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

Farm management practices have in recent times seen a shift towards a greater focus on sustainable agriculture, concerning environmental impacts and food safety. In New Zealand, the sheep dairy industry has seen rapid growth in the past decade as an alternative dairy source. The importance of sustainability in this industry has been recognised with New Zealand government programmes such as the Primary Growth Partnership, designed to boost the exports of the emerging industry, with a focus on sustainable production. Utilising a Life Cycle Assessment (LCA) based environmental certification scheme as a tool to support continuous improvement of on-farm environmental management can potentially support the emerging sheep dairy industry to define and communicate the sustainability of their farming practices.

This research aims to inform the practice of environmental labelling with application to sheep dairy products and offer a way of validating the sustainability statements made by New Zealand sheep dairy producers in their marketing approaches. The two key objectives of the study were (1) to determine the environmental hotspots of New Zealand sheep dairy farming and what mitigation strategies can be developed, and (2) Develop key performance indicators (KPIs) for an LCA-based farm certification system focussed on sheep dairy in New Zealand. To address objective 1, an LCA study was conducted on a New Zealand sheep dairy case-study farm. Sensitivity analysis around the type of imported grain feed and pesticide used were also conducted. To address objective 2, a review was conducting on four existing environmental certification schemes. Following this, a prototype list of KPIs based on the LCA findings was then designed.

The LCA study utilised a cradle-to-farmgate boundary and included the following activities: livestock emissions; the production and use of fertiliser, herbicides, and pesticides; production of imported supplementary feed; production and use of fuels and electricity; and lastly emissions from milking shed and effluent. The results showed that both the off-farm and on-farm stages contributed to environmental impacts and the production and use of fertilisers, application of pesticides, and enteric fermentation of livestock were found to be the biggest hotspot areas. A prototype environmental certification scheme comprising a Tier 1 KPI framework was then formulated, combining both the LCA results and previously consolidated indicators. Each KPI was categorised under the following themes: land management, nutrient, pesticide, water management, and lastly, energy and carbon management.

This is dedicated to my parents, Mohan and Shanti.

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Chapter 1: Introduction

New Zealand has an established reputation as one of the world's key dairy producers and while still a niche sector in comparison to bovine dairy, the country's sheep dairy industry has seen a rapid growth over the past decade, following the initial commercial start-up phase in the late 1990s (Prichard, 2017). 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 the research programme *'Boosting exports of the emerging NZ dairy sheep industry'* (Ministry of Business, Innovation and Employment, 2017). Another aspect of sustainability is also linked to the commonly perceived 'environmental friendliness' of dairy ewes in contrast to dairy cows, as publicised recently by local news outlets (Oram, 2016). An environmental certification scheme can provide a way for producers to demonstrate good farm management practices, as well as provide assurance for consumers that food has been produced in a sustainable manner, in accordance with a framework standard set by a certification scheme.

Utilising a Life Cycle Assessment (LCA) based certification scheme 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 production systems and/or products. It consists of the following four key stages: definition of goal and scope; inventory analysis; impact assessment; and lastly, the production of recommendations for decision making (ISO14044, as cited by Guinée, 2002). While originally developed for industrial operations, LCA usage for farming systems was first pioneered in Europe (Caffrey and Veal, 2013). The tool has since been utilised by food producers to determine the environmental impact and resource use of their farming systems, in the context of the impacts that come from the production, distribution, use and disposal of their products (Caffrey and Veal, 2013).

For the purposes of determining the environmental impacts of sheep dairy farming practices, the LCA study was conducted with a cradle-to-farmgate approach to the activities. This included the major material/energy flows and activities associated with the year-round maintenance of the sheep dairy farm including manufacture and application of agrichemicals (fertiliser, pesticides and herbicides), pasture and imported supplementary feed production, sheep emissions, milking parlour and lastly, production and use of fuels and electricity.

The aim of the thesis is to present the main results of the LCA, as well as identify environmental hotspot areas by providing an analysis of the impact categories, accompanied with recommendations for improvements as derived from the analysis. This is presented as key performance indicators (KPIs) for the prototype sheep dairy farm environmental certification system. Conducting an LCA for a dairy sheep operation can provide a better understanding of the energy requirements of the farm as well as identify potential areas for cost reduction whilst aiming for greater efficiency of the overall system. The results from this analysis will not only complement the existing effluent management research on various dairy sectors, it will also provide the sheep dairy operation with an organisational review of their processing structure – contributing to the development of a scalable supply model and environmental mitigation strategies.

1.1 Aim

The aim of the research reported in this thesis is to develop a prototype LCA-based farm certification system for sheep dairy farms.

Research Objectives

The two key objectives were (1) To determine the environmental hotspots of New Zealand sheep dairy farming and what mitigation strategies can be developed, and (2) Develop key performance indicators (KPIs) for an LCA-based farm certification system focussed on sheep dairy systems in New Zealand. The activities required to address objective 1 were firstly, identifying the environmental hotspot areas by conducting an LCA of the case-study sheep dairy farm. Secondly, identifying opportunities for improvement via scenario modelling for the case-study sheep dairy farm. The activities required to address objective 2 were conducting a review on the environmental certification systems and eco-labelling schemes utilised both in New Zealand and internationally. Lastly, designing a prototype environmental LCA farm certification scheme and formulating a prototype framework of KPIs based on the LCA results.

1.2 Method and Approach

This study is in many ways exploratory. This research aims to inform the practice of environmental labelling with application to sheep dairy products and offer a way of validating the sustainability statements made by New Zealand sheep dairy producers in their marketing approaches. Production of New Zealand-specific LCA results through this case study has the potential to provide producers with a better understanding of the environmental issues around farming management and insight into the environmental performance of sheep dairy farms.

The study first involved analysing and discussing pre-existing environmental certification across the world and their associated key performance indicators. The following schemes were reviewed: Sustainably Grown[1]; Origin Green[2]; LEAF Marque[3]; and Unilever Sustainable Agriculture Code[4]. Secondly. the environmental indicators were selected on their perceived relevance to sheep dairy production system in developed countries, like New Zealand.

There have been several LCA studies conducted on sheep and beef farming, as well as bovine and goat dairy farming, however majority of the studies in New Zealand have focussed on greenhouse gas emissions. At the time of publication, a full LCA study covering a broader range of environmental impacts had yet to be applied to the sheep dairy and goat dairy industries (Ledgard, Chobtang, Falconer, & McLaren, 2016; Robertson, Symes, & Garnham, 2015).

The LCA conducted in this thesis focuses on the environmental impacts associated with sheep dairy farming, utilising a case-study sheep dairy farm located in the North Island of New Zealand. Due to the commercial sensitivity of the data, the name of the agribusiness involved in the case-study cannot be disclosed. Operating on 63 hectares, the sheep dairy unit is part of a wider agribusiness including a sheep and beef, and bovine dairy units. As the newest addition to the agribusiness, the sheep dairy unit is currently in a development phase with the focus on establishing livestock numbers. As a result, the LCA study was conducted on a hypothetical – but likely - future scenario developed in collaboration with the agribusiness, utilising the farm inputs and livestock numbers modelled as part of the farm's early establishment goal.

This study aimed to contribute to the understanding of the environmental performance of New Zealand's sheep dairy industry by identifying environmental hotspot areas in a sheep dairy case-study farm. In addition to this, the study identified potential solutions to mitigate and reduce these impacts where possible using scenario modelling through GaBi LCA software and the OVERSEER ® nutrient budgeting tool. Following from this, a prototype environmental certification scheme was developed utilising KPIs formulated from the environmental hotspots identified in the LCA.

[1] SCS Global Services (2016) Sustainably Grown Standard - A Sustainable Agriculture Standard for Agricultural Crops. California, USA.
[2] Bord Bia (2013) Sustainable Dairy Assurance – Producer Standard. Dublin: Bord Bia.
[3] LEAF (2016). LEAF Marque Standard Version 14.1.
[4] Unilever (2017) Sustainable Sourcing Programme for Agricultural Raw Materials: Scheme Rules Version 4.7. United Kingdom: Unilever Sustainable Agriculture

Considering the (un)representativeness of this study, it is important to note that while the thesis offers recommendations on environmental performance and mitigation strategies, these have been derived from analysis of an individual sheep dairy farm. Therefore, this limitation must be considered when extrapolating the findings to be representative of the national sheep dairy farming industry due to variations in management practices, environmental conditions and farming/milking equipment utilised. Thus, it is advised that generalizations are not made from the results presented in this study.

Information for this research was gathered from a variety of sources: - Peer-reviewed journals, government publications, conference proceedings, certification schemes and text-books were the primary sources for chapters 2, 3, 4 and 6. Additional data was also sourced from the websites of organisations including Food and Agriculture Organization of the United Nations (FAO) Leap, New Zealand Beef and Lamb, and the New Zealand Life Cycle Management Centre (NZLCM)

Chapter 2: The Drivers of the Emerging New Zealand Sheep Dairy Industry

Farm management practices have shifted due to concerns over environmental impacts and food safety (Rao, Waits and Neilsen, 2000). This has led to a greater focus on sustainable agriculture, defined by Ruttan (1990) as the "management of land to ensure production and productivity are enhanced while sustaining a healthy ecological balance within the agricultural system". For the sheep dairy industry in New Zealand, sustainable farm practices are a key factor in the growing popularity of the sector (Prichard, 2017).

Section 2.1 discusses the various factors that have contributed to the growth of sheep dairying, focussing on the cultural, economic and environmental drivers of three key market segments. Secondly, current research and business initiatives are reviewed in Sections 2.2 and 2.3, with focus on the Primary Growth Partnership (PGP) Programme run in conjunction with the New Zealand government and Spring Sheep Dairy, as well as the effluent management practices guidelines for New Zealand sheep dairy farm published by AgResearch as part of the wider PGP Programme. These sections describe the perceptions of the target demographics, as well as the importance of perceived sustainability by industry and the steps taken to achieve environmentally-friendly farming practices.

2.1 Consumer Demands

As well as regulatory pressure, some consumers are looking for environmental returns and benefits from the foods they purchase. We can classify consumers in many ways, but following the suggestions of Prichard (2017) they could be regarded as three key categories: food anxious, food masters, and food resistors. In a report linking the trend of sustainable food consumption to luxury fashion, Fifita, Hong, Seo, Ko and Conroy (2017) similarly utilise a three-prong approach to market segments, defining them as: those driven by quality and health; those wanting to convey social standing and class; and, lastly, the 'experiential' segment interested in the sustainability message.

The food anxious group is primarily driven by their desire for a healthier lifestyle. Michaelidou and Hassan (2008) define this health consciousness as an awareness and concern over wellness and motivation for an improved health and prevention of ill health. For the food anxious, this is achieved by engaging in healthy behaviours and being conscious of the trends in nutrition and exercise (Kraft and Goodell, 1993). In their study on the relationship between health consciousness and selection of food products, Mai and Hoffmann (2012) state that while "health consciousness is a motivational construct which drives behaviour, nutritional self-efficacy is what captures the consumer's post-intentional assessment of eating healthier". Thus, this influences the decision-making as the consumer is led by an individual set of health-attributes which they hold. In New Zealand, majority of sheep dairy producers utilise nutritional and health benefits as key marketing points for their products; these points revolve around nutritional value claims – milk composition which is superior to cow milk in terms of fat and protein levels and levels of key vitamins (Prichard, 2017).

Mai and Hoffmann (2012) draw comparison between the “nutritional fact-checking” of the food anxious to the food masters, referred by them as the taste lovers. Prichard (2017) refers to this group, the food masters, as individuals in search of luxury, taste and distinction. While the food anxious focus on intrinsic values such as fat content and extrinsic values of health claims, as mentioned previously, the food masters are guided by the intrinsic values of taste and aroma, and extrinsic values of location of production, authenticity, branding and price (Mai and Hoffmann, 2012). In New Zealand’s sheep dairy industry, the majority of products sold for local consumption are targeted towards this group (mainly fine cheeses), whereas products produced for export (infant formula and supplements) are targeted towards the food anxious East Asian market (Prichard, 2017).

The food resistor market group is not driven by the product, instead this group focuses more on the background information on the product’s manufacture and history – the alternative story. Prichard (2017) defines this market segment as being driven by various factors such as animal welfare and environmental sustainability. New Zealand’s economy is heavily dependent on agricultural exports and a study on international consumer preferences by Saunders, Guenther, Tait and Saunders (2013) found that Chinese consumer attitudes towards New Zealand food products were determined not just by price, but also environmental and social attributes. Food products with certifications for animal welfare and sustainability could potentially be sold at a 10% price increase, compared to the currently uncertified products (Saunders et al., 2013). Thus, it can be concluded that the producers of sheep dairy products may be interested in the potential benefits arising from the evaluation of sheep dairy’s environmental performance.

2.2 New Zealand Government Initiatives

The demand of sheep dairy is not just from consumers but also from the New Zealand government as it seeks to support the diversification of agriculture away from the reliance on ingredient products, and towards higher-value consumer ready products. This has led the state to develop several funding and partnership programmes to boost the local industry. The following section discusses the initiatives developed by the Ministry of Business, Innovation and Employment (MBIE), and the Ministry for Primary Industries (MPI).

The Primary Growth Partnership (PGP) Programme started in 2016 and involves MBIE and their commercial partner, Spring Sheep Dairy NZ with the aim of creating a market driven end-to-end value chain for sheep milk valued with the maximum anticipated annual return of $700 million and environmentally, economically & socially sustainable (MPI, 2016). Scheduled for six years, the key opportunity identified for the programme was the significant market potential for high quality alternative dairy food products, however a problem faced is that farm systems in New Zealand are not suited for high performance dairy sheep due to climatic conditions and outdoor pasture grazing systems utilised, thus limiting the ability to expand supply under traditional farming methods utilised

(MPI, 2016). Thus, to combat this an aim of the PGP is the creation of a transformative farming system with relevant expertise and education to enable farmers to convert and become sheep milk suppliers.

A current obstacle is that while New Zealand has high sheep stock numbers, the performance of the locally bred dairy ewes does not enable producers to milk economically viable volumes (MPI, 2016). Therefore, to improve the milking performance the PGP Programme includes genetic importation with the aim of utilising artificial insemination to lead to the establishment of a self-sustained genetic improvement programme, thus leading to the eventual breeding of a specialised New Zealand dairy sheep breed with the capability to produce larger volumes of milk, as well as thriving in local conditions and farming systems (MPI, 2016).

2.3 Effluent Management Research

There are several concurrent research ventures focussing not only on the development of sheep dairy food products, but also the effluent management of sheep dairy farming systems. This is a key area of on-farm environmental management as demonstrated by the scrutiny on bovine dairy and effluent management (Oram, 2016). Led by AgResearch is a project titled 'Effluent Management on a Dairy Sheep Farm', conducted with the aim of determining the environmental footprint of sheep milk production as part of the environmental objective in the overall MBIE research project (Watkins, Longhurst and Smith, 2016). The project consisted of three sheep dairy farms, including Spring Sheep Dairy NZ, and was driven by the objective of characterising dairy sheep effluent to develop a better understanding of the modelling framework and information required to include dairy sheep into the OVERSEER® nutrient budget model (Watkins, Longhurst and Smith, 2016). At the time of this study, this model has yet to be released. This MBIE funded project focused on effluent management and included detailed advice on storage and spreading practices. While effluent management is a critical area in dairy systems, the project does directly measure the overall environmental impact of sheep dairying.

Another objective of the project was to design a low nitrogen footprint dairy sheep farm system to determine the performance of dairy sheep farming, in comparison to bovine dairy farming, as emitting only low levels of nitrogen to freshwater (Watkins, Longhurst and Smith, 2016). In accordance with this objective, a set of effluent management guidelines were published by Smith, Longhurst and Watkins (2017). The following sections discusses the areas identified in the effluent management guidelines.

2.3.1. Effluent Management Guidelines

As previously mentioned, a series of recommended good management practices were developed as part of the wider MBIE project. The guidelines were created for irrigation of farm dairy effluent and the minimisation of effluent volumes (Smith, Longhurst and Watkins, 2017).

Smith et al. (2017) state that sheep dairy farm units should regularly test the effluent streams as well as effluent paddocks or nutrient concentrations to avoid high levels of phosphorus and potassium. Following this, the guidelines recommend that fertiliser applications are adjusted to avoid exceeding nutrient levels. When irrigating effluent, Smith et al. (2017) state that irrigators should be operated at the maximum speed available to reduce the depth of effluent applied, noting the importance of this practice when applying effluent to high risk and poor-drainage soil types. With effluent holding, an appropriately sized pond is necessary to ensure that there is sufficient storage capacity to avoid overflow in seasonal conditions (Smith et al., 2017).

With collection of effluent from barns and feed pads, Smith et al. (2017) recommend that the effluent stream is separated (solids and liquids) and that separated solid effluent is applied to paddocks different to those that receive the liquid effluent.

2.4. Summary

Consumer demand contributes to the growing trend of sustainable development. While market segments are rather diverse and have often been categorised utilising a 3-prong approach (Prichard, 2017; Fifita et al., 2017), the role played by consumers in the transformation of farm environmental management process in New Zealand can be demonstrated by government initiatives such as the effluent management and genetics research programmes discussed. These programmes, as part of the PGP and MBIE funded projects are aimed at the development of a transformative farming system built on expertise and selected breeding attributes to increase sheep milk production, as well as a lower environmental footprint. While important, such work does not offer an overall evaluation or method of evaluating the environmental performance of sheep dairy on a wider farm-scale.

Chapter 3: LCA and the Sheep Dairy Industry - Literature Review

This literature review addresses the use of LCA and carbon foot printing studies relevant to sheep dairy production systems and the associated environmental hotspots identified in past literature. The limited availability of sheep dairy specific literature has led the review to be widened to include sheep/lamb meat case-studies. While the studies discussed below focus on meat as the main product, there are very few differences in the sheep rearing practices between the meat and dairy case-studies discussed in this review, with the exception of lamb housing in particular farms. Taking into the consideration the small amount of literature focussing on LCA usage in sheep dairy systems, the decision was made to include mutton/lamb meat production systems in the review.

Most of the literature discussed in Chapter 3 involved farms of varying geographical characteristics and farming systems/practices. The system boundary most utilised was cradle-to-gate with the functional unit of a kg of fat and protein corrected milk used for sheep milk production systems, and a kg of meat utilised for farm systems focussed on lamb and mutton production. Due to the presence of co-products, economic allocation was commonly used. The review found that most of the environmental hotspots identified were the usage of pesticides, artificial fertiliser and livestock emissions. LCA results are dependent on assumptions used in individual studies therefore consideration must be given to potential variation in farming systems, particularly with pasture-based grazing systems common in New Zealand. This, in addition to the differing modelling methods and parameterized emission factors for different regions used, posed a challenge when comparing LCA results and determining the applicability of sustainable farm practices, as stated in literature.

3.1 Introduction to LCA

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 with Baumann and Tillman (2004) stating that the concept of product in LCA extends to that of services, not solely on material goods.

In terms of methodology, there are several frameworks which have been published (Guinée, 2002) however a widely accepted framework is the ISO14044 series. The series specifies the procedure for conducting an LCA study and reporting the results of that study (Baumann and Tillman, 2004). The four key stages of an LCA are as follows: goal and scope definition; inventory analysis; impact assessment; and interpretation (Guinée, 2002). The following sections briefly introduces the key features of each stage of the LCA.

3.2 Stages of LCA

Determining the system boundary is a key aspect of the goal and scope stage of an LCA. As mentioned above, a LCA study traditionally takes a Cradle-to-Grave approach as per Guinée (2002), whereby the following factors are included: extraction of raw materials; processing, manufacturing and fabrication of product; transportation and distribution of product to consumer; storage and use of product by consumer; and lastly the disposal and recovery of the product after its 'useful' life.

With agricultural systems, LCA studies have commonly utilised a Cradle-to-Farmgate approach as it provides an overview of the efficiency of an operating system, whereas the Cradle-to-Grave approach is product-based approach and therefore may not be applicable for productions systems with multiple co-products. The usage of LCA studies conducted only from Cradle-to-Farmgate in Environmental Product Declarations (EPD) is disputed (Chai, 2014).

However, this is not uncommon with most agricultural studies in the literature conducted with those boundaries to determine the carbon footprint as studies often showcase that majority of environmental emissions occur within the farm boundary. The functional unit selected for the LCA study may also influence the potential for system comparisons to be conducted. Figure 1 highlights the relationship between the key phases in an LCA.

Figure 1 - Stages in a LCA study (Reproduced from Circular Ecology (2017))

3.3 Goal and Scope definition

The goal and scope definition of the study is a key decision-making process in a LCA as it determines the layout of the study (Guinée, 2002). When defining the goal, the target audience and the intended application is to be considered. Once the goal of the study has been stated and justified, this then leads to the definition of the scope of the study, whereby the main characteristics of the study such as the methodology, data sources and impact categories are determined. The impact assessment methodology is selected in this stage of the LCA study.

There are a variety of methods utilised in LCA studies, with the most common being the TRACI[5], CML 2002[6], Eco-Indicator 99[7] and ReCiPe 2008. For the purposes of this thesis, the ReCiPe 2008 impact assessment method was used as its mid-point indicators were assessed to hold most relevance to the case-study. This method was developed in 2008 by the RIVM and Radboud University, Centrum voor Milieukunde (*CML*), and PRé Consultants (Goedkoop et al., 2009). The model is a further development of Leiden University's CML 2002 impact assessment method, which modelled midpoint indicators, and the Eco- indicator method, first released in 1995 and then revised in 1999, which is an endpoint modelling approach (Goedkoop et al., 2009).

The ReCiPe 2008 method contains 18 impact categories at the midpoint level – climate change; ozone depletion; terrestrial acidification; freshwater eutrophication; marine eutrophication; human toxicity; photochemical oxidant formation; particulate matter formation; terrestrial ecotoxicity; freshwater toxicity; marine toxicity; ionising radiation; agricultural land occupation; urban land occupation; natural land transformation; water depletion; mineral resource depletion; and lastly, fossil fuel depletion (see Appendix A).

These categories are then converted to the three following endpoint categories: Damage to human health, ecosystem system diversity and resource availability (Goedkoop et al., 2009). The ReCiPe 2008 model is damage oriented; therefore, emissions of substances are linked to the impact on the endpoint indicators mentioned which is more comprehensive in comparison to methods such as Eco-indicator 99 where midpoints are not separated, with only an endpoint method.

The key components of this stage are the system boundary and functional unit. Tillman, Ekvall, Baumann and Rydberg (1994) state that the system boundary must be clearly specified to ensure comprehensiveness the following: between technological system and nature; the geographical area and time horizon; boundaries between production and production of capital goods; and lastly, the boundaries between the life cycle of the product studied and the related life cycles of other products.

[5] Tool for Reduction and Assessment of Chemicals and Other Environmental Impacts (TRACI) – EPA
[6] CML 2002 - Leiden University
[7] Eco-indicator 99 - PRé Consultants

The system boundaries are often defined in several ways (based on the key area of the product's processing / manufacture that the LCA practitioner is focussed on): cradle-to-grave, the full life cycle from resource extraction to disposal; cradle-to-gate, resource extraction to end of primary production (farm gate); gate-to-gate, focussed on production system only; and lastly gate-to-grave, production to disposal.

The functional unit of the LCA study is determined by the function/service provided by the product in question. When comparing the environmental performance of products, similar functional units are utilised. For example, when comparing different dairy production systems, the functional unit of 1 kg/ or 1 litre of milk is utilised as this is the key primary product of the system, prior to further value-addition such as milk powder. This is often used to determine the relative environmental impact across a unit of area in an agricultural setting.

3.4 Life Cycle Inventory

In the Life Cycle Inventory (LCI) phase, data for the study is collected and compiled based on the system boundary which has been determined. Baumann and Tillman (2004) state that during this stage of the LCA study, the data collection and calculation of environmental loads is guided by the constructed flowchart which is to be designed according to the system boundaries decided upon during the goal and scope definition stage.

The majority of recent LCA studies utilise LCA software tools such as GaBi and Simapro to model and scale the data in accordance with the functional unit utilised. This software automatically calculates the normalised data and produces an inventory table. In this thesis, the GaBi LCA software was utilised.

A key factor during the LCI stage of an LCA study is allocation. Allocation is required where a unit process has more than just one single functional flow resulting in the partitioning (allocating) of the inputs and outputs involved (Guinée, 2002).

1. Co-production: A unit process produces more than one product (An example of co-products is maize grain and silage).

2. Waste treatment: Commonly in waste treatment processes, more than one type of waste stream is processed at a time. As this thesis is utilising a cradle-to-farmgate approach, waste disposal of purchased/imported farm products will not be included in the LCA study. Effluent produced on farm however will be considered.

3. Recycling: In recycling, an output from a product system may become an input into another product system. As this thesis is utilising a cradle-to-farmgate approach, recycling will not be included in the LCA study.

3.5 Life Cycle Impact Assessment

During the Life Cycle Impact Assessment (LCIA) stage, all the inputs and outputs are processed and interpreted in terms of environmental impacts and societal preferences (Guinée, 2002). This stage is defined by ISO (2006) as "the phase aimed at understanding and evaluating the magnitude and significance of the potential environmental impacts of a product system" (as stated in Guinée, 2002).

Selection of impact categories: An impact category is a class representing environmental issues of concern to which LCIA results may be assigned to. The categories can be classified into 3 main groupings: resource depletion; impact on human health and lastly impact on the natural environment (Guinée, 2002).

3.6 Interpretation

The interpretation stage of the LCA involves the refinement of raw results with select indicators presented to determine conclusions for the study (Baumann and Tillman, 2004). Life cycle interpretation is defined by ISO (2006) as the "phase of life cycle assessment in which the findings of either the inventory analysis or the impact assessment, or both, are combined consistent with the defined goal and scope so to reach the conclusion and recommendations". During this stage, the raw data is screened to identify critical and missing data. Several tests are conducted to determine the robustness of the results, as highlighted below (Baumann and Tillman, 2004):

- Completeness check: Gaps in inventory and completeness of impact assessment
- Consistency check: Appropriateness of life cycle modelling and methodological choices in relation to scope and goal
- Uncertainty analysis: Check the effect of uncertain data
- Sensitivity analysis: Identify and determine effect of critical data
- Variation analysis: Effect of alternative scenarios and life cycle models

3.7 Limitations of LCA

In a LCA study, the environmental interventions from the various processes within the system are summed up irrespective of the location or time, and then extrapolated into impact category scores. Due to this, it is difficult to determine whether an emission leads to local contamination and the varying amount emitted over a period, thus making it a key limitation.

Another limitation is the effect of a precautionary attitude. Tukker (2002) describes the precautionary attitude as the need to act before conclusive scientific evidence is available to make links between cause and effect, to mitigate any potential effects. With the precautionary attitude to decision-making, alternatives thought to help prevent further emissions will be considered however with LCA, an alternative can only score better to the traditional system if it is a "truly source-oriented" approach with a definite decrease in emissions.

Thereby, factors such as irreversible damage to the environment are not evaluated as a separate theme when evaluating systems in LCA. Like the industrialist view described by Tukker (2002), risk assessment framing doesn't place heavy consideration into past issues, as each substance, in this example - chlorine, is viewed separately to past substances. This goes against the precautionary principle which follows the concept of payments for past ecological depth. Calculating approaches have a limited role when determining the impact of chemicals/substances that are yet to be well understood from a scientific point of view. However, tools like LCA do not take into consideration such precautionary methods as it focuses on data which is available and results which guide decision making are produced from a purely quantitative model (Tukker, 2012).

Lazarevic, Buclet & Brandt (2012) link this issue in decision making to epistemological differences in values. As opposed to traditional positivist view on sciences, they state that LCA is a post-normal science tool in which social constructs play a role in the interpretation of results with decision making, following the realist paradigm of science as not being devoid of any social or external influence. Social constructs such as 'sustainability' play a role in the application and utilisation of tools such as LCA. The realist paradigm however recognises a causal ontology of forces that includes social forces and influences the final decision-making stage.

Traditional quantitative research tools do not consider the impact/ role played by social constructs and values. However, LCA is used as a tool for interpreting data 'from yesterday to make plans for the future' therefore, interpretation of data in decision making can be influenced by the social views and paradigm used as a frame for the stakeholder involved in the analysis (Lazarevic et al., 2012).

Thus, these factors may question the suitability of basing decision-making solely on the results from an LCA study. As a result, other qualitative studies will often be conducted alongside to obtain information which will still be environmentally relevant to formulation a solution for decision-making scenarios.

3.8 Past and Present Literature

Within the past decade, the focus on the production of food and the associated material and energy usage has grown rapidly (Hobbs, 2007). The importance of sustainable agricultural food systems is demonstrated by the growing social movement of environmental consumerism which has been recognised by food producers; as demonstrated by the implementation of environmental product declarations (Lombardi, Berni & Rocchi, 2017; Selfa, Jussaume & Winter, 2008).

The following section reviews the past and present literature on the application of LCAs and relevant foot printing tools to sheep farming identifying the system boundaries, functional units, farming intensification and allocation methods for co-production. This will then be followed with a discussion focusing on the environmental hotspots identified in the literature.

3.9 Sheep Dairy System

The production of sheep milk can be categorised into two main sections: Flock, and Farm Impacts (as shown in Figure 2 below). The flock stage predominantly focuses on the rearing of the livestock. This includes feed inputs which may often be a combination of farm-grown feed, purchased feed and pasture. The manufacture, transport to farm and application of fertiliser and pesticides, as well as the irrigation is included in this section. Depending on the breeding season, the farm may contain a combination of the following livestock: lambs, replacement ewes, lactating ewes, dry ewes and rams. The enteric emissions of these livestock are included in this section. The Farm Impacts section involves activities around farm maintenance including milking and shearing activities. This section also includes the maintenance of machinery infrastructure and buildings on farm, electricity use, and water consumption.

Figure 2 – Overview of a dairy sheep farming operation (Reproduced from Vagnoni et al., 2015)

3.10 Sheep Dairy Case-studies

The FAO is an international authoritative figure on sustainable agricultural systems. In 2016, the handbook, *Greenhouse gas emissions and fossil energy use from small ruminant supply chains: Guidelines for assessment* was produced as part of the Livestock Environmental Assessment and Performance Partnership (LEAP). While the publication is not solely specific to sheep dairy systems, it provides guidelines on the methodology for quantifying GHG emissions as well as recommendations for the key stages of conducting an LCA from cradle-to-gate, with the usage of midpoint impact indicators in accordance with the International Reference Life Cycle Data System (ILCD). The publication also discusses multi-functional processes and allocation which is highly relevant to sheep dairy production system where the co-products are often fibre, milk and meat.

A highly cited LCA study focussing on sheep dairying was conducted by Vagnoni et al., (2015) in Sardinia. Three sheep dairy farms were selected based on their different input levels (low- pasture only; medium – pasture and some supplementary feed; high – indoor and feed only) and the LCA was conducted using two different assessment methods: Carbon Footprint-IPCC and ReCiPe endpoint. A cradle-to-gate approach was used and the functional unit used was 1 kg of Fat and Protein Corrected Milk (FPCM). The study identified the environmental hotspots of the production system as being the enteric methane emissions, field operations and production of farm machinery. These components of the farm system were found to heavily influence the overall environmental performance of the farms. The medium-input farm was most similar to the New Zealand's low intensity sheep rearing model due to pasture forming the largest part of the feed input for sheep, followed by arable land production, and a stocking rate of 4.6 ewes per hectare. Irrigation was also included for the mind-input farm, with a mechanical milking system.

Another highly cited study is the LCA of two sheep dairy farms conducted in Northern Spain. The analysis by Batalla, Pinto, Unamunzaga, Besga and Del Hierro (2014) utilised a cradle-to-gate approach. However, the study differs from Vagnoni et al. (2015) as the system boundary has been broadened to also include the following: Economic assessment (Cost inputs; taxes; net benefit of products) and Social assessment (Land occupation; manpower; farmer relations; farming practices). Similar to the study conducted by Vagnoni et al. (2015), the analysis focussed on farms of different intensities; however, while Vagnoni et al. (2015) categorised according to stocking rate intensities, Batalla et al. (2014) focussed on the average yield per sheep as well as stocking rate. The author proceeds to state that, traditionally, LCA studies on milk production have utilised a functional unit of 1 kg of Energy Corrected Milk (ECM) - however, due to the addition of the Social and Economic boundaries the following units were also measured in the analysis:

- Manpower Unit: Number of employee people on the farms. This functional unit is designed to quantify the human resource necessary for milk production;
- Net Margin: Difference between the sold price of outputs and the cost of all the inputs necessary for production including taxes i.e. profit of the farmer. This assists in correlating the potential economic value of the production system being analysed.

This study was expanded by Batalla et al. (2015) in the following year. While the cradle-to-gate approach was kept constant, the study involved LCAs conducted on 12 sheep dairy farms in Northern Spain, the focus shifted to the development of strategies for the correct use and improvement of grasslands in farms where pasture grazing was a high percentage of the ewe's overall on-farm life. This is quite relevant to New Zealand pastoral farming practices whereby pastures are the dominant source of food in NZ sheep farms, with grain feed provided only as a supplementary source during feed shortages and prior to mating period. Batalla et al. (2015) utilised four different frameworks, including the most common ILCD, to determine the effect of carbon sequestration in carbon footprint calculations and applied the various functional units for each boundary. However, while carbon sequestration was not found to dominate the results, they concluded that there is potential for misinterpretation of results between farms as they may operate in different socio-economic contexts. Therefore, while economic and social indicators are recommended to be included in LCA, conducting comparisons of farms may be complicated as agribusiness management may differ greatly. As this LCA was focussed on determining the environmental hotspot areas for a prototype certification system, economic and social indicators were not included. Table 2 showcases the results of the carbon footprint studies discussed above. While the median result is 2.2 kg CO_2[8]-eq/kg FPCM, the variation in the geographical scope, functional unit, as well as farming system must be considered to determine the validity of comparisons which may be drawn.

Table 1 - Sheep dairy carbon footprint studies

Author	System Boundary	Functional Unit	No. of Farms	Indicator	Results
Vagnoni et al. (2015)	Cradle to Gate	Kg CO_2-eq/ kg FPCM	3	Climate Change	Low: 2.0 kg CO_2-eq/kg FPCM Med: 2.3 kg CO_2-eq/kg FPCM High: 2.2 kg CO_2-eq/kg FPCM
Batalla et al. (2014)	Cradle to Gate	Kg CO_2-eq/ kg ECM	2	Climate Change	3.0 kg CO_2-eq/kg ECM
Batalla et al. (2015)	Cradle to Gate	Kg CO_2-eq/ kg ECM	12	Climate Change	Range: 2.1 – 5.4 kg CO_2-eq/ kg ECM

3.11 Sheep Meat Case-studies

The following section introduces a carbon footprint study on sheep meat production in Australia, and a carbon footprint LCA of lamb exports from New Zealand to the United Kingdom.

Utilising LCA to determine the greenhouse gas emissions of meat production is a common theme in sheep farming literature. In their analysis on Australian red meat production systems, Peters et al. (2010) conducted an LCA study on a sheep meat supply chain with a cradle to primary processing

[8] Carbon dioxide

gate approach. The functional unit of the study was 1kg of standard carcass weight (cwt) and the system boundary encompassed all on-site and upstream farm processes, and whole processing plant. Difficulty in utilising LCA to assess the environmental impacts of the extended supply chain led the authors to adopt an input-output analysis (IOA) method. The study found that sheep meat production had a smaller carbon footprint in comparison to the beef farms studied, with average footprints of 10.6 kg CO_{2-} eq/kg cwt and 15.4 kg CO_{2-} eq/kg cwt respectively.

A study by Ledgard, Lieffering, Coup and O'Brien (2011) utilised LCA to calculate the carbon footprint of New Zealand-grown lamb exported to the United Kingdom. The analysis used the Beef + Lamb database containing over 400 farms, and used a cradle-to-grave approach. This included the transport, retail, consumption and waste stages of the product which was analysed using the functional unit of 1kg of lamb meat. The study found 80% of the total emissions arose during the cradle-to-farmgate stage, with the retail/consuming/waste stages contributing the second highest at 12%. Therefore, this highlights the importance of focussing on the cradle-to-gate boundary of the case-study farm when evaluating environmental performance.

3.12 Discussion

3.12.1 System Boundaries

All the LCA studies discussed, apart from one study (Batalla et al., 2014), have been primarily focussed on the environmental impacts assessed. The production processes of medicines, machinery and buildings were excluded from most system boundaries (Batalla et al., 2015; Ripoll-Bosch et al., 2013; Vagnoni et al., 2014; O'Brien, Bohan, McHugh & Shalloo, 2016). Refrigerant emissions were only accounted for in one of the studies discussed (Ledgard et al., 2011).

3.12.2 Functional Unit

For farming systems focussing on the production of sheep milk, the functional unit most commonly used was 1 kg of fat and protein corrected milk [FPCM] (Batalla et al., 2014:2015; Vagnoni et al., 2015). For the study that included social and economic dimensions, different functional units were additionally utilised: net Margin (e.g. Euros) for the economic analysis, and manpower unit (number of workers) for the human resource component of the social boundaries (Batalla et al., 2014).

For farms which focussed on the production of sheep meat, the functional unit most commonly utilised was 1 kg of meat processed (Ledgard et al., 2011; Edwards-Jones et al., 2009; FAO, 2016). Depending on the system boundary, the functional unit varied from 1 kg of live weight solid (O'Brien et al., 2016; Ripoll-Bosch et al., 2013) to 1 kg of pre-chilled/hot carcass weight (Peters et al., 2010; Ibidhi, Hoektra, Gerbens-Leenes & Chouchane, 2017).

3.12.3 Allocation

Where a system has several co-products, allocation is required where a unit process has more than just one single functional flow resulting in the partitioning (allocating) of the inputs and outputs involved (Guinée, 2002).

In several of the case-studies discussed in this review, economic allocation has been used for farming systems with multiple products. With milk production being the key purpose of the dairy farms, with lamb and wool serving as co-products, allocation factors were derived based on the economic values of products at farm level (Batalla et al., 2014; Batalla et al., 2015).

Farming systems which focussed on the production of sheep meat utilised an economic allocation for lamb, mutton and wool products (Peters et al., 2010; O'Brien et al., 2016). However, with the New Zealand context whereby the co-rearing of sheep and beef together is common for farms, biophysical allocation is necessary to determine the relevant greenhouse gas emissions per animal type (Ledgard et al., 2011). Ripoll-Bosch et al. (2013) note that consideration must be given to studies where the economic allocation has been based on political decisions and the loss of agricultural production as regional variability in results may be due to political decisions rather than the farming production systems.

Where carbon footprint allocation has been utilised to determine relevant impact, emissions have been expressed in CO_2 equivalents in a 100-year Global Warming Potential (GWP) of CH_4 [9] and N_2O [10] of 25 and 298, stated to be in accordance with the IPCC guidelines (Batalla et al., 2015; Vagnoni et al., 2014).

3.12.4 Environmental Hotspots Identified

In the literature reviewed, numerous case-studies involved the comparison of farms with varying characteristics such as terrain, intensification and inputs. The three most common impact categories utilised to determine the performance of a farming system and contrast the factors associated with it were Climate Change, Acidification and Eutrophication Potential.

For each of these impact categories, the production and application of artificial fertiliser and manure were identified to be the largest contributors as identified by O'Brien et al. (2016). Regarding the acidification impact category, Peters et al. (2010) similarly found ammonia to be the main contributor, linking the housing type and resulting effluent management systems utilised to the variation in results observed. Furthermore, the feed type was identified to play a large role in the overall performance of sheep rearing systems with concentrate feeding identifies to be a key source of environmental impact for off-farm acidification (O'Brien et al., 2016; Peters et al., 2010).

[9] Methane
[10] Nitrous oxide

Similarly, Batalla et al. (2014:2015) identifies the usage of purchased feed such as concentrates and fodder to be the second largest contributor to the overall carbon footprint, following the enteric emissions occurring during the cradle-to- gate stage.

For carbon footprint of sheep rearing, the animal methane and nitrous oxide emissions were both found to be the largest contributors (Ledgard et al., 2011; Peters et al., 2010; Ibidhi et al., 2017) with the these on-farm emissions accounting for 80% of the total carbon footprint of 1 kg of lamb meat calculated from cradle-to-grave (Ledgard et al., 2011). The impact of different grazing systems can be demonstrated by the relative contribution of carbon dioxide, methane and nitrous oxide. Ripoll-Bosch et al. (2013) found pasture-based grazing to result in a higher contribution of methane and nitrous oxide when compared to zero-gazing systems. The largest difference was found in the contribution of carbon dioxide with pasture-based accounting for 8% and zero-grazing systems accounting for 29% of the total footprint of lamb production (Ripoll-Bosch et al., 2013). In the few studies which included the impact category for agricultural land occupation, this was found to contribute the biggest impacts of about 50% of the total estimated (Vagnoni et al., 2015).

3.12.5 LCA and Carbon Footprint Studies in New Zealand

There have been several recent studies on bovine milk production systems in New Zealand. Chobtang, Ledgard, McLaren and Donaghy (2017) conducted a LCA comparison of low and high intensification dairy farming in pasture-based systems in Waikato, New Zealand. Intensity level was determined by stocking rate, amount of supplementary feed and nitrogen fertiliser used. The study used a cradle-to-gate approach and utilised 12 midpoint impact indicators –climate change, ozone depletion potential, human health toxicity (cancer and non-cancer), particulate matter, ionizing radiation, photochemical ozone formation potential, acidification potential, terrestrial eutrophication, freshwater eutrophication, marine eutrophication, and freshwater ecotoxicity. The biggest environmental hotspots identified were imported supplementary feed, the manufacture of agrichemical and transportation of farm inputs to the case-studies (Chobtang et al., 2017). In an earlier study, Chobtang, Ledgard, McLaren, Zonderland-Thomassen and Donaghy (2016) analysed the environmental profiles of several dairy farm case studies in the Waikato region, utilising the identical 12 impact indicators and 53 case-study farms as was done in Chobtang et al. (2017). The study found that the production of imported feed contributed on average 11% of all impact categories assessed. The manufacture of agrichemicals was found to contribute 42% of the total ecotoxicity impact category.

The impact of imported feed on overall environmental performance was also identified in a study by Chobtang, McLaren, Ledgard and Donaghy (2017_a). Conducted utilising a cradle-to-gate boundary, the study utilised an attributional approach to determine the environmental trade-offs associated with intensification pasture-based dairy production systems in New Zealand with 8 scenarios. The study which used the same 12 categories as Chobtang et al. (2017) found that while increased milk production and pasture utilisation indicated a decrease in all categories, the production and import of grain feed was a key hotspot area (Chobtang et al., $2017_{a)}$. In the hypothetical scenarios modelled, the impact of imported feed on the overall carbon footprint was similar to the impact of rearing replacement livestock on farm (Chobtang, 2017_a). Imported feed on farm dominated the freshwater ecotoxicity category for 7 out of 8 scenarios (Chobtang, 2017_a).

In a study by Flysjö, Cederberg, Henriksson, and Ledgard (2011) a comparison of New Zealand and Sweden case-studies were used to determine the effect of co-product handling in LCA studies on the carbon footprint of milk production. Conducted on bovine dairy farms in both countries, the study used a cradle-to-gate approach and only focussed on the greenhouse gas emissions per 1 kg of FPCM[11]. The study found that New Zealand dairy production had a lower footprint in comparison to Swedish dairy systems due to pasture grazing (Flysjö et al., 2011), which resulted in Sweden having a footprint that was 16% higher (1.16 kg CO_2-eq/kg FPCM). In a study by AgResearch, Massey University's Institute of Agriculture and Environment, and the New Zealand Life Cycle Management Centre, an LCA analysis was carried out on bovine dairy farms in the Waikato to determine the results of intensification (Ledgard, Chobtang, Falconer and McLaren, 2016). The study by Ledgard et al (2016) utilised data obtained from DairyNZ's Dairybase for the years 2010-2011. The system boundary was identical to the environmental boundary utilised by Batalla et al (2014;2015) and Vagoni et al (2015) with the exclusion of the production of farm machinery from the analysis.

There have been several studies commissioned by the New Zealand government focussing on the carbon footprint of locally grown lamb and beef produced for export to the UK with majority taking a cradle-to-grave approach (Liffering et al., 2012; Ledgard et al., 2011). While the report produced by Ledgard et al. (2011) focuses on the carbon foot printing of NZ lamb produced for export, it discusses sheep farming systems in NZ and the various factors associated with the production of GHG emissions. The study includes a cradle-to-grave approach however the cradle-to-gate section of the analysis mirrors that of the cradle-to-gate stage of sheep dairy production, providing information on feed conversion and fertilizer usage.

In terms of small-ruminant dairy alternatives, sheep milk and goat milk are two of the developing industries in New Zealand (Cook, 2016). An LCA study on local dairy goat production was conducted by Catalyst Ltd in 2015. The analysis which was commissioned by New Zealand's Dairy Goat Co-operative focused only on the GHG emissions and concluded that the environmental results were on par with local bovine dairy. However, to determine the validity of that statement, other environmental indicators should have been included in the LCA, as opposed to solely the Climate Change indicator.

[11] Fat and protein-corrected milk

Table 2 contains a summary of the climate change results of the LCAs and carbon footprint studies conducted in New Zealand. Due to the variation in indicators utilised in the study, the table is intended to enable a comparison of the common indicator – climate change impact category.

Table 2 -Summary of NZ LCA and carbon footprint studies conducted on sheep, goat and bovine production systems

Industry	Author	System Boundary	Functional Unit	No. of Farms	Indicator	Results
Bovine[12] Milk	Chobtang et al (2017)	Cradle to Gate	Kg CO_2-eq/ kg FPCM	53	Climate Change[13]	Low: 0.73 kg CO_2-eq/kg FPCM High: 0.86 kg CO_2-eq/kg FPCM
Bovine[12] Milk	Chobtang et al (2017a)	Cradle to Gate	Kg CO_2-eq/ kg FPCM	8 (Future scenarios)	Climate Change[12]	0.80 kg CO_2-eq/kg FPCM
Bovine[12] Milk	Chobtang et al (2016)	Cradle to Gate	Kg CO_2-eq/ kg FPCM	53	Climate Change[12]	Range: 0.78 – 0.82 kg CO_2-eq/kg FPCM
Bovine[12] Milk	Ledgard et al (2016)	Cradle to Gate	Kg CO_2-eq/ha	(3 case-studies of varying intensities[14])	Climate Change[15]	Low: 11 t CO_2-eq/ha Med: 12.7 t CO_2-eq/ha High: 14.6 t CO_2-eq/ha
Bovine[12] Milk	Flysjö et al (2011)	Cradle to Gate	Kg CO_2-eq/ kg FPCM	NZ average	Climate Change	1.0 kg CO_2-eq/kg FPCM
Goat[12] Milk	Catalyst Limited - Robertson et al (2015)	Cradle to Gate	t CO_2-eq/ha	5 (3 indoors, 2 outdoor)	Climate Change	8.78 t CO_2-eq/ha
Beef meat	Lieffering et al (2012)	Cradle to Grave	Kg CO_2-eq/100g beef meat	460[16]	Climate Change	2.2 kg CO_2-eq/100g beef
Lamb meat	Ledgard et al (2011)	Cradle to Grave	Kg CO_2-eq/100g lamb meat	460[15]	Climate Change	1.9 kg CO_2-eq/100g lamb
Lamb meat	Ledgard et al (2009)	Cradle to Gate	Kg CO_2-eq/100g lamb meat	460[15]	Climate Change	1.52 kg CO_2-eq/100g lamb

[12] The studies included the on-farm rearing of replacements
[13] Other impact categories were assessed
[14] Primary data for Waikato farms was derived from DairyNZ DairyBase for 2010/2011, and covered farms across DairyNZ farm classes 1-5, ranging from system 1 with no brought-in feed through to system 5 with about 20-40% of the total feed derived from brought-in supplementary 3 feeds (Hedley and Bird 2006). In these studies, the farms were grouped into low, medium and high intensity farms, whereby 'low' covered dairy systems 1 and 2, 'medium' was system 3 and 'high' covered systems 4 and 5.
[15] Other indicators were utilised however study only explicitly states results for Climate Change indicator
[16] Beef + Lamb New Zealand dataset

3.13 Conclusion - Issues Identified

A key challenge when comparing the results of LCA and carbon footprints is that the environmental impact of a farming systems can differ based on the allocation method utilised as these are influenced by the co-products of a system (Chobtang et al., 2017; Ledgard et al., 2011). They may also differ because multiple system boundaries have been utilised, allowing for carbon footprint results to be misunderstood as stated by Batalla et al. (2014). In addition, LCA results are dependent on assumptions due to the data availability which is often an issue for pasture-based grazing systems (Ripoll-Bosch et al., 2013). In addition to this, majority of the literature discussed is focussed on carbon footprint as a sole indicator however this does not provide a comprehensive view on the environmental performance of a farming system (Ledgard et al., 2011).

Chapter 4: Environmental Certification & Eco-labelling Systems

The conscious consumer is a growing phenomenon worldwide (Marteau, 2017). Greater access to information as well as exposure has provided people with the knowledge of environmental, health and ethical issues as well as the ways in which our daily activities contribute to these issues

With the various consumer demands arising from current value production and realization through market segmentation (Prichard, 2017) as discussed in Chapter 2, there is an increased focus on methods in which verification of production methods and systems can occur. The following chapter discusses the development of certification and eco-labelling schemes, and introduces the certification systems reviewed as part of the development of the prototype farm environmental certification system discussed in Chapter 6.

While consumers remain price sensitive, the health and environmental conscious consumer is also shifting their focus to the production process and validation or credibility of the claims surrounding this process (Prichard, 2017; Marteau, 2017; 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 Life Cycle Assessments (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). Thus, it can be argued that LCA may also serve as a response to market differentiation, and not just the developing regulatory space.

The first major eco-labelling scheme was the 'Blue Angel' from Germany which was introduced in 1978 (Loureiro et al., 2001). Since then, there have been a diverse variety of other certification and labelling schemes such as the EU Eco-label, LEAF Marque Global Standard, Nordic Swan Eco-Labelling, Good Environmental Choice, Green Seal Programme; all of which cover single countries, apart from the EU Eco-label and Nordic Swan schemes which cover multiple areas in Europe (Allen, 2000).

4.1 New Zealand Environmental Schemes

According to McLaren, Singh and Clothier (2017), New Zealand has several environmental certification schemes in existence: CarboNZero; EnviroMark; Energy Star; WELS (Water Efficiency Labelling Scheme); SWNZ (Sustainable Winegrowers New Zealand); and lastly, the Australasian Environmental Product Declaration scheme. While there are several organic certification agencies which are available in New Zealand such as AsureQuality, BioGro NZ, Organic Farm NZ, and the Organic Exporters Association of New Zealand (MPI, 2017), there is yet to be a national programme that includes non-organic agricultural producers (McLaren et al., 2017).

In New Zealand, the current, biggest initiative focussing on the primary production sector is the Matrix of Good Management (MGM) project. The project was a collaboration between various governing and industry bodies in New Zealand such as Environment Canterbury, three Crown Research Institutes (CRIs; AgResearch, Plant & Food Research and Landcare Research), six primary sector organisations - DairyNZ, Beef + Lamb New Zealand, Deer Industry New Zealand (DINZ), NZPork, Horticulture NZ and the Foundation for Arable Research (FAR) (Williams et al., 2014). The aim of the matrix was to provide an estimation of nutrient losses from Canterbury farms; however, due to the general nature of the recommendations, the matrix was deemed to be applicable to other regions in New Zealand. As it was designed to serve only as best practice guidelines, there is no environmental certification associated with MGM.

Another scheme independently run is the Beef + Lamb New Zealand Farm Environmental Plan (Beef + Lamb New Zealand, 2018). Templates are provided for specific regions (Waikato, Gisborne, Hawkes Bay and Canterbury) and there is a general template available for farms located outside of these regions. The plans operate on a 3-level system with the level 3 plan offering the most comprehensive level of environmental management and auditing, and is only level that requires a nutrient budget to be completed (Beef + Lamb New Zealand, 2018). Farm environmental plans (FEPs) are increasing in prevalence with many regional and unitary authorities incorporating land and water management plans into their vison and strategy (Fietje and Carmichael, 2018; Campbell, 2018). However, a key issue is that while FEPs are intended to be a tool to aid the farmer/producer in achieving best environmental practice, there are several iterations on how the FEP fits into the regulation system, depending on the region where the farm is located (Tyler, Lissaman and Caseley, 2018). FEPs are required as part of the consenting process for certain regional authorities, however this means that completion of FEPs may be viewed as a compliance 'tick-box exercise' (Tyler et al., 2018). Where FEPs are completed as part of an external scheme (e.g. catchment management), the issue of auditability and flexibility of mitigations proposed are factors that need to be taken into consideration (Tyler et al., 2018).

Another industry FEP available is the Sustainable Milk Plan which is run by dairy co-operative, Fonterra (Chan and Kempson, 2018). Part of their Fonterra Farm Source Tiaki Sustainable Dairying Programme, the scheme involves tailoring of mitigations through on-farm visits and has met the regulatory requirements of the Canterbury Land and Water Plan (Chan et al., 2018). Similar to Tyler et al. (2018), the importance of understanding farmers' perception of FEPs and avoiding the view of FEPs being a compliance tick box requirement has been recognised (Chan et al., 2018). Powell and Heath (2018) link this to a key question on the future of FEP development – "How do we ensure plans connect to their purpose and prioritize the most important issues to address?"

The following section discusses what an environmental certification system consists of and the key characteristics of systems.

4.2 Characteristics of Certification Systems

There is a growing number of varying types of certification systems targeted towards a diverse range of products, in particular those from the primary industries due to an increasing focus on the long-term viability of farming/production systems and the social acceptance of welfare and environmental practices (McLaren et al., 2017; Lebacq, Baret and Stilmant, 2013).

Defined by Marx (2014) as a set of standards enforced as part of a regulatory initiative, environmental certification systems have two key fundamental characteristics, regardless of the product category targeted. McLaren et al. (2017) state the first characteristic to be whether the certification system is focussed on individual products and/or the wider organisation and the second key characteristic being the type of environmental indicator measured and how the environmental performance of the product and/or organisation is determined by the targeted demographic of the consumer market.

The following section introduces agricultural-focussed certification schemes aimed towards both products and organisations. The schemes were selected on the basis that they operate on a national level providing assurance on agricultural production and also provide marketing/eco-labelling for participants of the scheme.

4.2.1 Agricultural-Focussed Schemes

4.2.1.1 Sustainably Grown Certified – SCS Global Services – United States of America

The Sustainably Grown certification is a voluntary standard, targeted towards North America and developed on the goal of providing a comprehensive framework that included set environmental, social and economic requirements with the aim of ensuring crops were produced in a sustainable manner (SCS Global Services, 2016). The scope of the certification scheme covers all processes and inputs related to the production and harvesting of agricultural crops, including traceability and compliance if the certification claim is used in the marketing of the final product at the point of sale (SCS Global Services, 2016). The framework of the Sustainably Grown certification is classified into 4 key categories: General, Environmental, Economic and lastly, Social. The standard consists of 372 total indicators; however, producer groups are only audited to 96 of the total indicators. Within this standard, there are three conformance levels for each indicator: Required (R), General (G), or Optional (O) (SCS Global Services, 2016). In 2016, there were 39 suppliers registered with the Sustainably Grown scheme, with the US division of Zespri ® International Limited being one of the registered participants (SCS Global Services, 2016).

The certificate has been benchmarked to the American National Standard for Sustainable Agriculture (ANS/LEO-4000) Silver Tier as a baseline. The standard is reviewed every five years, at which stakeholder consultations involving the public, producers and others associated in the product supply chain are undertaken (SCS Global Services, 2016).

In terms of social indicators, the certification standard has been benchmarked to the Social Reference Code of the Global Social Compliance Programme which utilises best practice for industries internationally (SCS Global Services, 2016).

4.2.1.2 LEAF (Linking Environment and Farming) Marque – United Kingdom

The LEAF Marque is a farm assurance system with the objective of encouraging the delivery of sustainable food and farming through their Integrated Farm Management (IFM), with the availability of the LEAF Marque label certification for products produced in accordance with the LEAF Marque standards. To qualify and achieve the certification, the scheme requires that the entire farm, not just defined crops or enterprises within the farming business, meets the environmental performance of the standards which are generic and applicable for all agriculture and horticulture sectors. Thus, while LEAF certifies entire organisations, the LEAF Marque is designed to be displayed on products. The framework of the standard is reviewed regularly by a technical advisory committee involving notable organisational members in the UK such as The Royal Society for the Protection of Birds, RSPCA, SAI Global and the Department of Environment, Farming and Rural Affairs (DEFRA), with individual standards based upon the LEAF's IFM 9 key principles (LEAF, 2016) While the LEAF Marque and the relevant standards are centred in the UK, there are numerous certification bodies across the world that provide certification and auditing for producers interested in obtaining the certification. In New Zealand, AsureQuality is the sole provider of the LEAF Marque certification (LEAF, 2016). While a full list of New Zealand participants is unavailable, the scheme states that 36% of UK fruit and vegetables grown by LEAF Marque certified businesses, with a total 1032 business certified internationally (LEAF, 2016).

Similar to the Sustainably Grown certification scheme, the standards for LEAF Marque have three levels of conformance: Essential (E), Recommended (R), and lastly, Non-Applicable (NA) for each indicator, referred to as control points in the standard. Out of the 9 principles and total of 104 control points, a majority are directly linked to environmental performance, with the exception of 1 principle – Community Engagement, and the 3 associated control points (LEAF, 2016).

Control points classified as (E) are to be met by all businesses and annual inspection to ensure satisfactory conformance is conducted by certification bodies such as AsureQuality. While not compulsory, LEAF advises that the control points classified as (R) are complied with due to the possibility of such points being reclassified as (E) in following revisions of the standard. Across all three classifications, there are three different modes of verification as part of the process (LEAF, 2016). While some control points require physical audits i.e. either observation of activities and environment or a verbal interview with management conducted by a certification body, other points require a verification of submitted records/document.

4.2.1.3 Origin Green Ireland

Origin Green begun in 2012 as an initiative by Bord Bia-Ireland's Food Board. As of current, it is the only sustainability programme in the world which is run on a national level, involving both the government and private sector. While the programme was initially targeted towards producers, in 2016 retail and other organisations involved in the food services sector were included into the certification system (Bord Bia, 2013). Regarding the structure of the certification system, while it is not explicitly stated that the standards have been benchmarked against an external framework, the 2016, Sustainability Report for Origin Green was structured in alignment with the United Nation's (UN) Sustainable Development Goals and it was stated that the nine goals identified out of the total 17 in the UN framework will be utilised as a guiding tool for the certification system's future development.

Due to the wide breadth of the scheme, the certification system can be categorised into three different sections based on the supply chain level: farm; manufacturing; and retail and foodservice. Regarding the various indicators which are measured, there is an amount of overlap between each supply chain level. For the purposes of this review, we will be focussing on the 'Farm' supply chain level and the subsequent On-Farm Assessment methodology utilised. The Origin Green programme provides certification for farms as part of their Sustainable Beef and Lamb Assurance Scheme and the Sustainable Dairy Assurance Scheme, with the latter involving 85% of Ireland's dairy farms (Bord Bia, 2016). While there is yet to be a study on the success of consumer perceptions of the programme, it is estimated that 660 Olympic swimming pools-worth of water could have been conserved between 2016 and end of 2017 (Bord Bia, 2016). Both schemes are focused on the carbon footprint of the farm; this is calculated utilising 'The Carbon Navigator' – a software tool developed in part by Bord Bia. The software tool provides farmers with a performance evaluation based on their current, 3 and 5 year targets with the analysis scored out of ten points and mitigation advice is then generated by the tool. The tool also provides farmers with an economic analysis, calculating the resulting savings from emission reductions. Regarding the on-farm assessment, there are three different categories of information collected. While the Sustainably Grown and LEAF Marque systems utilised conformance levels, Origin Green specifies only one category of information (Black Box) as being assessed for score, with the other two types of standards: Green Box (serving as information collected but unassessed) and Orange Box (serving as recommendations only).

The following indicators are included in on-farm assessments: Energy, Emissions, Biodiversity, Water, Socio-economic, Traceability, Welfare, Animal Health, and lastly Food Safety. The initial assessment process involves data collected on grazing, agrichemical inputs, feed housing, energy usage, water consumption, effluent management and the biodiversity. Data is collected on-farm by an auditor and then synchronised into the Bord Bia database which then compiles information on herd profiles from the Department of Agriculture, Food and the Marine's (DAFM) Animal Identification and Movement Database, as well as the Irish Cattle Breeding Federation (ICBF)'s Production Information for that respective farm.

4.2.1.4 Unilever Sustainable Agriculture Code

The Unilever Sustainable Agriculture Code was established with the purpose of serving as best-practice guidelines for suppliers and producers to Unilever, developed from their initial Good Agricultural Practice documents first published in 1999 (Unilever, 2010). The standards set in the Sustainable Agriculture Code were determined by member of the Unilever Sustainable Agriculture Advisory Board (SAAB) consisting of individuals with expertise in agricultural practice as well as representatives from NGOs involved with sustainability (Unilever, 2010).

Regarding the structure of the certification system, it is not explicitly stated that the standards have been benchmarked against an external framework. However, the code states that certain external standards and industry level programmes are recognised by Unilever as fully compliant with the principles of sustainable agriculture, with SCS's Sustainably Grown certification system and Origin Green's Sustainable Dairy Assurance scheme both meeting the requirements (Unilever, 2017). However, the LEAF Marque system was determined to be only partially compliant with Unilever's principles of sustainable agriculture due to not covering the areas of animal welfare and value chain distribution (Unilever, 2017).

There is a total of 11 indicators in the Sustainable Agriculture Code and it involves the management of: agrochemicals and fuels; soils; water; biodiversity; energy; waste; social and human capital; animal welfare; value chain and local economy; and lastly, training (Unilever, 2010). The structure of the code involves two key conformance categories: Mandatory and Good Practice.

Within the Good Practice category, there are standards labelled as 'Must' which are obligatory unless there are exceptional circumstances which must be discussed prior with Unilever, and standards labelled as 'Should' which are recommendations however in similar fashion to the LEAF Marque's (R) classification, Unilever advises that 'Should' standards are obliged due to potential for such standards being made mandatory in future revisions of the standard (Unilever, 2010).

4.3 Categorising Environmental Indicators

The second key characteristic of an environmental certification system is the type of environmental indicator measured and the means by which the environmental performance of the product and/or organisation is determined. McLaren et al. (2017) identify this as a critical aspect when evaluating the efficiency of a certification systems and the associated eco-labelling. They state that while certification systems may take a life cycle approach when determining the environmental performance of a product/organisation, other systems may be solely focussed on a single aspect of the supply chain and measure only one aspect such as greenhouse gas emissions.

According to Lebacq et al. (2012), indicator selection is a critical decision area when designing any form of sustainability assessment. Lebacq et al. (2012, p.313) categorises indicators into four key types:

1. Means (Technology) -based indicators assessing technical means and inputs used on the farm, such as stocking rates;
2. System-state indicators concerning the state of the farming system, such as soil type;
3. Emission indicators related to the farm's polluting emissions into the environment and the potential impact of these emissions, such as quantity of acidifying gaseous emissions;
4. Effect (Performance) -based indicators reflecting the impact of the practices on the environment and consisting of direct measurements, such as biodiversity observations"

Means (Technology)-based and Effect (Performance)-based indicators are the primary types of indicators utilised in sustainability assessments whereas System-state and Emission indicators are categorised as intermediate indicators (Lebacq et al., 2012). The qualitative nature of means-based indicators makes it possible to apply to a variety of farms. As discussed in Chapter 3, the high level of variation in farming systems make it complicated to undertake comparisons of overall environmental performance, particularly intermediate indicators which look at slope (system-state indicators) and quantified emission levels (emission indicators). The impact of this on the potential scope of environmental assessment tools was recognised by De Olde, Oudshoorn, Sørensen, Bokkers and De Boer (2016) who state this as a key challenge in assessing sustainability at farm-level, thus making means-based indicators a common option for many sustainability schemes.

Lebacq et al. (2012) utilise a three-prong framework for sustainability, divided it into three main categories: environmental, economic and social. The environmental sustainability category is further divided into four key input management themes – nutrients, pesticides, non-renewable resources, and land management (Lebacq et al., 2012). While freshwater management and greenhouse gas emissions have been recognised as an important indicator in sustainability assessment tools (De Olde et al., 2016), these were not included in Lebacq et al., (2012).

4.4 Determining the Legitimacy of Certification Systems

While the selection and type of environmental indicators utilised is a critical issue for certification systems and determining their efficiency, there are also other factors that need to be considered when evaluating such systems, pertaining to their legitimacy. Marx (2014) identifies three key factors: openness of the standard-setting process; independence of conformity assessments; and lastly dispute settlement systems that may be in place. The ISO (1996) (as cited in FAO, 2003) defines standards as "documented agreements containing technical specifications or other precise criteria to be used consistently as rules, guidelines or definitions, to ensure that materials, products, processes and services are fit for their purpose".

Marx (2014) states that when designing a certification system, an important aspect is the openness of the standard-setting process and stakeholder involvement. This involves having consensus-based process when implementing decisions around standards set. Within this, the FAO (2003) labels environmental standards used in agriculture as 'process standards' and further defines them into two categories: 'Management system standards' and 'performance standards'. A key challenge identified with setting global standards is the prevalence of differing climatic and ecological conditions, therefore most environmental standards are set by non-governmental organisations (NGOs), often acting as an umbrella organisation consisting of various stakeholders with their respective constituencies, with the local government and the private sector forming multi-party coalitions (FAO, 2003). Sustainably Grown, LEAF Marque, Origin Green and Unilever's Sustainable Agriculture Code all utilise some form of stakeholder consultation whether through advisory boards (Unilever, 2010; LEAF, 2016; Bord Bia, 2013) or by benchmarking the standards/indicators utilised in the certification system to that of an external framework (SCS Global Services, 2016).

When determining the legitimacy of certification systems, it is important to evaluate the independence of the conformity assessments and the verification the standard (Marx, 2014). The Origin Green scheme utilises Bord Bia's pre-existing quality assurance department with in-house farm auditors undertaking assessments of farms (Bord Bia, 2013). A member of the ISEAL Alliance, LEAF Marque utilises ISEAL's standard-setting and assurance codes as well as independent evaluation and peer-review of audits (LEAF, 2016). The Sustainably Grown scheme utilises an in-house auditing process to evaluate producers, following which an independent SCS assessor will conduct an evaluation and make final approval of a producer's application (SCS Global Services, 2016). In comparison to the other schemes discussed, the Unilever's Sustainable Agriculture Code has the largest and most diverse range of participants due to the global nature of the scheme. As the scheme operates predominantly on suppliers with many farmers, a self-assessment approach is used. However, this does pose potential issues with verification. While risk assessment and random samples are utilised to assess the conformance of farmers, this does not ensure the validity of all assessments submitted (Unilever, 2010).

4.5. Summary

There is a growing number of varying types of certification systems targeted towards a diverse range of products, those from the primary industries due to an increasing focus on the long-term viability of farming/production systems and the social acceptance of welfare and environmental practices (McLaren et al., 2017; Lebacq, Baret and Stilmant, 2013). The three certification schemes discussed demonstrate the high level of variation present in sustainability requirements and the subsequent KPI framework utilised in awarding certificates. Thus, this highlights the relevance of utilising a standardised process such as LCA to evaluate and form the basis of a sector-focussed environmental certification system.

Chapter 5: The LCA Case Study

This study aimed to contribute to raising the environmental performance of New Zealand's sheep dairy industry by identifying environmental hotspot areas in a sheep dairy case-study farm using Life Cycle Assessment (LCA). Mitigation solutions to reduce these impacts were determined through the use of scenario modelling using GaBi LCA software and OVERSEER ® nutrient budgeting tool.

The different phases of the LCA study (definition of goal and scope; inventory analysis; impact assessment) are described in this chapter. The methodological framework provided by ISO 14040 was followed in the study (ISO, 2006), and the LCA was conducted with the ReCiPe 2008 model developed by RIVM and Radboud University, Centrum voor Milieukunde (*CML*), and PRé Consultants (Goedkoop et al., 2009).

The farm analysed in the LCA study is a sheep dairy operation based in the North Island, New Zealand. The farm is currently in the establishment stage and developing their milking mob. Forecasted farm inputs based on current pasture performance and nutrient intakes were provided by the farm owners and manager, based on a planned stocking rate of 12 RSU/ha. The farm input and production data used in the LCA study has been presented in Table 3.

As the LCA study was predominantly focussed on the overall environmental impacts associated with activities on the farm, the decision was made to initially model only the maximum stocking rate of dairy ewes/ha, with the assumption that all replacements and studs were grazed off-farm. The farm has a total of 63 ha, with effluent and solids spread across 15ha. The current mean lambing date is mid-July and mean weaning date is mid-September; however, there are plans for incorporating winter milking which would result in additional lambing in late-March. When fully operational, milk production is estimated to be 210 l/ewe/year with a 200-day lactation length, at 7% fat and 9% protein. The 35 ha of pasture grown on farm is a mix of ryegrass and clover and yields at 10 t DM/ha. Lucerne is grown as part of a cut and carry operation over 13 ha with a yield of 11 t DM/ha. In addition to this, 40 t/DM barley is imported into the farm and fed during the lactation length which runs for 200 days. The milking system on farm is 30-aside herringbone with an effluent system utilising a 1,257 m^3 effluent storage pond. In regard to nutrient use, 90kg N/ha/yr and 40 kg S/ha/yr is applied, with 0.5 t of lime applied annually. No P fertiliser is used due to the farm having high levels of phosphorus in its paddock soils.

Table 3 Sheep dairy farm input and production data

Farm Area		
Total Land Area (ha)	63	
Main Pastoral (ha)	35	
Effluent (ha)	11	
Solids(ha)	4	
Livestock Details		
Stocking rate (rsu/ha)	12	
Lactation length (days)	200	
Ewe weight (kg)	80	
Mean lambing date	15-Jul	
Mean weaning date	15-Sep	
Weaning weight (kg)	18	
Milk production		
Total (l/ewe/yr)	210	
Fat (%)	7	
Protein (%)	6	
Total Milk Solids (kg)	19	
Pasture and Crop Yield (t/DM/ha/yr)		
Ryegrass/Clover/Plantain pasture (50 ha)	10	
Lucerne (13 ha)	11	
Purchased Feed (t/DM/yr)		
Barley	40	
Electricity		
Jan-June (kWh/month)	3000	
July - Dec (kWh/month)	1500	
Fuel (l/yr)		
Diesel	1000	
Petrol	350	
Fertiliser and Lime (kg/ha/yr)		
Ammo 31 (Appl. 3 x months)	100	
(Total: 90 kg N/ha/yr + 40 kg S/ha/yr)		
Lime (kg)	500	
Pesticide (l/ha/yr)		
Paraquat/Gramoxone	0.6	
Atrazine	1	
Herbicide (l/ha/yr)		
Tmax	0.15	Aminopyralid
Thorndon Brush Killer	15.34	Picloram/Triclopyr/Fiethylene
Roundup Glyphosate	10.8	Glyphosate
Tandem	18.75	MCPB/MCPA
Effluent Management		
Pond Size (m^3)	1,257	
Application rate (mm/hr)	15	
Depth (mm)	12.6	

5.1 Goal and Scope

The intended application: The goal of this study was to quantify the life cycle-based environmental impacts of the farming and rearing practices of a case study dairy sheep farm to identify environmental hotspots that could form the basis of a future environmental certification scheme.

Functional Unit: The functional unit for this study was 1 hectare of land used in a sheep dairy farm operation. This was 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 comparing the impacts associated with different farming practices and inputs.

The system boundary of the LCA included the manufacture and application of agrichemicals (fertiliser, pesticides and herbicides), pasture and supplementary feed production, sheep emissions, and lastly, production and use of fuels and electricity.

The following processes and activities were excluded from the study.

- Establishment and construction of the farm and on-farm buildings: due to a lack of available data and as the current sheep dairy unit was converted from a bovine dairy unit, it is assumed that the environmental impacts of the establishment and construction of the farm are primarily associated with the previous bovine dairy operation.
- Production and maintenance of machinery: this was excluded due to a lack of data and it is assumed that any contributions to the overall environmental impact would be insignificant. This has also been excluded in other dairy LCAs reviewed.
- Veterinary medication and chemicals: Due to a lack of available data, such chemicals were excluded from the study.
- Contractor fuel: This was excluded due to a lack of available data. As the sheep dairy unit is part of a wider enterprise, external contractors for fencing and farm-related maintenance and repairs are not frequently utilised as majority of the work is conducted in-house.
- On-farm water use: This was excluded due to a lack of available data as water consumption has yet to be monitored for the sheep dairy farm. The majority of water use is for wash down of the milking shed and sheep consumption.
- Transport of external feed from production to farm: This was excluded as the feed was obtained from a neighbouring farm and therefore it is assumed that the environmental impact of the transport of the feed from the producer to the case-study farm would be minimal.
- Livestock that were culled or died naturally as data was not available for the specific proportion/period of the year they were removed from the mob.
- The rearing of replacements as this system modelled is intended to be the first stage of mob establishment.

- The lack of data around the manufacture requirements of specific agrichemicals brands/types used on-farm and the production inputs of the supplement feed resulted in data being sourced from literature

The following impact categories were used in this study:

- Climate change
- Fossil depletion
- Freshwater ecotoxicity
- Freshwater eutrophication
- Human toxicity
- Marine ecotoxicity
- Marine eutrophication
- Metal depletion
- Particulate matter formation
- Photochemical oxidant formation
- Terrestrial acidification
- Terrestrial ecotoxicity

A description of these impact categories is provided in Appendix A. Impact assessment results were calculated using the characterisation and normalisation factors for the ReCiPe (H/H) Europe 2000 (excluding biogenic carbon) method. The hierarchist (H) perspective was utilised as it was based on the assumptions and choices aligned with most common policy principles with regards to timeframe and other issues (Goedkoop et al., 2009).

Data were collected from a combination of farm visits and interviews conducted with the farm director and managers during a six-month duration from May 2017 to October 2017. The data were provided for a hypothetical future farm scenario based on the expertise of the farm director and managers. OVERSEER ®, a nutrient budgeting software designed for New Zealand farms (Wheeler et al., 2003), was used to calculate the nutrient losses based on farm inputs and these were then subsequently entered into GaBi software. As there were some initial issues around the nitrous oxide emission values provided by OVERSEER®, the emissions were also calculated manually for cross-checking purposes and to provide a comparison with the OVERSEER® software.

5.2 Inventory Analysis

The system boundary and the varying inputs and assumptions made for each aspect of the farm operations on the sheep dairy unit have been detailed below (see Figure 3). As mentioned in Chapter 1, the following LCA study is conducted on a future farm scenario utilising forecasted data provided by the farm owners and manager. Where it has not been stated otherwise, all farm input data were provided by the case-study farm during site visits.

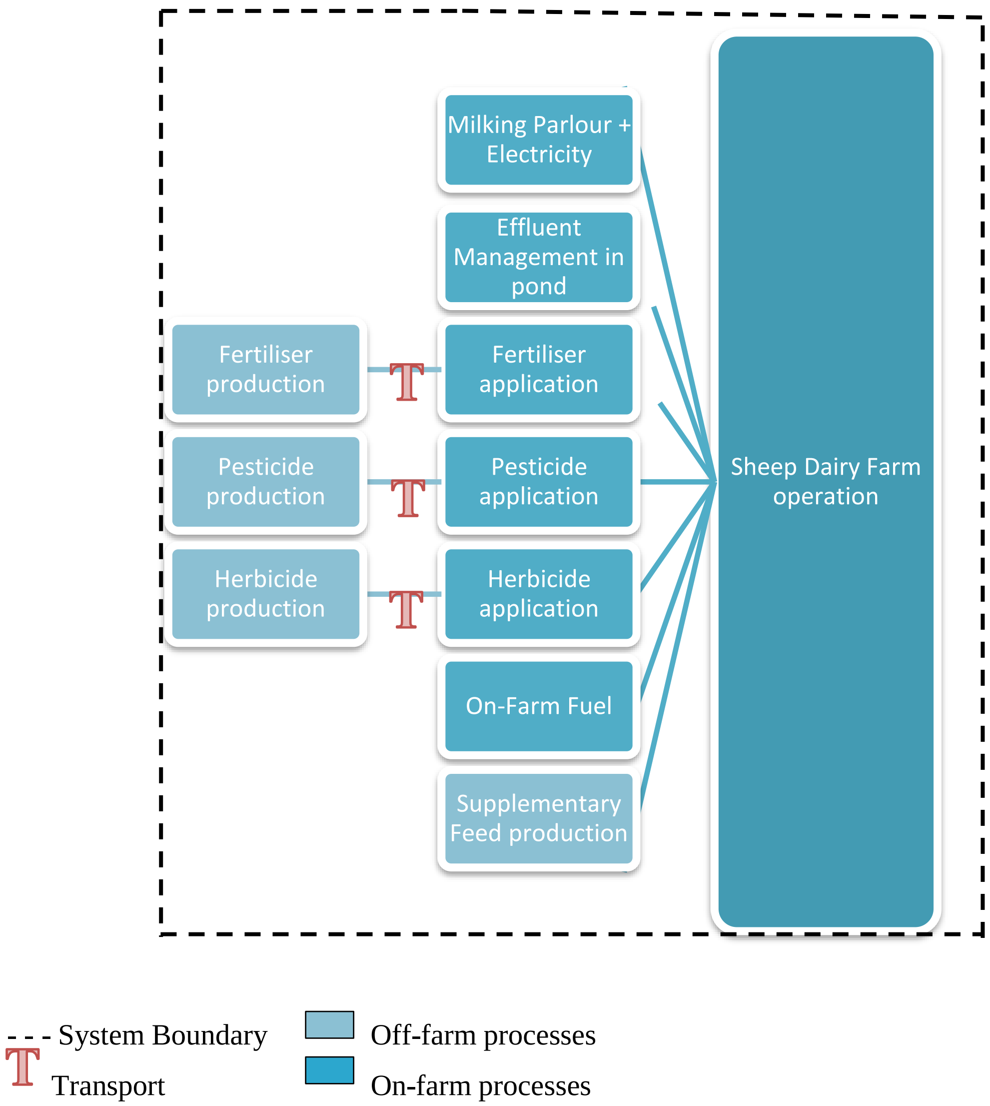


Figure 3 - System Boundary of Dairy Sheep Rearing LCA

The environmental impacts for the sheep dairy farm were modelled utilising various inputs identified within the system boundary in Figure 3, with the processes classified into: Fertiliser Production and Application, Pesticide Production and Application, Herbicide Production and Application, Milking Parlour and Electricity, Sheep Emissions, Production and On-farm Fuel Use and lastly, the Production of Imported Supplementary Barley Feed.

A list of the data sources and associated materials and activities is provided in the Table 4. In the case where datasets of relevant processes and products were not specifically available for New Zealand, the datasets deemed most suitable were utilised in the modelling. A full list of the emission factors and models utilised for livestock and fertiliser can be found in Appendix A.

Table 4 - Materials and activities dataset

Materials and Activities	Source	Geography of Technology
Materials		
Manufacture of N fertiliser	GaBi	United States of America
Manufacture of S fertiliser	GaBi	Generic
Manufacture of P fertiliser	GaBi	Generic
Transport of fertiliser	Zonderland-Thomassen, Boyles and Ledgard (2011)	New Zealand
Manufacture of herbicide	Green (1987)	Generic
Herbicide emissions	Chobtang (2016)	New Zealand
Transport of herbicide	Mueller et al (2011)	New Zealand
Manufacture of pesticides	Green (1987)	Generic
Pesticide emissions	Chobtang (2016)	New Zealand
Petrol production (refinery)	GaBi GLO	Australia
Diesel consumption (refinery)	GaBi GLO	Australia
Barley feed production	Chobtang (2016)	New Zealand
Livestock emissions	Supplied data inputted in OVERSEER ®	New Zealand
Transport modes		
Rail transport cargo – diesel 1000t	GaBi GLO	Generic
Transoceanic ship 50,000dwt	GaBi GLO	Generic
Container ship 27,500dwt	GaBi GLO	Generic
Euro 3 diesel truck	GaBi GLO	Generic
Euro 1 diesel truck	GaBi GLO	Generic
Euro 1 petrol car	GaBi GLO	Generic

5.3 Life Cycle Inventory Analysis (LCI)

The following section discusses the inventory analysis of the case-study farm.

Production and use of fertiliser

The fertiliser production was modelled utilising a GaBi nitrogen fertiliser process dataset for production in the United States. The case-study farm utilises Ammo31™, a Ravensdown product which is a blend of ammonia sulphate and urea, applied three times a year at a rate of approximately 100kg/ha, providing 90 kg of nitrogen per hectare per year (kg N/ha/yr) and 40 kg of sulphur per hectare per year (kg S/ha/yr).

Due to the lack of an ammonium sulphate production dataset in GaBi, the GaBi nitrogen dataset was selected to model the production of 90 kg N and a sulphur production datasheet in GaBi was used to model the 40 kg S to represent the blended Ammo31™ product.

As a large proportion of nitrogen fertiliser in New Zealand is exported from China (Zonderland-Thomassen, Boyles and Ledgard, 2011), the energy inputs for production and transport related to the production were changed from United States datasets to China datasets. The following processes were substituted in GaBi: diesel mix, natural gas mix, hard coal mix and electricity grid mix.

The transport of the fertiliser was modelled using the distances and transport modes as stated in the AgResearch (Mueller et al., 2011) publication, '*An ILCD database of three fertilisers for the kiwifruit industry*' for calcium ammonium nitrate fertiliser. As the transport data was only stated for the manufacturing-to-regional NZ storage stages of the fertiliser, it was assumed that the fertiliser would be transported to the Te Puke regional storehouse and then on to the case-study farm via truck. The distance between these two points was calculated using Google Maps ® and was modelled as 476 km (see Table 5).

Table 5- Transport of fertiliser from manufacture to farm

Mode	Dataset	Distance (km)	Country
Container Ship	GLO: Container ship ts heavy fuel 27,500 dwt	21,715	China
Rail transport	GLO : Rail transport cargo diesel ts 1000t	190	China
Truck	GLO: Truck	100	NZ
Truck	GLO: Truck	476	NZ

With regard to the application of the fertiliser and other agrichemicals, due to a lack of specific data regarding the fuel requirements for applying each type of agrichemical, the total diesel and petrol use on the farm have been presented as part of the 'sheep rearing' stage of this study. This is similar to other studies conducted in New Zealand focusing on the environmental footprint of dairy farming systems (e.g. Robertson, Symes and Garnham, 2015; Ledgard et al., 2011).

Nutrient Budgeting

The on-farm emissions from the fertiliser use were calculated using OVERSEER ® (using the built-in data for Ammo31 ™). N loss to water was 20 kg N/ha and N loss to atmosphere was 31 kg N/ha. Within the N loss to atmosphere, 0.9 kg was nitrous oxide emission and 0.19 kg was the emission of nitrogen oxides. These values were then added to the dairy sheep farming system modelled in GaBi. A copy of the emission factors can be found in Appendix A.

Use of other agrichemicals

Herbicides and pesticides are applied on the case study farm. Herbicides are utilised to inhibit the growth of unwanted plants in the pasture and lucerne crop. The case study farm utilised a combination of four different herbicides available commercially. These are Tmax™ (Aminopyralid), Tordon™ brush killer (Picloram, Triclopyr, Fiethylene glycol), Roundup® (Glyphosate), and Tandem™ (MCPB).

In terms of the energy requirements for the manufacture process, data were only available for MCPA (chemical composition similar to MCPB) and glyphosate in the commonly cited publication by Green (1987) (as cited by Audsley, Stacey, Parsons and Williams, 2009; Chobtang 2016). For the other herbicide active ingredients, however, data were unavailable, and so the glyphosate energy requirements were used to model the other active ingredients as well (see Table 6).

Glyphosate production utilises almost three times the energy requirements of MCPA, and therefore this indicated the high level of variation in the range of energy requirements for different herbicides. Therefore, consideration must be given to the emissions presented in the results section as the relative impact of the combined herbicide chemicals/ingredients utilised on farm has potential to be less than the emissions modelled with glyphosate as the sole chemical ingredient (see Table A6 in Appendix A).

Table 6- Herbicide used on case-study farm

Herbicide	Quantity	Active ingredient	l/ha/yr	Chemical
Brand name	(l/ha)	(l/ha)	-	-
Tmax™	5	0.15	-	Aminopyralid
Tordon ™ brush killer	20	15.34	-	Picloram, Triclopyr, Fiethylene glycol
Roundup® Glyphosate	30	10.8	-	Glyphosate
Tandem ™	30	18.75	-	MCPB
Total amount:	**85**	**45.04**	0.72	-

The emissions of the herbicide on-farm use to air, freshwater and agricultural soil were modelled utilising the factors from Webb et al (2013), Kellog et al. (2002) and Audsley et al. (2003), respectively, as cited by Chobtang (2016). The vapour pressure utilised in the emission models was calculated using the New Zealand Land Resource Inventory Portal *(NZLRI)* (NZLRI, retrieved October 2017). The emission factors can be found in Table A4 in Appendix A. The transport of the herbicide from manufacture to the farm was modelled utilising the transport modes and distances specified for glyphosate manufactured in China by Müller, Deurer and Clothier (2011) in the Plant & Food Research publication '*An ILCD database of three pesticides for the kiwifruit industry'.* As the transport data were only stated for the manufacturing-to-factory in NZ storage stages of the herbicides, it was assumed that the herbicides would be transported to the farm from the factory storehouse via truck. The distance between these two points was calculated using Google Maps ® and was modelled as 617 km (see Table 7).

Table 7-Transport of herbicide from manufacture to farm

Mode	Dataset	Distance (km)	Country
Truck	GaBi Euro 3 Truck	200	China
Container Ship	GLO: Container ship ts heavy fuel 50,000 dwt	9532	China
Truck	GaBi Euro 3 Truck	25	NZ
Truck	GaBi Euro 3 Truck	617	NZ

In terms of pesticides, the case-study farm utilises Gramoxone ® and Atrazine products annually (see Table 8). As there were no datasets available in GaBi for pesticide production, dummy models were utilised with the production inputs and energy requirements for the manufacture of paraquat and atrazine as stated by Green (1987) modelled (see Appendix A).

Table 8- Pesticides used on case study farm

Pesticide	Quantity	Active ingredient(s)	Chemical
Brand name	(l/ha)	(l/ha)	-
Gramoxone	2.4	0.6	Paraquat
Atrazine	2	1	Atrazine

The emissions of the pesticide on-farm use to air, freshwater and agricultural soil were modelled utilising the same procedure as stated above.

The transport of the pesticides from manufacture to the farm was modelled utilising the transport modes and distances specified for Iprodione manufactured in Germany by Müller, Deurer and Clothier (2011) in the Plant & Food Research publication '*An ILCD database of three pesticides for the kiwifruit industry'.* As the transport data was only stated for the manufacturing-to-NZ port storage stages of the pesticides, it was assumed that the pesticides would be transported to the farm from the port storage via truck. The distance between these two points was calculated using Google Maps® and was modelled as 617 km (see Table 9).

Table 9 - Transport of pesticide from manufacture to farm

Mode	Dataset	Distance (km)	Country
Rail	GLO: Rail transport cargo diesel ts 1000t	346	EU
Container ship	GLO: Container ship ts heavy fuel 50,000 dwt	12224	Germany
Truck	GaBi Euro 3 Truck	24	AU
Container ship	GLO: Container ship ts heavy fuel 50,000 dwt	3311	AU
Truck	GaBi Euro 3 Truck	617	NZ

On-farm fuel use

The AU dataset in GaBi for diesel mix at refinery was used to model the diesel used on-farm for application of agrichemicals and other sheep rearing activities. Due to a lack of specific information around the quantity of diesel used for each activity on-farm, it was modelled and presented just as one process ('on-farm fuel use'). The AU dataset for GaBi for gasoline mix (regular) at refinery was used to model the petrol used on-farm for application of agrichemicals and sheep rearing. The GLO Euro 1

Truck dataset and GLO Euro 1 Petrol Car datasets were utilised to represent the combustion of fuel on-farm in the absence of tractor datasets.

External Barley Feed Production

The case-study farm utilises 40 tonnes of barley grains per annum for supplementary feed which primarily used in the milking parlour with 350 grams fed per ewe per milking. Transport of the feed was excluded as the feed was obtained from a neighbouring farm and therefore it is assumed that the environmental impact of the transport of the feed from the producer to the case-study farm would be minimal. As it was not possible to gather specific data from the external barley supplier for the case-study farm, the production of the barley feed was modelled utilising the fertiliser and energy inputs specified by Chobtang (2016) (see Table 10). The manufacture and transport of agrichemicals such as fertiliser, pesticide and herbicides to the barley farm were modelled using the same process models used for the case-study farm. As the type of pesticide used in production of the barley grain was not specified by Chobtang (2016), the paraquat and atrazine datasets were used due to the chemicals' broad coverage. A key assumption was that these were used in the same ratio of active ingredients as the case-study farm (see Table 10).

Table 10 - Barley grain production inputs (retrieved from Chobtang, 2016)

Inputs	Quantity	Notes
Nitrogen (kg/ha/yr)	98	Manufacture and transport from case-study farm used
Phosphorus (kg/ha/yr)	15	Assumed that is Ravensdown Superphosphate product
Lime (kg/ha/yr)	500	Manufacture and transport from case-study farm used
Glyphosate (kg/ha/yr)	2.7 (kg a.i)	Manufacture and transport from case-study farm used
Pesticide (kg/ha/yr)	2.2 (kg a.i)	Assumed that same chemicals and ratio used as case-study farm
Diesel (l/ha/yr)	72	-
Electricity (kWh/yr)	3.91	-
Grain yield (kg/ha)	5874	-

The on-farm phosphorus fertiliser emissions were calculated using OVERSEER ™ utilising the Ravensdown Superphosphate product with the assumption that the 55 kg of the product is applied 3 times a year to provide 15kg P/ha/yr, as stated by Chobtang (2016), and the nitrogen fertiliser on-farm emissions were calculated using Ammo31® product. The runoff was calculated to be 0.3 kg P/ha/yr and the N leaching was assumed to be 6 kg N/ha/yr. The nitrogen oxide emissions were calculated to be 0.19 kg and the nitrous oxide emissions were calculated to be 0.98 kg, the other minor nutrient emissions were as follows: 34 kg K/ha/yr, 76 kg S/ha/yr, and 127 kg Ca/ha/yr. These values were then added to the dairy sheep farming system modelled in GaBi.

Table 11- Pesticide input for hectare of barley crop

Pesticide input (a.i kg/ha)	Case-study farm	Barley farm
Paraquat	0.6	0.825
Atrazine	1	1.375
Total	1.6	2.2

The emissions of the pesticide on-farm use to air, freshwater and agricultural soil were modelled utilising the factors from Webb et al (2013), Kellog et al. (2002) and Audsley et al. (2003), respectively, as cited by Chobtang (2016). The vapour pressure utilised in the emission models was calculated using the New Zealand Land Resource Inventory Portal (NZLRI) (NZLRI, retrieved October 2017). The emission factors can be found in Appendix A.

Calculation of livestock emissions

As previously mentioned, there were several challenges with calculating the greenhouse gas emissions of the livestock of the case-study farm. A goat dairy model in Overseer ® was used due to the unavailability of a sheep dairy model. There was initial difficulty with OVERSEER® due to a bug in the software's emission calculation system.

An issue was the presence of slight discrepancies between the total amount of feed produced on farm and the subsequent total dry matter intake (DMI) calculated by OVERSEER® for the stated number of livestock, and the current DMI of the dairy ewes reared in the case-study farm as stated by the farm. Another contributing factor is that OVERSEER® operates based on the assumption that the values are in a current state of equilibrium (Wheeler et al., 2003) This was an issue for the study as at the time of analysis, the case study farm was still in establishment and thus forecasted stocking rates were utilised to determine the relative impact of the farm when operational.

After consulting with research staff from the Fertiliser and Lime Research Centre (FLRC) and AgResearch, it was determined that the initial projected livestock numbers were not plausible as the DMI requirements of the ewes (2.34 kg/ewe/day annual average as stated by case-study farm) would not be met based on the sources of feed (fresh pasture, farm grown and imported supplements) as modelled by OVERSEER®. It was therefore decided to model the farm with a stocking rate of 12/ha based on the total DM available on the farm and DMI requirements of the dairy ewes, as was calculated by the farm manager. An utilisation factor of 70% was used in OVERSEER® to model the total feed available.

The methane emissions were from the enteric fermentation and faecal emissions, including the methane emissions from farm dairy effluent which is stored in pond prior to spreading/spraying on farm.

For methane emissions from faecal dry matter (FDM), typical values for non-dairy sheep breed stock excreta based on Whitehead (2000) were utilised (as recommended by Longhurst, B (2017) *Private communication*). The range of sheep defecations were highly varied with the weight of faecal material produced per day ranging from 0.2 – 0.6 kg DM, depending on body condition score and feed type. Due to the high DMI of dairy ewes, the 0.6 kg DM/ewe/day value was used in the model. As the methane emissions from faecal emissions are minor in comparison to the methane produced from enteric fermentation (Wiedemann et al., 2015; Vagoni et al., 2015), any variation in the actual FDM produced on farm per ewe would only make a very minor contribution to a change in the overall methane production from livestock.

The nitrous oxide produced was from direct emissions (excreta urine, excreta dung, synthetic N fertiliser) and indirect emissions (excreta volatilisation, excreta leaching, fertiliser volatilisation and leaching). For the urine and faeces deposited onto pasture, the emissions were calculated based on each ewe producing 13.2 kg N/yr in urine and 10.3 kg N/yr in faeces (as supplied by the case-study farm). These values were validated and deemed to be within an expected range (Longhurst, B (2017) *Private communication).* The value for leached N was calculated in OVERSEER®. The total list of emission models/factors used to quantify specific emissions in the sheep dairy farming system can be found in Appendix A.

For the milking stage, it was assumed that the dairy ewes spent 10% of the total year in the milking parlour. Therefore, 10% of the total emissions produced from enteric fermentation and faecal emissions were allocated to this stage, including the methane emissions from the farm dairy effluent which are subsequently spread on farm. As water use was not monitored, this has been excluded due to a lack of available data. All electricity use was allocated to this stage.

5.4 Life Cycle Impact Assessment (LCIA)

This section presents the results for each impact category and shows the relative contribution of the different life cycle stage to the specific impact category. The results are shown according to the following activities:

- Fertiliser and lime use: Manufacture, transport and application of nitrogen and lime fertiliser on farm.
- Herbicide use: Manufacture, transport and application of herbicides on farm
- Pesticide use: Manufacture, transport and application of pesticides on farm
- Sheep emissions: Greenhouse gas emissions of sheep on farm.
- Milking parlour: Electricity used on-farm and livestock emissions and effluent produced during milking.
- External feed (barley) production: Manufacture and application of farm inputs and emissions resulting from barley production.

Climate Change

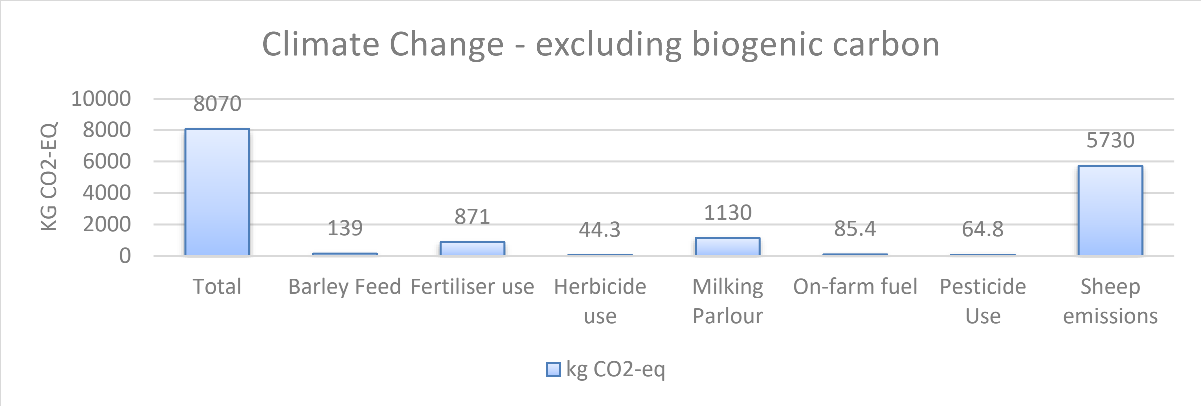


Figure 4 - Climate Change results for case study farm

The climate change impact category utilises the indicator of infrared radiative forcing (W/m_2) to determine the effect of greenhouse gases. The characterisation model used is an IPCC baseline model of 100 yr-time horizon. The characterization factor is the global warming potential (GWP) for each greenhouse gas (kg CO_2- equivalent/kg gas). Biogenic carbon has been excluded (Goedkoop et al, 2013).

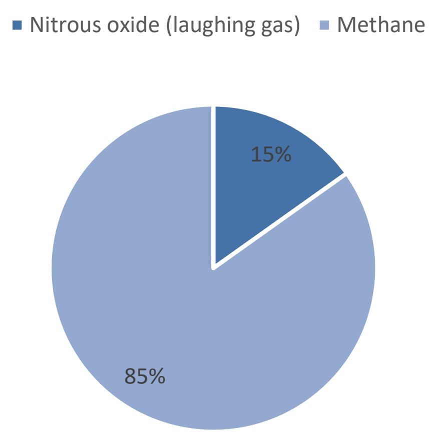


Figure 5 - Proportion of nitrous oxide to methane emitted by sheep

The greenhouse gas emissions from the livestock reared on the case-study farm was found to be the biggest contributor to the result. This was largely due to enteric fermentation of the livestock which leads to the production of methane. Figure 5 shows the percentage of methane and nitrous oxide emitted by the sheep reared on-farm.

The second biggest emitter in the study was from the fertiliser and lime use on the farm. The majority of the emissions from this stage of the sheep dairy farming were from the manufacture of the lime which is used as fertiliser on-farm, producing 604 kg CO_2-eq. This was considerably higher in comparison to the production of the nitrogen fertiliser which emitted 190 kg CO_2-eq.

When comparing the contribution for each stage of manufacturing the fertiliser and transporting it to the farm, the emissions for transport of both fertilisers were found to only contribute around 3.5%, with the manufacture of lime contributing 68.5%, and the manufacture of nitrogen contributing 21.5% overall. The production of the barley grains used as supplement feed was the third largest contributor to this impact category. As the environmental impacts for this study were modelled per hectare, the contribution based on the feed requirements of the maximum stocking rate (12 ewes/ha), thus the impact was relative to the feeding rate.

Fossil Depletion

The term fossil fuel refers to a group of resources that contain hydrocarbons. The group ranges from volatile materials like methane, to liquid petrol, to non-volatile materials like anthracite coal (Goedkoop et al, 2013). The characterisation factor for the impact category is fossil depletion potential (FDP) and the unit of the category is per kg oil equivalent.

Fertiliser use was the biggest contributor to the fossil depletion impact category with a total of 177 kg oil-eq. per hectare. Majority of this impact arose from the natural gas utilised in the production of the nitrogen fertiliser which contributed 71% of the total fossil depletion in the 'fertiliser use' stage of the study (see Figure 6).

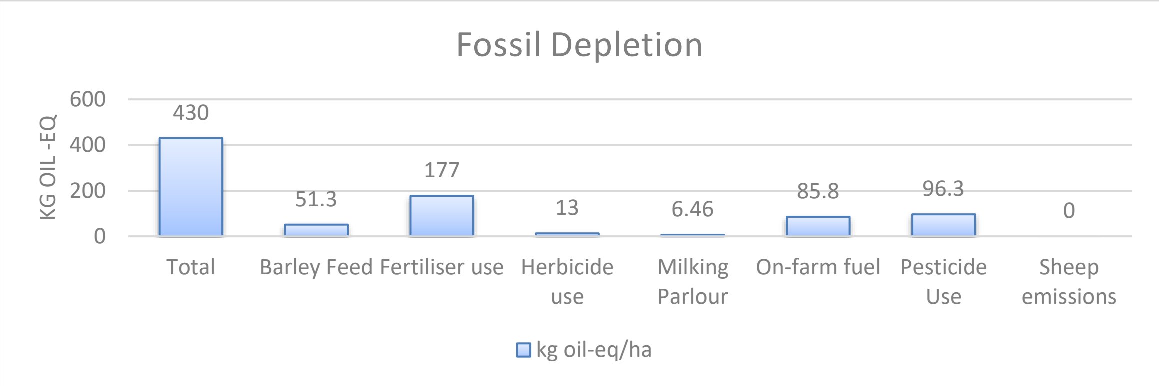


Figure 6 - Fossil Depletion results for case study farm

Pesticide use was the second largest contributor to the fossil depletion impact category. Out of the total 96.3 kg CO_2-eq, 90.7 kg CO_2-eq was produced from the production of the paraquat used on the case-study farm, utilising inputs from Green (1987). Similar to the nitrogen fertiliser production, the key contributing resource was the natural gas, equating to 88.2% of the total impact from paraquat production.

Freshwater Ecotoxicity

Freshwater ecotoxicity is defined as the assessment of the toxic effects of chemicals on freshwater ecosystems (and is assessed per kg 1, 4 DB equivalents). The largest contributing stage was the use of pesticides on the farm, with the impact coming from the release of pesticides into freshwater. Within the pesticide use, majority of the impact was derived from the emissions of atrazine which was 36.3 kg 1, 4 DB eq. (see Figure 7) with on-farm emissions from paraquat contributing only 0.19 kg 1, 4 DB eq. Emissions was calculated utilising general impact factors (Chobtang, 2016) with pesticide-specific datasets used to model the emissions. The production of the barley feed was the second largest contributing stage to freshwater ecotoxicity with a total of 15.9 kg 1, 4 DB eq. Within the barley production, pesticide use contributed a large proportion of that impact category with 6 kg 1, 4 DB eq produced due to the on-farm emissions. Following this, the use of fertiliser on-farm within the barley production contributed 3.94 kg 1, 4 DB eq from emissions resulting from application.

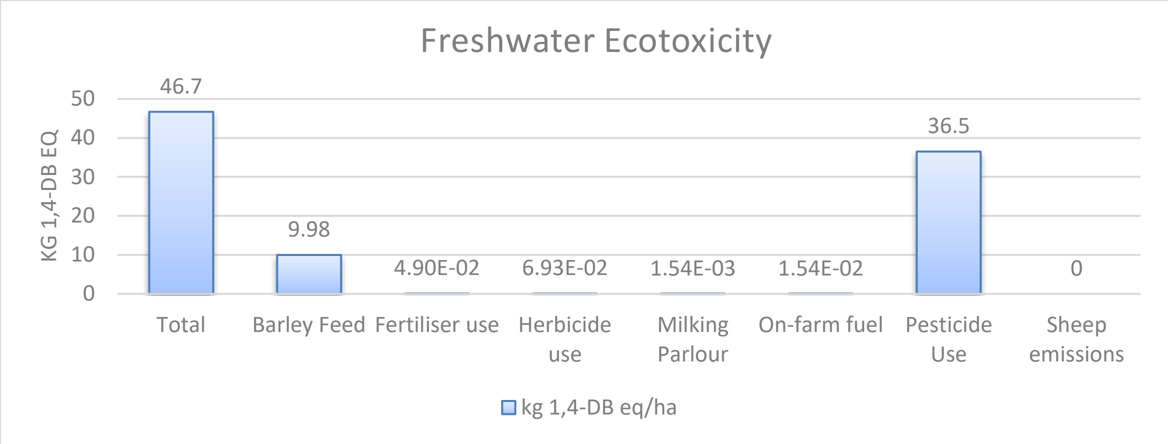


Figure 7- Freshwater Ecotoxicity results for case study farm

Freshwater Eutrophication

Aquatic eutrophication can be defined as nutrient enrichment of the aquatic environment. Eutrophication in inland waters because of human activities is one of the major factors that determine its ecological quality (Goedkoop et al, 2013). The freshwater eutrophication impact category is defined as the assessment of effects caused by nutrient accumulation. The impact indicator for freshwater is the increase in phosphorus (P) concentration and the undesirable associated formation of biomass. The characterisation factor is based on kg P – equivalent (Goedkoop et al, 2013). In New Zealand freshwater rivers and streams, P control is often utilised to alleviate eutrophication whereas freshwater lakes utilise N control. As there are several streams that intersect the case-study farmland, the characterisation factor is relevant to this scenario.

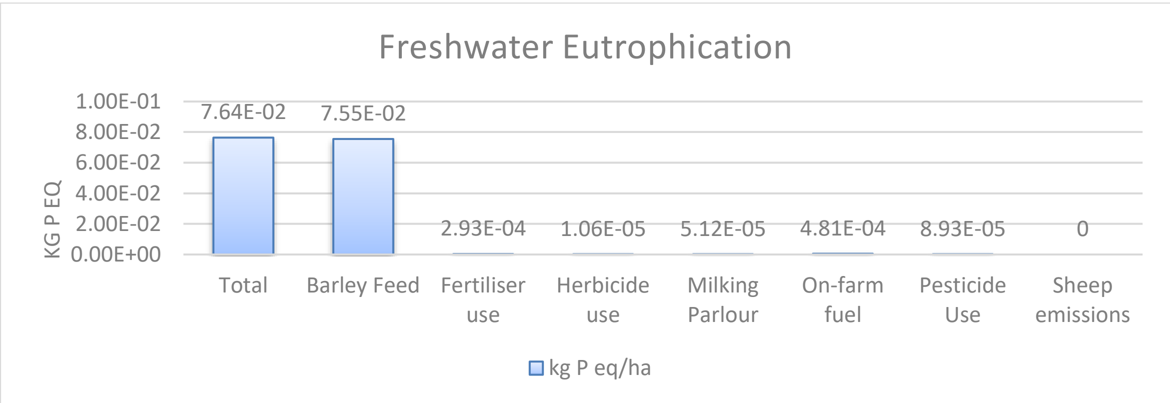


Figure 8- Freshwater Eutrophication results for case study farm

For the case-study farm, the only notable impact was from the barley feed production (see Figure 8) as while P fertiliser is not directly applied on-farm, it is however an input for the barley farm. In this stage, approximately half of the impact (0.0395 kg P eq) was due to the manufacture of the P fertiliser, with 0.0358 kg P eq of emissions from the release of P fertiliser to freshwater. It is important to note, however, that the assumption of P being the only relevant nutrient is not accurate for New Zealand as N may occasionally be the relevant nutrient (Payen & Ledgard, 2017). It has also been noted that due to the high Olsen P test results of the case-study, it is likely there will be P emissions from the pasture – however, this has not been assessed within the LCA as the focus is only the activities currently going on; thus, it is very unlikely that P fertiliser will be utilised by case-study farm in any recent future.

Human Toxicity

Human toxicity is defined as the assessment of the toxic effects of chemicals on human health is presented per kg 1, 4 DB equivalents to urban air (Goedkoop et al, 2013).

Barley feed is the sole largest contributing stage to this impact category, producing 346 kg 1, 4 DB eq of emissions (see Figure 9). Of this, 336 kg 1, 4 DB eq was produced emissions to freshwater from the application of P fertiliser to the barley farm. In regard to fertiliser used on the case-study farm, 19 kg 1, 4 DB eq. was produced, out of which 16 kg 1, 4 DB eq was the release of the heavy metal mercury to air. In regard to releases to freshwater, 0.55 kg 1, 4 DB eq was from the substance arsenic and 0.34 kg 1, 4 DB eq was from P.

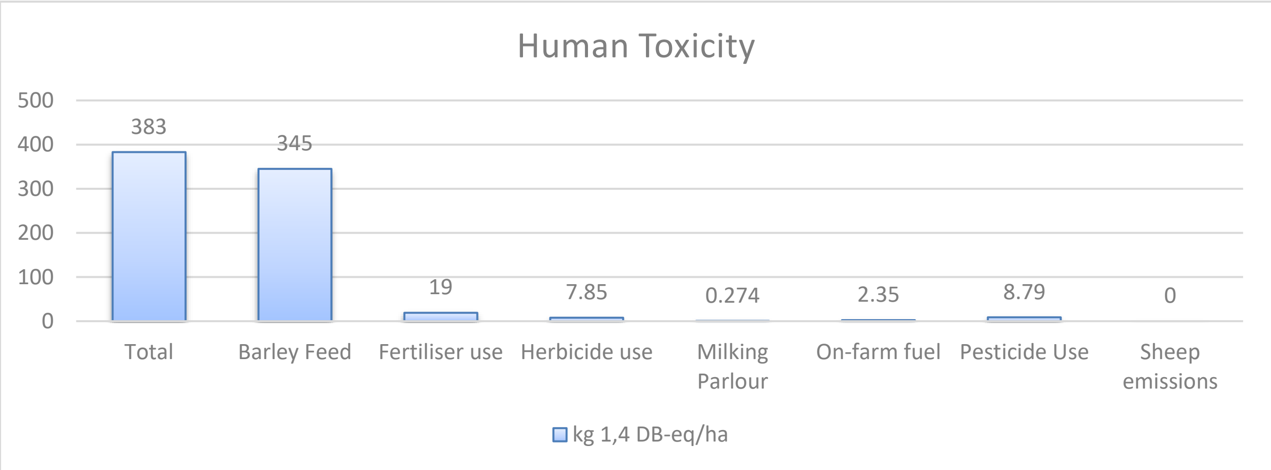


Figure 9- Human Toxicity results for case study farm

Marine Ecotoxicity

Marine Ecotoxicity is defined as the assessment of the toxic effects of chemicals on marine ecosystems and is presented per kg 1, 4 DB equivalents (see Figure 10). In this impact category, the use of pesticides was the largest contributing stage of the case-study.

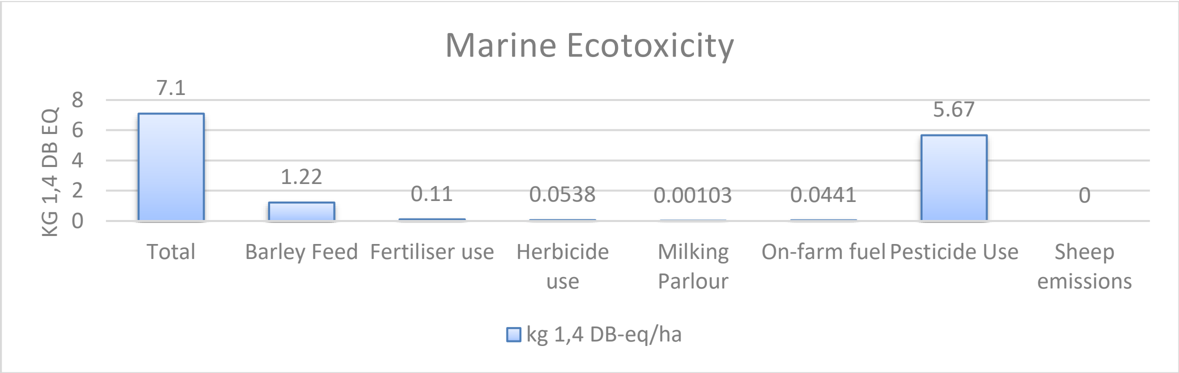


Figure 10 - Marine Ecotoxicity results for case study farm

Out of the total 5.67 kg 1, 4 DB eq. emitted, 5.66 was from atrazine and 0.015 was from paraquat. The majority of the atrazine emissions were releases to soil. It is important to take into consideration that percentage of emissions was modelled utilising the same model for both pesticides.

Marine Eutrophication

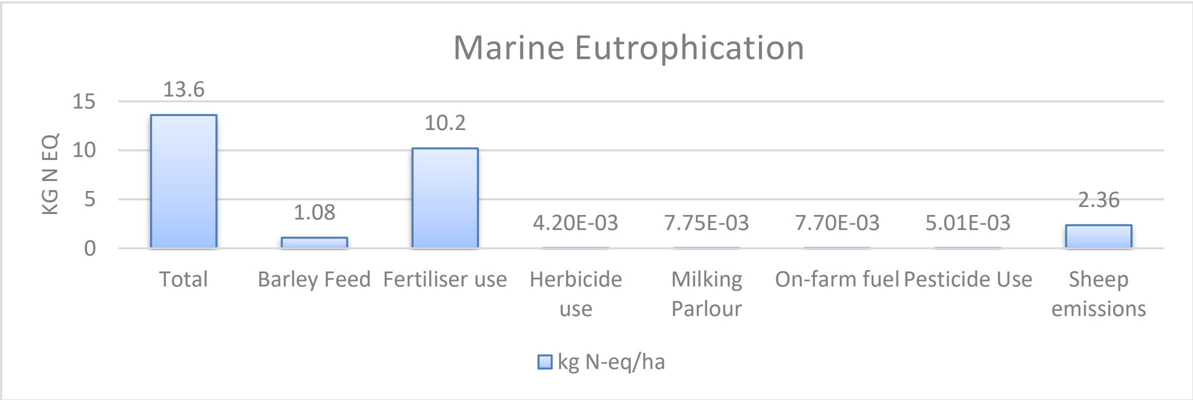


Figure 11 -Marine Eutrophication results for case study farm

Aquatic eutrophication can be defined as nutrient enrichment of the aquatic environment. The marine eutrophication impact category is defined as the assessment of effects caused by nutrient accumulation. The characterization factor of marine eutrophication accounts for the environmental persistence (fate) of the emission of N containing nutrients. The unit is year/kg N to freshwater equivalent (Goedkoop et al, 2013). Fertiliser use on the farm was the largest contributor (see Figure 11). Out of the total 10.2 kg N-eq. produced by the fertiliser, 10 kg N-eq was a result of inorganic emissions to freshwater from the leaching of the N fertiliser applied. Similarly, with the production of the barley feed which was the third largest contributor, although comparatively smaller, the releases from the N fertiliser used on-farm was the main source of emission. Leaching of N from urine patches resulted in sheep emissions being the second largest stage.

Metal Depletion

Metal depletion is defined as the assessment of the additional effort required by future generations for extracting a certain resource as a result of the reduced ore concentration due to today's exploitation of the higher concentrated ores (Peters & Weil, 2016). It is presented as per kg iron (Fe) equivalent (Goedkoop et al, 2013). The use of fertiliser for the case-study farm was the largest contributing stage for this impact category with a total of 0.93 kg Fe-eq produced (see Figure 12).

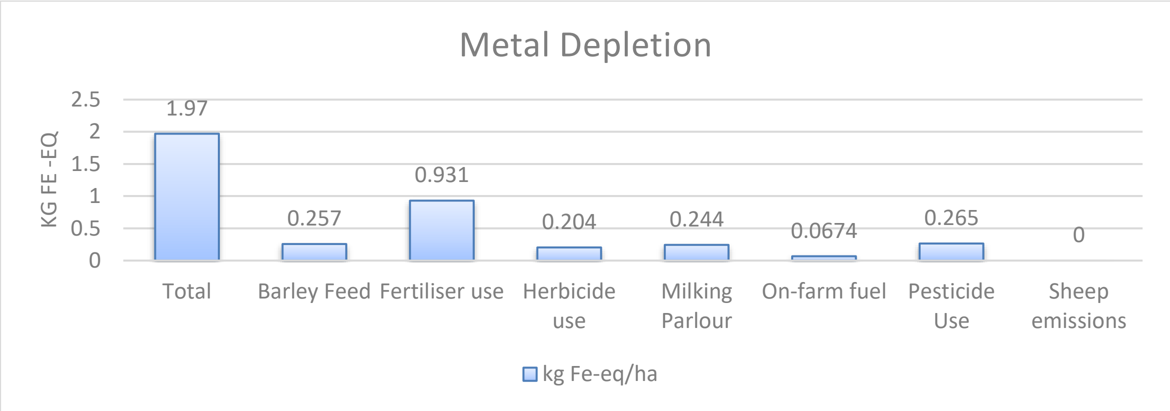


Figure 12 - Metal Depletion results for case study farm

Within this, manganese was identified as being the key non-renewable resource contributing to this impact category with the natural gas production used for manufacture of N fertiliser and the manufacture of lime fertiliser being the two main sources of metal depletion.

Particulate Matter Formation

Particulate Matter Formation is defined as the assessment of the increase in particles with a diameter of less than 10 µm suspended in air. These particles are a complex mixture of organic and inorganic substances, including acids, and are known to causes respiratory problems in humans when inhaled (Goedkoop et al, 2013). The impact category is presented as kg PM_{10} -eq to air.

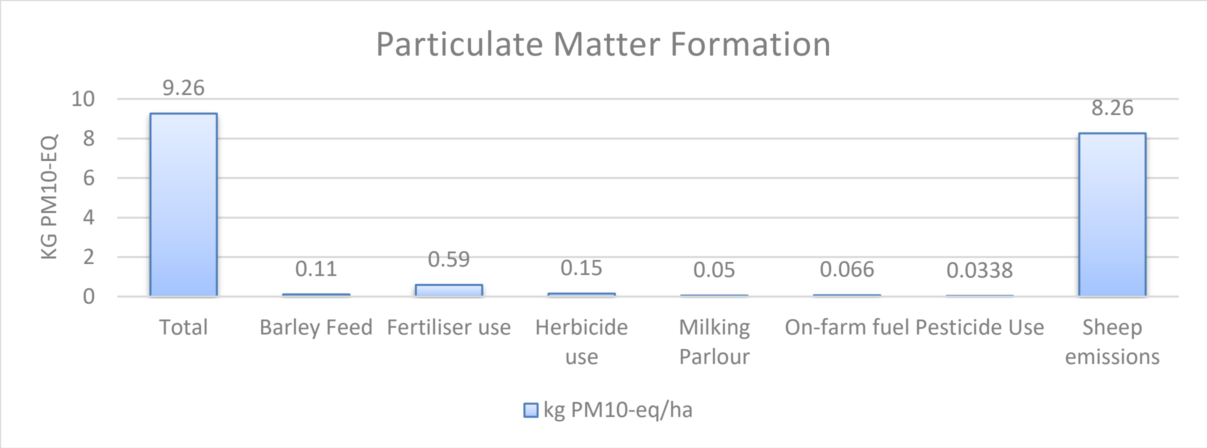


Figure 13 -Particulate Matter Formation results for case study farm

The emissions from sheep on-farm were found to be the biggest contributor to the impact category due to the release of ammonia which accounted for 8.12 kg PM_{10} –eq. The fertiliser used on the case-study farm was the second largest contributing stage to the impact category with 0.59 kg PM10 –eq produced (see Figure 13). In this, 73% of the impact was a result of the inorganic emissions to air, with 0.12 kg PM_{10} –eq produced. The remainder 0.0438 kg PM_{10} –eq produced was from the release of dust particles to air, majority of which were contributed by electricity generation used in the manufacture of N fertiliser, as well as the production of lime fertiliser. Figure 14 shows the proportion of particulate matter forming emissions from fertiliser use.

Herbicide use was the second largest contributing stage with 0.15 kg PM_{10} –eq produced. In contrast to the contributing sources in the fertiliser use stage, 70% of the emissions to air were from dust particles (0.106 kg PM_{10} –eq) resulting from the production of electricity used for the glyphosate production. In regard to inorganic emissions, these were nitrogen oxides and sulphur dioxides and formed 40% of the total produced by the herbicide use and were predominantly from the electricity production.

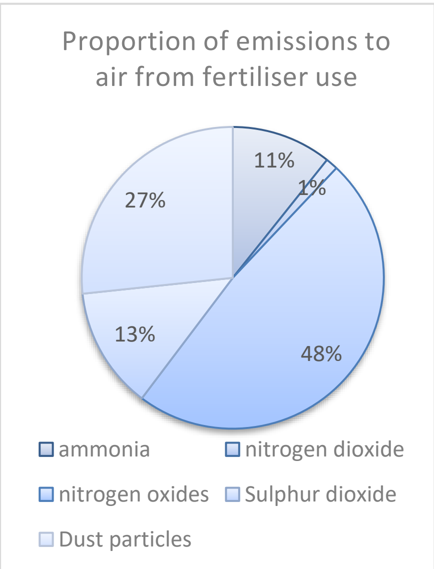


Figure 14-Proportion of emissions to air from fertiliser use

Photochemical Oxidant Formation

The photochemical oxidant formation impact category is defined as health damage due to ozone particulate matter and ozone creating substances and is presented as per kg NMVOC (Goedkoop et al, 2013).

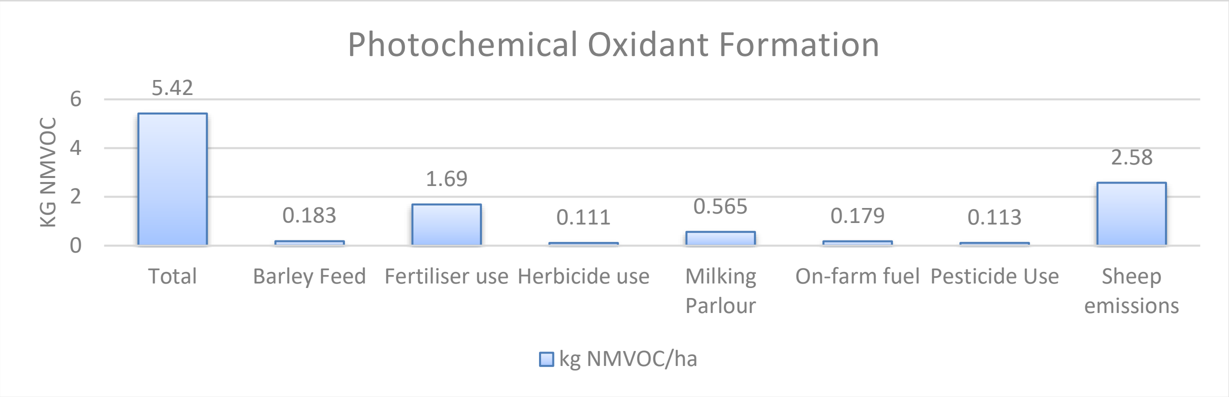


Figure 15-Photochemical Oxidant Formation results for case study farm

The emissions from the sheep reared on the case-study farm were the biggest contributing stage for this impact category with majority of the 2.58 kg NMVOC solely resulting from methane emissions (see Figure 15). The fertiliser used on the farm was the second largest contributing stage with 1.69 kg NMVOC produced.

Of this, 0.36 kg NMVOC was from nitrogen oxides, with almost 50% arising from the production of lime and the remainder from various energy input requirements needed for the manufacture of N fertiliser. The breakdown for the various contributing chemicals for the total 3.22 kg NMVOC produced can be found in Figure 16.

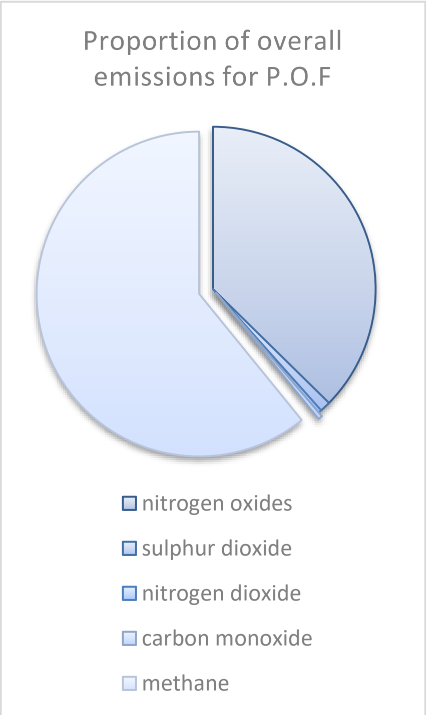


Figure 16 - Proportion of overall emissions for photochemical oxidant formation

Terrestrial Acidification

The terrestrial acidification impact category is defined as the assessment of the acidifying effects of anthropogenic emissions. Atmospheric deposition of inorganic substances, such as sulphates, nitrates, and phosphates, cause a change in acidity in the soil (Goedkoop et al, 2013). The characterisation factor is acidification potential and is presented in kg SO_2 – eq.

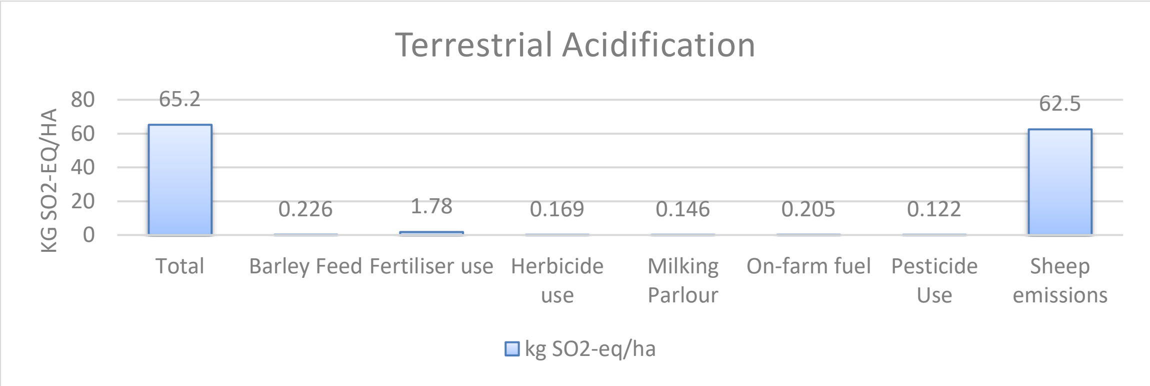


Figure 17- Terrestrial Acidification results for case study farm

The sheep emission stage was the biggest contributing stage to the impact category with the release of ammonia being the largest contributing substance forming 62.2 kg SO_2–eq of the total emissions (see Figure 17).

The on-farm fertiliser use was the second biggest contributing stage to the impact category with 0.202 kg SO_2–eq attributed to nitrous oxides, predominantly from the production of lime fertiliser and the natural gas utilised in the manufacture of N fertiliser (0.0856 and 0.0583 kg SO_2–eq respectively).

The production of barley feed was the third largest contributing stage, in which the two key main sources of emissions were the fertiliser and herbicide production. Figure 18 shows the proportion of overall emissions for the impact category.

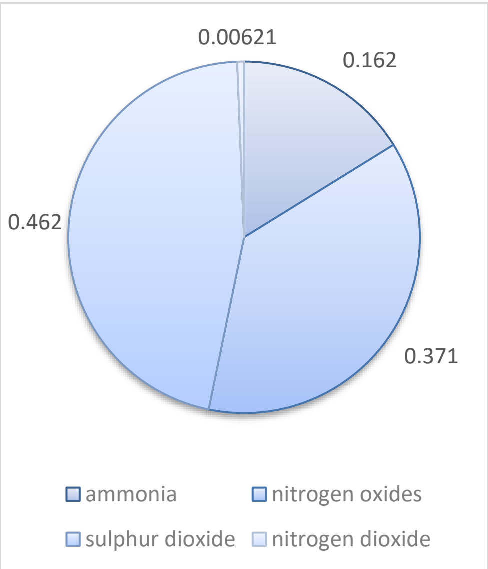


Figure 18-Proportion of contribution to terrestrial acidification impact category

Terrestrial Ecotoxicity

Terrestrial ecotoxicity is defined as the assessment of the toxic effects of chemicals on terrestrial ecosystems. It is presented as per kg 1, 4 DB to soil equivalent (Goedkoop et al., 2013).

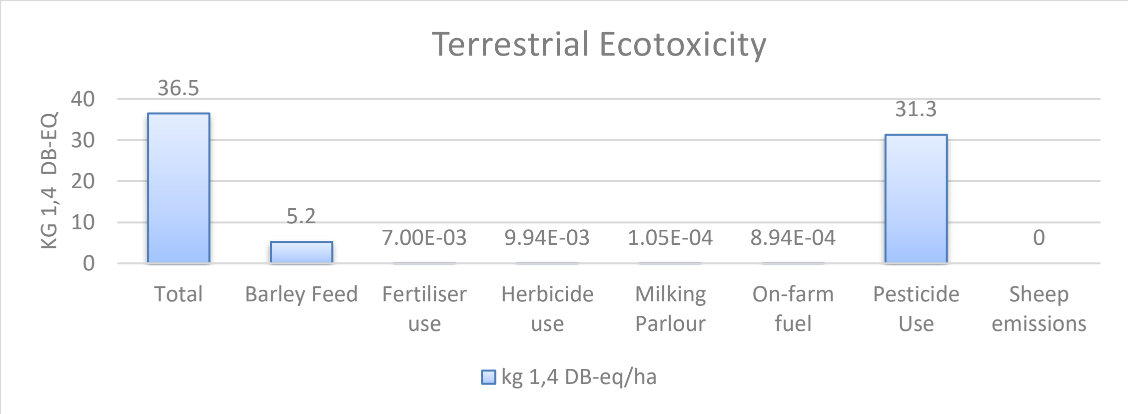


Figure 19- Terrestrial Ecotoxicity results for case study farm

The pesticide use on-farm was the biggest contributing stage to the impact category with a total of 31.3 kg 1, 4 DB –eq being produced (see Figure 19). Out of this, 89% was contributed by the release of atrazine to agricultural soil, and paraquat forming only 9.4% of the total emission from that stage. 0.285 kg 1, 4 DB –eq was a result of the release of atrazine to air (see Figure 20). The production of barley feed was the second largest contributor to the impact category with 10.3 kg 1, 4 DB –eq. emitted (see Figure 19). Similarly, the use of pesticides for barley production was a hotspot area with 9.18 kg 1, 4 DB eq resulting from the release of atrazine to agricultural soil.

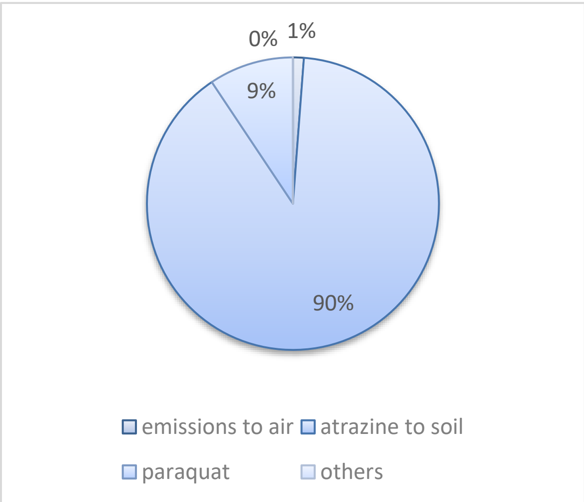


Figure 20 - Proportion of total emissions for terrestrial ecotoxicity

5.5 Normalisation

Normalisation was conducted utilising the ReCiPe 1.08 (H) Mid-Point Normalisation (Europe 2000) excluding biogenic carbon normalisation dataset. Results have been expressed in the same unit (person equivalents) 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). The graph below has been expressed with a logarithmic scale to offer a clear comparison of the results.

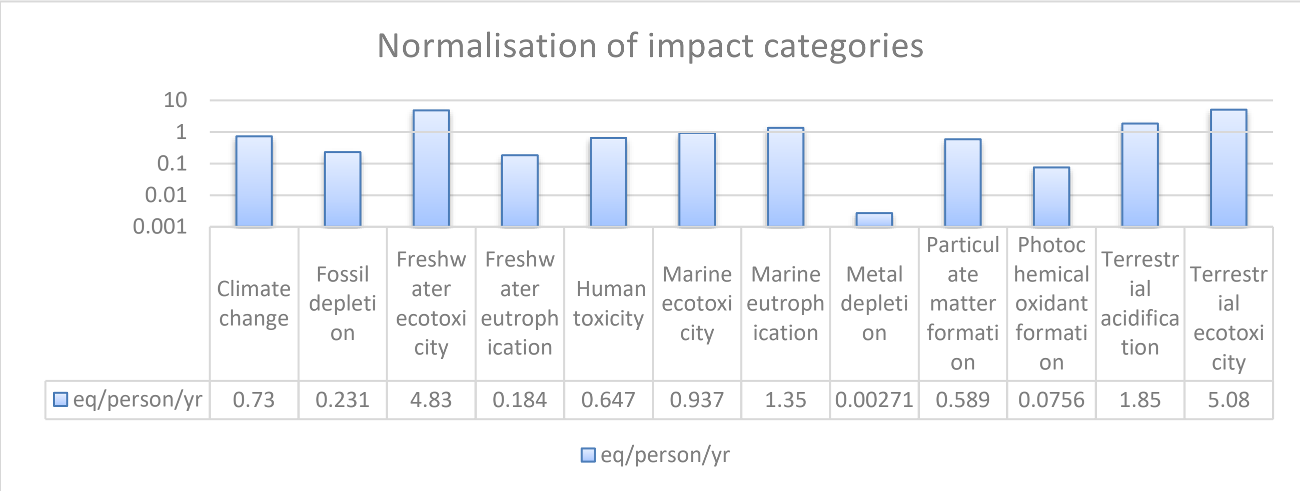


Figure 21- Normalised results for impact categories

After normalisation of the data, five categories were found to be the highest: freshwater ecotoxicity, marine ecotoxicity, marine eutrophication, terrestrial acidification, and terrestrial ecotoxicity. Terrestrial ecotoxicity was found to pose the largest environmental impact in the LCA study of the dairy sheep case-study farm (see Figure 21). Pesticide use was the largest contributor to the terrestrial ecotoxicity impact category, with 75% (3.82 eq/person/yr) of the total impact from that category resulting from the releases of atrazine. Similarly, in barley production, pesticide use was the biggest contributor (see Figure 19).

Freshwater eutrophication result was relatively small. This was not expected and may be a ‘false’ result as the impact category is only focussed on P nutrient losses and did not take into account the potential impact of P emissions arising from high P levels in soil from previous years. Another factor that hints at a potentially greater impact for that category is the high result for the marine eutrophication impact category which assesses the N emissions. It can be expected that the result for the freshwater eutrophication category would be higher if these two aspects were taken into account.

The metal depletion and photochemical oxidant formation impact categories were found to be the most insignificant.

5.6 Sensitivity Analysis

5.6.1 Maize grain supplement feed

As the use of pesticides were identified to be a key environmental hotspot area in the study both on- and off-farm, the sensitivity analysis considered the impact of utilising maize grain as a substitute supplementary feed to barley grain which is currently used by the farm, which is common feed type for sheep. Maize grain was selected on the basis that it has very similar nutritional value to barley grain and it utilised a lower amount of pesticide for a higher yield (Chobtang, 2016). Table 12 lists the input requirements for maize production (see Table 12).

Table 12- Nutritional value of barley versus maize (Retrieved from Mills, 1982)

Grain Type	Barley grain	Maize grain
Dry Matter %	86	86
Metabolisable Energy (MJ/kg)	13.7	14.2
Digestible Crude Protein	8.2	7.8
Digestive Value	86	87

The analysis utilised the input requirements for maize grain production from Chobtang (2016) and the various inputs were substituted into GaBi (see Table 13). For the purposes of the analysis, all product assumptions made in modelling the barley grain production were kept constant, including the assumption that the supplementary feed was obtained from a neighbouring producer in the vicinity of the case-study farm thus the transport from producer to farm was not modelled and thereby excluded.

Table 13 - Input requirements for maize grain production (retrieved from Chobtang, 2016)

Inputs	Quantity	Notes
-	kg/ha	-
Nitrogen	145	Manufacture and transport from case-study farm used
Phosphorus	23	Assumed to be Ravensdown Superphosphate product Manufacture and transport from case-study farm used
Lime	500	Manufacture and transport from case-study farm used
Glyphosate	0.91 (kg a.i)	Manufacture and transport from case-study farm used
Pesticide	3.89 (kg a.i)	Assumed that same chemicals and ratio used as case-study farm. Manufacture and transport from case-study farm used
Diesel	111	-
Electricity (kWh)	3.91	
Yield of Maize Grains	10,235	-

Results

Figure 22 showcases the results for the various impact categories utilised in the study solely for the modelled barley grain and maize grain production. The results have been presented as a ratio relative to 1 (original scenario) to show the difference in the results obtained in each respective category.

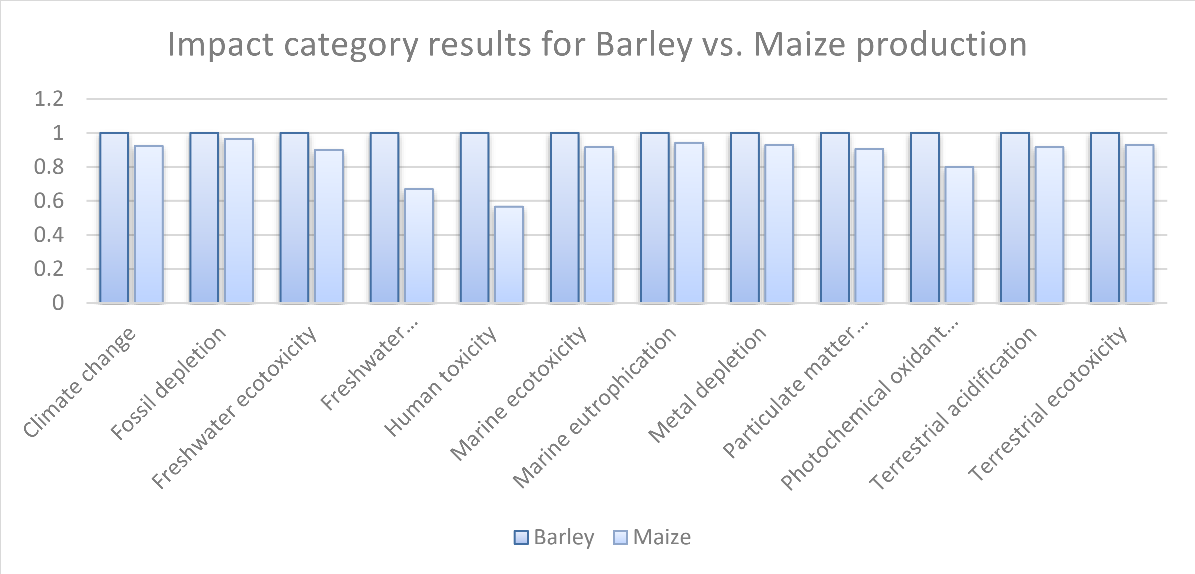


Figure 22 - Impact category results for maize vs. barley feed production

As seen in Figure 22, in all the impact categories there is a decrease in results. The biggest difference was in the human toxicity impact category where the emission decreasing from 0.108 to 0.0421 55 kg 1, 4 DB eq.

The total LCA results for the maize grain supplement feed scenario was then normalised to determine the relative significance of each impact category. Table 14 shows the percentage difference with the total normalised results for the dairy sheep farm with the original barley grain scenario and the maize scenario.

Table 14- Percentage difference in normalised total results for supplement feed scenarios

Impact Category	Maize	Barley	Difference
Climate change	0.67	0.73	-8%
Fossil depletion	0.22	0.23	-4%
Freshwater ecotoxicity	4.34	4.83	-10%
Freshwater eutrophication	0.12	0.18	-33%
Human toxicity	0.37	0.65	-43%
Marine ecotoxicity	0.86	0.94	-8%
Marine eutrophication	1.27	1.35	-6%
Metal depletion	0.003	0.0027	-7%
Particulate matter formation	0.53	0.59	-9%
Photochemical oxidant formation	0.06	0.076	-20%
Terrestrial acidification	1.69	1.85	-9%
Terrestrial ecotoxicity	4.72	5.08	-7%

As seen in Table 14, terrestrial ecotoxicity had the largest normalised result when maize grain was utilised instead of barley grain. Pesticide use in the production of the maize grain was the biggest contributing aspect of that stage, with the releases from atrazine being the highest contributing substances.

5.6.2 Impact of simazine use versus atrazine use

As previously mentioned, the application of pesticide is a key source of environmental impacts, primarily the use of atrazine. The sensitivity analysis considered the use of simazine as an alternative to the current atrazine being used, with the assumption that the same quantity of active ingredient was applied due to both types of commercial products having similar application rates (Ravensdown (2018) *Personal Communication*). This sensitivity analysis was only conducted on the on-farm use of pesticides and assumes that atrazine is still used for the imported barley feed produced. Simazine was selected as it is in the same triazine herbicide class like atrazine. Used to control broad-leaved weeds and annual grass pastures, simazine is also recommended to be used with paraquat and is suitable for use on lucerne crops (AGPRO NZ Ltd, 2013).

In terms of manufacturing, both simazine and atrazine are produced by the primary reaction of cyanuric chloride with ethylamine. (Muller and Appleby, 2010; Sittig, 1980).

Therefore, in this sensitivity analysis it has been assumed that the energy inputs for production of both chemicals are identical as there is only a slight variation in terms of ingredients.

It is important to note that, as this analysis is hypothetical, the production requirements for the specific chemical brands utilised on-farm can be very different and thus results may vary.

In terms of transportation and application rates of simazine, all the assumptions were kept constant as with atrazine. As the LCIA study has shown, the releases of the pesticide dominated the normalised LCIA results. Therefore, it is assumed that any changes to transportation will result in very minor environmental impact. Again, as this analysis is hypothetical, results may vary when considering specific brands/types of pesticide. Thus, generalisations should not be made based on the results displayed.

Results

Figure 23 shows the results for the toxicity impact categories utilised in the study for the total pesticide use on-farm stage for when atrazine and simazine are used alternatively. As demonstrated in Table 14, no change was found in the other impact categories. The results have been presented as a ratio relative to 1 (original scenario) to show the difference in the results obtained in each respective category.

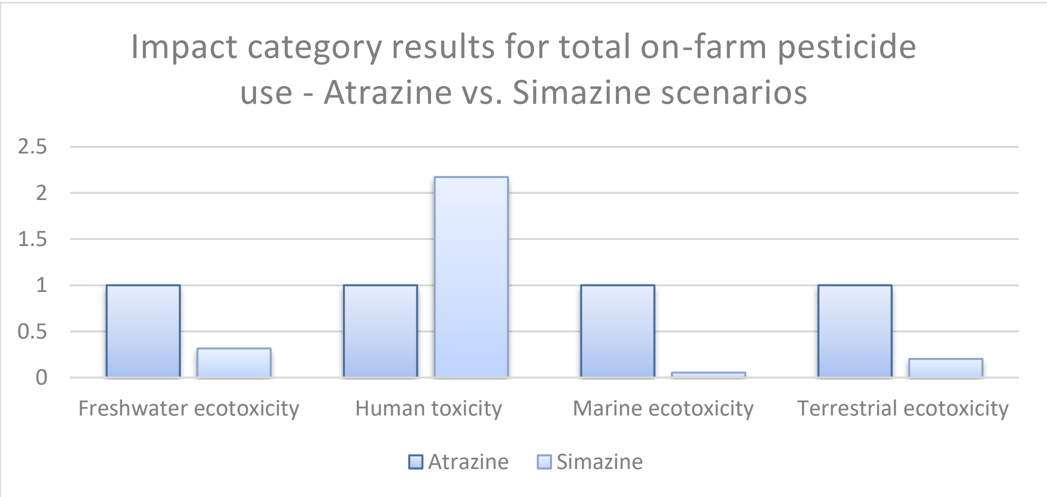


Figure 23 - Impact category results for on-farm simazine use scenario relative to original atrazine scenario

As seen in the Figure 23, while the use of the alternative pesticide resulted in a large decrease in terms of the terrestrial ecotoxicity, the contribution to the human toxicity impact category increased by 54%. The largest decrease in emissions was found in the marine ecotoxicity impact category with the emissions lowering from 5.67 to 0.30 kg D, B –eq.

The total LCA results for the simazine on-farm use scenario was then normalised to determine the relative significance of each impact category. Normalisation was conducted utilising the ReCiPe 1.08 (H) Mid-Point Normalisation (Europe 2000) excluding biogenic carbon normalisation dataset. Figure 24 has been expressed with a logarithmic scale to offer a clear comparison of the results.

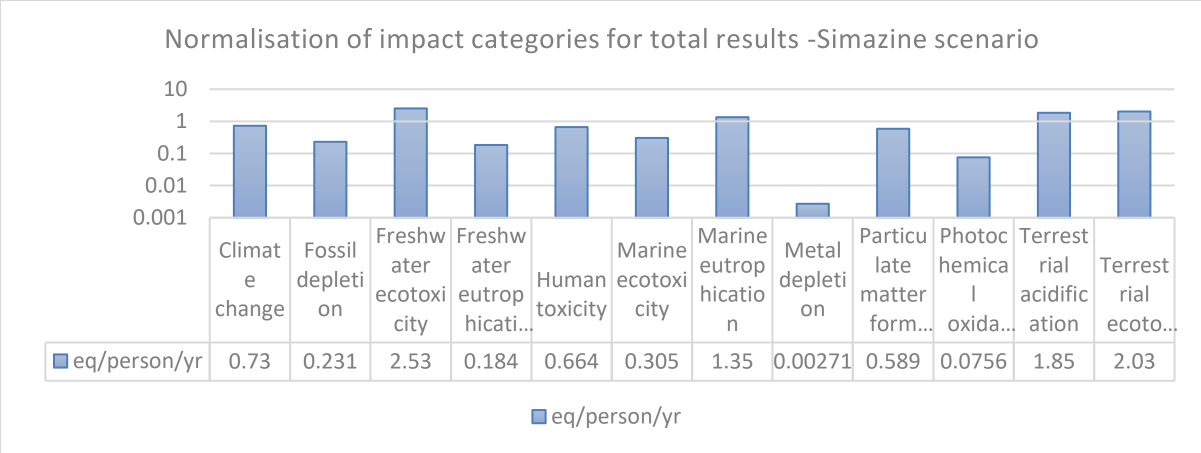


Figure 24 - Normalised results for total LCA – Simazine scenario

Table 15 shows the percentage difference with the total normalised results for the dairy sheep farming system with the original atrazine scenario and the simazine scenario.

Table 15 – Percentage difference in normalised total results for on-farm pesticide use scenarios

	Atrazine	Simazine	Difference
Climate change	0.73	0.73	0%
Fossil depletion	0.231	0.231	0%
Freshwater ecotoxicity	4.83	2.53	-48%
Freshwater eutrophication	0.184	0.184	0%
Human toxicity	0.647	0.664	3%
Marine ecotoxicity	0.937	0.305	-67%
Marine eutrophication	1.35	1.35	0%
Metal depletion	0.00271	0.00271	0%
Particulate matter formation	0.589	0.589	0%
Photochemical oxidant formation	0.0756	0.0756	0%
Terrestrial acidification	1.85	1.85	0%
Terrestrial ecotoxicity	5.08	2.03	-60%

As seen in Table 15, the biggest contributing category was the terrestrial ecotoxicity; however, the alternate use of simazine has resulted in a 60% decrease in this category, however with a 3% increase in the human toxicity category. Terrestrial ecotoxicity still poses the largest relative environmental impact in the LCA study from the cradle- to-milking parlour gate of the dairy sheep case-study farm with the on-farm use of pesticides and the resulting emissions being the key contributing factor.

5.7 Interpretation

In this section, the most significant normalised impact categories identified in Chapter 5.5 will be discussed: freshwater ecotoxicity, marine ecotoxicity, marine eutrophication, terrestrial acidification, climate change. and terrestrial ecotoxicity. While the normalised results for the climate change impact category was not as significant in comparison to the other impact categories listed above, the impact of livestock emissions has been highlighted in other studies (See Chapter 3. Thus it has also been included. Figure 25 shows the normalised results of each impact category as a percentage of each life cycle stages analysed in the study.

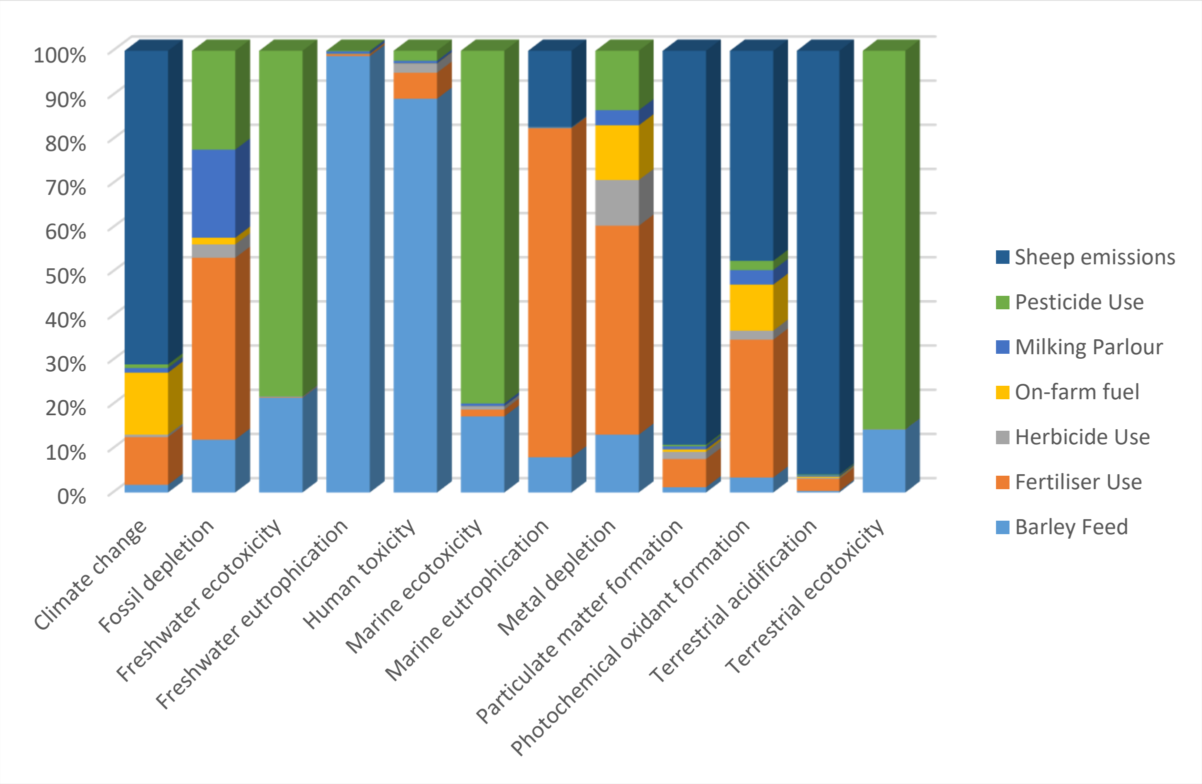


Figure 25 - Normalised results of impact categories for LCA stages

5.7.1 Freshwater Ecotoxicity

The largest contributing stage for the freshwater ecotoxicity impact category was the pesticide use, with majority resulting from the application of atrazine and the associated emissions. The second biggest contributing stage was the P fertiliser used in the production of the imported supplementary grain feed.

5.7.2 Marine Ecotoxicity

The largest contributing stage to the marine ecotoxicity impact category was the pesticide and herbicide use. Similar to the freshwater ecotoxicity impact category, the application of atrazine and the associated emissions was the main activity and in addition to fertiliser use, was also found to be a key contributing activity in the production of imported barley feed.

5.7.3 Marine Eutrophication

The use of N fertiliser on the case-study farm was found to be the largest contributing activity to the marine eutrophication impact category, followed by the N fertiliser used in the imported barley feed. Leaching of N from urine patches resulted in sheep emissions being the second largest stage.

5.7.4 Terrestrial Acidification

The sheep emission stage was the biggest contributing stage to terrestrial acidification with the release of ammonia being the largest contributing substance. The nitrous oxide emissions from fertiliser application served as the second largest contributing activity to the impact category.

5.7.5 Terrestrial Ecotoxicity

The pesticide use on-farm was the biggest contributing stage to the terrestrial ecotoxicity impact category with the application of atrazine being the key activity, followed by the application of simazine. Similarly, the application of both pesticides in the supplementary barley feed production was found to be another critical activity. It is, however, important to take into consideration that percentage of emissions was modelled utilising the same model for both pesticides and that the modelling of the barley feed was done with the assumption that production utilised the same products and quantity of active ingredients as used in the case-study farm.

5.7.6 Climate change

The enteric fermentation of dairy ewes grazing on the case-study farm was the biggest contribution to the climate change impact category. It is important to consider that as the scenario modelled is the first development stage of the case-stud's overall establishment plan, the overall footprint has potential to increase with increased stocking rates and other associated emitters. The second biggest emitter in the study was from the fertiliser and lime use on the farm. Most of the emissions from this stage of the sheep dairy farming were from the manufacture of the lime which is used as fertiliser on-farm

5.7.7 Freshwater Eutrophication

As mentioned in Section 5.5, the normalised result for freshwater eutrophication result was likely to be a 'false' result as the impact category is only focussed on P nutrient losses and did not take into account the potential impact of P emissions arising from high P levels in soil from previous years or the contribution from N nutrient losses. Thus, it can be expected that the normalised result for the impact category would potentially be higher if these other contributions plus the supplementary barley feed production system were taken into consideration.

5.8 Key Findings

5.8.1 Fertiliser Use

The release of heavy metals to air from the manufacturing process of lime and nitrogen was the second largest contributor to the human toxicity impact category. In regard to the application of the fertiliser on-farm, the emissions of nitrogen to freshwater resulted in the largest contribution to the marine eutrophication impact category.

5.8.2 Herbicide Use

While the case-study farm does utilise other herbicide chemicals (as stated in the LCIA), as there were no production processes available for the other active ingredients, glyphosate was used to model the total cumulative amount of active ingredients present in the four types of herbicide products applied. Therefore, consideration must be given to the emissions presented in the results section as the relative impact of the combined herbicide chemicals/ingredients actually utilised on farm has potential to be less than the emissions modelled with glyphosate as the sole chemical ingredient. The LCA found that the application of glyphosate led to herbicide use being the third highest contributing stage to the freshwater eutrophication impact category.

5.8.3 Pesticide Use

The use of pesticides on farm was the biggest contributing stage for both terrestrial and freshwater ecotoxicity which were also found to be the two highest impacting impact categories when the results were normalised. The environmental impact from the use of atrazine was much higher in comparison to the impact from paraquat. The result showing the significance of use of pesticides with respect to toxicity impacts has also been found in other studies in the literature (Chobtang, 2016).

Alternative pesticide use scenario

A sensitivity analysis was conducted on the use of simazine as an alternative to the current atrazine being used, with assumption that the same quantity of active ingredient was applied. This sensitivity analysis was only conducted on the on-farm use and assumes that atrazine is still used for the external barley feed produced. The analysis found that the alternate use of simazine resulted in a 60% decrease in the terrestrial ecotoxicity impact category and resulted in a 3% increase in the human toxicity category. However, terrestrial ecotoxicity still posed the largest relative environmental impact in the LCA study with the pesticide emissions from application being the key contributing factor.

5.8.4 On-farm Fuel Use

The use of diesel and petrol resulted in fuel use being the second highest contributing stage to the terrestrial acidification impact category, with diesel contributing 70.2% to the total impact due to the release of inorganic emissions. However, the overall impact of the on-farm fuel use across the LCA was considerably low, similar to what has been found in literature (Chobtang, 2016; Robertson et al., 2015).

5.8.5 Milking Parlour

The environmental impact from the electricity used on-farm was dwarfed by the impact of the livestock emissions and effluent when considering the contribution in the impact categories which accounted for substances produced by livestock. For example, with the freshwater ecotoxicity and metal depletion impact categories where methane and nitrous oxide were not calculated, the electricity use was the sole contributing element of that stage.

Livestock emissions and effluent

While the livestock emissions and effluent resulted in the milking parlour being the second largest contributing stage to the photochemical oxidant formation impact category, the emissions from the ewes during milking were considerably low in comparison to the overall sheep emissions produced when grazing in the pasture. Overall, the impact of the milking parlour across the LCA study was considerably low.

5.8.6 Sheep Emissions

The emissions from the livestock grazing out in pasture dominated the climate change impact category, largely due to enteric fermentation of the livestock which leads to the production of methane. Where the contributing GHG emissions were not included, the contribution of the sheep emission stage to the impact category was zero. For the particulate matter formation, photochemical oxidant formation and terrestrial acidification impact categories, the sheep emission stage contributed more than 85 % of the total impact result.

5.8.7 Barley Feed

As it was not possible to gather specific data from the external barley supplier for the case-study farm, the production of the barley feed was modelled utilising the fertiliser and energy inputs specified by Chobtang (2016) in Table 10.

The use of phosphate fertiliser for the production of barley feed production resulted in barley feed being the second largest contributing stage to the freshwater ecotoxicity impact category. Similar to the results found for fertiliser use on the case study farm, the use of natural gas in the manufacture process was a key contributing factor in several impact categories. In terms of freshwater eutrophication, the application of phosphorus led to this stage dominating the impact category with half of the impact resulting from the manufacture of the fertiliser and remainder from the emissions of the release of phosphorus to freshwater. The emissions from phosphorus also resulted in the barley feed being the sole largest contributing stage with more than 95% of the total emissions in the human toxicity impact category.

While pesticide use on-farm was found to be the biggest contributor to both terrestrial and freshwater ecotoxicity for the case-study, for the barley feed stage the releases of phosphorus to freshwater resulted in pesticide use being the second biggest contributing substance to the freshwater ecotoxicity impact category. However, in the terrestrial ecotoxicity impact category, the use of pesticides in barley production was a hotspot area with 92% of the total emissions from that stage resulting from the release of atrazine to agricultural soil. The overall impact from the use of glyphosate in the barley production was considerably lower than the impacts from the other agrichemicals utilised. The overall impact from the use of diesel and electricity in the barley production was the lowest in comparison to the other inputs associated with the production.

5.8.8 Consideration of Limitations

The following section states the potential limitations of the study that must be considered when interpreting the results presented from the LCA study.

The usage of pesticides on-farm was the biggest hotspot area with the emissions of atrazine releases to air, soil and freshwater resulting in terrestrial and freshwater ecotoxicity being the highest and second highest impact categories respectively following normalisation. Due to a lack of specific data for the emissions of pesticides on-farm, the proportion of pesticide emissions were calculated using models obtained from literature (Chobtang, 2016, thus consideration must be given to the relative impact of pesticides.

Glyphosate was used to model the total cumulative amount of active ingredients present in the four types of herbicide products applied - therefore, consideration must be given to the emissions presented in the results section as the relative impact of the combined actual herbicide chemicals/ingredients that may be used on farm has potential to be less than the emissions modelled with glyphosate as the sole chemical ingredient.

The variance in the results between the two modelled feed scenarios is largely due to the different yield quantities per hectare for both maize and barley production. As both the production inputs and requirements were obtained from literature (Chobtang, 2016), it is recommended that a further study is conducted on the current local supplier/producer of barley grain and other maize grain producers within the vicinity of the farm.

As the case-study farm is currently in the process of establishing livestock numbers, it is recommended that a revision of the farm inputs is undertaken once an equilibrium has been reached on-farm and the target livestock numbers have been reached.

Chapter 6: Development of Prototype Farm Environmental Certification Scheme

This chapter discusses the development of the prototype farm environmental certification scheme, informed by the results of the LCA study presented in Chapter 5. Section 6.1 discusses the process utilised to group the environmental indicators into category themes and topics. In Section 6.2, the relationship of the environmental indicator themes identified are then discussed in relation to the LCA results presented in Chapter 5.

6.1 Consolidated indicators for prototype scheme

The indicators selected for the prototype certification scheme were compiled from subsets of the four agricultural certification schemes discussed in Chapter 4:

- Sustainably Grown Certified
- LEAF
- Origin Green
- Unilever Sustainable Agriculture Code.

A primary review of the compulsory indicators in the certification schemes listed above was undertaken to determine the relevance of the indicators presented to the farming system of the sheep dairy case-study assessed in this research. Table 16 presents the indicators which have been included and those that have been excluded. As the certification scheme is focussed on environmental performance of the sheep dairy farming system, social and economic indicators have been excluded from the analysis. As the certification schemes are international, some environmental indicators present in the schemes were targeted towards indoor rearing systems, animal health and farming systems present in developing countries. These indicators have been excluded and are listed in Table 16. Similarly, indicators focussed on land use conversion and conservation management have been excluded as these factors are covered by the Resource Management Act No. 69 (1991), which is the key governing document for resource use in New Zealand. As the prototype certification scheme is intended for use in New Zealand sheep dairy systems, the framework has been designed to not derogate from the Resource Management Act (1991) and it is expected that farm operations are already operating in compliance with the Act.

Table 16 – Primary review of indicators from certification schemes

	Sustainably Grown	Origin Green	LEAF Marque	Unilever
Excluded sets of indicators				
Environmental	4.1.1 Crop diversity and quality 4.1.3 GMOs 4.7.4 Packaging	3.7 Dairy management[17] 3.10 Animal housing 3.19 General hygiene	3.0 Crop health and protection 8.0 Landscape Management[18]	5.0 Biodiversity[19]
Social	5.0 Social criteria	3.2 -3.4 Producer records and competence 3.8 Animal health 3.11 Transport regulations 3.13 Farm personnel	9.0 Community engagement	8.0 Social and human capital 9.0 Animal health 11.0 Training
Economic	6.0 Economic criteria	3.5 Identification and traceability 3.18 Milking equipment	Not applicable	10.0 Value chain and local economy

[17] Dairy management was excluded as the KPIs were focussed on animal husbandry.
[18] Landscape management was excluded as the indicators were focussed on land use conversion and management features which are already covered by the Resource Management Act (1991)
[19] Biodiversity was excluded as the KPIs were focussed on conversion/expansion of farmland and land use conversion which is covered by the RMA (1991)

	Sustainably Grown	Origin Green	LEAF Marque	Unilever
Included sets of indicators				
Environmental	4.1.2 Pest control 4.2 soil resources 4.3 Water resources 4.4 Air resources and climate 4.6 Energy efficiency 4.7 Integrated waste management	3.6 Land management 3.9 Biosecurity and pest control 3.12 Environment 3.14-3.17 Dairy-general 3.20 Chemicals	2.0 Soil management and fertility 4.0 Pollution control and waste management 5.0 Animal husbandry 6.0 Energy efficiency 7.0 Water management	1.0 Crop and pasture nutrient management 2.0 Pest, disease and weed management 3.0 Soil management 4.0 Water management 6.0 Energy and GHG emissions 7.0 Waste management

The environmental sustainability indicator framework of Lebacq et al. (2012) introduced in Chapter 4 was used to classify the indicators. It was modified, however, to include the additional themes of freshwater management and greenhouse gas emissions, as was recommended by De Olde et al. (2016). These themes were also supported by the LCA results presented in Chapter 5. Thus, the prototype included indicators classified under the following themes:

- Land management
- Nutrients
- Pesticides[20]
- Energy and carbon management
- Freshwater Management.

The following tables present the consolidated indicator topics for each theme. These indicators were selected on the basis of their perceived relevance and suitability to the New Zealand sheep dairy industry, and the results derived from Chapter 5. In each table, the relevant sub-indicators from each main indicator presented in Table 16 from each of the four agricultural certification schemes are shown in the right column (actual indicator numbers are shown in brackets).

Table 17- Land Management Indicators

Topic	Description	Indicators
Effluent	Appropriate facilities must be used for the collection and storage of all manure and effluent sources to prevent pollution.	Origin Green (3.6a) Unilever (3.1 F34; 7.1 F66)
Soil Map	A soil map must be prepared stating the different soil types present and the identification of areas prone to compaction, erosion, runoff and leaching.	Origin Green (3.6 S10) Unilever (3.1 F36) LEAF (2.1; 2.7)
Cropping and Grazing	Where the area of agricultural land acquired or used is expanded for any period, crop suitability and environmental implications must be assessed. Where possible, the grazing of livestock on poor draining soils should be avoided.	Unilever (3.1 F35) LEAF (5.1)
Soil Organic Matter	Strategies must be implemented to meet set goals for maintaining soil organic matter	Sustainably Grown (4.2.3.1; 4.3.2.2) Unilever (3.1 F30) LEAF (2.2)

[20] While this study has separated pesticides and herbicides, the pesticide theme by Lebacq et al. (2012) covers herbicides as well.

Table 18-Nutrient Management Indicators

Topic	Description	Indicators
Soil Nutrient Level	Soil fertility and crop nutrient status must be measured, with soil and plant testing conducted regularly to ensure that nutrient requirements are met. Application equipment must be re-calibrated annually in accordance with the manufacturers' guidelines.	Sustainably Grown (4.2.5.1)
Fertiliser Use	All applications must be recorded. Records should include the following: timing of application (e.g. avoid rainy periods on steep terrain); 2) choice of N-fertiliser type; 3) soil conditions (e.g. ensure soil moisture allows good infiltration, avoid water-logged or compacted soils); 4) application technique (e.g. split applications, incorporate or inject organic slurry and urea-based fertilisers).	Sustainably Grown (4.2.5.2; 4.2.5.3) Origin Green (3.6 S12) Unilever (1.1 F3, F4; 1.2 F10) LEAF (2.9; 2.10; 4.4)
Soil Quality Degradation (non-erosion)	Steps must be taken to minimise soil quality degradation resulting from accumulation of agrichemicals. Soil tests must be conducted to determine concentrations of toxic substances.	Sustainably Grown (4.2.4.1)
N and P Losses	Nutrient budgeting must be undertaken annually to determine nitrogen use efficiency, with mitigation measures documented.	Unilever (1.1 F1, F5, F6)

Table 19-Pest Management Indicators

Topic	Description	Indicators
Pest Control	All pesticides must be applied in accordance with government regulations and manufacturer guidelines.	Sustainably Grown (4.1.2.1)
Storage	An up-to-date inventory of the agrichemicals stored is to be kept with the inclusion of details of the agrichemical suppliers/vendors used by the farm	Unilever (2.2 F20; 7.1 F70)
Equipment Maintenance	Application equipment must be re-calibrated annually in accordance with the manufacturers' guidelines.	Sustainably Grown (4.1.2.4) Unilever (2.2 F24)
Pesticide Drift	A risk assessment must be conducted to assess the risk of pesticide drift, with measures undertake to minimize the drift.	Unilever (2.1 F12)

Table 20-Energy and Carbon Management Indicators

Topic	Description	Indicators
Energy Management	An energy use assessment must be conducted with an energy management plan produced to reduce farm energy consumption.	Unilever (6.1 F62)
Compliance	Farms must demonstrate compliance with government regulations regarding energy use and related emissions, greenhouse gas releases, fuels and fuel burning installations where relevant for the farming operation.	Unilever (6.3 F65)
Renewable Energy	Opportunities for the inclusion of renewable energy generation in grid and/or remote area power (RAP) systems must be explored, where relevant.	Unilever (6.1 F63)
Carbon Footprint	The total carbon footprint should be re-calculated with any major changes in livestock reared	Sustainably Grown (4.4.3.1) Unilever (6.1 S10)

Table 21-Water Management Indicators

Topic	Description	Indicators
Freshwater Quality	All potential wastewater sources and contaminant points must be identified. Agricultural and related operational wastewater streams must be treated appropriately. Disposal of agrochemicals and washings, veterinary medicine products, agrochemical containers, plastic waste, and untreated wastewater is prohibited.	Sustainably Grown (4.3.1.1; 4.3.1.2) Unilever (4.1 F42, F43, F44; 7.1 F71) LEAF (4.5)
Irrigation	Irrigation rates/intervals decision-making must be based on relevant crop and soil factors. With drought-prone climates, strategies must be implemented for efficient water usage. Equipment must be maintained in good working order.	Sustainably Grown (4.3.2.2) Unilever (4.2 F51, F53) LEAF (7.3)
Water Use	Water use must be recorded with all bores regularly monitored and a water management plan in place.	Sustainably Grown (4.3.2.4) Unilever (4.1 F38, F40) LEAF (7.1;7.2)
Compliance	Farms must comply with council regulations for abstraction, use and discharge of irrigation water; and the protection of water bodies, groundwater and aquatic ecosystems from pollution.	Unilever (4.1 F40)

6.2 LCA Results and Indicator Development

Following the grouping of indicators using the amended themes proposed by Lebacq et al. (2012), this section discusses the findings from the LCA case-study in relation to each indicator theme.

Land Management Indicators

The results for the terrestrial ecotoxicity and acidification impact categories following normalisation highlighted the importance of proper management of land and soil resources. The key contributing activities was the application of agrichemicals for pasture/feed production, and the associated emissions. Therefore, the soil map topic was identified as having key relevance to the LCA results.

Nutrient Indicators

The freshwater and terrestrial ecotoxicity impact categories had the highest results following normalisation, and the activities making the biggest contribution to these impacts were the type of fertiliser used and the method/rates of application. The N and P losses and fertiliser use topics were identified as holding greatest relevance to the LCIA results.

Pesticide Indicators

The terrestrial and freshwater ecotoxicity impact categories were related to the pesticide indicator theme. Pesticide application and the resulting emissions was found to contribute the most to the LCIA results. Through the sensitivity analysis, the type of pesticide used was found to have the greatest potential in reducing overall environmental impact. However, as the scenario modelled utilised a hypothetical pesticide manufacture application, further research is required to determine the impact of other pesticides. This, in addition to the variety of pesticides used throughout the New Zealand agriculture sector, makes it difficult to recommend the use of a specific pesticide. The pesticide drift topic was identified as holding the greatest relevance to the LCIA results.

Energy Indicators

The climate change impact category was most related to the energy indicator theme. The greenhouse gas emissions from livestock reared contributed the most to the LCA impact category. As demonstrated by the sensitivity analysis in Appendix B, any changes to stocking rate and type of livestock reared can greatly impact the overall carbon footprint of the farming unit. While the climate change category was not identified as a significant result in the LCIA, the carbon footprint topic was found to hold greatest relevance to the farming system.

Water Indicators

While the LCA study did not include the water depletion impact category due to the lack of data around direct water use on-farm and subsequent water quantity, the impact of on-farm and off-farm activities on water bodies is evident with the freshwater ecotoxicity being the second highest impact category, following normalisation. Thus, the freshwater quality topic was identified as holding greatest relevance to the LCIA results.

Summary

The following section states the relationship between the hotspot areas identified in the LCA study and the prioritised indicators. These have been classified according to the relevant indicator themes in Table 22.

Table 22 - Link between LCA result and indicator themes

Prioritised Focus (Based on LCA Results)	Hotspot Area	Indicator Theme
Terrestrial Ecotoxicity + **Acidification**	Agrichemical application and pasture/feed production	Land Management/Pesticide
	Fertiliser application	Nutrient
Marine + **Freshwater Eutrophication**	Pesticide use	Pesticide
Freshwater Ecotoxicity + **Marine Ecotoxicity** + **Acidification**	Agrichemical applications	Water
Climate Change	Emissions from livestock	Energy and Climate

Chapter 7: Discussion and Conclusions

Chapter 5 and 6 demonstrated the way LCA can be used to identify environmental hotspot areas and lead to the development of sustainability indicators for an environmental certification system. In this chapter, the LCA results are interpreted at the level of the New Zealand sheep dairy sector. The discussion addresses the following research objectives:

The two key objectives of the research were to: (1) determine the environmental hotspots of New Zealand sheep dairy farming and what mitigation strategies can be developed, and (2) develop key performance indicators (KPIs) for an LCA-based farm certification system for sheep dairy in New Zealand. The research results related to these objectives are discussed in Sections 7.1 and 7.2. Section 7.3 introduces the sample eco-labelling for the proposed certification scheme.

7.1 Environmental Hotspots – On-Farm Versus Off-Farm

While the study identified enteric fermentation as a major contributor to the overall climate change impact category, an indicator which is often solely focussed on in literature (Ledgard et al., 2011; Peters et al., 2010; Ibidhi et al., 2017), undertaking the LCA studymprovided a more comprehensive insight into the sustainability of the production system. This enabled identification of activities which contributed more, in terms of environmental degradation.

In the cradle-to-farmgate system boundary used for 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 normalised impact category results. Thus, this was 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 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. In the analysis, the modelling of production of barley grain feed using New Zealand production inputs from Chobtang (2016) gave relatively high results for the environmental impacts of this grain utilised on-farm. Notably, the manufacture and application of fertiliser used in barley grain cultivation was a key contributor to the human toxicity impact category. However, it is important to note that, while the data utilised in the modelling of this activity was obtained from New Zealand farming averages, the actual manufacturing requirements can vary drastically from each farm. Therefore, this highlights the importance of supplementary feed suppliers also meeting environmental certification criteria for their farm operations. This also demonstrates the potential role of such certification systems in encouraging the development of a network of sustainable, low-impact producers – a side effect of implementation of the framework and market competition at the producer level.

As part of the LCA sensitivity analyses, alternative farm scenarios were modelled: (i) alternative maize supplement feed, (ii) alternative pesticide use and lastly (iii) the on-farm rearing of replacement lambs (see Appendix B).

In the alternative supplement feed analysis, maize was modelled as an alternative to the barley grain used on farm. Maize grain was selected on the basis that it has very similar nutritional value to barley grain. All product assumptions made in modelling the barley grain production were kept constant, including the assumption that the supplementary feed was obtained from a neighbouring producer near the case-study farm thus, the transport from producer to farm was not modelled. However, transport may be a potential environmental hotspot and therefore it is recommended that transport of supplement feed to farm is included in LCAs studies of other sheep dairy producers who purchase externally grown feed.

In the alternative pesticide sensitivity analysis, simazine was modelled as an alternative to the atrazine used on farm. Simazine was selected as it is also recommended to be used with paraquat; like atrazine, it is suitable for use on lucerne crops and has a similar production process. Thus, all other manufacturing and transport variables were kept constant as it was assumed that any variations would be negligible in determining the overall impact of the simazine use. Similar to atrazine, the largest impact arose from the application and subsequent releases of simazine to water and soil. While it is important to note that being a hypothetical scenario, the production and application of the specific chemical brands utilised can result in varying impact, the results of the analysis showcased an average decrease of 54% in each of the two biggest impact categories (freshwater and terrestrial ecotoxicity) and a 3% increase in human toxicity. Therefore, this highlights just how greatly pesticide selection can affect the overall environmental performance of the farm. To further develop the certification system and provide KPIs relating to specific recommendations on pesticide use, more research needs to be undertaken around the products commonly used in sheep dairy farming systems – so as to better understand and evaluate the environmental impacts.

In Appendix B, the impact of the on-farm rearing of replacement lambs on the carbon footprint of the case-study farm was assessed. As the LCA study was focussed on the environmental impact of the case study farm, the decision was made to model only the maximum stocking rate of dairy ewes/ha, with the assumption that all replacements and studs were grazed off-farm. Therefore, a sensitivity analysis was conducted based on alternative stocking where 200 replacement lambs aged 4 months were added to the existing livestock scenario. To accommodate the DM requirements, the number of ewes was decreased in the analysis.

This sensitivity analysis only considered the methane emitted from replacements and no other emissions, thus there is potential for the normalised total results to differ when such additional contributions are included into an analysis. The inclusion of the methane produced by replacements on-farm only affected the photochemical oxidant formation and climate change impact categories. The biggest change was found in the climate change impact category with the incorporation of replacements on-farm resulting in an increase of 20% in emissions per hectare. The inclusion of the replacements did not greatly change the overall order of environmental impact as terrestrial ecotoxicity still posed the largest relative environmental impact; however, this situation might change if more comprehensive modelling of the scenario was undertaken (i.e. including more emissions in the analysis).

As data were only provided for the DMI of a lamb aged 4 months, these data were used to model the total annual feed consumption of a lamb reared on-farm as a replacement. This assumed that the DMI is constant from the age of 4 months to 12 months however, increases in the weight correlates with increased DMI. As the focus of this analysis was on the enteric fermentation, the lack of data around the relative differences in DMI of lambs at different ages was not viewed as a large limitation as the calculations were based on the total available DM. The carbon footprint of one litre milk for the case-study system modelled (with only dairy ewes on-farm) with a stocking rate of 12 SU/ha was found to be 3 kg CO_2- eq/litre. Where replacements were included, the carbon footprint was found to be 3.7 kg CO_2- eq/litre (see Appendix B).

As the case-study farm utilised a hypothetical scenario, generalisations cannot be made from the results of this analysis and further information and data collection on established sheep dairy units and DMI of replacement livestock are required to determine the validity of the results in this study.

7.2 Prototype KPIs for environmental LCA Farm Certification

7.2.1 Framework design

The key performance indicators (KPIs) for the prototype sheep dairy farm environmental certification system were developed using the Lebacq et al. (2012) input management framework for environmental sustainability outlined in Chapter 4. As discussed in Chapter 4, the qualitative nature of these indicators (e.g. pesticide use practices*)*, in contrast to the quantitative nature of effect-based indicators which focus on impacts (e.g. measurement of pesticide concentration in rivers) (Lebacq et al., 2012), increases the scope and potential applicability of the proposed certification scheme to a variety of farming operations with different characteristics. Utilising qualitative indicators also provide an easier method of measuring and determining sustainability.

Based on the LCA results in Chapter 5, and the analysis of their relationship to indicators in existing schemes, a limited number of means-based indicators were selected to form Tier 1 KPIs in the proposed certification system. These are shown in Table 23. Potentially other indicators could be selected to form a secondary tier in future development of the scheme. It is also important to note that normalised results were used, as opposed to weighted results. Therefore, these results could be weighted in a different manner by different stakeholders; indeed, the inclusion of the freshwater eutrophication and climate change impact categories despite their lower normalised results was, in effect, due to weighting them more importantly than the other impact categories.

Table 23 - Tier 1 Prototype KPIs

Prioritised Focus (Based on LCA Results)	Hotspot Area	Classification	Indicator Topic	Proposed Indicator(s)
Terrestrial Ecotoxicity + Acidification + Marine Eutrophication + Freshwater Eutrophication	Agrichemical application and pasture/feed production	Land Management	Soil Map	A soil map must be prepared stating the different soil types present and the identification of areas prone to compaction, erosion, runoff and leaching.
	Fertiliser application	Nutrient	Nutrient Budget	Nutrient budgeting must be undertaken annually to determine nitrogen use efficiency, with mitigation measures documented.
	Pesticide use	Pesticide	Pesticide Drift Assessment	A risk assessment must be conducted to assess the risk of pesticide drift, with measures undertake to minimize the drift.
Freshwater Ecotoxicity + Marine Ecotoxicity + Acidification	Agrichemical applications	Water	Freshwater Management Plan	All potential wastewater sources and contaminant points must be identified on farm map and be treated appropriately prior to discharge.
Climate Change	Emissions from livestock grazing	Energy and Climate	Carbon Footprint Management Plan	Impact on the overall carbon footprint should be considered before increasing stocking rate/any major changes in livestock type reared

7.2.2. Framework design

The prototype scheme is intended to be implemented in conjunction to the consenting and regulatory requirements of the respective regional council requirements. Sample marketing showcasing the structure of a prototype certification scheme can be found in Appendix C.

Soil Map: By preparing a soil map, the farm will identify sensitive soil areas. In large farming enterprises with multiple units, paddocks can be acquired by a different farming unit for a period of time before being transferred back into the management of the original unit. In this instance, data of livestock grazing/cropping must be recorded to assist in the allocation of environmental impact when determining the sustainability of a product of a particular unit (e.g. beef and lamb meat production versus. sheep dairy production).

Nutrient Budget: The framework requires that a nutrient budget be conducted on the current farm system in operation. Through efficient nutrient budgeting, the overloading of nutrients, and potential runoff and leaching can be avoided.

Freshwater Management Plan: As part of the framework, it is also recommended that farms identify all potential wastewater streams and ensure that wastewater treated in compliance with local regulations is discharged. Irrigation rates/intervals also need to be recorded, with regular maintenance and calibration of equipment. In addition to this, all water abstraction must be monitored, with the farm's water consumption recorded.

Pesticide Drift Risk Assessment: The framework requires that a pesticide drift risk assessment is conducted to assess the potential effect of emissions resulting from pesticide application, with the farm demonstrating measures that have been taken to mitigate any potential effect.

Carbon Footprint Management Plan: The final part of the KPI framework is focussed on the greenhouse gas emissions produced from livestock on-farm. As part of the scheme, the impact on the overall carbon footprint should be considered before increasing stocking rate/any major changes in livestock type reared.

7.3 Sample Eco-labelling

The following section presents the sample labelling for the prototype (see Figure 26). As discussed in Chapter 4, certification schemes incorporate marketing material for producers to utilise to demonstrate that the products have met the production requirements stated in the criteria of the scheme. As discussed in Chapter 2, a key driver of potential consumers of sheep dairy products is the desire for sustainable products. Labelling allows consumers to ensure that selected products are in alignment with their values. Administration of the label will be at the discretion of the auditors/evaluators of the certification scheme which is intended to be industry-led. A sample brochure can be found in Appendix B.

Figure 26 - Prototype eco-labelling

7.4 Conclusion – Areas for Further Research

By identification of the environmental hotspots and through the scenario modelling conducted, this thesis demonstrates how a LCA study can be used as a tool to facilitate continuous improvement of on-farm environmental performance. 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. Thus, the study also highlights the method in which the proposed scheme can support the regular validation of environmental claims by the New Zealand sheep dairy industry, and as such potentially offer a means of distinguishing the benefits of sheep dairy over other types of dairy.

The carbon footprint calculated in the climate change impact category indicates, as a piece of evidence, that the environmental performance of sheep dairy production can be on a par with goat dairy production on a per hectare basis. In comparison to bovine dairy, the results from the case-study indicate a similar carbon footprint to that of a low-intensity bovine dairy system on a per hectare basis (Ledgard et al., 2016; Robertson et al., 2015). When considering the carbon footprint on a per litre of milk/ kg of FPCM basis, the results of the case-study indicated that environmental performance is not equivalent (see Table 2), with the results for bovine dairy ranging from 0.73 to 0.86 kg CO_2-eq/kg FPCM (Chobtang et al., 2017) and the results for the case-study resulting at 3.0 kg CO_2-eq/litre.

However, it is important to acknowledge the large variation in data and farm management present in the different types of livestock dairy systems analysed in the literature. In addition, consideration must be given to the milk compositions that can be typically expected in the types of dairy systems mentioned above, trends in price of different milk solids, and the types of products. While dairy ewes produce less milk in comparison to their bovine counterparts, the higher milk pay-out and the production of value-added products provides sheep dairy farmers with the potential for higher earnings from lower production inputs/outputs.

Key considerations for the future development of the prototype include the role played by consumer perception and farmer uptake. In summary, areas for further research include:

- Conduct LCA studies on other established sheep dairy farms in New Zealand to determine the relevance of the KPIs developed.
- Determine the impact of replacement lambs reared on-farm on other impact categories, in addition to the enteric fermentation.
- Investigate the impact of different feed types on New Zealand dairy ewes and faecal and enteric emissions.

- Gather further information on the manufacturing processes, emission profiles and environmental impacts of commonly used pesticides in sheep dairy farms.
- Include data on transport of externally grown feed in future LCAs conducted on sheep dairy units to determine the impact of transportation.

In conclusion, the production of New Zealand-specific LCA results for the sheep dairy case-study farm and the KPIs showcase the potential for certification schemes in providing producers with an insight into the environmental performance of sheep dairy farms. Thereby, this provides a basis for the emerging sheep dairy industry to define and communicate the sustainability of their farming practices and facilitate continuous improvement of the sector.

Appendix A

Table A1 – Description of ReCiPe impact categories (Reproduced from Goedkoop et al., 2009)

Impact category Name	abbr.	Indicator name	unit*
climate change	CC	infra-red radiative forcing	W×yr/m^2
ozone depletion	OD	stratospheric ozone concentration	ppt†×yr
terrestrial acidification	TA	base saturation	yr×m^2
freshwater eutrophication	FE	phosphorus concentration	yr×kg/m^3
marine eutrophication	ME	nitrogen concentration	yr×kg/m^3
human toxicity	HT	hazard-weighted dose	–
photochemical oxidant formation	POF	Photochemical ozone concentration	kg
particulate matter formation	PMF	PM_{10} intake	kg
terrestrial ecotoxicity	TET	hazard-weighted concentration	m^2×yr
freshwater ecotoxicity	FET	hazard-weighted concentration	m^2×yr
marine ecotoxicity	MET	hazard-weighted concentration	m^2×yr
ionising radiation	IR	absorbed dose	man×Sv
agricultural land occupation	ALO	occupation	m^2×yr
urban land occupation	ULO	occupation	m^2×yr
natural land transformation	NLT	transformation	m^2
water depletion	WD	amount of water	m^3
mineral resource depletion	MRD	grade decrease	kg^{-1}
fossil resource depletion	FD	upper heating value	MJ

** The unit of the indicator here is the unit of the physical or chemical phenomenon modelled. In ReCiPe 2008, these results are expressed relative to a reference intervention in a concrete LCA study.*
† The unit ppt refers to units of equivalent chlorine.

Impact category Abbreviation	Unit*	Characterisation factor Name	Abbreviation
CC	kg (CO_2 to air)	global warming potential	GWP
OD	kg (CFC-11[5] to air)	ozone depletion potential	ODP
TA	kg (SO_2 to air)	terrestrial acidification potential	TAP
FE	kg (P to freshwater)	freshwater eutrophication potential	FEP
ME	kg (N to freshwater)	marine eutrophication potential	MEP
HT	kg (14DCB to urban air)	human toxicity potential	HTP
POF	kg (NMVOC[6] to air)	photochemical oxidant formation potential	POFP
PMF	kg (PM_{10} to air)	particulate matter formation potential	PMFP
TET	kg (14DCB to industrial soil)	terrestrial ecotoxicity potential	TETP
FET	kg (14DCB to freshwater)	freshwater ecotoxicity potential	FETP
MET	kg (14-DCB[7] to marine water)	marine ecotoxicity potential	METP
IR	kg (U^{235} to air)	ionising radiation potential	IRP
ALO	m^2×yr (agricultural land)	agricultural land occupation potential	ALOP
ULO	m^2×yr (urban land)	urban land occupation potential	ULOP
NLT	m^2 (natural land)	natural land transformation potential	NLTP
WD	m^3 (water)	water depletion potential	WDP
MRD	kg (Fe)	mineral depletion potential	MDP
FD	kg (oil†)	fossil depletion potential	FDP

** The unit of the impact category here is the unit of the indicator result, thus expressed relative to a reference intervention in a concrete LCA study.*
† The precise reference extraction is "oil, crude, feedstock, 42 MJ per kg, in ground".

Table A2 – Emissions factors and models used to quantify specific emissions in sheep dairy farming systems

Type	Emission Factor/model	Unit	Sources
Methane			
Enteric Fermentation	0.0209kg CH4/kg DMI (Adult) 0.0168 kg CH4kg DMI (lamb)	kg CH_4	MPI (2013)
Faecal Emissions	6.9×10−4 kg CH4/kg faecal DM	kg CH_4	MPI (2013)
Farm Dairy Effluent	0.06397826 x effluent FDM	Kg CH_4	MPI (2013)
Nitrous Oxide			
Urine N deposited onto pastures	Urinary N—0.01 kg N2O-N/kg N in urine	kg N_2O-N/kg N	MPI (2013)
Faecal N deposited onto pastures	Faecal N—0.0025 kg N2O-N/kg N in faeces	kg N_2O-N/kg N	MPI (2013)
N fertiliser	0.01 x Fert N	kg N_2O-N/kg Fert N	MPI (2013)
FDE application	0.01 x kg N applied	kg N_2O-N/kg N	MPI (2013)
Leached Nitrogen	0.0075 X Leached N	kg N_2O-N/kg N NO_3-N	MPI (2013)
Indirect N_2O from ammonia losses/ Deposition of volatized NH^3	0.01 kg N2O-N/kg NH3-N volatised	kg N_2O-N/kg N NH^3-N	IPCC (2006)
Nitrogen Oxides			
N_{Ox} emissions	0.21 x N_2O	kg N_{Ox}	Nemecek and Kägi (2007)
Ammonia			
Animal excreta	0.1 x total on-pasture N excreted	kg NH^3-N/kg N	MPI (2013)
Stored Manure	0.12 kg NH^3-N/kg N in stored manure	kg NH^3-N/kg N	IPCC (2016)
Farm dairy effluent	0.1 x total effluent N	kg NH^3-N/kg N	MPI (2013)
N Fert	0.01 x Fert N	kg NH^3-N/kg N	MPI 2013
Nitrate			
Leached Nitrogen	Overseer	kg NO^3-N/ha/yr	Wheeler et al. (2003)
Lime application	0.412	kg CO_2/kg lime	IPCC (2006)
Combustion of fossil diesel	3.12	kg CO_2/kg diesel	Nemecek and Kägi (2007)
Combustion of petrol	3	kg CO_2/kg petrol	Nemecek and Kägi (2007)
Phosphorus			
P losses	Overseer	Kg P/ha/yr	Wheeler et al. (2003)

Table A3- Overseer dairy goat model emission factors comparison

Overseer Emission Models		
Methane	***Emission Factors***	Unit
Type	Enteric Methane	
Sheep	20.9	g CH_4/kg DMI
Goat	20.9	g CH_4/kg DMI
Type	Dung methane	
Sheep	0.69	g CH_4/kg Dung
Goat	0.69	g CH_4/kg Dung
Nitrous Oxide	***Emission Factors***	Unit
Type	Direct Emissions	
Excreta Urine	0.01	kg N_2O-N/kg N
Excreta Dung	0.0025	kg N_2O-N/kg N
N fert	0.01	kg N_2O-N/kg fert N
FDE application	0.01	kg NH^3-N/kg N
Type	Indirect Emissions	
Excreta Volatisation	0.01	kg N_2O-N/kg N NH^3-N
Excreta Leaching	0.025	kg NH^3-N/kg N
Fert Volatisation	0.01	kg NH^3-N/kg N
Fert leaching	0.025	kg NH^3-N/kg N

Table A4 – Factors used to estimate pesticide active ingredients (a.i) released to air, water and soil. (as obtained from Chobtang, 2016)

Emissions		**Barley**		**Maize**		**References**
Paraquat		Quantity of active ingredient (a.i) used				
	Releases	**kg/ha/yr**	**L/ha/yr**	**Kg/ha/yr**	**L/ha/yr**	
To air	15%	0.12375	0.12375	0.218813	0.22	Webb et al. (2013
To water	5%	0.04125	0.04125	0.072938	0.07	Kellogg et al. (2002)
To soil	80%	0.66	0.66	1.167	1.17	Audsley et al. (2003)
Atrazine						
	Releases	**kg**	**L/ha/yr**	**kg**	**L/ha/yr**	
To air	15%	0.20625	0.20625	0.364688	0.36	Webb et al. (2013
To water	5%	0.06875	0.06875	0.121563	0.12	Kellogg et al. (2002)
To soil	80%	1.1	1.1	1.945	1.95	Audsley et al. (2003)

Table A5 – Inputs required for Maize grain production (obtained from Chobtang, 2016)

Inputs	Quantity /ha	Unit
N	98	kg
P	15	kg
Lime	500	kg
Glyphosate	2.7	kg a. i
Pesticide	2.2	kg a. i
Diesel	72	kg
Electricity	3.91	kWh
Yield	5874	kg

Table A6 – Energy requirements for production of pesticides in MJ/kg active ingredient (a.i) stated by Green (1987) (reproduced from Audsley et al., 2009)

			Total inherent energy†			Total process energy*			Total
Active ingredient		**Chemical family**[1]	**Naphtha**	**Gas**	**Coke**	**Fuel oil**	**Electricity**	**Steam**	**Energy**
MCPA	H	Phenoxy	53.3	12.0	0.0	12.6	27.5	22.3	127.7
2,4-D	H	Phenoxy	39.0	0.0	0.0	9.0	23.0	16.0	87.0
2,4,5-T	H	Phenoxy	43.0	23.0	0.0	2.0	42.0	25.0	135.0
Dicamba	H	Benzoic	69.0	73.0	0.0	4.0	96.0	53.0	295.0
Chloramben	H	Benzoic	92.0	29.0	0.0	5.0	44.0	0.0	170.0
Fluazifop-butyl	H	phenoxy, trifluoromethyl, pyridine	89.2	71.6	0.0	8.6	183.4	165.2	518.0
Propanil	H	Acetamide	62.0	40.0	0.0	3.0	64.0	51.0	220.0
Alachlor	H	Acetamide	98.6	27.8	0.0	12.1	86.4	52.6	277.5
Propachlor	H	Acetamide	107.0	29.0	0.0	14.0	84.0	56.0	290.0
Chlorsulfuron	H	urea, triazine	91.3	35.6	0.0	7.8	112.2	118.5	365.4
Butylate	H	Thiocarbamate	42.1	33.2	11.6	6.8	31.0	16.1	140.8
Diuron	H	Urea	92.3	63.1	0.0	5.2	85.6	28.3	274.5
Fluometuron	H	urea, trifluoromethyl	118.6	72.1	0.0	8.7	98.5	56.7	354.6
Atrazine	H	Triazine	43.2	68.8	0.0	14.4	37.2	24.7	188.3
Dinoseb	H	Nitro compound	49.0	9.0	0.0	11.0	3.0	8.0	80.0
Trifluralin	H	trifluoromethyl, dinitroaniline	56.4	12.8	0.0	7.9	57.7	16.1	150.9
Diquat	H	Bipyridylium	70.0	65.0	0.0	1.0	100.0	164.0	400.0
Paraquat	H	Bipyridylium	76.1	68.4	0.0	4.0	141.6	169.3	459.4
Glyphosate	H	Organophosphonate	33.0	93.0	0.0	1.0	227.0	100.0	454.0
Linuron	H	Urea	96.5	68.1	0.0	6.6	88.4	30.1	289.7
Cyanazine	H	Triazine	54.6	65.8	0.0	15.2	38.6	26.8	201.0
Bentazon	H	Benzothiadiazole	128.6	66.1	0.0	42.3	118.5	78.1	433.6
EPTC	H	Carbamate	16.5	39.6	0.0	8.9	66.7	28.1	159.8
Metolachlor	H	Acetamide	101.2	27.6	0.0	15.1	78.2	53.7	275.8
		Average	**71.8**	**45.6**	**0.5**	**9.4**	**80.6**	**56.7**	**264.5**
		Standard deviation	**29.5**	**25.6**	**2.4**	**8.3**	**51.6**	**50.7**	**126.3**
Ferbam	F	dithiocarbamate, organoiron	0.0	42.0	3.0	0.0	13.0	23.0	81.0
Maneb	F	dithiocarbamate, organomanganese	27.0	23.0	8.0	9.0	25.0	7.0	99.0
Captan	F	Phthalimide	38.0	14.0	0.0	0.0	52.0	11.0	115.0
Benomyl	F	benzimidazole, MBC	86.7	71.2	0.0	14.3	121.2	103.6	397.0
		Average	**37.9**	**37.6**	**2.8**	**5.8**	**52.8**	**36.2**	**173.0**
		Standard deviation	**36.2**	**25.3**	**3.8**	**7.1**	**48.4**	**45.5**	**150.0**
Methyl parathion	I	organophosphorus, nitro compound	37.0	24.0	6.0	2.0	73.0	18.0	160.0
Phorate	I	Organophosphorus	56.1	34.2	0.0	5.6	89.5	23.6	209.0
Carbofuran	I	Carbamate	137.0	63.0	1.0	44.0	127.0	82.0	454.0
Carbaryl	I	Carbamate	11.0	48.0	26.0	1.0	54.0	13.0	153.0
Toxaphene	I	Organochlorine	3.0	19.0	0.0	1.0	32.0	3.0	58.0
Cypermethrin	I	Pyrethroid	89.0	71.2	0.0	10.3	199.5	210.0	580.0
Chlordimeform	I	Formamidine	61.8	53.1	0.0	6.5	86.5	42.3	250.2
Lindane	I	Organochlorine	6.2	16.3	0.0	2.2	30.6	2.5	57.8
Malathion	I	Organophosphorus	62.0	41.2	0.0	6.1	92.1	27.4	228.8
Parathion	I	organophosphorus, nitro compound	35.0	23.1	5.2	1.6	57.1	16.0	138.0
Methoxychlor	I	organochlorine, bridged diphenyl	10.2	11.6	0.0	2.4	28.7	16.9	69.8
		Average	**46.2**	**36.8**	**3.5**	**7.5**	**79.1**	**41.3**	**214.4**
		Standard deviation	**41.1**	**20.0**	**7.8**	**12.5**	**50.4**	**60.1**	**165.8**

1. Hartley D. and H.Kidd (1987)
2. H herbicide, F fungicide, G growth regulator, I insecticide

† Energy retained in the chemical structure of each pesticide

* Energy used in providing heat etc.

Appendix B – Sensitivity Analysis - Impact of on-farm rearing of replacements on carbon footprint

As identified in Section 5.3, a notable issue was the data discrepancy around the required dry matter intake (DMI) of the dairy ewes and the stocking rate of the scenario, as stated by the farm. As the LCA study was predominantly focussed on the overall environmental impact of the farm, the decision was made to initially model only the maximum stocking rate of dairy ewes/ha, with the assumption that all replacements and studs were grazed off-farm.

To determine the additional impact of having the replacements grazed on-farm, this sensitivity analysis was conducted based on an alternative livestock scenario with a more intensive stocking rate resulting from the on-farm rearing replacements lambs from weaning through to the first 12 months of age. As this is a different farming system to the one modelled where lambs are reared on external support blocks,

As stated previously, methane emissions produced predominantly from enteric fermentation were found to be the biggest contributor to the climate change impact category. This in addition to the unavailability of measurement data on the amount of nitrogen deposited in urine and faeces by the replacements, led to the decision to focus only on the methane emissions.

The amount of faecal dry matter (kg of FDM) produced by the replacements was estimated to be 0.15 kg FDM/lamb/day, utilising the same ratio based on the DMI and FDM of the dairy ewes. As the replacement lambs spend 100% of their time out on pasture, none of the emissions were allocated to the milking parlour stage. As this is only an estimate for a hypothetical scenario, the results of this sensitivity analysis should be treated with caution as emissions from livestock can vary greatly based on variables such as type of feed, body condition score and live-weight. The calculations used in the original study and for the purposes of the sensitivity analysis are stated in Table B1.

Table B1 - Sensitivity analysis stocking rate data

Original Scenario		*Alternative Scenario*	
Ewes	DMI /ewe	***Replacements***	DMI /lamb
Lactation (200 days)	2.5 kg DM/day	*Mean DMI*	0.6 kg DM/day
Non-Lactation	2.15 kg DM/day	*Annual DMI/lamb*	219 kg DM/yr
Mean DMI	2.34 kg DM/day	*No. of replacements*	200
Annual DMI/ewe	854.1 kg DM/ewe/yr	*DMI for all replacements*	43800 kg DM/yr
Total DM available per ha	9922.8 kg DM/ha/yr	*No of replacements/ha*	200 ÷ 63 = 3.2
Number of ewes/ha	9922.8 ÷854.1 = 13	*Total DMI/ha/yr*	695.2 kg DM/ha/yr
	-	*Total DM available per ha*	9922.8 kg DM/ha/yr
	-	*DM available for ewes*	9227.6 kg DM/ha/yr
	-	*Annual DMI/ewe*	854.1 kg DM/ewe/yr
	-	*Number of ewes/ha*	10.8
Summary		***Summary***	
Ewes/ha	12	*Ewes/ha*	10.8
Lamb replacements/ha	-	*Lamb replacements/ha*	3.2
Total FDM/ha/yr	2190 kg/FDM/ha/yr	*Total FDM/ha/yr*	2278 kg FDM/ha/yr

Results

Figure B1 shows the results for the most significant impact categories following normalisation in the study for the sheep emissions stage when the methane produced by enteric fermentation and faecal emissions of replacement lambs are included in the livestock number. The results have been presented as a ratio relative to 1 (original scenario) to show the difference in the results obtained in each respective category.

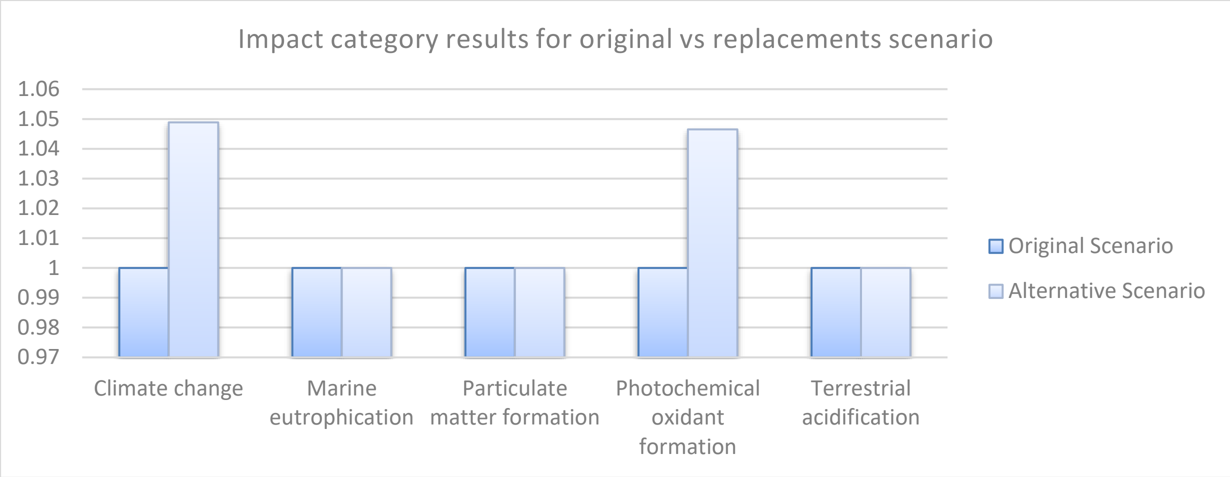


Figure B1 - Impact category results for increased stocking rate

As seen in the Figure B1, the inclusion of the methane produced by replacements on-farm only affected the photochemical oxidant formation and climate change impact categories however it is important to keep in mind that this is a partial analysis and there is potential for the results to be greater with inclusion of other GHGs. As mentioned, as this sensitivity analysis only considers the methane emitted from replacements and no other emissions, there is potential for the normalised total results to differ when such additional contributions are included into the analysis.

Impact of stocking rate on carbon footprint of milk production

In terms of the impact of having of different stocking rate of ewes per hectare, the carbon footprint of both the original scenario modelled and this replacements scenario was calculated.

The climate change result for the case-study system modelled (with only dairy ewes on-farm) with a stocking rate of 12 SU/ha was found to be 8070 kg CO_2- eq/ha (please refer to Chapter 5.4). Utilising the estimated milk production per ewe (210 l/ewe/yr) as stated in Chapter 5, the estimated milk production was calculated to be 2525 l/ha/yr When expressed on a kg CO_2- eq/litre of milk (kg CO_2- eq/l), the carbon footprint was calculated to be 3 kg CO_2- eq/l.

When incorporating the rearing of replacements on farm, the resulting stocking rate of ewes resulted to 10.8 SU/ha. The estimated milk production per hectare for the decreased stocking rate was then calculated to be 2268 l/ha/yr and the total carbon footprint was found to be 5% higher with the replacements on-farm at 8474 kg CO_2- eq/ha. When expressed on a kg CO_2- eq/litre of milk (kg CO_2- eq/l), the carbon footprint was calculated to be 3.7 kg CO_2- eq/l.

Appendix C – Sample marketing for prototype certification system

Page 1

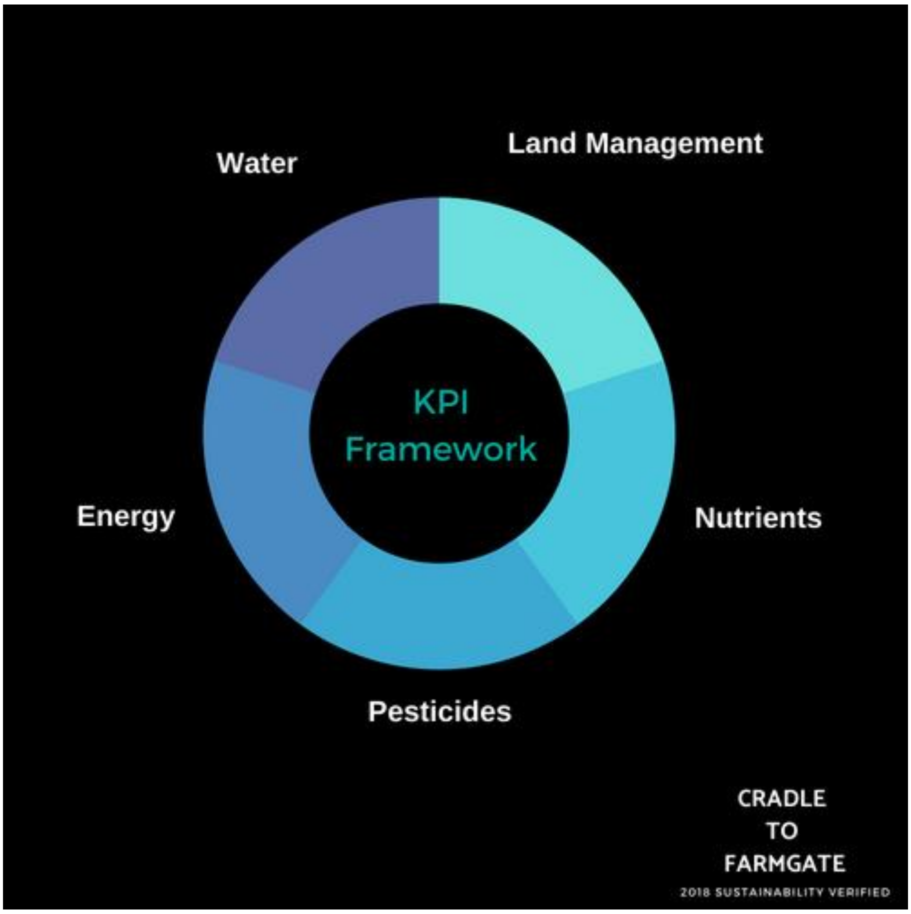
Page 2

CRADLE TO FARMGATE

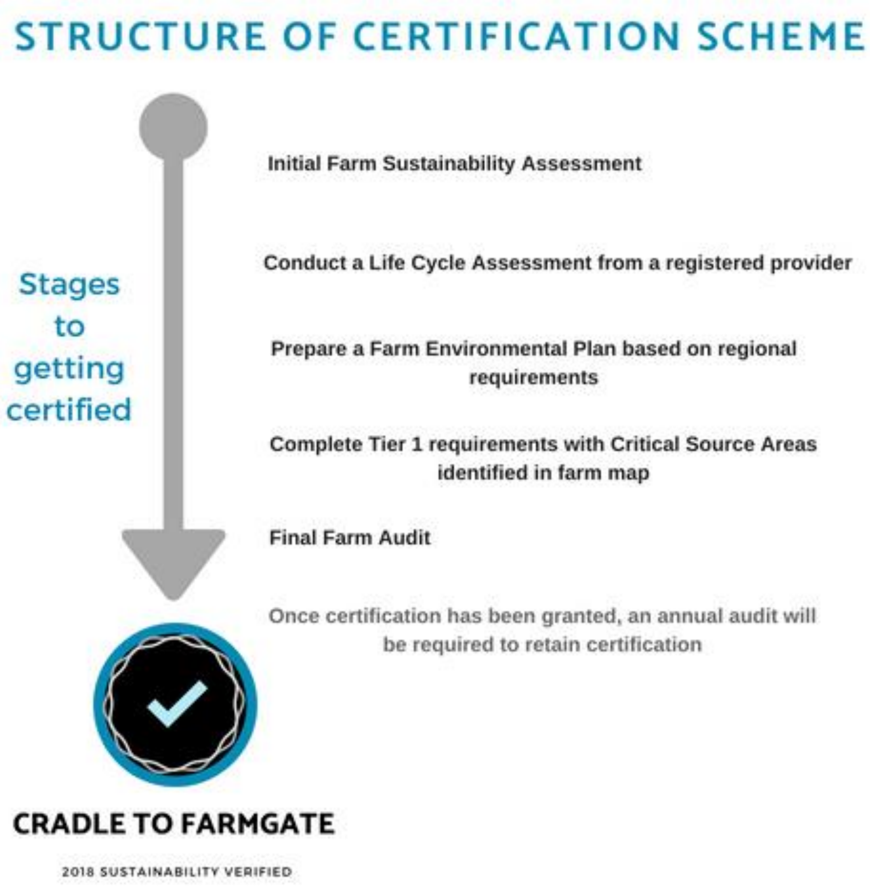
2018 SUSTAINABILITY VERIFIED

Page 3

Page 4


Water
Land Management
KPI
Framework
Energy
Nutrients
Pesticides
CRADLE
TO
FARMGATE
2018 SUSTAINABILITY VERIFIED

Page 5


STRUCTURE OF CERTIFICATION SCHEME
Stages
to
getting
certified
Initial Farm Sustainability Assessment
Conduct a Life Cycle Assessment from a registered provider
Prepare a Farm Environmental Plan based on regional requirements
Complete Tier 1 requirements with Critical Source Areas identified in farm map
Final Farm Audit
Once certification has been granted, an annual audit will be required to retain certification
CRADLE TO FARMGATE
2018 SUSTAINABILITY VERIFIED

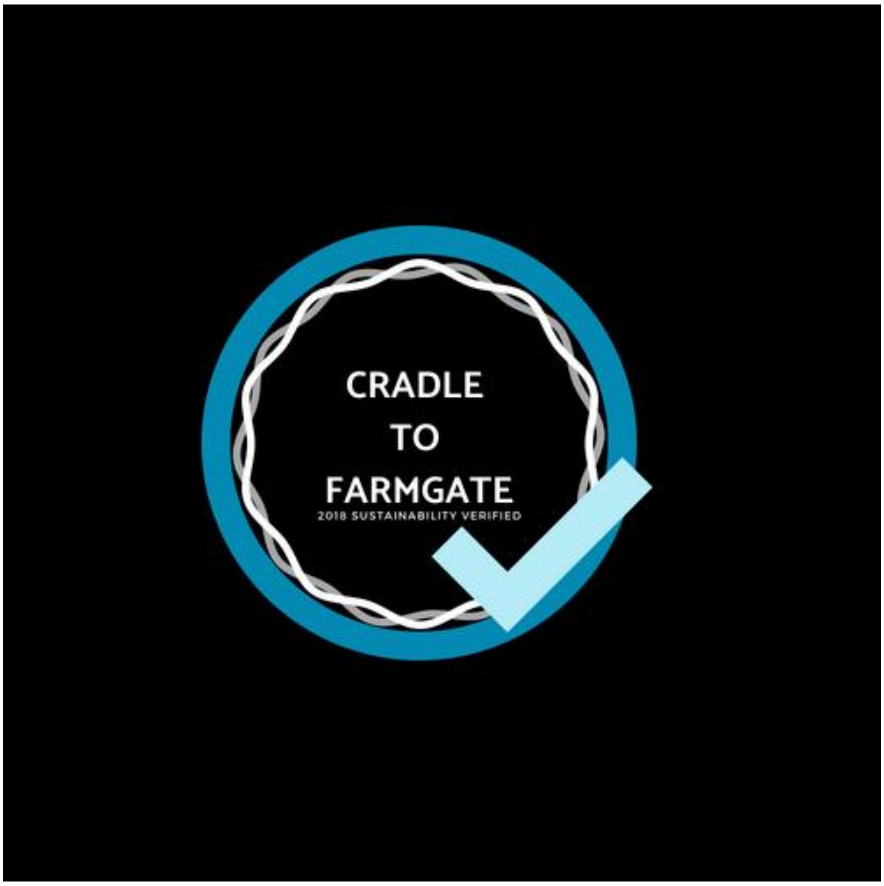
Page 6

KPI FRAMEWORK

Tier 1

Soil Map	A soil map must be prepared stating the different soil types present and the identification of areas prone to compaction, erosion, runoff and leaching.
Nutrient Budget	Nutrient budgeting must be undertaken annually to determine efficiency of fertiliser use, with mitigation measures documented.
Pesticide Drift	A risk assessment must be conducted to assess the risk of pesticide drift, with measures undertake to minimize the drift.
Carbon Footprint Evaluation	The total carbon footprint should be re-calculated with any major changes in livestock reared
Freshwater Quality	All potential wastewater sources and contaminant points must be identified on farm map and be treated appropriately prior to discharge.

Page 7



Page 8

CRADLE TO FARMGATE

2018 SUSTAINABILITY VERIFIED

End of Brochure

References

Allen, B (2010). Eco-labelling: legal, decent, honest and truthful? Green Chemistry, *1*(1)

Audsley, E., Stacey, K., Parsons, D., & Williams, A. (2009). *Estimation of the greenhouse gas emissions from agricultural pesticide manufacture and use*: Cranfield University

Batalla, I., Knudsen, M., Mogensen, L., del Hierro, Ó., Pinto, M., & Hermansen, J. (2015). Carbon footprint of milk from sheep farming systems in northern Spain including soil carbon sequestration in grasslands. *Journal of Cleaner Production*, *104*, 121-129.

Batalla, I., Pinto, M., Unamunzaga, O., Besga, G., & Del Hierro, O. (2014). Integrating social and economic criteria in the carbon footprint analysis in sheep dairy farms. In *Proceedings of the 9th International Conference on Life Cycle Assessment in the Agri-Food Sector* (pp. 8-10).

Baumann, H., & Tillman, A. M. (2004). *The Hitch Hiker's Guide to LCA: An orientation in life cycle assessment methodology and application*: Studentlitteratur AB, Lund, Sweden.

Beef + Lamb New Zealand (2018) *Farm Environmental Plans.* Retrieved from: https://beeflambnz.com/compliance/environment/environment-plans

Bord Bia (2013) *Sustainable Dairy Assurance – Producer Standard*. Dublin: Bord Bia.

Caffrey, K. R., Veal, M. W. (2013) Conducting an agricultural life cycle assessment: challenges and perspectives. The Scientific World Journal, 2013, 1-13

Campbell, A.M 2018. The Healthy Rivers Challenge – 5,000 farm plans in eight years. In: Farm environmental planning – Science, policy and practice. (Eds L.D. Currie and C.L. Christensen). http://flrc.massey.ac.nz/publications.html. Occasional Report No. 31. Fertiliser and Lime Research Centre, Massey University, Palmerston North, New Zealand. 5 pages.

Chan, D, and Kempson, A. 2018. Delivering tailored farm environment plans at scale. In: Farm environmental planning – Science, policy and practice. (Eds L.D. Currie and C.L. Christensen). http://flrc.massey.ac.nz/publications.html. Occasional Report No. 31. Fertilizer and Lime Research Centre, Massey University, Palmerston North, New Zealand. 6 pages.

Chobtang, J. (2016). *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 Massey University, Manawatū, New Zealand* (Doctoral dissertation, Massey University).

Chobtang, J., Ledgard, S. F., McLaren, S. J., & Donaghy, D. J. (2017). Life cycle environmental impacts of high and low intensification pasture-based milk production systems: A case study of the Waikato region, New Zealand. *Journal of Cleaner Production*, *140*, 664-674.

Chobtang, J., Ledgard, S. F., McLaren, S. J., Zonderland-Thomassen, M., & Donaghy, D. J. (2016b). Appraisal of environmental profiles of pasture-based milk production: a case study of dairy farms in the Waikato region, New Zealand. *The International Journal of Life Cycle Assessment*, *21*(3), 311-325.

Chobtang, J., McLaren, S. J., Ledgard, S. F., & Donaghy, D. J. (2017a). Environmental trade-offs associated with intensification methods in a pasture-based dairy system using prospective attributional Life Cycle Assessment. *Journal of Cleaner Production*, *143*, 1302-1312.

Circular Ecology (2017) *Life Cycle Assessment (LCA): Framework diagram.* Retrieved from: http://www.circularecology.com/lca.html (Accessed November 2017)

Cowell, S.J. (1998). *Environmental Life Cycle Assessment of Agricultural Systems: Integration into Decision-Making*. Ph.D. dissertation. University of Surrey, Guildford.

FAO (2003) *The concepts of standards, certification and labelling.* Food and Agriculture Organization of the United Nations, Rome, Italy. Retrieved from: http://www.fao.org/docrep/006/Y5136E/y5136e07.htm#fn7

FAO (2016) *Greenhouse gas emissions and fossil energy demand from small ruminant supply chains: Guidelines for quantification*. Livestock Environmental Assessment and Performance Partnership. Food and Agriculture Organization of the United Nations, Rome, Italy.

Fietje, L., Carmichael, L. 2018. Farmer Engagement in Farming Within Limits. In: Farm environmental planning – Science, policy and practice. (Eds L.D. Currie and C.L. Christensen). http://flrc.massey.ac.nz/publications.html. Occasional Report No.31. Fertliser and Lime Research Centre, Massey University, Palmerston North, New Zealand. 9 pages.

Fifita, I., Hong, D., Seo, Y., Ko, E., & Conroy, D. (2017). Sustainable food consumption as luxury fashion: insights from the organic market in South Korea. In *2017 Global Fashion Management Conference at Vienna* (pp. 368-368).

Flysjö, A., Henriksson, M., Cederberg, C., Ledgard, S., & Englund, J. E. (2011). The impact of various parameters on the carbon footprint of milk production in New Zealand and Sweden. *Agricultural systems*, *104*(6), 459-469.

Goedkoop, M., Heijungs, R., Huijbregts, M., De Schryver, A., Struijs, J., & Van Zelm, R. (2009). ReCiPe 2008. *A life cycle impact assessment method which comprises harmonised category indicators at the midpoint and the endpoint level*, *1*.

Goedkoop, M., Heijungs, R., Huijbregts, M., De Schryver, A., Struijs, J., & Van Zelm, R. (2013). ReCiPe 2008. *A life cycle impact assessment method which comprises harmonised category indicators at the midpoint and the endpoint level*, *1.08*

Green, M. B. (1987). Energy in pesticide manufacture, distribution and use. *Energy in world agriculture*.

Guinée, J. B. (2002). Handbook on life cycle assessment operational guide to the ISO standards. *The international journal of life cycle assessment*, *7*(5), 311-313.

Hobbs, P. R. (2007). Conservation agriculture: what is it and why is it important for future sustainable food production. *The Journal of Agricultural Science*, *145*(2), 127.

Houlbrooke, D. J., Horne, D. J., Hedley, M. J., Hanly, J. A., & Snow, V. O. (2004). A review of literature on the land treatment of farm-dairy effluent in New Zealand and its impact on water quality. *New Zealand Journal of Agricultural Research*, *47*(4), 499-511.

Ibidhi, R., Hoekstra A.Y., Gerbens-Leenes P.W. and Chouchane, H. (2017) Water, land and carbon footprints of sheep and chicken meat produced in Tunisia under different farming systems, Ecological Indicators, 77: 304-313

Intergovernmental Panel on Climate Change (2007) *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the IPCC*. Cambridge University Press, New York

ISO. (2006) ISO 14044:2006 *Environmental management – Life cycle assessment – Requirements and guidelines:* International Organization for Standardization.

Kellogg R, Nehring R, Grube A, Goss D, Plotkin S. (2002) Environmental indicators of pesticide leaching and runoff from farm fields. In: Ball VE, Norton G (eds) Agricultural Productivity, *2. Studies in Productivity and Efficiency.* Springer US, pp 213-256

Kraft, F., & Goodell, P. (1993) Identifying the health-conscious consumer. *Journal of Health Care Marketing, 13* (3), 18-25.

Lazarevic, D., Buclet, N. & Brandt, N. (2012). The application of life cycle thinking in the context of European waste policy. Journal of Cleaner Production 29-30: 199-207.

LEAF (2016). LEAF Marque Standard Version 14.1. Available at http://www.leafuk.org/eblock/services/resources.ashx/001/298/709/LEAF_Marque_Standard_v14.1_FINAL.pdf

Lebacq, T., Baret, P. V., & Stilmant, D. (2013). Sustainability indicators for livestock farming. A review. *Agronomy for Sustainable Development*, *33*(2), 311-327.

Ledgard, S. F., Lieffering, M., Coup, D., & O'Brien, B. (2011). Carbon foot printing of New Zealand lamb from the perspective of an exporting nation. *Animal frontiers*, *1*(1), 40-45.

Ledgard, S. F., McDevitt, J., Boyes, M., Lieffering, M., & Kemp, R. (2009). Greenhouse gas footprint of lamb meat: Methodology report. *Report to MAF (November 2009). AgResearch, Hamilton. 36p*.

Ledgard, S.F., Chobtang, J., Falconer, S.J. and McLaren, S., (2016) *Life cycle assessment of dairy production systems in New Zealand in: Integrated nutrient and water management for sustainable farming.* (Eds L.D. Currie and R. Singh). http://flrc.massey.ac.nz/publications.html. Occasional Report No. 29. Fertilizer and Lime Research Centre, Massey University, Palmerston North, New Zealand.

Lieffering, M., Ledgard, S.F., Boyes, M. and Kemp, R. (2012) *A Greenhouse Gas Footprint Study for Exported New Zealand Beef***.** Report prepared for the Meat Industry Association, Ballance Agri-Nutrients, Landcorp and MAF.

Lombardi, G. V., Berni, R., & Rocchi, B. (2017). Environmental friendly food. Choice experiment to assess consumer's attitude toward “climate neutral” milk: the role of communication. *Journal of Cleaner Production*, *142*, 257-262.

Loureiro, M. L., McCluskey, J. J., & Mittelhammer, R. C. (2001). Assessing consumer preferences for organic, eco-labeled, and regular apples. *Journal of agricultural and resource economics*, 404-416.

Marteau, T. M. (2017). Towards environmentally sustainable human behaviour: targeting non-conscious and conscious processes for effective and acceptable policies. *Phil. Trans. R. Soc. A*, *375*(2095), 20160371.

Marx, A. (2014) Legitimacy, institutional design, and dispute settlement: the case of ecocertification systems. Globalizations 11(3): 401-416.

McLaren, S., Singh, R., & Clothier, B., 2017. Environmental certification: adding value for New Zealand’s primary producers, or a waste of time and money? *Science and policy: nutrient* *management challenges for the next generation* (Eds L. D. Currie and M. J. Hedley). http://flrc.massey.ac.nz/publications.html. *30.* Fertilizer and Lime Research Centre, Massey University, Palmerston North, New Zealand

Michaelidou, A.M. (2008) Factors influencing nutritional and health profile of milk and milk products. *Small Ruminant Research*, *79*, 42-50.

Michaelidou, N., & Hassan, L. (2008). The role of health consciousness, food safety concern and ethical identity on attitudes and intentions towards organic food. *International Journal of Consumer Studies*, *32*(2), 163-170.

Mills, O. (1982). *Practical sheep dairying. The care and milking of the dairy ewe*. Thorson's Publishers Ltd.

Ministries of Primary Industries (2013) *Detailed methodologies for agricultural greenhouse gas emission calculation: Version 2*. Ministries of Primary Industries, Wellington

Ministry for Primary Industries (2016) *Outcome logic model for Sheep-Horizon Three-PGP Programme 2016-2022.* PDF retrieved from: https://www.mpi.govt.nz/funding-and-programmes/primary-growth-partnership/primary-growth-partnership-programmes/sheep-horizon-three/ (accessed July 2017)

Ministry for Primary Industries (2017) *Primary Growth Partnership: Sheep - Horizon Three*. Retrieved from http://www.mpi.govt.nz/funding-and-programmes/primary-growth-partnership/primary-growth-partnership-programmes/sheep-horizon-three/ (accessed November 2017)

Muller F, Appleby A (2010) *Ullmann's Encyclopedia of Industrial Chemistry 7th ed. (1999-2011).* NY, NY: John Wiley & Sons

Müller, K., Deurer, M., & Clothier, B. (2011). An ILCD Database of Three Pesticides for the Kiwifruit Industry. *The New Zealand Plant & Food Research Institute, Hamilton, New Zealand*, 24.

Nemecek T, Kägi T (2007) *Life cycle inventories of agricultural production systems*. Swiss Centre for Life Cycle Inventories, Dübendorf, Switzerland

New Zealand Land Resource Inventory (2017) *SCINFO Vapour Pressure Calculation*. Retrieved from: https://lris.scinfo.org.nz/layer/48091-lenz-october-vapour-pressure-deficit/

Norris, G. (2001). The requirement for congruence in normalization. *The International Journal of Life Cycle Assessment*, *6*(2), 85-88.

O'Brien, D., Bohan, A., McHugh, N., & Shalloo, L. (2016). A life cycle assessment of the effect of intensification on the environmental impacts and resource use of grass-based sheep farming. *Agricultural Systems*, *148*, 95-104.

Oram, R (2016, August 28) Herding sheep milk's potential. *Sunday Star Times*. Retrieved from: https://www.stuff.co.nz/business/opinion-analysis/83560142/Rod-Oram-Herding-sheep-milks-potential

Peters, G., Rowley, H., Wiedemann, S., Tucker, R., Short, M., & Schulz, M. (2010). Red meat production in Australia: life cycle assessment and comparison with overseas studies. *Environmental science & technology*, *44*(4), 1327-1332.

Peters, J., & Weil, M. (2016). A Critical Assessment of the Resource Depletion Potential of Current and Future Lithium-Ion Batteries. *Resources*, *5*(4), 46.

Powell, B.P and Heath, N., 2018. Farm Environment Planning: What Would Help Us Get to a Better Destination? In: Farm environmental planning – Science, policy and practice. (Eds L. D. Currie and C. L. Christensen). http://flrc.massey.ac.nz/publications.html. Occasional Report No. 31. Fertilizer and Lime Research Centre, Massey University, Palmerston North, New Zealand. 6 pages.

Prichard, C (2017) *Sheep dairy and market drivers.* Presentation Slides, School of Management, Massey University.

Rao, M. N., Waits, D. A., & Neilsen, M. L. (2000). A GIS-based modelling approach for implementation of sustainable farm management practices. *Environmental Modelling & Software*, *15*(8), 745-753.

Resource Management Act, No. 69. (1991). Retrieved from http://www.legislation.govt.nz/ act/public/1991/0069/latest/whole. html)

Ripoll-Bosch, R., De Boer, I., Bernués, A., & Vellinga, T. (2013). Accounting for multi-functionality of sheep farming in the carbon footprint of lamb: a comparison of three contrasting Mediterranean systems. *Agricultural Systems*, *116*, 60-68.

Robertson, K., Symes, W., & Garnham, M. (2015). Carbon footprint of dairy goat milk production in New Zealand. *Journal of dairy science*, *98*(7), 4279-4293.

Ruttan, V.W. (1990). Alternative agriculture sustainability is not enough. *Alternative Agriculture Scientists Review*. Special Publication No. 16. Council for Agricultural Science and Technology, Ames, IA, pp. 130–134.

Saunders, C., Guenther, M., Tait, P., & Saunders, J. (2013) Assessing consumer preferences and willingness to pay for NZ food attributes in China, India and the UK. In *Proceedings of the 87th Annual Conference of the Agricultural Economics Society, University of Warwick, United Kingdom* (pp. 8-10).

Schau, E., & Fet, A. (2008). LCA studies of food products as background for environmental product declarations. *The International Journal of Life Cycle Assessment*, *13*(3), 255-264.

SCS Global Services (2016) *Sustainably Grown Standard - A Sustainable Agriculture Standard for Agricultural Crops*. California, USA.

Selfa, T., Jussaume, R., & Winter, M. (2008). Envisioning agricultural sustainability from field to plate: Comparing producer and consumer attitudes and practices toward 'environmentally friendly' food and farming in Washington State, USA. *Journal of rural studies*, *24*(3), 262-276.

Sittig, M. (1980) *Pesticide Manufacturing and Toxic Materials Control Encyclopaedia.* Park Ridge, NJ: Noyes Data Corporation, 673

Smith, L., Longhurst, R., Monaghan, R., & Bartlett, N. (2017): Characterising the volumes and chemical characteristics of dairy sheep effluent in New Zealand, *New Zealand Journal of Agricultural Research,* DOI: 10.1080/00288233.2017.1397032

St-Onge, M. P., & Jones, P. J. (2002). Physiological effects of medium-chain triglycerides: potential agents in the prevention of obesity. *The Journal of nutrition*, *132*(3), 329-332.

Tillman, A. M., Ekvall, T., Baumann, H., & Rydberg, T. (1994). Choice of system boundaries in life cycle assessment. *Journal of Cleaner Production*, *2*(1), 21-29.

Tukker, A. (2002). Life Cycle Assessment and the Precautionary Principle. Environmental Science & Technology February 1, 71A-75A.

Unilever (2010) *Sustainable Agriculture Code.* United Kingdom: Unilever Sustainable Agriculture

Unilever (2017) *Sustainable Sourcing Programme for Agricultural Raw Materials: Scheme Rules Version 4.7*. United Kingdom: Unilever Sustainable Agriculture

Vagnoni, E., Franca, A., Breedveld, L., Porqueddu, C., Ferrara, R., & Duce, P. (2015). Environmental performances of Sardinian dairy sheep production systems at different input levels. *Science of the Total Environment, 502*, 354-361.

Ward, H. (1997). Trade and Environment Issues in Voluntary Eco–labelling and Life Cycle Analysis. Review of European, Comparative & International Environmental Law, 6(2), 139-148.

Watkins, N., Longhurst, R., Smith, C., & Monaghan, R. (2016) *Effluent management on a dairy sheep Farm*. Proceedings of the New Zealand Society of Animal Production 2016. *76.* 199-204.

Webb J, Hutchings N, Amon B, Dämmgen U, Baas J, Pain B, Chao AF, Lekkerkerk L, Runge E, Münch J, Kachniarz M, Lubera K (2013) Agriculture other including use of pesticides. EMEP/EEA Air Pollutant Emission Inventory Guidebook 2013: Technical Guidance to Prepare National Emission Inventories. Copenhagen, Denmark

Wheeler, D. M., Ledgard, S. F., De Klein, C. A. M., Monaghan, R. M., Carey, P. L., McDowell, R. W., & Johns, K. L. (2003). OVERSEER® nutrient budgets–moving towards on-farm resource accounting. In *Proceedings of the New Zealand Grassland Association* (Vol. 65, pp. 191-194).

Whitehead, D. C. (2000). *Nutrient elements in grassland: soil-plant-animal relationships*. Cabi.

Wiedemann, S. G., Ledgard, S. F., Henry, B. K., Yan, M. J., Mao, N., & Russell, S. J. (2015). Application of life cycle assessment to sheep production systems: investigating co-production of wool and meat using case studies from major global producers. *The International Journal of Life Cycle Assessment*, *20*(4), 463-476.

Williams, R., Brown, H., Ford, R., Lilburne, L., Pinxterhuis, I., Robson, M., Snow, V., Taylor, K. and von Pein, T. (2014) The matrix of good management: defining good management practices and associated nutrient losses across primary industries. *Occasional Report*, *27*(8).

Zonderland-Thomassen, M., Boyes, M., Ledgard, S. (2011) An ILCD database of three fertilisers for the kiwifruit industry. *AgResearch, Hamilton New Zealand.*