OVERSEER® Technical Manual

Technical Manual for the description of the OVERSEER® Nutrient Budgets engine

ISSN: 2253-461X

Carbon dioxide, embodied and other gaseous emissions

June 2018

Prepared by D M Wheeler

AgResearch Ltd

Published by:

OVERSEER Limited

http://www.overseer.org.nz

Preface

OVERSEER® Nutrient Budgets

OVERSEER® Nutrient Budgets (OVERSEER) is a strategic management tool that supports optimal nutrient use on farm for increased profitability and managing within environmental limits.

OVERSEER provides users with information to examine the impact of nutrient use and flows within a farm and off-farm losses of nutrients and greenhouse gases. An OVERSEER nutrient budget takes into account inputs and outputs and the key internal recycling of nutrients around the farm.

See the OVERSEER website for more detailed information: http://www.overseer.org.nz

This technical manual

OVERSEER is made up of a user interface and an engine. These two components work together to enable users to generate nutrient budget reports. The Technical Manual provides details of the calculation methods used in the OVERSEER engine.

The OVERSEER engine is based on extensive published scientific research. Technical information about the model's development and use can be found in a growing number of conference proceedings and peer-reviewed papers. Given the ongoing upgrades many of the earlier papers no longer reflect the current version.

The Technical Manual chapters provide detailed descriptions of the methods used in the OVERSEER engine's main sub-models. The Technical Manual sets out the underlying principles and sources of data used to build the model engine. It is a description of the model as implemented, and hence references may not now be the most appropriate or cover the range of data of information currently available, or may not necessarily be the most up to date. If the source of some information and/or assumptions is not known or could not be found, this is acknowledged.

The chapters will continually be updated to reflect the current version.

If readers have feedback or further technical information that they consider could contribute to the future development of the model, please provide feedback via the website http://www.overseer.org.nz.

Scientific contribution to model development:

OVERSEER is a farm systems model covering a wide range of science disciplines. Since the model's inception, a large number of researchers from many disciplines and organisations have contributed to its development.

Researchers contributing significantly to the hydrology component of the model described in this report include:

Mark Boyes, AgResearch Ltd.

Stewart Ledgard, AgResearch Ltd.

David Wheeler, AgResearch Ltd.

Contents

Carbon dioxide, embodied and other gaseous emissions

1. Introduction

1.1. Background

A range of New Zealand studies have determined the carbon footprint of primary products from the 'cradle-to-farm-gate' or 'cradle-to-grave' using life cycle assessment (LCA). These include milk (Ledgard *et al*., 2010; Flysjö *et al*., 2011), lamb meat (Ledgard *et al*., 2009b, c, 2010), beef meat (Lieffering *et al*., 2011), wool (Rankin *et al*., 2010), kiwifruit (Mithraratne *et al*., 2010) and apples (Frater, 2010). These footprints were produced using LCA procedures which meet PAS 2050 (BSI 2011) or ISO 14046 recommendations. For pastoral products such as milk, wool, velvet and live weight (meat), this represents about 70-90% of the total carbon footprint (Ledgard *et al*., 2008, 2009, 2010, 2012), largely due to animal-related methane and nitrous oxide emissions. In contrast, emissions to the farm gate represent 20-40% of the total emissions for crops used for human consumption (Barber *et al*., 2011) and 15-25% for horticultural products (Mithraratne 2010 for kiwifruit, Frater 2010 for apples).

This chapter documents the methods for calculating gaseous emissions from the farm that contribute to global warming (greenhouse gases) within the OVERSEER® engine (hereafter referred to as the model), except for methane and nitrous oxide which are described in separate chapters of the technical manual. This section also includes methods for estimating embodied carbon dioxide (CO_2) emissions. The methodology adopted was based on those used in the aforementioned New Zealand studies. These emissions are reported as part of the greenhouse gas emission reports. The relationship between the main reports and estimation of direct and embodied CO_2 emissions and greenhouse gas reporting is shown schematically in Figure 1.

Embodied greenhouse gas emissions are the amount of CO_2 equivalents, based on a 100-year cycle, required to produce and use a product on the farm. The embodied CO_2 of a product used on a farm includes all methane, nitrous oxide, and direct emissions required to produce and use that product. It also includes embodied CO_2 emissions of products used to produce that product.

In general, direct and embodied CO_2 emissions are estimated from existing model inputs that are required for other sub-models, although there are user-entered parameters for a more detailed analysis if required. The only exceptions are source and fate of stock, which are required inputs for each stock class.

Direct and embodied CO_2 emissions associated with 'private' residences or people living on the farm are not included. Respired CO_2 and CO_2 that accumulates or is released from soil are not included.

An energy report is also produced by the model. The amount of embodied energy is calculated using the same methods as for CO_2 except that energy emission factors are used.

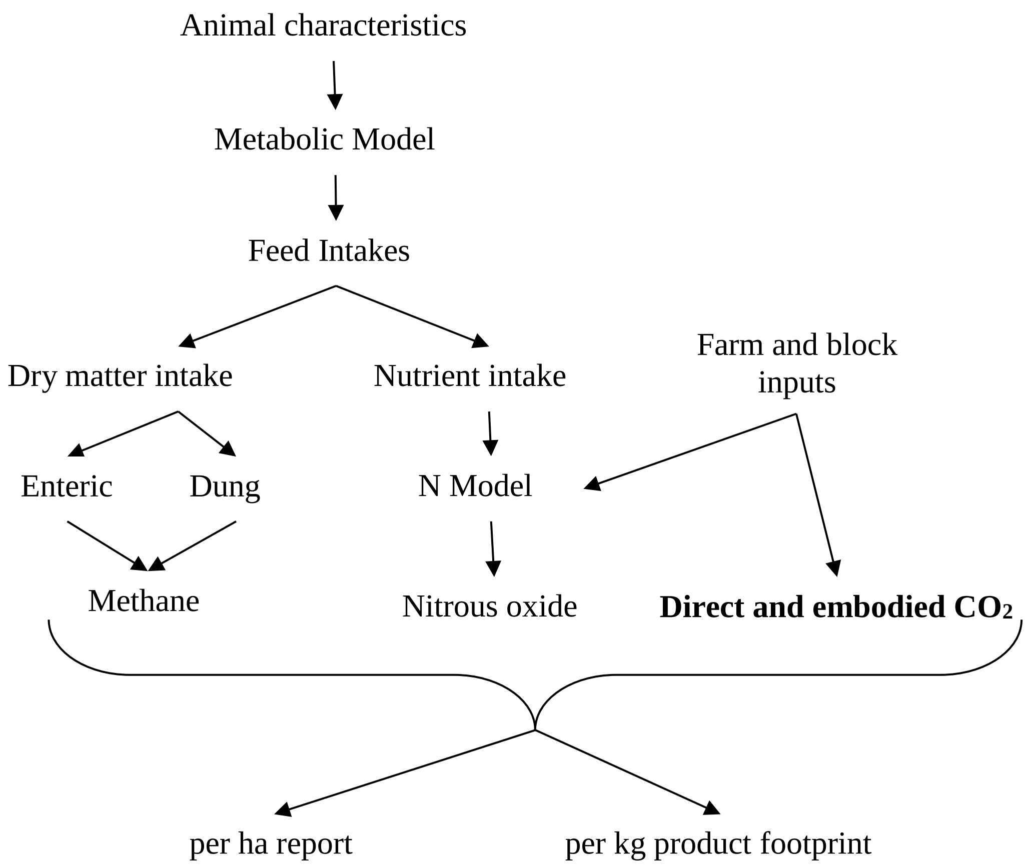

Figure 1. Relationship between main sections of the technical manual and estimation of direct and embodied CO_2 emissions.

1.2. Method of calculation

In this model, emissions (methane, nitrous oxide, direct and embodied CO_2) are estimated for products up to the point of leaving the farm gate. The model reports greenhouse gas emissions on per ha and per product basis. The model is fully integrated accounting for mixed enterprises on the same farm, or on the same block. The reporting requirements are achieved by allocating all emissions to a greenhouse gas report source. There are 10 report sources consisting of seven animal sources (dairy, dairy replacements, sheep, beef, deer, dairy goats, others), plus horticultural, cropping and export. The export report source includes emissions for supplements or fodder crops exported from the farm.

The generation of reports requires allocation rules, which were based on Wheeler *et al*. (2013), so that any inputs or emissions can be ascribed to a greenhouse gas report source (section 1.2.1). The emission type (e.g. embodied CO_2 for electricity, direct CO_2 from lime, etc.) is then allocated to a greenhouse gas report source, and these are then used to develop greenhouse gas reports (Figure 2).

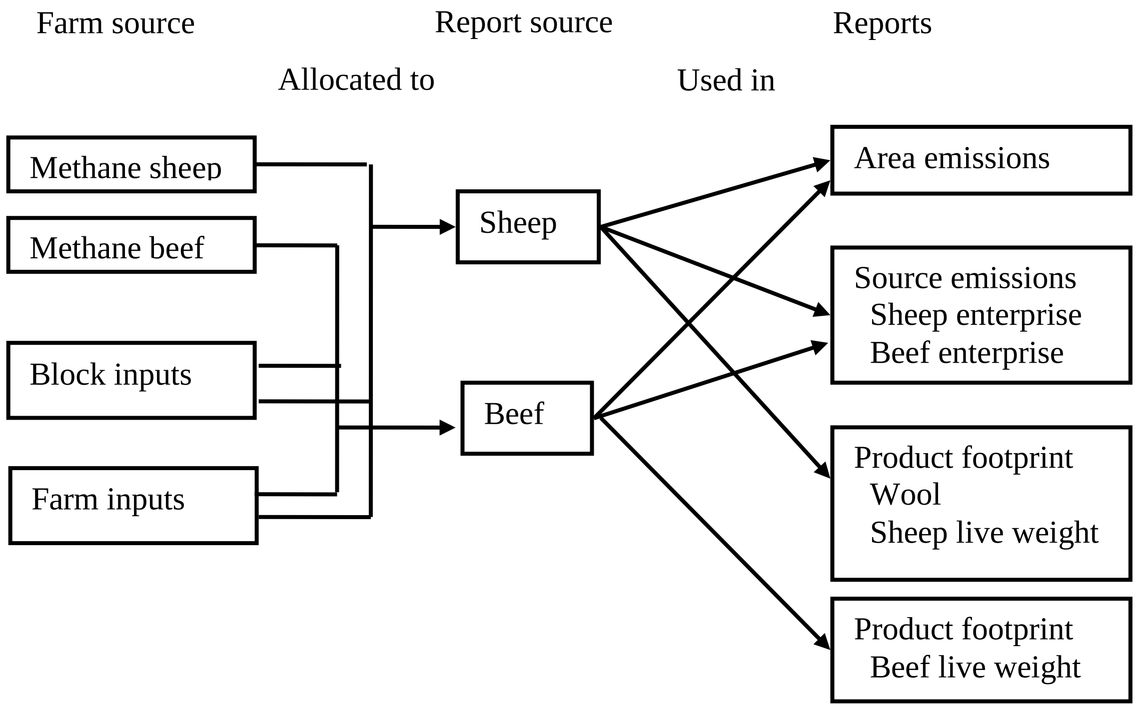

Figure 2. Schematic diagram of allocation of emissions to greenhouse gas sources, and then to greenhouse gas reports.

1.2.1. Allocation rules

Depending on the emission, it is easier to allocate to a greenhouse gas report source at either a farm or a block level. Thus, there are 2 primary allocations, psourceblock and psourcefarm. Other allocations are also used where appropriate.

$psource_{block, gsource}$

Emissions calculated on a block basis are allocated to one or more greenhouse gas report sources based on what the products of the block are used for. Thus, grazed pastoral block, emissions (e.g. due to fertiliser use) are allocated to the animals that graze the block. For supplements removed from the block, emissions are allocated to animals that the supplements are fed to, or to the exported greenhouse gas source if exported off farm. Thus for embodied emissions from fertiliser inputs, on pastoral blocks the emissions are divided between animal types grazing that block. For a cut and carry block, emissions are divided between animal types that consume the supplement or are allocated to the export greenhouse gas report source if sold off farm.

Similar methods have been developed to allocate farm scale inputs (e.g. embodied fuel and electricity emissions) between report sources on the farm.

$psourcefarm_{gsource}$

When there is no specific information available to allocate emissions, emissions are distributed based on the ratio of area allocated to a greenhouse gas report source (gArea, section 1.2.2) or to the total area allocated. This may cause distortions when a source has a large impact but only uses a small area, for example, milking goats may be permanently housed using a very small proportion of the farm area.

$psourceansys_{gsource}$

This is essentially the same as psourcefarm except that the ratio uses the total area allocated to animal report sources rather than all sources.

The method and basis behind allocations are described in more detail in Wheeler et al., (2013).

1.2.2. gArea

gArea (ha) is the estimated area allocated to a greenhouse gas source, and is estimated from pastoral, fodder, fruit crop or cropping blocks, as:

Equation 1: $gArea_{gsource} = \sum_{block}(area_{block} * psource_{block, gsource})$

area is block area (ha).

$psource_{block, gsource}$ is the block allocation [section 1.2.1].

1.3. Workings of the technical manual

The aim of the technical manual is to provide a level of detail so that users of OVERSEER can clearly see the underlying principles and sources of data used to build the components of the model. This technical chapter is part of a series of technical manuals currently under development to explain the inner working of the OVERSEER engine.

In the equations in this manual, units are shown using ( ) and cross-references other equations and sections within this manual or to other chapters of the technical manual are shown using [ ]. Equations with multiple '=' options are cascading alternatives in the order they are considered. The condition is shown on the right hand side. The variable and parameter names used are generally shortened names of the property, and this naming convention is similar to the convention used in the OVERSEER engine model.

Within the manual, a variable with subscripts implies that the option variable has values for multiple options, for example, $var_{block, mon}$ means that variable var has values for each block and each month (mon). A summation is indicated by the symbol Σ. The summation is over all options unless followed by a subscript before the variable name, in which case the summation is only over those variables, for example, $\Sigma_{block, mon}var_{block, antype, mon}$ means the variable var is summed over each occurrence of block and mon, to give values for each occurrence of antype.

1.4. Abbreviations and subscripts used

<u>Abbreviations</u>

DM Dry matter.

IPCC Intergovernmental Panel on Climate Change.

NZI New Zealand greenhouse gas emissions national inventory (Ministry of the Environment 2011).

RSU	Revised Stock Units, where 1 RSU is 6000 MJ/year intake (Woodford and Nicol 2004).

LCA	Life Cycle Assessment.

Subscripts:

gsource	greenhouse gas reporting source (dairy, dairy replacements, sheep, beef, deer, dairy goats, other, horticultural, cropping and export).

antype	animal types within the model (dairy, dairy replacements, sheep, beef, deer, dairy goats, other).

block	block set up within model.

sup	supplement.

2. CO_2 emissions

2.1. Urea

Direct CO_2 emissions (kg CO_2/ha/year) from the dissolution of urea ($CO(NH_2)_2$) for each greenhouse gas source is estimated for each block as:

Equation 2: $UreaDirectCO2_{gsource} = \sum_{block}(UreaCO2_{block} * area_{block} * psource_{block,\ gsource})$

$UreaCO2_{block}$ is the emission rate form urea (kg CO_2/ha/year) [Equation 2].

area is the block area (ha).

$psource_{block,\ gsource}$ is the block allocation [section 1.2.1].

where

Equation 3: $UreaCO2_{block} = CO2urea * ureaN$

ureaN is the amount of urea N applied (kg N/ha/year as urea).

CO2urea is the emission rate (1.570 kg CO_2/kg N) [Equation 4].

The emission rate for urea is estimated as:

Equation 4: $CO2urea = 0.2 * 44/12 / 0.467$

0.2 is the proportion of C in urea

44/12 is the proportion of C in CO_2

0.467 is the proportion of N in urea.

2.2. Lime and dolomite

The New Zealand Inventory (Ministry of the Environment 2011) uses the IPCC emission factor for dissolution of lime, which is 0.44 kg CO_2/kg $CaCO_3$ for lime and 0.477 kg CO_2/kg $MgCO_3$ for dolomite. To take account of the purity of the lime, varying $MgCO_3$ contents between limes, and that user-defined lime can be a dolomite material, direct CO_2 emissions are based on total Ca and Mg applied as lime.

Thus for lime, direct CO_2 emissions (kg CO_2/ha/year)

Equation 5: $LimeCO2_{block} = 0.44 * (LimeCa / 0.40)$

LimeCa is the total amount of Ca applied as lime (kg Ca/ha/year).
0.44 is the proportion of CO_2 in pure lime (kg CO_2/kg $CaCO_3$).
0.4 is the proportion of Ca in $CaCO_3$.

and for dolomite:

Equation 6: $DolomiteCO2_{block} = 0.477 * (LimeMg / 0.277)$

LimeMg is the total amount of Mg applied as lime (kg Mg/ha/year).
0.477 is the the proportion of CO_2 for pure dolomite (kg CO_2/kg $MgCO_3$).
0.277 is the proportion of Mg in $MgCO_3$.

Only lime applied in the current year is considered – lime applied in previous years or the first year of a crop rotation is ignored. The model assumes that all CO_2 is released in the first year, including capital lime applications. Capital applications should be discounted across years but this has been ignored. For high application rates, some of the lime may not dissolve until year 2. Although this effect has been included in the nutrient budget, it is ignored when calculating direct CO_2 emissions.

Total direct CO_2 emissions from lime (kg CO_2/year) for each greenhouse gas source are estimated as:

Equation 7: $LimeDirectCO2_{gsource} = \sum_{block}((LimeCO2_{block} + DolomiteCO2_{block}) * area_{block} * psource_{block, gsource})$

LimeCO2 is the direct CO_2 emissions from lime (kg CO_2/ha/year) [Equation 5].
DolomiteCO2 is the direct CO_2 emissions from Mg lime (kg CO_2/ha/year) [Equation 6].
area is block area (ha).
$psource_{block, gsource}$ is the block allocation [section 1.2.1].

2.3. Rock phosphate

Many rock phosphates (RPR) contain lime, with some containing up to 10% lime as an impurity. However, this source of direct CO_2 emissions has not been included in the model.

2.4. CO_2 from crop burning

Burning of crop residues is not considered a net source of CO_2 because the CO_2 released into the atmosphere is re-absorbed during the next growing season (Ministry of Environment 2011, p141).

2.5. CO_2 from effluent or waste decomposition

Carbon dioxide emissions from aerobic decomposition within the waste sector are not reported in the NZI because they are considered to be re-absorbed by growing organic matter in the following year (Ministry of Environment 2011, p241-242). The model assumes that the same applies to waste and effluent that is both produced and applied on-farm.

3. Embodied CO_2 and energy emissions

Embodied CO_2 emissions are CO_2 equivalents based on a 100-year cycle required to produce and use a product on the farm. Embodied CO_2 emissions can depend on the source of the material. However, when farmers purchase material the source is not always known. Therefore, typical average values are used to estimate embodied CO_2 emissions to a primary depot or warehouse, and then farm specific information is applied.

Embodied CO_2 emissions for products used on a farm are based on LCA analysis following PAS 2050 guidelines (BSI 2008) under the guidance of Stewart Ledgard and Mark Boyes, AgResearch. The LCA analyses were supplied in an Excel spreadsheet format so that it can be updated as new information becomes available. The full details of the LCA analyses are not included in this documentation. The emission factors are referred to as EFproductCO2 and EFproductEnergy.

The model makes use of the Ecoinvent database (Ecoinvent 2010). This database contains up-to-date and consistent life cycle inventories of nearly 4,000 industrial processes and has been compiled by internationally renowned research institutes and Life Cycle Assessment institutes.

3.1. Electricity

Electricity use can be entered directly otherwise default emissions are estimated for each greenhouse gas source. If electricity is entered, then electricity emissions are allocated to greenhouse gas source based on the estimated default electricity use.

3.1.1. Electricity use

The electricity use (kWh/year) allocated to greenhouse gas report sources is estimated as:

Equation 8: $electrictyKWh_{gsource} = Electricityfarm * pelectricity_{gsource}$
$= Electrictydefault_{gsource}$

Electricityfarm (kWh/year) is the farm component of user entered electricity use [section 3.1.2].
Electrictydefault (kWh/year) is default electricity use [section 3.1.3].

and where

Equation 9: $pelectricity_{gsource} = Electrictydefault_{gsource} / \sum_{gsource}(Electrictydefault_{gsource})$

Electrictydefault (kWh/year) is default electricity use [section 3.1.3].

3.1.2. Entered electricity use

Electricity use can be entered directly or default emissions are estimated. If electricity is entered, then electricity emissions are allocated to the greenhouse gas source based on the estimated default electricity use.

Equation 10: Electricityfarm = ElectricityIn * (1 – pPersonalUse)

ElectricityIn is the user entered value (kWh/year).
pPersonalUse is the proportion used for personal use [Equation 11].

The proportion of total electricity that is due to personal use is based on very limited data. The proportion is lower for dairy systems due to the electricity required for milking and refrigeration. Thus, the personal component of entered electricity use is estimated as:

Equation 11: pPersonalUse = 0.25 * ratio + 0.4 * (1 - ratio) if personnel included
= 0 if farm only

where

Equation 12: ratio = $psourceansys_{dairy}$ + $psourceansys_{dairygoats}$
$psourceansys_{gsource}$ is the animal allocation ratio [section 1.2.1].

3.1.3. Default electricity use

Default electricity use (kWh/year) was estimated using a default value based on stocking rate for each animal type, block based value for crop, cut and carry and horticultural blocks, and a block based value for blocks with irrigation. Thus:

Equation 13: $Electrictydefault_{gsource}$ = $Defaultelectricit_{antype}$ + $\sum(Electricityblock_{block} * psource_{block, gsource})$
Defaultelectricity (Kwh/year) [sections 3.1.3.1 to 3.1.3.3].
Electricityblock (kWh/year) [section 3.1.3.4 to 3.1.3.5].
$psource_{block, gsource}$ is the block allocation [section 1.2.1].

3.1.3.1. *Dairy*

Default electricity use for dairy farms was taken from survey data (Sims *et al.*, 2005) where the average energy demand was 163 kWh/cow/year. The average electricity use (with range in brackets) for primary activities was 51 (19-73) kWh/cow/year for water heating, 34 (21-47) kWh/cow/year for milk chilling, 29 (14-43) kWh/cow/year for milking systems, 29 (0-46) kWh/cow/year for water pumping and 20 (15-31) kWh/cow/year for miscellaneous uses.

In a more recent survey (Dairy Electricity Advisory Programme 2012), electricity use was 476 kWh per tonne of milk solids produced or 173 kWh per cow milked, with 24% required for water heating, 22% for water pumping, 17% for refrigeration, and 15% for vacuum pumps. These values are similar to those of Sims *et al*. (2005) and hence the model has not been updated.

Thus:

Equation 14: $Defaultelectricity_{dairy}$ = 163 * NumberMilkers
163 is the average energy use for dairy cow (kWh/cow/year).
NumberMilkers is the peak number of milking cows.

3.1.3.2. *Dairy goats*

No data was found describing the typical electricity usage for of dairy goat systems. Assuming typical electricity use to be similar to cows on an animal equivalent basis, and assuming 8 dairy goats are equivalent to one dairy cow, and then default electricity use (kWh/year) was estimated as:

Equation 15: $Defaultelectricity_{dairygoats} = 163 * NumberMilkerGoats / 8$

163 is the average energy use for dairy cow (kWh/cow/year).

NumberMilkerGoats is the number of milking dairy goats.

8 is the ratio of dairy goats to dairy cow equivalents.

3.1.3.3. *Non-dairy*

For non-dairy farms, a survey of eight farms showed an average electricity usage of 1.83 kWh/RSU/year, with a range of 0.18 to 7.05 (Ledgard pers. comm.). This could be split into two groups, with ranges of 0.18–0.93 kWh/RSU/year, and 1.52-7.02 kWh/RSU/year. The highest usage (7.02) was on a farm with water reticulation to every paddock, undertaking a lot of calf rearing. In another small survey of North Island farms (15 farms, A Barber, unpublished data), average electricity usage was 1.38 kWh/RSU/year, with no consistent difference between hill country and intensive farms. Average electricity use over both surveys was 1.14 kWh/RSU/year.

On dairy farms, an average of 49 kWh/cow/year was used for water pumping and miscellaneous activities (Sims *et al*., 2005). Assuming an average stocking rate of 25 RSU/ha for a typical dairy farm, this provides an average of 1.96 kWh/RSU/year as an upper limit for non-dairy systems.

It is probable that electricity use could be higher on flat to rolling country due to more intensive use of electric fences and water reticulation systems. The dollars spent on electricity per RSU on MAF monitor farms were higher on intensive or finishing farms, and higher on deer farms than hill country blocks although this was not consistent.

Therefore, a single mean value estimated from both surveys (1.14 kWh/RSU/year) was used due to the lack of consistent differences between intensive and hill country usage. Therefore, default electricity use (kWh/year) was estimated as:

Equation 16: $Defaultelectricity_{antype} = 1.14 * RSU_{antype}$

1.14 is mean electricity use (kWh/RSU/year).

RSU is the calculated RSU for each animal type [Animal model chapter].

3.1.3.4. *Crop, cut and carry and horticultural blocks*

The model assumes a default use of 10 kWh/ha/year for crop, cut and carry and horticultural blocks until further data is available. Thus, default electricity use (kWh/ha/year) is estimated as:

Equation 17: $Blockelectricity_{block} = 10 * area_{block}$

10 is estimated electricity use (kWh/ha/year).

area is block area (ha).

3.1.3.5. *Irrigation*

Aquilinc (2006) summarised data from McChesney and identified the following factors as having a moderate to strong effect on energy requirements for pastures and crops:

- Pump pressures, flow rates and efficiency factors
- Depth from which water is being lifted from a well (or other source)
- Pressure at which the water is released from the irrigation outlets
- Water demand of the crop (crop type, climate, soil characteristics)
- Area irrigated
- Motor and pump efficiency
- Efficiency with which water is delivered to the soil by the irrigation device
- Efficiency with which the farmer manages the timing and quantity of water applications

Wells (2001) reported a wide range of energy use for different irrigation systems, with average energy (range in parenthesis) of 8.8 (1-14), 16.9 (10-22) and 21.7 (4-35) GJ /irrigated ha/year for long-line lateral, big gun and travelling irrigators respectively (Wells 2001, table 4.8). Using conversion factor of 8.18 MJ/kWh Wells (2001), average electricity usage is estimated to be 1075, 2066 and 2653 kWh//irrigated ha/year for long-line lateral, big gun and travelling irrigator respectively. However, irrigation rates were not given.

From a survey (Longhurst pers. comm.), typical electricity use was estimated to be 0.444 kWh/m^3 for a rotorainer type systems and 0.166 kWh/m^3 for a Kline. Based on these values, the power usage of 2,653 kWh//irrigated ha/year reported by Wells (2001) would equate to about 600 mm irrigation for a rotorainer system, which is a reasonable application rate for Canterbury. The electricity usage for a centre pivot system was based on the ratio of electricity usage for long-line lateral systems versus big gun and travelling irrigator systems.

The available type of irrigation systems are split into three categories:

Kline systems	Spraylines, micro-irrigation (drip and sprinkler), solid set.
Centre privot systems	Linear and centre pivot
Rotorainer systems	Travelling irrigator

The default electricity use is estimated as:

Equation 18:
$$\text{Blockelectricity}_{block} = \text{mmIrrCentre}_{block} * 10 * \text{area}_{block} * \text{ElectUseIrrCentre} + \text{mmIrrRoto}_{block} * 10 * \text{area}_{block} * \text{ElectUseIrrRoto} + \text{mmIrrKline}_{block} * 10 * \text{area}_{block} * \text{ElectUseIrrKline}$$

mmIrrKline is irrigation applied (mm/year) using Kline systems.
mmIrrCentre is irrigation applied (mm/year) using Centre privot systems.
mmIrrRoto is irrigation applied (mm/year) using Rotorainer systems systems.
10 is the conversion m^3/mm.
area is the block area (ha).
ElectIrrCentre is 0.202 kWh/m^3
ElectUseIrrRoto is 0.444 kWh/m^3

ElectUseIrrKline is 0.166 kWh/m^3

3.1.4. Electricity embodied emissions

Default electricity emission factors for electricity were calculated based on the grid mix in 2004 (Nebel, 2008). Although renewable sources (hydro, geothermal, wind) made up 68% of the source of supply, it only accounted for 44% of the energy emissions. The user can enter their own emission factors.

Table 1. Embodied CO2 and energy emission factors for electricity.

Source	kg CO2 equivalents / kWh	MJ / kWh
Electricity	0.271	8.21

The embodied emissions (kg CO_2 equivalent/year and MJ/year) for electricity used on the farm are estimated as:

Equation 19: $electCO2_{agsource} = electrictyKWh_{gsource} * EFelectCO2$

Equation 20: $electEnergy_{gsource} = electrictyKWh_{gsource} * EFelectEnergy$

electrictyKW is electricity use (kWh/year) [section 3.1.1].

EFelectCO2 (kg CO_2 equivalents/kWh) and EFLimeEnergy(MJ/kWh) are emission factors [Table 1].

3.2. Fuel

Embodied fuel emissions include fuel delivered to the farm and used for farm purposes either on-farm or off-farm, external fuel purchased for farm purposes and fuel used by contractors for operations on the farm.

Separating fuel use for specific activities allows embodied fuel emissions to be either associated with the ‘fuel’ category or with a product category (such as supplements and fertilisers). Thus, fuel usage is estimated for specific activities such as making and feeding supplements; and transportation, spreading or application of applying products (such as fertiliser) on the farm. Fuel use for cropping activities is estimated by default if no fuel information is entered, or assumed to be that specified under contractor inputs or included in farm fuel use if fuel is entered. In addition, a base fuel use (fuel use for general activities) is shown as a separate output.

Thus by default, (when no fuel use data is entered) total fuel used for farm activity (farm fuel use) is estimated as the sum of base fuel use (section 3.2.3), activity based fuel use (section 3.2.5) and miscellaneous transport (3.2.6). This can be represented as:

Equation 21: Farm use = base + activity + miscellaneous

If fuel is entered, contractor’s diesel use should also be included to give a total for farm embodied fuel emissions. The proportion of some activities undertaken by contractors can also be specified. Thus activity based fuel use is estimated separately and removed from farm fuel use to give base fuel use, and this can be represented as:

Equation 22: base = (Farm purchased + contracted – activity)

3.2.1. Emission factors

3.2.1.1. *Fuel*

Default fuel emission factors are shown in Table 2. The user can also enter their own values for diesel and petrol fuel embodied emission factors.

Table 2. Embodied CO_2 and energy emission factors for fuel.

Source	kg CO_2 equivalents /litre	MJ /litre	Source
Diesel	2.989	42.24	1
Petrol	2.773	42.24	2
Engine Oil	0.79	68.23	3
Aviation fuel	2.608	35.28	4

Source:
[1] Nebel 2008, taken from GaBi
[2] MED, 2000 GHG report plus Average Petrol production in Australian Refineries (NGIG 2000)
[3] Ecoinvent for lubrication replacement- no combustion assumed
[4] Energy Information Handbook (CAENZ 2008).

3.2.1.2. *Transport*

The emission factors used in the LCA analysis for transport (Nebel 2008) are shown in Table 3, along with comparative European data. Road transport took account of road types and vehicles travelling at typical speeds. The transport of fertiliser, supplements, stock, and purchases was based on a 36 to 40 tonne truck/trailer with a payload capacity of 27 tonnes, with or without a backload. On-farm (non-contractor) trucks used are likely to be smaller vehicles and so an emission factor for a 16-32 tonne truck is used in this case.

Table 3. Embodied CO_2 and energy transport emission factors.

Transport method	kg CO_2 equivalents/tkm	MJ/tkm
Use in LCA analysis		
Truck (50 % loading) 1	0.093	1.315
Truck (85 % loading)	0.065	0.911
Rail	0.0250	0.35
Shipping	0.0132	0.16
Comparison with European emissions 2		
Transport, lorry 3.5-16t, fleet average/RER U	0.2745	3.8547
Transport, lorry >16t, fleet average/RER U	0.0981	1.3827
Euro3 3		
Transport, lorry 3.5-7.5t, EURO3/RER U	0.5514	7.8865
Transport, lorry 7.5-16t, EURO3/RER S	0.2912	4.7184
Transport, lorry 16-32t, EURO3/RER U	0.1370	1.9665
Transport, lorry >32t, EURO3/RER U	0.0924	1.3315

[1] For transport of fertiliser, supplement, stock, and purchases using a 36 to 40 t truck/trailer with a payload capacity of 27 t.
[2] The European Union emissions for newly registered road vehicles in 2008/9 (EcoInvent 2010).

[3] The Euro 3 standards came into force in 2000 and were for older vehicles in the Ecoinvent (2010) data base. Therefore, these values are probably closer to the NZ fleet emissions.

3.2.2. Oil use

Emissions due to oil use are a small proportion of total fuel emissions, and therefore a default is used for contractor and farm fuel use.

Wells (2001) estimated oil use was 0.0115 litres oil per litre of fuel. A more recent set of data indicated that oil use was 0.01 litres oil per litre of diesel use, and decreased to 0.005 litres oil per litre of diesel use after more than 10 l/ha diesel was used for a particular activity.

At this stage, it is not possible to identify easily fuel use per ha associated with each activity, and hence a rate of 0.1 litres oil per litre of diesel or petrol was used. It was assumed that there was no oil use associated with aviation fuel use.

3.2.3. Default base fuel use

Default diesel use (litres) is estimated as:

Equation 23: $$defaultdiesel_{gsource} = \sum_{block}(dieselofffarm_{block} * psource_{block, gsource} + diesel_{block} * psource_{block, gsource}) + diesel_{gsource})$$

dieselofffarm is off-farm diesel use (litres) [section 3.2.3.1].

$diesel_{block}$ is diesel use estimated on a block basis [section 3.2.3.5 and 3.2.3.6].

$diesel_{gsource}$ is diesel use estimated on a animal type basis [section 3.2.3.2 and 3.2.3.3].

$psource_{block, gsource}$ is the block allocation [section 1.2.1].

Default petrol use (litres) is estimated as:

Equation 24: $$defaultpetrol_{gsource} = \sum_{block}(petrolofffarm_{block} * psource_{block, gsource}) + petrol_{gsource}$$

petrolofffarm is off-farm petrol use (litres) [section 3.2.3.1].

$petrol_{gsource}$ is petrol use estimated on a animal type basis [section 3.2.3.2 and 3.2.3.3].

$psource_{block, gsource}$ is the block allocation [section 1.2.1].

3.2.3.1. *Off farm (on-road)*

Off farm (on-road) fuel use is fuel used for items such as going to town for business or purchase of products for use on the farm, etc. Off farm (on-road) fuel consumption was estimated at 2000 litres/farm based on a MAF 2007 cost model at a 3:1 petrol: diesel ratio (Rosevear 2008). This equates to off-farm consumption of 3 l/ha, made up of 2.25 l/ha petrol and 0.75 l/ha diesel. Off farm fuel use is applied to all pastoral, cut and carry, fruit and crop blocks. Thus:

Equation 25: $Dieselofffarm_{block} = 0.75 * area_{block}$

Equation 26: $Petrolofffarm_{block} = 2.25 * area_{block}$

area is block area (ha).

3.2.3.2. *Non-dairy animals*

Expenditure of fuel was determined from the Meat and Wool economic survey 2004/2005. Fuel use was estimated from the farm expenditure on fuel. Hence, they do not include any contracting fuel use. In addition the percentage of the farm under cultivation (summer and winter feed areas, plus pasture renewal) or used for hay/silage crops was extracted (Table 4). It was noted that:

- Cash crops and seed crop areas were not included because they do not have any input into livestock production.
- Hay/silage area: Pasture silage and hay are only fed to the beef animals on North Island farms. Pasture silage was fed to both species in the South Island farms.
- The summer feed area was used for lamb fattening/finishing.
- The winter feed area used only for beef grazing on the North Island farms. The winter feed area was used for beef and sheep grazing in the South Island farms.
- Pasture renewal was assumed to be the sum of the over-sown area and new grass areas. Class 1 had one farm with high over sowing rates. This outlier was removed.

In addition to the economic survey, Meat and Wool provided estimates of the proportion of an activity that is contracted out, based on each of the regional managers assessment of the proportion of operations contracted out (Table 4).

Small surveys showed that about a third of the expenditure was on petrol, while the rest was on diesel. In contrast, Rosevear (2008) reported 55% of total fuel was diesel. Therefore, typical diesel and petrol use per RSU was estimated for classes 1 - 7, assuming diesel to be 66% of total fuel use. Class 8 was ignored as it had high cropping.

Diesel use per RSU increased as the percentage of farm in hay/silage (Figure 3) or the area under cultivation (not shown) increased. Diesel use were, on average, 0.348 litres/RSU higher on the class 1, 2, and 7 farms in the South Island than in the North Island, although South Island class 6 farms were similar to North Island farms (Table 4 for class definitions). The reason for the higher diesel on South Island class 1, 2, and 7 farms is not clear. However, probable causes include:

- Lower pasture yields that are expected on class 1 and 2 farms may lead to higher fuel use when making supplements per unit feed.
- Higher cultivation costs.
- Longer travel times due to farm size and distance from main centres (class 1 and 2).
- Additional fuel use due to moving irrigation equipment on class 7 (intensive finishing).
- The proportion of contracting out operations on cultivated land was lower in the South Island than in the North Island, particularly for Class 1 and 2 farms (Table 4).

Extrapolating back to zero (to exclude supplement making and cultivation) gave an estimated base fuel use of 0.6827 l/RSU of diesel. Rosevear (2008) estimated that 86% of delivered fuel was used on-farm, although distributors indicated this to be 90-95%, and on-farm fuel consumption was about 80% of total fuel consumption. For this reason, the base rate was reduced by 80%, and an off-road component added. A similar approach was also applied for petrol.

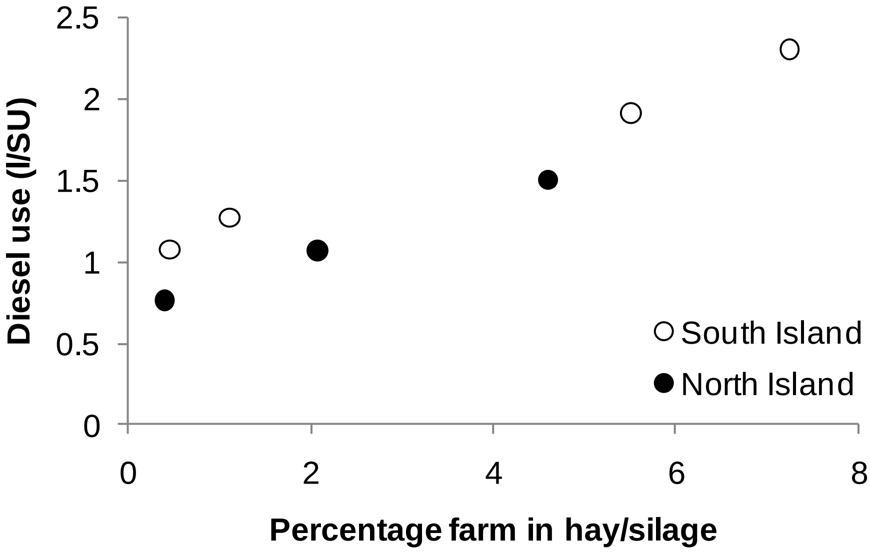

Figure 3. Relationship between percentage of farm in hay/silage and average diesel fuel use (l/SU) for Meat and Wool economic survey class farms.

Assuming an average of 11 RSU/ha across all farm classes, a fuel use of 7.5 l diesel/ha is obtained. This is similar to indicative fuel consumptions based on MAF 2007 Cost model (Rosevear, 2008) who reporting 10,000 litres of fuel brought for a 673 ha/farm, 80% for on-farm use, and with 65% fuel use being diesel to gives 7.8 litres diesel/ha.

Thus, in addition to off-farm fuel use, additional diesel use was estimated as:

Equation 27: $diesel_{antype} = baseSU * RSU_{antype}$

baseSU is 0.546 l/RSU diesel

RSU is the calculated RSU for each animal type [Animal model chapter].

and additional petrol use was estimated as:

Equation 28: $petrol_{antype} = baseSU * RSU_{antype}$

baseSU is 0.273 l/RSU petrol

RSU is the calculated RSU for each animal type [Animal model chapter].

Table 4. Average percentage of the farm activity undertaken by external contractors, and average percentage of a farm area used for hay/silage or cropping for Beef and Lamb economic survey farm classes 1 - 7.

	South Island High Country **Class 1**	South Island Hill Country **Class 2**	North Island Hard Hill Country **Class 3**	North Island Hill Country **Class 4**	North Island Intensive Finishing **Class 5**	South Island Finishing Breeding **Class 6**	South Island Intensive Finishing **Class 7**
Average percentage area that the following occur							
Hay/silage area	0.46	1.11	0.40	2.08	4.61	5.51	7.25
Summer feed area	0.00	0.31	0.60	0.83	1.77	0.95	0.00
Winter feed area	0.34	1.85	0.30	0.63	1.77	4.56	5.43
Ryegrass area	0.24	1.48	0.79	1.46	3.19	6.27	4.35
Average percentage of the farm activity undertaken by external contractors							
Fertiliser ground spreading	80	83	85	76	80	75	70
Lime ground spreading	100	100	95	92	91	100	75
Herbicide application	95	95	87.5	60	60	80	80
Summer feed production	20	25	75	72.5	72	50	0
Winter feed production	20	20	75	72.5	72	40	65
Pasture renewal	30	30	75	72.5	72	50	50
Hay and silage making	90	80	90	87.5	87	75	80

3.2.3.3. *Dairy animals*

Using a process LCA approach (Fonterra CFP project), average diesel fuel consumption for various farm operations were estimated using fuel use values listed in section 3.2.5. The base diesel fuel consumption excluded activities such as fertiliser spreading, off farm grazing for replacements, wintering off grazing and activities that could be part of the capital and infrastructure maintenance type activities. Thus, base average diesel use was approximately 35% of total fuel use (Fonterra CFP project).

An alternative approach is to use an Input-Output LCA methodology, which gives higher petrol and diesel consumption than the process approach used in the Fonterra CFP project (Flemmer *et al*., 2005). For example, for a typical dairy farm as used in the Fonterra CFP project, this gave a base fuel use of 13.3 l/ha diesel and 4.4 l/ha petrol. If all on-farm diesel use is included, this gave 35.8 l/ha diesel. In contrast, based on MAF farm cost models, average fuel use was 48 l/ha diesel and 16 l/ha petrol assuming 75% fuel used to be diesel, but this would include activities that are estimated separately (Rosevear 2008).

Dairy Base fuel expenditure data indicates that over a 5 year period, fuel use averaged 50 l/ha diesel and 16 l/ha petrol (M Boyes, pers. comm.), but this includes on-farm cropping and supplement making. However, data supplied indicated that while the area indicates cropping is small, there is a proportionally greater area used to make supplements. The amount spent on feeds is included but it is not clear how to determine the area of on-farm cropping and supplement making done using contracting and farm fuel supplies. The estimated total fuel cost for on-farm supplements and crops was subtracted from the total fuel cost to obtain the lowest farmer fuel use estimate. This results in a net fuel use of approximately 40 l/ha diesel and 13 l/ha petrol. Off-farm fuel use should be removed from this.

Input-Output LCA methodology would include some of the excluded activities. To get a consumption that reflected between farm differences, the base fuel consumption was based on the Fonterra CFP project, with off-farm consumption and fuel use due to specific activities was added on. Off-farm fuel use was set the same as non-dairy. Although distances are closer, there are probably more reasons for travelling with dairy systems. In addition, fuel is probably used to check animals that are grazed off. A low rate of use was applied, but no data was found to verify the rate used. Any differences in methodology for fuel consumption would have a minor effect on total emissions from dairy farms, and if more accuracy is required, actual farm data can be entered.

The Fonterra CFP project was based on typical milk solids per cow and number of cows per ha. Many of the base fuel uses are more likely to be aligned to cow numbers than milk solid production.

Hence, diesel use was estimated as:

Equation 29: $diesel_{dairy} = basecow * NumberMilkers$

basecow is 4.655 l/cow diesel

NumberMilkers is the peak number of milking cows.

and, petrol use was estimated as:

Equation 30: $petrol_{dairy} = basecow * NumberMilkers +$

petrolgrazeoff * NumbergrazeOff

basecow is 0.799 l/cow petrol

petrolgrazeoff is 0.0159 l/cow petrol

NumberMilkers is the peak number of milking cows.

NumberMilkers is the number of cows grazed off [Animal model chapter].

3.2.3.4. *Cut and Carry*

On cut and carry blocks, the fuel cost associated with supplement making and fertiliser spreading is estimated separately (section 3.2.5.1 and 3.2.5.4 respectively). Additional on-farm fuel use for other activities is expected to be negligible, and is ignored.

3.2.3.5. *Cropping*

Bloomer (pers. comm.) indicated that crops used between 35-80 l/ha diesel, with an average of about 60 litres diesel/ha per crop. The estimated fuel use for sowing a brassica fodder crop was 35 l/ha diesel (Boyes, pers. comm.). This does not include harvesting costs as the crop is eaten by animals. Rosevear (2008) indicated diesel for cropping averaged 98 l/ha, based on a MAF 2007 cost model but this would have included multiple crops within a year. Fuel use is also probably lower with a crop-to-crop rotation, with a total diesel use closer to 40 l/ha.

Therefore, diesel use was estimated for crops if time of sowing and/or time of harvest occurred in the assessment year. It was assumed that 35 l/ha was used at sowing, 25 l/ha used for mechanical harvesting, and there was no additional petrol use. Thus:

Equation 31: $diesel_{block} = \sum(area_{block} * cropfuel)$

cropfuel = 35 l/ha/crop diesel — if crop sown

= 25 l/ha/crop diesel — mechanically harvested

area is block area (ha)

3.2.3.6. *Fruit crops*

Rosevear (2008) reported diesel used for fruit crops averaged 324 l/ha, based on a MAF 2007 cost model, and that 50% of this diesel was used for frost control. Diesel is unlikely to be used for frost control on farms using frost control irrigation, and unlikely to be used in Northland. It was assumed that there was no additional petrol use. Therefore, diesel use for the fruit block was estimated as:

Equation 32: $diesel_{block} = area_{block} * hortfuel$

area is block area (ha).

where

Equation 33: hortfuel = 162 l/ha diesel — frost control irrigation

= 162 l/ha diesel — Northland

= 324 l/ha diesel — otherwise

3.2.4. Entered base fuel use

Entered fuel use also includes fuel used for activities that the model would have otherwise estimated based on farm specific information. Fuel for making supplements (hay/silage) or spreading fertiliser or lime is assumed by default to be undertaken by contractors and is estimated from input data. The percentage of activity undertaken using farm fuel supplies should be entered if farm fuel supplies are used for these activities (section 3.2.7.1).

If fuel data is entered, then all activities undertaken by contractors for cultivation or crop management should be entered. Where no contracting information is entered, the model reads this to mean that the all crop fuel used has been included as part of on-farm fuel use.

The base fuel use is thus the difference between entered fuel use and fuel use for specific activities (section 3.2.7.1). The distribution of entered base fuel use to greenhouse sources is assumed to be in the same ratio as default fuel use.

Equation 34: $diesel_{gsource} = diesel * pdiesel_{gsource} + contractdiesel * pdiesel_{gsource}$

Equation 35: $petrol_{gsource} = petrol * ppetrol_{gsource} +$

Equation 36: $avgas_{gsource} = aviationfuel * pdiesel_{gsource} + contractdiesel * pdiesel_{gsource}$

diesel is entered farm diesel use (l/year).
petrol is entered farm petrol use (l/year).
aviationfuel is entered farm avaiation fuel use (l/year).
contractdiesel is diesel use by contractors [section 3.2.4.1].
$pdiesel = dieselDef_{gsource} / \sum(dieselDef_{gsource})$
dieselDef is the default diesel use (l/ha) [section 3.2.3].
$ppetrol = petrolDef_{gsource} / \sum(petrolDef_{gsource})$
petrolDef is the default petrol use (l/ha) [section 3.2.3].

3.2.4.1. *Contracted cropping*

Contract fuel use is separated into three categories, cultivation, crop specific and user defined. The first two categories provide a pre-set range of activities, and for each, a default value for fuel use, although users can enter their own fuel use if known.

Contract diesel (litres/year) is estimated as:

Equation 37: $contractdiesel = \sum_k(contractedArea * contractDieselRate) + \sum_k(contractedCropArea * contractCropDieselRate) + \sum_k(contractedUserArea * contractUserDieselRate)$

Contractedarea is the total area (ha/year) of activity undertaken by contractor
= ∑area * number of times
contractDieselRate is the diesel use (l/ha) per contracted general activity
= entered value
= default value [Table 5].
contractcropDieselRate is the diesel use (l/ha) per contracted crop activity

= entered value
= default value [Table 6].
contractUserDieselRate is the diesel use (l/ha) per user-defined activity
= entered value

Table 5. Diesel consumed for general contracting activities.

Type	Diesel use/ha[1]	Source [2]	Default value
Ploughing	18 - 35	1, 2	25
Cultivating	6	1	6
Discing	12	1	12
30 cm Rip	18	2	18
50 cm Rip	25	2	28
Disc Ripper	30	2	30
Strip tilling	8	2	8
Min Till	10	2	10
Subsoil	21		21
Chisel plough	28		28
Rotary hoe 3m wide	25-28		28
Striptill Headlands	2	2	2
Rotor Spike	8	2	8
Rolling	4	1, 2	4
Power harrowing	8	1, 2	8
Light harrowing	4	1, 2	4
Conventional drill	4-5	1, 2	5
Direct drill	8-10	1, 2	10
Spraying	1 - 3	1, 2	3
Mulch	8 -12	2	10
Soil finisher	8 -15	2	11
Planting	2	2	2
Bedform	8	2	8

[1] Range between sources
[2] Source: 1 = Wells (2001)
2 = Bloomer (LandWise Cropping fuel use estimation tool)

Table 6. Diesel consumed for contracting specific crop activities.

Type	Diesel use/ha	Source [1]	Default value
Pea harvester	102	1	102
Potato planting	15	1	15
Potato ridging	5	1	5
Potato harvesting	45	1	45
Potato field collection	25	1	25
Potato loading (field)	10	1	10
Potato loading (shed)	6	1	6
Carrot planting	8	1	8
Carrot topping	6	1	6
Carrot lifting	20	1	20

[1] Source: 1 = Wells (2001)

2 = Bloomer (LandWise Cropping fuel use estimation tool)

3.2.5. Activity fuel emissions

Emissions due to fuel usage can be allocated to specific activities using the following guidelines:

- Fuel for transport of products to primary depots is included in the product-embodied costs, and is assumed to have been undertaken by contractors. The primary depot is the primary distribution point, and is typically a port, bulk warehouse or storage facility.
- Transport of animals is undertaken by contractors (default) or included in farm fuel use if farm fuel use is specified.
- Transportation of supplements, fertilisers, lime, organic material and other products from the primary depot to the farm is exclusively undertaken by contractors. Farms that have their own trucks for transporting these products should not include fuel use of these when estimating farm fuel use.
- Transportation of other products is exclusively undertaken by contractors
- Feeding out of supplements is undertaken exclusively using farm fuel supplies.
- On-farm pasture based supplement production is undertaken by contractors (default) or included in farm fuel use, if farm fuel use is specified.
- Spreading of fertiliser, lime or organic material is undertaken by contractors (default) or included in farm fuel use, if farm fuel use is specified.

As noted earlier, these are estimated separately so that the fuel use can be associated with a product. These are calculated as emissions as it provides a common unit.

3.2.5.1. *On-farm supplement production*

Diesel used to make pasture based supplements was based on pasture production of a North Island intensive sheep and beef farm with a stocking rate of 11.5 SU/ha and 80% utilisation. The fuel consumption rates were based on Wells (2001). The frequency of harvesting was set to maintain 2.5t DM/ha of silage or hay production.

The fuel use for hay and silage were similar, although the operations differed. This equated to about 0.015 litres diesel/kg DM made.

The emissions due to on-farm supplement production are allocated to the animal source the supplement is fed to, or export source if sold off-farm. Supplements made and placed in storage are also included. Thus, the amount of diesel required to make supplements was estimated as:

Equation 38: $dieselSupp_{antype} = 0.015 * suppMade_{antype}$

$suppMade_{antype} = DMsupp_{antype} + DMsuppstorage * gsourceSuppStore_{antype}$

$DMsupp_{antype}$ is the calculated DM (kg DM/year) of supplements made and fed to animal type.

DMsuppstorage is the calculated DM (kg DM/year) of supplements made and placed in storage.

Equation 39: $dieselSupp_{exported} = 0.015 * DMsuppexported$

DMsuppexported is the calculated total DM (kg DM/year) of supplements made and exported.

Supplements placed in storage are allocated to the animal source in the same ratio that supplements are fed out from storage, or on-farm supplements are fed out, or using the animal allocation ratio.

Equation 40: $gsourceSuppStore_{antype} = suppStoreDMfarm_{antype} / \sum(suppStoreDMfarm_{antype})$
$= DMsupp_{antype} / \sum(suppDMsupp_{antype})$
$= psourcefarm_{antype}$ [section 1.2.1]

The emissions from making supplements were then estimated as:

Equation 41: $FuelMakeSupplementCO2_{gsource} = dieselSupp_{gsourcee} * EFdieselCO2 + oil_{gsourcee} * EFOilCO2$

Equation 42: $FuelMakeSupplementEnergy_{gsource} = dieselSupp_{gsourcee} * EFdieselEnergy + oil_{gsourcee} * EFOilEnergy$

oil is estimated from diesel use [section 3.2.2].

EFdieselCO2, EFdieselEnergy, EFOilCO2, and EFOilEnergy are emission coefficients [section 3.2.1.1].

3.2.5.2. *Supplement feeding out*

Diesel required to feed out supplements was split into fuel required to cart the supplement on-farm, and fuel required for the actual feeding out process. This was estimated at 0.28 l diesel per tkm wet weight of supplement for carting, and 0.087 l diesel/t wet weight of supplement fed out (Boyes pers. comm.).

The distance supplements are transported on farm is unknown but was assumed to be the same average distance animals walk to the milking shed and return (0.5 km each way) for dairy animals on paddocks, and half that for supplements fed in-shed, or on pads. A higher transport distance is assumed for non-dairy animals fed on paddocks as the farms are typically larger.

Thus, diesel requirements for feeding out are estimated as:

Equation 43: $dieselSuppFeed_{gsource} = dieseltransport_{antype} + diselFeedout_{antype}$

$dieseltransport_{antype} = 0.28 * Tkm_{antype}$

$diselFeedout_{antype} = 0.08 * totalwetweight / 1000$

0.28 is the l diesel per tkm wet weight of supplement.

0.08 is l diesel/t wet weight of supplement.

$Totalwetweight_{antype} = \sum (wetweight_{antype,location})$

$Tkm_{antype} = \sum (wetweight_{antype,location} * distance_{antype,location})$

wetweigh = wetweight (t) feed (supplements brought in, made on farm, from storage and cut and carry crops) for each animal type at different locations (in-shed, feed pad, wintering pad or animal shelter, in paddocks).

distance = 0.5 km in-shed feeding or feeding on pads

= 1 km dairy on paddocks

= 3 km non-dairy on paddocks

location is feed pad, wintering pad and on paddocks for supplements brought in, made on farm, from storage and for cut and carry crops.

The emissions from supplements feeding were then estimated as:

Equation 44: $FuelSupplementFeedingCO2_{gsource} = dieselSuppFeed_{gsource} * EFdieselCO2$
$oil_{gsourcee} * EFOilCO2$

Equation 45: $FuelSupplementFeedingEnergy_{gsource} =$
$dieselSuppFeed_{gsourcee} * EFdieselEnergy$
$oil_{gsourcee} * EFOilEnergy$

oil is estimated from diesel use [section 3.2.2].

EFdieselCO2, EFdieselEnergy, EFOilCO2, and EFOilEnergy are emission coffciciencets [section 3.2.1.1].

3.2.5.3. *Fertiliser applications*

There is a large difference in emissions depending on whether fertiliser is applied by ground-spreading or by air. The application method is defined for N fertiliser, other fertiliser, lime, and organic material, and can be set by the user. By default, N fertiliser, non-N fertiliser, and lime is assumed to be applied by ground spreading on flat and rolling topography blocks, and aerial spreading on easy and steep topography blocks. All organic material is assumed to be applied by ground spreading.

Fertiliser spreading on flat ground uses 1.5-1.8 litres/ha/application (average 1.65 litres/ha) of diesel (Centre for Energy Research, 2004). A commercial fertiliser applicator estimated that 15% more fuel was used when spreading on rolling to hilly land, and 20% more when spreading on cultivated land. To estimate the number of applications, it is assumed that within any given month, all fertiliser except N is applied in a single application, and fertiliser N and lime are applied in separate applications.

Fuel use estimated by a commercial aerial applicator was 4.6 l/ha for super at 300 kg/ha and 18.4 l/ha for lime at 1.5 t/ha. Fuel use included the travel time to the site and spreading. This is equivalent to 0.0153 l/kg for super or 0.0123 l/kg for lime, or 0.0398 $rate^{-0.163}$ l/kg material applied. To estimate the application rate, it is assumed that within any given month, all fertiliser except N is applied in a single application, and lime is applied separately in a single application as is the case for N fertiliser. To simplify calculations the average weight (total weight of a given material applied divided by number of applications) was used.

For each material applied (N, non-N fertiliser, lime, organic material), the diesel required to spread material using ground spreading was estimated as:

Equation 46: dieselSpreadGround = area * applications * 1.65 if flat
area * applications * 1.98 if cultivated
area * applications * 1.898 otherwise

area is the block area (ha).

applications is the number of applications of material per year.

For each material applied by air, the aviation fuel (litres) used was estimated as:

Equation 47: fuelspreadair = Weightmaterial * Avfueluse

Weightmaterial is the total weigth of material applied by air (kg/year).

Avfueluse = 0.0398 rate $^{-0.163}$ (l/kg)

rate = Weightmaterial / number of applications (kg/ha/year)

The total emissions for a block are then estimated as:

Equation 48: $SpreadCO2_{block}$ = dieselSpreadGround * EFdieselCO2 + fuelspreadair * EFaviationCO2 + oil * EFOilCO2

Equation 49: $SpreadEnergy_{block}$ = dieselSpreadGround * EFdieselEnergy + fuelspreadair * EFaviationEnergy + oil * EFOilEnergy

oil is estimated from diesel use [section 3.2.2].

EFdieselCO2, EFdieselEnergy, EFOilCO2, EFOilEnergy, EFaviationCO2 and EFaviationEnergy are emission coffciciencets [section 3.2.1.1].

These emissions are then distributed to greenhouse gas sources as:

Equation 50: $FuelSpreadCO2_{gsource} = \sum_{block}(SpreadCO2_{block} * psource_{gsource, block})$

Equation 51: $FuelSpreadEnergy_{gsource} = \sum_{block}(SpreadEnergy_{block} * psource_{gsource, block})$

$psource_{block, gsource}$ is the block allocation [section 1.2.1].

3.2.5.4. *Transport of fertiliser, lime and organic material*

The transport of fertiliser, lime, and organic materials from the primary depot to the farm gate is dependent on the weight of material transported, and the distance transported.

The distance transported can be set by the user. Where not specified a default value is used. The default distance for fertiliser transport (Table 7) to dairy farms was based on a Fonterra survey (Ledgard *et al*., 2009). The default values for non-dairy systems were based on the Beef and Lamb Economic survey of 2004/5 (Table 8). The Beef and Lamb classes were aligned with OVERSEER data to generate Table 7. The default value for organic material is set at 30 km assuming that this type of material is usually transported over short distances.

Table 7. Default transport distances for fertiliser, lime, and organic material.

Farm type	Material	Condition		Distance (km)
Dairy	Fertiliser			145
	Lime			89
	Organic			30
Non-dairy	Fertiliser and lime	North	> 50% farm area Hard hill	202
			> 50% farm area Easy hill	149
			otherwise	130
		South	> 50% farm area High country (merino)	242
			> 50% farm area Easy and hard hill	139
			otherwise	88
	Organic			30
Crop and fruit crop blocks	Fertiliser			30
	Lime			30
	Organic			30

Table 8. Fertiliser transport distances from Meat and Wool economic survey 2004/2005.

South Island High Country **Class 1**	South Island Hill Country **Class 2**	North Island Hard Hill Country **Class 3**	North Island Hill Country **Class 4**	North Island Intensive Finishing **Class 5**	South Island Finishing Breeding **Class 6**	South Island Intensive Finishing **Class 7**
242	139	202	149	130	107	70

The tonne-km (tkm) for transport of fertiliser, lime, and organic materials is estimated by first calculating the tonne-km transported for each block as:

Equation 52: $Tkm_{block} = \sum_{material}(distance_{material} * rate_{material} /1000)$

$distance_{material}$ = entered distance (km/year) if entered

= default value (km/year) [Table 7]

$rate_{material}$ is the total weigth of material transported (T/year).

1000 converts kg to tonnes.

Fuel emissions are allocated to greenhouse gas emission source based on the block allocation. Thus:

Equation 53: $FertTransportCO2_{gsource} = \sum_{block}(Tkm_{block} * ftkmCO2 * psource_{block, gsource})$

Equation 54: $FertTransportEnergy_{gsource} = \sum_{block}(Tkm_{block} * ftkmCO2 * psource_{block, gsource})$

EFTkmCO2 (kg CO_2 equivalents/Tkm) and EFTkmEnergy (MJ/Tkm) are emission factors for truck with no backload [section 3.2.1.2].

$psource_{block, gsource}$ is the block allocation [section 1.2.1].

3.2.5.5. *Transport of supplements imported*

Supplement brought on to the farm is assumed to have been transported via the depot when supplied to the farm. The transport distance can be user defined, otherwise a default value of 30 km is used for hay and silage and 40 km for other supplements. Thus, the Tonnes km (tkm) of supplement transported is estimated as:

Equation 55: SuppInTkm = SuppHayTkm + SuppTkm

SuppHayTkm = TotalWetWtHay/1000 * distanceSuppHay

TotalWetWthay is the total wet weight (kg /year) of hay and silage supplements brought in.

1000 converts kg to tonnes.

distanceSupphay (km) is user defined or default transport distance (km) for hay and silage.

SuppTkm = TotalWetWt/1000 * distanceSupp

TotalWetWt is the total wet weight (kg /year) of supplements other than hay and silage brought in.

1000 converts kg to tonnes.

distanceSupp (km) is user-deifned or default transport distance (km) for other supplements.

Supplements brought in are allocated (fed) to animal types. In the same way emissions from transport are distributed between greenhouse gas sources.

Equation 56: $SuppInTransportCO2_{gsource}$ = SuppInTkm * EFtkmCO2 * $psourcesupp_{antype}$

Equation 57: $SuppInTransportEnergy_{gsource}$ = SuppInTkm * EFtkmEnergy * $psourcesupp_{antype}$

EFTkmCO2 (kg CO_2 equivalents/tkm) and EFTkmEnergy (MJ/tkm) are emission factors for truck with no backload [section 3.2.1.2].

$psourcesupp_{antype} = Suppmake_{antype}/\sum_{antype}(Suppmake_{antype})$

$Suppmake_{antype}$ is the total wet weight of supplement feed to an animal type (kg WW/year).

3.2.5.6. *Transport of dairy replacements*

On dairy farms, replacements can be grazed-off farm or grazed on farm, sometimes on blocks that are geographically separate from the milking platform. Currently internal transport is not included in the analysis. If replacements are specifically grazed off-farm, embodied fuel emissions associated with transport of the animals to and from grazing are estimated separately as the weight of animals is higher for animals returning than those leaving. The distance transported can be entered by the user or a default value (Table 9) is used. The default value is based on a survey.

If transport is from one block to another; this might occur when the run-off block is part of the farm analysis; then replacement transport emissions are estimated if a distance is entered.

Table 9. Default distance replacements animals are transported.

Region	Average distance (km)
Northland	10 *
Auckland	20
Waikato/Coromandel	30 *
BOP	30 *
Central Plateau	30
King Country/Taihape	30
Taranaki	30 *
Manawatu/Wanganui	15 *
Wellington	15 *
East Coast North Island	30
West Coast South Island	153 *
Nelson	30
Marlborough	30
Canterbury	50 *
Otago	40 *
Southland	40 *
High Country (> 300 m)	30

* data from survey in 2008 (Ledgard *et al.*, 2009), the remainder are estimated.

The tonne-km travelled in one direction is estimated as:

Equation 58: $Tkm_{antype} = liveweight_{antype} / 1000 * distance$

liveweight is the total liveweight leaving or returning (kg).

1000 converts kg to tonnes

distance = entered transport distance (km) if entered

= replacement transport distance (km) otherwise [Table 9]

The fuel emissions for transporting animals for wintering off in one direction are then estimated as:

Equation 59: $TransportReplaceCO2_{antype} = Tkm_{antype} * EFTkmCO2$

Equation 60: $TransportReplace_{antype} = Tkm_{antype} * EFTkmEnergy$

EFTkmCO2 (kg CO_2 equivalents/tkm) and EFTkmEnergy (MJ/tkm) are emission factors for truck with no backload [section 3.2.1.2].

3.2.5.7. *Transport of wintered-off animals*

Animals that are wintered-off have an embodied transport emission associated with their transport. The model assumes that the weight leaving and returning is the same. The distance transported can be entered by the user or a default value used (Table 10).

Table 10. Default distance wintered-off animals are transported.

Region	Average distance (km)
Northland	15 *
Auckland	40
Waikato/Coromandel	50 *
BOP	50 *
Central Plateau	50
King Country/Taihape	50
Taranaki	30 *
Manawatu/Wanganui	20 *
Wellington	20 *
East Coast North Island	40
West Coast South Island	250 *
Nelson	40
Marlborough	40
Canterbury	15 *
Otago	30 *
Southland	30 *
High Country (> 300 m)	40

* data from survey in 2008 (Ledgard *et al*., 2009).

The tonne-km travelled in one direction is estimated as:

Equation 61: $Tkm_{antype} = liveweight_{antype} / 1000 * distance$

liveweight is total liveweight of wintered animals leaving or returning (kg).

1000 converts kg to tonnes.

distance = entered wintering off distance (km) if entered

= default wintering off distance (km) otherwise [Table 10]

The fuel emissions for transporting animals for wintering off in one direction are then estimated as:

Equation 62: $TransportWinOffCO2_{antype} = Tkm_{antype} * EFTkmCO2$

Equation 63: $TransportWinOff_{antype} = Tkm_{antype} * EFTkmEnergy$

EFTkmCO2 (kg CO_2 equivalents/tkm) and EFTkmEnergy (MJ/tkm) are emission factors for truck with no backload [section 3.2.1.2].

3.2.5.8. *Transport of brought in animals*

Animals that are purchased or brought in have embodied transport emissions associated with their movement. Animals sold are not included as these movements are outside the farm gate. The distance transported can be entered by the user or a default value used. As no typical data was found, the default distance was based on wintering-off default.

The tonne-km travelled is estimated as:

Equation 64: $Tkm_{antype} = liveweightbrought_{antype} / 1000 * distance$

liveweightbrought = total live weight brought in (kg).
1000 = kg to tonnes
distance = entered distance for animals brought (km) if entered
= default distance for animals brought (km) otherwise [Table 10]

Fuel emissions for transport of animals brought onto the farm is then estimated as:

Equation 65: $TransportAnimalsCO2_{antype} = Tkm_{antype} * EFTkmCO2$
Equation 66: $TransportAnimalsEnergy_{antype} = Tkm_{antype} * EFTkmEnergy$
EFTkmCO2 (kg CO_2 equivalents/Tkm) and EFTkmEnergy (MJ/Tkm) are emission factors for truck with no backload [section 3.2.1.2].

3.2.6. Miscellaneous transport emissions

Users can enter the tonnes–kilometres of materials other than fertiliser, supplements or animals that are transported to the farm. As the emission factor for transport using a 36-40 tonne truck in the LCA analysis was similar to Euro3 emission factors for a > 32 tonne truck in Table 3, it was assumed that the emissions for smaller trucks were the same as Euro 3 values.

Emissions for miscellaneous transport were estimated as:

Equation 67: SumtkmCO2 = tonnekm1 * EFTkmlargeCO2 +
tonnekm2 * EFTkmmediumCO2 +
tonnekm3 * EFTkmmediumsmallCO2 +
tonnekm4 * EFTkmsmallCO2
tonnekm1 is the entered tonne km for large (> 32 tonne) truck.
tonnekm2 is the entered tonne km for medium (16- 32 tonne) truck.
tonnekm3 is the entered tonne km for medium small (7.5-16 tonne) truck.
tonnekm4 is the entered tonne km for small (< 7.5 tonne) truck.
EFTkmlargeCO2 is the emission factor for 36-40 tonne, 50 % back loading as used in LCA analysis [Table 3].
EFTkmmediumCO2 is the emission factor for 16-32 t Truck [Table 3].
EFTkmmediumsmallCO2 is the emission factor for 7.5-16 t Truck [Table 3].
EFTkmsmallCO2 is the emission factor for < 7.5 t Truck [Table 3].
Equation 68: SumtkmEnergy = tonnekm1 * EFTkmEnergylarge +
tonnekm2 * EFTkmEnergymedium +
tonnekm3 * EFTkmEnergymediumsmall +
tonnekm4 * EFTkmEnergysmall
EFTkmEnergylarge is the emission factor for 36-40 tonne, 50 % back loading as used in LCA analysis [Table 3].
EFTkmEnergymedium is the emission factor for 16-32 t Truck [Table 3].
EFTkmEnergymediumsmall is the emission factor for 7.5-16 t Truck [Table 3].
EFTkmEnergymall is the emission factor for < 7.5 t Truck [Table 3].

Other transport embodied emissions are then distributed to the greenhouse gas report sources as:

Equation 69: $TransportOtherCO2_{gsource} = SumtkmCO2 * pfarmsource_{gsource}$

Equation 70: $TransportOtherEnergy_{gsource} = SumtkmEnergy * pfarmsource_{gsource}$

$psource_{gsource}$ is the farm allocation [section 1.2.1].

3.2.7. Embodied base fuel emissions

a) Entered fuel data

If fuel use data is entered, embodied emissions (kg CO_2 equivalents/year or MJ/year) for fuel used on the farm are estimated as:

Equation 71: $InFuelCO2_{gsource} = diesel_{gsource} * EFdieselCO2 + petrol_{gsource} * EFpetrolCO2 + avgas_{gsource} * EFaviationCO2 + oil_{gsource} * EFoilCO2$

Equation 72: $InFuelEnergy_{gsource} = diesel_{gsource} * EFdieselEnergy + petrol_{gsource} * EFpetrolEnergy + avgas_{gsource} * EFaviationEnergy + oil_{gsource} * EFoillEnergy$

diesel, petrol and avgas is the entered fuel use [section 3.2.4].

oil is estimated from petrol and diesel use [section 3.2.2].

EFdieselCO2, EFpetrolCO2, EFaviationCO2 and EFoilCO2 are emission factors (kg CO_2 equivalents/litre fuel) [section 3.2.1.1].

EFdieselEnergy, EFpetrolenergy, EFaviationEnergy and EFoilenergy are emission factors (MJ/litre fuel) [section 3.2.1.1].

Emissions for specific activities included elsewhere are then removed to give base fuel emissions (kg CO_2 equivalents/year or MJ/year). Thus:

Equation 73: $FuelCO2 = (InFuelCO2_{gsource} – ActivityFuelCO2_{gsource})$

Equation 74: $FuelEnergy = (InFuelEnergy_{gsource} – ActivityFuelEnergy_{gsource})$

ActivityFuelCO2 (kg CO_2 equivalents/year) [section 3.2.7.1].

ActivityFuelEnergy (MJ/year) [section 3.2.7.1].

It is assumed that there is a minimum base fuel use of one l/ha/year for general-purpose use.

b) Default fuel

If fuel use data is not entered (the default), default base fuel use is estimated (section 3.2.3) and base fuel emissions (kg CO_2 equivalents/year or MJ/year) are calculated as:

Equation 75: $FuelCO2_{gsource} = defaultdiesel_{gsource} * EFdieselCO2 + defaultpetrol_{gsource} * EFpetrolCO2 + oil_{gsource} * EFoilCO2$

Equation 76: $FuelEnergy_{gsource} = defaultdiesel_{gsource} * EFdieselEnergy + defaultpetrol_{gsource} * EFpetrolEnergy + oil_{gsource} * EFoillEnergy$

defaultdiesel and defaultpetrol are default fuel use (litres) [section 3.2.3].

oil (litres) is estimated from petrol and diesel use [section 3.2.2].

EFdieselCO2, EFpetrolCO2, EFoilCO2 are emission factors (kg CO_2 equivalents/litre fuel) [section 3.2.1.1].

EFdieselEnergy, EFpetrolenergy, EFoilenergy are emission factors (MJ/litre fuel) [section 3.2.1.1].

Note that activity fuel emissions are also calculated.

c) both methods

For either method, miscellaneous transport emissions (section 3.2.6) are then added on:

$$FuelCO2_{gsource} = FuelCO2_{gsource} + TransportOtherCO2_{gsource}$$
$$FuelEnergy_{gsource} = FuelEnergy_{gsource} + TransportOtherEnergy_{gsource}$$

3.2.7.1. *Adjusting for activity fuel emissions*

Total CO_2 emissions for activities that the model estimates separately are estimated as:

Equation 77:
$$\begin{aligned} ActivityFuelCO2 = {} & FuelMakeSupplementCO2_{gsource} * FuelOnFarmSup / 100 \\ & + FuelSupplementFeedingCO2_{gsource} \\ & + FertSpreadCO2Nfert_{gsource} * FuelOnFarmN / 100 \\ & + FertSpreadCO2fert_{gsource} * FuelOnFarmFert / 100 \\ & + FertSpreadCO2Lime_{gsource} * FuelOnFarmLime / 100 \\ & + FertSpreadCO2FertOther_{gsource} * AFuelOnFarmOrg / 100 \\ & + TransportAnimalCO2_{gsource} * FuelOnFarmAnimals / 100 \\ & + AnimalTransportDairyearepCO2_{gsource} * FuelOnFarmAnimals / 100 \\ & + AnimalTransportWinteroffCO2_{gsource} * FuelOnFarmAnimals/ 100 \end{aligned}$$

where variables starting with FuelOnFarm is the percentage of activity undertaken using farm fuel supplies. The one exception is supplement feeding. This is zero by default, i.e., all activities are undertaken by contractors. However, this can be modified by the user. When fuel use is supplied, it is assumed that supplement feeding is undertaken using only farm fuel supplies.

A similar calculation is undertaken for energy.

3.3. Supplements imported

Embodied emissions of imported supplements include emissions for growing the supplement, and emissions associated with manufacturing and transport the supplement to a central depot. Emissions associated with fuel use for transport from the primary depot to the farm and feeding out are estimated separately (section 3.2.5.5 and 3.2.5.2 respectively).

A farmer generally knows the amount of supplement purchased, and possibly the location of the primary depot, but not necessarily the conditions under which a supplement is produced. For example, embodied emissions from palm kernel depend on whether deforestation occurred for growing the palm kernel. If it does, then under PAS 2050 guidelines (BIS 2008), the change in above and below ground biomass, litter and soil organic carbon of the forests in the regions should must be included. This influences the emission factors (Table 11).

Therefore, LCA analyses were undertaken for a range of supplements, weighted for origin on a national basis if this was known (Boyes, pers. comm.). Embodied emissions were then allocated to each supplement in the database based on these LCA analyses (Table 12 and Table 13).

Table 11. Effect of including forest conversion on embodied emissions for Palm kernel meal.

Forest conversion	kg CO2 equivalents/kg DM	MJ/kg DM
Did not occurred	0.3378	2.2513
Occurred	1.2652	2.2513

Analysis generally indicated that the most important factors influencing embodied CO_2 emissions for forages and arable crops were the rate of N fertiliser applied and the yield of the crop. Imported supplements can be fed to a specific animal type either on pads, in the milking shed, or on paddocks; or fed on a block where all stock on the block consume the supplement. Therefore, embodied CO_2 and energy emissions for imported supplements are estimated as:

Equation 78: $SuppImportCO2_{antype} = \sum_{supp}(DM_{antype} * EFsupCO2_{supptype}) + \sum_{supp}\sum_{block}(DMBlock_{block, gsource} * EFsupCO2_{supptype})$

Equation 79: $SuppImportEnergy_{antype} = \sum_{supp}(DM_{antype} * EFsupEnergy_{supptype}) + \sum_{supp}\sum_{block}(DMBlock_{block, antype} * EFsupEnergy_{supptype})$

DM_{antype} is the weight of supplement DM (kg DM/animal type/year) fed to a specifc animal type (kg/animal type).

$DMBlock_{block, gsource} = DM_{block} * area_{block} * psource_{block, gsource}$

DM_{block} is the weight of supplement DM (kg DM/ha/year) fed on specifc block(s).

$psource_{block, gsource}$ is the block allocation [section 1.2.1].

supptype is the supplement product shown in Table 12 or Table 13.

EFsupCO2 (kg CO_2 equivalents/kg DM) and EFsupEnergy (MJ/kg DM) are emission factors [Table 12 and Table 13].

Table 12. Emission factors for imported supplements.

Category	Product	kg CO_2 equivalents/kg DM	MJ/kg DM
Hay	Pasture good quality hay	0.129	1.329
	Pasture average quality hay	0.129	1.329
	Pasture poor quality hay	0.129	1.329
	Lucerne good quality hay	0.129	1.329
	Lucerne average quality hay	0.129	1.329
	Lucerne poor quality hay	0.129	1.329
Silages	Pasture good quality silage	0.150	1.781
	Pasture average quality silage	0.150	1.781
	Pasture poor quality silage	0.150	1.781
	Baleage	0.150	1.781
	Maize silage	0.171	1.564
	Cereal silage	0.150	1.781
	Triticale silage	0.211	1.168
	Lucerne silage	0.150	1.781
	Barley milky dough silage	0.150	1.781
Straws	Barley straw	0.025 [1]	0.187 [1]
	Wheat straw	0.025 [1]	0.187 [1]
	Oat straw	0.025 [1]	0.187 [1]
	Ryegrass straw	0.025 [1]	0.187 [1]
	Pea straw	0.025 [1]	0.187 [1]
	Corn stover	0.025 [1]	0.187 [1]
Green feeds	Annual ryegrass	0.844	6.942
	Turnips [2]	0.531	2.124
	Kale	0.292	1.655
	Rape	0.396	2.750
	Oats leafy	0.196	0.701
	Oats milky dough	0.196	0.701
	Sorghum	0.196 [3]	0.701 [3]
	Japanese millet	0.196 [3]	0.701 [3]
	Maize green feed	0.196 [3]	0.701 [3]
	Sulla	0.550 [5]	4.117 [5]
GrainsGrain/pulses	Barley grain	0.470	3.905
	Wheat grain	0.470 [4]	3.905 [4]
	Oats grain	0.470 [4]	3.905 [4]
	Maize grain	0.470 [4]	3.905 [4]
	Peas	0.550 [5]	4.117 [5]
	Soya bean meal	0.550	4.117 [6]
Vegetables	Potatoes	0.025 [1]	0.187 [1]
	Onions	0.025 [1]	0.187 [1]
	Cabbage	0.025 [1]	0.187 [1]
	Carrots	0.025 [1]	0.187 [1]
	Kiwifruit	0.025 [1]	0.187 [1]
	Squash	0.025 [1]	0.187 [1]
	Apples	0.025 [1]	0.187 [1]
	Apple pomace	0.025 [1]	0.187 [1]
	Grape pomace	0.025 [1]	0.187 [1]

Category	Product	kg CO_2 equivalents/kg DM	MJ/kg DM
	Citrus pulp	0.025 [1]	0.187 [1]
Byproducts	Brewers grain	0.450	1.123
	Bran	0.197	1.475
	Pollard	0.197 [7]	1.475 [7]
	Avonfeed	0.197 [7]	1.475 [7]
	Lucerne meal	0.505 [8]	14.69 [8]
	Molasses	0.099	6.012
	Palm kernel meal [9]	0.338	2.251
	Canola	0.505 [8]	14.69 [8]
	Copra	0.197 [7]	1.475 [7]
	Cottonseed meal	0.505 [8]	14.69 [8]
	Fishmeal	6.681	50.011 [6]
	Proliq	0.505 [8]	14.69 [8]
	Corn grits/hominy	0.197 [7]	1.475 [7]

[1] assumed to be waste and hence have low embodied emissions.
[2] average of Barkant and globe turnips.
[3] assumed to be same as green feed oats.
[4] assumed to be same as barley grain.
[5] estimated from soybean.
[6] energy emission factor estimated from other data.
[7] from the milling process, therefore based on bran which is also milled.
[8] requires energy input thus based on Canola.
[9] consistent with LCA procedures, emission factors include emissions arising from conversion of forest and peat lands to cropping. Thus GHG emission was based on all plantations derived from deforested lands and soils (Table 11). The analysis used estimated that about 56% of New Zealand's supply was is from deforested land. A more recent analysis suggests this is less, hence emissions may be lower (Koh *et al.*, 2011).

User defined supplements are allocated an emission factor based on the general supplement type as shown in Table 13.

Table 13. Emission factors for user-defined imported supplements.

Supplement general type	kg CO_2 equivalents/kg DM	MJ/kg DM
Grass Silage	0.150	1.781
Maize & Cereal Silage	0.171	1.564
Concentrates	0.150	1.800
Whole grain	0.470	3.905
Other (Palm Kernel)	0.3378	2.2513

3.4. Supplements exported

The on-farm emissions associated with exporting a supplement are estimated separately (export report source) and hence are not included in the animal source or product footprints.

To ensure that area based emissions from different farms can be added together, exported supplement should have the same emission as imported supplement, and the farm exporting them should have a credit (negative emission). Therefore, exported supplement emission factors are estimated in the same way as imported supplement emission factors. Technically, the farm receiving the supplement should use the same emission factor as the farm making and exporting the supplements.

Equation 80: $SuppExportCO2_{export} = \sum_{supp}(DMExport * EFsupExportCO2_{supptype})$

Equation 81: $SuppExportEnergy_{export} = \sum_{supp}(DMExport * EFsupExportEnergy_{supptype})$

DMExport is the weight of supplement DM (kg DM /year) exported.

supptype is the supplement type shown in Table 14.

EFsupCO2 (kg CO_2 equivalents/kg DM) and EFsupEnergy (MJ/kg DM) are emission factors [Table 14].

Table 14. Embodied CO_2 and energy emissions for exported supplements for the area report.

Supplement type	kg CO_2 equivalents/kg DM	MJ/kg DM
Hay	0.129	1.329
Silages	0.150	1.781
Baleage	0.150	1.781

Note that exported crops, including exported fodder crops, are allocated to the crop greenhouse gas report source. To be consistent with transferring of supplements between farms, the farm receiving the imported crop supplements should have the same emissions as the farm exporting the crop. This has not been implemented.

3.5. Fertiliser

Embodied emissions for fertiliser include emissions associated with mining raw materials, manufacturing and processing, and transport to a central depot. Emissions associated with fuel use for transport from the primary depot to the farm and spreading are estimated separately (section 3.2.5.3 and 3.2.5.4).

LCA analysis was used to estimate embodied emission for fertiliser products. Examples are shown in Table 15. However, in the model, the product is not always known, such as when the user defined option or total nutrient contents applied are used. Therefore, the emissions are based on nutrient form. Wells (2001) noted that calculating costs based on nutrient content gave higher values than those reported, but the difference was not too high when capital costs, transport etc. are taken into account.

Emission factors for NaCl (salt) used in LCA databases from Europe are based on the production of dry sodium chloride by underground mining and by solution mining. In Europe, salt production using solar evaporation accounted for less than 15 % of the total salt production. Salt production using solar evaporation, the principle method used in New Zealand, would have lower emissions. Therefore, it is assumed that energy costs for salt production by solar evaporation are similar to lime.

Table 15. Embodied CO_2 and energy emission factors for fertiliser products derived from LCA analysis.

Product	Unit	kg CO_2 equivalents /unit	MJ /unit	Source[1]
Urea	kg Urea	1.06	29.47	1
Calcium ammonium nitrate (CAN)	kg CAN	1.93	14.79	3
Sulphate of ammonia (SOA)	kg SOA	0.61	9.54	
NZ Single superphosphate (SSP)	kg SSP	0.22	2.64	2
KCl	kg KCl	0.58	8.91	3
K_2SO_4	kg K_2SO_4	0.77	11.42	3
DAP	kg DAP	1.12	16.50	
Triple superphosphate (TSP)	kg TSP	0.60	10.95	
PR	kg PR	0.32	4.05	
Elemental S	kg S	2.33	3.24	
MgO	kg MgO	2.82	11.93	

[1] Sources

1 Ledgard and Boyes (2010) and Ledgard *et al.* (2011a)
2 Industry data for the year 2009.
3 Production data from EFMA LCI database coupled with NZ fertiliser industry data on importation rates and sources.

The embodied emissions for each nutrient form are shown in Table 16. Other than taking account of the proportion of nutrient in a product, the following assumptions were made when deriving emissions based on nutrient contents:

- Other sources of N were based on CAN value
- N in DAP is ignored to prevent double accounting with P in DAP
- Embodied CO_2 emissions of P in super was 2.37 kg CO_2 equivalents/kg P and for P in TSP was 2.92 kg CO_2 equivalents/kg P. Therefore, the difference between triple and single superphosphate was ignored.
- P from other sources was treated as DAP. These sources tend to occur in complex mixes.
- Most K in New Zealand is applied as KCl and hence the emission factors for KCl are used for K fertiliser form. The emission factor for K_2SO_4 is 30% higher but this difference would have minimal effect on whole farm embodied emissions.
- S as sulphate has no embodied emissions as these are included in the embodied cost of products such as SSP or TSP.
- Ca fertiliser form has no embodied emissions as these are covered in the embodied cost of products such as SSP.
- Mined Mg products such as dunite are treated as if serpentine. A mean value of serpentine and MgO is used for other forms of Mg ($MgCl_2$, $MgSO_4$).

Table 16. Greenhouse gas and energy emission factors for fertiliser nutrient forms.

Nutrient form	Emission factor	Product based on	Percentage nutrient in product	kg CO2 equivalents/kg nutrient	MJ/kg nutrient
N as Urea	EFNurea	Urea	0.46	2.30	64.1
N as DAP	EFNDAP	Nil		0.00	0.0
N as otherNH3. NO3 and mixed	EFNother	CAN	0.27	7.15	54.7
P as super	EFPsuper	SSP	0.093	2.37	28.4
P as DAP	EFPDAP	DAP	0.201	5.57	82.1
P as rock	EFProck	PR	0.127	2.52	31.9
P as other	EFPOther	DAP	0.201	5.57	82.1
K	EFK	KCl		1.16	17.8
S as sulphate	EFSsulphate	Nil		0	0
S as elemental	EFSelem	Elemental S		2.33	3.24
Ca	EFCa	Nil		0.00	0.0
Mg as serpentine	EFMgOther	Serpentine – Mg	1.00	0.11	1.7
Mg as MgO	EFMgO	MgO	1.00	6.05	25.5
Mg as Dolomite	EFMgDolomite	Lime	1.00	See lime	See lime
Mg as Other	EFMgOther	average	1.00	3.08	14.5
Na	EFNa	NaCl	0.39	0.02	0.5

Thus, embodied fertiliser emissions (kg CO_2 equivalents/year or MJ/year) are estimated as:

Equation 82: $FertCO2_{gsource} = \sum_{block}(BlockFertCO2 * psource_{block,\ gsource})$

Equation 83: $FertEnergy_{gsource} = \sum_{block}(BlockFertEnergy * psource_{block,\ gsource})$

$BlockFertCO2 = \sum_{nut}(Rate_{fertnut} * area_{block} * EFfertnutCO2_{fertnut})$

$BlockFertEnergy = \sum_{nut}(Rate_{fertnut} * area_{block} * EFfertnutEnergy_{fertnut})$

rate is the amount of rate of fertiliser nutrient for a given form (kg nutrient/ha/year) applied during year (kg/ha).

area is block area (ha).

EFfertnutCO2 (kg CO_2 equivalents/kg lime) and EFfertnutEnergy (MJ/kg lime) are emission factors [Table 16].

$psource_{block,\ gsource}$ is the block allocation [section 1.2.1].

Note that direct CO2 emissions for dolomite Mg source is added to fertiliser embodied emissions.

3.6. Lime

Embodied emissions for mining lime include emissions associated with mining raw materials, crushing and screening, and transport to a central depot. Only lime applied in the current year is considered – lime applied in previous years or the first year of a crop rotation is ignored.

$LimeCO2_{gsource} = \sum_{block}(BlockLimeCO2 * psource_{block, gsource})$

$LimeEnergy_{gsource} = \sum_{block}(BlockLimeEnergy * psource_{block, gsource})$

$BlockLimeCO2_{block} = rate * area_{block} * EFLimeCO2$

$BlockLimeEnergy_{block} = rate * area_{block} * EFLimeEnergy$

rate is the amount of lime applied during year (kg/ha).

area is block area (ha).

EFLimeCO2 (kg CO_2 equivalents/kg lime) and EFLimeEnergy(MJ/kg lime) are emission factors [Table 17].

$psource_{block, gsource}$ is the block allocation [se section 1.2.1].

Table 17. Embodied CO2 and energy emission factors for lime.

Product	kg CO_2 equivalents/kg lime	MJ/kg lime
Lime	0.004	0.091

Source: Ledgard *et al*. (2011)

3.7. Organic material

Embodied CO_2 and energy emissions for composts, imported solid effluents and other organic products added as a fertiliser can be estimated as:

Equation 84: $OrganicCO2_{gsource} = \sum_{block}(BlockOrganicCO2 * psource_{block, gsource})$

Equation 85: $OrganicEnergy_{gsource} = \sum_{block}(BlockOrganicEnergy * psource_{block, gsource})$

$BlockOrganicCO2 = \sum_{nut}Rate * area_{block} * EFOrganicCO2$

$BlockOrganicEnergy = \sum_{nut}Rate * area_{block} * EFOrganicEnergy$

rate is the amount of organic material applied during year (kg/ha).

area is block area (ha).

EFOrganicCO2 (kg CO_2 equivalents/kg organic material) and EFOrganicEnergy (MJ/kg organic material) are emission factors [Table 18].

$psource_{block, gsource}$ is the block allocation [section 1.2.1].

For crops, only organic material applied in the current year of a crop rotation is included.

As most organic material is a waste by-product, embodied CO_2 and energy emissions are currently set to zero.

Table 18. Embodied CO_2 and energy emission factors for organic materials.

Product	kg CO_2 equivalents/kg material	MJ/kg material
Composts/mulches	0	0
Dairy factory effluent	0	0
Piggery effluent	0	0
Imported dairy effluent	0	0
Other organic material	0	0

3.8. Animal health supplements

Embodied CO_2 emissions for animal health products are calculated from the calculated rate of nutrients supplied to animal type and the type of product typically used. It was assumed that embodied emissions:

- of all Mg products used for animal health have the same embodied emissions factors as fertiliser MgO. Mg can be supplied as MgO, $MgSO_4$ or $MgCl_2$.
- are zero for S as S is applied as $MgSO_4$ and embodied emissions are already accounted for by Mg.
- of Ca is accounted for as lime.
- of Na is accounted for as fertiliser salt.
- of N is accounted for as urea.
- of P is accounted for as manufactured P product (P type other).
- of other nutrients is zero.

Embodied emissions of Animal health products (kg CO_2 equivalents or MJ) are estimated as:

Equation 86: $$AnHealthCO2_{antype} = drench_{antype,\ Mg} * EFMgOCO_2 + drench_{antype,\ Na} * EFSaltCO_2 + drench_{antype,\ Ca} * EFLimeCO_2 + drench_{antype,\ N} * EFUreaCO_2 + drench_{antype,\ P} * EFPOtherCO_2$$

Equation 87: $$AnHealthEnergy_{antype} = drench_{antype,\ Mg} * EFMgOEnergy + drench_{antype,\ Na} * EFSaltEnergy + drench_{antype,\ Ca} * EFLimeEnergy + drench_{antype,\ N} * EFUreaEnergy + drench_{antype,\ P} * EFPOtherEnergy$$

drench are nutrients added as animal health supplements (kg nutrient/year).

EFfertnutCO2 (kg CO_2 equivalents/kg nutrient) and EFfertnutEnergy (MJ/kg nutrient) are emission factors [Table 16].

3.9. Chemicals (herbicides and pesticides)

Chemicals used on farms include fungicides, bactericides, herbicides, insecticide, acids, and alkalis, pharmaceuticals and animal remedies (drench, bloat aids). All these have associated embodied greenhouse gas and energy emission factors for the manufacture and transport of these products. The emissions associated with the use of these chemicals are a very small proportion of total emissions. For this reason, only default values are used.

3.9.1. Parasite control

The average amount of active ingredient used per animal for parasite control was estimated using a survey of the national amount of chemicals used for external parasite control (Reid 2004) divided by the national number of animals. The emission per kg of active ingredient was estimated using manufacturing emission factors, 7.42 CO_2 equivalents and 213.75 MJ for unspecified chemicals (Ecoinvent 2010). In addition, it was assumed that these chemicals were made in Australia, shipped to Auckland and transported 100km to the farm. The transport component contributed less than 1% to the emissions per kg active ingredient. The emission factors are shown in Table 19.

Dairy animals were assumed to be the same as beef animals, and other animal types the same as deer, the exception being sheep. Sheep have higher emissions for parasite control on an animal and RSU basis than all other animal types.

Table 19. Embodied CO_2 and energy emissions for parasite control

Source	kg CO_2 equivalents/animal	MJ/animal
Sheep	0.010001	0.276667
Beef and dairy	0.005604	0.155033
Deer and other	0.000075	0.002079
Dairy goat	0.000160	0.004421

The above emission factors are on a per animal basis. The number of animals is estimated as revised stock units for animal type divided by a default RSU per animal. Thus:

Equation 88: $Nanimal_{antype} = RSU_{antype} / RSUanimal_{antype}$
RSU is the calculated RSU for each animal type [Animal model chapter].
RSUanimal is standardised RSU/animal [Animal model chapter].

The embodied emissions (kg CO_2 equivalents or MJ) for parasite control are estimated as:

Equation 89: $ParasiteCO2_{antype} = EFparasiteCO2 * Nanimal_{antype}$
Equation 90: $ParasiteEnergy_{antype} = EFparasiteEnergy * Nanimal_{antype}$
EFparasiteCO2 (kg CO_2 equivalents/animal) and EFparasiteEnergy(MJ/animal) arre emission factors [Table 19].

3.9.2. Bactericide, fungicide, herbicide, and insecticide use

A survey of the use of farm fungicides, bactericides, herbicides, and insecticides described the areas to which they were applied, the amount of farm fungicide, bactericide, herbicide, and insecticide used, and the active ingredients of a range of classes of chemicals used for pastoral, and fruit, vegetable and arable crops (Manktelow *et al*., 2005). This survey highlighted the greater use of bactericide, fungicide, herbicide, and insecticide on fruit crop systems compared to other land uses.

The embodied emissions for several classes of chemicals were unknown. Therefore, embodied emissions were estimated by estimating the amount of active ingredient applied from tables in Manktelow *et al*. (2005) and emission factors for an unspecified chemical of 7.42 kg CO_2 equivalents/kg active ingredient and 213.75 kg MJ/kg active ingredient. This approach is likely to misrepresent systems that predominately use chemicals with low or high emission factors. It is probable that chemical embodied emissions are overestimated for sheep and beef systems as they tend to use chemicals with lower emissions.

Estimates of emission factors based on data reported by Manktelow *et a*l. (2005) are shown in Table 20. Dairy replacements were assumed to have the same emission factor as sheep. Cut and carry blocks and grazed pasture within crop systems were also assumed to have the same emission factor as sheep. For crops, forages were assumed to have the same emission factor as 'Cereal silage' silage or 'Baleage'. Fodderbaleage', fodder crops and seed were assumed to have the same emission factor as 'Forage brassica'. The emission factors of other crops were used as specified in Table 20, and where these were absent, if not listed in this table, the average values were used.

Table 20. Embodied CO_2 and energy emissions for bactericide, fungicide, herbicide, and insecticide use.

Source	kg CO_2 equivalents / ha	MJ / ha
Pastoral		
Dairy	1.9	55.9
Dairy replacements	0.5	13.4
Sheep and beef	0.5	13.4
Deer and other	0.5	13.4
Forestry	2	57
Cut and carry	0.5	13.4
Fruit crops		
Kiwifruit	179	5165
Apples	267	7705
Grapes (wine)	82	2362
Peaches/Nectarines	339	9768
Avocado	232	6689
Vegetables		
Carrots	113	3244
Cauliflower/Cabbage/Brussels sprouts, Broccoli	90	2594
Cucumber, Capsicum	151	4338
Kumara	52	1484
Lettuce	129	3712
Onion/garlic	205	5919
Peas, Beans	25	708
Potatoes	147	4233
Pumpkins	76	2185
Silver beet, Spinach	65	1862
Squash	100	2890
Sweet corn	41	1189
Tomatoes (outdoors)	157	4519
Average	104	2991
Fodder and green feed		
Cereal silage or baleage	6	179
Forage brassica	14	401
Maize silage or baleage	29	832
Average	16	471
Grain		
Barley	16	471
Maize-grain	29	832
Oats	4	122
Wheat	20	571
Average	17	499

The embodied emissions (kg CO_2 equivalents or MJ) for bactericide, fungicide, herbicide, and insecticide use are estimated for pastoral blocks as:

Equation 91: $ChemSprayCO2_{gsource} = ChemCO2_{gsource} * area_{block} * psource_{block, gsource}$

$ChemCO2_{gsource} = blockspray$ for fodder crop and cropping blocks

= $EFChemCO2_{antype}$ for pastoral blocks
= 0.5 for cut and carry blocks
= $EFChemCO2_{crop}$ for fruit blocks

EFChemCO2 (kg CO_2 equivalents / ha) is the emission factor [Table 20].

area is the block area (ha).

$psource_{block, gsource}$ is the block allocation [section 1.2.1].

Blockspray is calculated for crops present during the current year and is the sum of the emission factors for crops crop at the time of sowing, plus for those crops with a 12-month emissions (pasture, annual ryegrass, seed crops), the crop emission factor divided by 12 multiplied by the number of months the crop was present.

The embodied energy emission was based on a regression fit between the emission factors shown in Table 20 that gave:

Equation 92: EFChemEnergy = 28.823 * EFChemCO2- 1.0295

3.9.3. Other chemicals

Other chemicals used on the farm include acids and alkalis for washing down milking plants, animal remedies such as drench or bloat aids, and other chemicals such as detergents. All these products have an embodied emission.

An industry source indicated that approximately 3.5 litres of chemical are used per dairy cows for wash down, bloat aid, etc. This was assumed to be the minimum amount of chemical used on the farm, and hence used as the default value. This chemical is assumed to be acid/alkalis.

The embodied emissions (kg CO_2 equivalents or MJ) for other chemicals are estimated as:

Equation 93: OtherChemCO2 = acidAlkaliAI * EFacidAlkaliCO2 * $psourceantype_{antype}$ +
AnRemAI * EFAnRemCO2 * $psourceantype_{antype}$ +
otherchemAI * EFotherchemCO2 * $psourceantype_{antype}$ +
DefaultDairyAI * EFacidAlkaliCO2 * $ratio_{antype}$

Equation 94: OtherChemEnergy = acidAlkaliAI * EFacidAlkaliEnergy * $psourceantype_{antype}$ +
AnRemAI * EFAnRemEnergy * $psourceantype_{antype}$ +
otherchemAI * EFotherchemEnergy * $psourceantype_{antype}$ +
DefaultDairyAI * EFacidAlkaliEnergy

acidAlkaliAI = acidAlkali * AIacidAlkali

acidAlkali is the entered amount of acids and alkalis used or zero (litres/year).

AIacidAlkali is the proportion of active ingredient in acids and alkalis [Table 21].

AnRemAI = AnRem * AIAnRem

AnRem is the entered amount of animal remedies used or zero (litres/year).

AIAnRem is the proportion of active ingredient in animal remedies [Table 21].

otherchemAI = otherchem * AIotherchem

otherchem is the entered amoutn of of chemicals used or zero ((litres + kg)/year).

AIotherchem is the proportion of active ingredient in other chemicals[Table 21].

DefaultDairyAI = (DefChemUse – chemused) * AIacidAlkali

Chemused = acidAlkali + AnRem + otherchem * $psourcefarm_{gsource}$

$psourcefarm_{dairy}$ is the farm allocation [1.2.1].

DefChemUse = 3.5 * NumberCows + 3.5 * (NumMilkingGoats / 8)

ratio	= (3.5 * ANumbercows) / DefChemuse	for dairy
	= (3.5 * (NumMilkingGoats / 8)) / DefChemuse	for dairy goats
	= 0	otherwise

EFacidAlkaliCO2, EFAnRemCO2, EFotherchemCO2 are emission factor for CO_2 (kg CO_2 equivalents /kg active ingredient) [Table 21].

EFacidAlkaliEnergy, EFAnRemEnergy, EFotherchemEnergy are emission factors for energy (MJ/kg active ingredient) [Table 21].

Table 21. Embodied CO2 and energy emissions for other chemicals.

Type / input	Unit	% active ingredient	Energy Coefficient (MJ/kg active ingredient)	CO_2 emission factor (kg CO_2 equivalents /kg active ingredient)
Acids and alkalis	litres/year	50	10	0.6
Animal remedies (drench, bloat aids)	litres/year	50	220	13
Other chemicals	(litres + kg)/year	50	220	13

Source: Wells (2001), section 3.4.2

Bug: Wells (2001) only included the CO_2 emissions in his calculation and hence the CO_2 emissions factors are underestimated.

3.10. Plastics

New Zealand farms use plastic for wraps and containers. A survey indicated that this amounted to 74 kg LDPE per farm and 42 kg HDPE per farm for both dairy, and sheep and beef farms (Dolan 2004).

The LDPE plastic is mainly used for wrapping silages and baleage. The model records supplements that are wrapped. Emissions factors for plastic use for supplements made on farm were based on 0.96 kg LDPE/ 200 kg bale and an LCA of New Zealand plastic use (Boyes pers. comm.), and expressed on a kg DM basis. For silage stacks, DM was divided by 4 as there is probably less plastic used per volume of silage. The plastic used for imported hays and silage is included as part of the embodied costs of those products.

The emission factors for HDPE were based on a LCA of New Zealand plastic use on dairy farms (Boyes, pers. comm.) to give 155 kg CO_2 equivalents/farm and 3,3343334 MJ/ farm. To ensure emission factors could be scaled to match the area of the farm, factors were expressed in terms of per unit area assuming a farm area of 123 ha, the area of the NZ weighted average dairy farm in 2004/2005 (Ledgard *et al*., 2009). As most of this type of plastic is used to store chemicals, default values are based on chemical emissions (Table 21). On average, compared to dairy farms, non-dairy farms are 4.2 times lower, fodder crops are 8.9 times higher, other crops 53.5 times higher and fruit blocks 92 times higher.

The embodied CO_2 emissions (kg CO_2 equivalents/year) for plastics are estimated as:

Equation 95: $PlasticCO2_{antype} = HDPECO2_{antype} + farmSupWrapCO2_{antype}$

where emissions from HDPE plastics is estimated as:

Equation 96: $HDPECO2_{antype} = plasticCO2_{gsource} + FodderCO2_{gsource}$

$plasticCO2_{dairy} = EFplasticdairyCO2 * gArea_{dairy}$

EFplasticdairyCO2 (kg CO_2 equivalents/ha) is emission factor for dairy [Table 22].

gArea is the area (ha) used by a greenhouse gas report source [section 1.2.2].

$plasticCO2_{antype} = EFplasticdairyCO2 / 4.2 * gArea_{antype}$

$plasticCO2_{crop} = EFplasticdairyCO2 * 53.5 * gArea_{Crop}$

$plasticCO2_{hort} = EFplasticdairyCO2 * 92 * gArea_{Hort}$

$FodderCO2_{gsource} = \sum_{block}(EFplasticdairyCO2 * 8.9 * area_{block} * psource_{block, gsource})$

area is block area (ha).

$psource_{block, gsource}$ is the block allocation [section 1.2.1].

and emissions from LDPE plastics (wraps) is estimated as:

Equation 97: $farmSupWrapCO2_{source} = EFplasticFarmsupCO2 * SupCO2$

EFplasticFarmsupCO2 (kg CO_2 equivalents/ha) is emission factor for on-farm supplement wrap [Table 22].

$SupCO2 = SupDMWrap_{block} * pSupsourceblock_{block, gsource}$

$SupDMWrap_{block}$ is the supplement DM removed from each block (kg DM/ha).

$pSupsource_{block, gsource}$ is the allocation based on the source of the supplement [section 1.2.1].

A similar calculation is undertaken for energy.

Table 22. Embodied CO_2 and energy emission factors for plastics.

Product	CO_2	Energy
On-farm supplement wrap	0.01237 kg CO_2 equivalents/kg DM	0.2792 MJ/kg DM
HDPE plastics Dairy	1.26 kg CO_2 equivalents/ha	27.11 MJ/ha

3.11. Importing or exporting effluents

Different effluents can be exported from or imported onto farms. The model has the facility to link the direct export of effluent from one farm (file) to importing of effluent into another, to apply imported effluent as an organic material, or to export effluent. Thus, imported effluent need not come from a farm of the same type.

IDF (2010) recommends that system expansion be applied to the export of manure, assuming that effluent is a substitute for chemical fertiliser. However, within a farm using imported effluent, fertiliser substitution is modelled by a change in N fertiliser use. In cases where system expansion is used it would double account for this.

For this reason, the model assumes that there are no embodied emissions associated with importing or exporting effluent. Emissions associated with application of effluents, such as methane or nitrous oxide, are determined separately and hence are only included on the farm where the application occurs.

3.12. Seeds

Seed weight for the whole farm can be entered, or a default value estimated from cropping regimes. The default seed weight is estimated for fodder crop and crop blocks only based on typical sowing rates as shown in Table 23. These values were based on reported values from a range of internet sites, including (in alphabetical order):

http://www.agriseeds.co.nz
http://www.pioneer.co.nz
http://www.ruralfind.co.nz
http://www.seedandfield.co.nz
http://www.specseed.co.nz
http://www.smithseeds.co.nz

Table 23. Typical sowing rate for crops

Crop	Sowing rate (kg/ha)
Barley (spring)	130
Maize (short)	50
Maize (medium)	50
Maize (long)	50
Oats (spring)	110
Oats (autumn)	110
Wheat (spring)	135
Wheat (autumn)	135
Broccoli (winter/spring)	3

Crop	Sowing rate (kg/ha)
Broccoli (summer)	3
Brussel sprouts	3
Cabbage (winter/spring)	3
Cabbage (summer)	3
Cauliflower (winter/spring)	3
Cauliflower(summer)	3
Lettuce	3
Spinach	3
Beans (green)	85
Beans (dried)	85
Lentils	18
Peas (green)	140
Peas (dried)	140
Kumara	100 [1]
Potato (short)	100 [1]
Potato (medium)	100 [1]
Potato (long)	100 [1]
Beets	8
Carrots	2
Parsnips	20
Clover seed	4
Ryegrass seed	20
Onions	3
Sweet corn	3
Squash	3
Tomato	3
Brassica	3
Lupins	150
Mustard	10
Oats and rye	120
Phacelia	5
Forages	
Annual ryegrass	25
Forage barley (spring)	130
Forage oats (spring)	110
Forage oats (autumn)	100
Maize silage	40
Rye corn (spring)	140
Rye corn (autumn)	140
Triticale (spring)	140
Triticale (autumn)	140
Fodder crops	
Fodder beet	5
Kale	5
Rape	4

Crop	Sowing rate (kg/ha)
Swedes	1
Turnips bulb	1
Leaf turnips	4
Pasture	
Pasture seed mix	18

[1] estimated seed equivalent for plants

Thus, default seed weight per block is estimated as:

Equation 98: $SeedweightDef_{gsource} = \sum_{block}(\sum_{crop}(sowingrate_{crop}) * area_{block} * psource_{block, gsource})$

sowingrate is default seed sowing rate (kg seed/ha) [Table 23].
area is block area (ha).
$psource_{block, gsource}$ is the block allocation [section 1.2.1].

User-entered seed weight is allocated to greenhouse gas source using estimated default seed weight. Thus:

Equation 99: $Seedweight_{gsource} = SeedweightIn * psourceseed$

SeedweightIn is the entered seed weight (kg seed/year).
psourceseed $= psourceseed_{gsource}$ if $\sum Seedweight_{gsource} > 0$
$= psourcefarm_{gsource}$ otherwise
$psourceseed_{gsource} = seedweightDef_{gsource} / \sum SeedweighDef_{gsource}$
$psourcefarm_{gsource}$ is the farm allocation [section 1.2.1].

Thus seed embodied emissions are estimated as:

Equation 100: $SeedCO2_{gsource} = Seedweight_{gsource} * EFSeedCO2$

Equation 101: $SeedEnergy_{gsource} = Seedweight_{gsource} * EFSeedEnergy$

EFSeedCO2 (kg CO_2 equivalents/kg seed) and EFSeedEnergy (MJ/kg seed) are emission factors [Table 24].

Emission factors (Table 24) are taken from Wells (2001, section 3.4.3).

Table 24. Embodied CO2 and energy emission factors for seed.

Product	kg CO_2 equivalents /kg seed	MJ/kg seed
Seed	0.6	1.0

Bug: Wells (2001) only included the CO_2 emissions in his calculation. Hence the CO_2 emissions factor is underestimated. A more appropriate value is about 1.0 kg CO_2 equivalent /kg seed. This will be updated in a future release.

3.13. Race aggregates

The amount of race aggregate (m^3/year) can be entered, or a default value is used. The entered amount is assumed to be used by all report sources. Hence emissions are allocated as:

Equation 102: $Aggregrate_{gsource}$ = AggregrateIn * $psourcefarm_{gsource}$
AggregrateIn is the entered amount (m^3)
$psource_{gsource}$ is the farm allocation [section 1.2.1].

Based on Wells (2001), a 100 ha farm with 2.2 km races, averaging at 5 m wide, with aggregate applied to a depth of 0.1 m, would require 16.5 tonnes aggregate per ha. Assuming a bulk density of 1500 kg/m^3, 11 m^3/ha would be needed. With a life span of 30 years and assuming some replacement is needed each year, a default of 0.5 m^3/year was used. It is assumed that the default rate was only applied to the dairy area. Thus:

Equation 103: $Aggregrate_{dairy}$ = 0.5 * $area_{dairy}$

Emission factors are based on an energy co-efficient of 0.1 MJ/kg, and a carbon dioxide coefficient equal to that of diesel (0.0808 kg CO_2/MJ) as reported in Wells (2001, section 3.4.2). Although Wells (2001) only included the CO_2 emissions in his calculation, most of the CO2 emissions were associated with fuel used to mine and transport the aggregate. For this reason, it was considered that this value was appropriate.

Table 25. Embodied CO_2 and energy emission factors for race aggregate.

Product	kg CO_2 equivalents/m^3 aggregate	MJ/m3 aggregate
Race aggregate	12.12	150

Thus, aggregate emissions are estimated as:

Equation 104: $AggregrateCO2_{gsource}$ = $Aggregrate_{gsource}$ * EFAggregrateCO2
Equation 105: $AggregrateEnergy_{gsource}$ = $Aggregrate_{gsource}$ * EFAggregrateEnergy
EFAggregrateCO2 (kg CO_2 equivalents /m^3 aggregrate) and
EFAggregrateEnergy (MJ/m^3 aggregrate) are emission factors [Table 25].

3.14. Pasture consumed

3.14.1. Wintering off pasture production

Embodied emissions associated with producing pasture dry matter eaten while livestock are wintering off were estimated for an average NZ dairy farm in 2004/05. The LCA analysis included emissions from the fertilisers and lime applied at rates based on an average NZ dairy farm during for 2004/05. The emission factors are expressed on a kg DM intake (DMI) of the animals wintered-off. Transport of animals is covered under transport fuel costs (section 3.2.5.6).

The emissions (kg CO_2 equivalents/year or MJ/year) for pasture eaten while animals are grazed off are estimated as:

Equation 106: $WinteroffCO2_{antype}$ = $MEWinter_{antype}$ / pastureME * EFwinteroffCO2

Equation 107: $WinteroffEnergy_{antype} = MEWinter_{antype} / pastureME * EFwinteroffEnergy$

$MEWinter_{antype}$ is the estimated ME intake while animals are wintered off (MJ/year).

pastureME (MJ/kg DMI) is the default value for the region [Characteristics of pasture chapter].

EFwinteroffCO2 (kg CO_2 equivalents/ kg DMI) and EFwinteroffEnergy(MJ/kg DMI) are emission factors [Table 26].

The default pasture ME is used as the pasture quality of the receiving farm is unknown.

Table 26. Emission factors for pasture eaten while wintering off

Source	kg CO_2 equivalents/kg DMI	MJ/kg DMI
Pasture eaten while wintering off	0.088	0.308

3.14.2. Off-farm dairy replacements' pasture production

The emissions factors associated with producing pasture dry matter eaten while replacements are grazed off was based on a LCA. Pasture production was based on a North Island intensive farm system, finishing sheep and beef, with a stocking rate of 11.5 RSU per ha, and fertiliser & lime applied at rates based on requirements of a sheep and beef farm operating at that level of production. Emission factors are expressed in terms of kg DMI of replacements grazed off. They are lower than those of dairy cows grazed off as fertiliser N use was typically lower on 'runoff' blocks. Transport of animals is covered under transport fuel costs (section 3.2.5.6)

The emissions (kg CO_2 equivalents/year or MJ/year) for pasture eaten while animals are grazed off are estimated as:

Equation 108: $RepGrazeoffCO2_{dairy} = MERepGrazeoff_{dairy} / pastureME * EFGrazeoffCO2$

Equation 109: $RepGrazeoffEnergy_{dairy} = MEWinter_{dairy} / pastureME * EFGrazeofffEnergy$

$MERepGrazeoff_{dairy}$ is the estimated ME intake of dairy replacements grazed off (MJ/year).

pastureME (MJ/kg DMI) is the default value for the region [Characteristics of pasture chapter].

EFGrazeoffCO2 (kg CO_2 equivalents / kg DMI) and EFGrazeofffEnergy (MJ/kg DMI) are emission factors [Table 27].

The default pasture ME is used as the pasture quality of the receiving farm is unknown.

Table 27. Emission factors for pasture eaten while replacements are grazed off-farm

Source	kg CO_2 equivalents/kg DMI	MJ/kg DMI
Pasture eaten while replacements are grazed off-farm	0.0574	0.5336

3.14.3. Non-pastoral blocks

There was no available method able to allocate emissions occurring on fruit blocks arising from pasture consumed by animals. DM intake by each animal type is estimated. Thus the embodied emissions due to pasture intake were estimated using the same method as for wintering off. These emissions were then added to animal emissions and subtracted from fruit emissions.

Hence the emissions (kg CO_2 equivalents/year or MJ/year) transferred from the fruit crop block to animal source are estimated as:

Equation 110: $FruitAnimalCO2_{antype} = (\sum Animalconsume_{antype}) * EFwinteroffCO2$

Equation 111: $FruitAnimalEnergy_{antype} = (\sum Animalconsume_{antype}) * EFwinteroffEnergy$

$Animalconsume_{antype} = pastureDMconsumed_{block} * BlockSU_{block, ansy} * area_{block}$

pastureDMconsumed is calculated pasture consumed on a block (kg/ha).

$BlockSU_{block, ansy}$ is the proportion of intake by each animal type.

$area_{block}$ is the area of block (ha).

EFwinteroffCO2 (kg CO_2 equivalents / kg DMI) and EFwinteroffEnergy(MJ/kg DMI) are emission factors for wintering off [Table 26].

3.15. Re-grassing

Implicit within the definition of a fodder crop block is the assumption that the pasture is re-sown after completion of the crop. Re-grassing was included as part of the LCA analysis for imported crops supplements (Boyes, pers. comm.).

Table 28. Emission factors for re-grassing pasture after growing fodder crops

Re-grassing	**kg CO_2 equivalents/ha**	**MJ/ha**
Re-grassing (exclude N2O from crop residue)	496	3746
Re-grassing (include N2O from crop residue)	1540	3846
Re-grassing (exclude N2O from crop residue, include maintenance fertiliser)	2679	15673
Re-grassing (include N2O from crop residue and maintenance fertiliser)	3201	15673

This analysis indicated that the after cultivation, emissions due to re-grassing increased with increasing fertiliser input, particularly N. Thus:

Equation 112: $regrassCO2 = 0.0268 + 0.0021 * FertN$

FertN = fertiliser N applied after sowing grass (kg N/ha)
= 50 if details for regrassing not entered

This approach assumes that inputs of other fertilisers also increase in a similar manner to N.

Equation 113: $ReGrassCO2_{antype} = 496 * EFwinteroffCO2$

Equation 114: $ReGrassEnergy_{antype} = 3746 * EFwinteroffEnergy$

3.16. Capital embodied CO_2 emissions

Embodied emissions due to capital development are a small proportion of total emissions from a farm. Therefore, default calculated values of base levels of capital emissions have been included largely to illustrate this point, and to maintain backwards compatibility with earlier versions. Capital emissions are not included in greenhouse gas reports following PAS 2050 standards (BSI 2008).

Equation 115: $capitalCO2_{gsource} = baseenergy_{gsource} * 0.107$
$+ CapitalIrrCO2_{gsource}$
$+ CapitalPadCO2_{gsource}$
$+ CapitalPondCO2_{gsource}$
$+ GoatMilkShedCO2_{gsource}$

Equation 116: $capitalEnergy_{gsource} = baseenergy_{gsource}$
$+ CapitalIrrEnergy_{gsource}$
$+ CapitalPadEnergy_{gsource}$
$+ CapitalPondEnergy_{gsource}$
$+ GoatMilkShedEnergy_{gsource}$

basenergy $= Enteredbase * Defaultbase_{gsource} / \sum_{gsource} Defaultbase_{gsource}$
$= Defaultbase_{gsource}$

Defaultbase is the base capital emissions [section 3.16.1].

Enteredbase is the base captial energy calcuated from inputs [section 3.16.2].

$CapitalIrrCO2_{gsource}$ and $CapitalIrrEnergy_{gsource}$ [section 3.16.2.3].

$CapitalPondCO2_{dairy}$ and $CapitalPondEnergy_{dairy}$ [section 3.16.2.4].

$CapitalPadEnergy_{dairy}$ and $CapitalPondEnergy_{dairy}$ [section 3.16.2.5].

$GoatMilkShedEnergy_{dairygoats}$ and $CapitalPondEnergy_{dairygoats}$ [section 3.16.2.6].

Note: These emission factors are based on Wells (2001) which only included the CO_2 emissions. For this reason, capital CO_2 emission factors are underestimated.

3.16.1. Base capital default energy emissions

The base capital energy emissions for dairy were taken from Wells (2001, section 3.5, Fig 4.16). Capital emissions decrease with area. For this reason, a minimum value for capital cost per-hectare was set to ensure low or negative base capital energy emissions would be reported for farms with large areas of land. As no areas except Canterbury included irrigation, the base capital energy emissions excluded irrigation. Base capital is estimated as:

Equation 117: basenergy = Edefcapdairy — dairy
= Edefcapdairygoats — dairy goats
= Edefcapnondairy * ratioAn — non-dairy animals
= 0 — otherwise

$Edefcapdairy = estdef * 1000 * area_{dairy}$

$estdef = 3.2 - 0.009 * area_{dairy}$ $estdef >= 0.8$

$Edefcapdairygoats = estdef * 1000 * area_{dairygoats}$

$estdef = 2 - 0.003 * area_{dairygoats}$ $estdef >= 0.8$

$Edefcapnondairy = estdef * 1000 * area_{nondairy}$

$estdef = 2.0 - 0.003 * area_{nondairy}$ $estdef >= 0.5$

ratioAn = AAreaansys[ansys] / AreaNondairy

Bug: Capital emissions for drainage should be included in base default but is currently not.

3.16.2. Capital energy emissions using entered inputs

The model allows specific capital inputs to be entered to calculate farm specific capital energy and CO_2 emissions in place of default values. The inputs and calculation methods are taken from Wells (2001, section 3.5). Thus capital energy and CO_2 emissions is calculated as:

Equation 118: $CapitalCO_2 = \Sigma(size * CO_2 / duration)$

Equation 119: $CapitalEnergy = \Sigma(size * Energy / duration)$

size, energy, CO_2 and duration are listed in Table 29.

When calculating capital costs for deer farms, fence costs were increased by 30% multiplied by the ratio of deer RSU to non-dairy RSU. This additional cost is included to account for the extra height requirements for deer fences.

3.16.2.1. *General methods*

The general methods are shown in Table 29.

Table 29. Size, energy and CO_2 emissions factors per unit, and duration for calculation embodied emissions for capital items (from Wells (2001), section 3.5).

Type / input	Unit	Size	Energy	CO2	Duration
Number of tractors	N	Tractormass[1]	160	12.8	15
Total horsepower of tractors	HP				
Number of light trucks/utes	N	N * 1400	160	12.8	15
Number of 2-wheel motorbikes	N	N * 90	160	12.8	10
Number of 4-wheel motorbikes	N	N * 190	160	12.8	10
Total weight of heavy trucks and machinery	kg	kg	160	12.8	15
Implements		Impmass[2]	80	7.2	20
Number of sets of cups	sets		Shedenergy[3]	shedenergy * 0.1	20
Total building floor area (excluding milking shed)	m^2	m^2	590	energy * 0.1	30
Total track/race length	km	km * 1000	75	energy * 0.09	30
Total boundary fence length	km	km * 1000	20 * fdeer	energy * 0.09	25
Total internal fence length	km	km * 1000 * fdeer[4]		energy * 0.09	25
	true		4.5		
Have 1 to 2 wire electric fences	false		20 * fdeer		
Stock water is reticulated	True	Pastoral area (ha)	2.1*1000	150	30
Total length of open drain	m	m	50	energy* 0.08	50
Total area of pipe system	ha	ha	40*1000	energy * 0.08	30
Total area of mole drain[5]	ha	ha	16*1000 + 1.7*1000	energy * 0.08	30 5
Total area of hump and hollow	ha	ha	25*1000	energy * 0.08	50

[1] tractormass = N * 189.97 + 40.77 * HP
[2] see Equation 120.
[3] shedenergy = (24.2 * sets + 2930 * 1000 [Wells (2001)].
[4] fdeer = 0.3 * SR_{deer} / (SR_{sheep} + SR_{beef} + SR_{deer})
[5] for collector drains and mole-tiling

The mass of implement is estimated as:

Equation 120: $impmass = \Sigma (capitalimp_k * implementmass_k)$

capitalimp$_k$ is the user input of number of impliements.
implementmass (kg) is mass of implements [Table 30].

Table 30. Calculation of default mass for implements (from Wells (2001), Table 3.11)

Type	Mass (kg)
Mower-conditioner	500
Forage Harvester	400
Silage feed wagon	1600
Bale feeder	500
Front end loader	500
Fertiliser spreader	200
Sprayer	100
Hay rake	500
Hay baler	20000
Plough	1500
Discs	1500
Cultivator	1000
Harrows	200
Roller	1500
Drill	2000
Trailer	1000
Post rammer	500
Grader blade	500

3.16.2.2. *Race, track and fence lengths*

Track/race length, boundary fence length and internal fence length can be estimated using the following formula (taken from Wells (2001, section 3.5.6)).

Total track/race length (m) is estimated as:

Equation 121: $TrackRaceLen = 0.0494 * area * (paddocks / Area)^{0.58}$
paddock is the number of paddocks
area is the area of pastore (ha).

Total boundary fence length (m) is estimated as:

Equation 122: $length = 0.7 * area^{0.5}$

Total internal fence length (m) is estimated as:

Equation 123: $length = area * (0.091 + 0.211 * \sqrt{(paddocks / area)} + 0.244 * Ln(TrackRaceLen) / Area)$ TrackRaceLen > 0
$= area * (0.091 + 0.211 * \sqrt{(paddocks / Area)})$ TrackRaceLen = 0
TrackRaceLen is the legnth of tracks and races (m) [Equation 121].
paddock is the number of paddocks.
area is the area of pastore (ha).

The formula for total internal fence length as given by Wells (2001, section 3.5.6) includes ln(TrackRaceLen / FarmArea) but this is known to give negative values. A better fit may be 0.244 * TrackRaceLen / Ln(Area) rather than the 0.244 * Ln(TrackRaceLen) / Area currently in the model.

3.16.2.3. *Irrigation and effluent systems*

Wells (2001, section 3.5.8.2) reported capital energy emissions of 13.5 and 12.5 GJ/ha for travelling irrigators and centre pivot systems respectively. Other systems such as big gun and long line laterals were assumed to have the same capital energy emission as a centre pivot system. The value used in the model was 12.5 GJ/ha (for centre pivots). The same capital energy emission was also used for other spray effluent systems including travelling irrigator. Border dyke systems had a higher capital energy emission of 25 GJ/ha.

Equation 124: $CapitalIrrEnergy_{gsource} = \Sigma_{block}((blockirr + blockEff) * psource_{block, gsource}) / 30$

$blockirr = 25 * 1000 * area_{block}$ if borderdyke or controlled flood

$= 12.5 * 1000 * area_{block}$ if irrigated

$Sprayenergy = \Sigma(effirr * panimal) / 30$

$effirr = 12.5 * 1000 * area_{block}$ if spray effluent block

$= 0$ otherwise

$panimal = 1$ dairy effluent only, gsource = dairy

$= pPad_{antype} / (\Sigma pPad_{antype} + FDE)$ mixed source

Equation 125: $CapitalIrrCO2_{gsource} = CapitalIrrEnergy_{dairy} * 0.06$

3.16.2.4. *Ponds*

Capital emissions for pond constructions are based on Wells (2001). For holding ponds, they are estimated as:

Equation 126: $CapitalPondEnergy_{dairy} = energycow * NumberMilkers / 30$

Equation 127: $CapitalPondCO2_{dairy} = CapitalPadEnergy_{dairy} * 0.08$

energycow (MJ/cow) [see below]

NumberMilkers is the peak number of milking cows

30 is number of years for depreciation.

For 2-pond system, energy per cow is estimated as:

Equation 128: Energycow = 500 + 690

500 MJ/cow =5 m^3 / cow * 100 MJ /m^3 anaerobic pond

960 MJ/cow =4.8 m^2 / cow * 200 MJ /m^2 aerobic pond

For a holding pond, energy per cow is estimated as:

Equation 129: $Energycow = holdingvolume_{region} * 100$

$holdingvolume_{region}$ is default (m^3/cow) [Table 31].

Table 31. Region based effluent holding volumes (m^3/cow).

Region	Effluent holding volume
Northland	3.4
Auckland	3.4
Waikato/Coromandel	5
BOP	6.9
Central Plateau	6.9
King Country/Taihape	5
Taranaki	5
Manawatu/Wanganui	6.9
Wellington	5
East Coast North Island	5
West Coast South Island	6.9
Nelson	3.4
Marlborough	3.4
Canterbury	1.6
Otago	5
Southland	5
High Country (> 300 m)	5

Source: From Wells (2001), Table 3.12.

3.16.2.5. *Pad area*

Capital emissions for wintering pad construction are based on the recommended areas (Dexcel 2005). The numbers of animals on feed pads and standoff pads are assumed. Thus:

Equation 130: $CapitalPadEnergy_{gsource}$ = padArea * EFBuildPadEnergy / 30

Equation 131: $CapitalPadCO2_{gsource}$ = padArea * EFBuildPadCO2 / 30

padArea = winpadarea + feedpadarea + standoffpadarea

winpadarea = 9 * (NumberMilkers + NumberMilkersEquival)

feedpadarea = 3.5 * (NumberMilkers + NumberMilkersEquival)

standoffpadarea = 3.5 * (NumberMilkers + NumberMilkersEquival)

9 is the recommended pad size for wintering pads

3.5 is the recommended pad size for feed pads

NumberMilkers is peak number of dairy cows that are on the pad

NumberMilkersEquival = $\sum_{antype}(RSU_{antype} / 8)$

antype is the animal type on the pad

30 is number of years for depreciation.

EFBuildPadCO2 (kg CO_2 equivalents /m^3) and EFBuildPadEnergy (MJ/m^3) are emission factors [Table 32].

Bug: Feed pad requirement should be 3.5 m^2, 1 m^2 is for milking shed area.

Table 32. Capital embodied CO2 and energy emission factors for building feed pads.

Product	kg CO_2 equivalents/m^3	MJ/m^3
Building feed pads	59	590

Source: Wells (2001).

3.16.2.6. *Milking goat shed*

Capital emissions for dairy shed construction are included in the default capital emissions, or calculated when number of cups data is entered. Without any additional information, a milking shed for dairy goats was based on that for dairy cows, but halved as the shed construction is probably lighter. Thus:

Equation 132: GoatMilkShedEnergy = (24.2 * 24 + 293) * 1000 / 20 /2

24.2 * 24 + 293 is the regression equation relating to number of cups to capital energy (GJ) [Wells (2001)].

24 is the number of cups per shed.

1000 converts GJ to MJ.

20 is number of years for depreciation.

2 is divisor has goats systems have lighter construction.

4. Other gases

4.1. Refrigerant loss

Dairy farms and dairy goat systems used refrigeration systems to cool milk. Each year, a small amount of refrigerant is lost. The embodied CO_2 emission per kg refrigerant loss was based on the weighted average of refrigerant types used in New Zealand and their associated emissions, assuming that on average 1 kg refrigerant is lost. The 1 kg was a “rough guess” obtained from the leading manufacturer and provider of vats and refrigeration units for the dairy industry. The emissions were based on IPCC 2007 using a 100-year horizon (Boyes pers. comm.). Farm emissions from a LCA using a ‘typical’ farm were 2826 kg CO_2 equivalents/farm and 152 MJ/farm. However, these values are not scalable for farm size. Rather, it is expected that vat size and the amount of refrigerant used would increase with milk volume production.

The model can convert the weight of dairy milk solids to litres of milk. The embodied refrigerant emissions shown in Table 33 were calculated using the weighted NZ average dairy farm milk production in the year 2004/05 (Ledgard *et al*., 2009). It was assumed that these emissions rates also applied to dairy goats.

The embodied emissions for refrigerant loss (kg CO_2 equivalents/year or MJ/year) are estimated as:

Equation 133: $RefrigCO2_{anttype} = EFRefrigerantCO2 * milkvolume_{anttype}$

Equation 134: $RefrigEnergy_{anttype} = EFRefrigerantEnergy * milkvolume_{anttype}$

Milkvolume is the total volume of milk (litres/year).

EFRefrigerantCO2 (kg CO_2 equivalents/litre milk) and EFRefrigerantEnergy (MJ/litre milk) are emission factors [Table 33].

Table 33. Embodied CO2 and energy emission factors for refrigerant loss.

Product	kg CO_2 equivalents/litre milk	MJ/litre milk
Refrigerant	0.002371	0.000128

4.2. Carbon monoxide and NOx emissions

The indirect effects on global warming of a number of gases, including carbon monoxide (CO), cannot currently be quantified. Consequently, these gases do not have global warming potentials (Ministry of Environment 2011, p 330) and are not included in NZI emissions totals or in this model. Similarly, CO emissions from burning savannah are not included.

5. References

Aqualinc 2006 Irrigation Efficiency Gaps - Review and Stock Take. Prepared for Sustainable Farming Fund and Irrigation New Zealand. Report No L05264/2. ISBN 0-478-29829-3.

Barber A, Pellow G and Marber M 2011 Carbon footprint of New Zealand arable production – wheat, maize silage, maize grain and ryegrass seed. Reported prepared by Foundation for Arable Foundation and Ministry of Agriculture and Fisheries. AgriLink New Zealand.

BSI 2008. Publicly Available Specification PAS 2050 – Specification for the Measurement of the Embodied Greenhouse Gas Emissions in Products and Services. Working Draft. London.

CAENZ 2008 New Zealand Energy information handbook. Third Edition Eds. Eng G, Bywater I, and Hendtlass G. Christchurch, New Zealand. Centre for Advanced Engineering.

Centre for Energy Research 2004 Report for EECA - Energy Use In the New Zealand Agricultural Industry. Massey University

Dairy Electricity Advisory Programme 2012 The opportunity to reduce the electricity footprint of New Zealand's dairy farms. Published by NZ Ministry of Agriculture and Forestry, Energy Efficiency & Conservation Authority and Fonterra Co-operative Group Ltd. 32 p.

Dexcel 2005 Minimising muck, maximising Money. Stand-off and feed pads design and management guidelines. Dexcel, Hamilton, New Zealand. 44 p.

ecoinvent Centre 2007 ecoinvent data v2.1.ecoinvent reports No.1-25. Swiss Centre for Life Cycle Inventories, Dubendorf. www.ecoinvent.org

Flemmer C L, Flemmer R C, McDonald G W, Archer R H and Cleland D J 2005 An Assessment of the Ecological Impact of the New Zealand Dairy Farming Sector. Proceedings ANZSEE Conference, Palmerston North, New Zealand. Pages 73-84.

Flysjö A, Henriksson M, Cederberg C, Ledgard S and Englund J-E 2011. The impact of various parameters on the carbon footprint of milk production in New Zealand and Sweden. Agricultural Systems 104, 459-469.

Frater T G 2010 Energy in New Zealand Apple Production. PhD theses, Massey University.

IDF 2010 A common carbon footprint approach for dairy. The IDF guide to standard lifecycle assessment methodology for the dairy sector. Bulletin of the International Dairy Federation 445/2010, Brussels, Belgium.

Koh L P, Miettinenb J, Liewb S C, and Ghazoula J 2011 Remotely sensed evidence of tropical peatland conversion to oil palm. Proceedings of the National Academy of Sciences 108: 5127-5132.

Ledgard S and Boyes M 2010 Life Cycle Assessment of fertilisers used in primary production in New Zealand. Report to MAF. AgResearch, Hamilton

Ledgard S F, Basset-Mens C, Boyes M and Clark H 2008 Carbon footprint measurement - Milestone 6: Carbon footprint for a range of milk suppliers in New Zealand. Report to Fonterra. AgResearch, Hamilton. 41p.

Ledgard S F, Basset-Mens C, Boyes M and Clark H 2009a Carbon footprint measurement- Milestone 6: Carbon footprint for a range of milk suppliers in New Zealand. Report for Ministry of Agriculture and Forestry. Wellington, New Zealand. 41p.

Ledgard S F, Boyes M., and Rollo M 2009b Greenhouse gas footprint of beef: Farm systems. Report to MAF (May 2009). AgResearch, Hamilton. 20p.

Ledgard S F, McDevitt J, Boyes M, Lieffering M and Kemp R 2009c Greenhouse gas footprint of lamb meat: Methodology report. Report to MAF (November 2009). AgResearch, Hamilton. 36p.

Ledgard S F, Lieffering M, McDevitt J, Boyes M and Kemp R 2010 A greenhouse gas footprint study for exported New Zealand lamb. Report for Meat Industry Association, Ballance Agri-nutrients, Landcorp and MAF. AgResearch, Hamilton. 26p.

Ledgard S F, Boyes M and Brentrup F 2011a Life cycle assessment of local and imported fertilisers used on New Zealand farms. In: 'Adding to the knowledge base for the nutrient manager'. Eds. Currie L D, Christensen C L. http://flrc.massey.ac.nz/publications.html. Occasional Report No. 24, Fertilizer and Lime Research Centre, Massey University, Palmerston North, New Zealand. 13p.

Ledgard S F, Lieffering M, Coup D and O'Brien B 2011b Carbon footprinting of New Zealand lamb from an exporting nations perspective. Animal Frontiers 1, 27-32.

Ledgard S F, Zonderland-Thomassen M, Lieffering M and McLaren S 2012 Role of life cycle assessment in agriculture for realising market opportunities and enhancing on-farm efficiency. In: 'Advanced Nutrient Management: Gains from the Past - Goals for the Future'. Eds Currie L D and Christensen C L. http://flrc.massey.ac.nz/publications.html. Occasional Report No. 25. Fertilizer and Lime Research Centre, Massey University, Palmerston North, New Zealand. 11 pages.

Lieffering M, Ledgard S, Boyes M and Kemp R 2010b. Beef greenhouse gas footprint: Final report. Report to MAF. AgResearch, Hamilton. 95p.

Manktelow D, Stevens P, Walker J, Gumsey S, Park N, Zabkiewicz J, Teulon D and Rahman A 2005. Trends in Pesticide Use in New Zealand 2004. Report to the Ministry for the Environment, Project SMF 4193.

Ministry of the Environment 2011 New Zealand's greenhouse gas inventory 1990 – 2009. Ministry of the Environment, Wellington, New Zealand.

Mithraratne N, Barber A, McLaren S J 2010 Carbon Footprinting for the Kiwifruit Supply Chain– Report on Methodology and Scoping Study. Landcare Research Contract Report LC0708/156 (Revised Edition). Prepared for Ministry of Agriculture and Forestry. Retrieved 8 November 2012, from http://www.landcareresearch.co.nz/publications/researchpubs/Kiwifruit_Methodology_Report_2010.pdf

Nebel B 2008 Electricity and transport data for MAF GHG project. Revised August 2008.

Sims R E H, Jayamah N P, Barrie J, Hartman K, and Berndt S 2005. Reducing economic and climate change impacts of dairy farm energy end use. Report prepared for Dairy Insight, Palmerston North, New Zealand.

Rankin D, Ledgard S and Boyes M 2010. Greenhouse Gas Footprint of Strong Wool. Report to MAF. AgResearch, Hamilton. 53p.

Reid T 2004 MWNZ Economic Service survey of external parasite use. Canesis commissioned survey.

Rosevear M 2008 Liquid Fuel use in New Zealand. Report for Ministry of Economic Development. Outcome Management Services, Wellington.

Wells C 2001 Total energy indicators of agricultural sustainability: Dairy farming case study. Technical paper 2001/13. MAF, Wellington, New Zealand.

Wheeler D M, Ledgard S F, and Boyes M 2013 Farm-specific carbon footprinting to the farm gate for agricultural co-products using the OVERSEER® model. Animal: an international journal of animal bioscience, 7:437-443.

Woodford K and Nicol A M 2004. A re-assessment of the stock unit system. MAF Information paper 2005/02. ISBN No: 0-478-07862-5. http://www.maf.govt.nz/mafnet/rural-nz/sustainable-resource-use/best-management-practices/reassessment-of-the-stock-management-system/index.htm