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USE OF LIFE CYCLE ASSESSMENT (LCA) TO FACILITATE CONTINUOUS IMPROVEMENT OF ON-FARM ENVIRONMENTAL PERFORMANCE: A SHEEP DAIRY CASE STUDY

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Abstract

While originally developed for industrial operations, the application of Life Cycle Assessment (LCA) methods in the agricultural sector is growing. To date it has primarily been utilised for carbon footprinting but can be used to assess a wider range of environmental impacts. An LCA provides an evaluation of resource use and the environmental emissions of a production system and/or products along the life cycle from extraction of raw materials, through manufacturing, distribution and on to use and waste management. Utilising a Life Cycle Assessment (LCA) as a tool to support continuous improvement of on-farm environmental management can support the emerging sheep dairy industry in realising and demonstrating more sustainable farming practices.

This case study assessed the following stages in the life cycle of sheep milk: raw material extraction, feed production, sheep rearing and milking. The following activities were assessed: the manufacture and application of agrichemicals, on-farm and external feed production, sheep emissions, milk production, and the generation and use of fuels and electricity. The aims of the study were to: (i) identify environmental hotspots in New Zealand sheep dairy farming and potential mitigation strategies, and (ii) formulate key performance indicators (KPIs) for a prototype LCA-based environmental certification system. The LCA assessed twelve impacts: Climate Change, Fossil Depletion, Freshwater Ecotoxicity, Freshwater Eutrophication, Human Toxicity, Marine Ecotoxicity, Marine Eutrophication, Metal Depletion, Particulate Matter Formation, Photochemical Oxidant Formation, Terrestrial Acidification, and Terrestrial Ecotoxicity.

The results showed that both the off-farm and on-farm stages contributed to environmental impacts and that the relative contributions of the life cycle stages varied across different impact categories. In general, the production and use of fertilisers, application of pesticides, and enteric fermentation of livestock were found to be the biggest contributing sources.

Introduction

New Zealand has an established reputation as one of the world's key dairy producers and the country's sheep dairy industry has seen rapid growth with four producers in 2014 growing to 16 producers in 2018 following the initial commercial start-up phase in the late 1990s. The importance of sustainability within the sector is demonstrated with New Zealand government research entities conducting studies on characterizing dairy sheep effluent and nitrogen (N) losses as part of their research programme 'Boosting exports of the emerging NZ dairy sheep industry' (Ministry for Primary Industries, 2017).

Utilising a Life Cycle Assessment (LCA) as a tool to support continuous improvement of on-farm environmental management can help the emerging sheep dairy industry with ensuring the sustainability of their farming practices. A LCA provides an evaluation of resource use and the environmental emissions of a production system or products. It consists of the following four key stages: definition of goal and scope; inventory analysis; impact assessment; and the production of recommendations for decision making (Guinée, 2002). For the purposes of determining the environmental impacts of sheep dairy farming practices, the LCA was conducted with a cradle-to-farmgate approach on the activities. This paper presents the key findings of the LCA, and identifies the environmental hotspot areas by providing an analysis of the impact categories, accompanied with recommendations for improvements as derived from the analysis.

Environmental certification systems

The conscious consumer is a growing phenomenon worldwide. Greater access to information as well as exposure has provided people with the knowledge of environmental and ethical issues as well as the ways in which our daily activities contribute to these issues. While market competition has traditionally been one of economics, the conscious consumer is shifting their focus from food prices to the process by which food is produced (Schau and Fet, 2008). Loureiro, McCluskey and Mittelhammer (2001) link this to the driving force behind the food industry's decision to introduce certification systems and eco-labels in both domestic and international food markets. This growing awareness is demonstrated with systems analysis such as LCA, a tool for producers to determine the environmental impact and resource use of their overall processing system including the impacts that come from the production and disposal of their products (Schau and Fet, 2008).

Overview of life cycle assessment

LCA is defined by the International Organisation of Standardisation (ISO) ISO14044 to be a "compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its life cycle" (Guinée, 2002). A LCA analysis covers the raw material acquisition, production, use and disposal stages of a product.

This study is in many ways exploratory. While there have been several studies conducted in sheep and beef farming, as well as bovine and goat dairy farming, the majority of these studies in New Zealand have focussed on greenhouse gas emissions. However, a full LCA study covering a broader range of environmental impacts has yet to be applied to these farming industries.

All efforts were made to follow the methodological framework provided by the ISO 14044 which provides guidelines for quantifying material and energy inputs to determine consequent emissions produced during the lifecycle of a product (ISO, 2006). The LCA was conducted with the ReCiPe 2008 model, developed in 2008 by RIVM and Radboud University, Centrum voor Milieukunde (*CML*), and PRé Consultants (Goedkoop et al., 2009).

Functional unit

The functional unit for this study is 1 hectare of land used on a sheep dairy farm -abbreviated to ha/yr. This is chosen on the basis that it is a commonly selected functional unit for agricultural LCA studies and it provides better opportunities for comparison with other farming scenarios and the impacts associated with the farming practices and inputs.

System boundaries

The system boundary of the LCA includes the major material and energy flows associated with the year-round maintenance of the sheep dairy farm including manufacture and application of agrichemicals (fertiliser, pesticides and herbicides), pasture and supplementary feed production, sheep emissions, and the production and use of fuels and electricity on-farm. Nutrient losses from fertiliser applications were calculated via OVERSEER®. Contractor fuels and veterinary chemicals were excluded (see Figure 1).

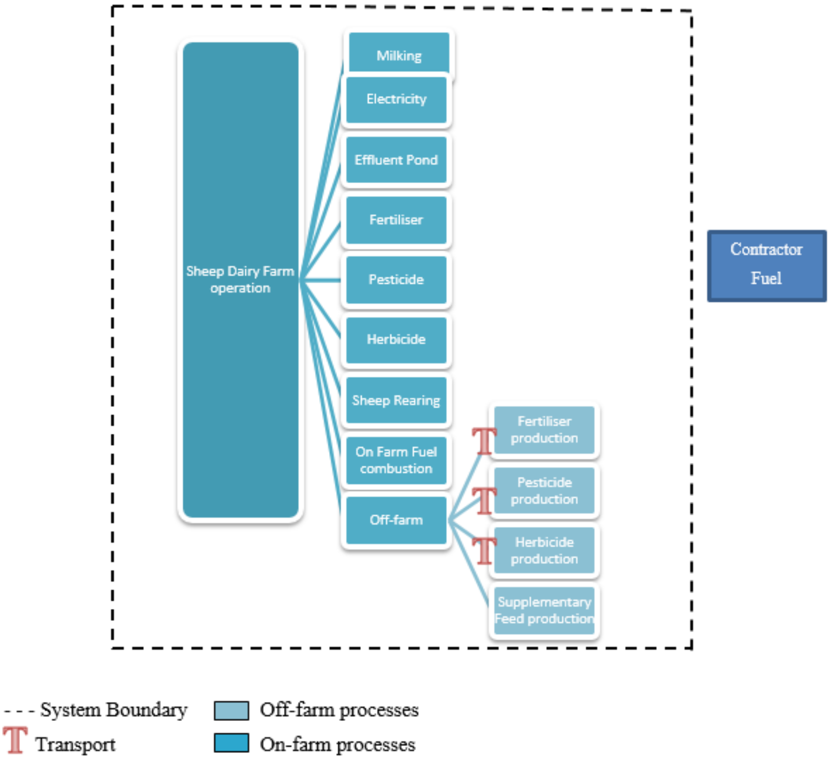

Figure 1: System boundary of dairy sheep case-study LCA

Key findings from impact assessment

The following impact categories were utilised in the LCA impact assessment: Climate change, Fossil depletion, freshwater ecotoxicity, Freshwater eutrophication, Human toxicity, Marine ecotoxicity, Marine eutrophication, Metal depletion, Particulate matter formation, Photochemical oxidant formation, Terrestrial acidification and Terrestrial ecotoxicity. These impact categories were selected on the basis that they cover all the relevant environmental issues associated with dairy farming systems.

Impact assessment results were calculated using the characterisation factors in the ReCiPe (H/H) Europe 2000 (excluding biogenic carbon) Normalisation Dataset. For the purposes of this analysis, perspective H has been utilised as it is based on the assumptions and choices aligned with most common policy principles with regards to timeframe and other issues (Goedkoop et al., 2009).

Results have been expressed in the same unit (eq/person/year) for each impact score thereby making it easier to determine the relative significance of each impact category and make comparisons between the impact scores of different impact categories (Norris, 2001). Figure 2 below shows the normalised results for the different impact categories, a logarithmic scale is used to offer a clear comparison of the results.

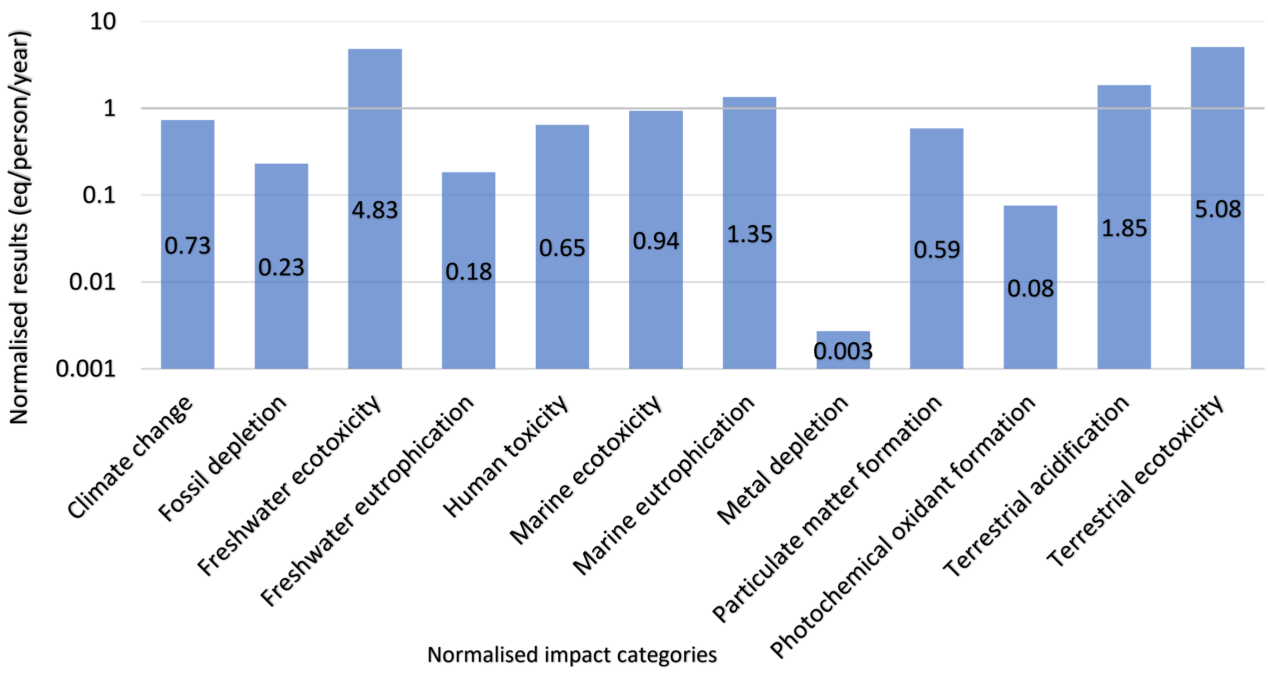

Figure 2:Normalised results for impact categories to demonstrate relative significance

Identifying the environmental hotspots

Terrestrial ecotoxicity was found to pose the largest environmental impact in the LCA study from the cradle- to-milking parlour gate of the dairy sheep case-study farm, followed by freshwater ecotoxicity (see figure 2). Pesticide use was the largest contributor to the terrestrial ecotoxicity impact category, with 75% (3.82 eq/person/year) of the total impact from that category resulting from the releases of atrazine. Similarly, in the supplementary barley grain production, pesticide use was the biggest contributor (see figure 3).

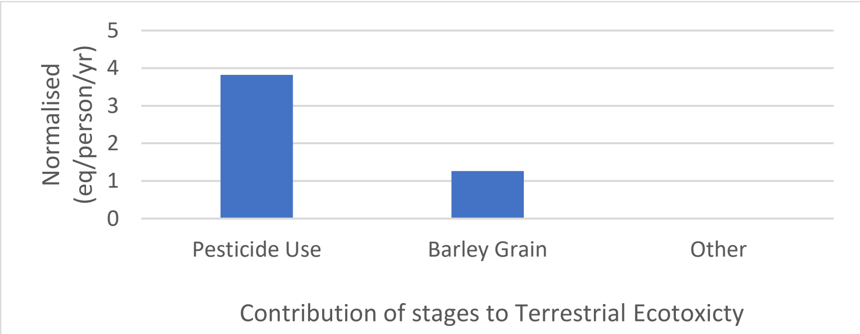

Figure 3 Contribution of sheep dairy farming stages to terrestrial ecotoxicity

Sensitivity Analysis

Following the impact assessment findings, sensitivity analyses were conducted. Alternative pesticide use on-farm was modelled utilising simazine – this found a 60% decrease in terrestrial ecotoxicity and 48% decrease in freshwater ecotoxicity. Maize grain was modelled as a supplementary feed – this resulted in a 7% decrease in the terrestrial ecotoxicity and 10% decrease in freshwater ecotoxicity. In both alternative scenarios, terrestrial ecotoxicity still posed the largest relative environmental impact in the LCA study.

Development of key performance indicator (KPI) framework for certification scheme

The first stage of the development process involved determining means-based KPIs using the results of the LCA study. Utilising the framework proposed by Lebacq et. al (2013), four KPIs were designed for each of the respective categories: land management, nutrient use, pesticide use, energy and climate, and water quality. This involved determining the scope and breadth of the KPIs within the respective environmental certification schemes: Origin Green – Dairy (Bord Bia, Ireland), LEAF Marque (UK), Unilever Sustainable Agriculture Code, and Sustainably Grown Certified (US). The framework has been designed to accompany a farm environmental plan (FEP) and a LCA of the farm.

Fundamental KPIS based on LCA results

The fundamental KPI for each respective category in the proposed framework is listed below. With the terrestrial and freshwater ecotoxicity being the highest impact categories in the LCA study, the importance of the appropriate management of land and soil resources, as well as sustainable nutrient use is highlighted.

Land management

Preparation of a farm-scale soil map stating the different soil types present and the identification of areas prone to compaction, erosion, runoff and leaching. This KPI has been included by Origin Green; Unilever; LEAF.

Nutrient use
Completing a nutrient budget and regular testing of soil fertility and crop nutrient levels, so to avoid nutrient overloading. This KPI has been included by Sustainably Grown; Origin Green; Unilever; LEAF.

Pesticide use

Conducting a pesticide drift risk assessment with mitigation strategies undertaken to minimize potential drift.

Energy and climate
Recalculating carbon footprint with livestock changes as stocking rate and type of livestock reared can greatly impact the overall carbon footprint of the case-study. This KPI has been included by Unilever.

Water quality
All potential wastewater sources and contaminant points must be identified. Agricultural and related operational wastewater streams must be treated appropriately. This KPI has been included by Sustainably Grown; Unilever; LEAF.

Discussion

Within the cradle-to-farmgate system boundary used in the study, the application of pesticides and the subsequent releases to soil and water resulted in the terrestrial and freshwater ecotoxicity being the highest and second highest impact categories respectively, following normalisation. These were subsequently identified in the KPI framework as being an area of importance, with the inclusion of an indicator requiring a risk assessment to be conducted to determine the potential risk of pesticide risk when utilising pesticides and similar agrichemicals.

Another hotspot area which demonstrates the importance of utilising a comprehensive life cycle viewpoint is the utilisation of externally grown supplementary feed. The analysis highlights the sensitivity of the environmental impact in relation to the varying production inputs required in the cultivation of supplementary feed sources. The results of the sheep dairy case study showcase the potential of LCAs in achieving sustainable milk production via an LCA-based certification scheme which incorporates means-based KPIs derived from the LCIA results, as seen in the prototype framework developed.

Conclusion

The aim of this research is to help develop the understanding of the environmental performance of sheep dairy farming and identify potential opportunities for improvement. As the first study of its kind, further research is needed to validate and confirm the findings stated in this study. Thus, LCA results from the sheep dairy case-study are not intended to be representative of the entire New Zealand sheep dairy industry.

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