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Appraisal of the Environmental Sustainability of Milk Production Systems in New Zealand

A thesis presented in partial fulfilment of the requirements for the degree of Doctor of Philosophy in Science

in

Life Cycle Management

at

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Executive Summary

Life Cycle Assessment (LCA) plays an important role in the environmental assessment of agricultural product systems, including dairy farming systems. Generally, an LCA study accounts for the comprehensive resource use and environmental emissions associated with the life cycle of a studied product system. The inventoried inputs and outputs are then transformed into different environmental impact categories using science-based environmental cause-effect mechanisms. There are different LCA modelling approaches (e.g. attributional LCA [ALCA] and consequential LCA [CLCA]) that can be used to address different research questions; however, there is currently no consensus on the most appropriate approach and when to use it. These LCA approaches require different types of data and methodological procedures and, therefore, generate different sets of environmental information which may have different implications for decision-making.

In the present research, a series of studies utilising different LCA modelling approaches were undertaken of pasture-based dairy farming systems in the Waikato region (the largest dairy region in New Zealand). The purposes of the studies were to: (i) assess the environmental impacts and identify environmental hotspots of current pasture-based dairy farming systems, (ii) compare environmental hotspots between high and low levels of dairy farm intensification, (iii) investigate the environmental impacts of potential alternative farm intensification methods to increase milk productivity, and (iv) assess the environmental impacts of different future intensified dairy farming scenarios. Twelve midpoint impact categories were assessed: Climate Change (CC), Ozone Depletion Potential (ODP), Human Health Toxicity - non-cancer effects (Non-cancer), Human Health Toxicity - cancer effects (Cancer), Particulate Matter (PM), Ionizing Radiation - human health effects (IR), Photochemical Ozone Formation Potential (POFP), Acidification Potential (AP), Terrestrial Eutrophication Potential (TEP), Freshwater Eutrophication Potential (FEP), Marine Eutrophication Potential (MEP) and Ecotoxicity for Aquatic Freshwater (Ecotox).

Firstly, the environmental impacts of 53 existing pasture-based dairy farm systems in the Waikato region were assessed using ALCA. The results showed that both the off-farm and on-farm stages made significant contributions to a range of environmental impacts per kg of fat- and protein-corrected milk (FPCM), and the relative contributions of the stages varied across different impact categories. Farms classified as high intensification based on a high level of farm inputs (i.e. stocking rate, level of nitrogen (N) fertiliser and level of brought-in feeds) had higher impact results than low intensification farms for 10 of 12 impact categories. This was driven mainly by the off-farm stage, including production of brought-in feeds, manufacturing of agrichemicals (e.g. fertilisers and pesticides), and transport of off-farm inputs for use on a dairy farm. The exceptions were the environmental indicators PM, POFP, AP and TEP; their results were determined mainly by ammonia emissions from the on-farm activities.

Secondly, environmental consequences resulting from meeting a future increase in demand for milk production (i.e. 20% more milk production per hectare relative to that in 2010/11) by using different farm intensification scenarios for dairy farming systems in the Waikato region were assessed using CLCA. In this study, only technologies/flows that were actually affected by use of different intensification options to increase milk production were accounted for. The identified intensification methods were: (i) increased pasture utilisation efficiency, (ii) increased use of N fertiliser to boost on-farm pasture production, and (iii) increased use of brought-in feed (i.e. maize silage). The results showed that improved pasture utilisation efficiency was the most effective intensification option since it resulted in lower environmental impacts than the other two intensification options. The environmental performance between the other two intensification options varied, depending on impact categories (environmental trade-offs).

Thirdly, prospective ALCA was used to assess the environmental impacts of six prospective (future) dairy farming intensification scenarios in the Waikato region, primarily involving increased stocking rate, that were modelled to increase milk production per hectare by 50% in 2025. In this study, prospective (future) average flows that were derived from extrapolation were accounted for. The potential intensification scenarios were: (i) increased animal productivity (increased milk production per cow), (ii) increased use of mixed brought-in feed, (iii) improved pasture utilisation efficiency, (iv) increased use of N fertiliser to boost on-farm pasture production, (v) increased use of brought-in maize silage, and (vi) replacement of total mixed brought-in feed in the second scenario by wheat grain. The results showed that, apart from improved animal productivity which was considered the best option, improved pasture utilisation efficiency was the second environmentally-preferential option compared with other intensification options for pasture-based dairy farming systems in the Waikato region. There were environmental trade-offs between other intensification options.

The present research demonstrated that pasture-based dairy farming systems in the Waikato region contribute to a range of environmental impacts. More intensive farming systems not only have increased milk productivity (milk production per hectare) but also increased environmental impacts (per kg FPCM) in most environmental impact categories. Farm intensification options associated with improved farm efficiency (e.g. animal productivity or pasture utilisation efficiency) are promising as they have lower environmental indicator results (per kg FPCM) compared with other intensification methods. Increased use of off-farm inputs (e.g. N fertilisers and brought-in feeds) increases some, and decreases other, environmental indicator results. Therefore, decision-making associated with choice of alternative farm intensification options beyond farm efficiency improvements will require prioritisation between different environmental impacts and/or focusing on the ability of key decision-makers to effect change (for example, by distinguishing between local and global activities contributing to environmental impacts).

The present research has shown that different LCA modelling approaches can be used in a sequential manner to maximise the usefulness of environmental assessment. Initially, ALCA (based on current average flows) can be used to identify environmental hotspots in the life cycle of dairy farming systems. This will generate environmental information that can assist in selection of improvement options. Subsequently, the improvement options selected should be evaluated using CLCA (based on marginal flows). This will produce comparative environmental information resulting from implementing the selected improvement options, strategies or policies in relation to a non-implementation scenario, when the wider contribution of co-products is accounted for. Finally, prospective ALCA (based on future average flows) can be used to assess total or net environmental benefits.

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Abbreviations and Acronyms

ALCA	Attributional Life cycle Assessment
AP	Acidification Potential
Cancer	Human Health Toxicity (cancer effects)
CC	Climate Change
Cd	Cadmium
CF	Carbon Footprint
CFC-11	Trichlorofluoro-methane
CH_4	Methane
CLCA	Consequential Life Cycle Assessment
CO	Carbon monoxide
CO_2	Carbon dioxide
Cr	Chromium
CTUe	Comparative toxic unit for ecosystems
CTUh	Comparative toxic unit for humans
Cu	Copper
DLUC	Direct land use change
DM	Dry matter
ECM	Energy-corrected milk
Ecotox	Ecotoxicity for Aquatic Freshwater
FCE	Feed conversion efficiency
FEP	Freshwater Eutrophication Potential
FPCM	Fat- and protein-corrected milk
FU	Functional unit
GHG	Greenhouse Gas
GWP	Global Warming Potential
ILUC	Indirect land use change
H^+	Hydrogen ion
Ha	Hectare
Hg	Mercury
IR	Ionizing Radiation (human health effects)
K	Potassium
kBq	kilobecquerel

kg	kilogram
L	Litre
LCA	Life Cycle Assessment
LCI	Life cycle inventory
LCIA	Life Cycle Impact Assessment
LU	Land use
LUC	Land use change
MEP	Marine Eutrophication Potential
N	Nitrogen
NH_3	Ammonia
NH_4^+	Ammonium
Ni	Nickel
NMVOC	Non-methane volatile organic compounds
NO_2^-	Nitrite
NO_3^-	Nitrate
Non-cancer	Human Health Toxicity (non-cancer effects)
NO_x	Nitrogen oxides
ODP	Ozone Depletion Potential
P	Phosphorus
Pb	Lead
PKE	Palm kernel expeller
PM	Particulate Matter and Respiratory Inorganics
POFP	Photochemical Ozone Formation Potential
SO	Sulphur monoxide
SO_2	Sulphur dioxide
SO_3	Sulphur trioxide
t	tonne
***t*-test**	Student’s t-test
TEP	Terrestrial Eutrophication Potential
VOCs	Volatile organic compounds
WSI	Water scarcity index
Zn	Zinc

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