

LIFE CYCLE ASSESSMENT OF LOCAL AND IMPORTED FERTILISERS USED ON NEW ZEALAND FARMS

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Executive Summary

This project aimed to provide updated information on the energy use and greenhouse gas (GHG) emissions of a range of fertilisers commonly used in New Zealand (NZ) using Life Cycle Assessment (LCA) methodology.

NZ weighted average values for GHG emissions from triple superphosphate (TSP), diammonium phosphate (DAP), muriate of potash (KCl), calcium ammonium nitrate (CAN) and urea (produced in Europe or in China) were calculated covering the cradle-to-NZport stage. These were determined using data from a detailed Life Cycle Inventory (LCI) database [from a project by Fertilizers Europe (formerly European Fertilizer Manufacturers Association)] in conjunction with data from NZ fertiliser companies on the international locations from where the various fertilisers are imported. LCA-based emission factors were then used to estimate total GHG emissions (including fertiliser transport from overseas plant to NZ port) for TSP, KCl, DAP, CAN and urea (from the Middle East) at 0.60, 0.58, 1.12, 1.93 and 0.93 kg CO₂-equivalents/kg, respectively.

Detailed primary data was obtained from the six main single superphosphate (SSP) manufacturing plants in NZ (from Ballance and Ravensdown). Results were used to produce estimates of the energy use and GHG emissions for the NZ weighted average values for SSP for the cradle-to-production-plant stage of 2639 MJ/t and 216 kg CO₂-equivalents/t, respectively. Of the total GHG emissions, 68% was from the shipping of raw materials to NZ and 22% was from the mining and beneficiation of phosphate rock (PR). Sensitivity analysis revealed a large effect of source of PR on total GHG emissions with up to 56% variation. Results from this study indicated lower GHG emissions per unit of P from NZ average SSP (to the manufacturing-plant-gate) than from imported TSP (based on overseas sources for the average TSP delivered to the NZ port) at 2.4 versus 2.8 kg CO₂-equivalents/kg P, respectively.

NZ weighted average values for energy use and GHG emissions were estimated for urea used in NZ, covering the cradle-to-NZport stage for imported urea and the cradle-to-NZplant for NZ-produced urea. This equated to 29.5 MJ/kg and 1.06 kg CO₂-equivalents/kg urea, respectively. Of the total GHG emissions, 89% was from the energy-intensive urea production stage. At the urea production stage, the GHG emissions per kg urea were almost 3-fold higher for urea produced in China (using 80% coal, 20% natural gas) compared to that produced in EU made totally from natural gas (for the same production efficiency i.e. difference due predominantly to source of energy).

An estimate of the energy use and GHG emissions for lime was made covering the cradle-to-plant gate using primary data from a major lime producer in the central North Island. This equated to 91 MJ/t and 4.0 kg CO₂-equivalents/t lime, respectively. This was largely associated with fuel use for extraction and grinding of the lime.

Revised estimates were made of the contribution of fertilisers and lime to GHG emissions for the cradle-to-farm-gate stage for milk from the average NZ dairy farm system. Use of results from the present fertiliser LCA study resulted in estimates of the contribution from the use of N fertiliser, non-N fertilisers (P, K, S) and lime to the total GHG footprint of 11.6, 2.1 and 1.0%, respectively. Fertiliser represented the largest single contributor after that from animal-specific emissions (methane from enteric fermentation and nitrous oxide from excreta).

Introduction

Globally, the efficiency of use of resources (particularly energy, water and nutrients) and the impacts of food production on the environment are seen as critical issues for future sustainability. Pastoral agriculture is a significant contributor to this, particularly for greenhouse gas (GHG) emissions (e.g. FAO 2006). This has led to a drive by overseas customers (such as supermarket chains) for information on the carbon footprint (i.e. total GHG emissions through the life cycle) of agricultural products and in some cases to the use in eco-labelling. Determination of resource and environmental efficiency of products is best carried out using a Life Cycle Assessment (LCA) approach in order to capture all contributing sources through the life cycle of a product. In New Zealand (NZ), there have been a series of projects determining the carbon footprint of primary products working with MAF and industry groups.

The previous NZ carbon footprinting projects have shown that fertiliser and lime can make a significant contribution to GHG emissions from the cradle-to-farm-gate stage of agricultural products. In the dairy carbon footprinting project, fertilisers and lime were estimated to contribute about 15% of farm-related GHG emissions or over 50% of farm-related CO₂ emissions (Ledgard et al. 2008). Corresponding values from the lamb carbon footprinting study were 7% and over 70%, respectively (McDevitt et al. 2009). In the kiwifruit carbon footprinting study, the orchard was a less significant part of the total GHG footprint compared to that for animal products but fertilisers and lime constituted 44% of the orchard-related emissions (Mithraratne et al. 2008).

These carbon footprinting projects were based on the use of relatively old data from Wells (2001; who used early published data from overseas), or an early study by Brentrup and Ledgard (2002) or from the Ecoinvent database (Frischknecht et al. 2005). The latter is considered to be relatively outdated based on current fertiliser manufacturing processes and Fertilizers Europe (formerly European Fertilizer Manufacturers Association) had initiated a project to develop new Life Cycle Inventory data for a number of the main fertilisers used in Europe. The latter project was carried out by Dr Frank Brentrup (from Yara International) who has considerable experience in the use of Life Cycle Assessment (LCA) associated with fertiliser production and use (e.g. Brentrup and Palliere 2008). While Life Cycle Inventory data from the Fertilizers Europe project have not yet been published, they have agreed to make the data available for this project.

The aims of the project reported in this paper were to:

1. Use a full Life Cycle Inventory (LCI) from the recent Fertilizers Europe supported EU project to carry out an LCA for some of the main overseas produced fertilisers that are imported into NZ.
2. Conduct a full updated analysis of energy use and GHG emissions associated with manufacturing of single superphosphate (SSP) in NZ and provide an NZ weighted average value for SSP.
3. Determine updated NZ weighted averages for GHG emissions for some of the main N, P and K fertilisers (to point of supply at the main manufacturing sites in NZ or 'typical' port at point of importation) based on weighted data on the sources of raw materials.
4. Conduct a sensitivity analysis of some key factors such as the effects of transportation distance for different sources of raw materials or imported fertilisers.
5. Estimate the GHG emissions from lime extraction and preparation.
6. Determine the contribution of fertilisers and lime to the total carbon footprint of milk produced on an average NZ dairy farm from the Fonterra project using updated and new fertiliser and lime data from the current project.

Methods

Goal and Scope

The goal of this project was to determine the energy use and GHG emissions associated with the production and use of fertilisers on NZ farms. Additionally, a goal is to make general data on total GHG emissions from this study on fertilisers used in NZ, available for use by NZ researchers, industry and policy groups. The latter will enable greater consistency in NZ projects on GHG footprinting in determining the contribution of fertilisers and lime to the total GHG footprint of primary sector products. Use of data from this project will also enable examination of the "hot-spots" in energy use and GHG emissions throughout the life cycle in the production and use of fertilisers in the primary sector.

The scope of the current study covers estimation of the GHG emissions associated with the production and delivery of the main fertilisers and lime used on NZ farms to sites of NZ manufacturing (for SSP) or to a 'typical' NZ port for imported fertilisers.

System boundary

The system boundaries relating to the fertilisers and lime covered all stages from cradle-to-NZport for imported fertilisers, from cradle-to-manufacturing-plant-gate for SSP and urea that is manufactured in NZ, and from cradle-to-processing-plant-gate for NZ lime. Thus, they included energy use and GHG emissions associated with the extraction of all raw materials, all transportation stages, the fertiliser manufacturing process and lime extraction and beneficiation.

At the fertiliser manufacturing stage, we have not accounted for the use of minor consumables or packaging since our previous research on non-N-fertilisers indicated that the total emissions for the manufacturing stage were small relative to the total for the cradle-to-manufacturing-plant-gate (Brentrup and Ledgard 2002).

To provide context for the fertiliser and lime GHG emissions relative to the life cycle of an agricultural product, the updated data from this study was used in the GHG footprint model for milk for the cradle-to-farm-gate stage (Figure 1).

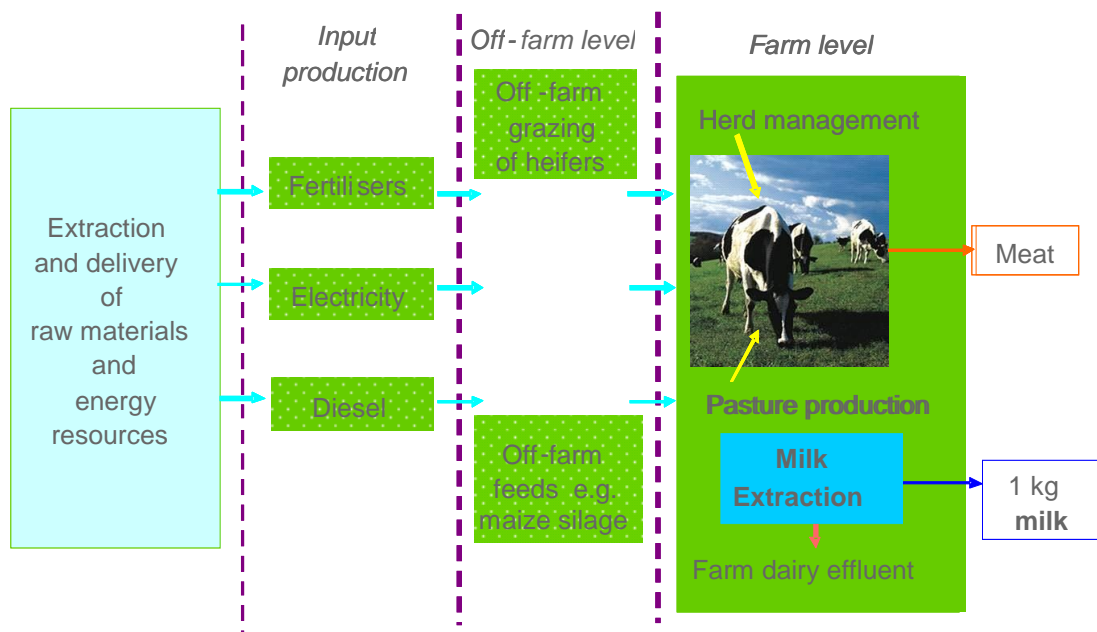


Figure 1: Simplified flowchart of the “cradle-to-farm-gate” for the NZ dairy farm system

Functional unit

The function analysed was the production and delivery of fertilisers and lime for use on NZ farms. Thus the functional units of this study were one kg of fertiliser, except for SSP and lime where it was one tonne of SSP or one tonne of lime.

Data quality

An attributional LCA approach was used in this project and relied on average data for all processes. Fertiliser industry personnel from Germany and NZ were consulted in the construction of the system boundary and in defining the data requirements. The LCA of imported fertilisers was based on development of a framework model using knowledge of the manufacturing process and data on the various unit processes from different plants with the aim of representing a “typical” European manufactured product (Brentrup and Palliere 2008). The latter is based on site-specific fertiliser manufacturing data from a range of EU countries and published data combined with LCI models integrating LCI data on energy supply systems, ancillary processes and materials. The entire LCI profile was independently reviewed by the Fraunhofer Institute for Building Physics including data consolidation, development of the LCI models, and calculation of the associated LCI datasets. The data on the imported fertilisers represents annual average data for 2006 from Fertilizers Europe based on literature from 1997-2007. The EU project also considered the potential for improvement, such as using ‘best available technology’ and an N₂O catalyst, but these were not included in the present study.

For SSP, a data template was prepared and provided to both Ballance Agri-Nutrients and Ravensdown companies which was completed for each of their individual SSP manufacturing plants (both companies have three plants). Similarly, a template was completed by Ballance Agri-Nutrients for NZ-produced urea from the Kapuni plant.

For lime, the LCA was based simply on data from a single large producer of lime in the North Island using average data on energy inputs associated with extraction, crushing and beneficiation of the lime at the processing site.

Life Cycle Inventory data

Imported fertilisers (using EU LCI)

Details of an LCI database were provided via Fertilizers Europe for use in this project and are summarised in an ILCD file which was made available (Milestone 1) for integration in the LCA NZ database and for use in an allied project comparing NZ and AusLCI database systems (by PE Australasia). This database covers a range of different fertilisers used in NZ including urea (produced using natural gas), calcium ammonium nitrate (CAN), diammonium phosphate (DAP), triple superphosphate (TSP), and muriate of potash (KCl). The LCI database contents for P-containing fertilisers had no allocation of emissions associated with the S source used in the fertiliser production process, because of conflicts in acceptable methodology (even though the Fraunhofer/PE report recommended including emissions from S).

The Fertilizers Europe LCI database does not include some fertilisers in moderate use in NZ such as sulphate of ammonia and urea produced from coal from China. Thus, separate analyses were carried out to provide an inventory for urea from China by Dr Frank Brentrup, who was responsible for developing the Fertilizers Europe LCI database, and for sulphate of ammonia from the Ecoinvent database.

NZ single superphosphate (SSP)

Data was provided by both NZ fertiliser manufacturers on the sources of PR and sulphur (S) used for production of SSP. This included data on the extraction of the raw materials in the country of origin (although in some Asian countries primary data was unavailable and was based on best assumptions by key NZ fertiliser staff). Data on shipping routes for raw materials from source to NZ port were provided.

Data on the manufacturing process for SSP was provided for each of the six main SSP plants in NZ for the 2008-2009 year. This included data on the average quantities of PR and S used relative to the SSP produced. Sulphur is used to produce sulphuric acid at all plants except one, where the acid is imported from Tasmania and is derived from a waste byproduct (no allocation was made to account for this product) of a zinc smelting process. The sulphuric acid is reacted with PR to form SSP. The latter reaction is exothermic and consequently electricity data collected from the plants included data on consumption of electricity as well as data on the amount of electricity generated and fed back into the NZ grid.

It was assumed that there was no allocation of emissions associated with the S source used in the SSP production process, as in our previous research and as discussed above for the Fertilizers Europe LCI database. However, a sensitivity analysis was done on the effect of accounting for S emissions based on energy content and mass using the Ecoinvent database factors for S produced as a byproduct from oil refining and this was used as a proxy for S as a byproduct from natural gas processing. An emission factor for sulphuric acid from metal refining was used, based on the Fraunhofer/PE report to Fertilizers Europe, to account for the imported sulphuric acid.

Data from each plant was used to determine total energy use and GHG emissions per kg SSP produced. This was used in conjunction with data on the quantities of SSP produced at each plant to calculate an NZ weighted average.

NZ Urea

Data on raw material use and flue gas emission measurements were used to calculate energy use and GHG emissions associated with production of urea from the Kapuni plant for 2009. Embodied emission factors for electricity and natural gas were derived from Nebel (2008) and Barber (2008) respectively. This represented an update from a previous project (Brentrup and Ledgard 2002). The urea production process involves reaction of ammonia with CO₂ under high pressure to form ammonium carbamate. This is then dehydrated using heat to produce urea and water. In this process the CO₂ used for urea production comes directly from the ammonia production process (although the same amount of CO₂ will be released again shortly after application to soil, as discussed later).

Data from the NZ plant was used in conjunction with data for urea produced in a 'typical' EU plant from the Fertilizers Europe study and additional data for urea produced in China from 80% coal and 20% natural gas using the Fertilizers Europe model modified to account for country-specific input data. This data-set was then used to calculate an NZ weighted average based on information provided by both companies on the relative amounts of urea from the different sources for 2008-2009. This calculation accounted for energy use and GHG emissions associated with transport of imported urea from overseas manufacturing plants to an NZ port.

NZ Lime

Data on energy use and GHG emissions associated with the production of lime was based on primary data from a single production plant in the central North Island. This accounted for energy use and GHG emissions from extraction of lime, crushing and beneficiation to the point of the production plant gate. It is recognised that this refers to data from a single site only and that a more detailed study including other sites from around NZ would have been desirable to obtain an NZ weighted average.

Transportation

This section describes the emission factors used in transporting the raw materials from site of extraction to local port and for shipping to the NZ port. For SSP, it also covers transportation from the NZ port to the manufacturing plant.

For the imported fertilisers and raw materials, expert opinion from the NZ fertiliser companies was used to define the mode of transport from the different manufacturing or extraction sites to the local port for export and the route of transport used. Emission factors for the relevant modes of transport in the different countries were derived from the Ecoinvent database.

Shipping distances from overseas ports to an NZ port (Napier was used as a typical mid-distance port in NZ for all imported products) were calculated using <http://www.searates.com/>. The emission factor used for shipping was 0.013 kg CO₂-equivalents/tkm from Nebel (2008).

For SSP, data on the mode of transport from the NZ port to the manufacturing site and the route of transport used was provided by the fertiliser companies. Emission factors for this transportation within NZ were derived from Nebel (2008).

Contribution of fertilisers and lime to GHG emissions from NZ milk

Data from NZ weighted average GHG emissions for the different fertilisers and lime described previously were used to replace default values in models from the previous GHG footprinting study for milk (Ledgard et al. 2008). This included data on fuel use and GHG emissions from the transportation of fertilisers and lime from plants or ports to example farms and on application to pasture. It also included CO₂ released from soil after application of urea and lime according to IPCC (2007).

The same harmonised GHG footprint calculations across other MAF-funded GHG footprinting projects were used for the production and delivery of NZ diesel, petrol and electricity (from Nebel 2008).

Calculation of GHG emissions

In all cases, the GHG emissions were calculated using the Global Warming Potential for a 100 year time horizon (GWP₁₀₀) based on the most recent IPCC characterisation factors (IPCC 2007). The GWP₁₀₀ factors for methane 25, nitrous oxide 298 and CO₂ 1 are expressed in carbon dioxide equivalents (CO₂-e) and relate to the impact of emissions on the heat radiation absorption of the atmosphere.

Results and Discussion

Imported fertilisers

Data extracted from the LCI provided from Fertilizers Europe by Dr Frank Brentrup was used to estimate the energy use (total and fossil fuel component) and GHG emissions for the cradle-to-manufacturing-plant-gate stage. This highlighted a large variation between fertilisers, being lowest for muriate of potash (KCl) which is extracted from soil reserves and undergoes no manufacturing (Table 1). In contrast, on a per-tonne of product basis, urea from China had the highest energy use and GHG emissions. The GHG emissions from urea produced in China were almost 3-fold higher than from EU-produced urea (assuming the same production efficiency) due to the high coal use (80% coal, 20% natural gas) compared to EU where it was produced entirely from natural gas. The ‘standard’ CAN from this study had the second highest GHG emissions/kg, but there is potential to reduce the GHG emissions from such nitrate-based products due to N₂O abatement in the manufacturing plant. This is now the standard technology within the Fertilizers Europe member companies and it reduces the GHG emissions to about 0.75 kg CO₂-e/kg CAN at the plant gate.

Table 1: Summary of energy use and GHG emissions for various fertilisers produced in EU (from Fertilizers Europe LCI database), or for urea produced in China, covering the cradle-to-manufacturing-plant-gate.

	TSP	KCl	DAP	CAN	Ammonium sulphate	Urea (Middle East)	Urea (China)
Total energy (MJ/kg)	7.92	6.12	12.35	11.4	7.84	23.93	33.08
Fossil energy (MJ/kg)	5.58	5.10	10.1	10.6	7.62	22.55	32.99
GHG (kg CO ₂ -e/kg)	0.35	0.36	0.7	1.66	0.47	0.73	2.14

Table 2 provides a summary of the average GHG emissions for the various fertilisers from the cradle-to-NZport. This data represents an NZ average in that it is weighted for the relative amounts of fertiliser imported in 2009 (by both Ballance and Ravensdown) from various countries around the world. This data highlights that the contribution from transport from site of production to local port was minor for all fertilisers and in a number of cases the production site is at a port. For Morocco, the transport from site to port is by a long conveyor belt system and emissions associated with it are included in the production data. Shipping represents a significant component of the total GHG emissions from the cradle-to-NZport ranging from 18% for DAP to 41% for TSP. This ratio is relatively high for TSP largely due to the smaller production-related emissions. The highest shipping emissions per tonne of fertiliser to an NZ port was from CAN and this is because it is largely sourced from northern Europe resulting in a long shipping distance to NZ.

For some fertilisers such as DAP there was a diverse range of countries of supply. A sensitivity analysis of the effect of sourcing all DAP from the nearest country Australia showed a 12% decrease in total GHG emissions from the NZ average compared to that for the most distant source in Morocco which showed a 3% increase in total GHG emissions. Note that this assumes that emissions from production of the DAP were the same in both countries.

For KCl, the estimate for GHG emissions to NZ of 0.58 kg CO₂-e/kg KCl is considerably higher than the previous estimates of 0.39 kg CO₂-e/kg KCl by Ledgard and Boyes (2008) or 0.31 kg CO₂-e/kg KCl from Wells (2001; which was based on Dawson 1978). In the Defra project ISO205 report, Williams et al. (2006) used values for production, packaging and delivery of K fertiliser (form not defined) equivalent to 0.28 kg CO₂-e/kg KCl.

The estimates for energy use and GHG emissions for TSP, DAP and CAN are all within the wide range reported by Jenssen and Kongshaug (2003).

Table 2: Summary of GHG emissions (kg CO₂-e/kg) for various fertilisers covering the cradle-to-NZport. Data represent a weighted average for the different countries of supply for 2009 but using production emissions from the Fertilizers Europe LCI database.

	TSP	KCl	DAP	CAN	Ammonium sulphate	Urea (Gulf)	Urea (China)
Production	0.350	0.365	0.910	1.657	0.473	0.732	2.140
Local transport	0.000	0.046	0.007	0	0.014	0.000	0.000
Shipping	0.246	0.172	0.199	0.274	0.121	0.201	0.130
TOTAL	0.596	0.583	1.117	1.931	0.608	0.933	2.270

NZ single superphosphate (SSP)

The energy use and GHG emissions were calculated for all stages covering extraction of raw materials, transportation and manufacturing. Separate analyses were made for each of the six NZ manufacturing sites and a weighted average was calculated according to data on the SSP production from each site for 2008/2009.

The NZ weighted average SSP had total GHG emissions of 216 kg CO₂-e/t SSP and used 2639 MJ energy/t SSP (Table 3). The shipping and PR mining and beneficiation stages were dominant, contributing 68% and 22% of total GHG emissions, respectively. Corresponding contributions to total energy use were 69% and 26%, respectively. Release of CO₂ from carbonate in the PR (based on an average of 2.3%) was estimated to contribute 6% to total GHG emissions.

Table 3: Contribution of different sources to GHG emissions and total energy use for the NZ weighted average SSP covering the cradle-to-manufacturing-plant-gate.

	GHG (kg CO ₂ -e/t SSP)	Total energy use (MJ/t SSP)
PR mining & beneficiation (including transport to port)	47.5	690
Train transport of S in Canada	2.3	33
Shipping of raw materials (PR, S and H ₂ SO ₄) to NZ port	147.9	1823
Truck transport of raw materials to plant	1.3	19
Net electricity and fuel use at plant	3.1	73
CO ₂ release from CO ₃ in PR	13.9	
TOTAL	216	2639

These estimates are lower than those from Ledgard and Boyes (2008) of 290 kg CO₂-e/t SSP and 3610 MJ energy/t SSP which were based on early data and assuming all PR was from Morocco and all S from Canada. The estimate for energy use is higher than that reported for European average SSP production of 1400 MJ/t SSP (Jensen and Kongshaug 2003), reflecting the larger transport distances for raw materials to NZ. Wells (2001) reported approximately 2000 MJ/t SSP and 120 kg CO₂/t SSP, but his calculations appear to have excluded raw material shipping to NZ and CO₂ from carbonate in the PR.

There was some variation between SSP plants in total GHG emissions but this variation was less than that associated with some other factors such as the source of PR (Figure 2). A simple sensitivity analysis indicated that GHG emissions per t SSP made from Chinese PR were only 64% of that from Moroccan PR because of lower emissions from reduced transport distances. However, this ignores other factors such as the need for greater electricity use in grinding PR from China for manufacturing, although this would only have a minor effect.

Presence of carbonate in PR results in CO₂ release during processing and this contributed 6% to total GHG emissions for the average SSP. This was based on an average of 2.3% CO₂ for Moroccan PR. If a high carbonate-containing PR such as Zin had been used with 12.2% calcium carbonate (5.4% CO₂; Rajan et al. 1992) it would have increased total GHG emissions for the average SSP by 9%.

Sensitivity analysis of the effects of allocating some GHG emissions associated with S production based on energy content and mass resulted in an estimate for the NZ weighted average SSP of 249 kg CO₂-e/t SSP (i.e. +15% relative to that for no S-related emissions). This is likely to represent the upper end of estimates accounting for S and if economic allocation had been used the estimated increase would have been much less. Future update of this work should account for S-related emissions when an agreed methodology has been developed.

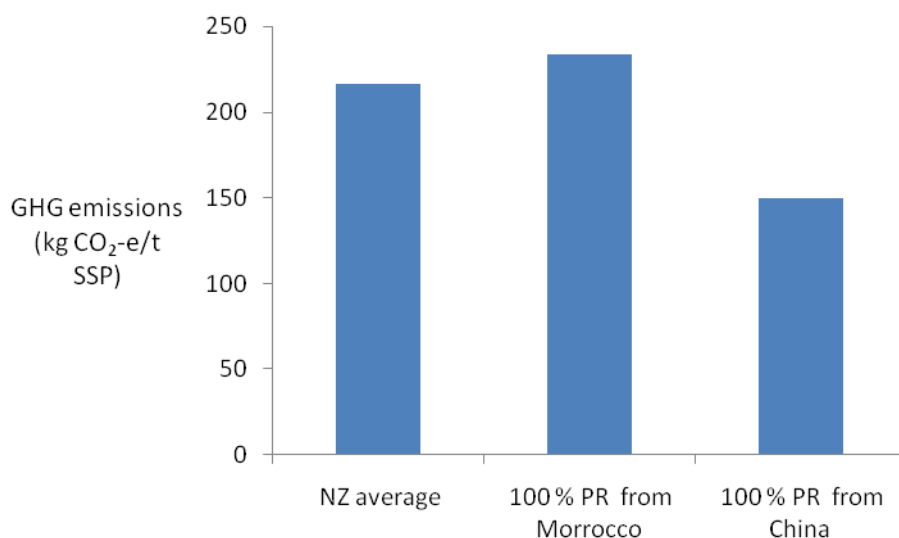


Figure 2: Effect of changes in source of phosphate rock (PR) on GHG emissions relative to that for the NZ weighted average SSP covering the cradle-to-manufacturing-plant-gate

Results from this study can be used to compare the GHG efficiency of fertilisers on a unit nutrient basis. In this way, the total GHG emissions for NZ average SSP (to the manufacturing-plant-gate) or TSP (based on the NZ average TSP from overseas sources to the NZ port) equated to 2.4 or 2.8 kg CO₂-e/kg P. This ignores the fertiliser value of the S contained in these products (which is roughly ten times higher per kg P for SSP than for TSP) and indicates greater GHG efficiency for the NZ average SSP (i.e. 16% less GHG emissions/kg P).

Urea

The urea used in NZ during 2008/2009 was sourced mainly from NZ (Kapuni, Taranaki), China, south-east Asia and the Middle East. Data on the relative quantities of urea from these various sources from Ballance and Ravensdown was used with data on GHG emissions and energy use from Kapuni and from Table 2 (and the EU LCI), together with data on transportation to NZ ports, to obtain weighted-average NZ values in Table 4. This data highlights that the dominant source of energy use and GHG emissions was the urea production stage.

Table 4: Contribution of different sources to GHG emissions and total energy use for the NZ weighted average urea covering the cradle-to-manufacturing-plant-gate for NZ-produced urea or the cradle-to-NZport for imported urea.

	GHG (kg CO ₂ -e/kg urea)	Total energy use (MJ/kg urea)
Ammonia and urea production	0.936	27.99
Transportation incl. shipping of imported urea to NZ port	0.120	1.48
TOTAL	1.056	29.47

The estimate of GHG emissions for the average urea used in NZ (1.06 kg CO₂-e/kg urea) is slightly lower than the value of 1.11 kg CO₂-e/kg urea from Ledgard and Boyes (2008), whereas the energy use is higher than their estimate of 23.9 MJ energy/kg urea. Earlier NZ estimates from Wells (2001) were 1.4 kg CO₂/kg urea and 30 MJ/kg urea (based on NZ production and allowance for capital). In the Defra project ISO205 report, Williams et al. (2006) used values for production, packaging and delivery of urea of 1.6 kg CO₂-e/kg urea and 23 MJ /kg urea. However, the latter two studies did not account for CO₂ consumption during urea production and therefore the GWP values for Wells (2001) and Williams et al. (2006) for comparison with the above calculations are 0.65 and 0.87 kg CO₂-e/kg urea, respectively.

When the updated NZ average estimate of GHG emissions for urea from Table 4 are applied in an agricultural study, the user must also include the emissions of CO₂ from urea on application to soil according to IPCC (2006). This equates to a further 0.73 kg CO₂-e/kg urea.

Lime

Lime is sourced from a large number of sites throughout NZ where it is extracted, ground and may undergo some degree of beneficiation. Table 5 summarises the GHG emissions and total energy use for lime (covering the cradle-to-production-plant-gate) for a single North Island supplier. This was based on primary data on total energy use provided by that supplier. We are unsure how representative that would be for the whole of NZ.

Table 5: Contribution of the two energy sources to GHG emissions and total energy use for lime covering the cradle-to-production-plant-gate for a North Island supplier.

	GHG (kg CO ₂ -e/t lime)	Total energy use (MJ/t lime)
Diesel	1.8	25.3
Electricity	2.2	65.7
TOTAL	4.0	91.0

When the updated NZ average estimate of GHG emissions for lime from Table 5 are applied in an agricultural study, the user must also include the emissions of CO₂ from the carbonate in lime on application to soil according to IPCC (2006).

Contribution of fertilisers and lime to GHG emissions from NZ milk

In the GHG footprint for milk from the average NZ dairy farm (i.e. cradle-to-farm-gate stage; Ledgard et al. 2008), N fertiliser, non-N fertilisers (P, K, S) and lime were previously estimated to contribute 12, 2 and 1%, respectively, based on relatively old fertiliser and lime data on emission factors. Use of updated results from the present study resulted in corresponding estimates for N fertiliser, non-N fertilisers (P, K, S) and lime of 11.6, 2.1 and 1.0%, respectively. These updated results reduced the cradle-to-farm-gate GHG emissions by about 0.2%. Note that these fertiliser and lime emissions included N₂O emissions (direct and indirect) from fertiliser-N in soil, and CO₂ released from soil after application of urea and lime (calculated using NZ GHG Inventory and IPCC 92006) methods and emission factors).

Some sensitivity analyses were carried out on aspects of fertiliser cartage and application in the dairy farm system. Total GHG emissions associated with fertiliser cartage from port or SSP-plant to the farm and applications on-farm represented only 0.13% of the cradle-to-farm-gate GHG emissions. Consequently, varying the cartage distance from between 10 and 200

km or increasing efficiency through reduced travel by combining cartage and applications of fertiliser products (N and non-N forms) had minimal effect (< 0.2%) on total GHG emissions. The total quantity of fertilisers and lime applied on farm can have a relatively large effect on total GHG emissions. This highlights the benefits of using soil testing and nutrient budgeting to ensure optimum levels of fertiliser-nutrients and lime are used and excess application rates are avoided.

Nitrogen fertiliser is used to increase N supply and enhance pasture growth at times of feed deficits on farm. However, N fertiliser was the largest contributor to GHG emissions out of all the fertiliser-nutrient types. Practices to enhance clover growth and symbiotic fixation of atmospheric N₂ could potentially represent an option to reduce N fertiliser use and thereby reduce GHG emissions. Ledgard et al. (2009) estimated that replacing fertiliser-N with fixed-N on an NZ dairy farm reduced fossil fuel use by 49% and decreased GHG emissions by 12%.

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