The Use of A New Zealand Dynamic Ecological-Economic Model to Address Future Scenarios

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EXTENDED ABSTRACT

A simulation model was used to illustrate logical outcomes of four scenarios of a future New Zealand up to 50 years hence. These scenarios were defined in consultation with government policy-makers using a range of qualitative driving forces: New Zealand governance, identity and social cohesion; and impacts of technology choices; and rates of resource use. Scenarios include independent projections of key social, economic, and environmental variables. The model has been designed to evaluate the interactions between these variables and to facilitate understanding, communication, and participation between stakeholders, social scientists, and modellers. This paper describes the overall structure of the model, linkages between the various modules, and early modelling results.

The model provides a flexible framework that can be used by stakeholders to test parameter values and relationships and the direct and indirect effects of parameters on the economy and the environment. The model has three independent modules running sequentially. The population module is a dynamic simulation model with 5-year age-sex cohorts. It outputs the population size and composition for each year until 2050. The labour force module applies assumed age- and sex-specific participation rates to the working-age population of each scenario. This module yields Full Time Equivalent (FTE) employment levels that are used as an input to the next module. The Environment-Economy module is based on a simplified Social Accounting Matrix for the New Zealand economy and estimates the environmental pressures of energy use and global warming potential (GWP) associated with economic activity and households.

Parameters estimated for each scenario included: fertility, mortality, migration, labour participation and unemployment rates; household expenditure and exports profiles; productivity, capital structure and environmental pressures changes. Results for one of the four scenarios ("Independent Aotearoa") are presented in this paper.

Under this scenario the modelled total population increases from 3.9m in 2001 to 5m in 2050. The population will age considerably, with people older than 65 increasing from 12% in 2001 to 21% in 2050, increasing the 65+ dependency ratio from 1:4 in 2001 to almost 1:2 in 2050. Given labour force and productivity growth, GDP increases from \$111billion in 2001 to 229$\$NZ_{2001}$billion in 2050. There is a significant relative shift from primary and manufacturing sectors to services and the public sector in comparison to the 2001economic structure.

While energy use per capita decreases in comparison with 2001, there is an increase in the total use of fuels and electricity driven by population growth and increased economic activity. Total energy use increases 10%, from 473PJ in 2001 to 520PJ in 2050. However, most of the electricity is by then generated from renewable sources, resulting in an 8% decrease on Energy generated CO_2 emissions, from 25Gg in 2001 to 23Gg in 2050. Green house gas (GHG) emissions decrease in 2050 due to reduced agricultural activities and technological change. As a result the total GWP decreased 9%, from 45Gg in 2001 to 41Gg in 2050.

Although limited, this first version of the New Zealand Dynamic Ecological-Economic Model (NZDEEM) has provided a tool that can be used to provide a 'more holistic view' of basic interactions between simplified social, economic, and environmental systems. Furthermore, a number of potential interpretation errors and omissions with the narrative scenarios and the quantitative model came to light through the modelling process. Thus NZDEEM has proved useful in providing common ground between modellers and social scientists to generate the critical debate that refines both models and narratives.

1. INTRODUCTION

Based on work begun in Wellington in 2004 with a team drawn informally from government, academia and business, Landcare Research created four contrasting future possibilities for NZ (Frame et al., 2005b). Interactive sessions have been run with various groups over the last 2 years using the '*100% Pure Conjecture*' game (Frame et al., 2005a) in order to stimulate interest in future directions for New Zealand and to aid strategic thinking on sustainability[1]. The four scenario descriptions are logically linked across two axes of socio-economic and environmental characteristics (Figure 1). The scenarios are either: rich or poor in accessible natural resources and ecosystem services, and strong or weak on social cohesion/'social capital'.

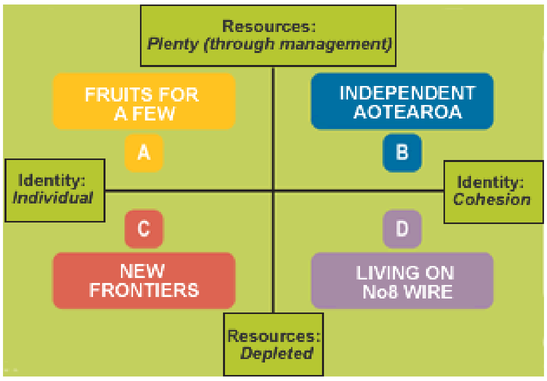

Figure 1. Graphical representation of four scenario 'spaces' created by two intersecting axes that show continua of resource availability and social cohesion

The NZDEEM was developed as a support tool for quantitatively testing assumptions made in the narrative describing the Four Futures for New Zealand (Frame et al., 2005b). The model is derived from statistical (population projections) and econometric (Social Accounting Matrix) models, and does not attempt to be a predictive tool. Moss (2007) argued that "neither classical statistical nor econometric theory can be presumed to be applicable in conditions of unpredictable volatile episodes in physical and social contexts. Furthermore, forecasting over periods long enough to include such unpredictable events cannot be reliable". NZDEEM is therefore no more likely to be in any sense true than are the four narrative scenarios. However, by integrating the modelling process into the development of narrative scenarios, scientists and modellers can obtain the benefits of both formal precision and the rich expressiveness of storylines (Khalil, 1992; Jager, 2000; Moss, 2007).

In support of the Four Futures for New Zealand, the model should be viewed as a picture of plausible social, economic, and environmental structures. The main purpose of the model is to illustrate the cumulative impacts individual parameters might have on a set of social, economic, and environmental results. The model is intended to be interactive. The main priority while developing the model was therefore to keep it as flexible and transparent as possible to facilitate its understanding. Complex systems models developed in isolation from stakeholders are often difficult to assess and accept (Jager, 2000; Barreteau et al., 2003). Therefore, it is envisaged that greater complexity between existing or new parameters and feedback loops will be added to the model after more interaction with the narrators. When possible, parameters needed for the model have been made exogenous. These are provided by interpretation of the narrative of each scenario.

The four scenarios are not equally likely to occur, and were designed to span a range of potential future conditions. The actual future is not likely to match any one of these four images, but it may fall somewhere within the 'possibility space' that the scenarios explore. For the sake of brevity, we present only one scenario: "Independent Aotearoa" here, because our main purpose is to present the scenario modelling approach. The scenario summary description is as follows:

"Independent Aotearoa: By 2050, Aotearoa-New Zealand is a dynamic cohesive society. Government seeks and coordinates solutions to climate, environmental and social sustainability challenges. Sustainability is a conscious lifestyle choice for many, resulting from a value shift as Aotearoa-New Zealand decided to 'go its own way'. In this scenario, geopolitical instability and cultural/social change override the incentives for economic globalisation. There has been a clear shift from a 'first-come first-served' market economics to more participative governance and regulation. These value social and cultural well-being and long-term benefits for future generations over short-term profits. Although the knowledge-based economy is slow-growing, its benefits are shared equitably. This demand from the State, however, discourages the individualist entrepreneurs, some of whom take their skills abroad. The amount of materials, water and energy required to produce goods has reduced, while economic benefits (and exports) flow from the introduction of clean, efficient technologies.

[1] Resources including the scenario game can be accessed at: www.landcareresearch.co.nz/services/sustainablesoc/futures/

Less unprocessed primary produce is exported in 2050 than in the past.”

Parameters (Table 1) for the scenario were interpreted from the narrative. Historical information was used to provide guidelines to establish some parameters within credible limits (e.g. fertility rates, productivity changes, etc). For example, the total fertility rate in 2006 was 2.05 (Statistics NZ, 2006). The fertility rate for the Independent Aotearoa scenario increases steadily to reach 2.1, within the limits of the Statistics NZ projections to 2051 (Statistics NZ, 2004).

Table 1. Scenario definition parameters

Population and Labour modules	Environment-Economy module
Fertility rates	Household expenditure profile
Mortality rates	Sector productivity changes
Long-term immigration	Exports profile
Long-term emigration	Sector value-added changes
Labour participation rates	Household environmental pressures profile
Unemployment rates	Productive sectors environmental pressures profiles
	Electricity generation profiles
	Land available for agriculture and forestry

2. METHOD

The model’s logic was based on the Auckland Region Dynamic Economic and Environmental Model (ARDEEM), developed by Garry McDonald of the NZCEE[2](McDonald, 2005, 2006). The model consists of three coupled modules run sequentially, as shown in Figure 2. A population module projects age-structure population for future years. Population values are inputs to the labour module, which calculates full-time-equivalent employees (FTE). Figure 3 shows in more detail the structure and information flows of the Environment-Economy module.

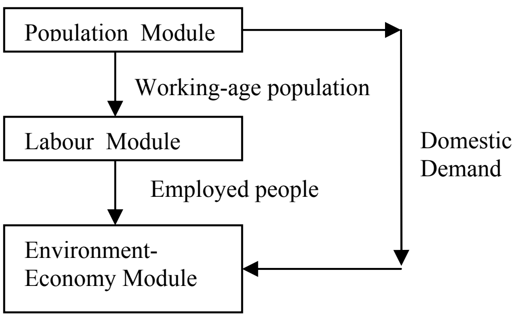

Figure 2. Basic NZDEEM structure and information flows

[2] The New Zealand Centre for Ecological Economics (www.nzcee.org.nz)

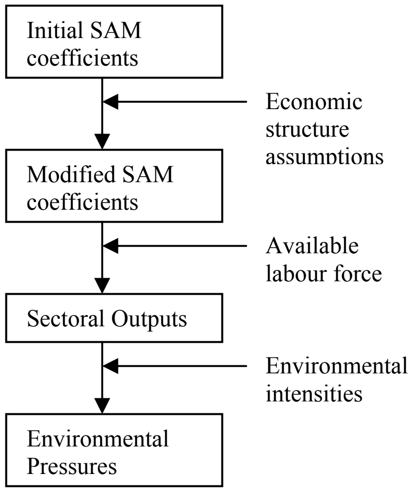

Figure 3. NZDEEM Environment-Economy module structure and information flows

2.1. Population and labour force modules

The population module is a dynamic simulation model with 5-year age-sex cohorts. The model assumes different fertility rates (non-zero for 10–49-year-old females), mortality rates, and long-term emigration and immigration per cohort. These exogenous values (see Figure 4) were informed by values used in Statistics NZ population scenarios (Statistics New Zealand, 2004). The module outputs the population size and composition for each year of the simulation. To run the population and labour modules, 2006 demographic data were used to initialise the model, since this improves the projection reliability. However, 2001 was chosen as the benchmark year for reporting of results, because comprehensive data for all modules were readily available for that year.

The labour force module applies assumed age- and sex-specific participation rates to the working-age population of each scenario (Table 2). Current participation rates were adjusted for the scenario, with specified terminal values interpreted from the narrative and linear interpolation used for intermediate years. This yields age- and sex-specific FTEs, although only total FTEs are used at this stage.

Table 2. Assumed labour participation rates and unemployment rates for 2001 and for 2050

Age Group	2001	Independent Aotearoa (2050)
15–24	52%	48%
25–44	80%	70%
45–64	76%	76%
65+	6%	5%
Unemployment rate	3.4%	5%

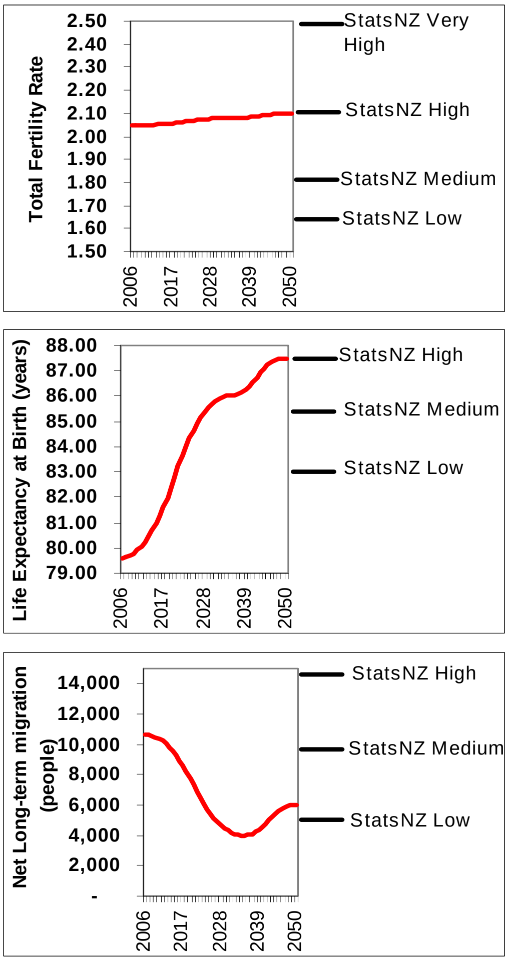

Figure 4. Comparison of parameters used for (top) fertility (centre) life expectancy and (bottom) net migration in Independent Aotearoa with Stats NZ population projections (Statistics New Zealand, 2004)

2.2. Environment-Economy module

The Environment-Economy module is based on a Social Accounting Matrix (SAM) for New Zealand (year ended March 2001). This matrix describes economic linkages between different industries, factors of production (labour and capital) and institutions.

	Industries	Factors / Institutions
Industries	I Intermediate use	II Final use
Factors / Institutions	III Factor inputs / Import	IV Inter-institutional transfers

Figure 5. SAM Quadrants used in NZDEEM

An existing inter-industry input-output table[3] provided data for quadrants one to three (Figure 5. SAM Quadrants used in NZDEEM). Data for quadrant four were sourced mainly from Statistics New Zealand national, central and local government accounts (Statistics New Zealand, 2001). The essential difference between the input-output and closed SAM structures is the endogenisation of factor and institutional accounts (ten Raa, 2005, p.83). The resulting SAM has 48 industries, two factors of production (labour and capital)[4], three institutions (households, government, and rest-of-world), and a savings and investment account. The SAM is a closed system in which income and expenditure balance for every account. The SAM transactions matrix *S* is normalised by its column sums (which equal row sums) **z**, to form the SAM shares matrix *A*:

$$S_0 = T_0 \hat{\mathbf{z}}_0^{-1} \quad (1)$$

where the subscript 0 indicates initial values. It can be seen that the vector of account totals **z** is[5] an eigenvector of *A* corresponding to the largest eigenvalue λ=1.

$$\left(\lambda I - S_0\right)\mathbf{z}_0 = 0 \quad (2)$$

In this system, all accounts of the SAM are treated as endogenous, and the SAM shares matrix implicitly defines the relative size of each account, but not the overall scale of the economy. This must be exogenously specified. We do this by starting with the size of the available labour force (in FTEs), reducing this by the unemployment rate, and multiplying by a factor that for 2006 converts labour (in FTEs) into 2001 dollars. For subsequent years, this factor may also account for increases in the macro average productivity of labour (i.e., increases in GDP per FTE). It should be noted that reducing the weighted average of labour input coefficients in the SAM and/or changes in the relative output of each sector may also lead to a change in the ratio of GDP to total labour.

Environmental intensities are then calculated from a matrix of industry and institution-specific

[3] This input–output matrix was provided by Market Economics Ltd (McDonald, pers. comm. 2007), based on tables produced by Statistics New Zealand for 1996.
[4] The scenarios narrative authors expressed concern that the SAM takes no account, as yet, of resource availability or ecosystem limitations identifying an area for further development
[5] Given the definition of *A*, the presence of the unit eigenvalue and associated positive eigenvector is guaranteed by the Perron-Frobenius theorem (Strang, 1988, p271).

environmental pressure accounts. For industries (subscript *ind*), the environmental accounts *R* are normalised in the same way as the economic accounts:

$$Q_{0,ind} = R_{0,ind}\hat{\mathbf{z}}_{0,ind}^{-1} \quad (3)$$

The environmental intensity is represented as a unit of pressure (i.e. electricity in GJ, etc.) per unit of output. However, for households (subscript *hh*), pressures are calculated per capita[6]:

$$\mathbf{q}_{0,hh} = \mathbf{r}_{0,hh} / p_0 \quad (4)$$

Environmental accounts were created from a range of sources. Energy-use data were taken from sources, including Jollands (2003), Ministry of Economic Development (2004), and Energy Efficiency and Conservation Authority (2004). Global warming potentials (100-year) were based on data provided in New Zealand's National Inventory Report (Ministry for the Environment, 2006) along with data obtained directly from the Ministry (Sonia Petrie, MfE, pers. comm.). Sequestration was divided between the farming industries and the forestry industry according to estimated afforestation rates. The New Zealand net sequestration total for the year ended March 2001 from the Land Use, Land Use Change, and Forestry (LULUCF) category of the UNFCCC[7] reporting process was approximately −21.3 Tg CO_2-e, or 30% of total emissions[8].

Under each scenario, changes are made to selected SAM share coefficients (within $S_{s,t}$) and environmental intensities (within $Q_{s,t}$) to reflect the general or specific features of the scenario narratives. The resulting changes to production outputs, institutional incomes and expenditures (in vector $z_{s,t}$), and environmental pressures (in matrix $R_{s,t}$) are calculated using the following equations:

$$\left(\lambda I - S_{s,t}\right)\mathbf{z}_{s,t} = 0 \quad (5)$$

such that

$$z_{s,t,L} = z_{0,L} w_{s,t} \quad (6)$$

where $w_{s,t}$ is the labour conversion/productivity factor, and

$$R_{s,t,ind} = Q_{s,t,ind}\hat{\mathbf{z}}_{s,t,ind} \quad (7)$$

$$\mathbf{r}_{s,t,hh} = \mathbf{q}_{s,t,hh} p_{s,t} \quad (8)$$

Scenarios are referenced by subscripts *s*, and time periods by subscript *t*. While the model runs with an annual time step, results are only reported for the final year of the scenario narrative, 2050. This is in keeping with the 'snapshot' style of the narratives, rather than being an inherent limitation of the simulation model.

2.3. Independent Aotearoa specification

The scenario narrative provided a rich source of material on which quantitative assumptions were based. In this first version of NZDEEM, parameters described in this section are subject to iterative reviews by modellers and narrators.

Household expenditure – Average tax rates increase by 20%, and household savings increase to 3% of income[9]. Increased taxes fund more public expenditure on health and community services, while private expenditures in these sectors are reduced. Households become more self-reliant in the area of food production and consumption, and travel less, with a resulting 20% decrease in the share of restaurants, takeaways and accommodation. This is balanced by small increases in the share of basic food goods, except for fruit and vegetables, where household production becomes more significant. A less consumer-oriented society means that the share of manufactured goods decreases by 5%, while there is a 140% increase in the share of public transport. The share of wholesale and retail margins also decreases by 20%. A less open economy is reflected lower shares for household direct imports (–80%) and air travel (–20%).

Exports – The share in exports of agricultural and food products decreased by 5% and that of manufactured goods decreased by 2%. Communication, pharmaceutical industries and education services increase their shares by 20%. All remaining sectors shares increase slightly to balance these changes.

Production costs – A macro total factor productivity (TFP) increase of 1% per annum (64% by 2050) was assumed, giving a factor of 1.64 in equation 6. Different rates were used for various sectors: agriculture 1%, manufacturing 2%, communication and pharmaceuticals 3.5%, other industries (mostly services) 0.4%. This was achieved by decreasing SAM labour and capital coefficients by the aforementioned percentages,

[6] For simplicity, we have not linked household environmental pressures to specific elements of household consumption (e.g. fuel use), which may rise, proportionally or otherwise, with income.

[7] United Nations Framework Convention on Climate Change

[8] Estimated from calendar-year data; this figure is for Kyoto afforestation, i.e. afforested land not forested in 1990.

[9] Note these are relative changes of shares, e.g. 10% increase of a 20% share gives a 22% share.

less the macro 1% rate, taken over 50 years. For example, coefficients in manufacturing decrease by 64%. Within this TFP change it was also assumed that there was a 10.5% deepening of capital in all sectors by 2050. Taxes on production for all sectors were increased by 20%. Finally, intermediate input coefficients were rescaled, to account for the above changes.

Primary distribution of income. All labour income is distributed to households (who then pay income and other taxes). Capital income (including depreciation and profits) is distributed to households, RoW, and the Savings-Investment account. In 2001, foreign ownership was 15.6% of total capital, household ownership was 52.1%, Government 3.3%, and Savings and Investment 29%. Under the scenario we reduced foreign ownership to 5.6%, and increased household ownership to 61%, Government share was 3.9%, and Savings and Investment share was 29.5%.

Selected environmental pressures. Independent Aotearoa will have access to technology that makes solar-electric (decentralised generation) a significant additional primary source of electricity, with only 5% of the total electricity coming from non-renewable sources. The emission factor was therefore assumed to be 5.6 $kgCO_2$/PJ delivered electricity.

3. RESULTS

Total population increased from 3.9 million in 2001 to 5 million in 2050 under Independent Aotearoa. The population composition for 2001 and 2050 under this scenario can be seen in Figure 6. Each bar represents a 5-year cohort.

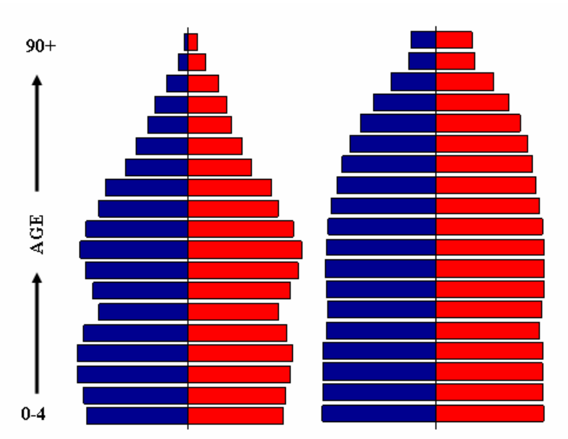

Figure 6. Population by age-sex cohort (males blue, females red) in 2001 (left) and Independent Aotearoa in 2050 (right)

There will be considerable population aging by 2050, with over-65s increasing from 12% to 21%. We account for this in the Environment-Economy module by increasing the share of healthcare expenditure in consumption. The 65+ dependency ratio increased from 1:4 in 2001 to almost 1:2 in 2050, while the total dependency ratio[10] increased from 2:3 in 2001 to almost 1:1 in 2050. (Table 3).

Table 3. Dependency ratio in 2001 and in 2050

Dependency ratios	2001	Independent Aotearoa (2050)
65+ dependency ratio	1:4	1:2
Total dependency ratio	2:3	1:1

Preliminary results of the Environment-Economy module showed that GDP increased from \$111b in 2001 to 229$\$NZ_{2001}$billion in 2050; a significant relative shift from primary and manufacturing sectors to services and public sector in comparison with the 2001 economy structure (Table 4).

Table 4. GDP contribution in 2001 & 2050

	2001	Independent Aotearoa 2050
Primary sectors	9%	6%
Manufacturing	17%	8%
Service sectors	70%	79%
Public sector	4%	7%

Energy use and GHG emissions for 2001 and for Independent Aotearoa in 2050 are shown in Table 5. Even when the ratios of energy use per capita decrease in comparison with 2001, there is an increase in the total use of fuels and electricity driven by population growth. Petrol use increases 25%, from 101PJ in 2001 to 127PJ in 2050. Diesel use increases 10%, from 87PJ in 2001 to 95PJ in 2050. Total energy use increases 10%, from 473 PJ in 2001 to 520PJ in 2050. However, by then most of the electricity is generated from renewable sources, resulting in a 9% decrease in Energy CO_2 emissions, from 25 Gg in 2001 to 23 Gg in 2050. GHG emissions decrease in 2050 due to reduced primary activities and technological change. Total GWP decreased 9%, from 45 Gg in 2001 to 41Gg in 2050.

4. CONCLUSIONS AND FUTURE WORK

This first version of NZDEEM has been useful in establishing a framework that can be used to complement the narrative in scenario creation. The model provides a 'more holistic view' of

[10] We calculated dependency ratio as the number of people aged 0–14 years and non-working 65+ years in comparison to the number of people in the workforce.

basic interactions between simplified social, economic, and environmental systems. Furthermore, a number of potential interpretation errors and omissions with the narrative scenarios and the quantitative model came to light through the iterative processes of quantitative specification and simulation. Thus NZDEEM has proved useful in providing common ground between modellers and social scientists to generate the critical debate that refines both models and narratives.

The model is clearly limited in its fundamental specification as an accounting-based model without endogenous behavioural responses of producers or consumers. This does have the advantage of not constraining the space of possibilities (cf. the Cobb-Douglas or CES specifications usual in computable general equilibrium models). However, it also requires that the modellers consider the behavioural implications 'offline', necessitating a relatively simple approach to any parameter changes. There is significant scope to improve the detailed specification of the Independent Aotearoa and other three scenarios.

The current NZDEEM model is also limited in the range of resource and environmental pressures included. CO_2 sequestration and water use will be included in the near future. Potential resource constraints, particularly of agricultural land, are also of concern. Nitrate contamination of water as well as soil erosion are also major issues for New Zealand. The treatment of household environmental pressures should also be revised, to tie the pressures to consumption of relevant goods (e.g. energy use and GHG emissions to fuels).

Table 5: Energy use and GHG emissions in 2001 and in 2050 (Independent Aotearoa)

Environmental	Primary sectors		Manufac-turing		Service sectors		Public sector		Households		Total	
pressure	2001	2050	2001	2050	2001	2050	2001	2050	2001	2050	2001	2050
Petrol (PJ)	3	3	1	1	13	14	0	1	84	108	101	127
Diesel (PJ)	21	19	7	8	45	51	2	3	12	15	87	95
Electricity (PJ)	6	5	45	42	25	26	2	4	42	55	120	132
Energy (PJ)	34	32	159	152	120	128	7	11	153	198	473	520
Energy CO_2 (Gg)	2	2	7	5	7	7	0	0	9	9	25	23
Ag & other GHG (Gg)	14	12	3	3	2	2	0	0	0	0	19	17
Total GWP (Gg)	17	14	10	8	9	9	0	0	9	9	45	41

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