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Greenhouse Gas Emission Factor Module: Land Use in Rural New Zealand—Climate Version 1

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Abstract

Several different New Zealand economic models produce measures of rural economic activity that have greenhouse gas implications. For climate change analysis, models need to translate economic activity into greenhouse gas emissions. This document estimates functions and creates projections for land-use related greenhouse gas emissions per unit of economic activity that are simple; are based on readily available data and strong science; are consistent with the national inventory in 2002; evolve so that implied net emissions approximately match past inventory totals (1990–2002); and can be linked easily to a variety of models so they can be used in simulations. We estimate dynamic greenhouse gas emission functions for five land uses: dairy, sheep, beef, plantation forestry, and indigenous forests; and for three greenhouse gases: methane, nitrous oxide, and carbon dioxide. We use an approach based on the consensus reached at the November 2004 "Land Use, Climate Change and Kyoto: Human dimensions research" project research workshop. These functions will allow different researchers who are studying activity levels in the rural sector to draw on a consistent set of emission functions when considering the greenhouse gas implications of their model results. All these data are available at www.motu.org.nz/dataset.htm so other researchers can easily apply these functions.

JEL classification
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Keywords
Climate change, greenhouse gases, methane, nitrous oxide, carbon dioxide, scrub, forest

1 Introduction

Several different New Zealand economic models produce measures of rural economic activity that have greenhouse gas (GHG) implications. ‘Land Use in Rural New Zealand’ (LURNZ) simulates land-use areas under different scenarios and translates these into simulations of animal numbers.[1] The ‘Pastoral Supply Response Model’ (PSRM) and the ‘Lincoln Trade and Environment Model’ (LTEM) directly produce predictions of national animal numbers. The Australian Bureau of Agricultural and Resource Economics’ ‘Global Trade and Environment Model’ (GTEM) and the various New Zealand computable general equilibrium (CGE) models (including those run by the New Zealand Institute of Economic Research, Infometrics, and Business and Economic Research Ltd.) produce forecasts of agricultural commodities. For climate change analysis, all of these models need to translate economic activity into greenhouse gas emissions.

This document estimates functions and creates projections for land-use related greenhouse gas emissions per unit of economic activity that are simple; are based on readily available data and strong science; are consistent with the national inventory in 2002; evolve so that implied net emissions approximately match past inventory totals (1990–2002); and can be linked easily to a variety of models so they can be used in simulations. This will allow different researchers who are studying activity levels in the rural sector to draw on a consistent set of emission functions when considering the greenhouse gas implications of their model results. All the data used to create the functions are available at www.motu.org.nz/dataset.htm (Greenhouse gas emissions factors v1) so other researchers can easily replicate and apply them.

We estimate dynamic greenhouse gas emission functions for five land uses: dairy, sheep, beef, plantation forestry, and indigenous forests, and for three greenhouse gases: methane, nitrous oxide, and carbon dioxide. We use an approach based on the consensus reached at the November 2004 “Land Use, Climate Change and Kyoto: Human dimensions research” project research workshop. We would like to acknowledge all of the participants at our workshop who contributed to designing this approach but are in no way responsible for any omissions or errors. Participants included Cecile deKlein and Harry Clark from AgResearch; Len Brown from the Climate Change Office; Barbara Hock and Steve Wakelin from Forest Research; Peter Kouwenhoven from the International Global Change Institute at Waikato University; Adrian Walcroft, Craig Trotter, Garth Harmsworth, Kevin Tate, Roger Parfitt, Surinder Saggar, and Troy Baisden, from Landcare Research; David Lillis and Rod Forbes from the Ministry of Agriculture and Forestry (MAF); Keith Lassey from the National Institute of Water and Atmospheric Research; and Mark Aspin from the Pastoral Greenhouse Gas Research Consortium.

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[1] For details of the construction and use of LURNZ v1 see Hendy, Joanna, Suzi Kerr, and Troy Baisden. 2005. "The Land Use in Rural New Zealand (LURNZ) Model: Version 1 Model Description." *Motu Working Paper*: Wellington.

1.1 National inventory report

Every year the Ministry for the Environment compiles a national greenhouse gas inventory for New Zealand as part of its obligations as a signatory to the United Nations Framework Convention on Climate Change and the Kyoto Protocol (Brown, Len and Helen Plume 2004). The report is an inventory of all human-induced emissions and removals of greenhouse gases in New Zealand. It covers six sectors of the New Zealand economy including two related to rural land use: agriculture, and land-use change and forestry.

The two main greenhouse gases emitted in the agricultural sector are methane (CH_4) and nitrous oxide (N_2O). Methane is emitted from enteric fermentation in domestic livestock and from animal excreta on agricultural soils; nitrous oxide is emitted directly from agricultural soils and animal excreta on agricultural soils, and indirectly from nitrogen used in agricultural fertiliser.

In the 2003 inventory report, emissions from agriculture are calculated using data on agricultural activity and estimates of emissions made by scientists. Data on animal productivity from MAF is used to estimate the amount of food eaten by the livestock (in terms of dry matter intake). From this intake, scientists from New Zealand Crown Research Institutes AgResearch and Landcare Research estimate the corresponding methane production and nitrous oxide emissions from excreta. Fertiliser data from FertResearch along with emission factors calculated by AgResearch and Landcare Research are used to estimate nitrous oxide emissions from fertiliser.

The key greenhouse gas related to the land-use change and forestry sector is carbon dioxide. Emissions and removals occur when forest and other woody biomass stocks are cleared or grow and when the land use is changed, including conversion of scrub into plantation forestry or grassland and the abandonment of managed land. Soil also emits or removes CO_2.

The 2003 inventory reports for GHG emissions related to clearing scrubland for forest or grassland and harvesting plantation forests. However, it only reports GHG removals by plantation forestry. This is because of insufficient data on removals by scrubland, indigenous forests, and soil. Emissions from soil are not counted because of lack of data.

GHG emissions and removals from changes in plantation forests are calculated using activity data from MAF forest surveys in conjunction with computer models developed by Forest Research, which are used to estimate the carbon sequestered when growing and released at harvest. They do not distinguish between Kyoto and non-Kyoto forests. Data on the clearance of scrubland comes from MAF, and research on scrubland and indigenous forest biomass from Forest Research and Landcare Research. Wildfire burning is included using data from the National Rural Fire Authority.

To calculate net emissions related to rural land use, the greenhouse gas emissions and removals are made equivalent by converting to a carbon dioxide equivalent, which then allows the different emissions to be summed. This conversion is done using measures of global warming potential (GWP). GWPs represent the relative warming effect of a unit mass of the gas when compared with the same mass of carbon dioxide over a specific period; for the inventory this period is 100 years (Table 1). We express emissions and removals in this paper as carbon dioxide equivalent, calculated using the GWPs specified by the UNFCCC requirements for national inventories (Intergovernmental Panel on Climate Change 1995). In 2002, the inventory reported that about 37 Mt of CO_2 equivalent was emitted from agriculture; this was around half of New Zealand's total emissions. In contrast, land-use change and forestry removed around 24 Mt (Brown, Len and Helen Plume 2004).

1.2 LURNZ GHG module

In this paper, we outline the implied emissions factor (IEF) approach included in the LURNZ greenhouse gas module. An IEF represents the expected emissions from a unit of economic activity. In theory the same emissions models could be used in LURNZ and for other economic analyses as in the national inventory. This is not feasible in reality because the models on which the national inventory is based are complex and often involve proprietary or confidential information. Thus they cannot be replicated or adapted for wider use. The complexity also makes it difficult to forecast emissions per unit of economic activity without in-depth knowledge of the underlying models. The GHG module in LURNZ contains functions designed to be consistent with the national inventory levels in 2002 and trends over the previous decade, and that can be used to calculate the GHG implications of changes in rural activity. Basing the LURNZ IEF approach on the national inventory allows relatively easy updating to future national inventories when the underlying models change.

Changes in activities related to rural land use will affect greenhouse gas emissions or removals. The purpose of creating emission functions is to allow us to calculate the greenhouse gas implications of simulated changes in future activity levels. Where appropriate, we create dynamic functions because emissions per unit of activity are not necessarily constant over time. Accounting for changes over time will increase the accuracy of simulations and mean that our simulations will be valid further into the future.

We designed the 'implied emissions factors' (IEFs) so that the total emissions, implied by different rural activity models, will match inventory total emissions in 2002. Matching inventory means that we can directly relate any results to the inventory. For example, we could consider questions like how will emissions in 2008 compare to emissions in 2002? Or, if a policy had been implemented in 1990, how much would it have reduced emissions in 2002?

This module includes estimated dynamic functions for methane and nitrous oxide emissions from dairy, sheep, and beef. The function for emissions from fertiliser is static. The emissions from other livestock are assumed constant in total and equal to their 2002 inventory value. The module's estimated emissions and removals for plantation forestry are a function of the distribution of age-classes of the forest; the function is constant over time. The function uses the same age-class carbon stock tables that the inventory is based on. For reverting indigenous scrubland, the module goes one step further than the inventory and accounts for all removals and emissions. The remaining emissions and removals related to rural land use accounted for in the inventory are included in the module as constants in our final emission functions.

We statistically estimate dynamic emission functions for each gas and at most two activity measures for each land use. The activity measures are animal numbers and fertiliser application. Where an economic model produces output in terms of a different activity measure, translation is needed. The LURNZ model produces estimates of areas in each land use but also provides a method to translate these into animal numbers and fertiliser use (Hendy, Joanna and Suzi Kerr 2005). A similar translation could be created between levels of agricultural commodity production and animal numbers and fertiliser use so these emission functions could be applied in GTEM or any of the New Zealand CGE models.

As our dependent variable, we use an historical series of IEFs for each greenhouse gas related to particular activities. We then fit linear trends to capture the systematic variation in each IEF.

We create our IEFs by taking estimates of emissions by land use at the national level and dividing by a contemporaneous measure of national activity levels. For example, we create an IEF for dairy methane emissions by dividing the national inventory report (Brown, Len and Helen Plume 2004) estimates of national methane emissions for dairy and dividing by Statistics New Zealand dairy animal number estimates.

The total emission implications of any activity prediction can be calculated using the IEF function. The IEF function is evaluated for the particular year of interest giving the amount of greenhouse gas emitted per unit of activity. Multiplying this by the forecast activity level for the specific year gives the total emissions related to the activity:

$$Total\,Emissions(Year) = \sum_{activity} IEF\,(Year) \times Activity\,level(Year) + constant \qquad (1)$$

PSRM and LURNZ estimate activity levels annually, and are estimated from annual data. LTEM is calibrated against annual data as are the CGE models. However, the national inventory is derived from three-year rolling averages of activity levels. We want the estimates of greenhouse gases, based on translating the activity levels from these models using the IEFs developed here, to match the inventory in 2002. Consequently, we developed IEFs using the inventory total emissions but based on annual activity level data.

2 Data

2.1 GHG emissions data

We use national emissions time-series (1990–2002) for enteric methane, and nitrous oxide and methane from livestock excreta on agricultural soils, by land-use type (dairy, sheep, beef). These were prepared by Len Brown at the Climate Change Office based on the data used in the national inventory report for 1990–2002 (Brown, Len and Helen Plume 2004) and are reproduced in Table 2, Table 3 and Table 4. Our carbon accumulation rates for plantation forestry are based on the age-class carbon yield tables given by (Te Morenga, L and S Wakelin 2003), which are the tables used for national inventory reporting (Table 5). Our scrub accumulation rates are based on Landcare Research's carbon calculator, developed by Craig Trotter (2004) based on sampling carried out by Landcare Research scientists, primarily on the East Cape (Table 6).

2.2 Activity data

Our stock number data were provided by Rod Forbes at MAF and are based on the Statistics New Zealand (SNZ) agricultural production census/survey data (see Table 2).[2] We use area by land-use data prepared by (Kerr, Suzi and Joanna Hendy 2004), based on SNZ agricultural production census area data calibrated to match the land cover database in 2002 (LCDB2) (Table 7). The volume of fertiliser applied was taken from the national inventory report (Table 4).

3 Developing implied emission factor functions

We first develop an enteric methane emission function per animal for each of three animal types and then, extending the results from this analysis, develop a function for nitrous oxide and methane emissions from livestock excreta per animal for each animal type, and a nitrous oxide emission function from fertiliser per hectare. Finally, we develop carbon emission and removal functions for the average hectare in plantation forest and in scrubland. All emissions are measured in millions of tonnes of carbon dioxide equivalent (Mt CO_2e).

3.1 Emissions from agriculture

3.1.1 Enteric methane emissions

Enteric methane emissions from ruminant livestock have risen over the last decade as a result of increased animal productivity (Clark, Harry, Ian Brookes, and Adrian Walcroft 2003). Methane is a by-product of the microbial fermentation of ingested feed in the rumen of livestock (including dairy cattle, sheep, and beef cattle), and thus is related to animal productivity. Over the last decade, beef and sheep animals have become larger and have increased the number of offspring they produce. Dairy cows have produced more milk per animal with extended milking seasons, and more bobby calves (Parliamentary Commissioner for the Environment 2004).[3] This increase in productivity has resulted in an increase in per animal emissions. When animals produce more meat, milk, or offspring in a year they require a higher energy intake. This means they consume more food and emit more methane.

As well as capturing productivity trends related to animals becoming fatter and producing more offspring, our IEFs will include trends in emissions related to the number of animals that are born and culled within the same farming year. This is because our livestock numbers are based on total number of animals at June 30 of each year, but our total emissions figures take into account emissions from all animals over a farming year. So our animal numbers will not include any increasing trends in these offspring, but their emissions will be captured by increases in the IEFs.

Figure 1 shows total dairy, sheep, and beef enteric methane emissions and June 30 animal numbers over the last decade. Total enteric methane emissions

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[2] These are the same data that were used to estimate LURNZ and PSRM.

[3] Bobby calves are culled before they reach one year of age.

from dairy increased by about 65% between 1990 and 2002, while dairy stock numbers increased by only 50%. Thus the amount of methane emitted per animal increased over time; Figure 2 illustrates this increase. Total enteric methane emissions from sheep decreased by about 15% between 1990 and 2002. Over the same period sheep stock numbers fell at about twice that rate. As with dairy, this indicates that more methane is being emitted per animal, showing that the animals are becoming more productive over time. Total enteric methane emissions from beef increased by about 10% between 1990 and 2002. Over the same period, beef numbers have fluctuated without an obvious long-term trend. This indicates that beef animals have become slightly more productive over time.

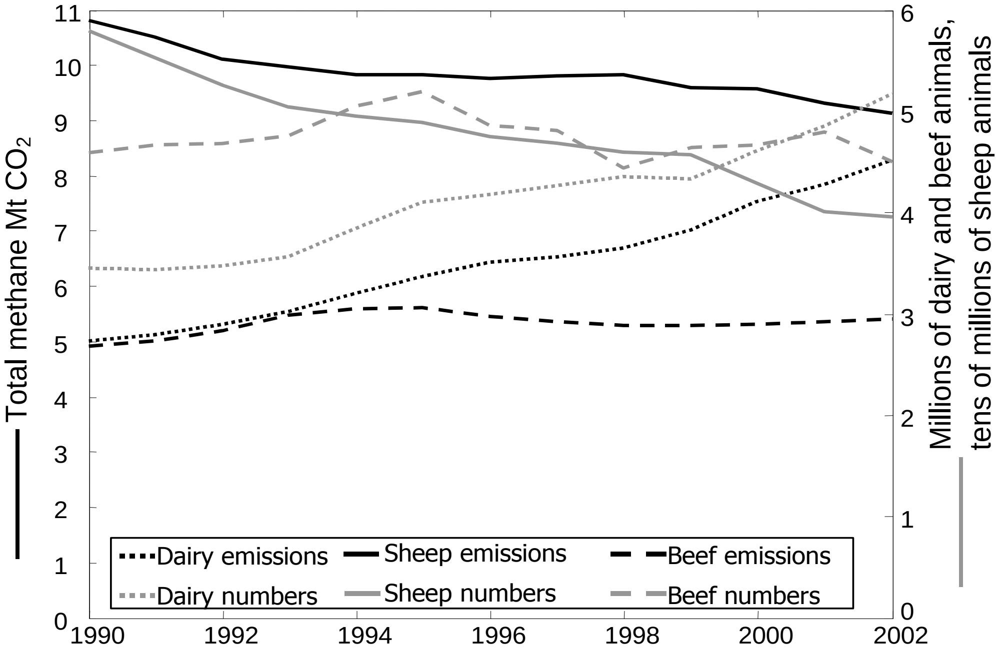

Figure 1: Enteric methane emissions and animal numbers[4]

The physical productivity of New Zealand's ruminant livestock is expected to continue to increase into the future (Clark, Harry, Ian Brookes, and Adrian Walcroft 2003). Because productivity in New Zealand is much lower than other countries, there is thought to be much scope for it to increase. Consequently, per animal emissions are also likely to continue to increase.[5]

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[4] Sources: Dairy methane emissions are from a personal communication in 2004 with Len Brown at the Climate Change Office, and are based on national inventory 2002 data. Animal numbers are from MAF, based on data from the agricultural production census. The total emissions calculations are based on three-year averages of stock numbers from the agricultural production census.

[5] There is a second order effect that could work to partially offset this trend. There is potential to increase animal productivity by decreasing per animal emissions. Production methods and new technologies that help animals become more efficient at converting food into energy could also result in lowering the emissions per unit of dry matter intake (DMI). Trends in increasing productivity per unit of DMI could work to dampen the positive trend in emissions per animal (from discussion at the Workshop on the Science of Atmospheric Trace Gases, 2004, Wellington New Zealand—a transcript of this report is given by Clarkson, 2004).

We fit trend models to historical series of emission functions. Commonly used growth models include linear, logarithmic, and exponential growth. Fitting a model that has non-decreasing slope, such as one of these models, will mean that any forecasts of the IEFs will have continued positive growth. In the long term, this is likely to be unrealistic as it is commonly expected that there will be a physical limit to productivity growth (Clark, Harry, Ian Brookes, and Adrian Walcroft 2003)). However, the IEF trends over the last decade appear to be roughly linear with definite positive slopes for each of the livestock types (see Figure 2) and, as we mentioned above, there is considered to be plenty of scope for more increases before any physical limit is reached. So, models with positive growth are likely to remain valid in the short to medium term.

Using an exponential growth model would imply exponentially increasing growth. This may be appropriate in the very short term, especially for dairy, which has had large increases in productivity in the last few years. Any model we fit that has exponential growth now, however, would likely need an inflection point at some time in the near future. We do not have enough explanatory data to fit this type of model. The linear and logarithmic models are likely to remain valid for longer without an inflection point. Consequently, we fit logarithmic and linear models to our IEF data and assess which is the better fit.[6] Table 1 shows the results of fitting the linear and logarithmic models to the IEF time-series, with both constrained to match the inventory in 2002. Both models have virtually the same explanatory power for dairy emissions, explaining around 70% of the variation. The linear trend model has greater explanatory power for sheep, explaining 94% of the variation. The linear model is also a better fit for beef. However, although the trend is highly significant, it explains only a small amount of the variation: about 25% in the linear model.

The low level of explanatory power in the beef IEF will be mostly due to a data artefact. The beef livestock numbers are very noisy. If the national emissions we use were created from the same livestock numbers, much of the noise would be cancelled out in the IEF series. The national inventory total emissions that we use to create the IEFs are created from three-year rolling averages of beef numbers, which dampens the noise. As a result, when we divide the national emissions series by the annual animal numbers to create the IEFs, the noise is not cancelled out.

The fact that we constrain our IEFs to match 2002 and we do not use three-year rolling averages means that our dairy IEF will slightly underestimate emissions per animal, and our beef and sheep IEF will slightly overestimate emissions per animal.

We selected the linear trend model for each of the animal types in our greenhouse gas module because of the greater explanatory power. The black lines in Figure 2 show the fitted lines. These fitted trends give us our dynamic methane implied emission functions, $IEF_{enteric\,methane,i}(t)$. The estimated IEF functions are:

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[6] Clark et al (2003) have already fitted linear trends to dairy, sheep, and beef IEFs. The functions they estimate are not constrained to equal 2002 emissions and are based on three-year rolling average measures of livestock numbers. We fit functions that are constrained to match inventory in 2002, and that are based on annual livestock numbers.

$$IEF_{enteric\,methane,dairy}(t) = 9.6 \times year - 17659 \tag{2}$$

$$IEF_{enteric\,methane,sheep}(year) = 3.9 \times year - 7515 \tag{3}$$

$$IEF_{enteric\,methane,beef}(t) = 11.2 \times year - 21305 \tag{4}$$

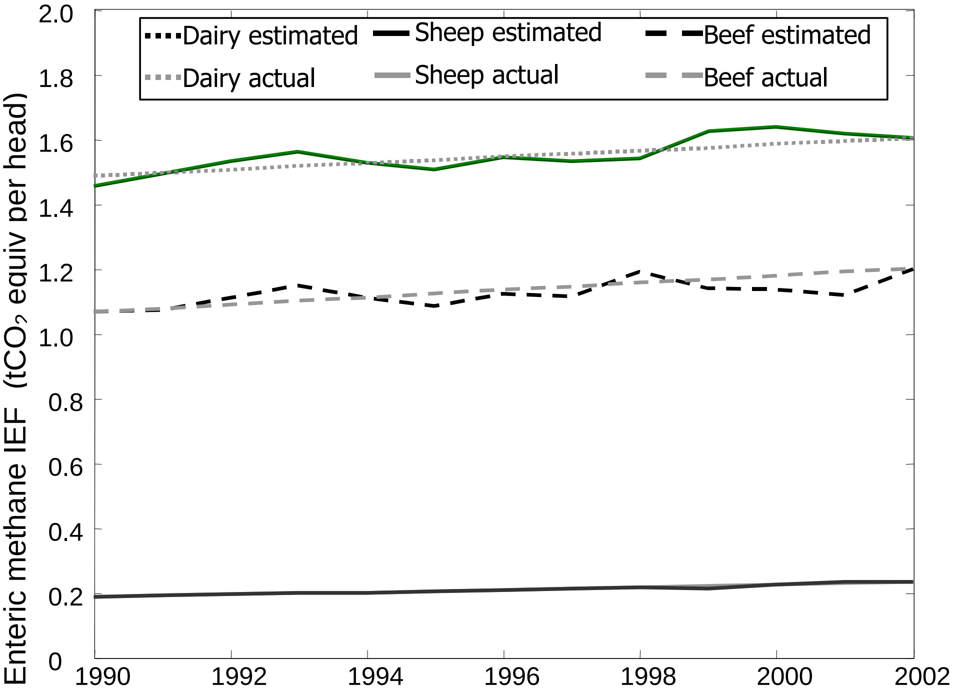

Figure 2: Implied emission factors—actual and estimated

Changes in total future emissions depend on changes in animal numbers and changes in emissions per animal. Total methane emissions can be estimated or projected for any year by inserting the estimated IEF functions for each animal type, (3) – (5), into Equation (2). The functions developed in this section can be multiplied with predictions of animal numbers to give predictions of total emissions.

$$Emissions_{enteric\,methane,i}(t) = IEF_{enteric\,methane,i}(t) \times AnimalNumbers_i(t) \tag{5}$$

where: i={Dairy, Beef, Sheep}

Total enteric methane emissions are given by:

$$Emissions_{enteric\,methane}(t) = \sum_i IEF_{enteric\,methane,i}(t) \times AnimalNumbers_i(t) + Constant_{enteric\,methane} \tag{6}$$

where the constant accounts for emissions related to goats, horses, swine, and deer.

3.1.2 Emissions from livestock excreta

In this section we develop dynamic IEFs for nitrous oxide and methane emissions from livestock excreta on soil per animal from dairy, beef, and sheep farming. Changes in the inventory emissions from livestock excreta over the period 1990–2002 are due to variation in nitrous oxide emissions based on trends in animal productivity, changes in manure management, and fluctuations in weather conditions as well as changes in animal numbers (Brown, Len and Helen Plume 2004). The inventory assumes that methane derived from excreta, a small part of total livestock methane emissions, is constant per animal.

The amount of nitrogen in animal excreta is related to animal productivity. As with enteric methane, nitrogen in animal excreta is a by-product of animal productivity (Kelliher, F. M., S. F. Ledgard, H. Clark, A. S. Walcroft, M. Buchan, and R. R. Sherlock 2003). As discussed earlier, animal productivity has increased over the last decade and is expected to continue increasing in the near future. Thus, we would expect nitrous oxide emissions to also increase in the future due to increasing productivity.

The amount of nitrous oxide and methane emitted from livestock excreta will also be influenced by manure management. Farmers can potentially reduce their livestock excreta emissions through manure management, especially for dairy, whereas they cannot reduce their enteric methane emissions. Thus, increases in animal excreta emissions could potentially be dampened by trends in emission reductions through manure management. We would not expect to see any systematic trend in emissions related to weather; it will only introduce noise into our series. Figure 3 shows total dairy, sheep, and beef excreta related emissions and animal numbers over the last decade. These include emissions from manure management before the manure goes on pasture, manure direct onto pasture, manure spread from lagoons onto pasture, volatised N from animal waste applied to soils, and leached N from animal waste applied to soils. Total emissions from dairy excreta increased by about 65% between 1990 and 2002. Total emissions from sheep excreta have decreased by about 15% between 1990 and 2002. Total emissions from beef excreta increased slightly by about 5% over the period. These are roughly the same as the corresponding trends in enteric methane emissions. This suggests that there are no strong trends related to manure management.[7]

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[7] The inventory for livestock excreta includes productivity changes as they affect nitrous oxide emissions, changes in manure management, and changes in the number of ‘average’ relative to June 30 animals. However, it ignores any productivity-related trend in methane emissions from livestock excreta. In contrast, our ‘productivity’ trend estimated from enteric methane emissions incorporates productivity changes and changes in ‘average’ livestock numbers but excludes manure management. Thus manure management is not the only difference between the two series, which weakens our conclusion about lack of a trend in manure management. However, methane emissions from livestock excreta are very small so this is probably not important.

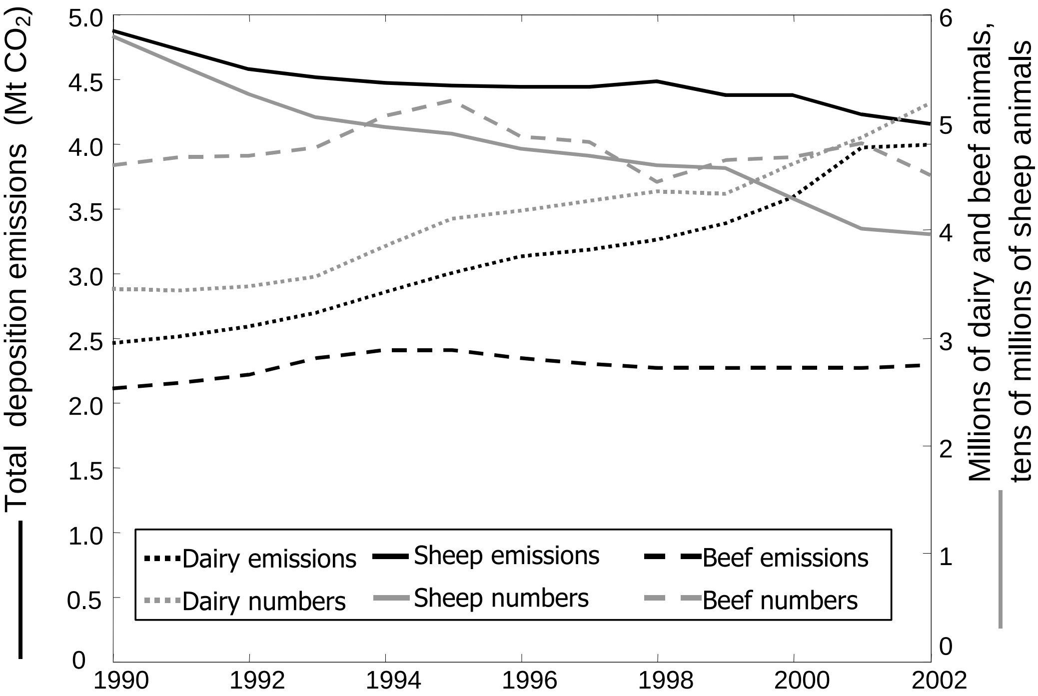

Figure 3: Livestock excreta emissions and animal numbers

The black lines in Figure 4 show the actual IEFs for dairy, sheep, and beef. The grey lines show estimated enteric methane IEFs scaled so that they match the 2002 livestock excreta IEF (i.e. multiply by livestock excreta emissions over enteric methane emissions). We can see that the two IEFs basically follow the same trend. So, for internal consistency within this module, we use the trend estimated from the enteric methane emissions time-series data as our measure of productivity, rather than estimating a new trend.

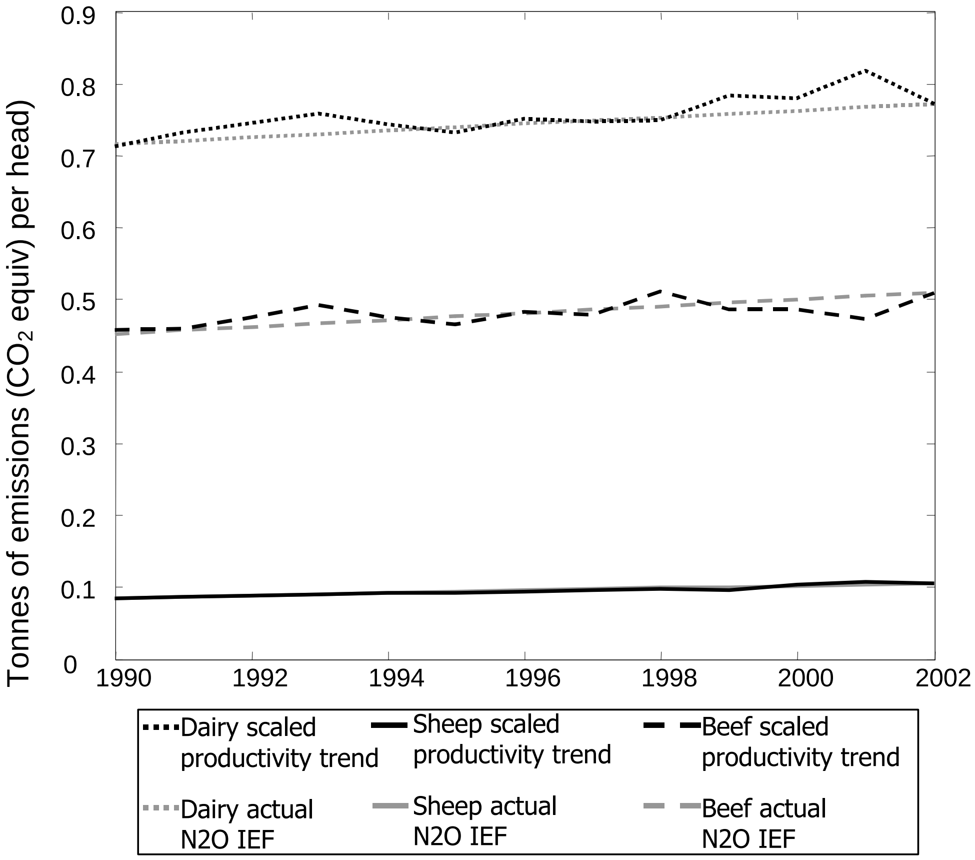

Figure 4: Livestock excreta implied emissions factors and scaled productivity trends

Our final IEF functions for soil excreta emissions are:

$$IEF_{livestock\ deposits,dairy}(t) = \frac{3.98}{8.27} \times IEF_{enteric\ methane,dairy}(t) \tag{6}$$

$$IEF_{livestock\ deposits,sheep}(t) = \frac{4.14}{9.12} \times IEF_{enteric\ methane,sheep}(t) \tag{7}$$

$$IEF_{livestock\ deposits,beef}(t) = \frac{2.29}{5.39} \times IEF_{enteric\ methane,beef}(t) \tag{8}$$

where the IEF for enteric methane includes a constant term so that the constant effect of methane emissions from livestock excreta is accounted for.

Total emissions related to soil can be calculated by:

$$Emissions_{livestock\ deposits}(t) = \sum_i IEF_{livestock\ deposits,i}(t) \times AnimalNumbers_i(t) + Constant_{livestock\ deposits}$$

where: *i={Dairy, Beef, Sheep}* (9)

The constant accounts for livestock excreta emissions related to other animals.

3.1.3 Emissions from fertiliser

In this section we measure the IEF in relation to the tonnes of nitrogen applied to the soil. Our IEF covers total fertiliser emissions, including direct emissions from fertilisers, indirect emissions from volatisation, and indirect emissions from leaching. When calculating fertiliser-related emissions, the inventory uses a constant emission factor, 6.82 tonnes CO_2e per tonne fertiliser, for nitrous oxide emissions from fertiliser with the amount of fertiliser applied varying over time (Brown, Len and Helen Plume 2004). This means that our fertiliser IEF will also be constant.

Thus, in the GHG module we assume the IEF from nitrous oxide is constant over time and equal to the actual IEF in 2002.

$$IEF_{fertiliser} = 6.820 \tag{10}$$

No time-series data on fertiliser application are available disaggregated by animal type (personal communication Hilton Furness, FertResearch, 2005). Thus our activity measure is simply tonnes of fertiliser. Then total emissions can be calculated as:

$$Emissions_{fertiliser}(t) = IEF_{fertiliser} \times Fertiliser(t) \tag{11}$$

3.2 Emissions and removals from land use change and forestry

3.2.1 Emissions and removals in plantation forestry

As plantation forests grow they remove carbon dioxide from the atmosphere, storing carbon in biomass. When the forests are harvested, this biomass carbon can be released through the logs that are removed and the harvesting residues that remain on the ground. If the harvested land is replanted, the residue remains on the ground and decays slowly over the first few years (Te Morenga, L and S Wakelin 2003). However, if the forest is converted to another land use it is probable that the residue is removed (e.g. burnt), and the biomass carbon from it is emitted immediately. Because forestry activity data is more complex than animal numbers, depending on age-classes as well as total activity, we take a different approach to IEFs.

We calculate two IEFs: one for land continually in forest, $IEF_{plantation\,forest}$, which includes sequestration as well as the effect of harvest, and one for land that is converted out of forestry, $IEF_{plantationdeforested}$. $IEF_{plantation\,forest}$ is negative as the forest grows and positive when the forest is harvested (year 0 in rotation 2). We assume that all the carbon in harvested logs is released into the atmosphere instantaneously; this is consistent with national inventory assumptions. After the harvest, the remaining biomass releases carbon gradually, offsetting part of the sequestration in the new trees. We assume rotation 3 will be identical to rotation 2. For $IEF_{plantationdeforested}$, we assume that the entire carbon stock associated with the plantation is released into the atmosphere instantaneously.

For both IEFs, we assume that carbon removals and emissions for a given age-class and rotation are constant over time.[8] We use constant IEFs for each age-class, *a*, and rotation, *r*, based on the age-class carbon yield table given by (Te Morenga, L and S Wakelin 2003), which is the table used for national inventory reporting. Thus our two IEFs are given by:

$$IEF_{plantation\,forest,a,r}(t) = constant_{a,r} \tag{12}$$

$$IEF_{plantationdeforest,a,r}(t) = constant_{a,r} \tag{13}$$

We calculate the IEF for forestry for each age-class (see Table 5) by calculating the change in carbon between the age-classes. The IEF for age-class zero in rotation 2 depends on the age of harvest of the previous rotation. We assume this to be on average 31 years, so that we are consistent with (Te Morenga, L and S Wakelin 2003) assumption for inventory reporting. The IEF for deforestation is equal to the amount of carbon stored on the forest land for a given age-class and rotation.

The inventory reports 2002 net emissions from plantation forestry derived from forest and deforestation area data, disaggregated by annual age-class and rotation. These data are not publicly available so we cannot directly replicate the inventory report results.

Hendy and Kerr (2005) use annual age-class area and deforested area, which are in the public domain. We assume that all forest is rotation 2 and that the deforested area is all 31 years old. We calibrate the annual age-class area to match LCDB2 in 2002, with the age-class distribution scaled uniformly. We also use annual rather than the three-year rolling averages used in the inventory. These assumptions require a constant of 1.61 in the equation below to match the inventory in 2002.

Thus, net emissions related to plantation forestry can be calculated by:

$$Net\,Emissions_{plantation\,forestry}(t) = \sum_a \sum_r \begin{bmatrix} IEF_{plantation\,forest,a,r} \times AreaForestry_{a,r}(t) \\ + IEF_{plantationdeforested,a,r}(t) \times AreaDeforested_{a,r}(t) \end{bmatrix} \times constant \tag{14}$$

3.2.2 Emissions and removals in scrubland

Land reverting to scrub will remove carbon dioxide from the atmosphere, storing it as carbon. If the scrub is cleared and the land converted to another land use, the carbon will be released.

Emissions related to scrubland being cleared are included in the national inventory but removals of GHG by land reverting to scrub are not included; the amount of carbon in the scrub comes from (Hall, G, S Wiser, R Allen, T Moore, P Beets, and C Goulding 1998), who do not provide data on scrub sequestration by age-class.[9] We create IEFs for both emissions and removals for all ages of scrub. Consequently, because we need our emissions and

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[8] In particular, we do not take account of pruning regimes or changes in the productivity of forest.

[9] Except when it is cleared for plantation forestry.

removals data to be consistent, we use different data than the inventory. We use the carbon accumulation rates by scrub age incorporated in the Landcare Research carbon calculator (Trotter, Craig 2004) to calculate an IEF for scrubland for reverting scrub, and an IEF for scrub clearance, both measured in tonnes of CO_2 per hectare. $IEF_{scrub\ reversion}$ will always be negative because the scrubland is removing carbon dioxide from the atmosphere. In contrast, $IEF_{scrub clearance}$ will always be positive as we assume that the carbon is released when it is cleared.[10] These IEFs are constant over time, and vary by year since the land began reverting to scrub:

$$IEF_{scrub\ reversion, yr}(t) = constant_{yr} \tag{15}$$

$IEF_{scrub\ reversion}$ is based on accumulation rates by age given in Table 6, adjusted to account for heterogeneous ages of scrub across a hectare of reverting land. We assume that a hectare of scrubland will be on average fully covered after 10 years of reversion, assuming a sigmoidal distribution of ages.[11] After 10 years, a small fraction of the hectare will be 10 years old, 50% will be 5 years and older, etc. We apply the carbon accumulation rate table to the age distribution for every year of reversion, creating carbon yield and accumulation rate tables by year since reversion began. Figure 1 shows how accounting for heterogeneous ages within scrub affects the average accumulation rate and hence the $IEF_{scrub\ reversion}$ which is the negative of average accumulation. Table 6 shows the $IEF_{scrub\ reversion}$ by year for the first 50 years of reversion. $IEF_{scrub clearance}$ is equal to the total carbon stock on a hectare of land that has been accumulated since reversion began.

$$IEF_{scrub\ clearance, yr}(t) = constant_{yr} = -\sum_{yr=0}^{scrubclearance\_yr} IEF_{scrubreversion, yr} \tag{16}$$

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[10] Available online at http://www.landcareresearch.co.nz/services/air.asp. The parameters for the carbon calculator are soil fertility and average annual rainfall. We selected medium-low soil fertility and an annual rainfall of 1500m.

[11] This functional form was suggested in a personal communication with Craig Trotter, Landcare, 2004.

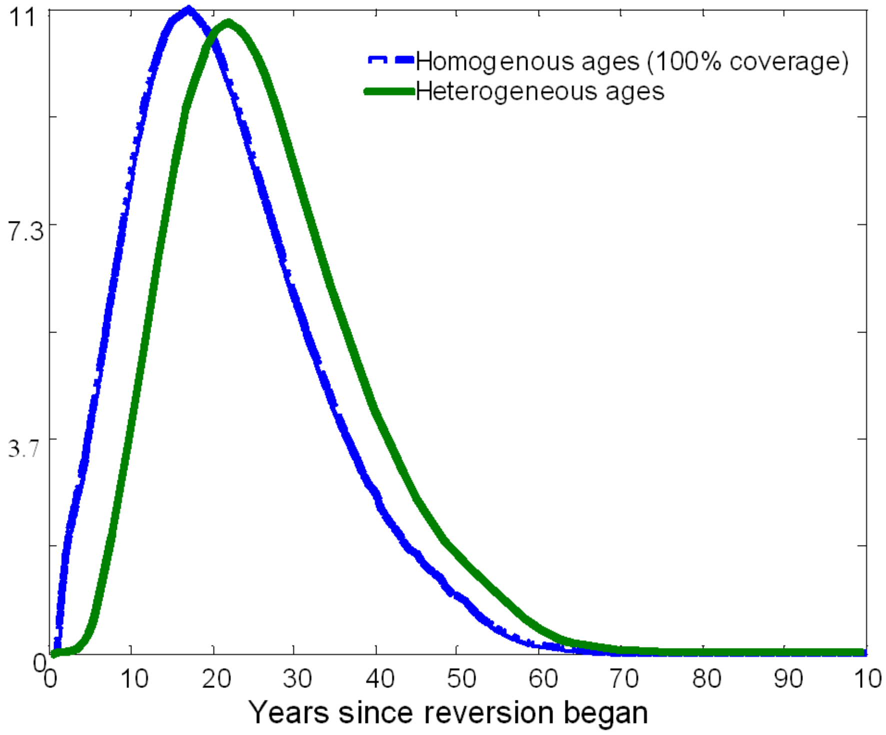

Figure 5: Carbon accumulation rate per hectare of fully covered, homogenously aged scrub and heterogeneously aged reverting scrubland

Net emissions related to reverting scrubland can be calculated by:

$$Net\ Emissions_{reverting\ scrubland}(t) = \sum_{yr} \begin{bmatrix} IEF_{scrub\,reversion,\,yr} \times AreaReverting_{yr}(t) \\ + IEF_{scrub\,clearance,\,yr}\, AreaCleared_{yr}(t) \end{bmatrix} \tag{17}$$

where *yr* is the years since reversion began.

4 Summary

The greenhouse gas module of LURNZ gives a way of translating simulations of rural activity levels from any model into their greenhouse gas emission implications. To do this, the rural activity levels first must be translated into dairy, sheep, beef numbers, fertiliser tonnage, plantation forestry area changes by age, scrubland area changes by age. LURNZ produces forecasts of land use, so has a separate land use intensity module to translate land use into implied animal numbers and fertiliser use. GTEM and the New Zealand CGE models could potentially use a similar approach to translate their forecast commodities into impacts on animal numbers, fertiliser, and forest area. Once the activity levels have been translated, the net greenhouse gas emissions for a specific year can be calculated by simply multiplying the IEF evaluated at that year by the translated activity levels:

$$Net\ Emissions_{enteric\ methane}(t) = \sum_{i} \begin{bmatrix} IEF_{enteric\ methane,i}(t) \times AnimalNumbers_{i}(t) \\ + Constant_{enteric\ methane,i} \end{bmatrix} \tag{18}$$

$$Net\ Emissions_{livestock\ deposits,i}(t) = \sum_{i}\begin{bmatrix} IEF_{livestock\ deposits,i}(t)\times AnimalNumbers_{i}(t) \\ +Constant_{livestock\ deposits,i} \end{bmatrix} \tag{19}$$

$$Net\ Emissions_{fertiliser}(t) = IEF_{fertiliser}\times Fertiliser(t) \tag{20}$$

$$\begin{aligned} &Net\ Emissions_{plantation\ forestry}(t) = \\ &\sum_{a}\sum_{r}\begin{bmatrix} IEF_{plantation\ forest,a,r}\times AreaForestry_{a,r}(t) \\ +IEF_{plantationdeforested,a,r}(t)\times AreaDeforested_{a,r}(t) \end{bmatrix} \end{aligned} \tag{21}$$

$$\begin{aligned} &Net\ Emissions_{reverting\ scrubland}(t) = \\ &\sum_{yr}\begin{bmatrix} IEF_{scrub\ reversion,yr}\times AreaReverting_{scrub\ reversion,yr}(t) \\ +IEF_{scrub\ clearance,yr}AreaCleared_{yr}(t) \end{bmatrix} \end{aligned} \tag{22}$$

where *i={Dairy Beef, Sheep}, a=age-class, r=rotation, yr= year* since reversion began.

5 Tables

Table 1 Global Warming Potentials (GWP)

Gas	GWP
Carbon dioxide	1
Methane	21
Nitrous oxide	310
Source: (Intergovernmental Panel on Climate Change 1995) Note: to convert from C to CO_2, multiply by 11/3.	

Table 2 Total enteric methane emissions[1] and livestock numbers[2] by species

Year	Dairy		Sheep		Beef	
	Numbers (thousands)	Emissions (Mt)	Numbers (thousands)	Emissions (Mt)	Numbers (thousands)	Emissions (Mt)
1990	3,441	4.996	57,852	10.808	4,593	4.899
1991	3,429	5.117	55,162	10.488	4,671	5.007
1992	3,468	5.303	52,568	10.097	4,676	5.175
1993	3,550	5.537	50,298	9.961	4,758	5.458
1994	3,839	5.862	49,466	9.814	5,048	5.593
1995	4,090	6.158	48,816	9.809	5,183	5.606
1996	4,165	6.424	47,394	9.744	4,852	5.443
1997	4,257	6.519	46,834	9.803	4,806	5.345
1998	4,345	6.685	45,956	9.824	4,432	5.271
1999	4,316	6.998	45,680	9.594	4,644	5.279
2000	4,599	7.523	42,845	9.570	4,670	5.294
2001	4,846	7.823	40,010	9.295	4,791	5.342
2002	5,162	8.272	39,546	9.121	4,495	5.392

Sources:
1 Len Brown (CCO) Personal Communication, based on the national inventory Report 2002 Data
2 Personal communication Rod Forbes, MAF

Table 3 Livestock excreta emissions by animal type

Total Dairy Emissions (Mt)	Total Sheep Emissions (Mt)	Total Beef Emissions (Mt)
2.45	4.87	2.10
2.50	4.72	2.14
2.58	4.57	2.21
2.69	4.51	2.33
2.85	4.47	2.39
2.99	4.44	2.40
3.12	4.43	2.34
3.17	4.43	2.29
3.25	4.47	2.26
3.38	4.37	2.26
3.58	4.37	2.26
3.96	4.22	2.26
3.98	4.14	2.29
Source: Len Brown (CCO) Personal Communication, based on the national inventory Report 2002 Data		

Table 4 Fertiliser use and emissions

Year	Fertiliser use (tonnes)	Total fertiliser emissions (Mt)
1990	59,265	0.392
1991	61,694	0.435
1992	70,122	0.536
1993	104,095	0.678
1994	124,131	0.863
1995	151,263	0.975
1996	153,780	1.019
1997	143,295	1.029
1998	155,467	1.058
1999	166,819	1.163
2000	189,096	1.373
2001	248,000	1.628
2002	279,148	1.976
Source: Len Brown (CCO) Personal Communication, based on the national inventory Report 2002 Data		

Table 5 Carbon yield table by age class and rotation (CO_2e)

Age	IEF$_{\text{plantation forest}}$		IEF$_{\text{plantation deforested}}$		Age	IEF$_{\text{plantation forest}}$		IEF$_{\text{plantation deforested}}$	
	R1	R2	R1	R2		R1	R2	R1	R2
Years	*CO2e Tonnes/Ha/Yr*		*CO2e Tonnes/Ha*		*Years*	*CO2e Tonnes/Ha/Yr*		*CO2e Tonnes/Ha*	
0	0	457.23		429.37	41	-2.2	-2.2	1215.87	1221.73
1	-0.73	71.87	0.73	357.5	42	-2.93	-2.93	1218.8	1224.67
2	-1.1	55.73	1.83	301.77	43	-2.57	-2.57	1221.37	1227.23
3	-5.13	40.33	6.97	261.43	44	-2.57	-2.93	1223.93	1230.17
4	-14.3	22.73	21.27	238.7	45	-2.93	-2.93	1226.87	1233.1
5	-30.8	0.37	52.07	238.33	46	-2.57	-2.57	1229.43	1235.67
6	-37.03	-27.87	89.1	266.2	47	-2.57	-2.57	1232	1238.23
7	-77.37	-13.57	166.47	279.77	48	-2.57	-2.93	1234.57	1241.17
8	-12.47	-6.97	178.93	286.73	49	-2.93	-2.57	1237.5	1243.73
9	-16.87	-15.77	195.8	302.5	50	-2.57	-2.93	1240.07	1246.67
10	-35.2	-1.83	231	304.33	51	-1.83	-1.83	1241.9	1248.5
11	-19.8	-14.67	250.8	319	52	-1.47	-1.47	1243.37	1249.97
12	-50.6	-43.27	301.4	362.27	53	-1.47	-1.47	1244.83	1251.43
13	-6.6	5.87	308	356.4	54	-1.1	-1.1	1245.93	1252.53
14	-33	-22.73	341	379.13	55	-1.47	-1.47	1247.4	1254
15	-12.47	-13.2	353.47	392.33	56	-1.47	-1.1	1248.87	1255.1
16	-20.9	-18.7	374.37	411.03	57	-1.1	-1.47	1249.97	1256.57
17	-31.53	-28.23	405.9	439.27	58	-1.1	-1.1	1251.07	1257.67
18	-31.17	-27.87	437.07	467.13	59	-1.1	-0.73	1252.17	1258.4
19	-34.83	-32.63	471.9	499.77	60	-0.37	-0.73	1252.53	1259.13
20	-37.4	-34.47	509.3	534.23	61	0	0	1252.53	1259.13
21	-37.77	-35.2	547.07	569.43	62	0	0	1252.53	1259.13
22	-37.03	-35.57	584.1	605	63	0	0	1252.53	1259.13
23	-37.03	-35.57	621.13	640.57	64	-0.37	0	1252.9	1259.13
24	-39.23	-37.77	660.37	678.33	65	0	0	1252.9	1259.13
25	-38.13	-36.67	698.5	715	66	0	-0.37	1252.9	1259.5
26	-38.5	-37.77	737	752.77	67	0	0	1252.9	1259.5
27	-38.13	-37.03	775.13	789.8	68	0	0	1252.9	1259.5
28	-37.4	-37.03	812.53	826.83	69	0	0	1252.9	1259.5
29	-37.77	-27.5	850.3	854.33	70	0	0	1252.9	1259.5
30	-36.3	-36.67	886.6	891	71	0	0	1252.9	1259.5
31	-35.93	-36.3	922.53	927.3	72	0	0	1252.9	1259.5
32	-35.2	-35.2	957.73	962.5	73	-0.37	0	1253.27	1259.5
33	-34.47	-34.83	992.2	997.33	74	0	0	1253.27	1259.5
34	-34.47	-34.47	1026.67	1031.8	75	0	0	1253.27	1259.5
35	-32.27	-32.63	1058.93	1064.43	76	0	0	1253.27	1259.5
36	-32.63	-32.27	1091.57	1096.7	77	0	0	1253.27	1259.5
37	-31.53	-31.9	1123.1	1128.6	78	0	-0.37	1253.27	1259.87
38	-30.43	-30.8	1153.53	1159.4	79	0	0	1253.27	1259.87
39	-30.07	-30.07	1183.6	1189.47	80	5.13	4.77	1248.13	1255.1
40	-30.07	-30.07	1213.67	1219.53	0				

R1 – rotation 1, R2 – rotation 2. Source: Te Morenga and Wakelin (2003)

Table 6 Sequestration of CO_2 in reverting scrubland

Age or Year	Accumulation Rate by Age*	IEF$_{\text{scrub reversion}}$ by year since reversion began	IEF$_{\text{scrub clearance}}$ by year since reversion began	Age or Year	Accumulation Rate by Age*	IEF$_{\text{scrub reversion}}$ by year since reversion began	IEF$_{\text{scrub clearance}}$ by year since reversion began
	Tonnes CO2/ha/year	Tonnes CO2/ha/year	Tonnes CO2/ha		Tonnes CO2/ha/year	Tonnes CO2/ha/year	Tonnes CO2/ha
1	1.6	-0.01	0.01	26	7.5	-9.84	160.91
2	2.3	-0.03	0.04	27	7	-9.46	170.75
3	3	-0.09	0.14	28	6.5	-9.03	180.21
4	3.8	-0.24	0.38	29	6.1	-8.58	189.25
5	4.7	-0.57	0.95	30	5.7	-8.12	197.83
6	5.6	-1.13	2.08	31	5.2	-7.66	205.95
7	6.5	-1.87	3.95	32	4.8	-7.19	213.61
8	7.4	-2.66	6.6	33	4.5	-6.72	220.8
9	8.2	-3.47	10.07	34	4.1	-6.27	227.53
10	9	-4.3	14.37	35	3.8	-5.84	233.8
11	9.6	-5.16	19.53	36	3.5	-5.42	239.64
12	10.1	-6.02	25.56	37	3.2	-5.01	245.06
13	10.5	-6.87	32.43	38	2.9	-4.64	250.07
14	10.8	-7.69	40.12	39	2.7	-4.28	254.71
15	10.9	-8.43	48.55	40	2.4	-3.95	258.99
16	11	-9.09	57.64	41	2.2	-3.63	262.94
17	10.9	-9.64	67.29	42	2	-3.33	266.57
18	10.7	-10.09	77.38	43	1.8	-3.05	269.9
19	10.5	-10.41	87.79	44	1.7	-2.79	272.96
20	10.2	-10.63	98.42	45	1.5	-2.54	275.75
21	9.8	-10.73	109.14	46	1.4	-2.31	278.29
22	9.4	-10.72	119.86	47	1.3	-2.11	280.6
23	8.9	-10.62	130.48	48	1.1	-1.92	282.71
24	8.4	-10.43	140.91	49	1	-1.75	284.63
25	8	-10.17	151.07	50	0.9	-1.6	286.38

Source: * Landcare Research’s Carbon Calculator (Trotter, 2004).

Table 7 Land use areas

Year	Dairy (ha)	Sheep (ha)	Plantation Forestry (ha)	Reverting Scrubland (ha)
1974	1,122,362	8,604,787	449,414	2,297,335
1975	1,090,601	8,593,358	507,242	2,393,188
1976	1,062,395	8,571,436	552,583	2,635,599
1977	1,049,634	8,652,961	572,137	2,693,737
1978	1,054,536	8,709,082	598,452	2,458,909
1979	1,050,077	8,680,133	628,198	2,475,965
1980	1,077,836	8,913,135	685,133	2,235,121
1981	1,059,882	8,737,680	742,287	2,155,530
1982	1,076,365	8,685,043	749,893	2,125,274
1983	1,101,201	8,544,679	779,896	2,158,310
1984	1,080,789	8,544,679	811,056	2,194,311
1985	1,072,077	8,544,679	854,985	2,372,428
1986	1,172,462	8,632,407	896,170	2,326,536
1987	1,089,457	8,807,862	917,763	2,381,871
1988	1,049,582	8,238,829	985,584	2,311,988
1989	1,066,242	8,272,803	973,158	2,323,207
1990	1,121,751	8,034,583	1,016,073	2,304,969
1991	1,111,081	8,065,846	1,035,520	2,336,809
1992	1,094,956	8,034,583	1,040,172	2,053,827
1993	1,118,443	7,594,508	1,087,371	1,917,628
1994	1,212,024	7,905,065	1,159,298	1,493,121
1995	1,290,646	7,834,484	1,245,504	1,347,662
1996	1,301,386	7,364,486	1,311,317	1,489,181
1997	1,370,547	7,457,342	1,379,931	1,468,873
1998	1,401,006	7,345,827	1,417,795	1,448,566
1999	1,391,059	7,378,650	1,458,167	1,428,258
2000	1,385,900	7,393,168	1,479,423	1,407,950
2001	1,469,080	7,308,743	1,516,818	1,407,950
2002	1,574,510	7,231,132	1,551,875	1,407,950
Source: (Hendy, Joanna, Suzi Kerr, and Troy Baisden 2005)				

Table 8 Regression Results – Trend models for enteric methane implied emissions factors by animal type

	Dairy 1		Sheep 2		Beef 3	
	Emissions (Gg)		Emissions (Gg)		Emissions (Gg)	
Year	9.6***		3.9***		11.2***	
	(2.3)		(0.26)		-2.6	
Ln(Year-1979)		171***		68***		197***
		36		6		45
Constant	-17659***	1066***	-7515***	17.4	-21305***	583***
	-4500	100	-520	17	-5200	130
N	13	13	13	13	13	13
R^2	0.69	0.70	0.94	0.89	0.24	0.13

Table 9 Livestock excreta Implied Emissions Factors and Animal Productivity Trends

Dairy (CO2 equivalent tonnes/head)		Sheep (CO2 equivalent tonnes/head)		Beef (CO2 equivalent tonnes/head)	
IEF**	Scaled Productivity*	IEF**	Scaled Productivity*	IEF**	Scaled Productivity*
0.711	0.716	0.084	0.084	0.457	0.452
0.73	0.72	0.086	0.086	0.459	0.457
0.743	0.724	0.087	0.087	0.473	0.461
0.757	0.729	0.09	0.089	0.49	0.466
0.742	0.734	0.09	0.091	0.474	0.47
0.731	0.738	0.091	0.092	0.464	0.475
0.749	0.743	0.093	0.094	0.482	0.479
0.745	0.747	0.095	0.096	0.477	0.484
0.747	0.752	0.097	0.097	0.509	0.489
0.782	0.757	0.096	0.099	0.486	0.494
0.778	0.761	0.102	0.101	0.485	0.499
0.817	0.766	0.106	0.103	0.472	0.504
0.771	0.771	0.105	0.105	0.509	0.509
Sources: * From Methane Trends. ** Derived from Table 3 data.					

References

Brown, Len and Helen Plume. 2004. "New Zealand's Greenhouse Gas Inventory 1990–2002: The National Inventory Report and Common Reporting Format Tables," *National Inventory Report*, New Zealand Climate Change Office, Wellington.

Clark, Harry; Ian Brookes and Adrian Walcroft. 2003. "Enteric methane emissions from New Zealand ruminants 1990–2001 calculated using an IPCC Tier 2 approach," Ag Research Ltd, Massey University, Landcare Research Ltd.

Hall, G, S Wiser, R Allen, T Moore, P Beets and C Goulding. 1998. "Estimates of the carbon stored in New Zealand's Indigenous forest and scrub vegetation for 1990," Ministry for the Environment, Landcare Research, and Forestry Research, Hamilton, New Zealand.

Hendy, Joanna and Suzi Kerr. 2005. "Land Use Intensity Module: Land Use in Rural New Zealand Version 1," in *Draft Motu Working Paper*.

Hendy, Joanna; Suzi Kerr and Troy Baisden. 2005. "The Land Use in Rural New Zealand (LURNZ) Model: Version 1 Model Description," in *Motu Working Paper*, Wellington, June 2005.

Intergovernmental Panel on Climate Change. 1995. "Climate Change 1995: The Science of Climate Change. Contribution of Working Group 1 to the Second Assessment of the Intergovernmental Panel on Climate Change.," (Eds, JT Houghton, LG Meora Filho, BA Callender, N Harris, A Kattenberg and K Maskell), Cambridge University Press, UK, p. pp 572.

Kelliher, F. M., S. F. Ledgard, H. Clark, A. S. Walcroft, M. Buchan and R. R. Sherlock. 2003. "A revised nitrous oxide emissions inventory for New Zealand 1990–2001," *Report for the Ministry of Agriculture and Fisheries*.

Kerr, Suzi and Joanna Hendy. 2004. "Drivers of rural land use in New Zealand: Estimates from National Data," Draft working paper, Wellington, June 2004.

Parliamentary Commissioner for the Environment. 2004. "Growing for good: Intensive farming, sustainability and New Zealand's environment," Wellington.

Te Morenga, L and S Wakelin. 2003. "Carbon Inventory of New Zealand's planted forests," *Contract Report for the Ministry of Agriculture and Forestry and the Ministry for the Environment*, Forest Research, Rotorua.

Trotter, Craig. 2004. "Carbon Calculator," webpage, Vol. 2005, Landcare Research. Available online at http://www.landcareresearch.co.nz/services/air.asp.