The Relationship between Environmental Sustainability and Input-Output Analysis of the New Zealand Dairy Farming Sector

Claire L. Flemmer and Rory C. Flemmer

Corresponding author: Dr. Claire Flemmer, email: c.l.flemmer@massey.ac.nz

ABSTRACT

The economic benefits deriving from the New Zealand dairy farming sector must be weighed against its environmental impact. That impact has been assessed using environmental input-output analysis which provides data on the total (direct and indirect) environmental resources used and the environmental outputs such as water effluent and greenhouse gases. The data is comprehensive but does not indicate whether the dairy farming sector operates sustainably. Because the use of a resource only implies poor sustainability if it results in environmental damage, there can be no direct correlation with sustainability. In this work, the relationship between environmental sustainability and the results of input-output analysis is examined for the New Zealand dairy farming sector in terms of its energy use, water use, land and fertilizer use, production of water effluent and greenhouse gas emissions. The future increase in population demands a sustainable increase in food and fibre production and it is anticipated that changing technology will permit this increase, just as it has done in the past.

Introduction

New Zealand's food and fibre products account for almost half of the country's annual export earnings (Ballingall et al. 2004). However, there are environmental and social effects associated with the economic value of the food and fibre sectors and these must be considered in assessing the sustainability of the sectors. The long term goal is to conserve soil quality (structure, nutrients, organic content, etc.) and productive capacity through sustainable agricultural practices. Sustainability may be thought of as ensuring that current practice does not jeopardise future practice (UNCED 1987). There are generally three types of sustainability; economic, environmental and social. In this work, we focus on environmental sustainability but acknowledge the complex interrelation with economic and social sustainability. Further, there is pressure not merely to continue to produce at the current levels, but to increase production to meet increasing demand. This means that the food and fibre sectors must not only be sustainable, but must also expand in a sustainable manner.

The Foundation for Research, Science and Technology is funding the Ecological Footprint Plus project (contract WROX0305) which uses environmental input-output analysis to determine the ecological footprint of New Zealand's major food and fibre sectors from the year 1997/98 onwards. The analysis computes the total (direct and indirect) resource use and the total output of the sector and may be thought of as a life cycle analysis of the sector as a whole, rather than the traditional life cycle analysis of a single product. In the case of the dairy farming sector, the results provide the total use of resources such as land, water, fertilizer, electricity, etc. and the total production of useful outputs, such as milk, as well as the total production of effluents such as greenhouse gases, water effluent, etc. The form of the results is a table consisting of 151 rows of physical inputs and outputs for each of 48 columns representing the 48 sectors of the New Zealand economy. While the 7,248 numbers provide information on total resource consumption and pollutant production, they tell us little about the sustainability of the dairy farming sector. The consumption of a resource (as an input needed to perform dairy farming) is only unsustainable if the resource is non-renewable or is being damaged in some way during its consumption. Similarly, the outputs from the dairy farming sector are only unsustainable if they are causing damage to the environment.

The physical inputs or resources of particular interest which are captured in the input-output analysis are water use, energy use (both fuel and electricity), fertilizer use and land use. The most important physical outputs or effluents captured in the input-output analysis are water effluent (both the amount of effluent and the level of pollution in it) and greenhouse gas production. An attempt is made to relate each of these environmental factors to sustainability.

2. Literature Review

A review of the literature on measures of sustainability by Flemmer et al. 2005a, notes that the measures do not address the problem of quantifying environmental damage. Instead, the measures are a set of metrics representing the amount of resource used and the amount of effluent produced by a product or a production system. In the case of the dairy farming sector, typical metrics are the amount of energy used and the amount of green house gas (GHG) produced per litre of milk. There are two common methods of assessment of resource use and environmental outputs; namely life-cycle analysis (LCA) and environmental input-output analysis (EIOA). These are reviewed below, and although neither method actually provides an assessment of sustainability, the metrics when viewed in a time sequence can indicate whether performance is becoming better or worse. In the case of dairy farming, for example, a decrease in energy consumption per litre of milk over a period of several years would indicate improved energy efficiency performance by the sector over that time frame.

LCA is used primarily to assess the overall environmental resource use and effluents of a single product or production system. Assessment covers the entire life-cycle ("cradle to grave") of the product, from extraction and processing of raw material, to final disposal (Landsiedel et al. 2002). The main disadvantage of traditional life-cycle analysis is that the process of data collection can lead to "double-counting" of resource use because the further down the supply chain, the harder it is to apportion the correct resource use to the product under investigation and the harder it is to track interactions between the contributing suppliers.

EIOA determines the overall environmental impact of an entire sector of the economy (in this instance, the dairy farming sector) and may be viewed as a macro-level LCA covering the "cradle to gate" portion of the life-cycle. In the analysis, national monetary flows, represented in a monetary input-output table (MIOT), are used to compute the total (direct and indirect) use of environmental parameters such as land

and energy and the resulting production of environmental pollutants such as emissions of CO_2 (Hite et al. 1972). EIOA has the limitation that it is intrinsically linear (disallowing economies of scale), it assumes homogeneity (each sector produces a single product) 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 LCA that it captures all the intra-sector flows, both direct and indirect, with no possibility of "double-counting".

In taking the step from measuring consumption of resources and production of effluents to gauging the effect on the environment, the Environmental Performance Index (EPI) is significant. The EPI was developed from Goal 7 of the Millennium Development Goals (MDG) from the United Nations 2000 Milleneum Declaration (Kakabadse-Navarro 2004). Esty et al. 2006 present the Environmental Performance Index (EPI) for 133 countries (with New Zealand having the highest rating). The EPI is a number whose maximum value of 100 is based upon "perfect" condition for 16 indicators such as child mortality, indoor air pollution, sanitation, nitrogen loading of water, water consumption, energy efficiency, etc. Past and present metrics are used to predict the future environmental performance of the countries. Esty et al. 2006 note that there are no indicators for several important issues such as soil productivity and erosion and GHG emissions.

Williams et al. 2006 used LCA of ten commodities produced in England and Wales to determine resource consumption and pollutant production and then related these to a set of sustainability indicators. The indicators included the Eutrophication Potential (EP), the Acidification Potential (AP), the Abiotic Resource Use (ARU), the Global Warming Potential (GWP) and primary energy use. These are defined in the Appendix. The merit of these indicators is that they combine a set of measured values into a single number. The weakness of these indicators is that they are not directly related to sustainability. For example, GWP combines the emissions of CO_2, CH_4 and N_2O into a single number (with units of kg of CO2 equivalents) but the value of GWP which is unsustainable is not known.

No matter which set of metrics is used in trying to assess the sustainability of a production system or sector, an intrinsic difficulty arises from Arrow's Theorem (MacKay, 1984) which points out that it is not possible to rank, unequivocally, quantities which have more than one dimension. For example, the dairy farming sector consumes energy and produces polluted effluent water and GHG's, but which of these is the most important parameter in assessing the sustainability of the sector?

3. METHOD OF EIOA

The method of environmental input output analysis is described in detail by Flemmer et al. 2005b. It is summarised briefly below.

The 1997/98 MIOT is used to generate 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. The Leontief inverse matrix, **L** is then computed using:

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

Where **I** is the 48 by 48 identity matrix.

The Leontief inverse matrix summarizes the direct and indirect monetary transactions between the 48 sectors of the economy, so that in the case of the dairy farming sector, **L** encapsulates the total (direct and indirect) dollar input required from each supplying sector in order to produce one dollar of output from the dairy farming sector. An inherent assumption in the formation of **L** is that all industries pay the same price for resource inputs. If this is not the case and one industry pays less than another (perhaps because of a quantity discount) then errors will exist when **L** is used as a multiplier.

Alongside the monetary flow between the sectors, there is a concurrent input of physical commodities and resources, such as raw materials, electricity and water, and environmental outputs such as polluted water and greenhouse gases. These physical inputs and outputs can be summarized in a resource matrix **G**, following the method outlined by Hite et al. 1972. **G** is thus the set of "n" direct physical inputs and outputs of the 48 sectors per unit dollar of net output from the sector (and is an "n" by 48 matrix). The resource matrix entries have a variety of units such as hectares, giga joules and tonnes. In the Ecological Footprint Plus project "n" had a value of 151.

Post multiplying **G** by the Leontief inverse, gives the matrix of total (direct and indirect) resource multipliers, $\mathbf{G_T}$, i.e.

(2) $$\mathbf{G_T} = \mathbf{G}\,\mathbf{L}$$

Total resource use (and pollutant output) in physical units, is then computed by multiplying $\mathbf{G_T}$ 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.

4. Results

Flemmer et al. 2005b present the results of the environmental input output analysis for the New Zealand dairy farming sector for the year 1997/98.

Table 1 shows the most significant results found in this work.

Table 1 Direct and indirect resource use and pollutants for the New Zealand dairy farming sector for the period 1997/98

Parameter	Direct	Total	Indirect % of Total
Land use (ha)	2,149,420	3,557,337	39.6
Electricity use (GJ)	1,849,376	3,433,780	46.1
Water use (Kt)	760,128	795,891	4.49
Mining and quarrying (including lime) use (Kt)	1,969	4,748	58.5
Fuel use (Kt)	176	312	43.5
Fertilizer use (Kt)	683	1,179	42.1
Water discharge (Kt)	695,023	770,719	9.82
CO_2 from energy use (Kt)	535	1,160	53.9
Animal CH_4 (Kt)	343	460	25.5
Animal NH_3 (Kt)	89.1	107	17.1
Point source water pollution – BOD (Kt)	1.32	1.59	17.0
- Water DRP (Kt)	0.18	0.21	16.0
- Water TP (Kt)	0.42	0.50	15.6
- Water NH_4-N (Kt)	1.33	1.39	3.81
Non-point source water pollution - N (Kt)	84.3	96.8	12.9
- P (Kt)	2.09	3.76	44.5

ha: hectares, GJ: Giga Joules, Kt: Kilo tonnes, CO_2: carbon dioxide, CH_4: methane, NH_3: ammonia, BOD: Biochemical Oxygen Demand, DRP: dissolved reactive phosphorous, TP: total phosphorous, NH_4-N: total ammoniacal nitrogen, N: nitrogen, P: phosphorous

5. Relating the Results to Sustainability

Input Parameters

On the consumption or input side of the environmental input-output analysis, the resources which are of particular interest are water use, energy use (both fuel and electricity), fertilizer use and land use. The relationship between each of these and sustainability is discussed below.

Energy Use

The primary sources of energy are coal, natural gas, oil, uranium (nuclear electricity) and renewable sources such as hydro-power, geothermal energy and wind energy. In 1997/98, 30.8% of New Zealand’s energy supply came from renewable resources and this has remained fairly constant with 31.0% renewable energy in 2004 (MED 2005).

Table 1 shows that in 1997/98 the dairy farming sector consumed 1.8 million GJ of electricity directly and 3.4 million GJ in total (46.1% of this from sectors supplying the dairy farming sector). Assuming that 30.8% of this came from renewable resources, the remaining 1.2 million GJ (direct) and 2.4 million GJ (total) are not sustainable. All of the fuel use; 176 Kt (direct) and 312 Kt (total) is not sustainable. Thus, the New Zealand dairy farming sector is not sustainable in terms of its energy use.

The sector can improve its energy efficiency in order to consume the non-renewable energy sources more slowly. This will have the added advantage of reducing the greenhouse gases associated with the burning of fossil fuels. However, New Zealand will have to move towards alternative, renewable energy sources in order to become sustainable in its energy use.

In the longer term, it is clear that fossil fuels will become depleted and that other forms of energy will become cheaper and more attractive in terms of GHG emissions. If New Zealand moves to a hydrogen-based energy economy (using fission and, ultimately, fusion) then it will become sustainable in terms of its energy use.

Water Use

The dairy farming sector consumed 760 million tonnes of water (direct) and 796 million tonnes of water (total) in 1997/98 (Table 1) and produced 11,042 million litres of milk or, 921 million kg of milksolids (NZDB 1998). Dairy farming has expanded since then (NZDB 1999, 2000 and LIC 2001, 2002, 2003, 2004) and in 2003/04 the production of milk was 14,599 million litres (1,251 million kg milksolids). Evidently New Zealand received enough rain over the intervening six years, not only to ensure sustainability of the dairy farming sector in terms of water availability, but also to permit expansion of the sector. There is no reason to suppose that the amount of rain and thus the amount of available water will change dramatically in the future and the implication is that the New Zealand dairy farming sector will remain sustainable at its current level in terms of water availability. The sector’s rate of expansion may be limited as New Zealand reaches a limit on available water which will limit the granting of new water resource consents.

In the longer term, with abundant energy, desalination will provide additional water for agriculture and allow for expansion of the food and fibre sectors.

Land and Fertilizer Use

EIOA computes the total land and fertilizer used by the sector (Table 1). Land use is only sustainable at the current level of operation (i.e., without expansion) if the soil is being conserved. No good measures of soil conservation exist today on a worldwide basis. The EPI (Esty et al. 2006) uses agricultural subsidies as a proxy for sustainable agriculture, asserting that subsidies distort planting decisions and encourage ecologically harmful practices such as intensive use of chemicals, farming in riparian zones and monoculture.

The soil can be damaged in two ways: firstly by erosion and secondly by critical contamination from intensive fertilizer application, until it becomes incapable of pasture growth (Kakabadse-Navarro et al. 2004). These two factors are discussed below.

Hicks et al. 2001 discuss soil erosion in New Zealand and estimate that about 23.3% of agricultural land in the North Island and about 74% of South Island is susceptible to sheet and rill erosion (running water removing soil from gently sloping land) but have no data on how much land is actually affected every year. In 1984, Salter found that about 13% of New Zealand soil (3.4 million hectares) was affected by wind erosion. The Global Assessment of Land Degradation (GLASOD) is the only comprehensive and uniform global assessment of the paucity of soil quality and land degradation (Esty et al. 2006). It represents a consensus opinion of national and regional experts on the extent of land degradation in various categories of severity in the early 1990's.

Average contamination of New Zealand soil from fertilizer application is estimated at a nitrogen loading of 17.5 mg/L (Esty et al. 2006). New Zealand dairy farmers are aware of this and use acceptable loadings for their farms. The increase in milk production from 1997/98 to 2003/04 indicates that over this period the dairy farming sector has operated sustainably. However, there is a finite amount of land available, so that in order for dairy farming to continue to increase its productivity, it will have to turn to new technologies such as hydroponics. Long-term sustainability is therefore dependent upon technology.

Output Parameters

On the output side of the environmental input-output analysis for the dairy farming sector, the most important parameters are water effluent (both the amount and the level of pollution) and greenhouse gas production. The relationship between each of these and sustainability is discussed below.

Water Effluent

In 1997/98, the New Zealand dairy farming sector produced 695 million tonnes of water effluent directly and 771 million tonnes of water effluent in total (Table 1). The water effluent from dairy farms contains substances such as nitrogen, phosphorous and organic matter (suspended solids) which find their way into the ground and surface waters via leaching, runoff or direct discharge. The waters then suffer from eutrophication; the growth of plants which consume all the oxygen in the water so that fish life cannot be supported. In a narrow sense, dairy farm effluent is not directly related to the sustainability of the dairy farming sector since the latter does not depend upon the existence of fish. However, recreational users of water ways in a democratic society will apply pressure to control the pollution from dairy farms, for example the "Dairying and Clean Streams Accord" agreed upon on 26th May 2003 between Fonterra Co-operative Group, the Minister for the Environment, the Minister of Agriculture and the regional councils.

Waterways are resilient; they recover when pollution levels drop as is demonstrated in the history of the Thames River (Owen 2005). However, contamination of the oceans leading to elevated levels of poisons such as mercury in fish are of greater concern and are more difficult to control. In the long-term, there will be increased use of fish farms to support the demand for fish, so that once again, technology or "changeability" will solve the problem of sustainability.

Greenhouse Gas Emissions

The greenhouse gases produced by the dairy farming sector are carbon dioxide (CO_2), methane (CH_4) and ammonia (NH_3) and Table 1 shows the quantities produced in 1997/98. Using the global warming potential (GWP) defined in the appendix, in 1997/98 the dairy farming sector had a direct GWP of 20.3 million tonnes equivalent CO_2 and a total GWP of 25.9 million tonnes equivalent CO_2. Although there is vigorous debate about the impact of greenhouse gas emission on global warming

(O'Rourke 1992), the Kyoto protocol dictates that NZ must reduce its emissions to 1990 levels. It is assumed that the 1990 levels of greenhouse gases have a negligible effect upon climate and are thus sustainable.

6. Conclusion

The debate on sustainability takes place within the context of growing world population and growing per capita expectation of goods and services. The social dimension of sustainability therefore demands not that present practice be sustained but that production of goods and services is steadily ramped up. A modest figure of 2% per annum growth in GDP implies a doubling of production every 35 years. This means that the food and fibre sectors must be more than simply sustainable at their current levels, but that their expansion must also be sustainable. It is anticipated that changing technology will permit future expansion in the same way that it has permitted expansion over the past. In environmental terms, the emerging demand will override any voices of moderation as we see with the industrial pollution occurring in China today. The real question becomes not "How can we return to Rousseau's Eden?" but "How can the environment and means of production survive this burden and where should we direct the environmental fire brigade?"

References

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*, 1 (1):48–58.

Esty, D. C., Levy, M. A., Srebotnjak, T., de Sherbinin, A., Kim, C. H. and Anderson, B., (2006) 'Pilot 2006 Envrionmental Performance Index', New Haven: Yale Center for Environmental Law and Policy, United States of America. Available at www.yale.edu/epi

Flemmer, C. L. and Flemmer, R. C., (2005a) 'Measures of sustainability: What do they mean and how well do they work?', 2005, *Proceedings ANZSEE Conference*, Palmerston North, New Zealand.

Flemmer, C. L., Flemmer, R. C., McDonald, G. W., Archer, R. H. and Cleland, D. J., (2005b) 'An assessment of the ecological impact of the New Zealand dairy farming sector', *Proceedings ANZSEE Conference*, Palmerston North, New Zealand, 73-84.

Hicks, D. H. and Anthony, T. (Editors) (2001) 'Soil Conservation Technical Handbook', ISBN: 0-478-24033-3, ME: 404, Ministry for the Environment, Wellington, New Zealand. Available at: http://www.mfe.govt.nz/publications/land/soil-conservation-handbook-jun01/soil-conserv-handbook-jun01.pdf

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

Houghton, J. T., L. G. Meira Filho, B. A. Callender, N. Harris, A. Kattenberg, and K. Maskell, (Editors) (1995) 'Climate Change 1995: The Science of Climate Change' *Cambridge University Press*, Cambridge, UK.

Kakabadse-Navarro, Y., McNeely, J and Melnick, D. J., (2004) 'Interim Report of Task Force 6 on Environmental Sustainability', Commissioned by the UN Secretary General and supported by the UN Development Group as part of the Millenium Project, 1-81, available at http://www.unmillenniumproject.org/documents/tf6interim.pdf

Landsiedel, R and Saling, P., (2002) 'Assessment of toxicological risks for life cycle assessment and eco-efficiency analysis', *International Jrnl. Of Life Cycle Assessment*, 7(5), 261-268.

LIC, (2001) 'Dairy Statistics 2000-2001', Livestock Improvement Corporation Ltd., Hamilton, New Zealand (www.lic.co.nz and www.dairyinsight.co.nz).

LIC, (2002) 'Dairy Statistics 2001-2002', Livestock Improvement Corporation Ltd., Hamilton, New Zealand (www.lic.co.nz and www.dairyinsight.co.nz).

LIC, (2003) 'Dairy Statistics 2002-2003', Livestock Improvement Corporation Ltd., Hamilton, New Zealand (www.lic.co.nz and www.dairyinsight.co.nz).

LIC, (2004) 'Dairy Statistics 2003-2004', Livestock Improvement Corporation Ltd., Hamilton, New Zealand (www.lic.co.nz and www.dairyinsight.co.nz).

MacKay, A. F., (1984) 'Arrow's Theorem: The Paradox of Social Choice: A Case Study in the Philosophy of Economics', *Yale University Press*, Reprint Edition, August.

MED (Ministry of Economic Development) 2005, 'New Zealand Energy Data File', July 2005, ISSN 0111-6592, Compiled by H. D. T. Dang, Energy Information and Modelling Group, Resources and Networks Branch, Ministry of Economic Development, Wellington, New Zealand, 1-182.

NZDB, (1998), New Zealand Dairy Board, 'Dairy Facts and Figures: 1997/98', Wellington, New Zealand.

NZDB, (1999), New Zealand Dairy Board 'Dairy Facts and Figures: 1998/99', Wellington, New Zealand.

NZDB, (2000), New Zealand Dairy Board 'Dairy Facts and Figures: 1999/2000', Wellington, New Zealand.

Owen, J., (2005) 'Dolphins, Seals at Home in London's Reborn River', *National Geographic News*, 1-2, available at: http://news.nationalgeographic.com/news/2005/04/0421_050422_riverthames_2.html

O'Rourke, P. J., (1992) 'All the troubles in the world', First Edition, The Atlantic Monthly Press, New York, ISBN: 0-87113-580-9.

UNCED (United Nations Conference on Environment and Development), (1987) Bruntland, G. (Chairperson), 'Our Common Future: The World Commission on Environment and Development', *Oxford University Press*, Oxford, 87

Williams, A. G., Audsley, E. and Sandars, D. L., (2006) 'Determining the environmental burdens and resource use in the production of agricultural and horticultural commodities', Defra Research Project IS0205, Bedford: Cranfield University and Defra,. Available on www.silsoe.cranfield.ac.uk and www.defra.gov.uk .

Appendix

Eutrophication Potential (EP)

The main agricultural sources contributing to eutrophication are nitrate (NO_3) and phosphate (PO_4) leaching to water and ammonia (NH_3) emissions to air which then suffer atmospheric deposition onto the soil followed by leaching. EP is expressed in terms of phosphate equivalents: 1kg NO_3-N and NH_3-N are equivalent to 0.44 and 0.43 kg PO_4 respectively. Thus, EP is defined as (Williams et al. 2006):

$$\text{EP (kg equiv. } PO_4) = \text{mass of } PO_4 + 0.44 \times \text{mass of } NO_3\text{-N} + 0.43 \times \text{mass of } NH_3\text{-N}$$

Acidification Potential (AP)

Air pollution is a leading cause of soil and water acidification (Esty et al. 2006). The main agricultural source is ammonia (NH_3) emissions, together with sulphur dioxide (SO_2) from fossil fuel combustion. Ammonia contributes despite being alkaline because when it is deposited in the atmosphere it is oxidised to nitric acid. AP is expressed in terms of SO_2 equivalents and is defined as (Williams et al. 2006):

$$\text{AP} = \text{mass of } SO_2 + 2.3 \times \text{mass of } NH_3\text{-N}$$

Abiotic Resource Use (ARU)

Abiotic means "non-living". The use of such resources is aggregated using the method of the Institute of Environmental Sciences, Leiden University (http://www.leidenuniv.nl/interfac/cml/ssp/index.html) with a weighting based on the scarcity of the resource and expressed in terms of the mass of the element antimony (Sb).

GWP

The definition of GWP depends upon the time frame being considered. The 100-year GWP is defined as (Houghton et al. 1995):

GWP (kg equiv. CO2) = mass of CO_2 + 21 x mass of CH_4 + 310 x mass of N_2O

Where CO_2 is carbon dioxide, CH_4 is methane, N_2O is nitrous oxide and N_2O-N is nitrogen from nitrous oxide.

Primary Energy Use

The primary fuels are coal, natural gas, oil and uranium (nuclear electricity). Primary energy use is expressed in MJ. The proportion of electricity produced by renewable sources (wind and hydro-power) must be taken into account.