Land-use Intensity and Greenhouse Gas Emissions in the LURNZ Model

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Motu Working Paper 14-03
Motu Economic and Public Policy Research

February 2014

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Acknowledgements

Funding for this research has been provided by the Ministry of Business, Innovation and Employment (formerly the Ministry for Science and Innovation) through the "Integrated Economics of Climate Change" programme and by the Ministry for Primary Industries through the "Sustainable Land Management and Climate Change" programme. We thank Simon Anastasiadis and Corey Allan for their assistance in implementation of the LURNZ model.

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ISSN 1176-2667 (Print), ISSN 1177-9047 (Online).

Abstract

This paper documents the development of new land-use intensity and greenhouse gas (GHG) emissions modules for the Land Use in Rural New Zealand (LURNZ) model. These modules translate simulated land-use outcomes into measures of rural economic activity and greenhouse gas emissions for dairy farming and sheep-beef farming. Emissions in LURNZ include those from livestock as well as from synthetic fertiliser use. We utilise the latest set of emission factors along with information on the distribution of rural activities to model GHG emissions in a spatially and temporally explicit manner. Our results at the national level are approximately consistent with New Zealand's Greenhouse Gas Inventory.

JEL codes

Q15, Q58

Keywords

Land-use intensity, greenhouse gas emissions, LURNZ

Contents

1. Introduction

This paper documents the development of new land-use intensity and greenhouse gas (GHG) emissions modules for the Land Use in Rural New Zealand (LURNZ) model. These modules translate simulated land-use outcomes into measures of rural economic activity and greenhouse gas emissions. The previous versions of these modules (Hendy and Kerr, 2005; Hendy and Kerr, 2006) yielded geographically homogenous outcomes within each land use; projected emissions per hectare of dairy land, for example, were identical across all of New Zealand. An important motivating factor for undertaking the current work was to introduce spatial detail into LURNZ's projections. Simulations based on the updated modules enable more detailed analyses of the regional impacts of climate change policy or water quality policy.

LURNZ is a dynamic partial equilibrium model of rural land use. Simulations in LURNZ are implemented via two econometric models (Kerr et al., 2012): a dynamic national land-use share model (Kerr and Olssen, 2012) and a static geographic land-use allocation model (Timar, 2011). Both of these models have a strong empirical basis by virtue of their revealed preference nature. For lack of data, we do not have a similarly strong empirical basis for modelling potential behavioural responses other than land-use change, such as farm-based mitigation strategies. Therefore, all adjustment in LURNZ takes place on the extensive margin: land-use intensity and emissions both remain exogenous in the model.[1]

The LURNZ model is primarily a tool for climate policy analysis. Emissions of methane and nitrous oxide from agriculture make up approximately half of New Zealand's total carbon dioxide-equivalent (CO2-e) emissions (MAF Policy, 2010). The New Zealand Emissions Trading Scheme (ETS), legislated to help the country meet its international obligations to reduce greenhouse gas emissions under the United Nations Framework Convention on Climate Change and the Kyoto Protocol, was designed to eventually cover emissions from agriculture. Mandatory reporting for agriculture began in 2012. The sector was scheduled to enter the scheme in 2015, but this has been delayed.

In the ETS, agricultural emissions are calculated using emission factors published by the Ministry for Primary Industries (MPI – previously Ministry of Agriculture and Forestry). These specify carbon dioxide-equivalent emissions per unit of specific activity. Emission factors are, for

[1] This is roughly consistent with the incentives provided by current New Zealand climate policy. The Emissions Trading Scheme, in its proposed form, is mostly a tax on agricultural products in proportion to average national emissions. Aside from encouraging reductions in fertiliser use, it offers little incentive to farmers to perform on-farm mitigation. It may therefore be expected to have little effect on land-use intensity and GHG emissions for a given land-use.

example, available for slaughtering ruminant animals, dairy processing and synthetic fertiliser use. The emission factors are derived from average production and average emission levels in a manner that is consistent with New Zealand's Greenhouse Gas Inventory (Ministry for Primary Industries, 2012).

Greenhouse gas emissions modelled in LURNZ include those from livestock as well as from synthetic fertiliser use. Previous versions of the model relied on aggregate (national-scale) data to estimate the emissions attributable to pastoral land-use sectors. In this paper, we use the latest set of emission factors, along with the most detailed information available nationally on the levels of the relevant rural activities, to model GHG emissions.

The next section discusses our major data sets and the main steps we take to prepare the data for analysis. The first part of section 3 describes in detail the methodology we employ in modelling emissions from the dairy sector. It also specifies the parameter values and functional forms we use. The second part of section 3 repeats this process for the sheep and beef sector. In section 4, we present summary simulation outcomes and also provide some robustness checks by comparing the simulation results to observations recorded in other data sources. Finally, section 5 provides concluding comments.

2. Description of data

In this section, we introduce our main data sets. For ease of readability of subsequent sections, we also discuss some of the basic data manipulations we perform. In addition to the data described here, we use auxiliary information from other sources as well – we cite these throughout the paper. Data sources for the other modules of the LURNZ model are documented in Kerr and Olssen (2012), Timar (2011) and Kerr et al. (2012).

2.1. Emission factors

An emission factor measures the amount of greenhouse gas emissions, in carbon dioxide equivalents, that is associated with performing a unit of a specific activity. We use the emission factors specified in the Climate Change Response (Emissions Trading and Other Matters) Amendment Act 2012. These were developed for the purpose of reporting and surrendering obligations under the New Zealand ETS, using a methodology that yields consistency with New

Zealand's Greenhouse Gas Inventory (Ministry for Primary Industries, 2012). Table 2.1 summarises the current emission factors relevant for LURNZ.[2]

Table 2.1. Emission factors in agriculture

Activity	Tonnes CO_2
Livestock slaughter	
Per tonne carcass weight of cattle[a]	12.70
Per tonne carcass weight of sheep[b]	12.70
Dairy processing of milk	
Per tonne milk solid	8.50
Synthetic fertiliser use	
Per tonne nitrogen	5.72

[a] Other than a calf or vealer: bulls, cows, heifers, steers.

[b] Hoggets, lambs, rams, ewes and wethers.

The guiding philosophy behind the development of these emission factors was that the principal economic outputs from agriculture are allocated all the emissions attributable to their production (MAF Policy, 2010). Separate emission factors apply, for example, to the production of meat and milk. One exception to this rule is the production of wool. Due to administrative and practical issues, wool production is not included as an activity in the ETS, and any emissions associated with the activity will be borne by the Crown (Ministry for Primary Industries, 2012). The implications of this with regard to LURNZ simulations are discussed later.

2.2. Dairy production statistics

The *New Zealand Dairy Statistics*, the Livestock Improvement Corporation (LIC) and DairyNZ's annual publication, provides statistical information on the dairy industry at a national as well as a regional level. We update and append our original dataset (LIC and DairyNZ, dataset, 2010) with observations for 2009 and 2010 using information publicly available from the 2010–2011 *Dairy Statistics*.

To model activities associated with dairy sector emissions, we make use of region-level summaries of the average number of dairy cows per hectare and of the average amount of milksolids produced per effective hectare. These observations are available for 17 regions of the country individually (as well as at the national level). Other data we use from the *New Zealand*

[2] An earlier (undocumented) version of the LURNZ model built on emission factors specified under previous legislation. The old emission factors for livestock slaughter were split into two components: a flat per-head charge and a variable per-kilogram charge. Simulations in Kerr et al. (2012) were based on this specification of the model. For completeness, the obsolete emission factors are reproduced in the appendix.

Dairy Statistics include total effective hectares in 2008 and survivability percentages for dairy cows of various ages.

2.3. Livestock population

Detailed data on livestock populations are available from agriculture industry sector variables through Statistics New Zealand's online data portal, Infoshare (Statistics New Zealand, dataset, 2012a). The dataset we acquired contains information on more than twenty stock types of cattle and sheep. Livestock population numbers in the Greenhouse Gas Inventory are also based on these data, but the inventory population figures for each sector represent aggregates across all adult livestock types.

The classification of livestock in the population data is different from the classification used by some of the other data sources we employ. For example, slaughter data and stock unit conversions are not available for all stock types represented in the population data. For consistency across our data sets, we reclassify the livestock population stock types according to table 2.2.[3] To accommodate differences in modelling methodology, the dairy and sheep-beef sectors are treated differently in this process. The new dairy cattle stock types correspond to those used in the slaughter data. Slightly more information is retained for sheep and beef cattle, where the new stock types are those for which stock unit conversions exist.

[3] In several cases, further classifications of the entries under original stock type are available in the population dataset. We omit any unnecessary detail from table 2.2.

Table 2.2. The reclassification of livestock population stock types

Sector	Original stock type	New stock type
Dairy	Rising 1 Year Old Dairy Heifers and Calves	heifers
	Dairy Cows and Heifers - not in Milk or Calf	heifers
	Dairy Cows and Heifers, in Milk or Calf	cows
	Dairy Bulls intended for Breeding	bulls
	Calves Born Alive to Dairy Heifers/Cows	calves
Beef	Beef Heifer Calves, under 1 Year Old	heifer weaners
	Steer Calves, under 1 year	steer weaners
	Beef Non-Breeding Bulls (under 1 year)	bull weaners
	Beef Cows and Heifers (not in calf) 1–2yrs old	heifers
	Beef Cows and Heifers (not in calf) 2yrs and over	heifers
	Steers, 1-2 years old	steers 1.5yr
	Steers, 2 years old and over	steers 2.5yr
	Beef Breeding Bulls	bulls
	Beef Non-Breeding Bulls 1–2yrs old	bulls
	Beef Non-Breeding bulls 2yrs and over	bulls
	Beef Cows and Heifers, Bred from	cows
Sheep	Breeding Ewes 2 Tooth and Over put to Ram	ewes
	Breeding Ewes 2 Tooth and Over not put to Ram	ewes
	Rams 2 Tooth and Over	rams
	Ewe Hoggets put to Ram	hoggets
	Ewe Hoggets not put to Ram	hoggets
	Total Ram and Wether Hoggets	hoggets
	Wethers 2 Tooth and Over	wethers
	Total Lambs Marked and/or Tailed	lambs

2.4. Livestock slaughter

Similarly to livestock population, annual time-series data on slaughter is available from industry sector information from Infoshare (Statistics New Zealand, dataset, 2012b). Because at the time of slaughter it may be difficult or impossible to trace cattle to a specific sector, this dataset combines dairy and beef livestock. In all, six different stock types of cattle and four different stock types of sheep are represented (ewes and wethers are combined into a single category). For each stock type, information is provided on the number of animals slaughtered and their total carcass weight.[4] From this, it is straightforward to determine the mean carcass weight of animals of each type. For example, the mean slaughter weight of heifers has increased by around twenty percent, from around 200 to 240 kilograms, since the early 1980s.

[4] Carcass is defined as the animal slaughtered from which the head, feet, skin, guts, viscera and blood have been removed.

2.5. Stock unit conversions

A livestock unit (or stock unit) is a standardisation of different classes and species of livestock based on their feed requirement. A piece of land that is able to support ten stock units of sheep could, in theory, alternatively support ten stock units of beef cattle. In modelling the sheep and beef sector, we use the conversion system developed by the Meat and Wool Board's Economic Service and MAF in 1992 (Woodford and Nicol, 2005).[5] This is a relatively comprehensive system, defining conversions for several stock types based on sex and age group. The stock unit conversions are reproduced in normal font in table 2.3. In addition, the table includes conversion factors for average sheep and beef cattle in bold. We calculate these by taking weighted (by livestock population) averages of the other conversion factors over a multi-year period. We note that the average stock unit conversions provided by an alternative system used in the Pastoral Supply Response Model (Gardiner and Su, 2003) are identical for sheep and very similar for beef cattle (0.93 and 4.8, respectively). We use the weighted average conversion factors when stock type is not specified.

Table 2.3. Stock unit conversions applied per head of sheep and beef cattle

Stock type	Stock units
Ewes	1.0
Hoggets	0.7
Wethers	0.7
Rams	0.8
Sheep	**0.93**
Heifer weaners	3.5
Steer weaners	4.5
Bull weaners	4.5
Cows	5.5
Heifers 1.5 yr	4.5
Steers 1.5 yr	5.0
Steers 2.5 yr	5.5
Bulls	5.5
Beef Cattle	**4.99**

2.6. Livestock carrying capacity

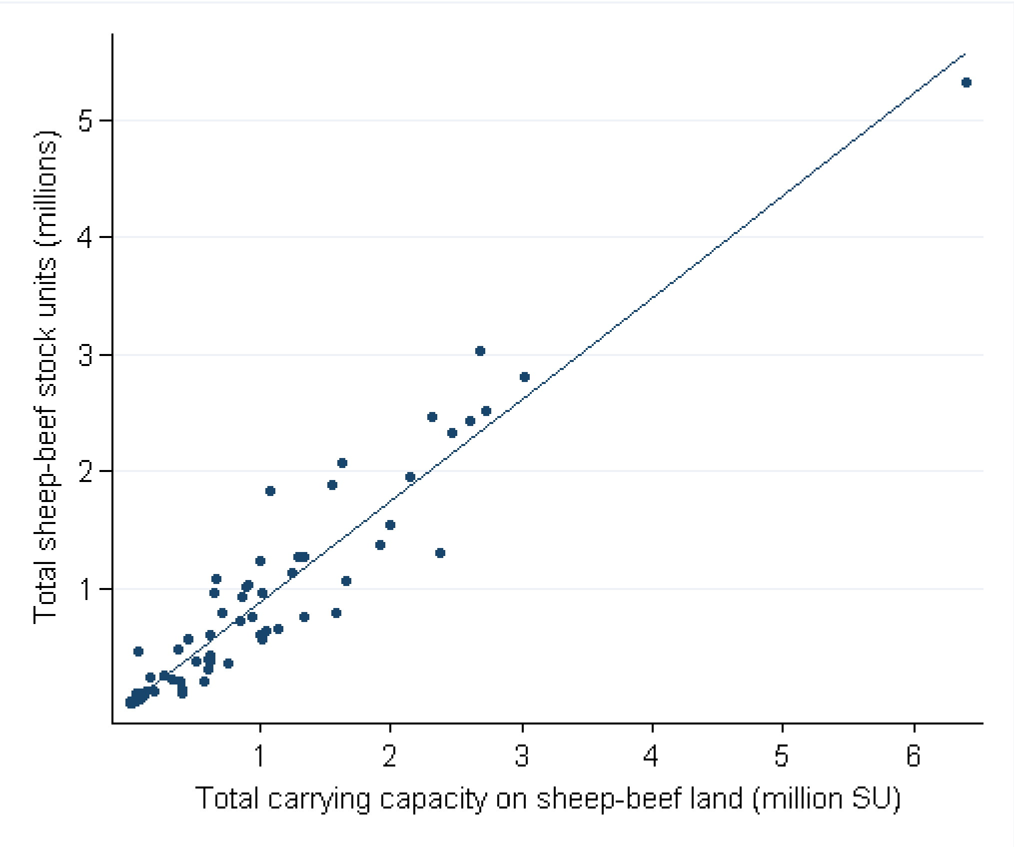
Average stock carrying capacity (CCAV) is a detailed geographic information system dataset of national coverage in the New Zealand Land Resource Inventory providing estimates

[5] On average, sheep and beef cattle have become larger over time – this can easily be verified using the livestock slaughter data. Their size must affect the feed requirement of these animals, yet we use constant (and potentially dated) stock unit conversions. As we discuss later, our modelling of emissions is robust to this.

of the average number of livestock units that a hectare of land can sustainably support (Landcare Research, dataset, 2002). Carrying capacity for potentially productive land varies from a fraction of a stock unit to over twenty stock units per hectare.[6]

In theory, the map provides a comprehensive and nationally consistent indicator of the relative suitability of land for pastoral agriculture. We seek empirical evidence for this through a simple analysis of the spatial distribution of sheep and beef livestock: we perform a univariate regression of the total number of sheep and beef animals (expressed as stock units) on the aggregate carrying capacity of sheep-beef land across Territorial Authorities. The relationship, illustrated in figure 2.1, is positive and statistically significant.[7]

Figure 2.1. The relationship between livestock numbers and aggregate carrying capacity within the sheep-beef sector across Territorial Authorities



We are unable to validate the dataset at a finer spatial resolution, but the assumption that carrying capacity provides useful information at other scales as well does not seem unreasonable.

[6] Bare mountaintops and other unproductive land areas have zero assigned carrying capacity.

[7] The estimation uses 2002 data on land use (AsureQuality, dataset, 2008) and livestock populations (Statistics New Zealand, dataset, 2003) – this is the only year with complete spatial information on pastoral land-use types. The slope of the regression line and the coefficient of determination are b=0.87 and R^2=0.91, respectively. The slope estimate is statistically significant at the one percent level. Weighting observations by animal numbers or land area does not affect the results materially.

Accordingly, we use the map to simulate the geographic distribution of livestock within the sheep and beef sector. As we describe in section 3.2.3, the stocking rate on sheep-beef land is approximated by scaling carrying capacity in order to satisfy an adding-up constraint.

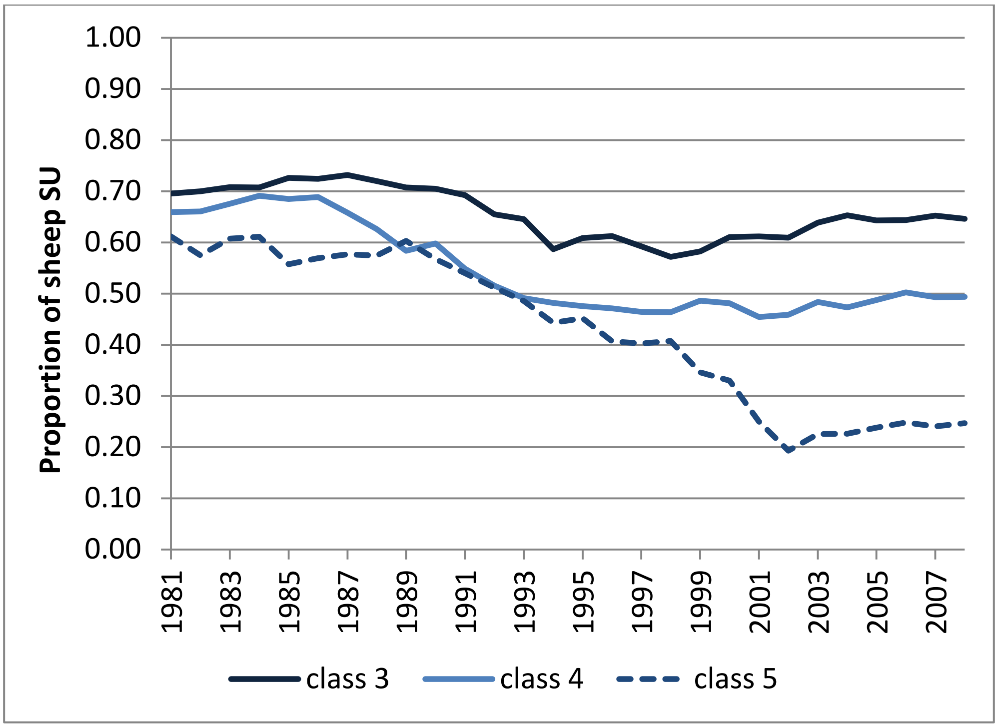
2.7. Herd composition

We define herd composition in sheep and beef farming as the proportions of sheep and beef cattle stock units characteristic of a location (the two proportions summing to one). We use these variables as weights in calculating an implied emission factor for meat produced in the sector.

We take livestock numbers reported by Meat and Wool New Zealand (Meat and Wool Economic Service, dataset, 2009) and the weighted average stock unit conversions shown in bold font in table 2.3 to calculate stock unit proportions. The original Meat and Wool dataset includes observations across five large geographic areas (most of them covering multiple farming regions) and eight farm classes over a period of nearly 30 years. We identify farm classes spatially (Hendy et al., dataset, 2009).

For illustration, in figure 2.2 we present the proportion of sheep stock units across three farm classes in the region encompassing Northland, Waikato and Bay of Plenty. While class 5 land in this region has been increasingly used to graze beef cattle instead of sheep, most farm classes in most regions have experienced little or no change in herd composition. In all cases, stock unit ratios have remained stable in recent years. Therefore, for each farm class within each region, we use the mean value of observations over the last seven years (2002–2008) as our measure of sheep stock unit proportion.

Figure 2.2. The proportion of sheep stock units in the Northland–Waikato–Bay of Plenty region



The proportion of sheep stock units for all region and farm class combinations is shown in table 2.4; the proportion of beef cattle stock units is given by subtracting from one the corresponding entry in the table. Farm class 9 represents a region-specific mean; we use this value for cells without farm class information. The New Zealand value is used for any areas not covered by one of the other regions.

Table 2.4. The proportion of sheep stock units by region and farm class

Region / **Farm class**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Northland–Waikato–BoP	-	-	0.64	0.48	0.23	-	-	-	0.48
Taranaki–Manawatu	-	-	0.69	0.66	0.67	-	-	-	0.67
East Coast	-	-	0.63	0.65	0.61	-	-	-	0.63
Marlborough–Canterbury	0.79	0.75	-	-	-	0.77	-	0.82	0.77
Otago–Southland	0.85	0.78	-	-	-	0.83	0.95	-	0.87
New Zealand	0.82	0.76	0.65	0.58	0.51	0.80	0.95	0.82	0.70

2.8. Fertiliser use by farm type

The land treatments (fertiliser) tables of the Agricultural Census show, among other things, the amount of various nitrogen-containing fertilisers used by farm type (Statistics New

Zealand, dataset, 2008). Table 2.5 reproduces the relevant information from the 2007 census.[8] For instance, dairy farmers applied 281,189 tonnes of urea, 63,407 tonnes of diammonium phosphate, 20,920 tonnes of ammonium sulphate and 94,612 tonnes of other nitrogen-containing fertilisers in that year. As explained later, we combine the fertiliser use table with other data in order to determine fertiliser intensity – the amount of nitrogen used per hectare of land – in the dairy and sheep-beef sectors.

Table 2.5. Tonnes of fertiliser applied by farm type in 2007

Original farm type (ANZSIC06)	Urea	DAP[a]	AS[b]	AON[c]
Sheep farming (specialised)	20,064	27,343	4,454	9,533
Beef cattle farming (specialised)	28,286	16,197	2,915	13,805
Sheep-beef cattle farming	35,712	48,912	6,078	23,916
Grain-sheep and grain-beef cattle farming	10,803	3,891	963	3,460
Dairy cattle farming	281,189	63,407	20,920	94,612
Total New Zealand[d]	**433,331**	**182,714**	**40,589**	**183,642**

[a] Diammonium phosphate.

[b] Ammonium sulphate.

[c] All other nitrogen containing fertilisers.

[d] Rows do not add up to total as all farm types are not reproduced here.

2.9. Greenhouse Gas Inventory

New Zealand's Greenhouse Gas Inventory is the official annual report of all anthropogenic emissions and removals of greenhouse gases in New Zealand. We extensively employ and refer to data found in the inventory reporting and background tables (Ministry for the Environment, dataset, 2011).[9]

The intention of the ETS is that agricultural outputs get charged with the emissions attributable to their production. In theory, therefore, aggregate emissions determined via the use of emission factors are consistent with inventory emissions. Hence, one way in which we use the inventory is to calibrate and cross check our results.

Inventory sources of greenhouse gas emissions relevant to pastoral agriculture include methane emissions from enteric fermentation, methane and nitrous oxide emissions from manure management, and direct and indirect emissions of nitrous oxide from agricultural soils. Not all of these sources are summarised at the sector level in the inventory. For example,

[8] These values are based on the ANZSIC06 industrial classification. We group the four industrial sectors that refer to some type of sheep or beef cattle farming into the sheep-beef sector.

[9] The background tables we originally started working with are from the Greenhouse Gas Inventory 1990–2009 (published in 2011). New versions of the inventory have since then become available.

emissions from synthetic fertilisers (which constitute one component of nitrous oxide emissions from agricultural soils) are reported in a separate category for all agricultural uses combined. Nevertheless, we are able to perform additional calculations to distribute emissions into the sectors we work with.

We convert the methane and nitrous oxide emissions of the inventory into carbon dioxide-equivalent emissions using global warming potentials (GWP). For consistency, we use the 100-year GWPs defined in the Second Assessment Report (SAR) of the United Nations Intergovernmental Panel on Climate Change (IPCC). This set of GWPs is stipulated by the Climate Change Convention reporting requirements for national inventories.

3. Methods and parameter values

Calculations of greenhouse gas emissions in the LURNZ model are based on emission factors given in the Climate Change (Agriculture Sector) Amendment Regulations 2012. We use some of these emission factors directly with data on the activities they are associated with. When there is insufficient information on the spatial and temporal distribution of the activity, we convert the emission factor to an implied emission factor that gives emissions in terms of a related activity that is more convenient to use.

The emission factors and implied emission factors remain constant through time in LURNZ simulations. On the other hand, the level of associated activities may vary through time (and space). For example, milk emissions in dairy farming are modelled as the product of a constant emission factor and projected milksolid production which varies by region and through time. A logical implication of relying on constant emission factors is that without additional information, LURNZ is ill-suited to model improvements in greenhouse gas production efficiency: the emission factors and implied emission factors define either explicitly or implicitly emissions per unit of production.

Emissions included in LURNZ include those from livestock as well as from other agricultural sources related to land use. In particular, they include emissions from the application of synthetic fertilisers.[10] But they do not include emissions from fuel and electricity use by farmers which are included in the energy and industrial processes sector.

[10] Under current ETS legislation, the obligation for emissions associated with the use of synthetic fertilisers falls on the manufacturers of these fertilisers. We nevertheless include fertiliser emissions in LURNZ because we assume that producers are able to pass on the costs of these emissions to farmers through raising the price of fertilisers.

We define land-use intensity as the volume of a selected activity in each sector. In modelling land-use intensity and emissions, we combine data from many different sources. Not all of these data sources may be consistent in their definition of a variable. For this reason, we scale some of our results so as to achieve (approximate) consistency with data in the Greenhouse Gas Inventory. This section documents the modelling decisions we have made for the dairy and the sheep-beef sectors in turn.

3.1. Dairy sector

We define land-use intensity in dairy farming as milksolid production per hectare, and we model greenhouse gas emissions under dairy land use as the sum of emissions from three activities: milk production, the slaughter of dairy cattle and synthetic fertiliser use. Specifically, for each hectare of land under dairy use in LURNZ simulations, greenhouse gas emissions in region *i* at time *t* are calculated as

$$GHG_{it} = EF^{milk}MS_{it} + IEF^{meat}SR_i + EF^{fert}N_{it} \quad (1)$$

Each term on the right-hand side of equation 1 is explained in table 3.1, and the remainder of this section is devoted to describing them in more detail.

Table 3.1. Explanation of terms used in modelling dairy emissions

Term	Description	Units (per year)
EF^{milk}	Emission factor for milk	kg CO2-e per kg milksolid
MS_{it}	Land-use intensity (milksolid production)	kg milksolids per hectare
IEF^{meat}	Implied emission factor for meat	kg CO2-e per dairy cow
SR_i	Stocking rate	dairy cows per hectare
EF^{fert}	Emission factor for fertiliser	kg CO2-e per kg nitrogen
N_{it}	Fertiliser intensity	kg nitrogen per hectare

Two tables in section 3.1.6 provide a summary of results and specify the parameter values and functional forms we use to model each term in table 3.1.

3.1.1. Emission factors for milk and fertiliser

The emission factors for milk and fertiliser are those applied to dairy processing and nitrogen-containing synthetic fertiliser use in the Climate Change (Agriculture Sector) Amendment Regulations 2012 (shown in table 2.1). Because of the availability of matching activity data on milksolid production and synthetic fertiliser application, it is straightforward to use these emission factors directly in calculations of emissions per unit land area. These emission factors are reproduced in table 3.2.

3.1.2. Implied emission factor for meat

The implied emission factor for meat, IEF^{meat}, captures average annual dairy cattle slaughter emissions per head of dairy cow. It is related to the slaughter emission factor for cattle shown in table 2.1, but it gives annual emissions per dairy cow instead of per tonne slaughter weight.[11] The conversion of the original emission factor is necessary because the corresponding activity level we use, the stocking rate, is expressed in heads of dairy cow per hectare.

The approach we take to estimate the implied emission factor for meat is based on records of the slaughter and population of cattle: in effect, we distribute emissions from the slaughter of dairy cattle (under ETS accounting rules) among all dairy cows alive in a given year. The livestock slaughter dataset does not differentiate between beef cattle and dairy cattle culls, so this approach requires that we estimate the number of dairy cattle among each class of livestock slaughtered. To do so, we simply assume that all vealers, heifers and steers slaughtered come from the beef sector, and that dairy cows and dairy bulls are slaughtered in proportion to their incidence in the population.[12,13] The mean (over a ten-year period) proportion of dairy cows among all cows culled derived under these assumptions is 0.781. This is highly consistent with the mean value based on sector-specific slaughter estimates made by Beef + Lamb New Zealand's Economic Service: 0.782 (Ministry for Primary Industries and Beef + Lamb New Zealand, dataset, 2012).

We calculate total emissions attributable to the slaughter of dairy cattle in a given year using average slaughter weights within each class of livestock, and then divide the result by the number of dairy cows alive in that year. We thereby allocate the emissions of dairy cows culled as well as the emissions of dairy bulls culled among the population of dairy cows. This results in a redistribution of emissions from bulls to cows – a necessary step because the activity data for the implied emission factor is expressed in heads of dairy cows per hectare, but we wish to account for emissions from all classes of dairy livestock.

Emissions per cow derived in this way vary from year to year with changes in the volume of slaughter and population of livestock. This is shown by the series labelled approach 1 in figure

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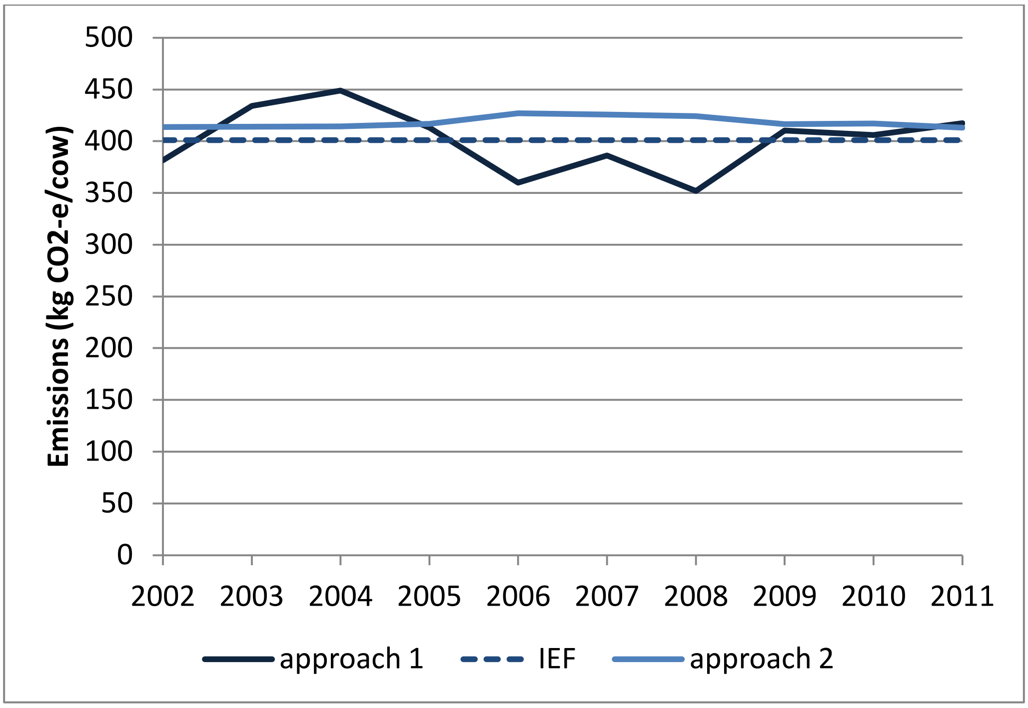
[11] A note on terminology: we use the expression "implied emission factor" for this term to distinguish it from the ETS emission factor for slaughtering cattle, from which it is derived.

[12] This is essentially equivalent to assuming that the life expectancy of dairy cows and dairy bulls is identical to the life expectancy of beef cows and beef bulls, respectively (and that all dairy heifers are grown into cows).

[13] There is no emissions charge associated with the slaughter of bobby calves. The emissions of calves are spread across all milk in the dairy sector and are thus accounted for in the emission factor for milk (Ministry for Primary Industries, 2012).

3.1. To address such fluctuations, we use the mean of the series from 2002 to 2011, labelled IEF in the figure, as the final value for the implied emission factor for meat.

Figure 3.1. Annual emissions per dairy cow attributed to slaughter



The approach described above could be expected to slightly underestimate emissions attributable to the slaughter of dairy cattle. Fundamentally, the issue arises because of population dynamics. Our approach takes emissions associated with observed slaughter and distributes these emissions among all dairy cows alive in the same year. However, the population of dairy cattle has been increasing over time, so the ultimate volume of slaughter associated with the population currently alive may, on average, be somewhat higher than the volume of the contemporaneous slaughter. An alternative approach to estimate the implied emission factor would therefore be to distribute all emissions anticipated from the slaughter of the current population over the expected lifespan of an average dairy cow (determined using annual survivability percentages in the *New Zealand Dairy Statistics*). Although this approach would theoretically provide a better estimate of slaughter emissions associated with each individual cow, it would tend to slightly overestimate contemporaneous emissions as long as the dairy cattle population is growing. Because the expansion of the dairy sector is expected to continue for some years to come, an implied emission factor based on contemporaneous emissions may better reflect the impact on farmers in typical LURNZ simulations.

For comparison, results based on the alternative approach are also depicted in figure 3.1. In terms of mean emissions per dairy cow, the difference between the two approaches is only around 4 percent. Because the choice of approach makes little practical difference, our calculations are based on the slaughter-based approach originally described. This also provides some consistency in methods across the two pastoral sectors we model.[14]

3.1.3. Milksolid production

The dairy sector has experienced large gains in intensity over recent decades. National average production has increased from 768 to 921 kilograms of milksolids per effective hectare, or by about 20 percent, between 1999 and 2010 (LIC and DairyNZ, dataset, 2010).[15] These gains have not been uniform across different regions of the country. While the fastest-growing region, North Canterbury, has increased its milksolid production per unit land area by a third, some regions have experienced only small gains, and production in the small (by dairy area) East Coast region has actually declined.

We project the likely future evolution of milksolid production per effective hectare in each region in a parsimonious way: by fitting a conservative logarithmic time trend to historical observations (1999 to 2010). The trend line is described by the equation

$$Y = \alpha + \beta * \ln(t - \gamma),$$

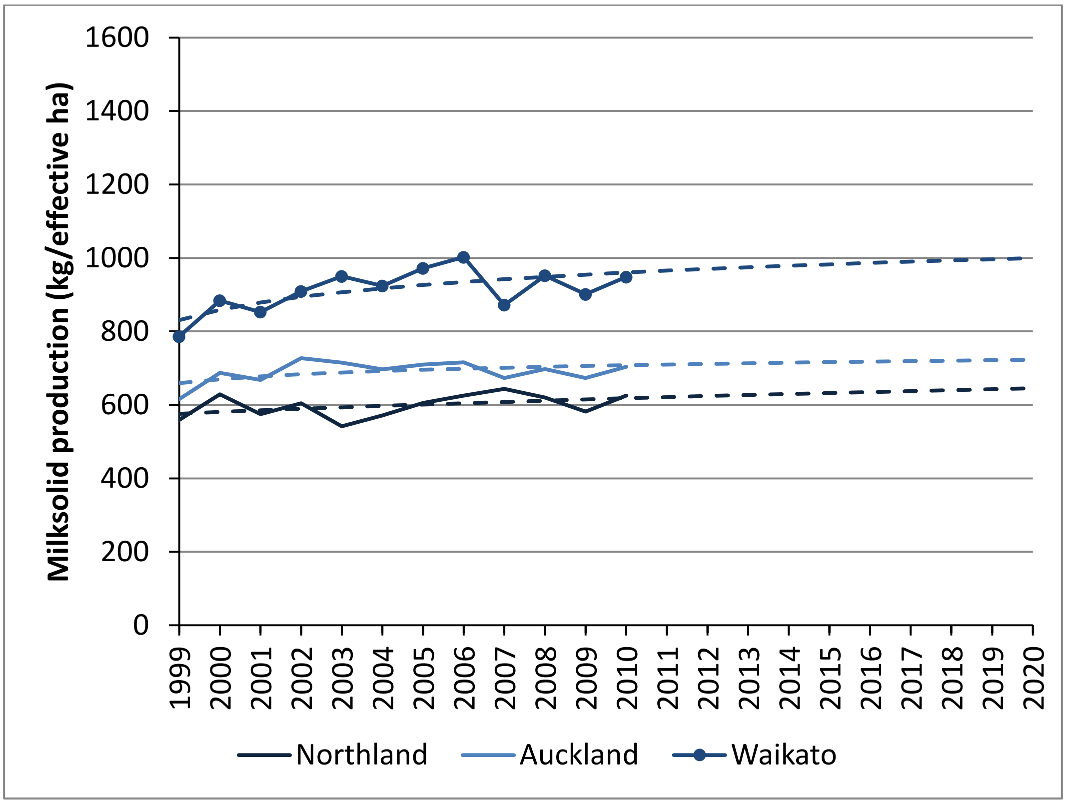
where the time variable, t, is year. The parameters α, β and γ are chosen to minimise the sum of squared residuals of the estimating equation, subject to the constraint that the value of γ is between 1979 and 1997. A low value for this parameter (close to 1979) yields a trend that is, within the projection period, almost indistinguishable from a linear trend, while a high value (close to 1997) leads to a trend with relatively high curvature and therefore quickly diminishing marginal gains in projected production.

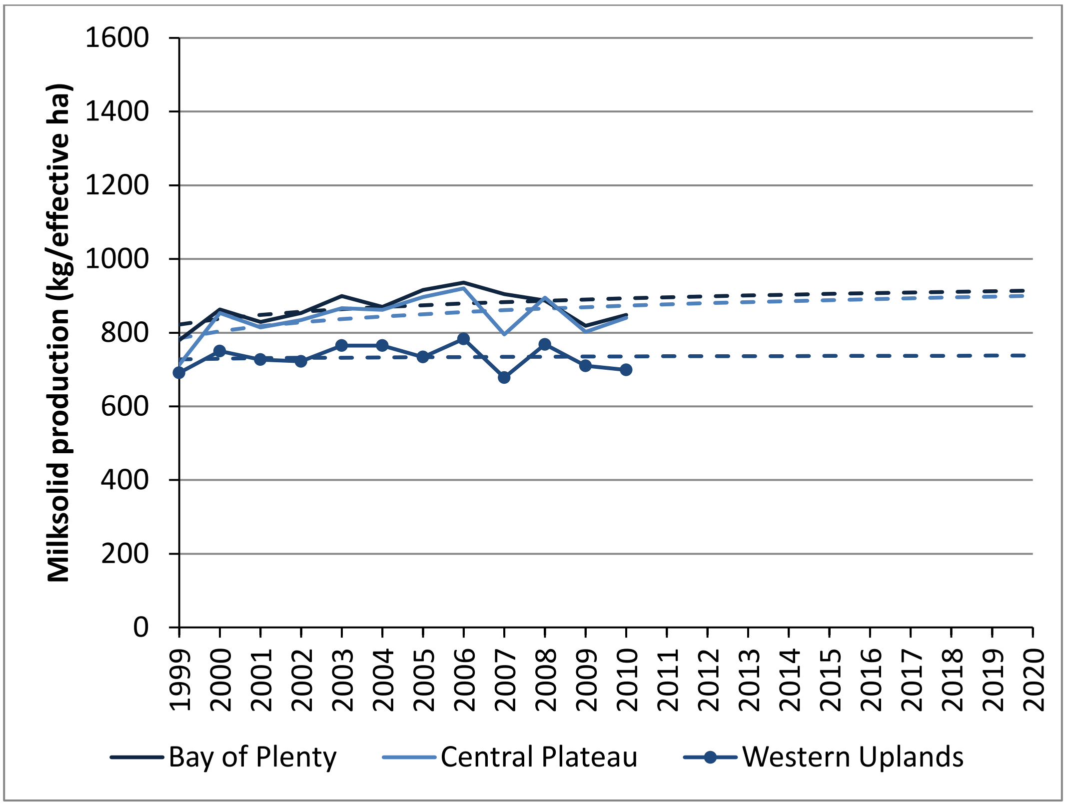
Tables 3.2 and 3.3 display our estimates. In addition, observed and projected production for each region is depicted across several panels of figure 3.2. In contrast to other regions, milksolid production per hectare in the East Coast exhibits a decreasing trend. We suspect that the apparent decline does not reflect a fundamental decrease in productivity over time. Instead, we attribute it to measurement issues arising from the small size of the local dairy sector: only 0.1 percent of New Zealand's dairy cows are held in this region. Therefore, rather than applying a declining trend, we constrain the value of milksolid production per effective hectare to its sample mean for future East Coast projections.

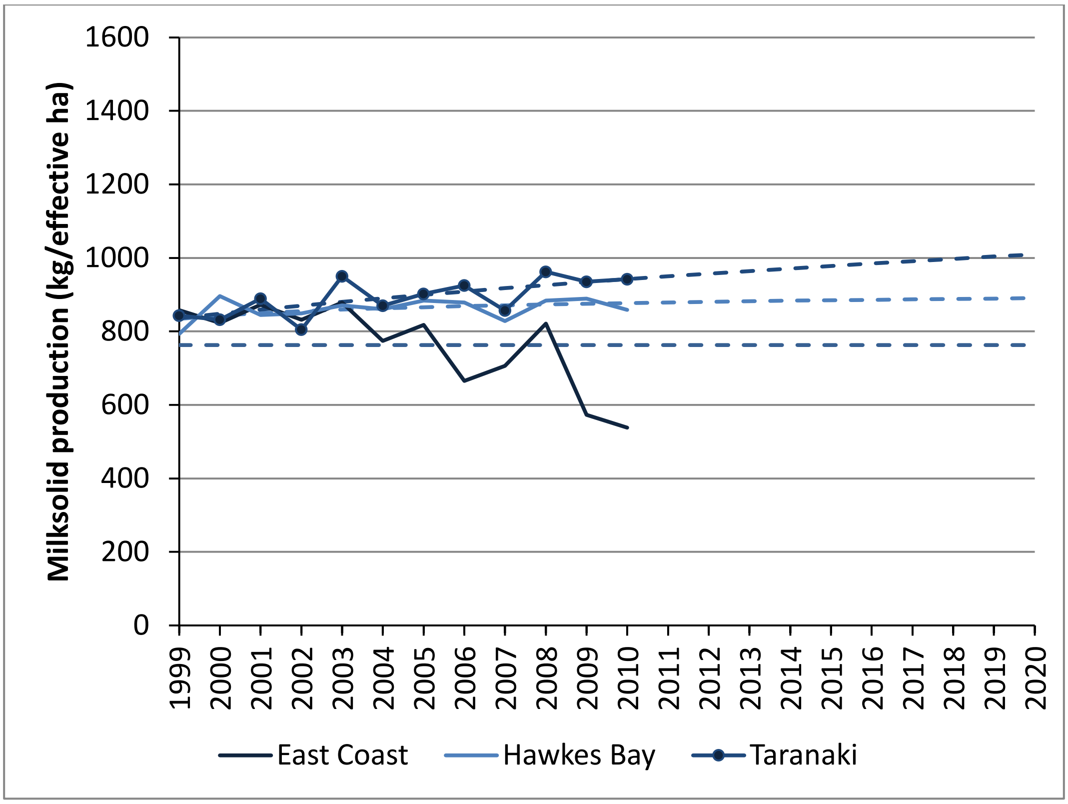
[14] The alternative approach cannot be applied to estimating sheep and beef emissions due to a lack of relevant life expectancy data in that sector.

[15] We exclude our first data point of 1998 from the analysis because of abnormally low production due to a drought in that year and update the original dataset as described in section 2.2.

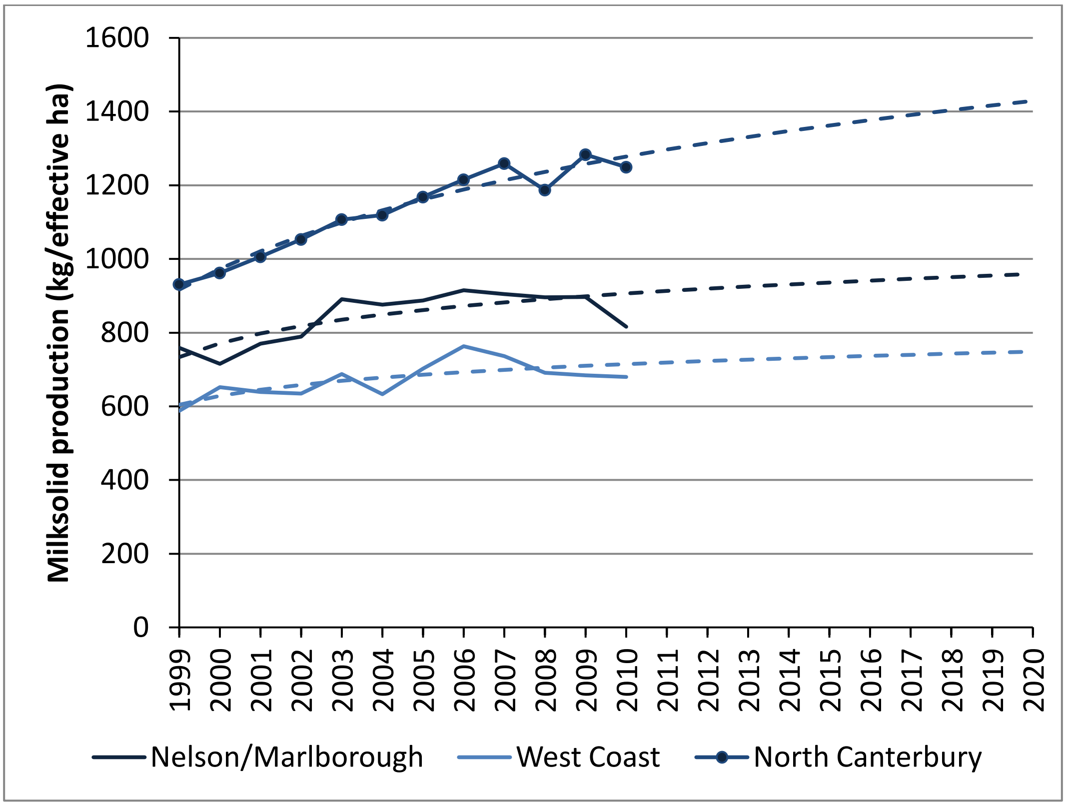
Figure 3.2. Observed and projected milksolid production by region



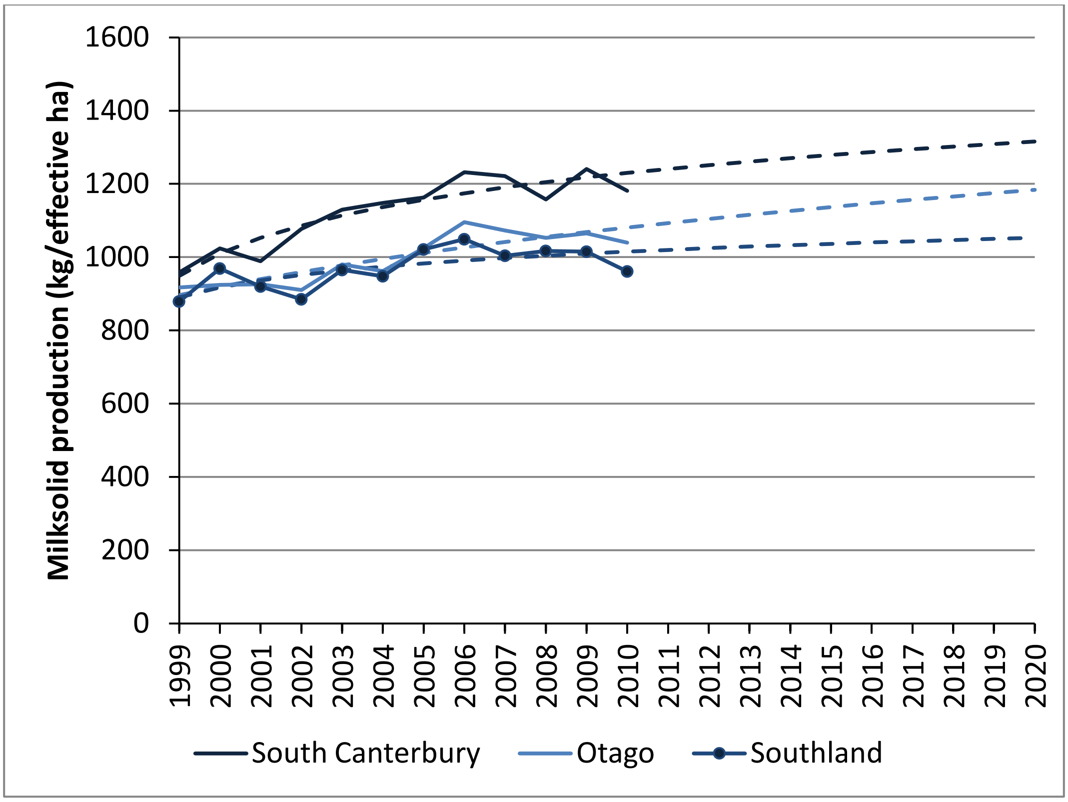




Milksolid production (kg/effective ha)
1600
1400
1200
1000
800
600
400
200
0
1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018 2019 2020
East Coast
Hawkes Bay
Taranaki



Milksolid production (kg/effective ha)
1600
1400
1200
1000
800
600
400
200
0
1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018 2019 2020
Nelson/Marlborough
West Coast
North Canterbury



An additional scaling operation is required to use these results for emissions calculations in LURNZ, because land area definitions are not consistent across our datasets. Milksolid production in the *New Zealand Dairy Statistics* is based on effective hectares (only areas of dairy farms where grass is grown), while the LURNZ land-use map contains all dairy land. Accordingly, we scale all projections for milksolid production by 0.901, the ratio of total effective dairy area (1,519,117 hectares) and total dairy map area (1,686,825 hectares) in 2008. With this scaling, simulated milksolid production for 2008 aggregates (approximately) to the amount recorded for that year in the *New Zealand Dairy Statistics* (see table 4.3).

3.1.4. Stocking rate

Stocking rate, expressed as number of dairy cows per hectare, is the activity we use with the implied emission factor for meat to calculate emissions from the slaughter of dairy cattle. Changes in the stocking rate over time have been much smaller than changes in per-hectare milksolid production. At the national level, the number of dairy cows per effective hectare grew by 2.2 percent between 1999 and 2010; in the same period, production per effective hectare grew by over 20 percent. North Canterbury had the largest change in its average stocking rate with a 14 percent increase, but even this relatively high growth pales in comparison to the more than 50 percent increase in production per hectare the region experienced over the same period. These data indicate that overall productivity gains have mostly come from livestock improvements (or changes in farm management leading to higher production per cow), rather than increasing stocking rates.

Because stocking rates have changed slowly over the past several years and because slaughter emissions make up only a relatively small fraction – roughly one eighth – of all agricultural emissions associated with dairy farming, modelling likely future increases in stocking rates would have an almost negligible effect on projected dairy emissions in LURNZ. For simplicity, we therefore abstract from any temporal trends in this variable. Instead, for each region, we simply take the mean number of dairy cows per effective hectare (over the seven-year period 2003–2010) and scale it by the ratio of effective hectares to total hectares. As explained in the previous sub-section, the reason for this scaling has to do with inconsistencies across the datasets. Results are shown in tables 3.2 and 3.3.

3.1.5. Fertiliser intensity

Fertiliser intensity is defined as kilograms of nitrogen applied per hectare. Detailed sector-level data on fertiliser use is scarce, and we combine multiple sources of information to establish the amount of nitrogen used at the national level on dairy farms in 2007. We distribute this total spatially by invoking a simplifying assumption that fertiliser intensity is proportional to land-use intensity: regions with higher milksolid production per hectare will also be associated with higher levels of fertiliser use per hectare. We apply the same assumption to projections of future fertiliser intensity.

The fertiliser tables of the Agricultural Census of 2007 contain some sector-level detail on synthetic fertiliser use in that year (table 2.5). A report by the Parliamentary Commissioner for the Environment (2004), in turn, provides information on the nitrogen content of most fertiliser types listed in the census. The most heavily used nitrogen-containing fertiliser, urea, has the highest nitrogen content: 46 percent by weight; diammonium phosphate and ammonium sulphate contain 18 and 21 percent nitrogen by weight, respectively. With this information, it is straightforward to determine the amount of nitrogen use attributable to these three types of synthetic fertiliser in each sector. However, we have no direct information on the average nitrogen content of the remaining category, "all other nitrogen-containing fertilisers", and without this information it is impossible to determine the total amount of nitrogen applied.

We rely on the National Inventory to augment our data on fertiliser use. The inventory reports, at the national level, total nitrogen input to agricultural soils from synthetic fertiliser use for all years since 1990. Nitrogen input differs from nitrogen use because some of the nitrogen applied to soils volatilises, but it can be used to infer total nitrogen use by applying the appropriate fraction to account for nitrogen emitted as nitrogen oxides (NOx) or ammonia (NH3) through volatilisation. We are thereby able to calculate total agricultural nitrogen use from synthetic fertilisers in 2007.

Next, we combine these pieces of information from the census and the inventory to determine the implied average nitrogen content of all other nitrogen containing fertilisers. The census accounts for 240,744,470 kg of nitrogen from the use of the three types of synthetic fertiliser whose nitrogen content is known exactly. This is less than the amount of nitrogen use calculated from the inventory for 2007 (315,920,000 kg). We assume that the difference is made up of nitrogen from the remaining synthetic source, all other nitrogen-containing fertilisers. That is, we allocate all nitrogen unaccounted for by the use of urea, diammonium phosphate and ammonium sulphate to this group of fertilisers. The assumption allows us to determine the implied average nitrogen content, over all agricultural sectors, of these fertilisers.[16]

Based on these results, we can determine total nitrogen use in each sector in 2007. Dairy farmers' use of synthetic fertilisers contributed 183,883,686 kg nitrogen, more than half of the total amount used in agriculture. We distribute this quantity spatially by assuming that fertiliser intensity is proportional to land-use intensity: each dairy cell in the LURNZ base map is assigned an allocation of nitrogen in proportion to the amount of milksolids produced in the cell.[17] This implies that each kilogram of milksolid production requires a certain amount of nitrogen from synthetic fertilisers. Dairy fertiliser intensity modelled in this way ranges from 65.1 to 131.6 kg nitrogen per hectare (in Northland and North Canterbury, respectively), with the national mean at 97.6 kg nitrogen per hectare in 2008.

For simulations of future periods, we assume that there are constant returns to scale to nitrogen input in milk production. Fertiliser intensity therefore increases at the same rate as projected milksolid production per hectare. In practice, these assumptions allow us to model fertiliser intensity simply by appropriately scaling land-use intensity.

3.1.6. Dairy sector parameters

To conclude this section, tables 3.2 and 3.3 summarise the results of dairy sector modelling. Table 3.2 specifies the value of each term in equation 1 in terms of primary

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[16] Hendy and Kerr (2006) omit other nitrogen-containing fertilisers because the nitrogen content of these fertilisers is unknown a priori. Our results indicate that the mean nitrogen content of this group of fertilisers is approximately 0.41 by weight, which seems (to our admittedly untrained eyes) plausible, for it is within the range of values associated with the other fertiliser types. We assume this value is constant across all sectors.

[17] In performing this allocation, we ignore a one-year gap between the fertiliser (2007) and land-use (2008) data. We also ignore the fact that some catchments in New Zealand have already implemented (or are currently planning to implement) nutrient limits that would affect the use of synthetic fertilisers. We are unable to account for such policies in both our land-use modelling and land-use intensity modelling.

parameters (parameters that are constant in the sector) and other parameters that may vary across regions. The values these secondary parameters take are presented in table 3.3. LURNZ simulations are based on these two sets of parameters (and a specific value for t, the year of projection).

Table 3.2. Primary parameters of dairy sector modelling

Term	Value
EF^{milk}	8.50
MS_{it}	$0.901 * [\boldsymbol{\alpha} + \boldsymbol{\beta} * \ln(t - \boldsymbol{\gamma})]$
IEF^{meat}	400.92
SR_i	$0.901 * \boldsymbol{\delta}$
EF^{fert}	5.72
N_{it}	$0.118 * MS_{it}$

Table 3.3. Secondary parameters of dairy sector modelling

Region / **Parameter**	$\boldsymbol{\alpha}$	$\boldsymbol{\beta}$	$\boldsymbol{\gamma}$	$\boldsymbol{\delta}$
Bay of Plenty	796.14	37.75	1997	2.86
Auckland	641.60	25.93	1997	2.41
Central Plateau	752.48	47.06	1997	2.71
East Coast	763.33	0	0	2.58
Hawkes Bay	817.86	23.18	1997	2.82
Nelson/Marlborough	669.68	92.23	1997	2.73
North Canterbury	416.81	310.52	1994	3.20
Northland	288.00	96.12	1979	2.21
Otago	189.65	284.28	1987	2.83
Waikato	782.59	69.26	1997	2.99
South Canterbury	844.70	150.13	1997	3.22
Southland	844.58	66.42	1997	2.69
Taranaki	112.35	241.63	1979	2.84
Wairarapa	793.58	35.87	1997	2.73
Manawatu	580.98	118.30	1993	2.73
West Coast	563.53	58.91	1997	2.20
Western Uplands	724.93	4.12	1997	2.62

3.2. Sheep and beef sector

We assume sheep-beef emissions are proportional to the stocking rate, which we define as the land use intensity of the sector. Stocking rates are not observed in a nationally consistent manner at a fine spatial scale, so we approximate the variable using livestock carrying capacity scaled for consistency with the average stocking rate nationally. Some of the country's sheep and beef area is located on public land. The land use of these cells is exogenous in LURNZ (that is, they never change land use in simulations). However, these areas do contribute to production and emissions, so we include them in the modelling of land-use intensity and greenhouse gas emissions.

For each cell under sheep-beef land use, whether private or public, in LURNZ projections, emissions are calculated as the sum attributable to livestock and to fertiliser.[18] For each location i,

$$GHG_i = IEF_i^{meat} SR_i + EF^{fert} N_i \quad (2)$$

Each term on the right-hand side of the equation is summarised in table 3.4.[19] The value of the implied emission factor at a particular location depends on the ratio of sheep to beef stock units characteristic of the location. Stocking rate and fertiliser intensity both depend on potential stock carrying capacity at the location. Neither land-use intensity nor emissions change over time in LURNZ simulations. The remainder of this section provides an in-depth discussion; tables 3.5 and 3.6 in section 3.2.5 specify the parameter values and the functional form we use to model each term.

Table 3.4. Explanation of terms used in modelling sheep and beef emissions

Term	Description	Units (per year)
IEF_i^{meat}	Implied emission factor for meat	kg CO2-e per stock unit
SR_i	Land-use intensity (stocking rate)	stock units per hectare
EF^{fert}	Emission factor for fertiliser	kg CO2-e per kg nitrogen
N_i	Fertiliser intensity	kg nitrogen per hectare

3.2.1. Emission factor for fertiliser

The emission factor for synthetic fertilisers is identical across the dairy and sheep-beef sectors: its value is determined directly by regulations under climate change policy. Table 3.5 reproduces it from table 2.1.

[18] There is no emissions charge in the ETS associated with the production of wool. Because farmers are not liable for these emissions, we do not account for them in equation 2. However, wool emissions are recognised in the inventory. Therefore, when drawing comparisons between aggregate LURNZ results and the National Inventory, one must remember to add exogenous wool emissions to the LURNZ results.

[19] For the sake of simplicity (and in order to avoid excessive indexing), some notation is recycled from equation 1: the same term may denote different variables in sections 3.1 and 3.2. The stocking rate, SR_i, for example, even has a different unit of measurement in the dairy and sheep-beef equations.

3.2.2. Implied emission factor for meat

The implied emission factor for meat approximates, under ETS rules, average annual emissions per unit of a weighted average livestock in the sheep and beef sector. The weighting is done across all livestock classes that are subject to an emissions charge at slaughter and takes into account the composition of livestock population that characterises each region and farm class. The implied emission factor is thus unique to a region-farm class combination.

We first approximate emissions per stock unit of sheep. Effectively, we distribute total emissions from the observed slaughter of sheep among all sheep stock units alive in a given year (by simply taking their ratio). Total emissions are given by the product of aggregate sheep slaughter weight across all livestock types and the corresponding per-tonne-carcass-weight emission factor from table 2.1. The total number of sheep stock units alive is calculated from livestock population data using the appropriate conversion factor from table 2.3 for each stock type.[20] The series labelled sheep in figure 3.3 illustrates changes in annual slaughter-related sheep emissions per stock unit over time.[21] To control for year-to-year fluctuations, we take the mean value of the series over the most recent 10-year period (2002 to 2011) – the mean is marked by the dashed line in the figure.

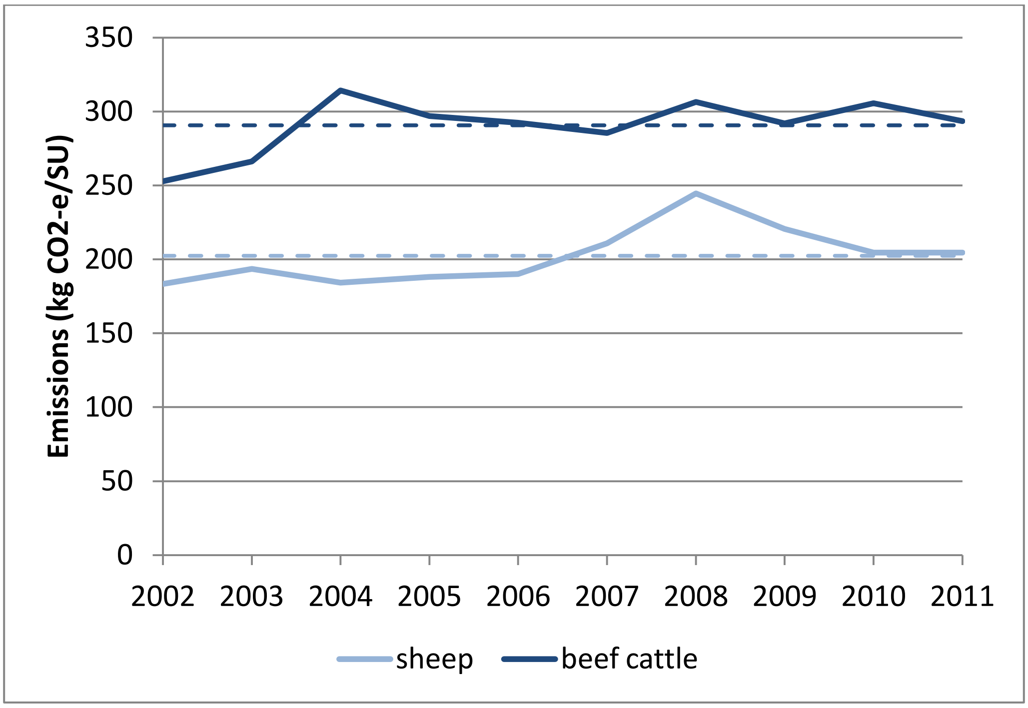
Next, a similar process is repeated for beef cattle. An important difference is that here we need to account for the fact that some of the slaughtered cattle originate in the dairy sector. The assumptions we make with regard to dividing the slaughter between dairy and beef have already been discussed in section 3.1.2: we allocate all vealers, heifers and steers slaughtered to the beef sector, and we split the slaughter of cows and bulls among the two sectors according to each sector's contribution to the population of the livestock type. As figure 3.3 illustrates, annual emissions from a stock unit of beef cattle are about 45 percent higher than emissions from a stock unit of sheep.[22]

[20] There is an asymmetry in the way lambs are treated in these calculations. Their slaughter emissions are included in total emissions, but lambs do not contribute to aggregate stock units as they are assumed to be accounted for in the stock unit value of a ewe.

[21] A drought in 2008 may have lead to an especially high slaughter rate, causing a spike in emissions. In any given year, slaughter decisions (and thus measured emissions) depend on market and weather conditions.

[22] The stock unit conversions in this calculation were developed two decades ago and do not reflect any changes in the size and feed intake of livestock. The difference between beef cattle and sheep emissions in figure 3.3 could, in theory, be explained by the use of obsolete stock unit definitions (if beef cattle have grown relative to sheep over time). We do not find evidence for this in the slaughter data: in proportional terms, sheep slaughter weights have increased slightly more than beef cattle slaughter weights since the 1980s.

Figure 3.3. Annual emissions per stock unit attributed to slaughter



A consequence of this difference in emissions is that average herd composition, for any given overall stocking rate, affects the amount of greenhouse gas emissions from a hectare of land. Herd composition systematically varies by region and farm class, so the final step we take in calculating the implied emission factor for sheep-beef meat involves taking a weighted average of sheep and beef emissions. We use the proportion of sheep and beef stock units characteristic of each location (as discussed in section 2.7) to establish the appropriate weights. As shown in table 3.6 at the end of the section, the emission factor for meat ranges from 349.9 kg CO2-e per stock unit on class 7 land in Otago and Southland, where the proportion of sheep stock units is highest, to 380.7 kg CO2-e per stock unit on class 5 land in Northland, Waikato and Bay of Plenty, where the proportion of beef stock units is highest.

To conclude this sub-section, we briefly discuss two additional points that affect our measure of the implied emission factor. First, as explained during our description of the implied emission factor for dairy cattle meat, using contemporaneous slaughter and population data may lead to a bias in the measurement of emissions attributed to a stock unit in a dynamic population. In the absence of life expectancy data for sheep and beef livestock types, we are unable to investigate the size of this potential bias. However, our results from the dairy sector suggest that it is likely to be small. Further, we find that introducing a time lag between the slaughter and population variables for sheep and beef does not affect the result significantly.

Second, we also note that our implied emission factor does not account for any potential improvements in animal genetics or other changes in production technology. For example, the mean slaughter weight of each sheep stock type has increased by at least 20 percent since the early 1980s, leading to a steady rise in the measured value of the implied emission factor historically. We abstract from such trends because of data limitations. However, we note that as long as larger animals also require more pasture to graze, there will be offsetting changes in emissions per livestock and livestock grazed per hectare: their product, emissions per hectare, is less sensitive to these trends.

3.2.3. Stocking rate

The stocking rate, expressed as number of stock units per hectare, is our measure of land-use intensity in sheep-beef farming, and it is the activity we use to calculate the sector's livestock-related emissions. We employ livestock carrying capacity (CCAV) from the New Zealand Land Resource Inventory (Landcare Research, dataset, 2002) to estimate stocking rate, which is unobserved, at a fine spatial resolution. We provide some justification for this relationship in section 2.6.

The relationship between carrying capacity and stocking rate is not one-to-one: national-level carrying capacity on sheep-beef land in 2008 is higher than the total number of sheep and beef stock units that were grazed in that year. One explanation for this is that land may sometimes be underutilised. Another explanation, as noted before, is that livestock genetics and farm management may have changed over time, and the constant stock unit conversions do not account for this. We therefore scale carrying capacity uniformly at each location to estimate the stocking rate. The scaling factor of 0.721 is chosen to achieve consistency with Statistics New Zealand livestock population data (on which the Greenhouse Gas Inventory is based): aggregating the estimated stocking rate on sheep-beef land in 2008 yields exactly the total number of sheep and beef cattle stock units represented in the livestock population data.[23] In other words, $0.721 * CCAV_i$, where $CCAV_i$ is the carrying capacity of the cell, is our estimate of the stocking rate of each hectare of land under sheep-beef use.

An analysis of observed trends in sheep-beef stocking rates across five farming regions and eight farm classes suggests that stocking rates have remained fairly constant over the last several years (Meat and Wool Economic Service, dataset, 2009). Consistent with these trends, we

[23] Any bias in stock unit conversions affects both our measure of the implied emission factor and of land-use intensity (through the scaling factor), but in the opposite direction. The product of these variables, emissions per hectare, is unaffected.

hold the stocking rate constant in simulations of future years. The implied emission factor for meat varies geographically by region and farm class because of variations in the mix of sheep and beef livestock.

3.2.4. Fertiliser intensity

Fertiliser intensity in sheep and beef farming is modelled in a similar manner to fertiliser intensity in dairy farming. First, we determine the amount of nitrogen applied by the sector from all nitrogen-containing synthetic fertilisers in 2007. The process matches exactly that described in section 3.1.5. Similar to dairying, this amount of nitrogen is distributed across all 2008 sheep-beef land in proportion to the land-use intensity (stocking rate, in this case) of the cell. As we do not simulate any changes in the stocking rate over time, fertiliser intensity remains constant as well. These assumptions suggest that around 0.86 kg nitrogen is applied annually for each stock unit of sheep and beef cattle.

3.2.5. Sheep and beef sector parameters

Tables 3.5 and 3.6 specify the parameters we use in modelling the sheep and beef sector. Parameters in the first table (the primary parameters) apply universally across the country, while the implied emission factor for meat in table 3.6 is specific to a farm class within each region. All parameters for the sheep-beef sector are held constant through time in LURNZ simulations.

Table 3.5. Primary parameters of sheep and beef sector modelling

Term	Value
SR_i	$0.721 * CCAV_i$
EF^{fert}	5.72
N_i	$1.65 * SR_i$

Table 3.6. The implied emission factor for sheep-beef meat, IEF_i^{meat}

Region / **Farm class**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Northland–Waikato–BoP	-	-	363.0	369.8	380.7	-	-	-	370.1
Taranaki–Manawatu	-	-	361.1	362.1	361.9	-	-	-	361.7
East Coast	-	-	363.4	362.8	364.2	-	-	-	363.3
Marlborough–Canterbury	356.4	358.4	-	-	-	357.3	-	355.2	357.3
Otago–Southland	353.9	357.0	-	-	-	354.7	349.9	-	353.0
New Zealand	355.4	358.0	362.6	365.5	368.8	356.3	349.9	355.2	360.6

4. Discussion of simulation results

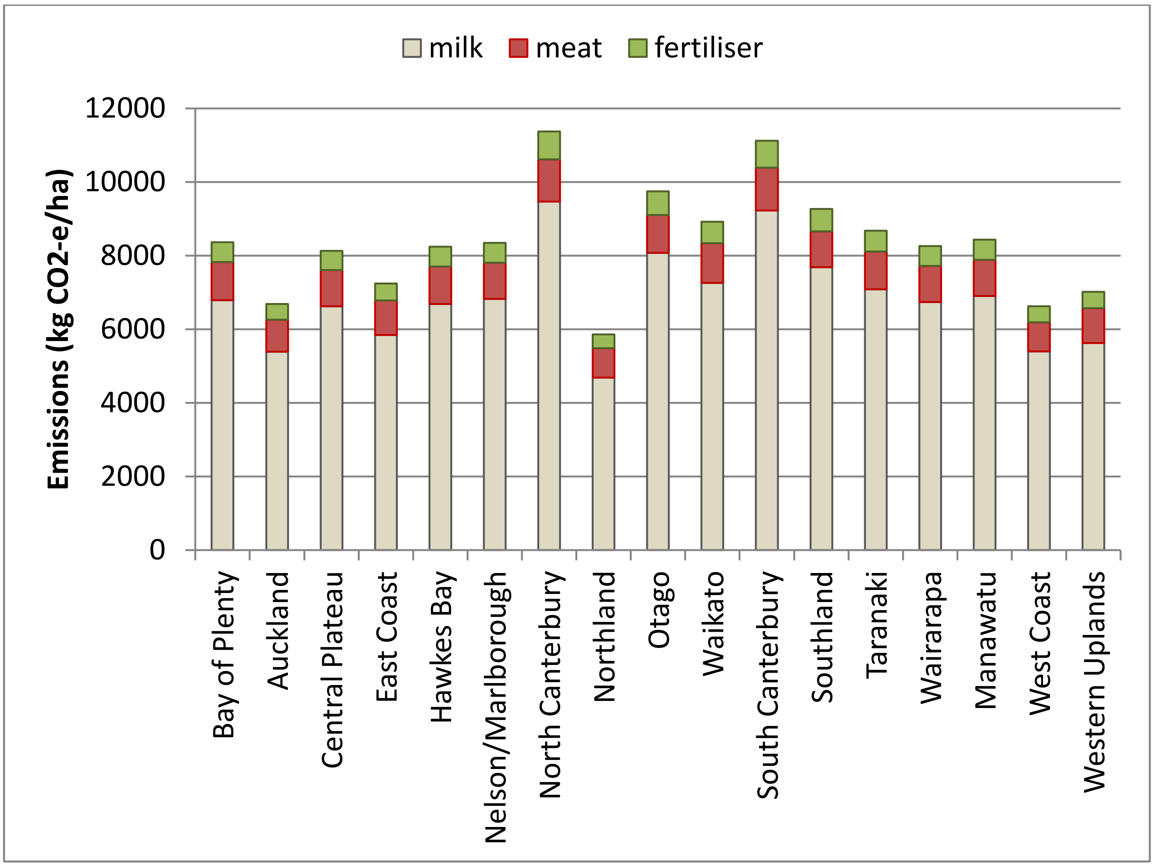
In this section, we summarise some of the results of modelling land-use intensity and emissions in LURNZ. Where possible, we also perform robustness checks by comparing these results to information known from other sources. We first present some descriptive simulation outcomes for the base year, 2008: the decomposition of emissions by sector and the distribution of emissions nationally. We then compare simulations of "future" land-use intensity and emissions to observed data.[24] Sheep and beef emissions simulated in LURNZ exclude the portion of emissions associated with wool production, as these are not charged to farmers under current ETS rules. We make an appropriate correction for this in our comparison.

Figure 4.1 identifies the modelled sources and amount of emissions from a hectare of dairy land in 2008.[25] Over 80 percent of all dairy emissions are allocated to milk production; 10–14 percent are associated with meat production; and emissions from synthetic fertiliser use represent less than a tenth, approximately 6.5 percent, of the total emissions of the sector. There is large variation in dairy emissions across different regions of the country. For example, emissions in North Canterbury are nearly twice as much as emissions in Northland on a per hectare basis. This is primarily due to differences in land-use intensity.

[24] Future, in this context, refers to years that have passed since the LURNZ base year, 2008.

[25] The standard output from the current version of LURNZ does not include this decomposition; it only shows total emissions for each grid cell. Future revisions to the model may address the reporting of these details as well as of estimated wool emissions.

Figure 4.1. Decomposition of dairy emissions in 2008 (kg CO2-e)



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In simulations of future time periods, milk and fertiliser emissions from dairy increase with land-use intensity (except in the East Coast region where, as described in section 3.1.3, milksolid production per hectare is assumed to remain constant). The volume of simulated meat emissions does not change over time.

Figure 4.2 illustrates emissions from a hectare of sheep-beef land supporting, by way of example, ten stock units. The variation across regions and farm classes has to do with differences in the stock types typically grazed: a stock unit of sheep produces fewer emissions than a stock unit of beef cattle.[26] By our assumptions, the volume of synthetic fertiliser use depends on the overall stocking rate, not on the type of livestock. Fertiliser emissions are therefore constant across all observations in figure 4.2, and they make up, on average, about four percent of all sheep-beef emissions.

[26] Not all region and farm class combinations from the previous section are represented in the figure. For example, all sheep-beef cells in the East Coast region in 2008 have a known farm class, so no cells in this region are assigned farm class 9 (the region-specific average).

Figure 4.2. Decomposition of emissions for sheep-beef land supporting ten stock units per hectare

Figure 4.2 is drawn for a stocking rate of 10 stock units per hectare. Both components of the sector's agricultural emissions are modelled as proportional to land-use intensity, so the amount of emissions associated with a different stocking rate are straightforward to determine by appropriately scaling all bars in the figure; for example, simulated emissions for 20 stock units are simply twice the amount shown in figure 4.2. For any particular piece of sheep and beef land, simulated emissions remain constant over time for we assume that land-use intensity within the sector remains constant.

In table 4.1, we present the decomposition of simulated base-year emissions at the national level. While we are able to account for beef cattle and sheep emissions from meat separately (using the estimated stock unit proportions by farm class and region), we only consider fertiliser emissions for the combined sheep-beef sector.

Table 4.1. Decomposition of simulated emissions in 2008 (Mt CO2-e)

<table>
<tr><th>Stock type</th><th>Milk</th><th>Meat</th><th>Fertiliser</th></tr>
<tr><td>Dairy cattle</td><td>11.84</td><td>1.69</td><td>0.94</td></tr>
<tr><td>Beef cattle</td><td>-</td><td>5.73</td><td rowspan="2">0.48</td></tr>
<tr><td>Sheep</td><td>-</td><td>6.38</td></tr>
</table>

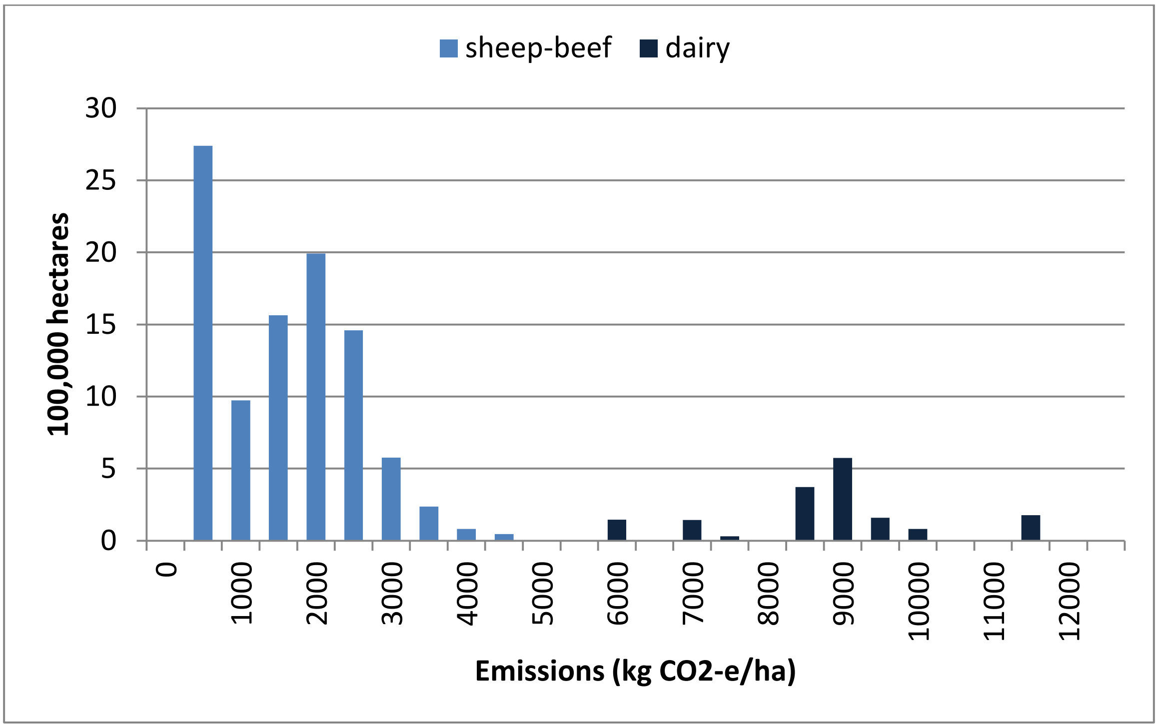
Simulation results for milk and meat emissions can be compared to estimates made by MPI (Ministry for Primary Industries, 2012). These are reproduced in table 4.2. We do not expect an exact match between the corresponding entries in the two tables because MPI's estimates are based on average emissions for the period 2004–2009. Nonetheless, we note that simulated dairy emissions are slightly higher than MPI's estimates and simulated sheep and beef emissions are slightly lower than MPI's estimates. Qualitatively, some of this difference may be explained by national trends in land use. Due to the expansion of the dairy sector and the contraction of the sheep-beef sector, our base-year simulations are likely based on more dairy activity and less sheep-beef activity than MPI's calculations.

Table 4.2. Decomposition of emissions by MPI (Mt CO2-e), averaged 2004–2009

Stock type	Milk	Meat	Wool
Dairy cattle	11.1	1.3	-
Beef cattle	-	6.8	-
Sheep	-	7.0	4.0

As an alternative way of summarising our results, figure 4.3 displays a histogram of simulated emissions in 2008. The distribution of dairy emissions is based entirely on inter-regional variation in milksolid production, and the distribution of sheep and beef emissions is based almost entirely on cell-level variation in carrying capacity (the variation in emissions caused by differences in average herd composition across regions and farm classes is relatively small, and it is not easily visible in the figure). A large number of cells are projected to produce a very low level of emissions under sheep-beef use. These represent marginal land with a low carrying capacity, often less than one stock unit per hectare.

Figure 4.3. The simulated distribution of emissions in 2008



The spatial scale of the underlying data means that we capture sub-farm detail in sheep-beef farming. Therefore, the distribution of farm emissions in the sector is almost certainly narrower than that shown in figure 4.3. Conversely, the distribution of dairy farm emissions is expected to be wider because our figures do not include intra-regional detail (Anastasiadis and Kerr, 2013).

Next, we compare LURNZ simulations for land-use intensity and emissions (in tables 4.3 and 4.4, respectively) to observations taken at the national level.[27] Recall that we define milksolid production per hectare as dairy land-use intensity and the stocking rate as sheep-beef land-use intensity. Projected milksolid production in 2008 is 1,393 million kg, only marginally higher than the 1,374 million kg recorded in the *New Zealand Dairy Statistics*. The manner in which we estimate the stocking rate in sheep and beef farming means that we match exactly the livestock population recorded in 2008, 51.24 million stock units.[28] This happens by construction and is therefore not an indication of the quality of predictive power.

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[27] These are baseline simulations using a zero carbon price.

[28] The Greenhouse Gas Inventory is based on the same Statistics New Zealand livestock population dataset, but it contains less detail as it groups various stock types together. Therefore, stock unit conversions based on inventory population figures may yield slightly different results.

Table 4.3. Observed and simulated production

Year	Observed	Simulated	Ratio
Dairy[a]			
2008	1,373.68	1,392.97	1.014
2009	1,437.71	1,533.99	1.067
2010	1,512.60	1,624.92	1.074
2011	1,686.86	1,624.19	0.963
Sheep-beef[b]			
2008	51.24	51.24	1.000
2009	49.62	49.57	0.999
2010	48.75	48.28	0.990
2011	46.87	47.68	1.017

[a] Million kilograms of milksolids.

[b] Million stock units.

Projections for all years beyond 2008 are expected to be less accurate because they are affected by potential errors in simulated land use. Nevertheless, some of the results for 2009–2011 in table 4.3 are close to observations.

Table 4.4 shows, at the national level, the comparison of simulated LURNZ emissions to inventory emissions. Although the ETS emission factors were developed to be consistent with the inventory, the latter, because it is not production oriented, uses a fundamentally different appropriation of emissions. Therefore, drawing this comparison requires some manipulation of the underlying data.

Table 4.4. Observed and simulated emissions

Year	Observed[b]	Simulated[c]	Exogenous[d]	Ratio
Dairy[a]				
2008	12.74	13.53		1.062
2009	13.41	14.89		1.111
Sheep-beef[a]				
2008	16.95	12.11	4.00	0.950
2009	16.55	11.69	4.00	0.948

[a] Both dairy and sheep-beef emissions are Mt CO2-e.

[b] Observed emissions are emissions calculated from inventory data.

[c] Fertiliser emissions have been subtracted.

[d] Exogenous emissions are associated with wool production.

Sources of pastoral greenhouse gas emissions in the inventory include methane emissions from enteric fermentation; methane and, in the case of dairy farming, nitrous oxide emissions from manure management; and nitrous oxide emissions from nitrogen input to agricultural soils. Not all of these sources are summarised at the sector level in the inventory. We perform the necessary calculations following a methodology that is consistent with that used in the inventory. For example, the term for dairy cattle nitrous oxide emissions from nitrogen excreted onto agricultural soils is itself a composite term that includes direct emissions from the nitrogen in urine and dung deposited onto the soil, as well as indirect emissions through atmospheric volatilisation and through leaching (and subsequent oxidisation). We use the appropriate emission factors that are recorded in the inventory background tables to calculate the emissions attributable to each of these processes, and convert everything to carbon dioxide equivalents at the end.

As noted previously, there is no emissions charge for wool production in the ETS. Nor are the emissions associated with wool production redistributed and charged to a different activity: the Crown assumes responsibility for these emissions. Wool emissions, estimated to be 4.0 Mt CO2-equivalent (Ministry for Primary Industries, 2012), are therefore exogenous in LURNZ. We evidently need to add the exogenous component to our simulation results when drawing comparisons to the inventory.

Table 4.4 does not include emissions from fertiliser; that is, each sector's share of fertiliser emissions has been subtracted from the simulation results. This does not affect the comparison materially. Recall that the inventory does not break up fertiliser use into individual sectors. However, we do make use of inventory data in the calculation of fertiliser intensity, so subject to the assumptions we have made there, our result are consistent with inventory fertiliser emissions.

We do not expect a perfect match between simulations and emissions measured in the inventory for several reasons that have been outlined throughout the paper. Recall that in dairy farming, a scaling operation is implemented to convert land areas between hectares and effective hectares in the base year. No other scaling is performed to make milksolid production or emissions completely consistent with inventory data. In sheep and beef farming, carrying capacity is scaled to ensure that, in the base year, the simulated livestock population is similar to the livestock population represented in the inventory. A closer correspondence between simulations and observations is therefore expected in this sector, particularly in 2008.

5. Conclusion

This paper documents the modelling of land-use intensity and greenhouse gas emissions for pastoral land uses in LURNZ. Both land-use intensity and emissions are exogenous in the sense that there is no feedback from either to simulations of land use: although emissions are modelled in a spatially explicit manner, the implied differences in emission liabilities have no direct bearing on modelled land-use decisions. Likewise, LURNZ emissions are not directly dependent on input, product and carbon prices.

Emissions in LURNZ are modelled via the use of emission factors (some of which are converted to implied emission factors) and data on the volume of associated agricultural activities. Sources of emissions include the slaughter of livestock, the dairy processing of milk and the application of synthetic fertilisers. Emissions attributed to wool production are not modelled as this activity is not included in the ETS (consequently, an emission factor has not been developed for it).

In dairy farming, we project changes in land-use intensity (milksolid production per hectare) by region through time. In sheep and beef farming, land-use intensity (the estimated stocking rate) is held constant in simulations, but it varies at a fine spatial scale with carrying capacity. Fertiliser intensity in both sectors is modelled as proportional to land-use intensity. Therefore, for a given location, simulated emissions under dairy use may change over time; simulated emissions under sheep-beef use do not change.

Emission factors remain constant through time in LURNZ simulations. Therefore, our methodology is not suited to capture any production efficiency gains – aggregate emissions per unit of production may change slightly in simulations due to the combination of geographic variation in emissions and the changing pattern of land use, but this does not meaningfully reflect changes in efficiency. Most of the spatial and temporal variation in simulated emissions is derived from variation in the associated activity levels that we model.

In each sector, we scale one of the variables to a more reliable data source. With this scaling, our methods yield outcomes that are approximately consistent with New Zealand's Greenhouse Gas Inventory.

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7. Appendix

Table A.1. The previous set of emission factors in agriculture

Activity	Tonnes CO_2	
Livestock slaughter	Per tonne carcass weight	Per animal
Cattle		
Vealers	5.2	1.98
Heifers	7.1	1.98
Steers	10.5	1.98
Bulls	11	1.98
Cows	7.9	1.98
Sheep		
Lambs	4.5	0.3
Hoggets	8.3	0.3
Rams	23.5	0.3
Ewes and wethers	15.7	0.3
Dairy processing of milk	Per tonne milk solid	
Bovine	6.14	
Synthetic fertiliser use	Per tonne nitrogen	
Fertiliser	5.72	

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