Large-scale forests for bioenergy: land-use, economic and environmental implications

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An analysis of national-level impacts of plantation forestry for energy production in New Zealand – a useful tool for strategic decision-making.

Concerns about climate change and energy security have driven many countries to reconsider their renewable energy options and strategies. Energy from biomass is expected to play an important role and has received significant attention in recent years. While its potential positive contributions are well recognized, development of biofuels may also have negative impacts. Assessment of a country's bioenergy options should thus include analysis of:

- potential biomass resources;
- consumer energy demand (given other potential renewable energy options);
- available technologies for converting biomass into consumer energy;
- economic cost;
- potential reduction in greenhouse gases;
- impacts of land-use change;
- competition with food production.

An assessment of this type has been carried out in New Zealand. It highlighted the country's potential for producing bioenergy from large-scale forestry and then examined the consequences this would have for land use, the economy and the environment. This article summarizes the results of the study. A longer report (Hall and Jack, 2009) provides more detailed discussion of the methodology and assumptions behind the work. Although the study was specific to New Zealand, it raises pertinent questions that other countries may consider in analysing their bioenergy options.

While socio-political aspects are also key components to such decision-making, they were outside the scope of this study and not addressed in detail.

The development of a large-scale forestry resource on marginal land represents New Zealand's greatest opportunity for bioenergy

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ANALYSIS OF BIOENERGY OPTIONS

The above parameters were assessed through:

- a situation analysis, examining current biomass residual resources, the potential of purpose-grown options, and the status of existing biomass-to-consumer energy technologies (Hall and Gifford, 2007);
- a pathways analysis, examining economic costs and environmental impacts (through life-cycle assessment) of nationally relevant biomass-to-consumer energy conversion pathways (Hall and Jack, 2008).

The study determined that the main role of bioenergy in New Zealand is likely to be for heat and liquid transport fuels, because of the significant potential of other renewable resources for electricity generation. The assessment also identified the development of a large-scale forestry resource utilizing marginal land as the most significant opportunity for bioenergy in New Zealand from the following perspectives.

- ***Potential scale of energy supply.*** New Zealand has sufficient low- to medium-productivity grazing land – over 60 percent (9.3 million hectares) of available productive land – to establish a plantation forest resource that, by 2040, would be of sufficient scale to supply all of the country's demand for liquid fuels. In contrast, only about 26 percent (2.4 million hectares) of productive land in New Zealand is suitable for agricultural crops; using all this area for crops for first-generation liquid biofuel would provide insufficient liquid fuels to meet the national demand and would be detrimental to food crop production and agricultural exports.
- ***Greenhouse gas reductions.*** Life-cycle assessment of the full production chain showed that producing lignocellulosic biofuel from plantation forestry feedstock would have much lower environmental impact than producing first-generation biofuel from oil and starch crops, mainly because of the less intensive farming practices per unit of biomass.
- ***Technological maturity and cost.*** Technology for converting lignocellulosic biomass to liquid transport fuels is progressing rapidly towards commercial viability (Sims *et al.*, 2008).

ASSESSMENT OF LARGE-SCALE FORESTRY FOR BIOMASS PRODUCTION

The authors assessed the impacts of displacing agriculture (mainly low-productivity grazing) with forestry on hilly land for four large-scale afforestation scenarios (Table 1). In these scenarios, potential land for afforestation was selected from a Geographic Information Systems land-use class database. The scenarios differ in land-use class, slope, altitude and current land use. It was assumed that lowest-value land would be used first (Scenario 1) and that subsequent scenarios would embrace land of progressively increasing value. The scenarios presume the use of scrub, idle, marginal and low-to-moderate productivity grazing land as the resource area and explicitly exclude conservation and arable land.

The potential biomass productivity for the scenarios was calculated based on soil and climate (Table 2) and the economic cost of biomass production (Table 3), assuming some flexibility between energy production and other end uses (e.g. timber or carbon credits), which mitigates risk for the forest owner.

Potential environmental impacts

All scenarios were associated with significant greenhouse gas emission reductions (estimated using Intergovernmental Panel on Climate Change [IPCC] methodologies), both from displacement of fossil fuel and from the change in land use from agriculture (which accounts for about half of New Zealand's emissions) to forestry (Table 4). The scenarios were associated with increased carbon stocks, because for a sustainably managed 25-year rotation forest, only 4 percent is harvested per year (Table 4). Emission reductions were lower in Scenarios 1 and 2 because of the lower-intensity land use that is displaced in these scenarios.

Because of reduced levels of pastoral production (Table 5), the scenarios also showed benefits in a number of areas of environmental concern in New Zealand including erosion, sedimentation and nutrient leaching into waterways (estimated using a nutrient model and a spatial erosion model) (Table 4).

Largely positive biodiversity impacts were also found, in improved species richness of insects, plants and native birds in comparison with pasture and exotic shrub lands. However, quantification of these benefits requires further research. Afforestation of land that was not historically forested may not be desirable from a biodiversity perspective as it reduces native grassland habitats.

The analysis showed that in some areas – those with low rainfall and high existing water allocations – large-scale afforestation could have negative impacts on water availability and its suitability would thus be questionable.

Potential for competition from alternative land uses

The current return for the land under the scenarios was assessed to determine the economic viability of forestry for biomass for energy production (Todd, Zhang and Kerr, 2009). Because of the greenhouse gas emissions associated with agriculture, the return from the land depends on the price of carbon (Table 6) and the competitiveness of biomass for fuel compared with current land use depends on the price of oil. Based on the biofuel production costs assumed in the study (Table 7), bioenergy from forestry is a more profitable option; it can provide

TABLE 1. Afforestation scenarios derived using criteria based on land-use class, slope, altitude and current land use (area from minor contributing land uses, such as deer farming, not included)

Scenario	Total area (‘000 ha)	Area from scrubland (‘000 ha)	Area of sheep and beef pasture (‘000 ha)
1	831	0	533
2	1 856	51	1 619
3	3 475	69	3 160
4	4 927	198	4 412

Note: New Zealand’s current plantation estate is 1.8 million hectares.

TABLE 2. Total sustainably extractable biomass and corresponding energy potential of each afforestation scenario to meet consumer energy demand

Scenario	Total extractable biomass (million m^3/year)	% of current consumer energy demand[a]
1	23	68% of heat, or 20% of liquid transport fuel
2	74	100% of heat and 42% of liquid transport fuel, or 72% of liquid transport fuel, or 73% of electricity
3	127	100% of heat and 100% of liquid transport fuel
4	169	100% of heat and 100% of liquid transport fuel and 85% of electricity

[a] In this table “heat” refers to all industrial and domestic heat, and “electricity” is large-scale centralized electricity generation.

TABLE 3. Range of biomass yields and production costs[a]

Scenario	Biomass yield (m^3/ha)	Costs per cubic metre[b]									
		Growing[c]		Roads		Harvest		Transport[d]		Total	
		NZ$	US$	NZ$	US$	NZ$	US$	NZ$	US$	NZ$	US$
1	640–850	21–28	15–20	4–6	3–4	34–38	24–27	13–15	9–11	72–87	50–70
2	940–1 240	14–19	10–13	3–4	2–3	34–38	24–27	13–15	9–11	64–76	45–53
3	940–1 240	14–19	10–13	3–4	2–3	34–38	24–27	13–15	9–11	64–76	45–53
4	910–1 200	15–20	11–14	3–4	2–3	34–38	24–27	13–15	9–11	65–77	46–54

[a] The range is based on a potential growth gain of 32% due to alternative species, tree breeding or genetic modification and potential improvements in transport and harvesting efficiency.
[b] All costs were determined under local conditions and converted to US$ assuming the exchange rate NZ$1 = US$0.7.
[c] Includes land rental, land preparation, planting, weed control and forest maintenance (discount rate, 6%).
[d] 75 km.

TABLE 4. Percentage change in key environmental parameters relevant to New Zealand

Scenario	Reduction in greenhouse gas emissions[a] (%)	Carbon stocks (million tonnes CO_2 equivalent)	Reduction in nitrogen leaching[b] (%)	Reduction in erosion[c] (%)	Reduction in available water[d] (%)
1	6	208	0.3	1	1
2	20	647	3	8	3
3	37	1 183	8	17	5
4	48	2 034	12	20	7

[a] Compared to New Zealand’s total emissions in 2006.
[b] Relative to current levels. Note that leaching rates can remain high for several years if the soil already contains a large amount of surplus nitrogen.
[c] Relative to current levels.
[d] As percentage of annual water balance.

TABLE 5. Reduction in livestock numbers (%)

Scenario	Beef cattle	Dairy cattle	Deer	Sheep
1	3.0	0.1	2.0	2.8
2	15.0	0.8	11.1	15.1
3	33.3	2.0	14.9	32.1
4	46.8	3.5	27.2	42.0

TABLE 6. Pre-afforestation average annual profit (earnings before interest and taxes) on land selected for bioenergy[a]

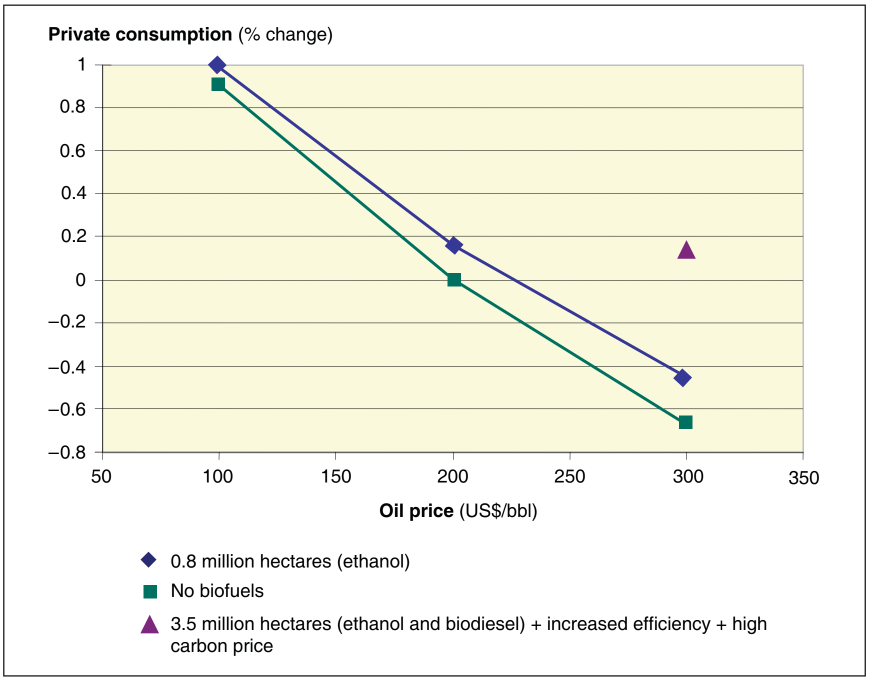
Scenario	Without carbon price		With carbon price[b]	
	NZ$/ha	US$/ha	NZ$/ha	US$/ha
1	94	66	60	42
2	144	101	100	70
3	162	113	114	80
4	160	112	108	76

[a] All prices were determined under local conditions and converted to US$ assuming the exchange rate NZ$1 = US$0.7.
[b] Assumes a carbon price of NZ$25 (US$17.5) per tonne of CO_2 equivalent.

TABLE 7. Assumed costs of biofuel production (per litre)[a]

Process	Bioethanol[b]		Fischer-Tropsch biodiesel[c]	
	NZ$	US$	NZ$	US$
Feedstock production[d]	0.61	0.43	0.89	0.62
Conversion[e]	1.12	0.78	0.70	0.49
Total	**1.73**	**1.21**	**1.59**	**1.11**

[a] All costs were determined under local conditions and converted to US$ assuming the exchange rate NZ$1 = US$0.7.
[b] Assumes a yield of 140 litres/m^3. Energy content of a litre of ethanol is 0.67 litres of petrol, meaning that total production costs are NZ$2.58 (US$1.81) per litre of petrol equivalent.
[c] Assumes a yield of 95 litres/m^3. Energy content of Fischer-Tropsch biodiesel is assumed to be the same as fossil diesel.
[d] This value represents the upper bound of the values shown in Table 3.
[e] See Hall and Jack, 2009 for more details on conversion cost assumptions.



Economic impact of changes in oil prices in New Zealand, with and without biofuels and other measures to mitigate climate change

a return of more than NZ$200 (US$140) per hectare when the oil price reaches US$180 to $250 per barrel (depending on the exchange rate). (Note that the oil price was US$147 per barrel in July 2008.) However, this economic driver may not be sufficient to lead to land-use change, as historically farmers have tended to stay with sheep and cattle farming even when its profitability is low. More research is required to understand the social drivers, which were not considered in this study.

Macroeconomic impact

A general equilibrium model was used to estimate the consequences of using the nation's land resources to produce biomass for fuel instead of other goods and services that are exported in exchange for oil (Stroombergen, 2009). Several economic scenarios based on assumed production costs, oil prices and carbon stocks were compared with a business-as-usual picture of the economy in 2050.

Currently, New Zealand obtains half its consumer energy and 93 percent of its transport fuels from imported oil, and its oil consumption per unit of gross domestic product (GDP) is the third highest in the world (Delbruck, 2005). A large part of the export earnings used to purchase this oil comes from agricultural production. Therefore, a rise in oil prices relative to agricultural goods would have detrimental effects on terms of trade and consequently the economy as a whole.

This trade also has a major impact on domestic greenhouse gas emissions, as it includes both the direct carbon emissions from oil consumption and the indirect greenhouse gas emissions from agricultural activities used to pay for imported oil. If carbon pricing in New Zealand includes all sectors of the economy in the future (which is likely under the New Zealand Emissions Trading Scheme), then this trade will magnify the potential impact of emission controls on the economy. Thus, domestic production of low-carbon biofuels could reduce the economic impact of both rising oil prices and stricter emission controls in the future.

The Figure demonstrates how biofuels could reduce the economic impact of higher oil prices in the future. The points show the impact of changes in oil prices and biofuel production on pri-

Residues from timber production for use in bioenergy: multipurpose forests producing a range of products including timber and biomass for fuel are likely to be the most economically viable option

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vate consumption (a measure of economic welfare) compared with a baseline scenario for 2050 that includes an oil price of US$200 per barrel, no biofuels and an economy similar in structure to today's.

With no biofuels, an increase in oil price to US$300 per barrel would reduce private consumption by about 0.7 percent (compared with the baseline) because of the reduction in terms of trade. With 0.8 million hectares used for ethanol production, oil imports would be 15 percent less and the same oil price increase would result in a smaller decline in private consumption (of about 0.45 percent). With an even greater expansion of biofuels (3.5 million hectares used, reducing oil imports by 63 percent), plus efficiency gains and a high carbon price, the macroeconomic impact of an increase in oil price to US$300 per barrel would be more than completely mitigated.

Multipurpose forests producing a range of products including timber and biomass for fuel are likely to be the most economically viable source of biofuels, and the economic benefits of biofuels are greatest when they are competitive with fossil fuels. However, as this example shows, long-term energy policies should take into account that biofuels may result in macroeconomic benefits in the future even though their current production costs are higher than the costs of imported fossil fuels.

CONCLUSIONS

A key finding of this assessment is that in New Zealand, growing large-scale forest plantations for bioenergy on low-productivity agricultural land can have a significant impact on greenhouse gas emissions through both land-use change from agriculture to forestry and displacement of fossil fuels. It can also have other environmental benefits in terms of improved water quality and erosion control in comparison with agriculture. This is a case where land-use change would thus have positive environmental impacts. These results would most likely hold for other countries where forests can be grown with low inputs on low-productivity agricultural land.

This type of assessment of land-use, environmental and economic impacts of bioenergy at the national level can help governments make strategic decisions about large-scale bioenergy opportunities as part of national energy supply. The approach can also help to identify national and regional issues that need to be addressed to realize the benefits of these opportunities. ◆

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