Environmental input-output analysis of the New Zealand dairy industry

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Abstract: This work presents data and analysis quantifying the total (direct and indirect) resource use and outputs (products and pollutants) of the New Zealand dairy industry for the year April 1997 to March 1998. It also identifies those sectors supplying the dairy industry which make significant indirect contributions to its total inputs and outputs. Although this data is 14 years old, it is the only large-scale, detailed data available. Further, more modern data can be compared with this baseline data.

Comparison with the other major New Zealand food and fibre sectors shows that the dairy farming sector has the highest total water consumption and the highest total effluent. It also has high total land use, electricity use and production of animal methane. The dairy processing sector is water and fuel intensive and has high total water effluent and greenhouse gas emissions. The high resource use and pollutants have to be weighed against the enormous economic value of the dairy sectors.

Keywords: dairy processing; dairy farming; land; energy; water; effluent; greenhouse gas emissions; environmental input-output analysis; EIOA; sustainability, New Zealand.

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1 Introduction

There is a perception that dairy production is harmful to the environment; it uses significant amounts of energy and water and produces large quantities of greenhouse gas emissions and effluent. It is important to quantify these environmental impacts as we try to assess the sustainability of dairy production.

New Zealand is a key player in world dairy production. Its climate and soils are ideally suited to milk production and mean that milk can be produced at much lower cost compared with other countries in the world (Sankaran and Luxton, 2003). While most countries consume most of their dairy produce and export only a small portion of it, New Zealand exports over 90% of its production and is the world's largest exporter (Evans, 2008). New Zealand is the second largest international dairy trader (despite being almost tariff and subsidy-free) and only the European Union has a greater share of the international market (Stukenberg et al., 2006).

Within New Zealand, food and fibre production account for almost half of the country's annual export earnings (Ballingall and Lattimore, 2004) and the highest of these earnings come from dairy production. However, tourism is another significant source of income to the country and it is obvious that the environmental impacts from food and fibre production have the potential to damage New Zealand's 'clean, green' image. This formed the basis to the Ecological Footprint Plus (EFPlus) project; a FoRST[1]-funded project which aims at measuring the ecological footprint of New Zealand's major food and fibre sectors starting from the year 1997/1998. The work reported here is a subset of the EFPlus project and is an environmental input-output analysis (EIOA) of the New Zealand dairy farming and dairy processing sectors.

It might seem that data from 1997/1998 is obsolete and of no value. However, there are several reasons why this is not the case. Firstly, the data and results of the 1997/1998 analysis provide a useful baseline against which analyses for subsequent years may be compared, allowing quantitative assessment of the changes in resource use and pollutant output over time. Secondly, the warm El Nino weather patterns in the 1997/1998 season created a record production of 11.2 million tonnes of milk in New Zealand (Sankaran and Luxton, 2003). Thirdly, dairy processing facilities are very cautious about publishing operating data because such data is commercially sensitive and therefore scarce. However, the author was given access to hitherto confidential data on the processing of 98.5% of the year's milk production and permission to publish this data. The background to this data is as follows: in the 1990s, 13 New Zealand dairy companies, processing 98.5% of the total milk produced in the country, took part in a confidential annual benchmarking exercise wherein extensive data was collected on costs, milk processed, water use, energy use, energy type, etc. The New Zealand dairy industry coalesced over time until in 2002 all but two of the 13 companies were a part of the Fonterra Cooperative, the world's largest dairy exporter (Evans, 2008). Fonterra inherited the benchmark data and agreed to keep it confidential until it was judged to be no longer commercially sensitive. In 2005, Fonterra agreed to participate in the EFPlus project and to allow the data to be analysed and made public. The data is presented in this paper and although it is 14 years old, there is no other published data of this scale and this detail either before or since.

Dairy production has two parts; the production of milk by the farming sector and the production of dairy products by the dairy processing sector. Data for the New Zealand dairy farming sector in 1997/1998 has already been published (Flemmer et al., 2005) but is reported here for the sake of completeness. Data for the processing sector includes land use, energy use (by type), water use, water effluent and carbon dioxide (CO_2) emissions. The boundaries of these two sectors differ slightly in New Zealand compared with dairying in the rest of the world because milk collection (with its associated costs, fuel use, etc.) from the farms is done by the processing sector.

Input-output analysis is performed on the data for the dairy farming sector and the dairy processing sector for the year 1997/1998 using an environmental accounting procedure in order to determine the total[2] (direct and indirect) environmental inputs or resources used (such as land and water) and the total outputs such as water effluent and greenhouse gases. Direct inputs are those used directly by the dairy sectors, for example the land used, the electricity consumed and the diesel purchased. Indirect inputs are those which the dairy sectors inherit from sectors which supply them with goods, from sectors which supply those sectors with goods, and so on. Thus in the case of fuel, the total use of fuel by the dairy farming sector arises from its own purchase of fuel (direct), the fuel embodied in the purchase of agricultural services (such as pasture preparation) by the dairy farming sector, the fuel embodied in the purchase of agricultural equipment by the agricultural services and the fuel embodied in the infinite interactions between all the sectors of the economy.

The results of the 1997/1998 analysis provide a useful baseline against which analyses for subsequent years may be compared, allowing quantitative assessment of the changes in resource use and environmental impacts over time. The results also show which sectors contribute directly and indirectly to the total ecological footprint of the dairy sectors and highlight areas where adverse ecological impacts are greatest, so that strategies can be developed for improvement. Finally, the results allow comparison between the main food and fibre sectors of New Zealand.

2 Literature review

There are two questions which are considered in this review; firstly, what methods are available for assessing environmental impact and secondly, what published data and assessment currently exists for dairy farming and for dairy processing?

Three common methods of assessing environmental impact are life-cycle analysis (LCA), EIOA and system flow analysis (SFA) or materials flow analysis (MFA).

LCA is used primarily to assess the overall environmental impact of a single product or production system, however, recently the Food and Agriculture Organisation (2010) have used LCA to assess greenhouse gas emissions from the global dairy industry. An explanation of the method and an assessment tool are available from Carnegie Mellon University.[3] EIOA determines the overall environmental impact of an entire sector of the economy (in this instance, the dairy farming and dairy processing sectors) and may be viewed as a macro-level LCA. The method was first used by Hite and Laurent (1972) and, since it is the method used in this work, details are given in the next section.

The two types of assessment are discussed extensively in Hendrickson et al. (2006) and Flemmer et al. (2005). EIOA has the limitation that it is intrinsically linear (disallowing economies of scale), it assumes product homogeneity and it assumes a single technology in the production process. However, as a tool for environmental impact analysis (or LCA at the macro or national level), it has the strong advantage over traditional LCA that it captures all the intra-sector flows, both direct and indirect, with no possibility of ‘double-counting’. Thomassen and de Boer (2005), show that both LCA and EIOA provide effective environmental indicators in terms of relevance, quality and data availability. SFA derives from EIOA and tends to be on a much smaller scale than EIOA. Bouman et al. (2000), present a comparison between LCA and SFA.

For dairy farming, there are many sources of data on energy use and greenhouse gas emissions. These are reviewed in Basset-Mens et al. (2009) and Flemmer et al. (2005), the former providing a comparison between New Zealand and European studies. Similar data is also provided by Gomiero et al. (2008) and van der Werf et al. (2009) for European dairy farms, Dyer and Desjardins (2006) for Canadian farms and by Pinares-Patino et al. (2009) for New Zealand farms. Gomiero et al. (2008) note that energy assessments are difficult to compare because of differences in methodologies and accounting procedures from one study to the next. Data on New Zealand dairy farming water use, water effluent, land use and fertiliser use are provided by Flemmer et al. (2005) and Flemmer and Flemmer (2007, 2008). There are also many studies on organic dairy farming (Muller-Lindenlauf et al., 2008, 2010; Thomassen and de Boer, 2005) and on comparisons between organic farming, pasture-based conventional farming and confinement systems (Arsenault et al., 2009; Pimental et al., 2005; Cederberg and Mattsson, 2000).

In contrast with the dairy farming sector, there is very little published data on the inputs and outputs of dairy processing as an aggregated sector of a nation's economy. Published studies tend to focus on a single processing plant producing a few products. For example, Ozbay and Demirer (2007) present data on raw milk use, water use, chemical cleaner use, product quantities and amount of waste water and clean discharge water for a Turkish plant producing milk and cream. The plant processes 34,000 kg raw milk per day compared with the New Zealand data presented here for 41.5 million kg raw milk per day. Hogaas Eide (2002) presents LCA results for milk production from farm to one of three Norwegian processing plants. Danalewich et al. (1998), provides data from 15 US dairy processing plants on waste water volumes. The total milk processed is 8.7 million kg/day (about one-fifth that processed in New Zealand in 1997/1998). Xu et al. (2009) compare energy efficiency for cheese processing in the USA, Great Britain, Netherlands, Denmark and Norway and note that the energy efficiency data on dairy products is 'limited and at best fragmented'. The transport of milk to the plant is not included in their data. There is some early data (1979 to 1982) on energy efficiency for Australian and New Zealand dairy products (Cox and Miller, 1986). Berlin and Sonesson (2008) and, Berlin et al. (2007, 2008) review LCA for single dairy products and discuss production sequencing as a way to minimise environmental impact for two European dairy processing plants.

At the national level, Ramirez et al. (2006) present dairy processing energy data for four European countries over the period 1985–2000 and show the energy 'mix' (electricity, natural gas and 'other fuels') and CO_2 emissions (direct and indirect). The energy associated with milk collection is not included in their data. As mentioned in the introduction, in New Zealand, the transport of milk from farms to processing sites is done by the dairy processing companies so that inputs (such as tanker fuel) and outputs (such as fuel emissions) arising from transport are attributed to the dairy processing sector. Miller (1984) cites energy consumption for the New Zealand dairy processing industry in 1969 and 1979. Ridoutt et al. (2010) look at the water footprint associated with skim milk production in Australia.

3 Method

The EIOA first described by Hite and Laurent (1972) and described in detail by Andrew and Forgie (2007) was followed. This method uses direct or primary input-output data and computes total (direct plus indirect) resource use and outputs. It has the following steps:

1. Gather economic input and output data for a sub-section of the New Zealand dairy processing sector. Scale the data up to 100%.
2. The monetary flows between the 48 sectors of the New Zealand economy in 1997/1998 are captured in a monetary input-output table (MIOT) produced by McDonald and Patterson (2003). Modify this MIOT by inserting the superior data (from Step 1) together with data for the New Zealand dairy farming sector into the MIOT.
3. Compute the transaction coefficient matrix, *A*, showing the monetary inputs and outputs of each of the 48 primary sectors per unit dollar of net input or output by the sectors.
4. Compute the Leontief inverse matrix, *L* using:

   $$L = (I - A)^{-1} \tag{1}$$

   where *I* is the 48 by 48 identity matrix.
5. Gather physical/ecological input and output data for the same sub-section of the New Zealand dairy processing sector and scale the data up to the national level.
6. Market Economics[4] provided a 1997/1998 physical resource use and ecological output table (for each of the 48 primary sectors of the New Zealand economy) called the resource matrix, *G*. Modify *G* by inserting the superior physical/ecological data for the dairy farming and dairy processing sectors and by dividing throughout by the net economic output of each sector.
7. Post multiply the resource matrix, *G*, by the Leontief inverse, to get the matrix of total (direct and indirect) resource multipliers, G_T, i.e.,

   $$G_T = GL \tag{2}$$

8. Compute total resource use (and pollutant output) in physical units, by multiplying G_T by the matrix of net economic outputs of the 48 sectors. The indirect resource use (and pollutant output) is merely the difference between total resource use and direct resource use.

The accuracy of the analysis depends upon the accuracy of the economic and physical input and output data itself. The data for the dairy processing sector is judged to be very accurate, having come from benchmarking data and representing a very large percentage of the milk processed in 1997/1998. The sources of data for the dairy farming sector are discussed in Flemmer et al. (2005)[5] and the accuracy varies. Land use, electricity use, water use, mining and quarrying, fertiliser use, raw milk, water discharge and animal methane emissions were based on national data [such as Livestock Improvement Corporation reports on cow numbers, fertilisers sales records, Ministry for the

Environment (MFE) guidelines for greenhouse gas emissions, etc.] and are judged to be very accurate. However, fuel use (and emissions from fuel) was estimated from Ministry of Agriculture and Forestry farm monitoring reports (1998) on survey data representing about 5,000 dairy farms (90% of the total) in eight regions. This was scaled up using regional milk solids production and is less accurate than the other data; there are inherent errors in the surveys themselves and only a small number of farms (producing about 0.06% of the total milk produced in 1997/1998) were surveyed.

The MIOT for all sectors other than the dairy farming and processing sectors was derived from an earlier table developed by statistics New Zealand and, while presenting an approximately accurate view of the New Zealand economy in 1997/1998, is likely to have some error. The same is true for the physical resource table. However, Flemmer et al. (2005), note that there is reasonable agreement between the results from EIOA of the dairy farming sector and those of Wells (2001), and Carran et al. (2004), both based upon traditional LCA. It therefore seems reasonable to assume that the results from the analysis presented in this work are broadly accurate.

The gathering of economic and physical data in Steps 1 and 5 have several subtleties and are discussed below for the dairy processing sector.

3.1 Economic input-output data

Economic inputs are the moneys spent by a sector (such as the dairy processing sector) in purchasing the commodities such as fuel, labour, etc. needed in order to perform dairy processing. Economic outputs are the moneys received by the sector from, for example, the sale of milk, stock and dairy products.

The 1997/1998 benchmarking dataset provided aggregated economic data in broad categories such as ‘consumables’ for various cost centres such as ‘milk supply’. From 2002 onwards, Fonterra created detailed economic databases and the 2002/2003 data was used to disaggregate the 1997/1998 data. Thus, in order to disaggregate the single dollar value for the 1997/98 ‘milk supply – consumables’ into more detail, the following steps were taken:

1 Get a representative sample of disaggregated economic data for the 2002/2003 milk supply consumables consisting of 2,213 consumable items costing a total of about $500,000. Abstract from this a sub-sample of the main items on the basis of price (selecting only those items costing over $100) and on quantity (selecting those items purchased in quantities over 100).

2 Assume the same percentage was spent on each item in 1997/1998 as in 2002/2003, so that the 1997/1998 single dollar value for the cost centre can be disaggregated into the amount spent on each principal item. This data forms the superior economic input data in the MIOT.

3 Estimate the unit mass of each item and adjust the unit price using the producer price index (reported by statistics New Zealand) to get the 1997/1998 unit price, quantity of the item and total mass of the item. This data forms the superior physical input data (discussed in the next section).

4 Repeat the procedure for each cost centre (such as reception and treatment, butter, powders, effluent treatment, administration, etc.).

5 Allocate the items to one of the sectors of the economy and sum the dollar amounts and the mass over all cost centres for each sector of the economy.

It is recognised that this method of disaggregation based upon 2002/2003 data has some error because the economies of scale available to the Fonterra Cooperative (and inherent in the 2002/2003 data) were not available to the constituent dairy processing companies operating in 1997/1998.

The (now disaggregated) economic data stemmed from the processing of 10,877 million litres of milk (890,342 tonnes milk solids). The total (domestic and export) milk processed for the year was 11,042 million litres (Livestock Improvement Corporation, 1998) so the economic data represented 98.5% of total production. The economic data was scaled up by a factor of 11,042/10,877 to represent the total annual production and inserted into the MIOT as superior data for the sector.

3.2 Physical/ecological input-output data

Physical or ecological inputs are the physical components, such as hectares of land, gigajoules of electricity, tonnes of water, tonnes of fuel, etc., which the sector needs in order to function. Physical outputs from the dairy sector include both desirable outputs, such as tonnes of milk and dairy products, as well as undesirable outputs such as tonnes of water effluent and tonnes of greenhouse gases.

The sources of data for the dairy farming sector are presented in Flemmer et al. (2005) and Flemmer and Flemmer (2007, 2008).

For the dairy processing sector, Fonterra provided data on the volume of milk collected, tanker fuel use, processing energy consumption and product tonnage for the entire annual milk production in 1997/1998 (so that no scale up was needed). Cogeneration systems returned some electricity to the national grid and this was taken into account in the computation of electricity use and greenhouse gas emissions. Fonterra also provided detailed data on transport costs (fuel, oil, tyres, road user charges, etc.), water use, water effluent,[6] and land use. In some instances, this data was only available from 2002/2003 onwards and the corresponding data for 1997/1998 had to be inferred from the later data.

Greenhouse gas emissions were computed according to the New Zealand MFE guidelines (2005). Landcare Research[7] provided data on land use and electricity consumption for the all sectors of the economy except the dairy farming sector and the dairy processing sector.

4 Results

The most significant input and output results found in this work follow. They are presented firstly for the dairy farming sector and then for the dairy processing sector.

4.1 1997/1998 New Zealand dairy farming sector results

Table 1 shows the resource use and outputs for the dairy farming sector. Note that 'fuel use' refers to the use of petrol and diesel on the farm itself but does not include fuel used for transport of the milk to the processing centre. The latter is included in the dairy processing sector since this is the sector which manages and pays for the transport.

Table 1 Direct and indirect inputs (resource use) and outputs (product and effluent) for the New Zealand dairy farming sector for the year 1997/1998

Parameter	*Direct*	*Total*	*Indirect % of total*
Inputs			
Land use (ha × 10^6)	2.030	3.436	40.9%
Electricity use (GJ × 10^6)	2.569	4.154	38.2%
Water use (kt × 10^3)	933	969	3.7%
Mining and quarrying (lime, gravel) (kt)	513	3,283	84.4%
Fuel (including petrol and diesel) (kt)	72	207	65.2%
Fertiliser (excluding lime) (kt)	683	1,179	42.1%
Outputs			
Raw milk (kt × 10^3)	11.395	11.491	0.83%
Water discharge (kt × 10^3)	864	940	8.1%
CO_2 from fuel use (kt)	216	838	74.2%
Animal CH_4 (kt)	343	460	25.4%

Notes: ha: hectares, GJ: Giga Joules, kt: kilo tonnes, CO_2: carbon dioxide, CH_4: methane

From Table 1, it is apparent that water use by the dairy farming sector is largely direct and there is only a small contribution (3.7%) to its total water use from its supplying sectors. Similarly, most of the water effluent arises directly from the dairy farming sector with only 8.1% indirect contribution. Predictably, the dairy farming sector produces almost all the raw milk directly with only 0.83% contribution from its supplying sectors (in this case the sector called ‘other livestock and cropping’ which produces some raw milk itself).

The resources (inputs) and pollutants (outputs) for the dairy farming sector with the most significant indirect contributions are land, electricity, mining and quarrying (including lime and gravel), fuel (including petrol and diesel), fertilisers, carbon dioxide emissions from fuel use and animal methane. Table 2 shows the main sectors contributing to the indirect use.

In the case of land use, the dairy farming sector accounts for 59.4% of its total land use with 59.1% directly from the land it uses (2,030,000 hectares) and the remaining 0.3% from transactions within its own sector. The remainder of the (indirect) contributions to the total land use by the dairy farming sector come from the livestock and cropping sector (39.3%), other farming (1.0%) and the remaining sectors (0.3%). The livestock and cropping sector supplies the dairy farming sector with feed and seed, both of which are land intensive which is why the livestock and cropping sector has such a large indirect contribution to the total land use of the dairy farming sector.

Total electricity use by the dairy farming sector arises from itself (61.8% direct use and 0.3% indirect use) and from indirect contributions from the metal manufacturing sector (6.9%), the non-metallic mineral product manufacturing sector (5.8%), the petroleum and industrial chemical manufacturing sector (3.7%) and the remaining sectors

(21.5%). The non-metallic mineral product manufacturing sector supplies the dairy farming sector with fertilisers (other than lime), while the petroleum and industrial chemical manufacturing sector supplies petrol, diesel, insecticides, detergents and animal health products.

Table 2 Sectoral contributions to total inputs and outputs of the New Zealand dairy farming sector in 1997/1998

Parameter	*Dairy farming sector (direct + indirect) (%)*	*Main contributions (indirect) from other sectors(%)*	
Land use	59.4%	39.3	Livestock and cropping
		1.0	Other farming
		0.3	All other sectors
Electricity use	62.1%	6.9	Basic metal manufacturing
		5.8	Non-metallic mineral product manufacturing
		3.7	Petroleum and industrial chemical manufacturing
		21.5	All other sectors
Mining and quarrying use (including lime)	15.7%	63.5	Non-metallic mineral product manufacturing
		5.4	Livestock and cropping
		3.7	Basic metal manufacturing
		11.7	All other sectors
Fuel use (including petrol and diesel)	34.9%	8.4	Livestock and cropping
		7.5	Services to agriculture
		4.8	Petroleum and industrial chemical manufacturing
		44.4	All other sectors
Fertiliser (excluding lime)	58.3%	20.4	Non-metallic mineral product manufacturing
		6.6	Petroleum and industrial chemical manufacturing
		5.8	Livestock and cropping
		8.9	All other sectors
CO_2 from fuel use	25.9%	21.7	Non-metallic mineral product manufacturing
		11.1	Road transport
		7.25	Livestock and cropping
		34.1	All other sectors
Animal CH_4	74.9%	24.8	Livestock and cropping
		0.3	Other farming

Notes: CO_2: carbon dioxide, CH_4: methane

4.2 1997/1998 New Zealand dairy processing sector results

The main direct and indirect inputs and outputs for the New Zealand dairy processing sector in 1997/1998 are summarised in Table 3.

Table 3 Direct and indirect inputs (resource use) and outputs (product and effluent) for the New Zealand dairy processing sector for the year 1997/1998

Parameter	*Direct*	*Total*	*Indirect % of total*
Inputs			
Land use (ha × 10^6)	0.005	3.382	99.9%
Electricity use (GJ × 10^6)	2.749	6.681	58.9%
Water use (kt × 10^3)	36.0	803.5	95.5%
Raw milk (kt × 10^3)	11.40	11.41	0.1%
Mining and quarrying (including coal) (kt)	309	3,260	90.5%
Fuel (including petrol and diesel) (kt)	29	251	88.4%
Oil and gas (including LPG, engine oil, fuel oil, biogas) (kt)	21	384	94.5%
Chemical, rubber and plastic (kt)	137	399	65.7%
Outputs			
Dairy products (kt)	1,764	1,766	0.1%
Chemical, rubber and plastic products (including lactose, casein, ethanol) (kt)	133	546	75.6%
Other food (including whey) (kt)	26	102	74.5%
Water discharge (kt × 10^3)	47	846	94.4%
CO_2 from energy use (kt)	1,092	2,010	45.7%
CO_2 from non energy use (including tanker diesel, LPG, engine oil, etc.) (kt)	91	682	86.7%
Animal CH_4 (kt)	0	413	100%

Notes: ha: hectares, GJ: Giga Joules, kt: kilo tonnes, CO_2: carbon dioxide and CH_4: methane. 'Including' is used to indicated direct components. Thus, 'mining a quarrying' includes coal used directly by the dairy processing sector but also includes other components such as lime contributed indirectly from other sectors such as the dairy farming sector.

Predictably, the dairy processing sector uses very little land directly but imports an enormous amount indirectly from its major supplying sector, namely the dairy farming sector which is very land intensive. Similarly, the dairy processing sector imports large indirect contributions from supplying sectors to its total inputs of water, mining and quarrying, fuel and oil and gas. Conversely, its total raw milk input is mostly from direct use.

On the output side, the output of dairy products is predominantly directly from the dairy processing sector. Its energy-related CO_2 emissions are those emissions from fuels such as coal, LPG, natural gas etc. used in the dairy processing plants and these emissions are mostly direct. However, there are large indirect contributions to dairy processing's water effluent and non-energy related CO_2 emissions. Predictably, all the animal methane is indirect; being imported mainly from the dairy farming sector. Note that the total animal methane emission from dairy farming is (Table 1) 460 kt with large indirect contributions from the livestock and cropping sector, while that from dairy processing is 413 kt, with a much smaller contribution from the livestock and cropping sector.

In 1997/1998, the direct water effluent from the dairy processing industry was 47 million tonnes. Remember that the term ‘effluent’ used here means ‘flowing from’ and does not imply a particular level of contamination. In fact, 35% of this 47 million tonnes is clean water (for example, from evaporators during milk powder production) which has no adverse environmental impact. Of the remainder, 29% goes into rivers, 23% is irrigated onto land and 13% undergoes biological treatment. An additional 5.2 million tonnes of high strength waste is produced by the sector and is treated in municipal waste treatment facilities.

Table 4 summarises the main sectors contributing to the indirect inputs and outputs of the dairy processing sector. For example, in the case of electricity use: The dairy processing sector accounts for 41.2% of its total electricity use with 41.1% directly from the electricity it uses and the remaining 0.1% arising from transactions within its own sector. The remainder of the (indirect) contributions to the total electricity use by the dairy processing sector come from the dairy farming sector (29.8%), basic metal manufacturing (6.0%), non-metallic mineral product manufacturing (2.9%) and the remaining sectors (20.1%).

Table 4 Sectoral contributions to total inputs and outputs of the New Zealand dairy processing sector in 1997/1998

Parameter	*Dairy processing sector (direct + indirect) (%)*	*Main contributions (indirect) from other sectors (%)*	
Land use	0.2%	49.0	Livestock and cropping
		46.6	Dairy farming
		2.4	Services to agriculture, hunting and trapping
		1.8	All other sectors
Electricity use	41.2%	29.8	Dairy farming
		6.0	Basic metal manufacturing
		2.9	Non-metallic mineral product manufacturing
		20.1	All other sectors
Water use	4.5%	90.2	Dairy farming
		2.1	Mining and quarrying
		1.3	Electricity generation and supply
		1.9	All other sectors
Mining and quarrying use (including coal)	9.5%	50.5	Non-metallic mineral product manufacturing
		12.2	Dairy farming
		6.9	Livestock and cropping
		20.9	All other sectors

Table 4 Sectoral contributions to total inputs and outputs of the New Zealand dairy processing sector in 1997/1998 (continued)

Parameter	*Dairy processing sector (direct + indirect) (%)*	*Main contributions (indirect) from other sectors (%)*	
Fuel (including petrol and diesel) use	11.8%	22.3	Dairy farming
		8.7	Livestock and cropping
		8.0	Air transport, services to transport and storage
		49.2	All other sectors
Oil and gas (including LPG, engine oil, fuel oil, biogas) use	5.5%	36. 6	Petroleum and industrial chemical manufacturing
		27.2	Wholesale trade
		15.4	Gas supply
		15.3	All other sectors
Chemical, rubber and plastic product (including lactose, casein and ethanol)	24.4%	63.7	Petroleum and industrial chemical manufacturing
		8.4	Rubber, plastic and other chemical product manufacturing
		1.9	Wholesale trade
		1.6	All other sectors
Water effluent	5.6%	79.2	Dairy farming
		2.8	Personal and other community services
		2.6	Water supply
		9.8	All other sectors
CO_2 emissions from energy use	54.4%	8.4	Dairy farming
		7.2	Non-metallic mineral product manufacturing
		6.4	Road transport
		23.6	All other sectors
CO_2 emissions from non-energy (including tanker diesel, LPG, engine oil) use	0.9%	80.5	Dairy farming
		11.4	Non-metallic mineral product manufacturing
		4.7	Other food manufacturing
		2.5	All other sectors

The dairy farming sector is the main contributing sector to the dairy processing sector and, as such, many of the inputs and outputs of the dairy farming sector flow through (and contribute indirectly) to the dairy processing sector. Typical examples of this are dairy farming's large contributions to dairy processing's total land use, water use, fuel use, water effluent and non-energy-related CO_2 emissions. Similarly, because there is such a strong interaction between the dairy farming sector and the dairy processing sector, any sectors which have strong interactions with the dairy farming sector will ultimately affect the dairy processing sector. A good example of this is the non-metallic metal manufacturing sector which supplies fertilisers to the dairy farming sector and, as a consequence is seen to contribute to dairy processing's electricity use, mining and quarrying use (dairy farming consumes lime and gravel from this sector) and CO_2 emissions.

4.3 A comparison between the food and fibre sectors of New Zealand in 1997/1998

The total (direct and indirect) resource use and pollutant output of the nine food and fibre sectors of New Zealand is shown in Table 5. In making any comparison between the sectors it is important to remember that total resource use and pollutant output are *not* additive. For example, total land use for the dairy farming sector is 3.44 million hectares and total land use for the dairy processing sector is 3.38 million hectares. This does not mean that in 1997/1998 dairy farming and dairy processing accounted for a total combined land use of 6.82 million hectares. Direct resource use is a measure of what the sector itself consumes. Total resource use is a measure of cumulative consumption to produce the product from the sector and is akin to the LCAof the product.

Table 5 Comparison of total resource use and pollutants for the main food and fibre sectors of New Zealand in 1997/1998

Sector	*Land (ha × 10^6)*	*Electricity use (GJ × 10^6)*	*Water use (kt × 10^3)*	*Fuel use (kt)*	*Water output (kt × 10^3)*	*CO_2 from energy use (kt)*	*Animal CH_4 (kt)*
Livestock and cropping farming	12.206	1.453	65	263	76	915	1,054
Dairy cattle farming	3.436	4.,154	969	207	940	838	460
Other farming	0.908	0.656	15	77	12	348	39
Services to agriculture, hunting and trapping	0.167	0.666	8	114	14	160	14
Forestry	1.855	0.479	7	266	18	535	12
Meat and meat product manufacturing	7.900	3.967	185	348	246	1,765	674
Dairy processing	3.382	6.681	803	251	846	2,010	413
Wood product manufacturing	0.716	2.,718	15	211	31	893	8
Paper and paper product manufacturing	0.123	8.986	45	95	113	4,249	3

It is obvious that land-intensive operations such as farming will use significantly more land than the manufacturing sectors. It is less obvious and therefore noteworthy, that the dairy product manufacturing sector and the meat manufacturing sector have high total animal methane emission although neither sector has any direct emission of animal methane. Both sectors inherit a large indirect contribution from their primary raw material supplier (milk from dairy farms and meat from livestock and cropping respectively) and, in addition, further indirect contributions from sectors which supply the dairy farming and livestock and cropping sectors. Once again, it is stressed that total animal methane emissions of 460 kt (Table 3) for the dairy farming sector and of 413 kt for the dairy processing sector do not imply a combined total of 873 kt since the sectors operated simultaneously. Direct inputs and outputs are additive, total inputs and outputs are not.

If the values in Table 5 are normalised using the data for the dairy processing sector and expressed as a percentage then it becomes easier to compare the sectors. The values are shown on Table 6.

Table 6 Comparison of total resource use and pollutants for the main food and fibre sectors of New Zealand in 1997/1998 normalised and expressed as a percentage of the dairy processing sector

Sector	*Land use*	*Electricity use*	*Water use*	*Fuel use*	*Water output*	*CO_2 from energy use*	*Animal CH_4*
Livestock and cropping farming	361	22	8	105	9	46	255
Dairy cattle farming	102	62	121	83	111	42	111
Other farming	27	10	2	31	1	17	9
Services to agriculture, hunting and trapping	5	10	1	46	2	8	3
Forestry	55	7	1	106	2	27	3
Meat and meat product manufacturing	234	59	23	139	29	88	163
Dairy processing	100	100	100	100	100	100	100
Wood product manufacturing	21	41	2	84	4	44	2
Paper and paper product manufacturing	4	134	6	38	13	211	1

Table 7 Food and fibre contributions to New Zealand's international exports in 1997/1998 ($ million) and to GDP ($ million)

Sector	*Contribution to international export*	*Contribution to GDP*
Livestock and cropping farming	340	1,642
Dairy cattle farming	0.74	2,138
Other farming	162	353
Services to agriculture, hunting and trapping	0.00	509
Forestry	647	1,314
Meat and meat product manufacturing	3,601	1,369
Dairy processing	4,160	684
Wood product manufacturing	931	841
Paper and paper product manufacturing	796	1,058

Source: Calculated from the 1997/1998 MIOT (Market Economics Ltd.)

The dairy farming sector has the highest total water use and effluent of all the sectors. It ranks third highest in its total land use, total electricity use and total animal methane emissions. The dairy processing sector is the second most intensive user of total electricity and total water and it is the second highest producer of water effluent and CO_2 emissions from energy use. 95.52% of its total water use and 91.9% of its total effluent is indirect, being imported largely from the dairy farming sector. Once again, the intimate interaction between the dairy processing sector and the dairy farming sector is apparent.

Table 7 shows the contributions each of the nine sectors made to New Zealand's international exports and to its GDP in 1997/1998.

Table 8 Comparison of total resource use and pollutants for the main food and fibre sectors of New Zealand in 1997/98 normalised by GDP contribution and expressed as a percentage of the dairy farming sector

Sector	*Land use*	*Electricity use*	*Water use*	*Fuel use*	*Water output*	*CO_2 from energy use*	*Animal CH_4*
Livestock and cropping farming	463	46	9	166	11	142	298
Dairy cattle farming	100	100	100	100	100	100	100
Other farming	160	96	9	224	8	251	51
Services to agriculture, hunting and trapping	20	67	4	232	6	80	13
Forestry	88	19	1	209	3	104	4
Meat and meat product manufacturing	359	149	30	262	41	329	229
Dairy processing	308	503	259	379	281	750	280
Wood product manufacturing	53	166	4	259	8	271	4
Paper and paper product manufacturing	7	437	9	93	24	1,024	1

The dairy farming sector made the greatest contribution to GDP of all nine sectors and the dairy processing sector made the greatest contribution to international export earnings. Normalising the total inputs and outputs (Table 5) by contribution to GDP and by contribution to international export gives the results shown in Tables 8 and 9 respectively. Note that the sector 'services to agriculture, hunting and trapping' is not included in Table 9 as it has no export contribution.

When the contribution to GDP is taken into account in the comparison between the sectors' total inputs and outputs (Table 8), dairy farming ranks second highest in its total water use and effluent but its rankings for total land use and total electricity use drop to fifth highest. Obviously, normalisation by GDP contribution presents exporting sectors (such as the dairy processing sector) in a poor light.

When export contribution is taken into account (Table 9), the dairy processing sector performs relatively well compared with the other food and fibre sectors in terms of total fuel use (eighth of the eight sectors), total CO_2 emissions from energy use (eighth), total electricity use (sixth), total land use (sixth) and total animal methane emissions (fifth). However, it is the second most intensive user of water and the third highest in terms of its total water effluent. Obviously, normalisation by export contribution makes sectors which primarily supply the domestic market, such as dairy farming, look artificially poor in terms of their overall resource use and pollutant output.

Table 9 Comparison of total resource use and pollutants for the main food and fibre sectors of New Zealand in 1997/1998 normalised by export contribution and expressed as a percentage of the dairy processing sector

Sector	*Land use*	*Electricity use*	*Water use*	*Fuel use*	*Water output*	*CO_2 from energy use*	*Animal CH_4*
Livestock and cropping farming	4,413	266	99	1,283	110	556	3,122
Dairy cattle farming	572,297	350,250	679,625	464,852	625,657	234,900	627,814
Other farming	689	252	48	783	37	444	241
Forestry	353	46	6	682	13	171	18
Meat and meat product manufacturing	270	69	27	160	34	101	189
Dairy processing	100	100	100	100	100	100	100
Wood product manufacturing	95	182	8	375	16	199	9
Paper and paper product manufacturing	19	703	30	198	70	1,105	4

It is recognised that comparisons based upon economic contributions are not necessarily good indicators of the sustainability of the sectors; sustainability is also affected by social and environmental factors. However, economic parameters such as contribution to international export and GDP are easily determined, whereas it is difficult to put a value to the environmental and the social factors.

4.4 A comparison with other published data

As mentioned in the literature review, there is little published data on dairy processing at the national level and of similar scale to the data published here. Further, New Zealand dairy processing has somewhat different boundaries compared with other countries because in New Zealand the collection of raw milk from farms is undertaken by the processing sector. In other countries, the farming sector is responsible for delivery of milk to the processing centres.

The only source of data on dairy processing at the national level is the energy data of Ramirez et al. (2006), for France, Germany, the Netherlands and the UK in 1990 and in 2000. By interpolation, the direct CO_2 emissions from energy use in 1997 for the dairy processing industry in these four nations ranges from 33 to 74 tonnes CO_2 per kilo tonne of raw milk. The value for the New Zealand dairy processing sector is 96 tonnes CO_2 per kilo tonne of raw milk. The reason for the high value is that the New Zealand dairy processing sector produces more highly processed products (such as milk powders) compared with the European dairy industries which produce a lot of milk and cheese. Ramirez et al., note that energy efficiency is dependent not only on differing product mix but on many other factors such as the differing state of technologies and the average dairy processing facility size from one country to another.

5 Discussions and conclusions

EIOA on the data for the New Zealand dairy farming and dairy processing sectors for the year 1997/1998 has provided a clear assessment of the total (direct and indirect) resource use and pollutant output for these sectors and provides a baseline against which future analyses can be compared. There has been enormous change in the corporate structure of the dairy processing sector; in 1997/1998 there were 13 dairy companies and in 2002 all but two of these became part of the Fonterra Cooperative. The latter, by virtue of its size, will benefit from economies of scale. However, despite the change in corporate structure, the manufacturing processes have remained substantially the same as they were. This means that the baseline established here is suitable for comparison with more modern data. The accuracy of this baseline assessment is good, being based on high quality input-output data.

Compared with the other major food and fibre sectors of the economy (Table 6), the dairy farming sector has the highest total water use and effluent of all the sectors. It ranks third highest in its total land use, total electricity use and total animal methane emissions. When the contribution to GDP is taken into account in the comparison between the sectors, dairy farming ranks second highest in its total water use and effluent but its rankings for total land use and total electricity use drop to fifth highest.

The dairy processing sector performs relatively well in terms of total land use, total fuel use and total animal methane emissions. However, it is intrinsically water and fuel intensive and has high total water effluent and total CO_2 emissions from energy use.

In some cases, there is a direct relationship between resource consumption and environmental damage. For example, consumption of petroleum releases greenhouse gases so that a sector wishing to improve its sustainability might focus on minimising its petroleum consumption and on targeting petroleum-efficiency in the sectors supplying it. Similarly it might move toward clean energy sources. The dairy processing sector does not have complete freedom in its choice of supplying sectors; it must purchase milk from the dairy farming sector in order to function and, in doing so, will inherit resource use (such as land) and pollutants (such as animal methane).

The environmental impact from the consumption of other resources, such as water, is more complex. The consumption of water by a sector is not environmentally damaging unless, as the sector's activity increases, the limit of availability of water is reached.

The environmental impact from the consumption of fertilisers, chemicals, plastic and paper products is still more complicated. Fertiliser consumption does have an environmental impact so at a simplistic level, environmental damage is proportional to fertiliser use. However, the actual environmental impact will depend upon many factors such as the type of fertiliser, the condition of the soil being fertilised, the level of leaching of nutrients through the soil and into the ground water, etc. The environmental damage from chemicals, plastic and paper is probably related at a simple level to leachate from land fills, but obviously some products are worse than others.

The environmental impact from water effluent depends upon the amount of effluent, the level of contamination of the effluent and the method of effluent disposal; large quantities of concentrated effluent discharged directly into rivers or used for land irrigation will have a more damaging environmental impact than small quantities of dilute effluent discharged into the ocean. A surprising 35% of the direct water effluent from the

New Zealand dairy processing sector is very clean water with no adverse environmental effect.

Another aspect which has to be taken into account in the discussion of resource use and production of effluents is the amount of valuable product from the sector. Obviously, the dairy farming and dairy processing sectors could reduce their production and, in doing so, reduce their resource use and pollutant output. However, this would have a strong negative effect on the New Zealand economy.

Given the tenuous relationship between resource use and environmental damage, it is therefore impossible to say whether the dairy farming and dairy processing sectors operated sustainably in 1997/1998. Similarly, when this assessment is applied to future years the results will not yield any pronouncement on the overall sustainability of the sectors. However, they will indicate the trends in the use of major resources and in the production of effluents by the food and fibre sectors.

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References

Andrew, R. and Forgie, V. (2007) 'Investigating the direct and indirect environmental pressures of New Zealand's food and fibre industries', *International Journal of Sustainable Development*, Vol. 10, No. 4, pp.319–344.

Arsenault, N., Tyedmers, P. and Fredeen, A. (2009) 'Comparing the environmental impacts of pasture-based and confinement-based dairy systems in Nova Scotia (Canada) using life cycle assessment', *International Journal of Agricultural Sustainability*, Vol. 7, No. 1, pp.19–41.

Ballingall, J. and Lattimore, R. (2004) 'Farming in New Zealand: the state of play and key issues for the backbone of the New Zealand economy', *Farm Policy Journal*, Vol. 1, No. 1, pp.48–58.

Basset-Mens, C., Ledgard, S. and Boyes, M. (2009) 'Eco-efficiency of intensification scenarios for milk production in New Zealand', *Ecological Economics*, Vol. 68, No. 6, pp.1615–1625.

Berlin, J. and Sonesson, U. (2008) 'Minimizing environmental impact by sequencing cultured dairy products: two case studies', *Journal of Cleaner Production*, Vol. 16, No. 4, pp.483–498.

Berlin, J., Sonesson, U. and Tilman, A-M. (2007) 'A life cycle based method to minimize environmental impact of dairy production through product sequencing', *Journal of Cleaner Production*, Vol. 15, No. 4, pp.347–356.

Berlin, J., Sonesson, U. and Tilman, A-M. (2008) 'Product chain actors' potential for greening the product life cycle', *Journal of Industrial Ecology*, Vol. 12, No. 1, pp.95–110.

Bouman, M., Heijungs, R., van der Voet, E., van den Bergh, J. and Huppes, G. (2000) 'Material flows and economic models: an analytical comparison of SFA, LCA and partial equilibrium models', *Ecological Economics*, Vol. 32, No. 2, pp.195–216.

Carran, R., Ledgard, S., Wedderburn, M. and Jollands, N. (2004) 'A life cycle assessment of milk production on a New Zealand dairy farm', Dairy Insight Report, New Zealand, November, pp.1–30.

Cederberg, C. and Mattsson, B. (2000) 'Life cycle assessment of milk production – a comparison of conventional and organic farming', *Journal of Cleaner Production*, Vol. 8, No. 1, pp.49–60.

Cox, G.C. and Miller, E.J. (1986) 'Comparative energy efficiencies of the dairy manufacturing and processing industry: Australia and New Zealand', *Engineering Costs and Production Economics*, Vol. 10, pp.293–303, available at http://www.sciencedirect.com/science?_ob =MImg&_imagekey=B6X22-45TVDXB-1H-1&_cdi=7258&_user=572227&_pii= 0167188X8690056X&_origin=&_coverDate=03%2F31%2F1986&_sk=999899998&view=c &wchp=dGLzVlz-zSkWz&md5=27b45d0595fd4f07c1303d30bb0ad588&ie=/sdarticle.pdf.

Danalewich, J.R., Papagiannis, T.G., Belyea, R.L., Tumbleson, M.E. and Raskin, L. (1998) 'Characterization of dairy waste streams, current treatment practices and potential for biological nutrient removal, *Water Research*, Vol. 32, No. 12, pp.3555–3568.

Dyer, J.A. and Desjardins, R.L. (2006) 'An integrated index of electrical energy use in Canadian agriculture with implications for greenhouse gas emissions', *Biosystems Engineering*, Vol. 95, No. 3, pp.449–460.

Evans, G. (2008) 'N.Z. forecasts fall in dairy prices though 2009 (update 1)', Bloomberg, available at http://www.bloomberg.com/apps/news?pid=newsarchive&sid=a4O5KrquIb90 (accessed on 20 December 2010).

Flemmer, C.L. and Flemmer, R.C. (2007) 'Water use by New Zealand dairy farms, 1997 to 2000', *New Zealand Journal of Agricultural Research*, Vol. 50, No. 4, pp.479–489.

Flemmer, C.L. and Flemmer, R.C. (2008) 'Water effluent from New Zealand dairy farms from 1997 to 2000', *New Zealand Journal of Agricultural Research*, Vol. 51, No. 2, pp.181–189.

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', *2005 Proceedings ANZSEE Conference*, Palmerston North, New Zealand, pp.73–84.

Food and Agriculture Organisation (FAO) of the United Nations (2010) 'Greenhouse gas emissions from the dairy sector: a life cycle assessment', pp.1–98, available at http://www.fao.org/docrep/012/k7930e/k7930e00.pdf (accessed on 24 June 2011).

Gomiero, T., Paoletti, M.G. and Pimental, D. (2008) 'Energy and environmental issues in organic and conventional agriculture', *Critical Reviews in Plant Sciences*, Vol. 27, No. 4, pp.239–254.

Hendrickson, C.T., Lave, L.B. and Matthews, H.S. (2006) 'Environmental life cycle assessment of goods and services: an input-output approach', Resources for the Future Press, Washington DC, ISBN: 1-933115-23-8.

Hite, J.C. and Laurent, E.A. (1972) *Environmental Planning: An Economic Analysis*, pp.1–155, Praeger Publishers, New York.

Hogaas Eide, M. (2002) 'Life cycle assessment (LCA) of industrial milk production', *International Journal of Life Cycle Assessment*, Vol. 7, No. 2, pp.115–126.

Livestock Improvement Corporation (LIC) (1998) Dairy Statistics 1997–1998, pp.1–45, Livestock Improvement Corp. Ltd., Hamilton New Zealand.

McDonald, G.W. and Patterson, M.G. (2003) 'Ecological footprints of New Zealand regions', Environmental Reporting Technical Paper, Ministry for the Environment, Wellington, New Zealand, ISBN 0-478-24085-6, pp.1–162, available at http://www.mfe.govt.nz/ publications/ser/eco-footprint-sep03/eco-footprint-sep03.pdf (accessed on 19 August 2011).

Miller, E.J. (1984) 'Energy use in the New Zealand dairy processing industry', *Energy in Agriculture*, Vol. 3, pp.307–312, available at http://www.sciencedirect.com/science?_ob=MImg&_imagekey=B75CF-4903KB0-3R-1&_cdi=13009&_user=572227&_pii=0167582684900391&_origin=&_coverDate=12%2F31%2F1984&_sk=999969999&view=c&wchp=dGLzVzz-zSkzk&md5=d9b089a7b0f7e766bf48af1d0b6d40b6&ie=/sdarticle.pdf.

Ministry for the Environment (MFE) (2005) 'New Zealand's greenhouse gas inventory 1990–2003', *The National Inventory Report and Common Reporting Format Tables*, April 2005, ISBN 0-478-25920-4, pp.1–172, Wellington, New Zealand.

Ministry of Agriculture and Forestry (MAF) Policy Farm Monitoring Reports (1998), North, North Central, South Central and Southland Regions.

Muller-Lindenlauf, M., Deittert, C. and Kopke, U. (2008) 'Environmental impacts and economic differences in grassland based organic dairy farms in Germany – modelling the extremes', *16th IFOAM Organic World Congress*, 16–20 June, Modena, Italy.

Muller-Lindenlauf, M., Deittert, C. and Kopke, U. (2010) 'Assessment of environmental effects, animal welfare and milk quality among organic dairy farms', *Livestock Science*, Vol. 128, pp.140–148.

Ozbay, A. and Demirer, G.N. (2007) 'Cleaner production opportunity for a milk processing facility', *Journal of Environmental Management*, Vol. 84, No. 4, pp.484–493.

Pimental, D., Hepperly, J., Douds, D. and Seidel, R. (2005) 'Environmental, energetic and economic comparisons of organic and conventional farming systems', *BioScience*, Vol. 55, No. 7, pp.573–582.

Pinares-Patino, C.S., Waghorn, G.C., Hegarty, R.S. and Hoskin, S.O. (2009) 'Effects of intensification of pastoral farming on greenhouse gas emissions in New Zealand', *New Zealand Veterinary Journal*, Vol. 57, No. 5, pp.252–261.

Ramirez, C.A., Patel, M. and Blok, K. (2006) 'From fluid milk to milk powder: energy use and energy efficiency in the European dairy industry', *Energy*, Vol. 31, No. 12, pp.1984–2004.

Ridoutt, B.G., Williams, S.R.O., Baud, S., Fraval, S. and Marks, N. (2010) 'Short communication: the water footprint of dairy products: case study involving skim milk powder', *Journal of Dairy Science*, Vol. 93, No. 11, pp.5114–5117.

Sankaran, J.K. and Luxton, P. (2003) 'Logistics in relation to strategy in dairying. The case of New Zealand dairy', *International Journal of Operations and Production Management*, Vol. 23, No. 5, pp.522–545.

Stukenberg, D., Blayney, D. and Miller, J. (2006) 'Major advances in milk marketing: government and industry consolidation', *Journal of Dairy Science*, Vol. 89, No. 4, pp.1195–1206.

Thomassen, M.A. and de Boer, I.J.M. (2005) 'Evaluation of indicators to assess the environmental impact of dairy production systems', *Agriculture, Ecosystems and Environment*, Vol. 111, No. 3, pp.185–199.

Van der Werf, H.M.G., Kanyarushoki, C. and Corson, M.S. (2009) 'An operational method for the evaluation of resource use and environmental impacts of dairy farms by life cycle assessment', *Journal of Environmental Management*, Vol. 90, No. 11,pp.3643–3652.

Wells, C. (2001) 'Total energy indicators of agricultural sustainability: dairy farming case study', Technical Paper 2001/3, ISBN: 0-478-07968-0, Prepared for the New Zealand Ministry of Agriculture and Forestry (MAF), Wellington, New Zealand, pp.1–81.

Xu, T., Flapper, J. and Kramer, K.J. (2009) 'Characterization of energy use and performance of global cheese processing', *Energy*, Vol. 34, No. 11, pp.1993–2000.

Notes

1 FoRST: Foundation for Research, Science and Technology, New Zealand.

2 Strictly speaking, the impacts reported are not the total impacts as they do not include the impacts associated with the products purchased from other nations, i.e., embodied in imports.

3 'EIO-LCA: Free, Fast, Easy Life Cycle Assessment' explanation and tool available at: http://www.eiolca.net/ retrieved on 20/12/10.

4 An independent consulting company located in Auckland, specialising in NZ market and economic analysis and environmental and ecological research (http://www.marketeconomics.co.nz/).

5 The publication referred to is a conference paper and is available from the author upon request.

6 The term 'effluent' is used here meaning 'flowing out from', i.e., all water-based discharges from processing. About one-third of such discharges are extremely clean and have no negative environmental impact.

7 Landcare research: a New Zealand environmental research organisation and independent crown research institute (CRI) founded in 1992 and a founding member of the New Zealand business council for sustainable development. http://www.landcareresearch.co.nz/.