	303,623,821	116,813,013	59,574,637	207,885,138	- 757,529	3,410,240
26	2036	765,181	19,588,634	283,030,000	108,163,608	59,574,637	207,885,138	- 757,529	3,410,240
27	2037	765,181	19,588,634	283,030,000	108,163,608	59,574,637	207,885,138	- 757,529	3,410,240
28	2038	765,181	19,588,634	283,030,000	108,163,608	59,574,637	207,885,138	- 757,529	3,410,240
29	2039	765,181	19,588,634	283,030,000	108,163,608	59,574,637	207,885,138	- 757,529	3,410,240
30	2040	765,181	19,588,634	283,030,000	108,163,608	59,574,637	207,885,138	- 757,529	3,410,240
31	2041	765,181	19,588,634	283,030,000	108,163,608	59,574,637	207,885,138	- 757,529	3,410,240
32	2042	765,181	19,588,634	283,030,000	108,163,608	59,574,637	207,885,138	- 757,529	3,410,240
33	2043	765,181	19,588,634	283,030,000	108,163,608	59,574,637	207,885,138	- 757,529	3,410,240
34	2044	765,181	19,588,634	283,030,000	108,163,608	59,574,637	207,885,138	- 757,529	3,410,240
35	2045	765,181	19,588,634	283,030,000	108,163,608	59,574,637	207,885,138	- 757,529	3,410,240
36	2046	765,181	19,588,634	283,030,000	108,163,608	59,574,637	207,885,138	- 757,529	3,410,240
37	2047	765,181	19,588,634	283,030,000	108,163,608	59,574,637	207,885,138	- 757,529	3,410,240
38	2048	765,181	19,588,634	283,030,000	108,163,608	59,574,637	207,885,138	- 757,529	3,410,240
39	2049	765,181	19,588,634	283,030,000	108,163,608	59,574,637	207,885,138	- 757,529	3,410,240
40	2050	765,181	19,588,634	283,030,000	108,163,608	59,574,637	207,885,138	- 757,529	3,410,240

Scenario 2: 1.8 million hectares

		Total ha	Established	Rotation, years	MAI, m^3 / ha / pa	Yeild, m^3 / ha			
Scen 2, 1.8 million hectares		1,855,669	over years	25	37.2	930			
Area Established per annum		74,227	25						
							Carbon stock	t / CO$_2$ yr, Displaced	t / CO$_{2\ yr,}$ Reduced
Year	Year	Area, ha	MAI, m3/pa	Volume, m3	Wood, odt	Carbon, t	t / CO$_2$ eq	emissions	transport emissions
1	2011	74,227	2,761,235	2,761,235	1,159,719	591,457	2,170,645	- 135,835	-
2	2012	148,454	5,522,471	8,283,706	3,479,156	1,774,370	6,511,937	- 271,670	-
3	2013	222,680	8,283,706	16,567,412	6,958,313	3,548,740	13,023,875	- 407,505	-
4	2014	296,907	11,044,942	27,612,354	11,597,189	5,914,566	21,706,458	- 543,340	-
5	2015	371,134	13,806,177	41,418,532	17,395,783	8,871,849	32,559,688	- 679,175	-
6	2016	445,361	16,567,413	57,985,944	24,354,097	12,420,589	45,583,563	- 815,010	-
7	2017	519,587	19,328,648	77,314,593	32,472,129	16,560,786	60,778,084	- 950,845	-
8	2018	593,814	22,089,884	99,404,477	41,749,880	21,292,439	78,143,251	- 1,086,680	-
9	2019	668,041	24,851,119	124,255,596	52,187,350	26,615,549	97,679,063	- 1,222,515	-
10	2020	742,268	27,612,355	151,867,950	63,784,539	32,530,115	119,385,522	- 1,358,350	-
11	2021	816,494	30,373,590	182,241,541	76,541,447	39,036,138	143,262,627	- 1,494,185	-
12	2022	890,721	33,134,826	215,376,366	90,458,074	46,133,618	169,310,377	- 1,630,020	-
13	2023	964,948	35,896,061	251,272,427	105,534,420	53,822,554	197,528,773	- 1,765,855	-
14	2024	1,039,175	38,657,297	289,929,724	121,770,484	62,102,947	227,917,815	- 1,901,690	-
15	2025	1,113,401	41,418,532	331,348,256	139,166,268	70,974,796	260,477,503	- 2,037,525	-
16	2026	1,187,628	44,179,768	375,528,024	157,721,770	80,438,103	295,207,837	- 2,173,360	-
17	2027	1,261,855	46,941,003	422,469,027	177,436,991	90,492,866	332,108,816	- 2,309,195	-
18	2028	1,336,082	49,702,238	472,171,265	198,311,931	101,139,085	371,180,442	- 2,445,029	-
19	2029	1,410,308	52,463,474	524,634,739	220,346,590	112,376,761	412,422,713	- 2,580,864	-
20	2030	1,484,535	55,224,718	579,859,458	243,540,972	124,205,896	455,835,638	- 2,716,700	-
21	2031	1,558,762	57,985,945	637,845,402	267,895,069	136,626,485	501,419,201	- 2,852,534	-
22	2032	1,632,989	60,747,180	698,592,583	293,408,885	149,638,531	549,173,410	- 2,988,369	-
23	2033	1,707,215	63,508,416	762,100,999	320,082,419	163,242,034	599,098,265	- 3,124,204	-
24	2034	1,781,442	66,269,651	828,370,650	347,915,673	177,436,993	651,193,765	- 3,260,039	-
25	2035	1,855,669	69,030,887	897,401,537	376,908,645	192,223,409	705,459,912	- 3,395,874	-
26	2036	1,855,669	69,030,887	828,370,650	347,915,673	177,436,993	651,193,765	- 3,395,874	12,017,780
27	2037	1,855,669	69,030,887	828,370,650	347,915,673	177,436,993	651,193,765	- 3,395,874	12,017,780
28	2038	1,855,669	69,030,887	828,370,650	347,915,673	177,436,993	651,193,765	- 3,395,874	12,017,780
29	2039	1,855,669	69,030,887	828,370,650	347,915,673	177,436,993	651,193,765	- 3,395,874	12,017,780
30	2040	1,855,669	69,030,887	828,370,650	347,915,673	177,436,993	651,193,765	- 3,395,874	12,017,780
31	2041	1,855,669	69,030,887	828,370,650	347,915,673	177,436,993	651,193,765	- 3,395,874	12,017,780
32	2042	1,855,669	69,030,887	828,370,650	347,915,673	177,436,993	651,193,765	- 3,395,874	12,017,780
33	2043	1,855,669	69,030,887	828,370,650	347,915,673	177,436,993	651,193,765	- 3,395,874	12,017,780
34	2044	1,855,669	69,030,887	828,370,650	347,915,673	177,436,993	651,193,765	- 3,395,874	12,017,780
35	2045	1,855,669	69,030,887	828,370,650	347,915,673	177,436,993	651,193,765	- 3,395,874	12,017,780
36	2046	1,855,669	69,030,887	828,370,650	347,915,673	177,436,993	651,193,765	- 3,395,874	12,017,780
37	2047	1,855,669	69,030,887	828,370,650	347,915,673	177,436,993	651,193,765	- 3,395,874	12,017,780
38	2048	1,855,669	69,030,887	828,370,650	347,915,673	177,436,993	651,193,765	- 3,395,874	12,017,780
39	2049	1,855,669	69,030,887	828,370,650	347,915,673	177,436,993	651,193,765	- 3,395,874	12,017,780
40	2050	1,855,669	69,030,887	828,370,650	347,915,673	177,436,993	651,193,765	- 3,395,874	12,017,780

Scenario 3: 3.3 million hectares

		Total ha	Established	Rotation, years	MAI, m^3 / ha / pa	Yeild, m^3 / ha			
Scen 3, 3.4 m	3.4	3386648	over years	25	37.2	930			
Area Established per annum		135,465	25						
							Carbon stock	t / CO_2 yr, Displaced	t / $CO_{2\ yr,}$ Reduced
Year	Year	Area, ha	MAI, m3/pa	Volume, m3	Wood, odt	Carbon, t	t / CO_2 eq	emissions	transport emissions
1	2011	135,466	5,039,332	5,039,332	2,116,519	1,079,425	3,961,489	- 292,471	-
2	2012	270,932	10,078,664	15,117,996	6,349,559	3,238,275	11,884,469	- 584,942	-
3	2013	406,398	15,117,997	30,235,993	12,699,117	6,476,550	23,768,937	- 877,413	-
4	2014	541,864	20,157,329	50,393,322	21,165,195	10,794,250	39,614,896	- 1,169,884	-
5	2015	677,330	25,196,661	75,589,983	31,747,793	16,191,374	59,422,344	- 1,462,355	-
6	2016	812,796	30,235,993	105,825,976	44,446,910	22,667,924	83,191,282	- 1,754,826	-
7	2017	948,261	35,275,326	141,101,302	59,262,547	30,223,899	110,921,709	- 2,047,296	-
8	2018	1,083,727	40,314,658	181,415,960	76,194,703	38,859,299	142,613,626	- 2,339,767	-
9	2019	1,219,193	45,353,990	226,769,950	95,243,379	48,574,123	178,267,032	- 2,632,238	-
10	2020	1,354,659	50,393,322	277,163,272	116,408,574	59,368,373	217,881,928	- 2,924,709	-
11	2021	1,490,125	55,432,654	332,595,927	139,690,289	71,242,047	261,458,314	- 3,217,180	-
12	2022	1,625,591	60,471,987	393,067,913	165,088,524	84,195,147	308,996,190	- 3,509,651	-
13	2023	1,761,057	65,511,319	458,579,232	192,603,278	98,227,672	360,495,555	- 3,802,122	-
14	2024	1,896,523	70,550,651	529,129,883	222,234,551	113,339,621	415,956,409	- 4,094,593	-
15	2025	2,031,989	75,589,983	604,719,867	253,982,344	129,530,995	475,378,753	- 4,387,064	-
16	2026	2,167,455	80,629,316	685,349,182	287,846,657	146,801,795	538,762,587	- 4,679,535	-
17	2027	2,302,921	85,668,648	771,017,830	323,827,489	165,152,019	606,107,910	- 4,972,006	-
18	2028	2,438,387	90,707,980	861,725,810	361,924,840	184,581,669	677,414,723	- 5,264,477	-
19	2029	2,573,852	95,747,312	957,473,122	402,138,711	205,090,743	752,683,026	- 5,556,948	-
20	2030	2,709,318	100,786,644	1,058,259,767	444,469,102	226,679,242	831,912,818	- 5,849,418	-
21	2031	2,844,784	105,825,977	1,164,085,744	488,916,012	249,347,166	915,104,100	- 6,141,889	-
22	2032	2,983,766	110,996,107	1,275,081,851	535,534,377	273,122,532	1,002,359,694	- 6,441,951	-
23	2033	3,115,716	115,904,641	1,390,986,492	584,214,327	297,949,307	1,093,473,955	- 6,726,831	-
24	2034	3,251,182	120,943,973	1,511,930,465	635,010,795	323,855,506	1,188,549,706	- 7,019,302	-
25	2035	3,386,648	125,983,306	1,637,913,771	687,923,784	350,841,130	1,287,586,946	- 7,311,773	-
26	2036	3,386,648	125,983,306	1,511,930,465	635,010,795	323,855,506	1,188,549,706	- 7,311,773	21,932,786
27	2037	3,386,648	125,983,306	1,511,930,465	635,010,795	323,855,506	1,188,549,706	- 7,311,773	21,932,786
28	2038	3,386,648	125,983,306	1,511,930,465	635,010,795	323,855,506	1,188,549,706	- 7,311,773	21,932,786
29	2039	3,386,648	125,983,306	1,511,930,465	635,010,795	323,855,506	1,188,549,706	- 7,311,773	21,932,786
30	2040	3,386,648	125,983,306	1,511,930,465	635,010,795	323,855,506	1,188,549,706	- 7,311,773	21,932,786
31	2041	3,386,648	125,983,306	1,511,930,465	635,010,795	323,855,506	1,188,549,706	- 7,311,773	21,932,786
32	2042	3,386,648	125,983,306	1,511,930,465	635,010,795	323,855,506	1,188,549,706	- 7,311,773	21,932,786
33	2043	3,386,648	125,983,306	1,511,930,465	635,010,795	323,855,506	1,188,549,706	- 7,311,773	21,932,786
34	2044	3,386,648	125,983,306	1,511,930,465	635,010,795	323,855,506	1,188,549,706	- 7,311,773	21,932,786
35	2045	3,386,648	125,983,306	1,511,930,465	635,010,795	323,855,506	1,188,549,706	- 7,311,773	21,932,786
36	2046	3,386,648	125,983,306	1,511,930,465	635,010,795	323,855,506	1,188,549,706	- 7,311,773	21,932,786
37	2047	3,386,648	125,983,306	1,511,930,465	635,010,795	323,855,506	1,188,549,706	- 7,311,773	21,932,786
38	2048	3,386,648	125,983,306	1,511,930,465	635,010,795	323,855,506	1,188,549,706	- 7,311,773	21,932,786
39	2049	3,386,648	125,983,306	1,511,930,465	635,010,795	323,855,506	1,188,549,706	- 7,311,773	21,932,786
40	2050	3,386,648	125,983,306	1,511,930,465	635,010,795	323,855,506	1,188,549,706	- 7,311,773	21,932,786

Scenario 4: 4.9 million hectares

		Total ha	Established	Rotation	MAI, m^3 / ha / pa	Yeild, m^3 / ha			
Scen 4, 4.9 million hectares		4927040	over years	25	36.32	908			
Area Established per annum		164,235	30						
							Carbon stock	t / CO_2 yr, Displaced	t / $CO_{2\ yr}$, Reduced
Year	Year	Area, ha	MAI, m3/pa	Volume, m3	Wood, odt	Carbon, t	t / CO_2 eq	emissions	transport emissions
1	2011	164,235	5,965,003	5,965,003	2,505,301	1,277,704	4,689,172	- 333,396	-
2	2012	328,469	11,930,006	17,895,009	7,515,904	3,833,111	14,067,517	- 666,793	-
3	2013	492,704	17,895,009	35,790,018	15,031,808	7,666,222	28,135,035	- 1,000,189	-
4	2014	656,939	23,860,012	59,650,031	25,053,013	12,777,037	46,891,724	- 1,333,585	-
5	2015	821,173	29,825,015	89,475,046	37,579,519	19,165,555	70,337,587	- 1,666,982	-
6	2016	985,408	35,790,019	125,265,065	52,611,327	26,831,777	98,472,621	- 2,000,378	-
7	2017	1,149,643	41,755,022	167,020,087	70,148,436	35,775,703	131,296,828	- 2,333,775	-
8	2018	1,313,877	47,720,025	214,740,111	90,190,847	45,997,332	168,810,208	- 2,667,171	-
9	2019	1,478,112	53,685,028	268,425,139	112,738,558	57,496,665	211,012,760	- 3,000,567	-
10	2020	1,642,347	59,650,031	328,075,170	137,791,571	70,273,701	257,904,484	- 3,333,964	-
11	2021	1,806,581	65,615,034	393,690,204	165,349,886	84,328,442	309,485,381	- 3,667,360	-
12	2022	1,970,816	71,580,037	465,270,241	195,413,501	99,660,886	365,755,450	- 4,000,756	-
13	2023	2,135,051	77,545,040	542,815,281	227,982,418	116,271,033	426,714,692	- 4,334,153	-
14	2024	2,299,285	83,510,043	626,325,325	263,056,636	134,158,885	492,363,106	- 4,667,549	-
15	2025	2,463,520	89,475,046	715,800,371	300,636,156	153,324,439	562,700,693	- 5,000,946	-
16	2026	2,627,755	95,440,049	811,240,421	340,720,977	173,767,698	637,727,452	- 5,334,342	-
17	2027	2,791,989	101,405,053	912,645,473	383,311,099	195,488,660	717,443,384	- 5,667,738	-
18	2028	2,956,224	107,370,056	1,020,015,529	428,406,522	218,487,326	801,848,487	- 6,001,135	-
19	2029	3,120,459	113,335,059	1,133,350,588	476,007,247	242,763,696	890,942,764	- 6,334,531	-
20	2030	3,284,693	119,300,062	1,252,650,650	526,113,273	268,317,769	984,726,213	- 6,667,927	-
21	2031	3,448,928	125,265,065	1,377,915,714	578,724,600	295,149,546	1,083,198,834	- 7,001,324	-
22	2032	3,613,163	131,230,068	1,509,145,783	633,841,229	323,259,027	1,186,360,628	- 7,334,720	-
23	2033	3,777,397	137,195,071	1,646,340,854	691,463,159	352,646,211	1,294,211,594	- 7,668,117	-
24	2034	3,941,632	143,160,074	1,789,500,928	751,590,390	383,311,099	1,406,751,732	- 8,001,513	-
25	2035	4,105,867	149,125,077	1,938,626,005	814,222,922	415,253,690	1,523,981,043	- 8,334,909	-
26	2036	4,270,101	155,090,080	2,093,716,086	879,360,756	448,473,986	1,645,899,527	- 8,668,306	27,000,066
27	2037	4,434,336	161,055,084	2,254,771,169	947,003,891	482,971,984	1,772,507,183	- 9,001,702	28,038,530
28	2038	4,598,571	167,020,087	2,421,791,256	1,017,152,327	518,747,687	1,903,804,011	- 9,335,098	29,076,995
29	2039	4,762,805	172,985,090	2,594,776,346	1,089,806,065	555,801,093	2,039,790,012	- 9,668,495	30,115,459
30	2040	4,927,040	178,950,093	2,773,726,438	1,164,965,104	594,132,203	2,180,465,185	- 10,001,891	31,153,923
31	2041	4,927,040	178,950,093	2,594,776,346	1,089,806,065	555,801,093	2,039,790,012	- 10,001,891	31,153,923
32	2042	4,927,040	178,950,093	2,594,776,346	1,089,806,065	555,801,093	2,039,790,012	- 10,001,891	31,153,923
33	2043	4,927,040	178,950,093	2,594,776,346	1,089,806,065	555,801,093	2,039,790,012	- 10,001,891	31,153,923
34	2044	4,927,040	178,950,093	2,594,776,346	1,089,806,065	555,801,093	2,039,790,012	- 10,001,891	31,153,923
35	2045	4,927,040	178,950,093	2,594,776,346	1,089,806,065	555,801,093	2,039,790,012	- 10,001,891	31,153,923
36	2046	4,927,040	178,950,093	2,594,776,346	1,089,806,065	555,801,093	2,039,790,012	- 10,001,891	31,153,923
37	2047	4,927,040	178,950,093	2,594,776,346	1,089,806,065	555,801,093	2,039,790,012	- 10,001,891	31,153,923
38	2048	4,927,040	178,950,093	2,594,776,346	1,089,806,065	555,801,093	2,039,790,012	- 10,001,891	31,153,923
39	2049	4,927,040	178,950,093	2,594,776,346	1,089,806,065	555,801,093	2,039,790,012	- 10,001,891	31,153,923
40	2050	4,927,040	178,950,093	2,594,776,346	1,089,806,065	555,801,093	2,039,790,012	- 10,001,891	31,153,923

Appendix 4:
Biodiversity in New Zealand plantation forests – current state of knowledge

Steve Pawson - Scion Research

New Zealand is a world leader in the adoption of exotic tree species to create large-scale plantations. The first plantations were established over 100 years ago (Roche 1990) on a range of different land types. Plantations have been established on degenerating agricultural land (currently reverting to exotic or native shrubland) and purposely cleared native forest lands. However, native forest conversion formally ceased with the adoption of the NZ Forest Accord (Anon 1991). New Zealand has a deeply entrenched division that separates conservation and productive land-use types. This paradigm has also contributed to a significant imbalance in research effort. Norton (2001) reviewed the focus of ecological research in New Zealand over the last 30 years and found that only 19% of all ecological research occurred on private land. Furthermore, only 27% of the 1311 articles considered exotic species (Norton 2001). This lack of basic ecological research on private land is reflected in our relatively poor understanding of native species diversity in plantation forests. Before the mid-1990s little was formerly published apart from a few studies on the native bird fauna and understorey vegetation. Since the 1990s additional avian research has focussed on threatened species; however, more comprehensive fundamental research has occurred on a greater variety of species including understorey vegetation, invertebrates, Herpetofauna, fish and bats. Here we provide a brief summary of the current knowledge about native species in New Zealand's plantation ecosystems.

Birds

An 8-year assessment of the birds of Kaingaroa Forest (central North Island) by Weeks (1949) is the earliest published record of wildlife research in New Zealand's exotic plantation forests. Since that time birds have been the subject of multiple studies, although geographically they have been restricted to the central North Island (Gibb 1961; Jackson 1971) or Nelson (Clout 1984; Clout & Gaze 1984). The most recent and comprehensive study by Seaton (2007) in Kaingaroa forest found that 89% of the abundance of birds was due to 8 species, including 4 native species, the silvereye (*Zosterops lateralis*), whitehead (*Mohoua albicilla*), tomtit (*Petroica macrocephala*) and the grey warbler (*Gerygone igata*). Total bird diversity was 31 species of which 13 were native. Seaton's findings corroborate earlier work by Clout and Gaze (1984) in the Golden Downs forests (upper South Island) that highlight the importance of plantations as habitat for insectivorous birds. In fact plantations have such high densities of some insectivorous birds, e.g., the NI-Robin (*Petroica australis*) that they have been used as a source to re-establish populations in native forest reserves (Armstrong *et al.* 2006).

Only two studies have attempted to assess changes in the abundance and composition of bird species as a function of plantation age (Clout & Gaze 1984; Seaton 2007). Seaton (2007) observed an increase in bird species richness and abundance with stand age. In contrast, Clout and Gaze (1984) recorded no increase in overall bird density, however they did note a shift in dominance from exotic species in young stands to increasing native species richness with stand age. The actual reason for the discrepancy between the two studies is unknown, but may be due to variations in methodology (Seaton 2007).

At least 10 threatened bird species have been recorded in plantation forests (Pawson, unpublished data). This includes the iconic North Island brown kiwi (*Apteryx australis mantelli*) (Kleinpaste 1990) and the native bush falcon (*Falco novaeseelandiae*) (Seaton et al. 2009; Seaton et al. 2007; Stewart & Hyde 2004). Threatened bird species are found throughout the entire 25-to 30-year rotation period, for example, falcons prefer recent clearfells, whereas kiwi and other species such as the long-tailed cuckoo (*Eudynamys taitensis*) prefer mature forest stands.

Plants

Exotic commercial tree species are the most obvious floristic element of our plantations. However, a rich diversity of native plants is often hidden in the understorey. High native vascular plant species richness in plantations was observed by Brockerhoff et al. (2003), Allen *et al.* (1995), and Ogden et al. (1997), with 202, 147 and 36 species recorded respectively. Note: Ogden *et al.* (1997) does not list total plant richness but do refer to 36 species of ground ferns. A recent study by Brockerhoff *et al.* (2003) covered the widest geographic range and unsurprisingly recorded the most native species. Their total of 202 species corresponds to approximately 10% of the NZ flora. Without doubt further surveys in other biogeographic regions will record other native plants living in plantations. Many of these plantations were established on typical pasture dominated by exotic species. Despite this native plants can rapidly colonise this newly afforested habitat, for example at Puruki forest (near Taupo) a 27-year-old pine stand established on pasture was found to accumulate 65 species of native plant (Brockerhoff *et al.* 2005a). Source populations of seed were present about 1km away, illustrating the dispersal power of these plants, which is mediated by birds and wind.

In addition to native species many exotic plants are also present, particularly weedy pioneer species that colonise recent clearfells (Allen *et al.* 1995). However, plant community composition follows a distinct successional pathway where young stands have a high number of exotic species that give way to native species as stands age (Allen *et al.* 1995; Brockerhoff et al. 2003). The time taken to recover to a pre-harvest understorey as not been studied in detail, although plant species richness has been shown in a small study to return to pre-harvest levels within 8 years (Pawson 2006).

Apart from stand age several critical abiotic factors influence plant species richness in plantations, including temperature and rainfall. Increases in either of these parameters (particularly moisture) can significantly increase the abundance and diversity of native plants in plantations (Brockerhoff et al. 2003). Furthermore, fine-scale variation due to changes in topographic position, e.g., moist toe slopes versus drier ridge crests, can have a significant effect on microclimatic and soil conditions, thus altering understorey plant communities (Allen *et al.* 1995). Other factors that influence native plant diversity in plantations are the variation in substrate (e.g., elevated seedling establishment sites) and distance to available seed sources (Ogden *et al.* 1997).

Concerns have been raised over the sustainability of the NZ plantation model. It has been suggested that short rotation times and whole tree extraction are detrimental and are not sustainable in the long-term (Rosoman 1994). Although a comprehensive project has not been undertaken to assess these claims, a basic comparison by Allen et al. (1995) of second rotation forests and earlier first rotation flora (McQueen 1961) showed few major changes to understorey plant diversity.

Vascular plants are the dominant group of threatened species known to utilise plantation forests. At least 64 species of threatened plants have been identified from plantations in their broadest sense (including embedded native remnants) (Pawson, unpublished data). The dominant threatened plant groups are shrubs (25 species) and dicot-herbs (18 species). Although many of the 64 species are found primarily in embedded native remnants, some thrive directly in plantation stands. Given the patchy nature of plant surveys in plantations, further research may identify additional threatened species.

Insects

Invertebrates have received comparatively less research attention than birds or plants. Studies to date have largely focussed on beetles and show that plantations can provide surrogate habitat for many native forest species (Berndt *et al.* 2008). Indeed, native beetle diversity is high in plantations (Hutcheson & Jones 1999; McLean & Jones 2006; Pawson 2006; Pawson *et al.* 2008). Studies of other invertebrate orders in NZ plantations are less common; however, an ordinal-level analysis across habitat edges between native and plantation forests by Neumegen (2006) found that the abundance of flies (Diptera), spiders (Araneae) were not different across a native – plantation forest edge, however millipede abundance (Diplopoda) increased significantly in plantation forest compared to adjacent native forest and pasture.

As yet little is known about the impact of specific forest management actions on insect diversity. We know that clearfell harvesting alters species composition and that the severity of this response is linked to clearfell harvest size (Pawson 2006). However, clearfell harvest sensitive species do recover post-harvest in regenerating stands (Pawson 2006). The recovery post-harvest is in part responsible for the differences observed in beetle species composition as a function of stand age. In a study of 5-, 14- and 30-year-old pine stands, Hutcheson and Jones (1999) found distinctly different beetle communities in Kaingaroa forest.

Bats and Herpetofauna

New Zealand's two species of bats are the only surviving native land mammals. The nationally vulnerable long-tailed bat (*Chalinolobus tuberculata*) was first reported from a plantation forest near Tokoroa in 1976 (Daniel 1981). Long-tailed bats have since been the subject of several intensive studies including a Masters thesis (Moore 2001) and PhD study currently underway. Field surveys using ultrasonic detectors and radio telemetry have shown that long-tailed bats are present and have roosts in stands of *Pinus radiata* and Eucalyptus spp. stands as well as indigenous reserve areas within Kinleith Forest (Kerry Borkin, pers. com.).

The most interesting herpetological feature of plantation forests is their ability to support populations of Hochstetter's frog (Leiopelma hochstetteri) in seepages, streams and riparian areas in both plantation stands and embedded native remnants from the upper North Island and Bay of Plenty. Baseline surveys of frog populations have been established in some regions and on-going monitoring has been conducted to assess the impacts of harvesting within the catchments. Considerable inter-annual variation in frog numbers has been recorded; however, this has been attributed to seasonal microclimatic factors affecting survey efficiency (Douglas 2001). Two streams that were affected by harvesting and an associated wind throw event in 1997 were resurveyed in 2001 and the habitat quality and L. hochstetteri populations were both recovering from the disturbance (Douglas 2001).

Freshwater Fish

Native fish assemblages in plantation and native forest streams are more similar to each other than those found in agricultural streams (Rowe *et al.* 1999). The tall stature of mature plantation trees maintains key stream attributes such as incident light and water temperature (Quinn *et al.* 1997), although forest management practices can have significant impacts on aquatic ecosystems, largely through temporary changes in stream volume, stream temperatures and sediment runoff (Fahey 1994; Morgan & Graynoth 1978; Quinn & Wright-Stow 2008). The severity of many of these in-stream impacts of harvesting have been reduced by the extensive use of riparian vegetation buffer strips. Riparian buffers are designed to separate aquatic ecosystems from forest management impacts (Boothroyd & Langer 1999; Harding et al. 2000; Rowe *et al.* 2002). At present, the maintenance of riparian vegetation is a key performance indicator in the; environmental principles of the Forest Stewardship Council (FSC), NZ Environmental Code of Practice for Plantation Forestry (NZFOA 2007) and as a condition for forestry as a permitted activity by many regional councils.

An important caveat to the value of plantation forest as habitat for fish species is the high percentage of diadromous species in New Zealand (McDowall 1990). The absence of some diadromous fish from plantation streams may be independent of silvicutural management and could be due to down-stream factors, such as degradation of the migratory passage or artificially induced dispersal barriers (Eikaas & McIntosh 2006). For example, parts of the Kaingaroa Forest are situated in many of the headwaters and tributaries of the Rangitaiki River. The flow of the Rangitaiki is interrupted by both the Matahina and Aniwhenua dams. Such dams are known to impact severely on the migration of diadromous fish. Natural barriers also exist, for example, streams in the southern Kaingaroa Forest drain into Lake Taupo. The Huka falls just below the lakes outflow present a similar but natural barrier to the upstream migration of fish.

Appendix 5: Abbreviations

C	Carbon
CH_4	Methane
CO_2	Carbon dioxide
CO_2e	Carbon dioxide equivalent
GHG	Greenhouse gas
ha	hectare
IPCC	Intergovernmental Panel on Climate Change
LCDB	Land cover database
LRI	Land resource inventory database
LULUCF	Land use, land use change and forestry
LUNZ	Land Use New Zealand database
kt	10^3 tonnes (kilotonnes)
MAI	Mean annual increment
MED	Ministry for Economic Development
MfE	Ministry for the Environment
Mha	10^6 hectares
Mt	10^6 tonnes (megatonne)
N	Nitrogen
NIR	National inventory report
N_2O	Nitrous oxide
pa	per annum
su	stock unit
t	Tonne
UNFCCC	United Nations Framework Convention on Climate Change

Chapter 3

Competition for land between biofuels, pastoral agriculture and scrub lands

Maribeth Todd, Wei Zhang and Suzi Kerr

Introduction

In this chapter we explore three questions: how economically viable are biofuels likely to be given the alternative uses of the land it competes for? What level of response to the opportunity to grow biofuels can we expect from landowners? What would the effects of biofuel production be on food production in New Zealand?

This chapter complements analysis by Adolf Stroombergen (Infometrics) in chapter 4 on the general equilibrium effects of biofuel production and informs the choice of elasticities between biofuels and livestock production in the general equilibrium model.

Any biofuel production will occur on land that is currently being used for something else. Landowners will lose the profits from this existing activity if they move to biofuel production. They need to be offered a level and reliability of profits that are sufficiently attractive to induce them to change land use.[4] These displaced profits are reflected in the land rent (or land cost) that Scion incorporates in their cost structure. We want to estimate how much landowners are currently earning from land that is likely to transition and also how much they are likely to need to be offered to induce them to change land use. The loss of profit is directly linked to a loss in production so we estimate this simultaneously. This provides a key input to the general equilibrium modelling. We use two contrasting methodologies to estimate profitability and likely land use responses so we can gain insight into the robustness of each methodology and interpret the differences between them. One is a traditional comparison of profitability. Its advantage is that it uses detailed spatial data on actual profitability. Its shortcoming is that it implicitly assumes that landowners simply move to the land use that is on average the most profitable. This assumes that landowners choose the currently most profitable land use. This ignores many of the features of landowners' optimisation decisions. Many purely economic differences such as access to capital, the cost of farm labour (which is dependent on the size and ages of the landowner's family and other idiosyncratic factors) and subtle differences in productive capacity between farms are hard to observe. Some land use decisions will have long term implications. Facing costs of conversion, landowners will only change land use if they think that the higher profitability in the new use will persist.

Landowners also must make decisions under highly uncertain conditions. What appears to be a good decision now, may turn out badly. This is not a big problem if land use decisions are easily reversed. Where a new land use is hard to reverse, however, the extra anticipated profit from moving into it must be higher to justify the transition than the required profit would be in a certain world. Biofuels are a long-term land use option. Landowners that choose it are losing some of their future flexibility – economists call the value of this flexibility the 'option value'. While landowners are carrying out an economic activity non-economic factors such as differences in landowners' goals are also important particularly where the land use is an integral part of their lifestyle because they live and work on the land.

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[4] Or a land price that persuades them to sell to someone who will produce biofuel. Simplistically, the land price should be the present value of the future stream of profits from the land.

To implement this methodology we take data on farm profitability and stock numbers and, using data on the location of pasture, regional distribution of farm classes, and land quality, create maps of returns and livestock production. By overlaying maps of areas expected to convert to biofuels, we can extract the characteristics of the alternative land uses biofuels would need to displace.

The second approach estimates land use change based on historical evidence of the relationship between changes in commodity prices (as a proxy for profitability) and land use. The data used here are less detailed but this has the advantage of encapsulating all aspects of real behaviour.

We use the Land Use in Rural New Zealand model (LURNZ) to simulate the likely impacts on land use of the opportunity to produce biofuel at varying levels of profitability. The first version of LURNZ cannot directly simulate land use changes in response to a potential return to biofuels. However, if we assume that biofuel forestry and scrub areas both compete with low quality sheep and beef farms for land, we can use previous modelling of the likely response of scrub reversion to a reward for the carbon sequestered in scrub ((Shepherd *et al.*) and (Kerr, Power, and Zhang)) to infer what will happen to the area of biofuel forestry.

The previous analysis used version 1 of LURNZ- (Hendy, Kerr, and Baisden) -which is based on econometrically estimated relationships between national rural land use shares and commodity prices associated with four key land uses: dairy, sheep/beef, forestry and scrub. They assumed the sheep-beef land would respond to a price on scrub in the same way that scrub responds to a change in the price of sheep-beef land (Slutsky symmetry). In this paper, we use the same method to simulate a return to biofuel production.

Our methodologies are very data intensive. We use data that vary spatially and sectorally. Rather than trying to forecast these data, thereby introducing potentially important and non-transparent assumptions, we focus on how biofuels would play out if the future world looks much like today, where today is spatially defined in 2002 and, in terms of agricultural profitability, defined as the average over the period 2000 – 2008. The only way we incorporate likely changes in the future is that we consider the effect that application of the emissions trading system to agriculture would have. We include this because the impacts on biofuels are too significant to ignore.

The paper next describes the data sources used. Finally we present and discuss our results.

Data

Method 1: Estimate alternative profit and output on land displaced by Scion biofuel scenarios

Scion provided four mapped scenarios for land that could potentially be converted to biofuels.[5] We take these as given. Each scenario has a set of criteria based on elevation, slope, private ownership, land cover and farm type which results in a particular area of land being available for conversion to biofuel production. These scenarios are not strictly nested, so while the 4.9 million hectare scenario is the largest area of land, the 3.4 million hectare scenario includes land that is not included in the largest scenario. This means that we estimate a greater loss of production and higher cost of land, than is necessary for the smallest scenarios and the non-linearity of the relationship between loss of sheep/beef production and increase in biofuels is understated.

0.8 million ha scenario

The strictest biofuel scenario includes land in only two land cover types, “Low Producing Grassland” and “Depleted Grassland” and only those areas where the farm type is reported in the Agribase enhanced LCDB2 as beef (BEF), deer (DEE), grazing (GRA), idle (NOF), sheep (SHP), sheep and beef (SNB) or unspecified (UNS). This leads to a total of 831,158 hectares available for conversion to biofuels. This scenario is presumed to include the lowest quality land of the four scenarios, capable of producing 640 cubic meters of wood per hectare for biofuel production.

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[5] See the Scion report "Evaluation of Land Use Change and Recoverable Biomass for 4 Afforestation Scenarios for Large-Scale Bioenergy," (Hall *et al.* 2008) for more information on how these were created.

1.8 million ha scenario

In addition to the land in the 0.8 million scenario, the 1.8 million hectare scenario includes the land cover type “High Producing Grassland” that is not classified as a beef farm in Agribase/LCDB2. This scenario does not require that scrubland have a farm type, so all scrubland in land cover types “Gorse and Broom” and “Mixed Exotic Shrubland” that meets the other criteria (slope, elevation, LUC and not public land) is available for conversion under this scenario. These criteria result in 1,855,669 hectares of land for biofuel production. Relative to the 0.8 million ha scenario, some very low quality land (scrub) is added as is some high quality land (high producing grassland) but some other high quality land (less than 7 degree slope) is removed.

3.4 million ha scenario

The 3.4 million ha scenario includes all of the land in the 1.8 million scenario and additionally allows land with slopes less than 7 degrees. This scenario allows for 3,474,550 hectares of land to be converted into biofuel production. The 1.8 and 3.4 million scenarios include the highest quality land on average of the four scenarios presented here and Scion’s assumption is that this land is capable of producing 930 cubic meters of wood per hectare on average.

4.9 million ha scenario

The 4.9 million ha scenario allows elevations up to 1000m in both the North and South Islands and includes a total of 4,927,040 hectares of land. This scenario expands biofuel production onto more low quality land (higher altitude) than the mid-range scenarios, so average volume per hectare of wood production is assumed to be slightly lower, 908 cubic meters per hectare.

We converted these to a 25-hectare grid in order to align them with some of the Motu data layers. This rasterization will lead to some distortion from the original polygon data but generally preserves total areas.

Profit data

Our goal is to assign potential profitability and output values for the land in its current use to each 25-hectare grid cell. Profit values for sheep and beef farms were estimated from Meat and Wool NZ farm financial data. Meat and Wool NZ reports average financial data and also average effective farm area for eight different farm classes across five regions in New Zealand.

Table 14 in Appendix A contains a description of these farm classes. The sheep and beef farm profit values used for this analysis are Earnings Before Interest and Taxes (EBIT), averaged over 2000 to 2008 and inflation-adjusted to 2007 dollars. These data were used to calculate EBIT per hectare by region and class, shown in Table .

Table 1: Average (2000 to 2008) sheep/beef EBIT per effective hectare by region and farm class in 2007 dollars

Production Region	Farm Class								
	1	2	3	4	5	6	7	8	9 (average)
East Coast			$124	$269	$356				$228
Marlborough-Canterbury	$14	$73				$212		$475	$132
Northland-Waikato-BoP			$155	$237	$438				$245
Otago-Southland	$14	$112				$245	$467		$179
Taranaki-Manawatu			$155	$276	$332				$240
New Zealand (average)	$14	$80	$140	$258	$374	$225	$467	$475	$186

Direct financial effects of the emissions trading system (ETS)

Emissions were estimated for an average farm in each region/class. There are four sources of greenhouse gas emissions on a sheep and beef farm: fuel usage, electricity usage, fertilizer and livestock. These emissions are converted into a standard unit, tonnes of CO_2 equivalent, to determine the total emissions liability per effective hectare by farm class and region. Details on how emissions from each of these sources were estimated can be found in Appendix B. We assume a carbon price of $25 per ton of CO_2 equivalent and report estimated EBIT net of ETS costs per hectare by farm class and region in Table .

Table 2: Average (2000 to 2008) sheep/beef EBIT per hectare by region and farm class with ETS, assuming \$25 per tonne of CO_2 in 2007 dollars

	Farm Class								
	1	2	3	4	5	6	7	8	9
Production Region									(average)
East Coast			\$74	\$202	\$285				\$167
Marlborough-Canterbury	\$5	\$44				\$147		\$442	\$98
Northland-Waikato-BoP			\$96	\$164	\$372				\$176
Otago/Southland	\$2	\$68				\$189	\$395		\$140
Taranaki-Manawatu			\$93	\$204	\$253				\$171
New Zealand (average)	\$4	\$49	\$85	\$187	\$303	\$163	\$395	\$442	\$138

Data on stock numbers

Stock numbers are opening animals from Meat and Wool NZ farm financial data. Sheep and beef animal numbers are aggregated into a measure of stock units using a conversion factor based on the amount of feed that each animal requires. As defined in the MAF Pastoral Supply Response Model, one sheep is roughly equivalent to 0.92 stock units and one cow is equivalent to 4.87 stock units.

Assigning data to geographic areas

We need a map of sheep and beef farm classes to assign these profit and stocking values geographically. Agribase Enhanced LCDB2, converted to a 25-hectare grid, and a map of land quality serve as the basis for this assignment. Agribase/LCDB2 is used to identify land that is classified as sheep, beef or sheep and beef farming. To this area, we add a small amount of other pastureland, including deer farms, grazing land or other farm types, identified by Scion as potential biofuel land. Land quality is measured by land use capability (LUC) and within each LUC class, by pastoral productivity. We assign farm class by assuming that the highest value farm types will be located on the highest quality land.

Meat and Wool NZ provided us with estimates of the effective area of each farm class in each region for 2002. These data were used to determine what proportion of the sheep and beef (and other) farm area identified from Agribase/LCDB2 should be assigned to each class within each region. Table 3 shows how the farm classes were distributed in each region by LUC class. LUC class 8 is the worst quality land and NI Hard Hill Country and SI High Country are the lowest value per hectare farm classes. Additional details on how this map was created can be found in Appendix C.

Table 3: Allocation of Farm class by land use capability class

Region	Farm Class	LUC
Northland-Waikato-Bay of Plenty	NI Hard Hill Country	6, 7, 8
Northland-Waikato-Bay of Plenty	NI Hill Country	3, 4, 5, 6
Northland-Waikato-Bay of Plenty	NI Intensive Finishing	1, 2, 3
East Coast	NI Hard Hill Country	6, 7, 8
East Coast	NI Hill Country	4, 5, 6
East Coast	NI Intensive Finishing	1, 2, 3, 4
Taranaki-Manawatu	NI Hard Hill Country	6, 7, 8
Taranaki-Manawatu	NI Hill Country	2, 3, 4, 5, 6
Taranaki-Manawatu	NI Intensive Finishing	1, 2
Marlborough-Canterbury	SI High Country	6, 7, 8
Marlborough-Canterbury	SI Hill Country	6
Marlborough-Canterbury	SI Finishing-Breeding	3, 4, 5, 6
Marlborough-Canterbury	SI Mixed Finishing	1, 2, 3
Otago-Southland	SI High Country	6, 7, 8
Otago-Southland	SI Hill Country	6
Otago-Southland	SI Finishing-Breeding	4, 5, 6
Otago-Southland	SI Intensive Finishing	1, 2, 3, 4

All pastureland is assigned potential sheep and beef farming profits in this analysis. Other farm types are assigned to some of this land, such as deer, grazing or idled land, however these areas are small. For the three smaller scenarios, between 4 and 5 percent of included pasture land is in a use other than sheep and beef. For the largest scenario, 4.9 million hectares, about 5 percent of pasture on the North Island and 9 percent of included pasture on the South Island are classified as another farm type. We assume that all pasture could potentially support sheep and beef farms in the current land cover, so sheep and beef profits are used for all farm types. They may be a lower bound on profits for this land. The 0.8 million scenario is all pasture land, so all land is assigned sheep and beef profits. The 1.8, 3.4 and 4.9 million scenarios include pasture of various farm types and scrubland, so pasture is assigned potential sheep and beef profits and scrubland is assigned zero profits.

Similarly, we estimate the production loss from conversion of sheep and beef farms to biofuel production by mapping the number of animals stocked on displaced hectares by farm class and region. Again, we assume that all pasture land included in Scion's scenarios is in sheep and beef farming. We assume scrubland has zero stock.

Cost structure for biofuel production

Cost estimates for biofuel production were provided by Scion. There are two types of costs of biofuel production. The first is the cost of forestry incurred over the lifespan of the forest, and the second is the conversion of woody biomass to fuel. Minimal management is performed on the forest, so the most significant costs of forestry are land preparation and planting at the beginning of the rotation, and roading and logging at harvest time. Once the trees are harvested, they must be transported, comminuted and processed into biofuel, incurring significant costs after harvest.

The following assumptions have been incorporated into Scion's cost structure.

- Trees are harvested in 25-year rotations.
- The volume of wood produced per hectare depends on the quality of the land, as described above.
- Logging costs are $38 per ton (cubic meter.)
- Roads must be built to access the forest at a rate of 1 km per 20 hectares of logging and cost $3,750 per hectare to build.
- Wood must be transported 75 km for processing.
- Each cubic metre of wood can produce 140 litres of ethanol.
- Each litre of ethanol produces the same amount of energy as 0.67 litres of petrol.
- Land rent is $280 per hectare per year (This depends on the assumed interest rate, here it is 8 percent.)

We take all these assumptions as given except the land rent assumption.

Method 2: Land Use in Rural NZ Model

The data for LURNZ come from a wide variety of sources and are described in (Hendy, Kerr, and Baisden). These were updated in (Kerr, Power, and Zhang).

Results

Method 1: Estimate alternative profit on land displaced by Scion biofuel scenarios

Displacement of profit

Table 4 shows how the 0.8 million ha are allocated across farm types. Most is in the South Island and nearly two thirds are currently returning less than $100 per year.[6] When the effects of the ETS are included (assuming no change in farm management in response) the benefit to New Zealand from 80% of the displaced ha is below $100. To put this in perspective, we see in Table 10 that in New Zealand as a whole, only 30% of sheep/beef land has value this low (44% with emissions cost included). However, a large area of very low value sheep/beef land in New Zealand is not exploited in this scenario.

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[6] The small area displaced that is suggested to be currently returning over $400 probably just indicates the effect of the lower resolution of our data relative to the underlying Scion maps.

Table 4: 0.8 million hectare scenario, area of land by potential sheep and beef farm returns (EBIT) without ETS and with ETS and CO_2 price of $25 per ton

	Area of land in hectares by returns per ha in 2007$ without ETS					Total area for conversion
	$0 - 100	$100-200	$200-300	$300-400	$400-500	All values
North Island	0	52,250	33,500	75	0	85,825
South Island	527,975	89,725	127,850	0	100	745,650
NZ	527,975	141,975	161,350	75	100	831,475

	Area of land in hectares by returns per ha in 2007$ with ETS					Total area for conversion
	$0 - 100	$100-200	$200-300	$300-400	$400-500	All values
North Island	52,250	13,650	19,925	0	0	85,825
South Island	617,700	127,850	0	0	100	745,650
NZ	669,950	141,500	19,925	0	100	831,475

In the 1.8 million scenario shown in Table 5, only an extra 100,000 ha of low value land is added (probably scrub), while large areas of moderate profitability begin to be displaced.

Table 5: 1.8 million hectare scenario, area of land by potential sheep and beef farm returns (EBIT) without ETS and with ETS and CO_2 price of $25 per ton

	Area of land in hectares by returns per ha in 2007$ without ETS					Total area for conversion
	$0 - 100	$100-200	$200-300	$300-400	$400-500	All values
North Island	52,125	420,975	441,550	1,300	0	915,950
South Island	572,800	107,550	257,425	0	100	937,875
NZ	624,925	528,525	698,975	1,300	100	1,853,825

	Area of land in hectares by returns per ha in 2007$ with ETS					Total area for conversion
	$0 - 100	$100-200	$200-300	$300-400	$400-500	All values
North Island	473,100	111,700	331,150	0	0	915,950
South Island	680,350	257,425	0	0	100	937,875
NZ	1,153,450	369,125	331,150	0	100	1,853,825

In Table 6 we see that around 300 thousand ha of low value South Island land and nearly 1 million hectares of land with returns between $200–300 are added by relaxing the restriction that excludes land with a slope of less than 7 degrees.

Table 6: 3.4 million hectare scenario, area of land by potential sheep and beef farm returns (EBIT) without ETS and with ETS and CO_2 price of $25 per tonne

	Area of land in hectares by returns per ha in 2007$ without ETS					Total area for conversion
	$0-100	$100-200	$200-300	$300-400	$400-500	All values
North Island	69,700	725,575	1,148,475	6,500	25	1,950,275
South Island	883,425	157,850	482,775	0	800	1,524,850
NZ	953,125	883,425	1,631,250	6,500	825	3,475,125

	Area of land in hectares by returns per ha in 2007$ with ETS					Total area for conversion
	$0 - 100	$100-200	$200-300	$300-400	$400-500	All values
North Island	795,275	377,725	777,250	25	0	1,950,275
South Island	1,041,275	482,775	0	0	800	1,524,850
NZ	1,836,550	860,500	777,250	25	800	3,475,125

Finally in Table 7 we can see the effect of the addition of high elevation and LUC class 4 land. Nearly half a million hectares of low return land is added, mostly in the South Island, along with more than 700 thousand ha of medium return land (200–300 per ha), relatively evenly spread across the islands. The decrease in low value land in the North Island seen from Table 6 to Table 7 is likely due to the change in the scrub criteria between the two scenarios. The 3.4 million ha scenario includes scrub regardless of the fact that it does not have a farm type in Agribase/LCDB2. The 4.9 million ha scenario subjects all land with a blank farm type (including all scrub) to the additional criteria that it must have slope greater than 15 degrees and LUC greater than 4.

Table 7: 4.9 million hectare scenario, area of land by potential sheep and beef farm returns (EBIT) without ETS and with ETS and CO_2 price of $25 per ton

	Area of land in hectares by returns per ha in 2007$ without ETS					Total area for conversion
	$0 - 100	$100-200	$200-300	$300-400	$400-500	All values
North Island	68,600	857,375	1,552,875	25,175	50	2,504,075
South Island	1,416,375	192,650	809,725	0	2,675	2,421,425
NZ	1,484,975	1,050,025	2,362,600	25,175	2,725	4,925,500
	Area of land in hectares by returns per ha in 2007$ with ETS					Total area for conversion
	$0 - 100	$100-200	$200-300	$300-400	$400-500	All values
North Island	925,975	636,800	941,250	50	0	2,504,075
South Island	1,609,025	809,725	0	1,600	1,075	2,421,425
NZ	2,535,000	1,446,525	941,250	1,650	1,075	4,925,500

For comparison, Table 8 shows the total effective area of sheep and beef farming by profit level, derived from the sheep and beef farm class map created for this project. These areas include all land identified in Agribase/LCDB2 as BEF, SHP, or SNB regardless of land cover type as well as the small areas of other farm types included as potential biofuel land. Scrubland is not included. By this measure, total effective area of sheep and beef farming in 2002 was 3.35 million hectares for the North Island and 5.20 million hectares for the South Island. Nearly 95 percent of the land included in the 4.9 million hectare scenario is pasture, so converting this land to biofuel production would displace more than half of all sheep and beef farms in New Zealand.

The $0-$100 columns in the tables above also include a small amount of scrubland for the 1.8, 3.4 and 4.9 mill scenarios. We estimate the total area of scrub in land cover types “Gorse and Broom” and “Mixed Exotic Shrubland” on non-DOC land in 2002 was about 77,000 hectares in the North Island and 157,500 hectares in the South Island. So even though almost all of this scrub is converted to biofuel production under the larger scenarios, it still makes up a relatively small proportion of total converted land.

Table 8: Total effective area of sheep and beef farming in 2002 by EBIT values

	Area of land in hectares by returns per ha in 2007$ without ETS					Total area for conversion
	$0 - 100	$100-200	$200-300	$300-400	$400-500	All values
North Island	0	911,375	1,918,475	392,400	124,125	3,346,375
South Island	2,610,625	238,150	1,588,150	0	765,875	5,202,800
NZ	2,610,625	1,149,525	3,506,625	392,400	890,000	8,549,175
	Area of land in hectares by returns per ha in 2007$ with ETS					Total area for conversion
	$0 - 100	$100-200	$200-300	$300-400	$400-500	All values
North Island	911,375	873,200	1,437,675	124,125	0	3,346,375
South Island	2,848,775	1,588,150	0	523,250	242,625	5,202,800
NZ	3,760,150	2,461,350	1,437,675	647,375	242,625	8,549,175

The lowest value per hectare farm land on the South Island is High Country, defined by Meat and Wool NZ as extensive run country located at high altitudes carrying fine wool sheep. Much of this land is excluded from potential biofuel land, particularly for the smaller scenarios, by including only elevations less than 700 meters. However, the largest scenario, 4.9 million hectares, includes land up to 1000 meters in elevation. Accordingly, there is a significant jump in the area of the lowest value farmland included in the 4.9 mill scenario compared with the 3.4 million hectare scenario. The lower quality farm classes on the North Island, Hard Hill Country and Hill Country, are not generally located at very high elevations so these areas are not excluded from potential biofuel production by the elevation criteria.

The average returns per hectare, reported in Table 99, are fairly consistent with Scion's initial assumptions about land productivity under each scenario. Their cost structure assumes that the smallest scenario will convert the lowest quality land, supporting only 640 cubic meters of woody biomass per hectare. The 1.8 and 3.4 mill scenarios will convert higher quality land on average, able to produce 930 cubic meters per hectare. The 4.9 mill scenario will start to expand into more marginal land, supporting slightly less wood production on average, at 908 cubic meters per hectare. The average value per hectare of land converted to biofuels under the 0.8 mill scenario is $94 without ETS. The average returns per hectare for the 1.8 and 3.4 mill scenarios are $144 and $162 respectively and average returns on land included in the 4.9 mill scenario are $160 per hectare.

Table 9: Annual profit (EBIT) on pasture and scrub land converted to biofuels for all four scenarios (average 2000–08, 2007$)

	Total value for all land converted		Average value per hectare	
	Without ETS	with ETS	without ETS	with ETS
0.8 mill scenario				
North Island	$16,313,425	$10,915,650	$190	$127
South Island	$61,663,575	$39,062,875	$83	$52
New Zealand	$77,977,000	$49,978,525	$94	$60
1.8 mill scenario				
North Island	$174,179,150	$120,302,100	$190	$131
South Island	$92,254,600	$64,341,225	$98	$69
New Zealand	$266,433,750	$184,643,325	$144	$100
3.4 mill scenario				
North Island	$400,333,100	$280,034,875	$205	$144
South Island	$163,879,775	$116,439,950	$107	$76
New Zealand	$564,212,875	$396,474,825	$162	$114
4.9 mill scenario				
North Island	$526,213,650	$338,200,850	$210	$135
South Island	$260,644,050	$191,614,125	$108	$79
New Zealand	$786,857,700	$529,814,975	$160	$108

These profit values suggest that the land costs incorporated into Scion's initial estimates of growing cost structure may be unnecessarily high. With the least restrictive criteria, the 4.9 mill scenario includes more than 2.5 million hectares of land that are earning less than $200 per hectare in sheep and beef farming, compared with Scion's land rent estimation of $280 per hectare per year. Average returns for all land in this scenario are $160 per hectare without ETS. With the ETS the value of displaced profit falls even further – to only $108 per hectare on average - and around 2.5 million hectares are earning less than $100 per hectare.

The 0.8 mill scenario, which is the lowest cost per hectare option of these four scenarios, does not include any scrubland. It is likely that conversion of 800,000 hectares of land into biofuels could be achieved at a lower cost per hectare than that presented here by allowing scrubland to be used for biofuel production. Even where scrubland is included it is limited to only two classes of scrub. Manuka/Kanuka scrub is not considered eligible for conversion. This may be a very limiting assumption.

We can also compare the area of sheep and beef farming identified in Agribase/LCDB2 with area of sheep and beef farming estimated by Meat and Wool NZ. Meat and Wool NZ estimates the effective area of sheep and beef farming to be about 3.4 million hectares for the North Island and 5.8 million hectares for the South Island (as of 2002). Agribase/LCDB2, the basis for identifying potential land for conversion in this analysis, identifies about 3.2 million hectares effective area of sheep and beef farming on the North Island and 5.0 million hectares on the South Island. Depending on which dataset we believe to be more accurate, about a million hectares of sheep and beef land of varying quality may not be considered here. Thus the potential for biofuel production may be understated.

Displacement of production

Table 10 reports total stock units lost and the percentage of the national livestock population lost for each scenario. We assume that production is proportionate to livestock numbers.

Table 10: Impact on livestock numbers from conversion of farmland to biofuels

Scenario	Total stock units lost	Percent stock lost
0.8 mill		
North Island	778,400	2.34
South Island	2,833,575	9.23
New Zealand	3,611,975	5.65
1.8 mill		
North Island	7,868,625	23.69
South Island	4,011,100	13.06
New Zealand	11,879,725	18.59
3.4 mill		
North Island	17,520,300	52.75
South Island	7,012,175	22.84
New Zealand	24,532,475	38.38
4.9 mill		
North Island	22,924,175	69.03
South Island	11,098,450	36.15
New Zealand	34,022,625	53.23

Aggregating average stocking rates per hectare by the total effective area of sheep and beef farms reported by Meat and Wool NZ, the total population of sheep and beef for 2002 was 33.2 million stock units for the North Island and 30.7 million stock units for the South Island. The smallest scenario, 0.8 million hectares, results in a 5.3 percent loss in stock units while the largest scenario would cause a decrease in stock units of about 52.3 percent nationally. Average stocking rates per hectare tend to be higher for North Island farms than South Island, so sheep and beef production on the North Island is affected more significantly by conversion to biofuel production.

The most interesting result is that the effect of expanding the scenarios on production loss is non-linear. When very low quality land is converted to biofuels, the loss of production is relatively low (even when scrub land is excluded from the scenario). The loss per hectare grows at first and then stabilises.

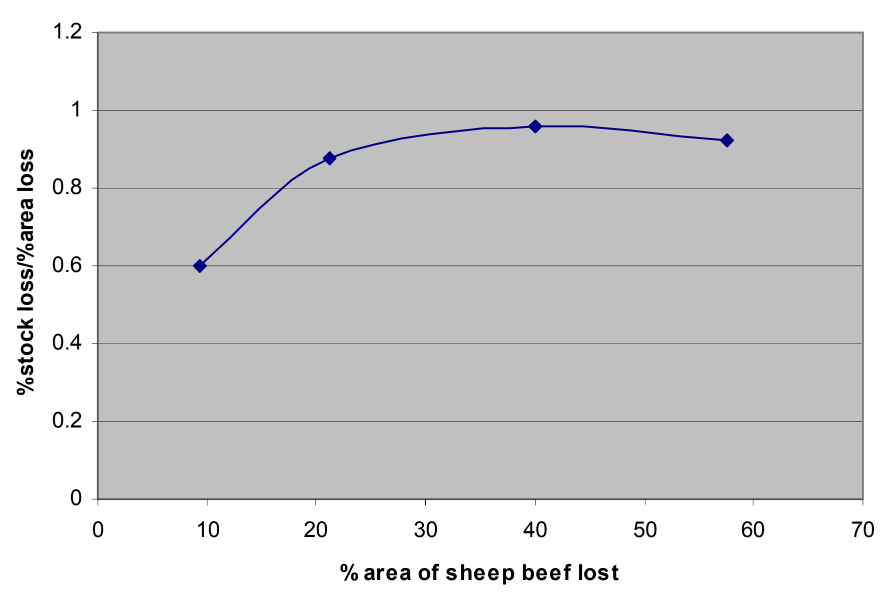

Figure 1: Percentage loss of stock relative to percentage area converted across scenarios

Comparison with potential return from biofuel

Biofuel production costs, provided by Scion, were converted from dollars per litre to dollars per hectare in order to compare potential biofuel returns to other uses. The $/ha figures shown in Table 11 are total costs accumulated over a 25-year forest growing cycle, adjusted to year 25 (the time of harvest and fuel production) using a discount rate of 8 percent. We assume zero cost for land rental so that we can infer returns on the land across different uses.

Table 11: Biofuel growing and production costs by scenario

Expense	0.8 mill		1.8 mill and 3.4 mill		4.9 mill	
	$/litre	$/ha	$/litre	$/ha	$/litre	$/ha
Capex	0.620	55,552	0.620	80,724	0.620	78,814
Land	-	-	-	-	-	-
Grow	0.144	12,895	0.099	12,895	0.101	12,895
Road	0.046	4,131	0.032	4,131	0.032	4,131
Log	0.271	24,320	0.271	35,340	0.271	34,504
Transport	0.123	11,003	0.123	15,989	0.123	15,611
Comminution	0.030	2,688	0.030	3,906	0.030	3,814
Handling	0.010	896	0.010	1,302	0.010	1,271
Enzymes	0.150	13,440	0.150	19,530	0.150	19,068
Electricity	0.130	11,648	0.130	16,926	0.130	16,526
Chemicals	0.030	2,688	0.030	3,906	0.030	3,814
Fixed costs						
Salary/Wages	0.070	6,272	0.070	9,114	0.070	8,898
Admin	0.020	1,792	0.020	2,604	0.020	2,542
R&M	0.060	5,376	0.060	7,812	0.060	7,627
Distribution	0.035	3,136	0.035	4,557	0.035	4,449
Total	**1.739**	**155,837**	**1.680**	**218,736**	**1.683**	**213,964**

Given these costs, we can determine the annualized returns on the land for a range of ethanol prices. Total future profits are calculated as revenue minus costs at year 25 and are then annualized by multiplying by a factor of $\frac{r}{(1+r)^t - 1}$ using a discount rate of $r = 0.08$ and time $\mathrm{t} = 25$. We assume that ethanol and petrol can be easily substituted at a rate of 1 litre of ethanol for 0.67 litre of petrol and examine returns in terms of petrol prices.

From Figure 2, we can see that, assuming the low biofuel productivity of the 0.8 million scenario, biofuel production just becomes profitable at around $2.65 per litre on the lowest quality land (excluding land costs) and becomes more profitable than the lowest value sheep and beef farming in the $2.70 to $2.80 range. At $2.75, if the higher average productivity land is converted to biofuels, the figure also suggests that the 4.9 million ha scenario would also be viable as the average profitability displaced in this scenario is only $210 per ha even in the North Island. Thus at high but not impossible petrol prices we might expect more than half our sheep beef land to be converted to biofuels.

Since the scenarios are not nested, we cannot easily combine these curves to show how profitability would change as more land is converted to biofuel production in response to increasing petrol prices.

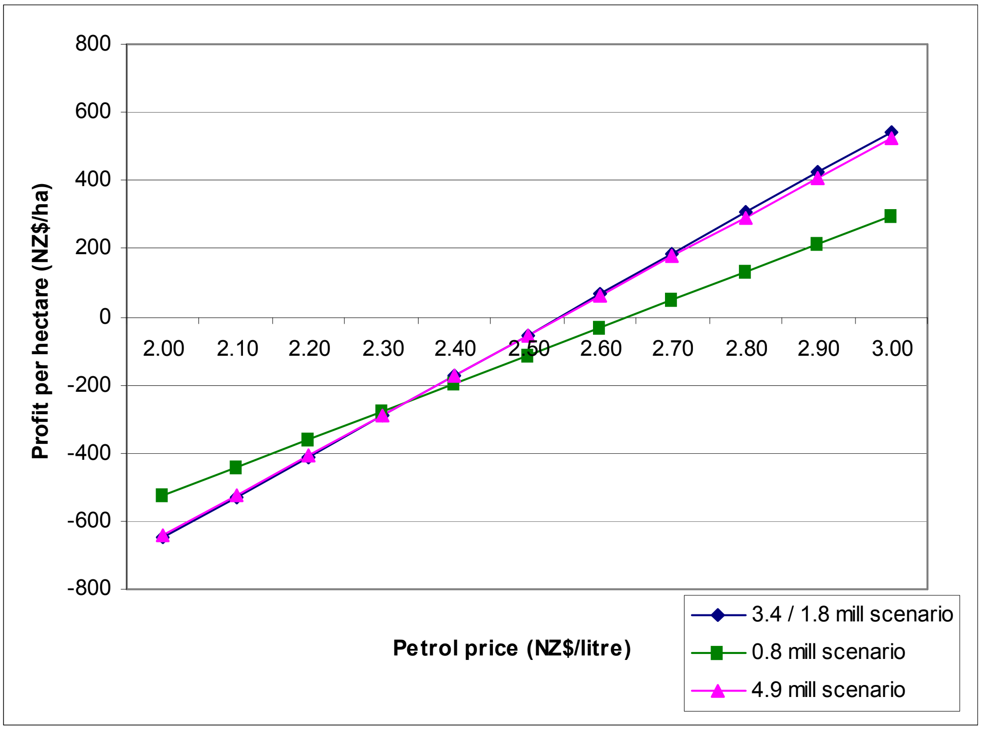

Figure 2: Profitability of ethanol production from PGF by petrol price

Method 2: LURNZ – modelling biofuels as equivalent to payments for regenerating scrub

The preceding analysis suggests that if petrol prices reach $2.75 and hence yield an annual profit per hectare of around $100, it is possible that 0.8 million hectares could be converted from sheep beef farms to biofuels. More radically, it suggests that it might be profitable to convert more than half of New Zealand's sheep beef land to biofuels at these prices.

In this section we use a different approach to explore how reasonable these results are as predictors of land use change. We assume that dairy and plantation forestry are unaffected by any incentive to convert land to biofuels. The former seems reasonable but the latter may not be.

In Table 12, scenario 1 (S1) is a reference case forecast of land use in 2015.[7] Both dairy and plantation forest are expected to continue to grow while sheep/beef and scrub contract. Scenario 2 (S2) raises the return on shrubland from zero to $75 per ha. This is close to the profit per ha on low quality land if the petrol price reaches 2.70. For the purposes of this paper we assume that biofuel production is a perfect substitute for shrubland that is at risk of conversion to pasture or plantation forestry.

Table 12: Land use changes from 2007 to 2015 for 2 scenarios (1000s ha)

		$25			
	Scenario	2007	2015	Change (percentage)	Change (1000ha)
Dairy	S1	1462	1646	13%	184
	S2	1462	1646	13%	184
Sheep/Beef	S1	6878	6654	-3%	-223
	S2	6878	6431	-6%	-447
Plantation	S1	1451	1776	22%	326
	S2	1451	1776	22%	326
Shrubland	S1	1188	901	-24%	-287
	S2	1188	1125	-5%	-63

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[7] These results are drawn directly from (Shepherd et al.).

Table 13 shows the impact that profitability of $75 per ha might have on the area of land dedicated to biofuel production. It suggests conversion of only 224,000 ha, much lower than the areas suggested by the analysis above.

Table 13: Price induced change in shrubland/biofuel area (1000s ha)

	Scenario	2007	2015	Change from reference case (percentage of shrubland)	Change from reference case (1000ha)
Shrubland/ Biofuel	S1	1188	901	0%	0
	S2	1188	1125	25%	224

Why the difference? The first method assumes a very simple decision making rule by land owners that ignores uncertainty. Because biofuel conversion is relatively difficult to reverse, uncertainty makes it relatively less attractive. Sheep beef farmers can always convert next year if they choose, but biofuel growers, like those who convert land to scrub, are relatively locked in. Historically farmers have tended to stay in sheep beef farming for very long periods even when profitability is low. Other key drivers of this observed 'stickiness' in sheep beef farming are that farmers enjoy the livestock raising lifestyle and that many people find pastoral land attractive and believe that this type of landscape will have a higher market value. Finally, some Regional Councils limit conversion to forestry on the basis either of aesthetics or water demand.

In addition, both of our analyses assume that plantation forestry will not expand as a result of ETS and that natural scrub reversion will not compete with biofuels. Thus they are over-estimates of likely response. They also however do not account for potential carbon sequestration benefits from biofuel forests. Our second approach does not account for the decreased attractiveness of sheep beef farming if agricultural emissions are fully costed.

Summary and other considerations that affect the likely economic viability of biofuels in New Zealand

We cannot give a clear indication of the economic value of biofuels as a new land use and the likely response to this opportunity but offer some evidence that sheds light on these questions.

The average value of farming displaced, even under the largest of Scion's scenarios is much lower than Scion's initial estimate of land rent of $280 per hectare per year which suggests their analysis of attractiveness on low quality land is unduly negative. Our analyses suggest that if we anticipate high ($2.75 per litre) but not impossible petrol prices, biofuels could be an attractive land use. At these prices, our lowest estimate for how much land is likely to be converted to biofuels is around 200,000 ha while a very high estimate could lead to as much as 4 million ha being converted. This high estimate would occur only if biofuels are not regarded as a high risk land use option and if the emissions trading system significantly affects the profitability of sheep/beef farming.

This analysis ignores other policy constraints – or opportunities – such as those that could arise from efforts to manage water and water quality. Based on historical data, the amount of land converted to biofuels is more likely to be toward the low end of the scale.

Several other factors, however, make Scion's scenarios unduly pessimistic. These scenarios assume biofuels will be derived from newly planted forests on sheep and beef and scrubland; what about existing low value forest land? Their scenarios also assume that forests are grown only for biofuels. It seems likely that multi-purpose forests that can yield carbon benefits, sawn logs and biofuels may be more attractive partly because their expected returns may be higher but also because they may be less risky.

We find that the impacts of an expansion of biofuels largely onto sheep beef land would lead to non-linear impacts on meat production. Initial losses would be relatively low because the land converted is relatively unproductive for meat production.

Appendices

Appendix A

Table 14: Meat and Wool NZ farm class descriptions

Class	ES Farm Class	Characteristics
1	South Island High Country	Extensive run country located at high altitude carrying fine wool sheep, with wool as the main source of revenue. Located mainly in Marlborough, Canterbury and Otago.
2	South Island Hill Country	Mainly mid micron wool sheep mostly carrying between two and seven stock units per hectare. Three quarters of the stock units wintered are sheep and one-quarte beef cattle.
3	North Island Hard Hill Country	Steep hill country or low fertility soils with most farms carrying six to ten stock units per hectare. While some stock are finished a significant proportion are sold in store condition.
4	North Island Hill Country	Easier hill country or higher fertility soils than Class 3. Mostly carrying between eight and thirteen stock units per hectare. A high proportion of sale stock sold is in forward store or prime condition.
5	North Island Intensive Finishing Farms	Easy contour farmland with the potential for high production. Mostly carrying between eight and fourteen stock units per hectare. A high proportion of stock is sent to slaughter and replacements are often bought in.
6	South Island Finishing-Breeding Farms	A more extensive type of finishing farm, also encompassing some irrigation units and frequently with some cash cropping. Carrying capacity ranges from six to eleven stock units per hectare on dry land farms and over twelve stock units per hectare on irrigated units. Mainly in Canterbury and Otago. This is the dominant farm class in the South Island.
7	South Island Intensive Finishing Farms	High producing grassland farms carrying about ten to fourteen stock units per hectare with some cash crop. Located mainly in Southland, South and West Otago.
8	South Island Mixed Finishing Farms	Mainly on the Canterbury plains with a high proportion of the revenue being derived from grain and small seed production as well as stock finishing.
9	Average	Average

Appendix B - Calculating profits per hectare with ETS for sheep-beef farms

This is drawn from Kerr, Power, and Zhang. The methodology used to generate the regional emission costs are derived from Con William's Meat and Wool New Zealand model. The model assigns a hypothetical price for a ton of CO_2 equivalent (we use \$25 a ton of CO_2-e). By identifying the sources of CO_2 emissions for a sheep/beef farm, the model calculates emission costs from each source.

There are four different sources of CO_2 emissions: fuel usage, electricity usage, N fertiliser and livestock. Livestock include sheep, beef cattle, deer and dairy cattle.

Fuel emissions

For fuel emissions, the raw data provides fuel expenses data only. Con makes an assumption on the petrol and diesel split that 36% of fuel use is due to petrol consumption, while 64% is due to diesel consumption. For 2006 data, the petrol price is assumed at \$1.48 per litre and the diesel price is assumed to be \$1 per litre. The number of litres of petrol and diesel usage is calculated by dividing expenses on both kinds of fuel by their prices.

The Emission Factors (EF) for petrol and diesel are 0.0024 and 0.0027 per litre. The emission from fuel consumption is therefore calculated by: *Petrol usage * EF_petrol + Diesel usage * EF_diesel (1)*

Electricity emissions

The raw data provides the expense on electricity. Con breaks the expenses into two categories: fixed charges and electricity charges. The fixed charge is calculated by:
*Fixed Charges = \$1.5*365(days)* (2)

The electricity charge is calculated by:
Electricity charge = Total electricity expense – Fixed charge (3)

By assuming the price of electricity is \$0.2 per Kwh, the electricity usage is then calculated by dividing electricity charge by the assumed price. Given an EF for electricity of 0.000233 ton of CO_2-e per Kwh usage[8], the electricity emissions are calculated and hence the charge on electricity emissions.

N fertiliser emissions

The data on tons of N fertiliser used is directly extracted from Con's model, where the usage measure by ton is given for each class from Class1 to Class9 at year 2006. The emission factor for N fertiliser emissions is assumed to be 5.27 ton of CO_2-e per one-tonne usage of the fertiliser.

Livestock emissions

The raw data provides the number of animals at open date (July 1) each year. There are 4 types of animal accounted: sheep, beef cattle, deer and dairy cattle. By using the animal number to stock unit factor from LURNZv1, the number of animal is transferred to stock units. The conversion factors are:

- Dairy cattle = 6.15 Stock Unit (SU)
- Beef cattle = 4.874 SU
- Sheep = 0.923 SU
- Assume: deer = 0.923 SU as well

(Note: In Con's model, there are stock unit data, which are not included in the raw data. Moreover, Con does not include the deer into the calculation. However, what I have produced using the way described above is not significantly different from Con's results)

The EFs for each type of animal are given as:

- EF_sheep = 0.359 tons of CO2 eqv per SU of sheep
- EF_beefcattle = 0.35
- EF_dairycattle = 0.381
- EF_deer = 0.362

The total emission cost will be the sum of above four different sources. The emission per hectare is calculated by dividing the total emission cost by total effective farm areas.

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[8] The emission factor for electricity is from Table 1 of Page 9 in a CRA report - Impact of the NZ ETS on Cement Manufacturing

Appendix C - Creating a sheep/beef farm by class and region map

All maps are raster maps at 25 ha pixel resolution.

Identifying sheep/beef farms

We use Agribase-Enhanced-LCDB2 map provided by AssureQuality to identify the sheep-beef farms. Table 15 provides the detailed categorization we use, where the “FTYPE01 code” is either BEF or SHP or SNB is classified as sheep-beef farm.

Table 15: Categorical information in Agribase-Enhanced-LCDB2 map

FTYPE01 code	Description	Number
API	Honey production / processing	1
ARA	Arable cropping	2
AVOC	Avocados	3
BEF	Beef cattle farming	4
BERR	Berryfruit production	5
CITR	Citrus	6
DAI	Dairy milk production	7
DEE	Deer farming	8
DOG	Kennels / catteries	9
DRY	Dairy drystock rearing	10
EMU	Emu	11
FIS	Aquaculture / fish hatcheries	12
FLO	Cut flower growing	13
FOR	Forestry	14
FRU	Orchards of unspecified type	15
GOA	Goat farming	16
GRA	Grazing other peoples’ stock	17
HAYF	Hay fodder production	18
HERB	Herbs	19
HOR	Horses (equine)	20
KIWF	Kiwifruit orchards	21
LIF	Lifestyle blocks	22
MAIZ	Maize growing	23
NAT	Native forest blocks	24
NOF	Not farmed - idle	25
NUR	Plant nursery	26
NUTS	Nut trees	27
OAN	Miscellaneous animal types	28
OFRU	Other fruits eg. Cherimoyas	29
OLAN	Other land use eg. Quarries	30
OPL	Other plant types eg Meadowfoam	31
OST	Ostrich farming	32
OTH	Other land use not covered elsewhere	33
PIG	Piggeries	34
PIPF	Pipfruit	35
POU	Poultry or egg layers	36
SEED	Seed crops eg Clover, lucerne	37
SHP	Sheep farming	38
SNB	Mixed sheep and beef farming	39
SQUA	Squash	40
STON	Stonefruit	41
TOU	Tourism eg. Homestays	42
UNS	Unspecified	43
VEG	Vegetables / market gardening	44
VIT	Viticulture	45
ZOO	Zoological gardens	46
No value	Rest of NZ	47

Creating a map of Meat and Wool NZ regions

Regional definitions were provided by Meat and Wool NZ. They divide New Zealand into 5 large regions (MW regions, hereafter), with three in the North Island and two in the South Island. The MW regions are obtained by combining Territorial Authorities, as described in Table 16, from the Statistics New Zealand Territorial Authority map.

Table 16: TAs in each MW region

MW_Region	TA_Name
Northland-Waikato-BoP	Far North District Whangarei District Kaipara District Rodney District North Shore City Waitakere City Auckland City Manukau City Papakura District Franklin District Thames-Coromandel District Hauraki District Waikato District Matamata-Piako District Hamilton City Waipa District Otorohanga District South Waikato District Waitomo District Taupo District Western Bay Of Plenty District Tauranga District Rotorua District Whakatane District Kawerau District Opotiki District Ruapehu District
East Coast	Gisborne District Wairoa District Hastings District Napier City Central Hawke's Bay District Tararua District Masterton District Carterton District South Wairarapa District
Taranaki-Manawatu	New Plymouth District Stratford District South Taranaki District Wanganui District Rangitikei District Palmerston North City Horowhenua District Kapiti Coast District Manawatu District Porirua City Upper Hutt City Lower Hutt City Wellington City
Marlborough-Canterbury	Tasman District Nelson City Buller District Grey District Westland District Marlborough District Kaikoura District Hurunui District Waimakariri District Christchurch City Banks Peninsula District Ashburton District Timaru District Mackenzie District Waimate District Chatham Islands Waitaki District Selwyn District
Otago-Southland	Central Otago District Queenstown-Lakes District Dunedin City Clutha District Southland District Gore District Invercargill City

Identifying farm classes

For each MW region, M&W Ltd classifies sheep-beef farms by farm size, farm production and farm soil type. Table 17 shows the classifications and their descriptions in every MW regions.

Table 17: Farm classifications in each MW region

North Island

Region	Class	Description of Class
Northland-Waikato-BoP	Class 3	NI hard hill country
Northland-Waikato-BoP	Class 4	NI hill country
Northland-Waikato-BoP	Class 5	NI intensive finishing
East Coast	Class 3	NI hard hill country
East Coast	Class 4	NI hill country
East Coast	Class 5	NI intensive finishing
Taranaki-Manawatu	Class 3	NI hard hill country
Taranaki-Manawatu	Class 4	NI hill country
Taranaki-Manawatu	Class 5	NI intensive finishing

South Island

Region	Class	Description of Class
Malborough-Canterbury	Class 1	SI high country
Malborough-Canterbury	Class 2	SI hill country
Malborough-Canterbury	Class 6	SI finishing-breeding
Malborough-Canterbury	Class 8	SI mixed finishing
Otago-Southland	Class 1	SI high country
Otago-Southland	Class 2	SI hill country
Otago-Southland	Class 6	SI finishing-breeding
Otago-Southland	Class 7	SI intensive finishing

For the M&W farm survey data, we obtain the information of the effective farm area in each class and region in the year 2002, from which we calculated the proportion of farm area in each class given a certain region shown in the following table (18)

Table 18: Proportion of farms across classes in each region

North Island	Northland-Waikato-BoP	East Coast	Taranaki-Manawatu
Class 3	0.16864	0.329656	0.330951
Class 4	0.727115	0.461799	0.545795
Class 5	0.103002	0.20804	0.123579

South Island	Marlborough-Canterbury	Otago-Southland
Class 1	0.319325	0.422288
Class 2	0.252442	0.097817
Class 6	0.340794	0.26489
Class 7	0	0.214957
Class 8	0.087696	0

We assume that farm classes are associated with land qualities. Classes with high farm profit per hectare are located in high land quality area[9]. In North Island, Class 5 is assumed to be on the best land, followed by Class 4 and 3. In South Island, Class 7 is assumed to be the best, followed by Class 8, 6, 2 and 1.

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[9] The land quality map is created by a nested sort: first sorting on Land Use Capability and then sorting by Pastoral Productivity.

The Algorithm used to identify farm classes is:

- Step 1: pick all the sheep-beef farm pixels in a region
- Step 2: rank these pixels according to the Land Quality map
- Step 3: assign the X% of pixels to the best Class, Y% to the next best Class ect. Table 1818 provides the % figures.
- Step 4: repeat the above 3 steps for each region to get a sheep-beef farm map by region and class

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INFOMETRICS

Chapter 4

General Equilibrium Analysis of bioenergy Options

Adolf Stroombergen

Introduction

With widespread anxiety about long-term oil prices and availability, coupled with concerns about climate change, Scion has sought to investigate the options for producing biofuels for transport from forestry. Scion looked at converting forest residues into biofuels as one option, but the amounts involved are too small to have a significant impact on New Zealand's demand for oil. Consequently their emphasis, and the focus of this report, is on forest that is grown specifically for the production of biofuels. We refer to this as Purpose Grown Forestry (PGF).

This report uses a general equilibrium (GE) model of the New Zealand economy to analyse the economy-wide effects of a large increase in plantation forestry, grown specifically to produce either ethanol or biodiesel. We examine the case for these PGF biofuels under a range of alternative assumptions about the price of oil, the price of carbon, the price of agricultural products and cost of manufacture.

New industries for the production of ethanol and biodiesel are incorporated into the model, with data being provided by Scion.[10] In most of the scenarios examined the cost per MJ of PGF biofuel is more than the cost of petrol or fossil diesel. It is therefore assumed that regulatory intervention in the form of mandatory blends is used to force consumption of biofuels up to some exogenously imposed constraint that is determined by the amount of land devoted to PGF and its productivity in terms of biomass delivered.

The model estimates the effects of the various bio-energy scenarios on the allocation of resources in the economy, the terms of trade, our international competitiveness and so on, and through these variables the effect on measures of economic welfare such as the standard of living of households.

An accompanying report by Motu[11] looks at how allocating large amounts of land to PGF could affect the land available for pastoral agriculture.

Methodology

We begin with a 'business as usual' (BAU) scenario which represents a picture of the economy in 2050/51. The BAU is not necessarily the most likely forecast of what the economy might look like. Rather it is intended to be a plausible projection of the economy that can constitute a frame of reference against which other scenarios may be compared.

The main inputs into the model that are required to produce the BAU are as follows:

- Population and labour force
- Capital stock and total factor productivity
- Energy efficiency and generation mix
- Carbon price
- Oil price
- Balance of payments

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[10] See in particular: Hall, P. & M. Jack (2008): *Bioenergy Options for New Zealand: Pathways Analysis*, Scion, Energy Group.

[11] Todd, M., W. Zhang & S. Kerr (2009): *Competition for land between biofuels, pastoral agriculture and scrub lands*, report prepared for Scion.

More detail on these is provided in Appendix A.

Given the BAU, the model is then 'shocked' with a number of bio-energy scenarios, described in the following section. The model then converges to a new equilibrium.[12] In all scenarios the following macroeconomic closure rules apply:

1. Total employment is held constant at the BAU level, with wage rates being endogenous (generated by the model) – the equilibrating mechanism.
2. Total capital stock (plant, equipment, buildings etc) is held constant at the BAU level, with the user costs of capital being endogenous.
3. The balance of payments as a proportion of GDP is fixed at the BAU proportion, with the real exchange rate being endogenous.
4. The fiscal surplus is held constant at the BAU level, with personal income tax rates being endogenous.

The first two macroeconomic closure rules imply that the overall level of resource use in the economy is not dependent on bio-energy developments. Other closure rules are possible. For example instead of fixed employment, wage rates could be fixed at BAU levels. This implies, however, that the long run level of total employment is driven more by the price of oil and its substitutes than by the forces of labour supply and demand – an unlikely state of affairs.

The third rule ensures for example, that the cost of more expensive oil is not met simply by borrowing more offshore, as this is not sustainable. Relaxing this constraint would mean that in the long term New Zealand could run a larger external deficit than it other wise would – not a view likely to be shared by foreign lenders and investors.

The fourth rule prevents the results from being confounded by issues around the size of government. If for example the government was to forego petroleum excise tax on locally produced ethanol, it would need to make up the potential revenue short-fall in some other way. Changes in personal income tax rates are assumed to be the default equilibrating mechanism, but changes in corporate taxes would also meet this objective. Reducing spending on say health, would not. If it is believed that government should be smaller, then this scenario should be investigated in its own right; it is unlikely that changing taxes on transport fuels is the most efficient way of doing this.

Taken together the closure rules as specified above enable us to analyse the effects of various bio-energy scenarios on the allocation of resources in the economy, the terms of trade, our international competitiveness and so on, and through these variables the effect on measures of economic welfare.

The following model limitations should be noted:

- *Aggregation bias*: All industries in the model represent aggregations of companies, products and processes, but even with 53 industries, aggregation bias remains. For example we cannot distinguish between the production of fertilizer and paint in the Chemicals industry.

- *Lumpiness in production* The model assumes that small increments and decrements in production are possible. For industries that are dominated by a single plant dependent on economies of scale this could be unrealistic, especially with respect to increments in output.

- *Pricing*: Being an 'equilibrium' model, unless specifically altered, industries must price their output at the average cost of production, including a return to capital. There are no long run economies of scale so marginal costs equal average costs.

- *Costs of Resource Re-Allocation*: The model looks at the situation after resources have been reallocated in response to changes in relative prices and changes in policy. It does not measure transition costs

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[12] For more information on the use of general equilibrium modelling in policy analysis the reader is referred to www.monash.edu.au/policy/

Note also that although scenarios are run as ‘shocks’ relative to the BAU, it is implicitly assumed that the various policies are implemented early enough for the economy to reallocate labour and investment in response to new price signals.

Biofuels from Purpose-grown Forestry

Introduction

Based on the price of petrol in the December quarter of 2007 of 96.13 c/l prior to taxes and levies,[13] the figures supplied by Scion (see Appendix B) show that the cost of producing ethanol from purpose grown forestry (PGF) is about 3.1 times more expensive per unit of delivered energy. Compared with the model’s base year of 2005/06, the price factor is about 3.8, with the rise in oil prices since then accounting for the difference.

As might be expected with this sort of price difference, incorporating ethanol in the model as a substitute for petrol at those relative prices would see a voluntary take-up rate of zero. Hence we must assume that regulation forces ethanol to be mixed with petrol, with the motorist buying the blended product and seeing only the weighted average price.

The model treats such a scenario as a reduction in the productive efficiency of producing petrol. That is, instead of resources being used in exporting industries to earn foreign exchange to import petrol (or crude with some resources being used for refining); resources are diverted out of exporting industries and into forestry and ethanol manufacture. There will be a macroeconomic welfare loss to the extent that forestry and ethanol production use the economy’s resources less efficiently than exporting industries. Judging by the price ratio of 3.1, the opportunity cost could be significant. However, there are a number of considerations that work in the opposite direction, and we which we pick up in the modelling:

1. The real oil price in 2050 is assumed to be US$200/bbl, not the US$90/bbl or so that prevailed at the end of 2007. (See appendix A). On it’s own that would reduce the bio-ethanol cost penalty from 3.1 to about 1.6.

2. Reducing imports of oil will raise the terms of trade, as the price of oil rises faster than the prices of other traded goods and services, relative to 2005/06.

3. At the margin there may be further gains in the terms of trade gains as exporters can no longer compete in low value products and markets.

4. If the direct plus indirect carbon content of PGF ethanol is less than that of exporting to buy and consume imported oil, New Zealand will not have to purchase as many emission rights offshore. This allows a larger proportion of GDP to be directed to private consumption. Given that forestry is carbon neutral, that burning oil is not, and assuming that the electricity required to produce ethanol is not met from thermal generation, a net reduction in carbon emissions seems likely.

Points (1) and (4) above are significant, and may be sufficient to produce a net welfare gain from PGF ethanol.

Modelling Results

Table 1 shows the main results if PGF planting is 0.8 million ha. The first column shows the average annual percentage change relative to BAU. It is presented purely to provide the reader with a general flavour of the characteristics of the economy in 2050/51. As noted above, it is not intended as a best guess forecast.

Scenario 1: BAU plus PGF Ethanol

The second column, labelled Scenario 1, shows the results of the PGF ethanol scenario, expressed as changes relative to the BAU. This reflects the strength of the model being in comparative scenario analysis, rather than in forecasting absolute levels of economic activity over a four decade horizon. Numbers are shown to two decimal places simply to better indicate the directions of relative differences, but the implied accuracy is spurious.

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[13] MED Energy Data File, June 2008

Two measures of economic welfare are presented; real private consumption and real gross national disposable income (RGNDI). The former is almost 0.2% higher relative to BAU, but the latter is about 0.1% lower. [14] Overall the effects are very small; amounting to no more than $100 per person, but the difference in directions is interesting. Although the gain in the terms of trade is nearly 1%, which would tend to raise RGNDI, as would the reduction in remissions offshore from having to buy fewer emission permits[15], there is a reasonably strong decline in GDP (0.4%) that offsets these favourable effects. GDP falls because the production of PGF ethanol has lower productive efficiency than exporting industries.

Nevertheless despite the loss in productive efficiency, private consumption (household spending) rises slightly through fewer resources being needed for exports because of the favourable terms of trade effect (which is a change in allocative efficiency) and the reduction in offshore payments for emission permits.

Table 1: Summary of Model Results

	BAU	**Scenario 1**	**Scenario 2**	**Scenario 3**
	% pa on	**PGF ethanol**	**PGF ethanol**	**PGF ethanol**
	2005/06	**0.8m ha Oil: US$200**	**0.8m ha Oil: US$100**	**0.8m ha Oil: US$300**
		(% ∆ on BAU)	**(% ∆ on BAU with oil at US$100)**	**(% ∆ on BAU with oil at US$300)**
Private Consumption	2.5	0.16	0.09	0.22
Exports	2.7	-1.50	-1.53	-1.51
Imports	3.1	-0.33	-0.44	-0.27
GDP	2.2	-0.43	-0.45	-0.42
RNGDI	2.6	-0.06	-0.12	-0.03
Terms of trade	0.7	0.87	0.74	0.96
Real wage rate	2.5	0.13	0.02	0.22
Oil (PJ)	1.2	-15.0	-14.7	-15.2
Electricity (PJ)	0.8	6.9	6.6	7.1
CO_2e emissions (Mt)	1.4	-3.9	-4.2	-3.6
Forestry gross output	2.6	28.9	29.0	28.9
Biofuels gross output	-	[64.8 PJ]	[65.5 PJ]	[64.2 PJ]

With lower exports it is not surprising that agricultural output is less than in the BAU, although the changes are less than 2%, so there is certainly no absolute decline in agricultural output relative to 2005/06 – refer Table 2. All agricultural industries display a greater reduction in land use than in output, implying a (small) shift to more intensive farming. In absolute terms the largest agricultural land use change occurs in sheep and beef farming, where 0.11 million ha is no longer farmed.

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[14] As a comparison, if the Maui gas field was still producing at its peak rate of around 200 PJ per annum, the value of the output would be approximately 0.6% of GDP.

[15] This could equally be interpreted as New Zealand being able to sell more emission permits offshore if net allowable emissions are less than zero.

Table 2: Scenario 1: Changes in Agricultural Output

	Output (% Δ on BAU)	Land Use (% Δ on BAU)	Land Use (Δ million ha on BAU)
Horticulture and fruit growing	-1.7	-1.9	-0.01
Sheep, beef & mixed cropping	-1.1	-1.2	-0.11
Dairy cattle farming	-0.9	-1.2	-0.02
Other farming	-1.6	-1.8	-0.01
			-0.16
Regular forestry (to PGF biofuels)			-0.22
Land previously in scrub			-0.46
Total land converted to PGF			-0.83

As the model has no spatial component we cannot infer that all of the 0.11 million ha moves from directly sheep and beef into forestry. Only net changes are shown. It is equally possible that the land reverts to scrub and that other land which is currently in scrub is used for PGF. Similarly, some dairy land could shift into sheep and beef farming, with more of the lowest grade sheep and beef land shifting into PGF.

There is also some shift of land out of 'regular' forestry and into PGF. In reality of course this not so much a change in land use as a change in end use of the forest harvest. Although the Scion analysis assumes no such substitution, this is difficult to do in a general equilibrium model – both conceptually and practically.

In partial equilibrium analysis it is standard to assume that the rest of the economy is unaffected by, and has no feedback effects on one's particular area of interest. For small scale projects such as a few megawatts of wind generation this is reasonable, but 0.8 million hectares of forestry is nearly half the amount of land currently in plantation forest. It is not a small event. Indeed that is why a general equilibrium analysis is being used to complement Scion's analysis.

The model tells us that, given certain costs and prices, some regular forestry is better used for biofuels than for timber, paper etc. Inferior trees, younger trees, and trees planted in slow growth areas (such as Canterbury) might be better directed into biofuel production. Preventing the ESSAM model from re-directing output in this manner would essentially render the general equilibrium analysis superfluous.

We return to the land use issue in Scenario 7.

Scenarios 2 and 3: PGF Ethanol under a Different Oil Price

Scenario 2 shows the effect of producing PGF ethanol if the oil price is halved to US$100/bbl. Conceptually, if the real oil price is lower the relative resource cost of producing PGF ethanol is higher – as shown in the table below. Thus we would expect to see smaller positive or larger negative effects than observed in Scenario 1.

Ratios of producer price of PGF ethanol to producer price of oil for various oil prices

Oil price (US$/bbl)	Price Ratio
100	3.0
200	1.6
300	1.1

The results are shown in Table 1. Note that for this scenario they are expressed relative to a BAU re-run with the lower oil price in order to prevent the welfare effect of producing PGF ethanol being confounded by the welfare effect of a change in the oil price. As an aside, the latter raises private consumption by 0.9%, driven by a lift in the terms of trade of 2.2%.[16]

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[16] In the BAU oil consumption is 430 PJ, with a value of around $12 billion. Approximately two-thirds is imported, which accounts for 4.3% of export earnings. Halving the oil price therefore means that about 2.2% of the resources that go into producing exports can instead be used to produce goods and services for private consumption. Exports are about 50% of private consumption, implying a benefit to private consumption of 1.1%, which is close to the model result of 0.9%.

As expected, the changes in real private consumption and RNGDI are lower than in Scenario 1 by about 0.07 percentage points. Under a lower oil price a switch away from oil to PGF ethanol has a smaller beneficial effect on the terms of trade. This negatively affects both private consumption and RGNDI.

The overall level of private consumption is always going to be higher, the lower the oil price, but the value of oil substitutes is less the lower is the oil price. If productive efficiency was the only relevant metric, no oil substitute that cost more than oil (per unit of energy) would ever represent a good use of resources. But a price on carbon, which effectively reduces the productive efficiency penalty, coupled with favourable allocative efficiency effects via the terms of trade, means that more expensive oil substitutes may deliver a welfare gain. As parameterised above, PGF ethanol does raise private consumption, but not RGNDI.

Scenario 3 is the mirror image to Scenario 2, with the oil prices raised by US$100 to US$300/tonne. As expected the results are large symmetrical to those in Scenario 2. Private consumption shows a rise of 0.22%, but the effect on RGNDI is still net negative, albeit very marginal.

There is a second order effect on the PGF ethanol industry, with output slightly lower than in Scenario 1. This is attributable to the income effect of higher oil prices. The opposite effect occurs in Scenario 2.

Scenario 4: BAU plus PGF Biodiesel

An alternative to the use of biomass produced from 0.8 million ha of forestry is to produce biodiesel instead of ethanol. Scion has made some assumptions about the cost of producing biodiesel versus ethanol, as given in Appendix C, although they caution that these assumptions may not be robust. The annual yield is 69.5 PJ, just above the 64.8 PJ obtained under the ethanol scenario.

The cost of PGF biodiesel is $1.975/litre. In the December quarter of 2007 the price of fossil diesel was $1.05/l prior to taxes and levies,[17] so PGF biodiesel is about 1.9 times more expensive than fossil diesel. This ratio is considerably less than that for ethanol, suggesting that the loss in national productive efficiency should also be less.

In fact, as shown in Table 3, the reduction in GDP is virtually the same as in Scenario 1 and the welfare effects are more negative. Private consumption falls by 0.03% compared to a gain of 0.16% in Scenario 1, and RGNDI falls by 0.08% compared to a fall of 0.06% in Scenario 1.

Judging by the effects on private consumption when the oil price is raised in the ethanol scenario, the biodiesel scenario would generate a lift in private consumption if the oil price was about 25% higher.

Biodiesel production is estimated to be 25% more labour intensive per dollar of value-added than ethanol production. Capital intensity is very similar. Hence the loss in productive efficiency is larger than the crude unit price ratio suggests, which goes some way to explaining why the fall in GDP is almost identical to that in Scenario 1.

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[17] MED Energy Data File, June 2008

Table 3: Summary of Model Results

	Scenario 1	Scenario 4
	PGF ethanol	PGF biodiesel
	0.8m ha Oil: US$200	0.8m ha Oil: US$200
	(% Δ on BAU)	(% Δ on BAU)
Private Consumption	0.16	-0.03
Exports	-1.50	-1.23
Imports	-0.33	-0.12
GDP	-0.43	-0.45
RNGDI	-0.06	-0.08
Terms of trade	0.87	0.77
Real wage rate	0.13	-0.05
Oil (PJ)	-15.0	-15.9
Electricity (PJ)	6.9	4.4
CO_2e emissions (Mt)	-3.9	-4.1
Forestry gross output	28.9	27.8
Biofuels gross output	[64.8 PJ]	[69.5]

Also relevant is the different mix of users between petrol and diesel. Notwithstanding the increasing proportion of diesel cars in household consumption, diesel is used primarily by industry. This means that a higher (bio-) diesel price has a bigger negative effect on international competitiveness than a higher price for petrol that is blended with ethanol. Thus some of the country's most productive industries are relatively worse off.
A smaller proportion of the total diesel supply is imported than of the total petrol supply. As diesel is also cheaper (per MJ), the gain in the terms of trade from importing less diesel is smaller than from importing less petrol – the difference is 0.1%. (Lower crude oil imports are common to both scenarios.) This has a downward effect on both private consumption and RGNDI.

Overall, the differences between the ethanol and biodiesel scenarios are very small. Neither delivers a marked gain or loss in national economic welfare relative to the BAU, although ethanol has the edge with its positive change in private consumption.

It is important, however, not to overlook the effect of the macroeconomic closure assumptions. The total level of factor inputs was deliberately held constant so that the pure effects on national allocative and productive efficiency from producing PGF biofuels could be understood – which is where the strength of the model lies.

However, we may infer from the changes in real wages shown in Table 1 that altering the labour market closure rule from fixed employment to fixed real wages would increase employment in Scenario 1, but reduce employment in Scenario 4, further promoting PGF ethanol over PGF biodiesel. This is useful knowledge as it means that if there is uncertainty about the correct form of the labour market closure rule, it does not reverse the sign of the welfare effect between ethanol and diesel.

Scenarios 5 and 6: Larger-scale PGF Ethanol

Scenario 5 is specified identically to Scenario 1 except that the scale of PGF plantation is increased from 0.83m ha to 3.47m ha.

Scion's calculations assume that ethanol production is linearly scalable, so the increase in planted area of 318% leads to an equivalent increase in ethanol production. For this scenario we also assume a constant per unit cost, but arguably there may be economies of scale. We look at this in Scenario 9. On the other hand, the cost of land may rise – the 0.83m ha scenario is estimated to use mostly scrubland, but 3.5m ha of forestry is likely to entail some substitution of agricultural land and/or timber-based forestry.

If the whole 3.5m ha is used for ethanol it would displace more than 100% of the anticipated demand for petrol. We could assume that some diesel demand switches back to petrol/ethanol, but this seems unlikely. Instead we assume that some PGF is used to produce biodiesel instead of ethanol. Out of the 3.5m ha, about 1m ha is used for biodiesel.

Table 4 shows the results with Scenario 1 repeated for convenience.

Private consumption rises by 0.43%, equivalent to about $240 per person in current prices. This is largely driven by the better terms of trade, but there is no escaping the reduction in national productive efficiency. Relative to Scenario 1 the rise in private consumption is larger by a factor of 2.7, but the loss in GDP is larger by a factor of 4.3, as increasingly more productive resources move into the production of PGF bio-fuels.

Table 4: Summary of Model Results

	Scenario 1	Scenario 5	Scenario 6
	PGF ethanol 0.8m ha	PGF ethanol & biodiesel	As in Scenario 4 with higher
	Oil: US$200	3.5m ha Oil: US$200	carbon price
	(% Δ on BAU)	(% Δ on BAU)	(% Δ on BAU*)
Private Consumption	0.16	0.43	0.74
Exports	-1.50	-5.80	-6.31
Imports	-0.33	-1.05	-0.68
GDP	-0.43	-1.86	-1.97
RNGDI	-0.06	-0.33	-0.09
Terms of trade	0.87	3.51	3.75
Real wage rate	0.13	0.41	0.52
Oil (PJ)	-15.0	-63.0	-64.2
Electricity (PJ)	6.9	25.6	25.3
CO_2e emissions (Mt)	-3.9	-16.2	-17.0
Forestry gross output	28.9	118.2	114.5
Biofuels gross output	[64.8 PJ]	[270.7 PJ]	[270.7 PJ]

*BAU with higher carbon price

There is a considerable fall in emissions which leads to a reduction in net factor payments offshore which, while attenuating the fall in RGNDI, is not enough to reverse it given the reduction in GDP.

This raises a question though about the sensitivity of results to the carbon price. It was noted above that the price on carbon has an analogous effect to an increase in the relative productive efficiency of biofuels as it effectively internalises an externality produced by other industries, particularly agricultural methane emissions. Thus in Scenario 6 the price of carbon is raised by 50% – with a fairly dramatic effect. While RGNDI is still negative because the cost of emission permits is higher, the gain in private consumption rises to 0.74%, or about $410 per person.

Table 5 shows the estimated impacts on agricultural production, agricultural land use, and how the 3.5 million ha is obtained.

Table 5: Scenario 5 - Changes in Agricultural Output

	Output (% Δ on BAU)	Land Use (% Δ on BAU)	Land Use (Δ million ha on BAU)
Horticulture and fruit growing	-6.8	-7.5	-0.04
Sheep, beef & mixed cropping	-4.2	-4.6	-0.42
Dairy cattle farming	-3.5	-4.4	-0.08
Other farming	-6.4	-7.2	-0.06
			-0.59
Regular forestry (to PGF biofuels)			-0.98
Land previously in scrub			-1.92
Total land converted to PGF			-3.48

As discussed with regard to Scenario 1, there is some re-direction of the BAU forest harvest out of traditional uses and into biofuels. At about 28% (1 million ha) this makes a sizable contribution to the assumed 3.5 million ha in PGF. To put this in perspective, in the model's base year (2005/06) an estimated 1.85 million ha was in exotic plantation forestry. In the BAU this rises to about 2.2 million ha – without any specific allowance for increased planting that might be induced by the possibility of securing carbon credits.

Also as in Scenario 1 some PGF land comes out of agriculture. Total land used in agriculture falls by 0.59 million ha, most of which is removed from sheep and beef farming. As before this is a model-endogenous result, stemming from general equilibrium effects that lead to less demand for agricultural output (and thus for agricultural land) for exports, not from any input assumption about which land will be used for PGF.

Scenarios 7 and 8: Focus on Agriculture

Scenarios 7 and 8 look in more detail at how agricultural parameters affect the case for biofuels. In particular, how does the case for PGF biofuels look if more land is lost from sheep and beef farming than occurs in Scenario 5, and if agricultural commodity prices are lower than envisaged in the BAU?

Scenario 7: Decline in Sheep and Beef Production

In Scenario 5 the model assumes that there is enough scrubland available at a cheap enough cost to convert at least 1.9 million ha into PGF. In the ESSAM model any amount of land can theoretically be brought into use in agriculture or forestry, but there is a cost associated with doing so. For small changes in land use this works reasonably well, but when dealing with changes of several million hectares this structure is probably unrealistic.

In the accompanying paper by Motu[18] (by their Method 1) only 0.23 million ha of scrubland is converted to PGF, with the difference coming from ready conversion of land used for sheep and beef farming. Motu also assume, in line with Scion, that no current forest is used for biofuels production. The consequent demand for agricultural land leads to a reduction in the livestock population of 38% in the 3.5 million ha scenario, which is effectively the loss in beef and sheep meat production.

In Scenario 7 we re-run Scenario 5 but force the model to reduce its use of scrubland from 1.9 million ha to around 0.23 million ha, and use sheep and beef land instead.
This is conceptually a different issue from the use of existing forestry land for biofuels. That is essentially just a change in the destination of forestry output, whereas the use of agricultural land for PGF is a question of the land-use elasticity of substitution. Accordingly we simulate more use of sheep and beef land (and less use of scrubland) by raising the elasticity of substitution, with the loss in sheep and beef output being manifested in lower meat exports.

The model generates a fall in sheep and beef output of 23% relative to BAU, less than the 38% in Motu's analysis, although the latter is anchored on 2007 output while the ESSAM model is projected to 2050, with some increase in production being anticipated over the interim. The land composition of the 3.5 million ha is as follows:

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[18] op cit

Land from agriculture	-2.31 (of which 2.11 from sheep & beef)
Regular forestry (to PGF biofuels)	-0.94
Land previously in scrub	-0.22
Total land converted to PGF	-3.47

The macroeconomic results (Table 6) are sharply down on Scenario 5, with private consumption 0.4% lower and RGNDI 1.0% lower than in the BAU. Were it not for the greater reduction in GHG emissions (less methane), which reduces the need to purchase international emission permits; the welfare measures would decline even further.

These results add an interesting dimension to the bioenergy debate. In Scenario 5 there is a rise in private consumption, even though some land switches out of sheep and beef farming (and very small amounts out of other types of farming). If, however, a large amount of sheep and beef production is displaced, the change in private consumption turns negative. This is not because domestic meat prices rise as a result of lower supply – there is more than enough supply for the domestic market. The welfare loss is due to the reduction in export earnings. Beyond some point the gain from using the nation's resources to produce PGF biofuels instead of agricultural exports (and using the export earnings to import oil) becomes negative. That is, the opportunity cost in terms of lost agricultural production becomes too high.

Motu point out, however, that their Method 1 analysis may over-estimate the degree to which land use would change from sheep and beef into PGF for a land rent (assumed by Scion) of up to $280/ha per annum. Motu's Method 2 suggests that a much smaller amount of land would shift out of sheep and beef farming. Furthermore the available scrubland is estimated at 1.19 million ha (presumably including Manuka and Kanuka) – rather more than the 0.23 million ha that converts in Method 1, although still well short of the 1.9 million ha in Scenario 5.

Given the uncertainty about: the value of the elasticities of substitution between land used for scrub, forestry and sheep & beef farming, what the relative profitability of sheep and beef farming might be in 2050, how much scrubland is actually potentially available for PGF and at what cost, we retain the model's agricultural and forestry production functions for the other scenarios examined below. Readers should nonetheless note that to the extent that the model under-estimates the switch of land out of sheep and beef farming and/or over-estimates the potential to convert scrubland to PGF, the macroeconomic welfare effects will be positively biased.

Table 6: Summary of Model Results

	Scenario 5	Scenario 7	Scenario 8
	PGF ethanol& biodiesel	As in Scenario 5 with more	As in Scenario 5 with lower
	3.5m ha Oil: US$200	sheep and beef land conversion	food prices
	(% Δ on BAU)	(% Δ on BAU)	(% Δ on BAU*)
Private Consumption	0.43	-0.38	0.38
Exports	-5.80	-6.46	-5.89
Imports	-1.05	-3.28	-1.05
GDP	-1.86	-1.81	-1.92
RNGDI	-0.33	-0.97	-0.37
Terms of trade	3.51	1.56	3.53
Oil (PJ)	-63.0	-63.6	-64.3
Electricity (PJ)	25.6	25.9	25.8
CO_2e emissions (Mt)	-16.2	-21.3	-17.3
Forestry gross output	118.2	119.9	111.2
Biofuels gross output	[270.7 PJ]	[273.3 PJ]	[270.7 PJ]

*BAU with lower world food prices

Lower World Prices for Agriculture and Food

A related issue that could affect the case for PGF biofuels is the price of agricultural commodities in the world market. In Scenario 8 world prices for dairy, meat, horticulture, fish and processed food products are all reduced by 20%. The aim of the scenario is to ascertain whether the economic case for PGF biofuels is enhanced under poorer returns from exporting agricultural and food products. In other respects the scenario is specified identically to Scenario 5. Table 6 shows the results.

Ignoring the second decimal place, which again is not really significant, the macroeconomic results are the same as in Scenario 5. One might have expected a more favourable result for biofuels under lower world food prices as the cost of importing oil is effectively higher through the terms of trade effect. However, consider the following:

1. The change in national productive efficiency from producing biofuels is not affected by lower world agricultural prices, so the change in GDP (relative to a BAU with lower world food prices) must be much the same as in Scenario 5.
2. As the amount of biofuels production is fixed by assumption, the change in emissions and hence the change in the cost of international emission permits must be the same as in Scenario 5.
3. While the level of the terms of trade is lower with lower food export prices, this does not affect the percentage change in the terms of trade when imports of oil are reduced.

The last point is not obvious. Lower terms of trade caused by lower world food prices restricts the country's importing ability, leading to a small increase in the share of imports accounted for by oil (crude, plus refined petrol and diesel) – from 4.6% to 4.8%, as demand is relatively inelastic. However, this change is not sufficient to noticeably boost the gain in the terms of trade from displacing imported oil by PGF biofuels.

In the base year 2005/06, oil accounted for 6.8% of the total import bill. Rising fuel efficiency (refer Appendix A) and higher demand for more income-elastic imports such as financial and travel services, and foreign foodstuffs, account for the declining share of oil over time.

Ironically, the pursuit of energy efficiency in the transport fleet reduces the relative economic benefit of displacing imported oil by domestically produced ethanol and biodiesel. This is analogous to the economic case for more efficient space heating – the better a house is insulated, the weaker the relative economic gain from switching out of say electric fan/convection heaters and into heat pumps.

In Scenario 8 the change in gross output of the Forestry industry is slightly smaller in proportionate terms than in Scenario 5 simply because output is somewhat higher prior to PGF being established. That is, with lower prices for agricultural and food exports, forestry exports are in a more competitive position.

Scenario 9: Lower Costs of PGF Biofuels Production

Scion has supplied a scenario that contains a number of productivity improvements over those examined above. Briefly, 100% self-sufficiency in electricity from the use of lignin (in ethanol production), an increase in biomass per hectare, and a yield gain in terms of litres of ethanol and biodiesel per tonne of biomass.[19] Details are provided in Appendices B and C, and the results are shown in Table 7.

Greater productive efficiency in PGF biofuels is immediately evident in GDP, which falls by 1.5% compared to 1.9% in Scenario 5. However, the composition of GDP also changes. Recall that the model simulates a regulatory regime that forces the blending of ethanol with petrol – in proportions of 100%-0% respectively. (The fossil diesel - biodiesel blend is less.) In effect this enables the bio-fuels industry to bid up input prices which draws resources away from other industries, in particular export industries. Greater productivity in PGF biofuels, such as in Scenario 9, means that this effect is ameliorated. Accordingly exporters regain some lost international competitiveness and are able to sell more product – effectively transferring some of the benefit from greater productivity in New Zealand to foreign consumers. There is a concomitant small reduction in the favourable terms of trade effect from substituting biofuels for imported oil, and hence a smaller lift in private consumption.

In contrast, the fall in RGNDI is not as severe in Scenario 9 where the change is only -0.04%, compared to -0.33% in Scenario 5.

A smaller increase in forestry output is evident as less biomass (tonnes or cubic metres of wood) is required to produce a litre of biofuel.

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[19] Scion has suggested that even greater productivity gains could be achieved through the use of genetic engineering to increase biomass per hectare by another 5-10%.

Table 7: Summary of Model Results

	Scenario 5	Scenario 9	Scenario 10
	PGF ethanol and biodiesel	As in Scenario 5 with higher	As in # 5 with ↑ productivity,
	3.5m ha	productivity in PGF biofuels	higher oil and carbon prices
	(% Δ on BAU)	(% Δ on BAU)	(% Δ on BAU)
Private Consumption	0.43	0.38	0.81
Exports	-5.80	-5.02	-5.44
Imports	-1.05	-0.55	-0.06
GDP	-1.86	-1.48	-1.53
RNGDI	-0.33	-0.04	0.29
Terms of trade	3.51	3.17	3.56
Oil (PJ)	-63.0	-63.0	-63.0
Electricity (PJ)	25.6	0.2	0.1
CO_2e emissions (Mt)	-16.2	-16.3	-16.1
Forestry gross output	118.2	69.5	64.8
Biofuels gross output	[270.7 PJ]	[270.7 PJ]	[270.7 PJ]

Scenario 10: All Go for Biofuels

Our final scenario combines the various factors that promote the case for biofuels into a favourable variation of Scenario 5 that includes:

- higher oil price (US$300/bbl) as in Scenario 3
- higher carbon price (US$150/tonne CO_2e) as in Scenario 6
- greater productive efficiency as in Scenario 9.

The results are also shown in Table 7 above.

Private consumption is 0.8% above BAU, or about $440 per capita. Real gross national disposable income is $240 higher per capita. Both consumer welfare measures change in the same direction in this scenario as the initial high cost of PGF biofuels is mitigated by enhanced productivity in biofuels production, by a higher price of oil and by a greater value on the reduction in carbon emissions from using PGF biofuels rather than imported oil.

Indeed these three factors are more than sufficient for the price of ethanol and biodiesel at the pump to be lower than the price of petrol and fossil diesel respectively. Thus under these conditions there should be no need to mandate a particular biofuels blend. Private interests and national interests align.

In contrast, in Scenario 5 (for example) private and national interests do not align.
There can be a net gain to consumers through the general equilibrium effects of changes in the terms of trade and lower net payments overseas, even if fuel is dearer at the pump. However, while the potential may exist for regulatory measures to deliver a net welfare gain, it is by no means guaranteed. Thorough testing with respect to different assumptions and different welfare metrics is recommended.

Figure 1 presents a graphical summary of how Scenario 10 is built up from the other scenarios. The line connecting Scenarios 1-3 shows how the rise in private consumption varies with the world oil price, for 0.8 million ha planted in PGF forestry and producing ethanol. Moving from Scenario 1 to Scenario 5 illustrates the effect of increasing PGF forestry to 3.5 million ha and producing a mix of ethanol and biodiesel.

Scenario 7 has the same specification, but with more land taken out of sheep and beef farming. As noted above this causes the change in private consumption to turn negative.

Scenario 10 can be thought of as a variation on either Scenario 5 or Scenario 3. That is:

- Scenario 3 plus PGF plantation raised from 0.8 to 3.5 million ha, producing a mix of ethanol and biodiesel, higher carbon price and greater productivity in biofuels; or
- Scenario 5 plus a higher oil price, a higher carbon price and greater productivity in biofuels.

Results are approximately linear for small changes. For example, imposing the Scenario 7 fall in sheep and beef output on Scenario 10, would deliver (coincidentally) about the same change in private consumption as in Scenario 5.

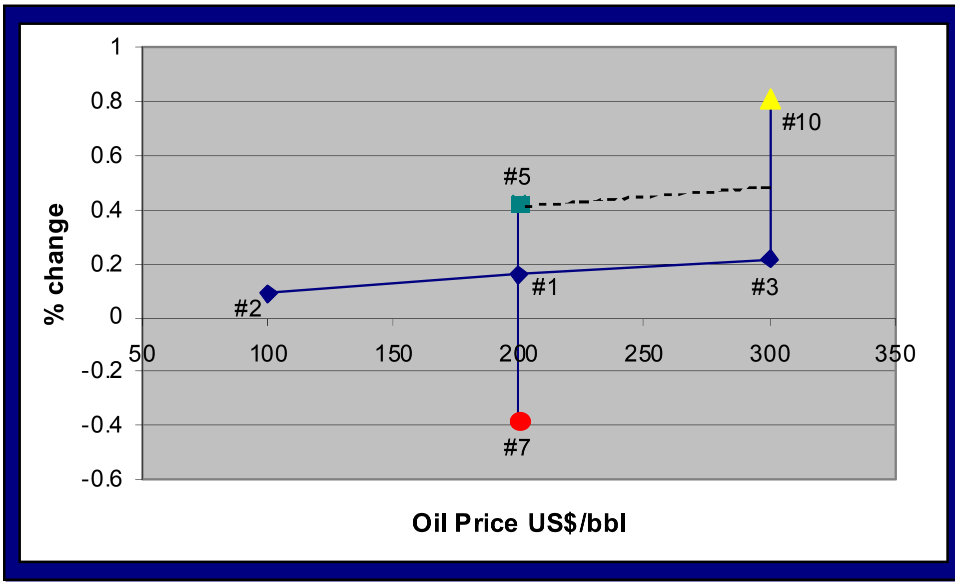

Figure 1: Changes Private Consumption from PGF Biofuels

Conclusions and Further Research

The various scenarios explored above all examine the economy-wide effects of using the nation's resources to produce biofuels instead of producing other goods and services that are exported in exchange for imported oil.

All scenarios assume no change in the total usage of labour and capital, which means that the economy-wide effects are entirely attributable to changes in productive efficiency and changes in allocative efficiency. The main conclusions are as follows:

- As long as a MJ of energy from PGF biofuels costs more than a MJ of energy from imported oil, there is likely to be a loss in national productive efficiency, reflected in lower GDP.
- However, under high oil prices the economy benefits from an increase in the terms of trade as imports of oil fall. In other words there is gain in allocative efficiency.
- The production and use of PGF biofuels reduces CO_2 emissions, so if there is a price on carbon New Zealand's liability to purchase offshore emission units is ameliorated. This generates a gain in real national disposable income.
- Increasing the efficiency of PGF biofuels production has a mixed macroeconomic effect. The effect on GDP and real national disposable income is strongly positive, but the effect on private consumption is slightly negative as some of the benefit from greater efficiency is captured by foreign consumers through agricultural exporters selling goods at lower prices.
- The results are sensitive to the oil price and to the carbon price, but are not sensitive to world agricultural food prices (which affect export revenue).
- Differences in the economic impacts of PGF ethanol and PGF biodiesel are not substantial.
- Under the 3.5m ha scenario, the model suggests that there will be a loss of 0.59m ha in agricultural land, including very small amounts moving out of dairy farming and horticulture.
- If a substantial area of land converts from agriculture (sheep and beef) to PGF, as occurs in the first part of Motu's analysis, the opportunity cost of PGF biofuels rises significantly, making a net welfare gain less likely.

- Our analysis shows that under the core set of prices assumed by Scion for the 3.5 million ha scenario, approximately 28% of the envisaged PGF output would actually come from re-directing forest harvest from lower value uses such as chipping and pulp into biofuels.
- The right combination of oil prices, carbon prices and efficiency in biofuels production can lead to biofuels being competitive with petrol and diesel at the pump, as well as enhancing consumer welfare (under both measures – private consumption and RGNDI). This avoids the need for regulatory intervention such as mandatory biofuels requirements which are less likely to enhance consumer welfare.

Following on from the above, there are two aspects of the case for PGF biofuels that merit further analysis:

- Owing to the uncertainty about just how much agricultural (notably sheep and beef) land might convert to PGF under various oil prices (or under different biofuel regulations), more research into land substitutability is a high priority.

- Land use substitutability is inextricably tied up with options for the forest harvest. We have not looked at exporting some of the PGF crop as logs or pulping it instead of using all of it for biofuels production, although this may be a viable option if biofuels production turns out to be uncompetitive. Much would depend on the degree to which New Zealand could drop up to another 90 million m^3 or so of round wood (or its pulped equivalent) onto world markets without depressing the price. As a comparison, exports of logs and sawn timber currently average about 8 million m^3 per annum out of a total harvest of around 19 million m^3.

Glossary

Private Consumption	Spending on goods and services by private individuals and households. A measure of the economic standard of living of households.
(Real) GDP	Gross Domestic Product, defined as the total value of payments to labour and owners of capital, plus indirect taxes; equivalent to spending on consumption goods (by households and government), plus capital goods, plus changes in stocks, plus exports, less imports. Real GDP is GDP net of price changes, relative to some base year.
Terms of trade	An index of export prices divided by an index of import prices, relative to some base year. In a stylised sense, the terms of trade measures the number of kilograms of milk solids that must be exported in order to import a car.
RGNDI	Real Gross National Disposable Income, equal to real GDP adjusted for payments to foreigners and for changes in the terms of trade. Another measure of economic welfare.
MJ	Megajoule, one million joules. A joule is a unit of energy, equivalent to 0.278 kWh.
PGF	Purpose Grown Forestry – forest grown especially for biofuel production, requiring less silviculture than forest grown for timber.
Productive efficiency	The technical efficiency with which inputs are used to produce outputs – ‘producing things right’.
Allocative efficiency	The degree to which the industrial composition of the economy reflects the use of resources where they are most valued – ‘producing the right things’. (Being the world’s most technically efficient producer of widgets is of little value if the world does not want to buy them.)
Exogenous / endogenous	Models have a mix of exogenous and endogenous variables. Values for endogenous variables are generated by the model, whereas exogenous variables require the model user to set their values. In the ESSAM model for example, world oil prices are exogenous, but NZ electricity prices are endogenous.
Capital Stock	The stock of buildings, plant and equipment (and sometimes land) used by an industry to produce goods and services.
Net Factor Payments	Remissions or payments offshore of dividends, interest payments on debt, emission permits etc.

Appendix A: BAU Input Assumptions

The assumptions below are intended to produce a plausible picture of the economy in 2051. They are not forecasts. The main inputs to the model relate to the following:

- Population and labour force
- Capital stock and total factor productivity
- Energy efficiency and generation mix
- Carbon price
- Balance of payments

Population and Labour Force

The Series 5 population projection produced by SNZ assumes a middle path with respect to fertility, mortality and migration; namely medium fertility, medium mortality and net immigration of an average 10,000 people per annum. For 2050/51 this implies a population of 5.481 million.

In 2005/06, which is the base year for SNZ's projections, the population was 4.185 million implying an average growth rate of 0.60% per annum.

Again SNZ Series 5, with medium (as opposed to low or high) labour force participation rates, projects a figure for 2050/51 of 2.764 million.

For such a long term projection the model requires either total employment or the average wage rate to be set exogenously. Our preferred approach is make an assumption about the rate of unemployment and let the model produce whatever profile of wage rates is consistent with this, rather than the other way around.

In a modern economy the rate of unemployment in the long run is driven primarily by demographic factors and labour market regulations, whereas as wage rates are ultimately a function of the growth of the economy. Thus it is more plausible to assume some rate of unemployment that society is prepared to tolerate, which is likely to cover a fairly narrow range, than to assume some set growth path for wages – which could easily produce totally unrealistic projections of unemployment.

For the first scenario we assume an unemployment rate of 3.0%; on the low side of historical rates, but recognising the projected aging of the population and associated slow growth in labour force.

Capital Stock and Total Factor Productivity

Over the last 30 years or so the economy's productive capital stock has grown at an average real rate of 2.5% pa,[20] although over the last five years growth has averaged 3.3% pa. We expect growth to continue at about 3% pa for next two decades as aging infrastructure is replaced and major new investment occurs in roading, public transport and energy. Thereafter we assume growth to decline to around 2.4% pa.

Total factor productivity in the 'measured sector' of the economy has grown at just under 1% pa over the last 30 years.[21] Over the last five years growth has been only 0.3% pa. For the period to 2050 we assume an average value of 0.8% pa with somewhat faster growth over the first half of the period. The composition by broad industry groups is shown below, along with historical rates estimated by Black et al.[22]

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[20] Source: SNZ.

[21] Source: SNZ. The measured sector comprises ANZSIC divisions A to K and P from 1978, and includes divisions LC (Business services) and Q (Personal and other community services) from 1996 onwards. The main exclusions are property services, health, education and government services.

[22] Black. M., M. Guy & N. McLellan, 2003: *Productivity in New Zealand 1988 to 2002*, New Zealand Treasury Working Paper 03/06, Wellington.

Total Factor Productivity

	1988 to 2002 (%pa)	2005 to 2025 (%pa)	2025 to 2050 (%pa)
Agriculture & Forestry	1.4	1.5	0.5
Mining	-0.2	2.0	1.0
Construction	-1.5	0.2	0.0
Manufacturing	0.0	1.0	1.0
Utilities	-0.2	0.5	0.5
Transport	{ 5.8	0.5	0.5
Communication	{	3.0	1.5
Business Services	-0.4	1.0	0.5
Community & Personal Services	1.2	0.5	0.25
Trade & Hospitality	0.8	0.5	0.25

Energy and Energy Efficiency

The model requires projections of rates of improvement in energy efficiency – often referred to in energy models as the AEEI; the autonomous energy efficient improvement parameter. This is fuel specific and hence is required for coal, natural gas, oil products and electricity.

Typically in our modelling we have used 1% pa for all fuels except for electricity use by households where a lower rate of 0.5% pa has been used. This is not because the efficiency of household appliances is assumed to improve at a slower rate than industrial machinery. Rather it is a crude way to capture the increasing use of electrical appliances (such as computers and television decoders) that were previously less prevalent and that are frequently left on, even if only in stand-by mode, for extended periods of time. To this one might add the increasing use of clothes driers associated with the move to apartment living, and heat pumps which, while very efficient, are often used for air conditioning in homes which had no air conditioning prior to installation of a heat pump.

In MED (2006) the AEEI is about 0.5-1.0% pa. We assume 1.0% pa for industrial and commercial use of all fuels. Assumptions for road transport and household energy are as follows:

Household electricity use

We assume an underlying AEEI of 0.5% pa as a crude balance between the increasing technical efficiency of household appliances, the use of in-home solar power and the offsetting effect of more appliances and air conditioning. However, Beacon Pathway[23] looked in detail at some key opportunities for improvements in household energy efficiency, notably in space heating (retrofit insulation and more efficient heating mechanisms such as heat pumps), water heating and lighting. Not all houses are amenable to cost-effective retrofitting insulation. Nor do we expect 100% penetration of compact fluorescent lighting (barring legislation) or efficient heating appliances. Nevertheless, by 2050/51 cost-effective household energy savings could easily amount to over 30%. This raises the effective AEEI for household electricity use to 1.3% pa.

Road transport

Fuel efficiency in road transport is a difficult area. For private household travel in particular, improvements in vehicle fuel efficiency and diesel-petrol substitution are being offset by a trend to larger petrol vehicles and diesel SUVs (at least up to the sharp increases in oil prices in 2008). Further offset comes from the increasing weight of cars caused by more stringent safety standards. Based on MED (2006) estimates which take into account real income growth, greater diesel use, better technical energy efficiency and a changing fleet mix, the implicit efficiency gain is about 1.2% pa up to 2030.

For commercial vehicle use we assume a lower figure of 1% pa (up to 2050/51), as the relative shift to diesel vehicles is much smaller. To maintain the MED average this implies a rate for vehicle use by private households of 1.6% pa.

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[23] Beacon Pathway Ltd., 2007: *National Value Case for Sustainable Housing Innovations*, Auckland.

Electricity generation
Left to itself the model will configure a generation mix that is similar to the 2005/06 mix, subject to changes in relative prices such as may be caused by a carbon price. Clearly this is unsatisfactory – the gas supply could be much lower than anticipated or there maybe significant technological advances in generation from tidal or wave power, or from waste.

The assumed profile below is based on the MED (2006) 'renewables' scenario to 2030. Coal-fired generation has disappeared on the assumption that carbon capture and storage is not competitive with wind and tidal power. However, for 2050/51 we assume a small amount of coal-fired generation to cover dry or non-windy years.

Solar-generated electricity on a large scale is assumed to be insignificant in New Zealand, although this is not to discount its potential. Direct use of solar (photovoltaic) power by households is captured with the household energy efficiency parameter – see above.

Electricity Supply by Fuel (%)

	2005/06	2030	2050/51	
Hydro	58	58		}
Wind	1	17	87	}
Tidal/wave		6		} renewables
Geothermal	7	9		}
Cogen	5	5		}
Gas	17	5	11	includes gas cogen
Coal	12	0	2	>0 for dry years
	145 PJ	174 PJ	213 PJ	

Carbon Price
Forecasting the international price of carbon in 2050 is impossible. Critical factors are which countries participate in international agreements to lower emissions, the tightness of international obligations, and the path of emissions over the intervening four decades. We take the view that by 2050 a carbon charge will have had a strong enough impact on GHG emissions such that the price of carbon will have declined from a peak during the 2030s. We assume a price of US$100/tonne CO_2e. This might be seen as an optimistic scenario, but could equally reflect a lack of international political will to accept a high carbon price.

Oil Price
The oil price is almost as difficult to forecast as the price of carbon. We defer to the comprehensive discussion and analysis in NZTA (2008)[24] which shows a number of projections for the price of oil in 2028 ranging between US65/bbl and US$230/bbl, with an average of about US$115/bbl (all in 2008 prices). Most of the projections estimate a higher price before 2028.

We assume an average increase in price of 2.5% pa from 2028 to 2050, which is roughly its rate of real price increase over the last fifty years – albeit with much volatility. This gives a price in 2050 of about US$200/bbl (in 2008 prices).

Exchange Rate and Balance of Payments
The model does not simulate the absolute price level – it deals entirely in relative prices. The price *numeraire* is the average import price, excluding oil. With a fixed balance of payments constraint, the change in the real exchange rate – inflation in New Zealand relative to world inflation, multiplied by the change in the nominal exchange rate – is endogenous to the model. Any given value of the change in the real exchange rate is consistent with many different combinations of relative inflation rates and changes in the nominal exchange rate. For example, New Zealand inflation at 2% p.a., world inflation at 3% p.a. and an appreciation of the nominal exchange rate of 1% p.a., would leave the real exchange rate unchanged. Doubling all of these amounts would yield the same outcome, as would New Zealand inflation of 2% pa, world inflation of 1% pa and a devaluation of the nominal exchange rate of 1% pa.

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[24] New Zealand Transport Agency, 2008: *Managing transport challenges when oil prices rise,* Research Report 04/08, Wellington.

We can express the change in the price of oil (or of any international commodity) relative to the change in world prices in general but, given a model-endogenous value for the change in the real exchange rate, the change in the real price of oil in New Zealand dollars is independent of the nominal exchange rate.

To illustrate, let us assume a change in the international oil price from US$70/bbl in 2005/06 (the model's base year) to $200 in 2050/51. Without loss of generality, we further assume zero inflation in other world prices.

If the model produces a change in the real exchange rate of plus 10%, then either New Zealand inflation is 10% over the period with no change in the nominal exchange rate, or New Zealand inflation is zero and the exchange rate appreciates by 10%, or some linear combination of these two scenarios prevails.

It might appear that this means that the price of oil in New Zealand currency could be anywhere between NZ$200/bbl and NZ$180/bbl. This is indeed the case, but the point is that the difference is irrelevant. If the former price prevails it means that the real price of oil in 2005/06 prices is NZ$180/bbl – because of New Zealand's 10% general inflation. This is exactly the real price that occurs if New Zealand has no inflation, but the nominal exchange rate appreciates by 10%.

What matters in the model is the real or relative price of oil, not its nominal price. This is no different than saying that if all prices in the economy doubled, there would be no real effects. In economics this is known as the principle of *no money illusion*. It is fundamental to the model.

Returning then to the issue of the balance of payments, we presume that New Zealand's long record of balance payments deficits cannot continue. With other countries improving their economic management and providing profitable opportunities for investment, New Zealand will find it more difficult to attract foreign investment to cover a persistent balance of payments deficit. Hence we assume a small balance of payments surplus of 1% on GDP in 2050/51. With positive net factor payments (servicing of past debt) this will likely imply a larger surplus on the balance of trade in goods and services.

Appendix B: PGF Ethanol Costs

The cost estimates in the following table were calculated by Scion.

Costs of Ethanol from Purposely Grown Forestry (enzyme technology)	$/litre	$/MJ	$/l/Peq	Lower Cost Scenario $/litre
Capex	0.620	0.0288	0.925	0.500
Feedstock				
Grow	0.410	0.0191	0.612	0.240
Road	0.040	0.0019	0.060	0.024
Log	0.270	0.0126	0.403	0.184
Transport	0.110	0.0051	0.164	0.072
Comminution	0.030	0.0014	0.045	0.024
Handling	0.010	0.0005	0.015	0.008
Enzymes	0.150	0.0070	0.224	0.070
Electricity	0.130	0.0060	0.194	0.000
Chemicals	0.030	0.0014	0.045	0.024
Fixed costs				
Salary/Wages	0.070	0.0033	0.104	0.056
Admin	0.020	0.0009	0.030	0.016
R&M	0.060	0.0028	0.090	0.048
Distribution	0.035	0.0016	0.052	0.033
Total	1.985	0.0923	2.963	1.299

The pre-tax price of petrol in 2005/06 was about $0.0243/MJ, rising to $0.030/MJ in the last quarter of 2007.[25] This means that the real resource cost of PGF ethanol at the end of 2007 was approximately 3.1 times the cost of petrol, per unit of energy.

The ‘Grow’ cost includes the cost of land, which varies with land quality.

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[25] Source: Ministry of Economic Development *Energy Data File*.

Appendix C: PGF Biodiesel Costs

The cost estimates in the following table were calculated by Scion.

Costs of Biodiesel from Purposely Grown Forestry (gasification & Fischer Tropsch technology)

	$/litre	$/MJ	$/l/Peq	Lower Cost Scenario $/litre
Capex	0.390	0.0115	0.371	0.349
Feedstock				
Grow	0.610	0.0179	0.581	0.440
Road	0.050	0.0015	0.048	0.040
Log	0.400	0.0118	0.381	0.031
Transport	0.170	0.0050	0.162	0.139
Comminution	0.040	0.0012	0.038	0.036
Handling	0.010	0.0003	0.010	0.009
Enzymes	0.000	0.0000	0.000	0.000
Electricity	0.130	0.0038	0.124	0.054
Chemicals	0.030	0.0009	0.029	0.027
Fixed costs				
Salary/Wages	0.060	0.0018	0.057	0.054
Admin	0.020	0.0006	0.019	0.018
R&M	0.030	0.0009	0.029	0.027
Distribution	0.035	0.0010	0.033	0.031
Total	1.975	0.0581	1.881	1.255

The pre-tax price of diesel in 2005/06 was about $0.0255/MJ, rising to $0.0309/MJ in the last quarter of 2007.[26] This means that the real resource cost of PGF biodiesel at the end of 2007 was approximately 1.9 times the cost of fossil diesel, per unit of energy.

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[26] Source: Ministry of Economic Development *Energy Data File*.