Life Cycle Assessment and the New Zealand Wine Industry: A tool to support continuous environmental improvement

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"If we want things to stay as they are,
things will have to change"

Giuseppe di Lampedusa, 1896 - 1957

ABSTRACT

As the marketplace becomes increasingly environmentally conscious, demonstration of environmental credentials and evidence of continuous improvement will likely become of increasing strategic and economic importance to New Zealand wine exporters. Keeping pace with such market changes will ensure local exporters remain competitive against other wine producing countries, and help secure their share in important foreign markets such as the UK.

This thesis uses Life Cycle Assessment (LCA) to identify how the New Zealand wine industry can improve its standard of environmental management and inform its practice of environmental labelling. Through the identification of environmental hotspots, use of sensitivity analysis, and normalisation of results, all using a product life cycle framework, this research provides the industry with some direction as to how to better measure, manage and reduce its environmental impact, and identifies various ways of improving the quality of information being conveyed to the consumer through environmental labelling.

This research shows environmental improvement opportunities lie particularly in the areas of packaging systems, frost protection, agrichemical application, waste management, energy efficiency in the winery, and crop regulation. It provides some evidence to indicate that the carbon footprint is not the most significant environmental impact in the wine life cycle, and that other environmental impacts should be considered in development of improved environmental management systems. It also highlights the importance of using a standardised methodology in environmental labelling programmes.

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LIST OF ABBREVIATIONS USED

ADP Abiotic Depletion Potential

AP Acidification Potential

CF Characterisation factor

EP Eutrophication Potential

EPD Environmental Product Declaration

FAETP Freshwater Aquatic Ecotoxicity Potential

GHG Greenhouse Gas

GWP Global Warming Potential

HTP Human Toxicity Potential

IPCC Intergovernmental Panel on Climate Change

IWCC International Wine Carbon Calculator

LCA Life Cycle Assessment

LCI Life Cycle Inventory

LCIA Life Cycle Impact Assessment

MAETP Marine Aquatic Ecotoxicity Potential

MAF New Zealand Ministry of Agriculture and Forestry

NI North Island (case study) winery

ODP Ozone Depletion Potential

PAG Product-at-gate

PCF Product Carbon Footprint

POCP Photochemical Ozone Creation Potential

SI South Island (case study) winery

TETP Terrestric Ecotoxicity Potential

WRAP The British Waste and Resources Action Programme

CHAPTER 1: INTRODUCTION

The international wine industry is in a sizable and increasingly competitive market environment (Castali, Cholette, & Hussain, 2006; 2009; Thorpe, 2009). Current global wine production is estimated to be between 262 and 270 million hectoliters, with almost eight million hectares planted for viticultural purposes (OIV, 2010a). The world's leading wine producing countries are Italy, France and Spain, with other major countries including the USA, Argentina and China.

While global wine production has been relatively constant over the recent decade (OIV, 2010a) the New Zealand wine industry has undergone significant growth. Over this period the area of planted vineyards more than tripled, with an associated increase of wine production of more than 240% (NZWINE, 2010a). At the end of 2009 there were 643 wineries throughout New Zealand, with 1,128 vineyards covering 31,964 hectares (which equates to half the size of Lake Taupo). There are ten main wine growing regions distributed throughout the country, with around half of New Zealand's vineyards located in the Marlborough region. Sauvignon Blanc is the predominant grape variety grown, which makes up around half of New Zealand's vineyards (NZWINE, 2010a).

Over recent years the New Zealand wine industry has made an increasingly significant contribution to the New Zealand economy. The industry currently contributes over $1.5 billion (0.84%) to New Zealand's GDP and provides over 16,500 full time equivalent jobs (NZIER, 2009). Wine was the eighth largest export commodity group leaving New Zealand in the year ended February 2010, and total wine exports now value around $1,036,000,000 (StatsNZ, 2010). Around 38% of New Zealand's exported wines head to Australia, 30% to the UK and 18% to the USA (NZWINE, 2010b).

Figure 1 illustrates the increasing economic importance the export market has played in the New Zealand wine industry in recent years. Over the period shown, the volume of exported wine increased by more than 450% (NZWINE, 2010a). White wine makes up a significant majority (around 87%) of exported wines, of which Sauvignon Blanc is the most common (NZIER, 2009).

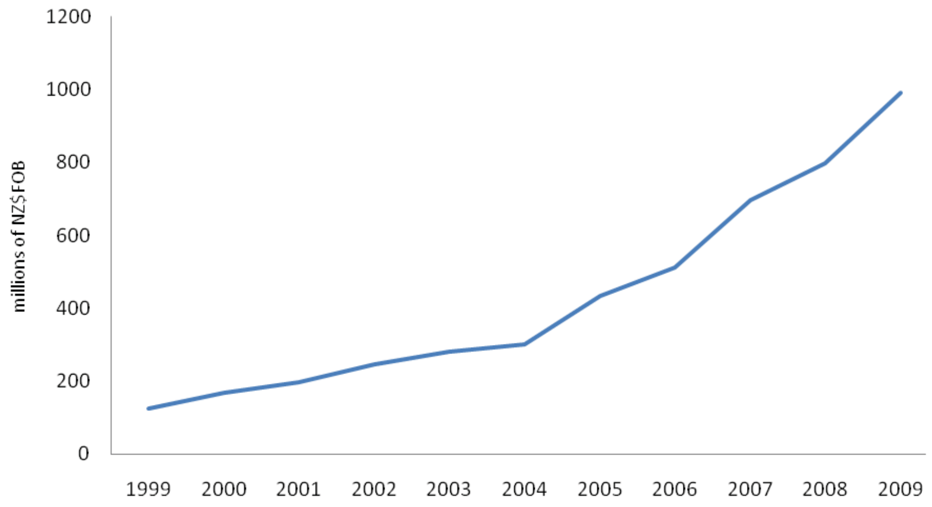

Figure 1: Value of New Zealand wine exports between 1999 and 2009. Source (NZWINE, 2010a)

As it grows, the New Zealand wine industry is facing increasing pressure from various areas to improve and demonstrate its environmental credentials. In recent years there have been increasing information demands from consumers and foreign importers regarding the environmental impact of the products they purchase (BW, 2010; Finkbeiner, 2009; LEK, 2007). Also, a number of New Zealand's international competitors have placed increasing attention on improving their own environmental performance. Some authors note that New Zealand wine exporters risk being shut out of the largest wine import markets unless they continue to address their standards of environmental stewardship (MAF, 2008; Marshall, Akoorie, Hamann, & Sinha, 2009).If the industry fails to react to these drivers, it could potentially lose substantial export market share.

The leading environmental management system in the New Zealand wine industry is the Sustainable Winegrowing New Zealand (SWNZ) programme. SWNZ was developed to provide a best practice model of environmental practices in the vineyard and winery and to address consumer concerns relating to the environmental impacts of wine grape production (SWNZ, 2010). More than 70% of wine produced in New Zealand comes from SWNZ members, with 135 member wineries and 1,244 member vineyards (NZWINE, 2010b).

The wine industry is interesting from an environmental perspective. The wine making process involves a number of quite different processes, varying across the agricultural (grape growing), to industrial (bottling), to transportation phases. Many of these processes contribute to climate change, which will in turn directly affect the industry itself, such as through changes in precipitation, occurrence of droughts and higher temperatures. Given that many wine grape varieties can only be grown across a fairly narrow range of climates for optimum quality and production, the wine industry is therefore at a greater potential risk from climate change than many other broad-based crops (Jones, 2006).

Life Cycle Assessment (LCA) is one environmental management tool that the New Zealand wine industry could utilize to manage and improve its environmental performance. LCA assesses the environmental burdens of a product throughout its life cycle, from the extraction of raw materials, through to the manufacture, distribution, use and on to end-of-life disposal. LCA can assist in identifying opportunities to improve the environmental performance of products at various points in their life cycle (ISO, 2006). It is used in a range of industries and is widely recognized as one of the most sophisticated and comprehensive environmental assessment methods available (ECJRC, 2010; Sharma, 2002).

A life cycle approach has been used in undertaking carbon footprint studies to assess the environmental performance of a number of New Zealand's important primary industries, including kiwifruit, lamb, merino wool and wine, though these studies focused specifically on greenhouse gas (GHG) emissions (MAF, 2010a). A LCA was conducted in the New Zealand milk industry by Basset-Mens, Ledgard and Carran (2005) and the apple industry by Canals, Burnip and Cowell (2006). A full LCA study is yet to be applied to a number of primary industries, including wine. Given the increasing market demands on the wine export industry to improve and demonstrate its environmental credentials, it seems appropriate and timely to apply the LCA tool to the New Zealand wine industry.

1.1 Aim

The aim of this thesis is to identify how the New Zealand wine industry can use LCA to improve its standard of environmental management and inform its practice of environmental labelling.

1.2 Research Questions and Objectives

Research questions define the nature and scope of a research project, and help guide the development of research objectives (Blaikie, 2000). This thesis focuses on addressing three primary research questions, which are listed below with their corresponding research objectives.

<u>Research Question 1</u> Is there a need for the New Zealand wine industry to improve its environmental practices and demonstrate its environmental credentials?

- Demonstrate the importance of raising the standard of environmental management in the New Zealand wine industry (Chapter 3)

<u>Research Question 2</u> What is the role of LCA in measuring and improving environmental management in the New Zealand wine industry?

- Describe the LCA method and its application to the wine industry (Chapter 2) and its use relative to other environmental management approaches in the wine industry (Chapter 3)
- Conduct LCA case studies on two New Zealand wineries (Chapter 5)

<u>Research Question 3</u> How can LCA contribute to the New Zealand wine industry's environmental labelling programmes?

- Compare the LCA results with a product carbon footprint (Chapter 5)
- Demonstrate the sensitivity of case study LCA results to various parameters (Chapter 5)
- Make recommendations about
    - relevant environmental impacts in addition to carbon footprint
    - additional relevant factors to be included in existing programmes

1.3 Method and Approach

This research is exploratory, as it involves working in an area that has not yet been studied in New Zealand. Most LCA research conducted in New Zealand to date has focused on GHG emissions; this includes a study on the local wine industry funded by the New Zealand Ministry of Agriculture and Forestry (MAF, 2008). However, a full LCA study – covering a broader range of environmental impacts - is yet to be applied to a number of industries, including wine.

This study contributes to raising the standard of environmental management in the New Zealand wine industry, by identifying significant environmental impacts in the case study wineries and suggesting ways these impacts might be reduced. This research also intends to inform the practice of environmental labelling in the wine industry, through considering, among other things, whether the product carbon footprint is an adequate indicator of the full environmental impact of the wine product, and use of alternative management and labelling schemes. The analytical approach developed in this thesis could be applied to other food and beverage industries in New Zealand.

It is important to consider the representativeness of the findings in this research. While this thesis provides recommendations on environmental performance and environmental labelling in the wine industry, these recommendations are based on two case study wineries (and the wine LCA literature). It can be argued these findings cannot be extrapolated to be representative of the entire industry, due to the influence of individual management practices, climatic conditions, and the size and sophistication of the machinery and equipment used on different vineyards and in different wineries.

Nonetheless, this research is the first of its type in New Zealand. Future research is obviously needed to test the validity of these findings, and to further substantiate (or otherwise) the various arguments and recommendations made.

Information for this research was gathered from a variety of sources. Peer-reviewed journals, government publications, conference proceedings and text books were the primary sources for chapters 2, 3 and 4. Information was also sourced from the websites of numerous organisations, including the GHG Protocol Initiative, the European Commission, the UNEP-SETAC[1] Initiative and New Zealand Winegrowers.

[1] The United Nations Environment Programme (UNEP) and the Society for Environmental Toxicology and Chemistry (SETAC)

In terms of the LCA study itself, the various data sources used are described in detail in Section 5.2. This also includes a description of the wine life cycle, with all relevant activities and processes that are measured in this study.

1.5 The LCA Case Study

The LCA conducted in this thesis focuses on Sauvignon Blanc produced in the 2010 vintage in two New Zealand case study wineries. The LCA is in accordance with the procedures specified in ISO 14040[2] and 14044[3], which provide the principles, framework and guidelines for conducting a LCA study. Three books have been published which provide operational guidance on these standards and are constantly referred to throughout the LCA study:

- Handbook on Life Cycle Assessment: Operational Guide to the ISO Standards (Guinée, 2002);
- ILCD Handbook: General Guide for Life Cycle Assessment - Detailed Guidance (ILCD, 2010b);
- The Hitchhikers Guide to LCA (Baumann & Tillman, 2004).

Due to a confidentiality agreement, the names of the two wineries involved in the case studies cannot be disclosed. One winery is based in the Hawke's Bay and the other in Blenheim. According to New Zealand Winegrowers, the leading industry body, both these wineries are classified as medium-sized[4] operations.

Both wineries produce a range of white and red wines for the local and international market, but the focus of this LCA is on Sauvignon Blanc. This variety was chosen for the following reasons. Firstly, around half of New Zealand's vineyards are planted in Sauvignon Blanc, so the findings from this research would

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[2] ISO 14044 (2006). Environmental management. Life cycle assessment: Principles and framework

[3] ISO 14044 (2006). Environmental management. Life cycle assessment: Requirements and guidelines

[4] New Zealand Winegrowers classifies a medium-sized winery as having an annual wine production between 200,000 and 4,000,000 litres.

be relevant to a sizable portion of the industry. Secondly, Sauvignon Blanc makes up a significant portion of New Zealand's wine exports and many of the pressures to demonstrate environmental credentials currently facing the New Zealand industry are related to the international marketplace. Finally, Sauvignon Blanc is a type of early-release tank fermented white wine, meaning the time frame of its life cycle (from vineyard to market) fits with the time frame of this thesis. The studied life cycle covered from June 2009 to September 2010, which was sufficient to cover all relevant processes and activities associated with this product's life cycle.

This study covers the following four life cycle stages: grape growing, wine making, packaging, and distribution to a consumer in the UK. Consistent with LCA methodology, the goals of the LCA research are provided under the Goal and Scope definition (see Chapter 5.1). These goals were developed to be complementary to the various research objectives of this thesis.

1.6 Disciplinary Context

The topics in this thesis cover three main topics: environmental management, marketing and LCA. Environmental management is concerned with how wine industry practices impact on the natural environment, and how these practices might be improved to achieve a higher standard of sustainability. The relevant marketing issue covered is how environmental labelling is conducted in the marketplace, in terms of the methodology used to inform it and the accuracy of the message being communicated to the consumer. Finally, LCA is a sophisticated tool used within the field of Life Cycle Management; its growth has coincided with an increasing recognition of the importance of life cycle thinking. In LCA, the boundaries defining the area of study are not set by an individual company, organisation or country, but are rather defined by the life cycle of the studied product itself.

CHAPTER 2: LCA AND THE WINE INDUSTRY

This chapter describes the LCA method and outlines its various applications, strengths and weaknesses. It concludes with a review of LCA case studies in the wine industry.

2.1 What is Life Cycle Assessment?

ISO 14044 defines LCA as “a compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its life cycle” (ISO, 2006, p. 2). Thus, a LCA study typically extends from the extraction and processing of raw materials, through to product manufacture, distribution, consumption and product end-of-life. Such a complete life cycle is often named a "cradle-to-grave " assessment (ECJRC, 2010). LCA is widely regarded as one of the leading tools available to assess the environmental impact of a product or service (ECJRC, 2010; Hospido, Davis, Berlin, & Sonesson, 2010).

2.2 The LCA Method

A widely accepted framework for LCA has been provided by the International Organisation for Standardisation (ISO) through the ISO 14040 series. ISO 14040 specifies the general framework, principles and requirements for conducting and reporting LCA studies (ISO, 2006). This framework is illustrated in figure 2, which shows the four basic phases in a LCA study: Goal and Scope Definition, Inventory Analysis, Impact Assessment and Interpretation. Each of these phases are described in this section.

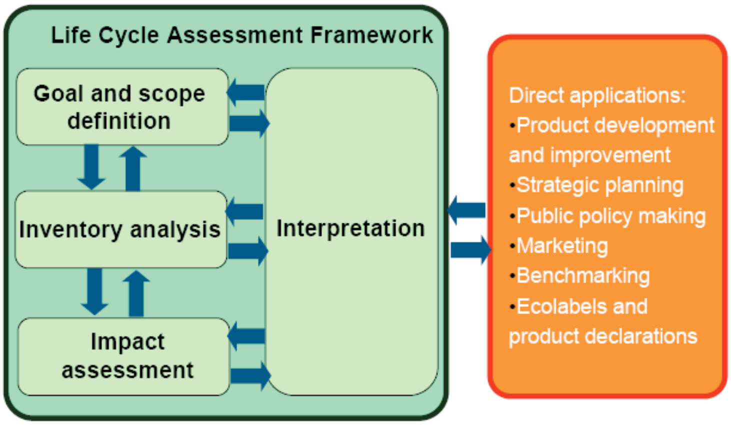

Figure 2: Illustration of the four phases of the LCA process as defined by the International Standards Organisation. Source (ISO, 2006)

2.2.1 Phase 1 - Goal and Scope Definition

The goal definition covers, among others, the goal of the study, the intended application of the study and the target audience. The goal definition guides the scope definition, which in turn sets the analytical framework for the rest of the LCA study. Common study goals might include the identification of environmental hotspots, identification of environmental improvement opportunities, or the comparison of two products.

The scope definition involves providing details on study methodology, data sources, data quality requirements, and the selection of impact categories and impact assessment methods (ILCD, 2010b). Two key concepts under this phase are the functional unit and system boundary. The functional unit is essentially a reference unit, to which the relative values of all the inputs and outputs of the system boundaries are expressed. For example, a LCA study on a music compact disc (CD) might determine that throughout the life cycle of a single CD, 9 g of carbon dioxide (CO_2) and 2 g of sulphur dioxide (SO_2) are released into the atmosphere.

The functional unit also relates to the function that the studied product can provide, which means the environmental performance of two products with identical functions can be directly compared. In the case of the CD, the functional unit might be "a transportable device on which up to 20 songs can be played, and which will last for at least 20 years". In defining this functional unit, comparative LCA studies can then compare the environmental performance of products that provide a similar function, such as a tape, record or MP3 disc.

The system boundary is the interface between the studied product system, and either the environment or other product systems (ILCD, 2010b). It defines which parts of the life cycle and which processes will be assessed in the studied system. A clear definition of the boundary is important to ensure that all relevant processes are included in the system, and that all potential environmental impacts are sufficiently addressed.

There are four commonly used ways to define the system boundary, based on where the LCA practitioner chooses to begin and end the studied life cycle. These are illustrated in figure 3:

- Cradle-to-grave: covers the full life cycle of the product system, from resource extraction through to end-of-life;
- Cradle-to-gate: from resource extraction through to the end of production (the gate of the factory);
- Gate-to-gate: considers the production phase only, typically used to establish the impact of a single production step or process;
- Gate-to-grave: covers everything post production.

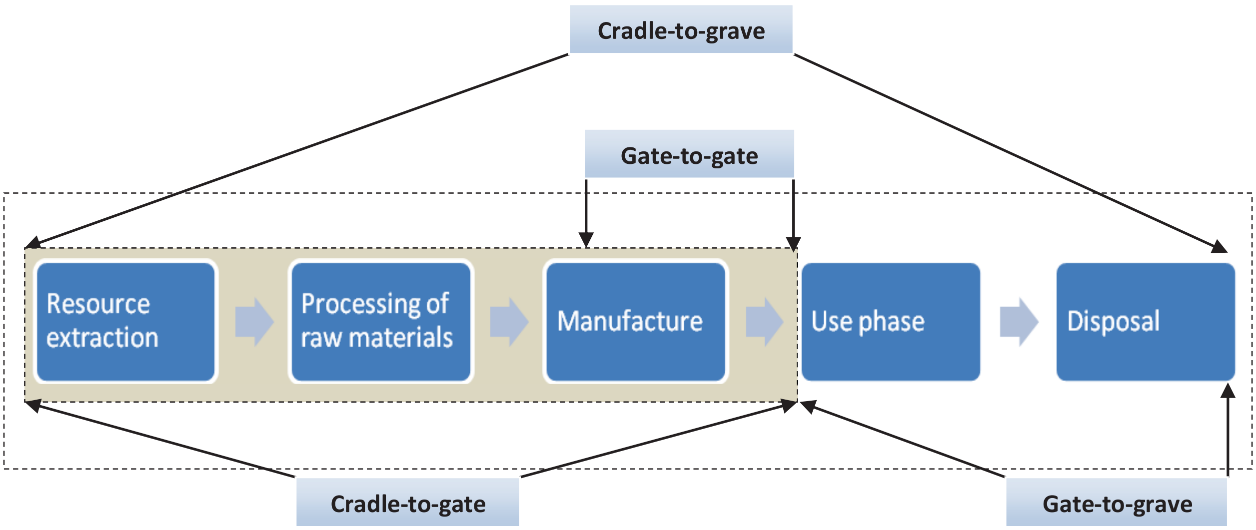

Figure 3: Four common options for defining system boundaries used in Life Cycle Assessment. Based on (PE, 2009)

For reasons of practicality and feasibility, a system's boundaries can be further defined by cut-off criteria. A commonly used cut-off criteria is the 1% threshold, where inputs that are estimated to contribute less than 1% to the overall environmental impact of the product are excluded (ILCD, 2010b).

At this phase, the impact assessment method is identified. A range of impact assessment methods are used in LCA, such as TRACI, Eco-Indicator 99 and CML 2001. The type of assessment method used influences various elements of the Life Cycle Impact Assessment (LCIA) phase; CML 2001 is the chosen method for this thesis. CML 2001 is a European LCA method developed by the Institute of Environmental Sciences (CML) at Leiden University in the Netherlands and is widely used in LCA studies.

2.2.2 Phase 2 - Life Cycle Inventory Analysis

This phase involves the collecting and compiling of data to form a Life Cycle Inventory (LCI). A LCI is often presented as a table listing and quantifying all the material and energy inputs (such as materials and fuel consumption) and outputs (such as waste products and air emissions) for each activity or process in the product system (SAIC, 2006). The data is then modelled and scaled appropriately to fit the functional unit. Modelling is typically done using LCA software tools such as GaBi or SimaPro; the former is used in this thesis. A LCI for a hypothetical product is shown in Table 1, which quantifies all the inputs and outputs associated with production of the functional unit (2,000 oranges).

Table 1: A hypothetical life cycle inventory table for a study with a functional unit of 2,000 oranges

Flow	Unit	Quantity
Inputs		
Total energy	MJ	1,100
Electricity	MJ	856
Diesel	kg	9.2
Irrigation water	litres	2,100
Fertilisers	kg	22
Outputs		
CO_2	kg	4
SO_2	kg	2.1

The results of the LCI become the input into the following phase.

2.2.3 Phase 3 - Life Cycle Impact Assessment

This is where the inputs and outputs reported in the LCI are translated into their contribution to various environmental impact categories (Guinée, 2002). ISO 14044 defines the LCIA as the “phase of life cycle assessment aimed at understanding and evaluating the magnitude and significance of the potential environmental impacts of a product system" (ISO, 2006). The standard specifies three mandatory steps at this phase: selection of impact categories, classification and characterisation.

Selection of impact categories Environmental impact categories typically fall under three overarching categories: impacts on human health, the natural environment, and resource depletion. There are a range of different impact categories available in LCA, and the types used will depend on the chosen impact assessment method.

The following impact categories are used in this study; Global Warming Potential (GWP), Ozone Depletion Potential (ODP), Abiotic Depletion Potential (ADP), Primary Energy Use (MJ), Photochemical Ozone Creation Potential (POCP), Acidification Potential (AP), Eutrophication Potential (EP), Marine Aquatic Ecotoxicity Potential (MAETP), Freshwater Aquatic Ecotoxicity Potential (FAETP), Terrestric Ecotoxicity Potential (TETP), Human Toxicity Potential (HTP). A description of these impact categories is provided in Appendix 1.

Note that each category name includes the word potential. LCA addresses impacts in systems which typically occur at different locations, which means a detailed site-specific assessment is not feasible across the entire life cycle. For this reason, methodological development has focused on potential impacts, regardless of their location. This shortcoming has more relevance for those impact categories that are local or regional in scale (such as AP, EP, MAETP, FAETP, TETP and THP) than for global scale impact categories such as GWP, ODP and ADP.

Classification This is where the LCI results are assigned to one or more impact categories. For example, figure 4 shows the allocation of various emissions to air and water to their respective impact categories. An emission of 1.3 kg of CO_2 is classified as contributing to the GWP impact category, while 0.1 kg of ammonia is assigned to the EP impact category. Note that in some cases, an emission can contribute to more than one impact category, seen in this figure with nitrogen oxides (NO_x) contributing to both AP and EP. The way LCI results are assigned is determined by the type of impact assessment method used.

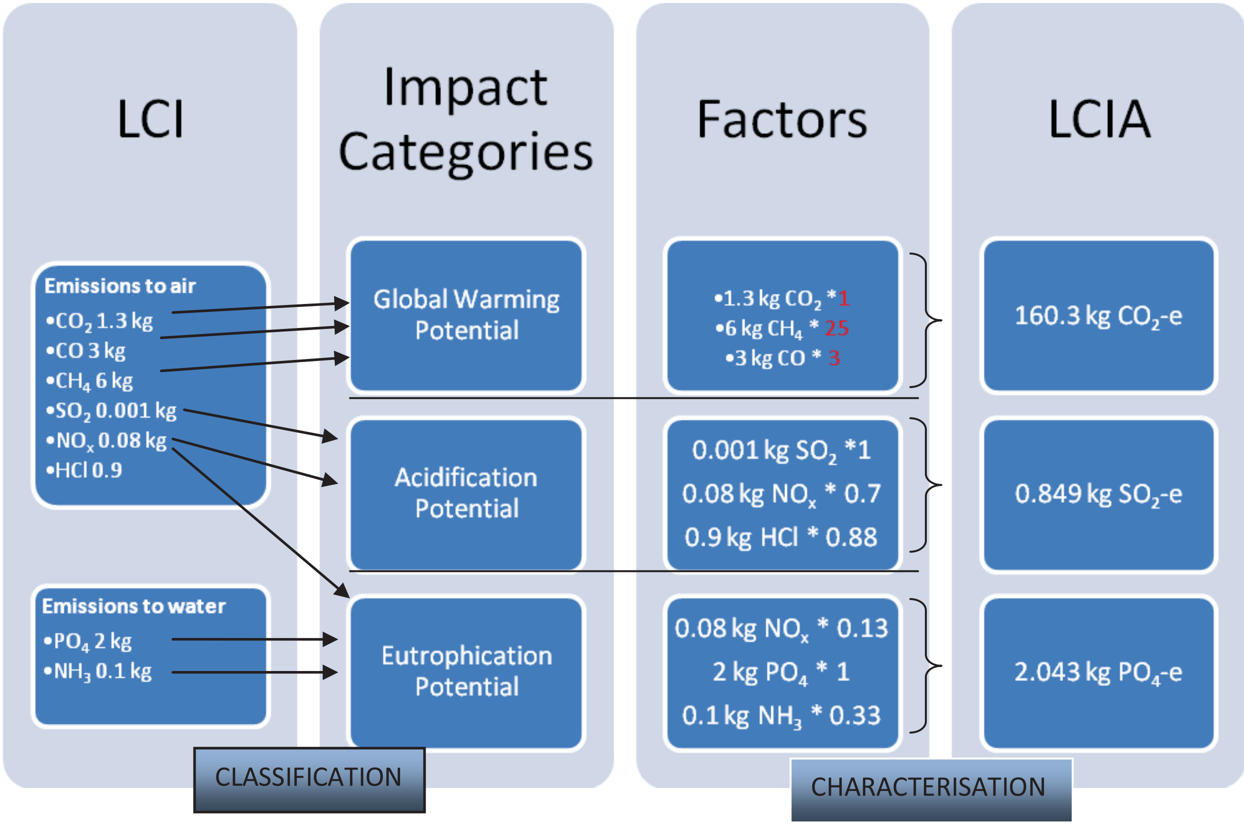

Figure 4: Taking data from the Life Cycle Inventory, going through steps of classification and characterisation, onto the Life Cycle Inventory Analysis. Adapted from (PE, 2009)

Characterisation The estimated scale of the impact associated with each emission is determined using a characterisation factor (CF). A CF is a type of weighting or equivalency factor, which is multiplied by the raw data in the LCI to convert it into a common unit. In the example shown, with focus on GWP (shown in red) emissions of CO_2, CH_4 and CO are converted into a common unit, which in this case is CO_2-equivalent[5]. This common unit is referred to as the category indicator.

The CF applied to each emission (or other flow type) is a reflection of its ability to contribute to the environmental impact relevant to that particular impact category. For example, the CFs used in this example come from Intergovernmental Panel on Climate Change (IPCC) figures, based on the extent to

[5] CO_2-equivalent will be shortened to CO_2-e for the remainder of this thesis

which each gas contributes to radiative forcing in the environment (thus leading to global warming). The CF for CH_4 is 25, which means 1 kg of CH_4 is 25 times more potent at causing this effect than 1 kg of CO_2. Once all emissions have been multiplied by their respective CF, a total sum is derived for that impact category, in this case 160.3 kg CO_2-e.

ISO 14044 also identifies three optional steps in a LCIA: normalisation, grouping and weighting. Briefly, normalisation involves dividing all the impact category results by a common reference value, so that the relative significance of each category result can be compared. Weighting involves assigning a weighting factor to each impact category (depending on their relative importance) to produce a single impact indicator. Grouping, as the name implies, involves grouping various impact categories together. One option is to rank each impact category according to whether they have a high, medium or low environmental significance. Of these three options only normalisation is used in this thesis.

2.2.4 Phase 4 - Interpretation

Three elements are typically considered at this final phase: identification of significant issues, evaluation, and conclusions/recommendations. Identifying significant issues might include looking for environmental hotspots; these might be stages in the life cycle, waste flows, groups of activities, or individual processes.

Evaluation involves the following: a completeness check, to assess the significance of areas where data are of low quality or missing; a consistency check, to investigate whether the assumptions, methods, and data have been applied consistently throughout the study; and a sensitivity check, to investigate how results are affected by changes in data for significant processes or materials. The latter is often supported by scenario analysis, through which environmental improvement opportunities, among others, can be identified (ILCD, 2010b). The importance of the evaluation is that it adds interpretative value to the conclusions and recommendations made, thereby enhancing the reliability of the conclusions that can be drawn from the study (ILCD, 2010b; PE, 2009).

The conclusions and recommendations are based on the outcomes of the earlier elements of the interpretation phase and on the main findings of the LCA. Recommendations for the intended audience are stated in accordance with the goal definition and intended application of the study (ILCD, 2010b).

Limitations of the study are also identified, which need to be highlighted in terms of their relevance to any conclusions and recommendations.

2.3 Applications of LCA

The LCA method has been used in a variety of industries for a range of applications, these include:

- *Comparative assessments* LCA can be used to compare the environmental performance of different products and processes. For example, a Seattle study used LCA to compare the environmental performance of three different options for replacing an old pavement (TRB, 2010);
- *Research and design* LCA can inform product and process designers on which types of materials to use, how products are assembled and which life cycle stages to focus RD & D efforts (Keoleian, 1993);
- *Public policy* LCA can provide useful environmental information in policy decision making. For example, a simplified LCA of the agro fuels supply chain, including biomass production, conversion, and use, will be used by the Swiss government in determining the basis for tax exemption of agro fuels (Klöpffer & Heinrich, 2009);
- *Driving environmental performance* LCA has been used to improve standards in a number of environmental management systems. Various examples include: several green building programmes in the USA (Bowyer, Lindburg, Bratkovich, Fernholz, & Howe, 2008), forestry operations in Sweden (Berg, 1997), car manufacturing in Germany (Finkbeiner & Hoffmann, 2006), arable farming in the Netherlands (de Snoo, 2006) and shrimp farming in Thailand (Scharnhorst, Kohler, Rebitzer, Hischier, & Jolliet, 2004);
- *Marketing* Environmental labelling programmes use LCA to establish and monitor environmental performance criteria (Lim & Park, 2009). Examples include the green building industry (MTS, 2010) and office furniture products (BIFMA, 2008);

- *Carbon footprinting* LCA can be used to measure the life cycle GHG emissions of a product or service, a process also known as carbon footprinting (Finkbeiner, 2009). This will be discussed in more detail in the following chapter.

The last three applications in this list are of most relevance to this thesis.

2.4 Advantages of LCA

LCA has a number of strengths, these include:

- Covering the whole product life cycle in the analysis helps ensure that environmental improvements do not result in a shifting of burdens; either to other life cycle stages, from one geographic area to another, or from one environmental medium to another (EC, 2007; ECJRC, 2010);
- Potential impacts on a wide range of environmental media can be assessed. These include impacts on society and human well being, impacts of changing land use, and emission impacts on air, water, and land;
- Scenario modelling in LCA allows the identification of environmental improvement options for the product or service under study, and an assessment of the impact of various environmental trade-offs;
- LCA presents environmental data in a quantifiable way, meaning it can be useful in accreditation programmes, or for making comparisons between two or more products or processes;
- The systematic nature of LCA means it can provide high quality environmental information regarding a product or service's life cycle (LCI, 2010).

2.5 Disadvantages of LCA

There are, nonetheless, a number of disadvantages associated with LCA:

- The LCA process is relatively complex and can be time-consuming to undertake. For example, a survey of 65 international LCA practitioners found that two of the key factors limiting the uptake of LCA were the time and resource requirements for the collection of data, and the complexity of the LCA method (Cooper, 2006). For this reason streamlined LCA methods can be used. These are effectively shortened versions of LCA, which might exclude certain life cycle stages, activities or processes (Camilleri, 2009);
- Even among LCA studies that are ISO-conformant there is still a high degree of subjectivity in methodological choices, in terms of system boundary setting, selection of data types and impact categories, and choice of impact assessment method (Cleary, 2009; Ulgiati, Raugei, & Bargigli, 2006). This can be a problem because it affects the comparability of results from different studies;
- For many impacts and processes there is limited availability of high quality, consistent data (ILCD, 2010b).

2.6 LCA Studies in the Wine Industry

Most LCA research in the wine industry takes place in Italy and Spain, though a small number of studies have been conducted in other countries including Australia, Canada and the USA. Research has been focused on the assessment of different waste treatment options (Ruggieri et al., 2009), applying LCA with emergy evaluation (Pizzigallo, Granai, & Borsa, 2008) and LCA case studies of wine products. Studies that fall into the latter category have most relevance to this thesis and are accordingly covered in this review.

For most studies referred to below, the functional unit is one 750 ml bottle of wine. In terms of impact assessment methods, CML appears to be the most commonly used (Notarnicola, Tassielli, & Nicoletti, 2003; L. Petti et al., 2006; Point, 2008), though other studies have employed Eco-Indicator 99 (Gonzalez, Klimchuk, & Martin, 2006) and EPS 2000 with EDIP 96 (Montedonico, 2005).

This section discusses a number of aspects raised in these case studies: System boundaries, environmental hotspots, variability in GWP results and normalisation.

2.6.1 System Boundaries

In terms of life cycle stages, most studies begin at the grape growing stage, and continue through to the wine making, packaging and distribution to consumer stages (Aranda, Zabalza, & Scarpellini, 2005; Ardente, Beccali, Cellura, & Marvuglia, 2006; Petti, et al. 2006), while others extend the life cycle through to the end of life stage (Colman & Päster, 2009; Gazulla, Raugei, & Fullana-i-Palmer, 2010; Gonzalez et al., 2006; Pizzigallo et al., 2008; Point, 2008). One of the earlier studies in this area covered the grape growing, wine making and packaging stages only (Notarnicola et al., 2003).

The vineyard establishment stage is generally excluded, although it was included by Fearne, et al. (2009), Montedonico (2005), Pizzigallo, et al. (2008) and Point (2008). The product consumption stage was omitted by most studies, probably because it was deemed irrelevant by researchers (L. Petti et al., 2010). This was investigated by Point (2008) who confirmed that this stage does have minimal impact on the overall life cycle (for example, 0.07% of total GWP).

Most studies reviewed include the manufacture of agrichemicals in the analysis (Aranda et al., 2005; Gonzalez et al., 2006; Notarnicola et al., 2003; Penela, García-Negro, & Quesada, 2009; Point, 2008; Zabalza, Aranda, & Scarpellini, 2003), while the manufacture and distribution of wine making additives (such as bentonite, enzymes and yeasts) tend to be excluded from analysis (Ardente et al., 2006; Notarnicola et al., 2003; L. Petti et al., 2006; Point, 2008). The commonly stated reason for this exclusion is a lack of available data.

The environmental impact of waste products from the grape growing and wine making stages is not considered by most studies, although this was covered by (Ardente et al., 2006; Cichelli, Raggi, & Pattara, 2010). It is interesting to note that while waste is excluded in most studies, Cichelli et al. (2010) reported the emissions resulting from its decomposition is one of the major contributors to the total GWP. However, this study used a waste emissions factor provided in the International Wine Carbon

Calculator (discussed later) which the authors of the calculator acknowledged was of low quality and had a high degree of uncertainty. Gazulla et al. (2010) considered the various waste products generated, but offset the impacts of their decomposition on the assumption that the waste will be used to generate electricity.

While water consumption is considered in many studies (Aranda et al., 2005; Ardente et al., 2006; Gonzalez et al., 2006; Pizzigallo et al., 2008; Zabalza et al., 2003) this data is generally presented in the LCI and not carried through to a full impact assessment. This is due to a current lack of suitable water footprinting methods. Water is not considered in some studies (Penela et al., 2009; Point, 2008).

One area of contention is the question of whether carbon sequestered from the vines should be counted as an environmental credit. However, at this point in time it is generally accepted that the amount of carbon sequestered by the vines is approximately the same as the carbon released during fermentation, and therefore both processes should be excluded from analysis (Greenhalgh, Barber, Mithraratne, Sinclair, & McConachy, 2008). The exclusion of sequestration and fermentation is commonly seen in wine LCA studies (Notarnicola et al., 2003; L. Petti et al., 2006; Point, 2008).

2.6.2 Environmental Hotspots

In general, most studies identified either packaging (Ardente et al., 2006; Notarnicola et al., 2003; L. Petti et al., 2006; Point, 2008) or distribution to consumer (Aranda et al., 2005; Gonzalez et al., 2006) as the life cycle stages with the greatest environmental impact. These two stages are linked, as the impact from transportation is largely related to the type of packaging used. This is because heavier glass bottles require more energy to transport than either shipping in bulk, or using plastic or lightweight bottles. For example, Ardente (2006) found through scenario analysis that transporting bulk wine to market (rather than glass bottles) could reduce the GWP from 1.6 to 1 kg CO_2-e per bottle. Point (2008) found that modelling a consumer who drives a 5 km round trip to purchase the wine contributes 30% towards the total life cycle GWP, although this study allocated the entire environmental burden of this trip to the wine product which may not be considered appropriate.

Depending on the country in which the study is conducted and the purpose of the research, a variety of distribution to consumer distances are modelled in wine LCA studies. Due to the significance of this life cycle stage, this variability can not only make it difficult to compare study results, but also – at least in part – explains the range of results being reported in LCA studies.

The impacts of packaging are largely related to production of the glass bottle, which makes a significant contribution to energy consumption and GWP (Ardente et al., 2006; Notarnicola et al., 2003). In one study bottle production was found to account for 60% of the total GWP (Notarnicola et al., 2003). Bottle production also makes significant contributions to AP and POCP (Gazulla et al., 2010; L. Petti et al., 2006).

The grape growing stage is also generally highlighted as being significant, largely due to the manufacture and application of agrichemicals (Aranda et al., 2005; Gazulla et al., 2010). The application of nitrogen and phosphorus fertilisers also make notable contributions to EP and AP (Gazulla et al., 2010; Notarnicola et al., 2003). The wine making stage is generally recognised as being the stage with the least environmental impact (Aranda et al., 2005; Gazulla et al., 2010; Notarnicola et al., 2003; Point, 2008).

2.6.3 Variability in GWP Results

As noted earlier a wide range of results are reported in the literature. This is illustrated in figure 5 which provides the GWP for the functional unit of one 750ml bottle of wine, from a number of case studies. Given that a range of distribution scenarios are used in wine LCA studies, it is more useful to compare studies based on the grape growing, wine making and packaging stages only. This boundary definition is similar to the cradle-to-gate described in Section 2.2, and will be referred to as the product-at-gate (PAG) for the remainder of this thesis. The blue bars indicate where GWP results for each individual life cycle stage were not available. From this graph, it would seem reasonable to state that the GWP from a bottle of wine is typically somewhere between 0.750 kg to 1.5 kg CO_2-e per bottle.

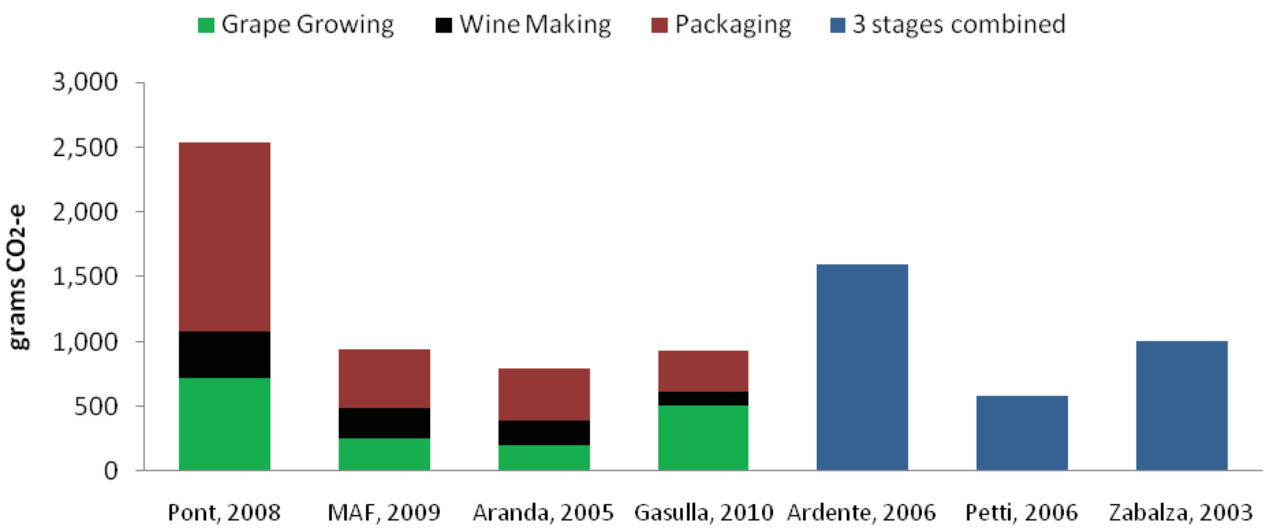

Figure 5: Global Warming Potential for product-at-gate reported in a number of studies[6]

This high variability is likely due to, among others things, variation in the: defining of system boundaries, GHG emissions factor for the glass bottle, data sources, and data quality. Another important contributor might be regional variation in management practices, which are influenced by climate conditions such as rainfall, temperature, humidity and frost occurrence (Ardente et al., 2006).

2.6.4 Normalisation

In terms of studies that have presented normalised results, Petti et al. (2006) found that MAETP had the highest normalised index value, of which hydrogen fluoride from glass production was the largest contributor. FAETP had the second highest index value, with GWP ranking third. Normalisation factors were taken from CML parameters for Europe. It is worth noting this high figure of MAETP is likely to be erroneous; a more recent study has highlighted inaccuracies in normalising this particular impact category. Specific issues relate to the residence times for modelling cause-effect pathways in oceans (Sim, Barry, Clift, & Cowell, 2007).

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[6] Note: The MAF study was not a full LCA study as such, though did apply a full life cycle method with a specific focus on GHG emissions. It is not clear from the Ardente figure if this is CO_2 or CO_2-e. Also, it was not possible to remove the distribution to consumer stage from the Ardente study, so this figure includes a small transportation component.

Aranda (2005) used normalisation factors from Eco-Indicator 99 based on Europe. The study found the Fossil Fuel impact category had the highest normalised value, due largely to vehicle fuel consumption and the energy used in bottle production. The second highest normalised value was Respiratory Inorganics, followed by GWP.

In summary, packaging appears to be the most dominant life cycle stage, largely due to the production of the glass bottle. While the ISO standards offer guidance on how to define system boundaries, there is still an absence of a harmonised approach in terms of which activities are being included and excluded in wine LCA studies. There is also a variety of data sources used for the glass bottle. These are two possible reasons for the high variation in results reported in the literature. Of course, the differences are also explained by the actual differences between bottled wines being produced in different countries, transported to different markets, and produced using different methods and technologies. However, it is likely that as more wine LCA studies are published into the future, a more consistent methodological approach will be adopted by practitioners.

CHAPTER 3: ENVIRONMENTAL MANAGEMENT AND THE WINE INDUSTRY

This chapter describes various elements of environmental management that are relevant to the wine industry. It begins by discussing various drivers that are increasing the demand on the New Zealand wine industry to improve its environmental performance (Section 3.1). It then describes Sustainable Winegrowing New Zealand, the predominant environmental management system in the New Zealand wine industry (Section 3.2). In Sections 3.3 and 3.4 various GHG accounting methods are presented, at both the company- and product-level, and finally a brief description of the Environmental Impact Quotient method (Section 3.5).

3.1 Drivers Influencing Environmental Management in the Wine Industry

There are a number of significant trends occurring in the global market relevant to the environmental profile of the New Zealand wine industry, and these may have a significant impact on future patterns of production and consumption. For New Zealand to remain competitive in the global wine market, it is arguably important that it responds to these drivers and seeks to continuously improve its standard of environmental management. This section outlines four such trends: changing consumer preferences, increasing information demands from retailers, market competition and regulation.

Interestingly, two recent local studies have found that dependence on export markets is an important driver for the adoption of environmental practices in New Zealand wineries (Marshall et al., 2009; Sinha & Akoorie, 2010). This might suggest these pressures are more relevant for wine companies who operate in the international, rather than the local market.

3.1.1 Changing Consumer Preferences

It is generally accepted that consumers worldwide are increasingly interested in knowing more about the environmental impact of the products they buy (Deloitte, 2009; Finkbeiner, 2009; Forbes, Cohen, Cullen, Wratten, & Fountain, 2009; LEK, 2007). For example, in a 2007 UK survey, 56% of consumers stated that they would value information regarding a product's carbon footprint when making a buying decision. Also, 44% of respondents said they would change their buying behavior in some way, if they were equipped with reliable information regarding the carbon footprint of a product or service (LEK, 2007).

A more recent USA study by Deloitte Touche found that a "significant portion of consumers are now considering social and environmental benefits as part of their calculation of product value and purchasing decisions" (Deloitte, 2009). This trend also appears to be evident in the wine market. A New Zealand study by Forbes et al. (2009) reports that 76% of survey respondents indicated they prefer to drink wines that had been produced using environmentally sustainable practices.

These trends pose a potential threat to the New Zealand wine industry. Marshall et al. (2009) note that New Zealand wine exporters risk being shut out of the largest wine import markets unless they begin to develop new standards of environmental stewardship. This was highlighted in a recent report about the New Zealand wine industry prepared for MAF (Greenhalgh & McConachy, 2008, p. 11):

> The UK market appears to be changing, with consumers and retailers paying greater attention to the GHG emissions associated with the products they purchase. If the New Zealand wine industry is to continue to enjoy healthy export sales into the UK and other international markets, it must adapt to these changes…In the future…the disclosure (public or not) of the product GHG emissions may become an 'access right to market'.

Further, a recent study evaluated the impact of changes in consumer preferences in several European countries regarding imported agro-food commodities. Modelling found that New Zealand exporters would likely face significant losses should buyers in the UK, France and Germany start to actively substitute locally-produced food and beverage products for imported items (Ballingall & Winchester, 2009, p. 19):

Our analysis shows that the potential economic impacts of sustainability-related demand shifts could be significant. Preferences have – and will likely continue to – change as major retailers and consumers become more aware of the sustainability credentials of the products that they purchase. This suggests that New Zealand firms will need to continue to invest in measuring, monitoring, reducing and then communicating the environmental footprint of their products, as export income is at stake.

Indirect evidence of changing consumer preferences is shown by the experience of the New Zealand Wine Company. The company achieved carbon neutral certification in 2006, after which it reported an increase in business opportunities and a significant increase in sales growth (NZWC, 2008).

3.1.2 Increasing Information Demand from Importers

As with consumers, a number of major international retailers are also giving greater consideration to the environmental profile of the products they purchase (NZTE, 2009). In 2007 British supermarket giant Tesco's embarked on a plan to provide carbon labels on all of their products (BW, 2010). Tesco's Chief Executive Sir Terry Leahy promotes the carbon label as a tool for customers to compare the carbon footprint of different products, as they can currently compare their price or their nutritional profile (Leahy, 2007). Also, British supermarket chain Sainsbury's has set a target of reducing its CO_2 emissions by 25% by 2012 (Sainsbury's, 2008).

Major supermarket chains in the USA are also involved, such as WalMart, whose Supplier Sustainability Assessment programme encourages suppliers to measure, reduce and report their GHG emissions (Walmart, 2009). In February 2010 Walmart announced its goal of eliminating 20 million tonnes of GHG emissions from its global supply chain by the end of 2015 (WalMart, 2010).

A number of major UK supermarket chains, including Marks and Spencer, Tesco's and Sainsbury's are also signatories to the Global Partnership for Good Agricultural Practice (GLOBALGAP). GLOBALGAP is an international body of retailers that sets voluntary standards for the certification of agricultural products around the world. It requires suppliers of agricultural products to meet standards relating to, among other things, environmental performance. Retailers who become members of GLOBALGAP can "demonstrate that their purchasing policy is in line with the GLOBALGAP core values" (GLOBALGAP, 2010).

A report by SWNZ (2002) raised caution that compliance with GLOBALGAP's regulatory standards[7] may become mandatory for some products in some markets, while Marshall et al. (2009) noted these types of regulatory bodies have the potential to exclude New Zealand wine exporters from certain key markets.

Finally, a number of major British retailers are also signatories to the Courtauld Commitment, which is a voluntary agreement aimed at reducing the carbon and wider environmental impact of the grocery retail sector. The agreement includes a target that requires signatories to reduce the carbon impact of their packaging; wine is one of the product categories. Signatories to the agreement include Marks and Spencer, Tesco's, Sainsbury's, Waitrose and Asda (WRAP, 2010b).

3.1.3 Market Competition

In light of these changing market conditions, a number of major wine producing countries have implemented strategies to improve their environmental performance. These strategies include developing certification programmes (similar to SWNZ), along with codes of practices, toolkits and training (Marshall et al., 2009). For New Zealand to remain competitive in the global wine market, it is arguably important that the standard of environmental management practiced by New Zealand wine producers is at least comparable with major exporters located in other countries.

Australia In 2007 the federal government's Australian Wine and Brandy Corporation published *Directions to 2025*, an overarching strategy for the Australian wine industry. This strategy seeks continuous improvement in the Australian wine sector's environmental performance, with the following strategic responses:

- Illustrate the sector's environmental credentials through effective communication of the sector's programmes and performance (AWBC, 2010);
- Continue to develop and implement systems-based approaches to minimise the wine sector's environmental footprint.

[7] GLOBALGAP guidelines cover grape growing, but not wine production

The major implementation of such a systems-based approach was the Australian Wine Industry Stewardship (AWIS) programme (NLWRA, 2008). Developed in 2004, AWIS was overseen by the Wine Industry National Environmental Committee, and provided a reporting system for wineries to ensure their grape growers are reporting specified environmental assessment criteria. In 2009 AWIS concluded and became the Entwine Australia scheme.

Entwine is administered by the Winemakers Federation of Australia, the leading industry body in Australia. Entwine is a voluntary certification scheme, in which members must report their performance against specified environmental indicators. These include the consumption of electricity, fuels and water, quantity of nitrogen applied, quantity of waste water produced, and the percentage of solid waste that is recycled. Member wineries are also required to report a Scope 1 and 2 carbon footprint[8] each year. At the time of writing, 209 vineyards and 34 wineries had either full or preliminary membership (Entwine, 2010).

California, USA Introduced in 2002, the Sustainable Winegrowing Program (SWP) is administered by the California Sustainable Winegrowing Alliance (CSWA). Under SWP member wineries are given a self-assessment workbook the *Code of Sustainable Winegrowing Practices*, which is essentially a tool for member wineries to assess their practices and learn how to improve their sustainability. The book addresses 227 best practices under environment, social and economic criteria, with a system of metrics which members can use to measure and monitor their performance. The following highlights the aim of the programme (SWP, 2010):

> CSWA will ensure that the California wine community is recognised as a change leader in the global marketplace. CSWA will aggressively develop partnerships for funding education and outreach to advance the understanding and adoption of sustainable practices.

In their 2009 report, SWP reported to have 1,237 vineyards and 329 wineries as members (SWP, 2010). Related to the SWP is a third-party certification programme called the Certified California Sustainable Winegrowing programme. To be certified annual reports must be submitted that show 58 specified environmental performance criteria are met. The winery is also required to develop an annual Action Plan, which states prioritised areas for improvement and demonstrates that continual environmental improvement is being achieved over time (CSWA, 2010; Heckman, 2010). Certified wineries are not

[8] Scope 1 and 2 emissions will be discussed in Section 3.3

currently required to measure their GHG emissions, although this specification is currently undergoing development (CSWA, 2010).

Figure 6: Logo used by certified wineries and vineyards under the California Sustainable Winegrowing programme

South Africa Under the Integrated Production of Wine (IPW) scheme, members are provided with best practice management guidelines, along with a specified set of minimum environmental standards (IPW, 2010). Accredited members receive a label (figure 7) that guarantees, among other things, that sustainable production practices have been adopted. A member winery is not required to disclose its GHG emissions under IPW, though wineries are awarded points towards their label if they measure these emissions (IPW, 2010). At the time of writing around 500 vineyards and wineries were members of the IPW scheme (Schietekat, 2010).

Figure 7: Logo used by certified wineries and vineyards under the Integrated Production of Wine scheme

3.1.4 Regulation

An additional threat facing the New Zealand wine industry is that of regulation. The overarching environmental regulation affecting the wine industry is the Resource Management Act 1991 (RMA). This Act aims to promote the sustainable management of resources, and could be used to manage or mitigate the environmental impact of certain vineyard and winery activities. Such activities might include fertiliser and pesticide use, water and waste management, or the consenting of new vineyards.

Hughey et al. (2005) highlight the following concern regarding the RMA (p.1185):

> In spite of the winegrowing industry's generally proactive environmental positioning, legislation ruled and enforced standards could be introduced. A recent record of significant and persistent non-compliance with consent conditions in the industry has ramifications such as a more regulatory approach being adopted by local councils, a situation the industry would wish to avoid.

A tightening of resource management standards could present a number of difficulties, financial or otherwise, to the New Zealand wine industry. Also, as the Emissions Trading Scheme is rolled out in coming years, the industry will likely face increasing costs from both upstream suppliers (such as electricity companies and agrichemical manufacturers) and downstream service providers (transportation). GLOBALGAP and the Courtauld Commitment (discussed earlier) are other forms of regulation that will likely affect New Zealand wine exporters.

3.2 Sustainable Winegrowing New Zealand

Developed in 1997, SWNZ is a set of voluntary standards, which "provides the framework for companies to continually work towards improving all aspects of their performance in terms of environmental, social and economic sustainability in both the vineyard and the winery" (SWNZ, 2010).

SWNZ is administered by New Zealand Winegrowers, who is the leading body that represents the New Zealand wine industry. It was developed to provide a best practice model of environmental practices in the vineyard and winery, and to address consumer concerns relating to the environmental impacts of wine grape production (SWNZ, 2010).

Figure 8: Logo used by certified wineries and vineyards under the Sustainable Winegrowing programme

Each season members are provided with a score card, which is used to record vineyard and winery activities. These relate to areas such as soils, fertiliser use, irrigation, pest and disease control, and waste management. Every three years score cards are verified through an external audit, and members who meet the accreditation requirements are awarded the use of the SWNZ logo (figure 8). Score cards also allow member wineries to benchmark and monitor their environmental performance over time, as well as against the region and the wider industry. Members are not required to report their GHG emissions. More than 70% of wine produced in New Zealand comes from SWNZ members, with 135 member wineries and 1,244 member vineyards (NZWINE, 2010b).

3.3 Greenhouse Gas Accounting Methods

This section discusses two main types of environmental management approaches relating to GHG management; company-level and product-level methodologies.

3.3.1 Company-level GHG Accounting

One response to the trends described in section 3.1 would be for a company to undertake GHG accounting, which is widely used throughout the world as an environmental management tool (GHGPI, 2010). By measuring its associated GHG emissions, a company can proceed to better manage and subsequently reduce these emissions (carboNZero, 2010). Other potential benefits to a company include the potential for cost reduction (through identifying areas of high energy requirements) and risk management (preparing for future regulation or market demands).

A broad definition of a company GHG footprint is "the total amount of CO_2 and other greenhouse gas emissions for which an individual or organisation is responsible" (CT, 2007, p. 2). This section describes two prominent international standards that provide methodologies for company-level GHG accounting: the GHG Protocol and the Scope 3 Accounting and Reporting Standard.

A brief description of what GHGs are and how they are expressed as a common unit is given in box 1.

Box 1: Greenhouse Gases

A number of GHGs are typically assessed in GHG accounting. The most common ones are listed below along with their respective Global Warming Potentials (GWPs). The GWP is an indicator that reflects the relative potency of a given GHG compared to CO_2. Given that the lifespan of each GHG varies, GWPs are also expressed for a specified period of time, such as 100 years (Forster et al., 2007). For example, the table shows that methane is 25 times more potent in causing global warming over a 100 year period than CO_2.

Table 2: Most common greenhouse gases and their respective Global Warming Potentials.

Greenhouse Gas	Chemical Formula	GWP over 100 years	Common Source
Carbon dioxide	CO_2	1	Fossil fuel use
Methane	CH_4	25	Ruminant animals
Nitrous oxide	N_2O	298	Agriculture
Sulphur hexafluoride	SF6	22,800	Electricity industry
Hydrofluorocarbons	e.g. CHF_3, CH_2F_2, CHF_2CF_3	124 – 14,800	Refrigerants
Perfluorocarbons	e.g. CF_4, C_2F_6, C_3F_8	7,390 – 12,200	Aluminum industry

Source: (IPCC, 2007)

The main reason for using GWPs is to simplify reporting, by allowing a carbon footprint to be expressed as a single figure. This unit is known as CO_2-equivalent or CO_2-e. To illustrate, a product that emits 1kg of CO_2 and 1kg of methane throughout its life cycle will have a carbon footprint of 26 (1 + 25) kg CO_2-e.

3.3.1.1 GHG Protocol

The GHG Protocol is the most widely used international accounting tool for companies (GHGPI, 2010; IDF, 2010). Developed by the World Resources Institute and the World Business Council for Sustainable Development, this protocol provides companies and organisations with a methodology to measure, classify and report emission sources at a corporate level (WEF, 2010).

The GHG Protocol provides the framework for a number of international GHG programmes, including the New Zealand Wine Growers Protocol (GHGPI, 2010) and Landcare New Zealand's carboNZero programme, which is discussed in the following chapter.

The Protocol covers the accounting and reporting of the six GHGs covered by the Kyoto Protocol: CO_2, methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulphur hexafluoride (SF6). It provides guidance on activities such as where to set organisational boundaries, data collection methods, reporting emissions and obtaining verification.

The GHG Protocol divides emission sources into three categories for GHG accounting and reporting purposes. These are based on the level of control an organisation has over them, and are briefly described below (WRI. & WBCSD., 2004):

- Scope 1 (Direct GHG emissions) Occur from sources that are owned or controlled by the company, for example, emissions from the vehicle fleet or the onsite combustion of fuels in boiler rooms;
- Scope 2 (Electricity indirect GHG emissions) Stem from emissions related to the generation of electricity that is purchased by the company;
- Scope 3 (Other indirect GHG emissions) An optional reporting category that allows for the treatment of all other indirect emissions. These emissions are a consequence of the activities of the company, but occur from sources not owned or controlled by the company.

3.3.1.2 Issues with the GHG Protocol

As the adoption of company-level GHG accounting has increased in recent years, there has been growing recognition that in many industries, Scope 3 emissions, despite being significant, are not being counted and reported (Huang, Lenzen, Weber, Murray, & Matthews, 2009).

Recent studies have provided evidence for these concerns. In a review of all 491 economic sectors in the US economy, it was found that Scopes 1 and 2 represent only a small fraction of the total supply chain footprint for most industries. It found that nearly two-thirds of all economic sectors (323 of the 491 industries) would have less than 25% of their total carbon footprint represented by Scopes 1 and 2 emissions. The authors concluded “our results suggest that these protocols will, in general, lead the organisations to footprint estimates that are relatively small in comparison with their total life cycle footprints” (Matthews, Hendrickson, & Weber, 2008, p. 5842).

Another study by Scipioni, Mastrobuono, Mazzi and Manzardo (2010) on Tetra Pak products found that the "great percentage of emissions was due to indirect activities that took place outside of the organisation's control…where there is no monitoring obligation" (Scipioni et al., 2010, p. 305). Increasing concern about the optional nature of the Scope 3 category led to the development of the following standard.

3.3.1.3 Scope 3 Accounting and Reporting Standard

The GHG Protocol Initiative is currently developing the Scope 3 Accounting and Reporting Standard, which is designed to help companies measure and report emissions throughout their supply chain (both upstream and downstream of their operations). Designed largely for companies with significant Scope 3 emissions that wouldn't be covered by the GHG Protocol, this standard takes a wider, life cycle approach to measuring and reporting corporate emissions (WBCSD & WRI, 2009). Under this standard, companies are required to account for and report all Scope 1 and 2 emissions (as required by the GHG Protcol) and the largest Scope 3 sources that collectively account for at least 80% of the total anticipated Scope 3 emissions (WBCSD & WRI, 2009).

3.3.2 Product-level GHG Accounting

While the methods described in the previous section focus at the company-level, this section describes GHG accounting methods at the product-level. Product-level methods take a different approach to company-level methods, in that the system boundaries are oriented around the life cycle of the studied product. They therefore cover the entire value supply chain, covering production processes, distribution and consumption of the studied product.

The result obtained from a product-level GHG assessment is commonly referred to as a product carbon footprint (PCF), which the European Commission defines as the overall amount of CO_2 and other GHG emissions associated with a product, along its supply chain and sometimes including use and end-of-life recovery and disposal (EC, 2007).

As with LCA and company-level GHG accounting, product carbon footprinting enables the identification of environmental hotpots, from which point environmental improvement opportunities can be determined. The following four standards provide methodologies for product-level GHG accounting (note two of these are currently being developed):

- *Publicly Available Specification (PAS 2050)* Published in 2008 by the British Standards Institute, PAS 2050 specifies requirements for the assessment of GHG emissions associated with the life cycle of a product or service. PAS 2050 has been used by a wide range of organisations in many countries and has been adopted by a number of organisations as the default approach to product carbon footprinting (Sinden & Krishnan, 2009);

- *ISO 14040/44* This is the same as the LCA method employed in this thesis, but with a sole focus on the GWP impact category. Hence, a product's carbon footprint can be thought of as a LCA with the analysis limited to emissions that contribute to climate change (EC, 2007);

- *ISO 14067* This ISO standard is currently under development and will specifically focuses on measuring the carbon footprint of products and services (Finkbeiner, 2009). This standard will build largely on ISO 14040/44 and ISO 14025, but will also address how carbon footprinting results are to be communicated. It is planned to be published sometime in 2012 (PCF, 2010);

- *The Product Life Cycle Accounting and Reporting Standard* Currently being developed by the GHG Protocol Initiative alongside the Scope 3 Accounting and Reporting Standard (GHGPI, 2010). It is expected to be completed by December 2010.

3.4 Application of GHG Management Approaches in the New Zealand Wine Industry

Two methods are used in the wine industry that are derived from the above product based standards: the New Zealand GHG Product Accounting Guidelines for the Wine Industry, and the International Wine Industry Greenhouse Gas Protocol and Accounting Tool.

3.3.1 GHG Product Accounting Guidelines for the Wine Industry

These guidelines were developed through a collaboration between New Zealand Winegrowers, Landcare Research, HortResearch and AgriLINK. They are designed with guidance from PAS 2050 for wine companies who are interested in undertaking GHG product accounting (MAF, 2008).

The guidelines provide a method to estimate the life cycle GHG emissions of a bottle of wine, covering the following life cycle stages: construction of new winery (optional), grape growing, wine making, bottling, packaging, distribution, storage at retail (optional) and consumer purchase (optional). In terms of product boundaries, a wine process table is provided, listing which processes need to be included in the analysis and those which are optional to include. Information is also provided on emission factors, reporting metrics, along with a number of relevant methods and equations that can be used for various processes and activities.

These guidelines were used to assess the life cycle GHG emissions of a 750ml bottle of Sauvignon Blanc from a Blenheim-based winery, Wairau River Wines. The total GHG emissions per bottle of wine was 1.2 kg CO_2-e. In terms of individual processes, the largest single contributor was glass bottle production, making up around 28% of the total GHG emissions. The second largest contributor was the shipping of the wine to a foreign port, and thirdly, the electricity consumption of the winery (MAF, 2008). The results of this study were presented in figure 5 in Section 2.6.

3.3.2 International Wine Industry GHG Protocol and Accounting Tool

In 2008, the International Wine Industry GHG Protocol and Accounting Tool was developed through a partnership between the Wine Institute of California, New Zealand Winegrowers, South Africa's IPW scheme and the Winemakers' Federation of Australia.

The International Wine Carbon Calculator (IWCC) is a freely available tool that is based on the GHG Protocol and PAS 2050. It provides a wine industry specific calculator that measures the carbon footprint of winery and vineyard operations. The authors of the calculator note that in terms of product-level carbon emissions, this tool will not satisfy the requirements of international standards for LCA. At any rate, it will provide general guidance on the most significant activities and processes throughout the wine product life cycle (Provisor, 2008). The IWCC is integrated into a number of international environmental management systems in the wine industry, such as the Entwine programme in Australia and the IPW scheme in South Africa.

3.5 Environmental Impact Quotient Method

The Environmental Impact Quotient (EIQ) method was developed by Cornell University in New York, and is designed to quantify the environmental impact of agrichemical application. The method calculates a single indicator for the environmental impact of over 120 common fruit and vegetable agrichemicals (insecticides, pesticides, fungicides and herbicides) used in commercial agriculture. The intended purpose is to help growers make more environmentally sound pesticide choices, by being able to determine which programme or pesticide is likely to have the lower environmental impact (IPM, 2010).

The EIQ uses a ranking method that ranks toxicological data and chemical property information on a set scale and then multiplies that score by the application rate (Striegler, Allen, Bergmeier, & Harris, 2009). The formula is provided below:

EIQ value * rate of active ingredient * application rate = EIQ Field Use Rating

While this method may lack a degree of accuracy (due to the complexities of the fate pathway systems) it nonetheless serves as a useful management tool for vineyard managers (IPM, 2010).

3.6 Summary

In response to the market trends identified in this section, wine companies can employ GHG assessment methods to measure and manage their environmental performance. Such methods are available at the company-level, which is based on the activities of a given company, or at product-level, which is based on the life cycle of the product. One issue with the GHG protocol is that it does not require the measurement of Scope 3 emissions, through this will be dealt with under the Scope 3 Accounting and Reporting Standard. Two GHG assessment methods have been developed for the wine industry, though these do not address non-GHG related impacts. Wine industries in a number of other countries are actively involved in improving their standards of environmental management; some of these industries are working towards integrating GHG accounting with their management programmes.

CHAPTER 4: ENVIRONMENTAL LABELLING AND THE WINE INDUSTRY

The practice of environmental labelling is often linked to the environmental management system of a given company. If a company improves its standards of environmental management and wishes to demonstrate this to the market, it will use some form of environmental labelling. This is a dynamic two-way process, as the increasing presence of environmental labelling in the marketplace has created a more competitive environment in which companies compete on their environmental credentials.

Environmental labels can take many forms, but their general aim is to provide consumers with information about the environmental impact of a product, service or company. This chapter describes various types of environmental labelling programmes currently used by the wine industry. It is divided into sections on company-level schemes (Section 4.1), product-level labelling (Section 4.2) and finally a brief discussion on several issues associated with product carbon labelling (Section 4.3).

4.1 Company-Level Schemes

There are a number of ways in which wine companies might demonstrate their company's environmental credentials. Two options currently used are certification as a "sustainable wine grower" under industry-specific programmes and/or through claiming carbon neutrality. The former was discussed in Chapter 3, while Section 4.1.1 discusses carbon neutrality claims.

4.1.1 Carbon Neutrality

This section briefly describes some examples of carbon neutral programmes being used by the wine industry around the world.

CarboNZero is administered by the New Zealand Crown Research Institute Landcare Research and has the claim of being the world's first accredited ISO14065[9] GHG verifier outside of the USA (carboNZero, 2010). CarboNZero, along with the Certified Emissions Measurement and Reduction Scheme (CEMARS) (see below) were also the world's first GHG certification schemes to be accredited under the International Accreditation Forum (IAF) (carboNZero, 2010).

Through carboNZero companies can receive carbon neutral certification at both the company- and product-level. To obtain carbon neutral certification for a given product, the company must obtain certification for its company first. The operational boundaries covered at a company-level require a range of Scope 1 and 2 emissions to be reported, along with the embodied emissions associated with packaging as a Scope 3 emission. System boundaries, among other things, are provided in carbon disclosure statements available on the carboNZero website. GHG measurement is conducted in compliance with ISO 14064-1 2006[10].

Under this scheme companies are required to provide a reduction plan to reduce their emissions, and can then purchase offsets against any remaining unavoidable emissions (carboNZero, 2010). In 2006, the New Zealand Wine Company became the first winery to achieve carbon neutral certification. At the time of writing four other New Zealand wine companies held certification, at both the company-level and for some of their wine products (carboNZero, 2010).

CarboNZero also operate CEMARS, which enables companies to measure their GHG emissions in compliance with the GHG Protocol and ISO 14064 (carboNZero, 2010). It is particularly suitable for large companies, such as large industrial emitters, where offsetting is not a viable option. CEMARS gives companies an opportunity to demonstrate to the market that they have measured their carbon

[9] ISO 14065 (2007). Greenhouse gases: Requirements for greenhouse gas validation and verification bodies for use in accreditation or other forms of recognition

[10] ISO 14064-1 (2006).Greenhouse gases - Part 1: Specification with guidance at the organisation level for quantification and reporting of greenhouse gas emissions and removals

footprint, and are actively engaged in environmental management. At the time of writing two New Zealand wine companies held CEMARS certification (carboNZero, 2010).

The Carbon Reduction Institute (CRI) in Australia administers the carbon neutral certification programme $NoCO_2$. $NoCO_2$ requires the company to measure all emissions associated with their products throughout the supply chain. Hence, it also covers various Scope 3 emissions, including waste production, air travel, and emissions associated with the extraction, refinement and transport of any fuels used (CRI, 2010b). A number of wine companies have $NoCO_2$ certification, including Brand New Vintage Ltd in South Australia (CRI, 2010b). It is worth noting that while $NoCO_2$'s assessment method is based on ISO 14064-1, it is not internationally accredited under the IAF (CRI, 2010a).

In 2007 the Oregon Environmental Council and the Oregon Wine Board joined together to develop the Carbon Neutral Challenge. This is an initiative for Oregon wineries and vineyards to assess and reduce their carbon footprint, with the ultimate goal of becoming carbon neutral. At the time of writing fourteen Oregon wineries participating in the programme had completed their first year of the carbon neutral programme (CNC, 2010).

4.2 Product Labelling

There are a variety of environmental labelling schemes available at a product-level. This section includes a description of three ISO standards relevant to environmental labelling, and some examples of carbon neutral labelling in the wine industry.

4.2.1 ISO Environmental Labelling Standards

The ISO 14020[11] series of standards provide guiding principles for the development and use of environmental labels and declarations. This series defines three types of environmental labels: Type I, Type II and Type III labels. To follow is a description of Type I, II and III, along with their associated advantages and disadvantages.

[11] ISO 14020 (2000). Environmental labels and declarations: General principles

ISO 14024 (1999) (Type I) Environmental Labelling

Type I labels help consumers identify the most environmentally preferable products within a given product category by means of a label. These labels tell the consumer that this product has reached a recognised standard of environmental performance, while claims are verified by an independent third-party.

Labelling schemes that comply with ISO 14024 require that the environmental criteria be based on life cycle considerations, which is why the LCA tool can be used to identify and set the relevant environmental criteria and thresholds for a product category.

Two key advantages of programmes that conform to this standard are that labels are easily identifiable in the marketplace, and that product claims are independently verified. The main disadvantages are that the information the label provides is generally very limited, and that not all relevant environmental issues might be covered.

A common example of a Type I label is the carbon label, which has been increasingly prevalent in the marketplace over recent years (Finkbeiner, 2009; WEF, 2010). A carbon label states the carbon footprint of the product and is typically expressed in grams or kilograms. The life cycle stages covered will vary depending on the requirements of the labelling programme; some provide a cradle-to-gate footprint while others also include the distribution to consumer stage.

One of the most prominent international product carbon labelling programmes is the Carbon Reduction Label, which was launched in 2007 in the UK. The label displays the product's carbon footprint in grams, as well as a statement of the producer's commitment to lowering the product's carbon footprint. PAS 2050 is used to set requirements for companies to follow in becoming certified under their programme (CT, 2010). A number of different products currently use the label, ranging from crisps,

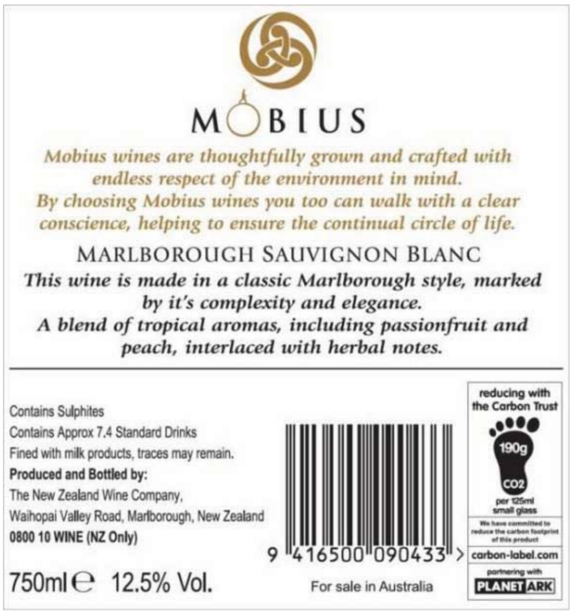

Figure 9 Mobius wine bottle featuring the Carbon Reduction Label

toilet tissue to paving products. At the time of writing nearly two billion pounds worth of goods bearing the label are sold each year in the UK (BG, 2010). British supermarket giant Tesco's is one of the major supermarket chains in the UK promoting this label (BW, 2010).

In early 2011 the New Zealand Wine Company will be launching its Mobius brand, which will be the first wine brand to feature the Carbon Reduction Label on its bottles (figure 9). As the programme requires the inclusion of the distribution to consumer stage, the label will be adapted for each export market (NZWC, 2010). Also, Tesco's is currently working with New Zealand winery Highfield Estate to develop a house brand New Zealand Sauvignon Blanc and Pinot Noir (Tesco, 2010). Similar carbon labelling programmes are also operating in Japan (McCurry, 2008), Switzerland (climatop, 2010) and Germany (PCFP, 2010).

ISO 14021 (1999) (Type II) Self-declared Environmental Claims

This standard is focused on the way wording is used in self-declared environmental claims. Among other things, it sets specifications and qualifications for the use of terms like: Recyclable, recycled content, reduced resource use, reduced energy consumption and reduced water consumption (Lee & Uehara, 2003). It also bars the use of terms such as ozone friendly, green and non-polluting, on the grounds of their vagueness.

The goal of this standard is to make environmental claims in voluntary labelling more precise, to promote environmental improvements, to reduce inaccurate claims and to allow the consumer to make well informed choices (Lavallée & Plouffe, 2004). An example of a Type II label comes from the Epsom Group, which uses the label below (figure 10) on one of their products.

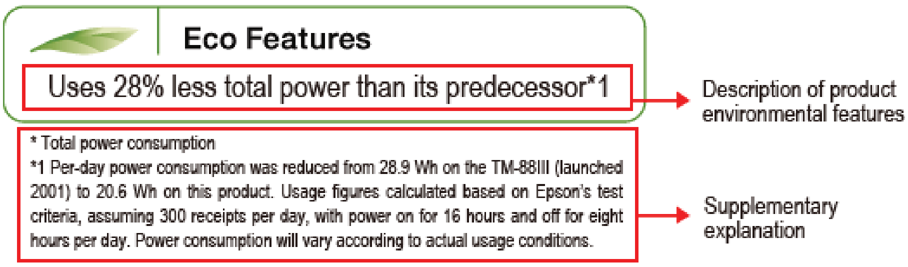

Figure 10: An example of a Type II label from the Epsom Group

Unlike Type I and III standards, claims under the Type II standard do not need to be verified by an impartial third party; these claims are 'self-declared'. Despite this, the information used to inform the claim must be verifiable and made available to anyone requesting it.

Though a product LCA is not required, this standard does require that the product's life cycle is considered when specific environmental claims are made.

The main advantage of Type II labelling is its ease of uptake. Given that no LCA is required it is cheaper and easier for companies to make claims under this standard. A major disadvantage is that the declared product information does not have to accurately reflect the full environmental impact of a given product, which can be misleading. For example, a product bearing the label containing recycled content might actually have a greater overall environmental impact than a product using 100% virgin materials (Lavallée & Plouffe, 2004). Another shortcoming is that environmental claims do not need to be verified by independent third parties.

ISO 14025 (2006) (Type III) Environmental Declarations

This standard describes the process for developing Environmental Product Declarations (EPDs). An EPD is used by producers to describe and communicate the life cycle environmental profile of their product in a report card like format. It states the product's performance on a number of pre-set categories of environmental parameters, these might include: 'content of recycled materials', 'information on toxic substances' or 'CO_2-e emissions' (Christiansen, Wesnæs, & Weidema, 2006).

Development of an EPD requires consideration of the Product Category Rules (PCR). A PCR is a document that provides a standardised LCA methodology for a given product category or service type. The consistent use of PCRs within a given product category helps ensure that consumers are comparing 'apples with apples', and that all significant environmental impacts are covered.

The main advantages with EPDs are that the consumer is provided with comprehensive product information, that claims are verified by a third party, and direct product comparisons can be made (Christiansen et al., 2006).

Disadvantages of EPDs include the fact they can be costly and time consuming to produce, they do not state whether or not a product has passed a threshold level on certain environmental criteria, and that the information provided to the consumer can sometimes be difficult to comprehend (Lavallée & Plouffe, 2004). In recognition of this latter issue, the International EPD System introduced the concept of "single-issue EPDs", which only focus on one or a small number of impact categories (IEPDS, 2010). The first example of a single-issue EPD was the "Climate Declaration", which only describes GHG emissions, expressed as CO_2-e, for a product's life cycle (ClimateDec, 2010).

At the time of writing, two PCRs had been developed in the wine industry; for Packaged Sparkling Red, White and Rose Wines (EPD, 2006) and for the Wine of Fresh Grapes (except sparkling wine) and Grape Must (IEC, 2009). These cover the grape growing (including vineyard planting), wine making, packaging and distribution life cycle stages. Contributions to the following impact categories are required to be considered: GWP, OCP, POCP, AP, EP and energy consumption.

4.2.2 Carbon Neutrality Labelling

As stated earlier (Section 4.1.1) a number of New Zealand wine companies have obtained carboNZero certification for their wine products. The required product system boundary covers both vineyard and winery activities, along with packaging and distribution to the consumer. There appears to be at least some degree of variability in terms of what needs to be included in the system boundaries. For example, some companies include waste production and the emissions associated with the manufacture of agrichemicals in the vineyard, while others do not (carboNZero, 2010).

In September 2009, Australian-based Taylors Wines became the first winery in the world to produce, market and sell a range of 100% carbon neutral wines following the requirements of the LCA standard ISO 14044. While the label is self-claimed, the assessment was conducted by consultancy firm Provisor[12] and was verified by a third party (Taylors, 2009).

The $NoCO_2$ programme in Australia also certifies carbon neutrality for products. To achieve neutrality, all of the GHG emitted during the product life cycle, covering vineyard practices, packaging and delivery of the product are required to be reduced to zero. Offsets are allowed for any remaining emissions. Two wine products that have received $NoCO_2$ certification are Bulloak range from Zilzie Wines in Victoria) and Nuevo Mundo wine from De Martino winery in Chile (CRI, 2010a; Morganstern, 2009).

[12] Provisor was the leading developer of the International Wine Carbon Calculator.

4.3 Issues Associated with Product Carbon Labelling

Firstly, some authors argue that a single-indicator approach, such as a carbon footprint can be misleading, especially if other important environmental impacts are not considered. In these cases it can lead to a shifting of environmental burdens (Schmidt, 2009). This may occur where consumers begin purchasing more products that, despite having a low carbon footprint, are associated with high levels of environmental damage in other impact categories (EC, 2007; Feifel, Walk, & Wursthorn, 2010).

These concerns are valid, given that a number of studies have shown that while a product or process might have a low carbon footprint, significant other environmental impacts exist. Such studies include:

- waste management, where processes that have a minor carbon footprint have significant respiratory, acidification and nitrification impacts (Fallaha et al., 2009);
- manufacturing, where certain metals (such as copper, mercury and nickel) are used in production (Laurent, 2009);
- coffee production, where the impact of water usage dominates (Humbert et al., 2009);
- biofuels, which have a low carbon footprint but can involve major impacts on land use change, water consumption and the application of fertilisers and pesticides (Jungbluth et al., 2008).

A second issue is a lack of a standardised method for carbon footprinting, as there is not one single harmonised methodology for the measuring and communication of a PCF (de Koning, Schowanek, Dewaele, Weisbrod, & Guinée, 2010). For carbon labelling to work effectively in the marketplace, identical assessment methods need to be applied to identical products. Two carbon footprint values have to be directly comparable with each other so that misleading or oversimplified conclusions can be avoided (de Koning et al., 2010; Pant et al., 2008; Schmidt, 2009).

4.4 Summary

A number of wine producing countries, including New Zealand, are actively engaged in environmental labelling programmes, both at the company- and product-level. At the company-level, wineries may wish to demonstrate their environmental credentials through claiming carbon neutrality, or through becoming certified as a “sustainable wine grower” under industry-specific programmes. At the product-level, labelling might involve claiming carbon neutrality, or simply disclosing the PCF on the label. Two issues with product carbon labelling are whether GHG emissions sufficiently represent the full environmental impact of a given product, and the importance of ensuring a standardised assessment method so that two products can be directly compared in the marketplace. In terms of providing better information to the consumer, it is arguably more appropriate to have environmental labels that represent a broader range of environmental impacts, in other words, beyond the carbon footprint.

CHAPTER 5: THE LCA CASE STUDIES

This chapter presents the method and results for the LCA case studies.

5.1 Goal and Scope Definition

5.1.1 Goal Definition

The goal definition involves stating and justifying the goal of the study and specifying the intended use of the results (Guinée, 2002).

The Intended Application The goal of this LCA is to identify the various environmental impacts associated with producing a bottle of Sauvignon Blanc wine at two New Zealand wineries during the 2010 vintage. These wineries are located in the Hawke's Bay and Blenheim, and will be referred to as the North Island (NI) and South Island (SI) wineries respectively for the remainder of this thesis. The results of this LCA will be used to recommend ways to improve the standard of environmental management in the New Zealand wine industry and inform its practice of environmental labelling. The study will identify environmental hotspots throughout the wine life cycle and look for environmental improvement opportunities.

Reasons for Conducting the Study The commissioner and part-funder of this project is the wine company that owns both the studied wineries. The reason for conducting the study itself is to support the wider aim and objectives of this thesis.

Target Audience The intended audience of this study is any New Zealand vineyard or winery who wishes to improve its environmental performance. Another interested party is the administrators of SWNZ, who may wish to incorporate various recommendations made in this study into their management programme.

Limitations of the Study This LCA focuses on Sauvignon Blanc produced in the 2010 vintage in two New Zealand case study wineries; the results cannot therefore be considered representative of all New Zealand wineries producing Sauvignon Blanc. This is acknowledged in the interpretation of the study results.

5.1.2 Scope Definition

The goal definition guides development of the scope definition, which describes what exactly will be analysed and how (ILCD, 2010b).

Functional Unit The functional unit for this study is a 750ml bottle of Sauvignon Blanc wine that is purchased by a consumer in the UK. This is chosen because the objective of the entire studied process is to produce wine and sell it to consumers. Further, this size bottle is most commonly used as the functional unit for wine LCA studies, while the client company also packages their Sauvignon Blanc in this sized bottle. The alcoholic content of this wine is 13%.

System Boundaries The studied life cycle begins when pruning commences at the beginning of June 2009 and continues through to bottling of the wine product in September 2010. The bottle is then transported to a supermarket in the UK where it is purchased by a consumer.

Activities Excluded From Analysis The following processes and activities are excluded from this study:

- Establishment of the vineyard, which has been excluded for three main reasons. Firstly, due to a lack of available data, as both vineyards were constructed between 10-15 years ago. Secondly, vineyards have an economic lifespan of around 25-30 years, meaning the impacts associated with vineyard establishment that are attributed to the functional unit are assumed to be minimal. Thirdly, the vineyard site was previously used for agricultural purposes, so the various potential impacts of land use change – such as the quantity of soil organic carbon, nutrient losses and soil erosion – are considered to be relatively minor;
- The consumption stage, as this impact is considered to be negligible (see Section 2.6.1);
- Carbon sequestration from the vines. There is still ongoing debate as to whether this should be included in the carbon accounting of vineyards. However the IPCC considers that the amount of

carbon sequestered by the vines is approximately the same as the carbon released during fermentation (Greenhalgh et al., 2008);

- Emissions of volatile organic compounds (VOCs) from wine production, due to difficulties in collecting relevant data.

Modelling Principles This study uses the attributional modelling approach, which is more appropriate than consequential modelling for three main reasons. Firstly, the studied model aims to depict the wine life cycle as it can be observed, and links various processes and flows throughout the supply chain that can be *attributed* to the functional unit. Secondly, given that the studied wineries have a limited share of the total wine production in New Zealand, changes in their operations would have little effect or consequence on other surrounding systems (such as other wineries or the functioning of the market). Finally, this study does not attempt to model the forecasted consequences of any decisions made by the winery.

Impact Assessment Method and Impact Categories The following impact categories will be used in this study; Global Warming Potential (GWP), Ozone Depletion Potential (ODP), Abiotic Depletion Potential (ADP), Primary Energy Use (MJ), Photochemical Ozone Creation Potential (POCP), Acidification Potential (AP), Eutrophication Potential (EP), Marine Aquatic Ecotoxicity Potential (MAETP), Freshwater Aquatic Ecotoxicity Potential (FAETP), Terrestric Ecotoxicity Potential (TEP), Human Toxicity Potential (HTP).

A description of these impact categories is provided in Appendix 1. It appears from the literature that these impact categories cover all relevant environmental issues associated with the wine life cycle. Impact assessment results will be calculated using the characterisation factors available in CML 2001. Normalised results will be calculated using CML 2001.

Assumptions The following assumptions are made in this LCA:

- On the vineyard the vine prunings are shredded and left on the rows. They are assumed to undergo aerobic decomposition, so the methane emissions associated with their decomposition are considered to be minimal. The same applies to the winery waste water, which is constantly aerated while being treated;

- The trellising wire and irrigation piping used on the vineyard are assumed to have a lifespan of 50 and 70 years respectively;

- All materials shipped from overseas to New Zealand are assumed to be delivered to the nearest ports to each winery;
- 100% backhauling, that is, for all container ship and truck movements the transport mode is assumed to be filled to capacity on the return journey (though admittedly this is not likely to be the case all the time);
- There are no losses of wine during the shipping process, either through bottle breakages or wine left over in the tank for bulk shipping (though admittedly this is not likely to be the case all the time);
- A range of average figures are used to estimate production-based emissions of agrichemicals (discussed in detail in Section 5.2).

Allocation The only activity that might be relevant to allocation in this study is the grazing of sheep on the vineyard. The question is whether the methane (and other emissions) associated with the sheep grazing should be modelled within this studied product system, or attributed to the product system from which they came (the neighbouring farm). The baseline scenario in this study assumes there are no sheep emissions, that is, allocation is avoided by attributing these emissions to another product system. This is discussed in more detail in the LCI (see Section 5.2). Other activities where allocation could potentially become an issue include marc and electricity use. Allocation is avoided in both these cases, which is also discussed in Section 5.2.

Data Collection, Software and Databases The foreground system in this study (see figure 11) includes the grape growing, wine making and bottling processes. Given that data quality is of higher importance for foreground systems (ILCD, 2010b) much of the data collected for these processes are from primary sources. These sources include data collected by the vineyard and winery staff, power company websites, a carbon accounting report from the bottling facility and the Franklin study (see Section 5.2).

The background system covers all relevant processes associated with the foreground system. This includes: distribution of the final product to consumer, the fuel and electricity supply chain, and the manufacturing and transportation of agrichemicals, wine making additives and the glass bottle. Given that data quality is of lesser importance for background systems (ILCD, 2010b) much of the data collected for these processes are from secondary sources. These include two databases contained in the GaBi software (GaBi and Plastics Europe) and the method developed by Green (1987) for estimating embodied GHG emissions in agrichemicals.

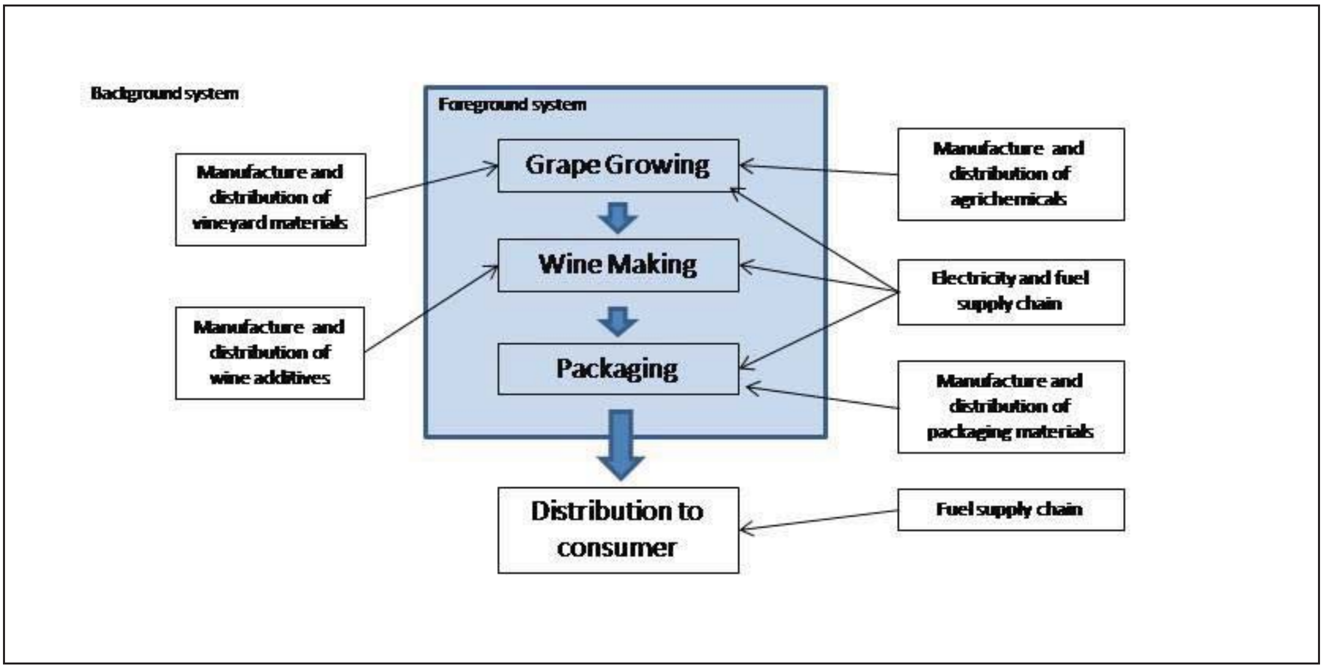

Figure 11: Illustration of the foreground and background systems in this study

GaBi 4 was used to create the LCA model. Two databases contained in the software (GaBi and Plastics Europe) provide a majority of the LCI data for the various raw and process materials used in the studied system. Other key sources include: the GHG Accounting Guidelines for the New Zealand Wine Industry (MAF, 2008), Barber (2009) who provides a list of life cycle based GHG emission factors for various energy and electricity inputs, and the Guidance for Voluntary, Corporate Greenhouse Gas Reporting document, published by the Ministry for the Environment (MfE, 2008).

A full list of data sources and the associated materials and activities is provided in table 3 below. Note the fuel based method is applied to estimate all mobile and stationary fuel emissions. Effort has been made to achieve a level of methodological consistency in the use of secondary data sets. For example, New Zealand specific data were prioritised where this was available. Where this was not available the dataset with the highest perceived quality was selected.

Table 3: Data sources used for the various materials and activities throughout the studied life cycle

Materials and Activities	Relevant Life Cycle Stage	Source/s	Geography of Technology
Materials			
Replacement posts	Grape Growing	(Nebel, Alcorn, & Wittstock, 2009)	New Zealand
Lubricating oil	Grape Growing	GaBi	Not known
Polyvinyl chloride pipe (irrigation)	Grape Growing	Plastics Europe	Europe
Polyethylene low density granulate (irrigation)	Grape Growing	Plastics Europe	Europe
Manufacture of agrichemicals	Grape Growing	(Green, 1987)	Generic
Manufacture of wine making additives	Wine Making	EcoInvent V.2. (MAF, 2008)	Generic
Lees waste to landfill	Wine Making	(MfE, 2008)	New Zealand
Shrink wrap	Packaging	Plastics Europe	Europe
Manufacture of glass bottle and cardboard carton	Packaging	(Franklin, 2006)	Australia
Manufacture of screw cap	Packaging	(PWC, 2008)	France
Paper labels	Packaging	GaBi	Not known
Electricity consumption	All	GaBi	New Zealand
International travel	Wine Making	GaBi	Generic
Stationary Fuel Combustion			
LPG	Grape Growing	(Barber, 2009)	New Zealand
Diesel	Grape Growing	(MfE, 2008)	New Zealand
Fuel and energy inputs into bottling process	Packaging	Bottling facility in Hawke's Bay	New Zealand

Mobile Fuel Combustion			
Diesel	Grape Growing	(MfE, 2008)	New Zealand
Jet A1 fuel	Grape Growing	(MED, 2007)	New Zealand
Grazing sheep[13]	Grape growing	(MfE, 2010)	New Zealand
Transportation			
Truck - 20-26 t, 17.3 t payload	All stages	GaBi	Used for all long distance road travel
Solo truck, up to 7.5 t, 3.3 t payload	All stages	GaBi	Used for local product deliveries and waste removal
Container ship	All stages	GaBi	Generic

Data Quality Requirements Effort has been made to compile an inventory data set that is fully representative and appropriate for each of the life cycle stages. It is of course desirable to attain an inventory data set that accurately reflects the full environmental impact of each process and activity, though in some cases (due to data availability) this is not possible.

The following considerations relate to data quality in this study:

- While the time period under study extends from June 2009 to September 2010, the data used for a small number of activities – such as emission factors for electricity and fuel combustion - relates to the previous year (due to the absence of up-to-date data);
- Emissions factors for sheep are taken from the New Zealand GHG Inventory. While emission factors are dependent on a number of variables (such as the age, diet and weight of the sheep) the figures used are based on national averages (MfE, 2010);
- Due to a shortage of data, many figures derived for production-based emissions of agrichemicals are taken from *average data* using a method developed by (Green, 1987). This is discussed in more detail in the LCI (Section 5.2).

[13] Sheep grazing data is taken from the National GHG Inventory. Pers Comm, Mike Rollo at AgResearch 27th September. The figures used here are those used to develop the Inventory.

In terms of temporal considerations, as in many agricultural applications, nutrients from fertilisers applied in the previous year's vintage may remain in the field and be utilised by the vines during this year's growth. However, due to the complexity involved of accurately modelling this effect, it is ignored and assumed to be irrelevant.

5.2 Life Cycle Inventory Analysis (LCI)

The LCI analysis covers the collection of data and modelling of the product system, and is done in a way that fits with the requirements specified in the goal and scope definition (ILCD, 2010b). This section lists and quantifies the various input flows (materials, energy and consumables) and output flows (emissions and waste) that are relevant to this study. A brief description of each studied process follows, and each section relates to a separate life cycle stage. More detail on data source and methodology is provided for certain processes that have been identified by previous studies to be significant in the wine life cycle.

Consistency and quality of data and methodologies are important requirements for a valid LCA study (ILCD, 2010b) and this has been a key consideration in the development of this inventory.

A flow chart of the studied system is provided in figure 12:

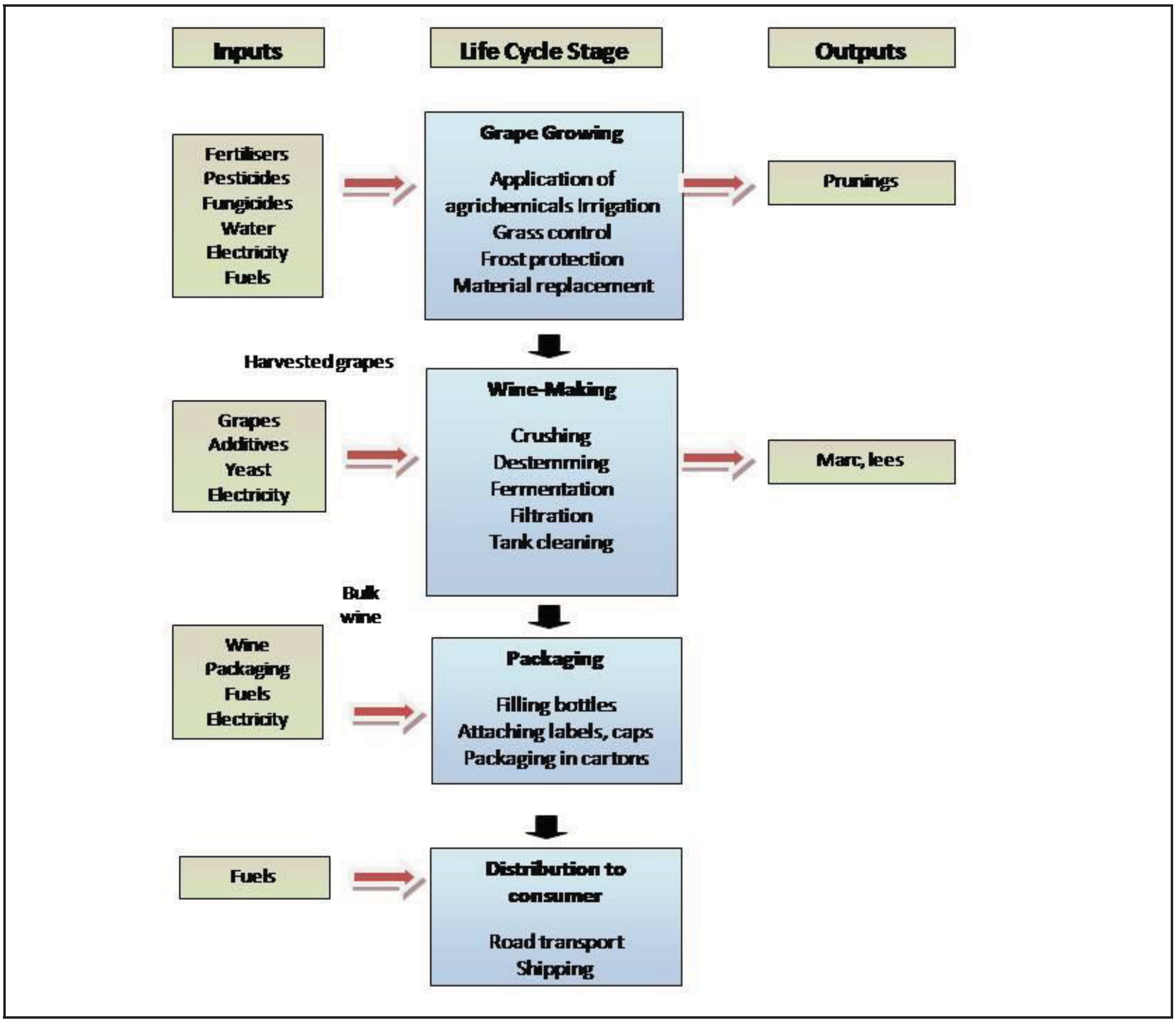

Figure 12: Flow chart of the product system as defined in this study

5.2.1 Grape Growing

The grape growing stage models the following processes and activities for the 2010 vintage: the use of agrichemicals, frost protection, irrigation, mowing between the rows, harvesting, trimming and mulching, bird management, maintenance oil top-ups, the grazing of sheep on the rows and the replacement of various infrastructural materials. The only capital goods included in this study are the irrigation system and trellising wire. The data collected for these activities have been scaled to a relevant reference flow for this life cycle stage: one hectare of vineyard.

While water is arguably one of the most important resources, a widely standardised water footprinting method is yet to be developed. For this reason, water quantities are presented in this LCI, but not carried through to full impact assessment.

Use of Agrichemicals Fungicides, herbicides and pesticides were applied in the vineyard from September 2009 to March 2010. Fungicides are chemical compounds that inhibit the growth of various fungi, such as leaf rot, black spot, dead arm, downy mildew, powdery mildew and botrytis. Herbicides are applied to control the growth of weeds under and between the rows, while fertilisers are applied to encourage growth of the vines and grapes.

The diesel consumption required for the application of these products is included in this study, along with the manufacture and transportation of all products used.

The embodied energy associated with each agrichemical is estimated using the methodology described in MAF (2008). The embodied energy is a sum of the energy requirements involved in the manufacture, formulation and packaging of a given agrichemical. To estimate the resultant GHG emissions, this sum is multiplied by a standard emissions factor of 64.1 g CO_2-e/MJ. This method is based on that developed by Green (1987) and is commonly cited in the literature (Audsley, Stacey, Parsons, & Williams, 2009; Canals, 2003; Weidema & Meeusen, 2000). Note this method only considers GHG emissions, and that non-GHG related impacts are not considered.

In accordance with this method, where manufacturing data were not available for a specific product, an average for that type of agrichemical class was used (see table 4).

Table 4: Default manufacturing energy requirements for agrichemicals. Source (Green, 1987).

	Manufacture MJ/kg ai	Country of origin
Fungicide	97	Germany
Fungicide – inorganic (Cu and S)	5	New Zealand
Herbicide, general	203	Australia
Herbicide (glyphosate)	437	Australia
Insecticide	185	Australia
Plant growth regulator	87	Germany
Biological control agent	77	Australia/Germany
Oil	9	Australia
Other	10	Australia

In terms of product formulation, where data were not available for a specific product, an average for that formulation type is used. The three most common types of formulation are emulsifiable concentrates, wettable powders and granules, which have embodied energy contents per tonne of agrichemical of 20, 30 and 15 MJ/kg respectively (Green, 1987). The energy content in packaging is assumed to be 2 MJ/kg product (Green, 1987). For each product, transportation from the country of manufacture is modelled in GaBi, assuming a container ship with a 20-26 tonne-truck delivering the product from the nearest port to the winery.

Given this method uses average figures for each agrichemical class and formulation type, as opposed to actual data for each product used, it inherently brings a degree of uncertainty into the results. Despite this uncertainty it is considered more appropriate to include these emissions rather than exclude them, as inclusion would arguably provide a more accurate representation of the studied product's life cycle.

Methods used to estimate field-based emissions from fertilisers were derived from (Brentrup, Kusters, Lammel, & Kuhlmann, 2000) and (Dalgaard, Halberg, Kristensen, & Larsen, 2006). It is important to note these estimates are based on average figures. Actual emission quantities for a specific site will depend on variables such as soil type and climatic conditions around the time of spraying (Brentrup et al., 2000).

In terms of field-based pesticide emissions, this LCA assumes that 10% of pesticides are released to air and 5% are released to the soil and groundwater. These assumptions are based on average figures provided in EPA (1995) and Birkveda & Hauschild (2006). It is important to note these estimates are based on average figures and that the actual emission quantities are extremely difficult to predict. Actual releases to the environment for a given vineyard will depend on a number of variables, such as: soil type, spray application techniques, geological conditions, crop stage and climatic conditions at the time of spraying (USEPA, 1995).

In terms of impact assessment factors, those for captan and glyphosate were used to represent all fungicides and herbicides (respectively) applied[14] in the vineyards. These are the only two active ingredients for which impact assessment factors were available. Captan was also used to represent the only insecticide applied; Thiovit Jet, which is a combined fungicide and miticide. The EIQ method (Section 3.5) identifies captan as having a lower toxicity than most of the other active ingredients used, which suggests the full environmental impact of agrichemical emissions may be slightly understated. While this is an approximate method, it is considered more appropriate to include these emissions rather than exclude them, as inclusion would arguably provide a more accurate representation of the studied product's life cycle.

Frost Protection Frost can be a major problem in the vineyard. It can kill green tissue on the vines and cause bud damage, significantly reducing the crop yield. Three frost control methods were used during this vintage: helicopters (generally used in frost events to remove water and frost from the vines), wind machines (which help mix the warm upper air strata into the cooler vineyard) and frost pots (which burn diesel to heat the air between the rows) (Trought, Howell, & Cherry, 1999). The associated jet and diesel fuel requirements are included in this study.

Electricity for Irrigation Electricity consumption data were collected from the respective power providers, who provide separate meter readings for a number of irrigation pumps at both vineyards.

[14] The brand names of all agrichemical products used were; Scala, Pristine, Quintec, Captan, Dithane, Kumulus, Glyphosate, Brownout, Browndown, Buster, Amino Quelant Calcium, Panda, Biostart Folacin, Mycorrin, Magnesium sulphate, Switch and Du-wett.

Mowing The grass in between the rows is cut a number of times throughout the year. The associated diesel consumption is included in this study.

Harvesting The grapes are harvested using tractors, harvesters and a truck. The associated diesel consumption is included in this study.

Trimming and Mulching At both wineries the vine prunings are hand-picked, mechanically shredded and left on the rows. As the vines are shredded they are assumed to undergo aerobic decomposition, so the methane emissions associated with their decomposition is considered to be minimal. However, the diesel consumption of the tractor/shredder unit is included in this study. According to the Principal Viticulturalist at both wineries, the nitrogen content of these clippings does not displace the need for nitrogen fertilisers. As such, the return of nutrients in the clippings back into the soil is considered to contribute to a steady state system, or part of the biogenic cycle, and is not modelled in this study.

Bird Management Birds can be a problem from when the fruits first arrive through to harvest, because they either damage or eat the fruit. Liquefied Petroleum Gas (LPG) fired bird control guns are used to scare birds away from the vineyards. The associated combustion emissions are included in this study.

Maintenance Oil During the vintage a range of equipment and machinery was topped up with engine oil. The manufacture and local distribution of this product is included.

Sheep Grazing A number of sheep were grazed on the vineyards between July and September 2009. Sheep help limit the growth of grass, while their manure also releases nutrients back into the soil. The Principal Viticulturist estimated the use of sheep displaced the need for two mower passes and one application of herbicide.

There are various arguments for and against modelling this displacement of mower passes and herbicide application in the LCA study. On one hand, the sheep will be emitting methane on the vineyard, but they would be doing this anyway at some other farm (as part of another product system). One could therefore argue that these methane emissions should not be attributed to the vineyard system. On the other hand, the grazing of sheep means emissions from mowing and herbicide application are avoided, so can the vineyard claim this environmental credit while not bearing the environmental burden of the sheep? Given this dilemma, sheep emissions are not modelled in the baseline results, neither are the avoided emissions associated with mowing and herbicide use. However scenario analysis is performed to compare the resultant impacts of different ways of modelling for this activity (see Chapter 6).

Replacement Materials Each year a number of infrastructural materials are replaced in the vineyard, either because they have reached the end of their useful life or due to damage from a heavy vehicle. The manufacture and transportation of three such materials - posts, clips and staples – is included in this study.

Capital Goods In terms of vineyard infrastructure that is relatively more permanent, the trellising wire and irrigation piping are included in this study. These items are assumed to have a lifespan of 50 and 70 years respectively. The impact of manufacturing and distributing these materials is allocated to this vintage by dividing the material quantities by their respective life spans.

Table 5 provides the relevant inputs and outputs of the studied system during the grape growing stage. The data source for all flows is the vineyard and winery staff, apart from electricity consumption, which is taken from power company websites.

Table 5: Inventory table for the grape growing life cycle stage

Flow	Unit	Quantity per ha		Transport from manufacturer included
		NI	SI	
Inputs				
Agrichemicals[15]				
Fungicides	kg or litres	26 (18)	28 (21.4)	Y
Herbicides	kg or litres	14 (4.4)	10 (3.3)	Y
Fertilisers	kg or litres	16.5 (10.3)	19.5 (12.2)	Y
Frost Protection				
Helicopter passes, jet fuel	litres	0	73	Y
Wind machines, diesel	litres	73	176	Y
Frost pots, diesel	litres	194	12	Y

[15] Re: Agrichemicals. Figures are the total product weights/quantities applied; quantities of active ingredients are given in brackets. Note that for estimating the impacts of 'transport from manufacturer', 1 litre of product is assumed to weigh 1 kilogram.

Irrigation				
Electricity for pumps	kWh	1,271	934	Y
Water	m^3	Unknown	1,693	N
Mobile fuel consumption				
Spray application	litres	40 (7 runs)	51 (9 runs)	Y
Herbicide	litres	20 (3 runs)	20 (3 runs)	Y
Mower	litres	18 (3 runs)	18 (3 runs)	Y
Mower, trimmer, mulcher	litres	36.5	36.5	Y
Harvester	litres	30	30	Y
Other				
LPG for bird guns	kg	0	0.3	N
Maintenance oil	litres	13	9.2	N
Grazing sheep	heads	6	10	N
Replacement posts	no.	8	5	Y
Replacement clips	no.	35	27	Y
Replacement staples	no.	20	14	Y
Trellising wire	m	27,812	27,812	Y
Irrigation (laterals)	m	3,818	3,818	Y
Irrigation (mains and submains)	m	175[1]	175[1]	Y
Outputs				
Grapes – Sauvignon Blanc	tonnes	14.24	9.67	
Vine trimmings	tonnes	14.25	11.11	N/A

5.2.2 Wine Making

The grapes are mechanically harvested from the end of March to around mid April. They are then transported to the winery, which is on the same site (in the case of SI) or 22km away (NI). The grapes are destemmed by machine and then crushed. The resulting mixture, composed of juice, skins, seeds and pulp is called must. This is drained, filtered and transferred to an insulated stainless steel fermentation tank. After a number of months, and various yeasts and wine additives have been added, fermentation is complete. The wine then undergoes one more filtration process and is then left in the tank ready to be bottled. The data collected for these activities have been scaled to a relevant reference flow for this life cycle stage: the entire Sauvignon Blanc production at each winery.

Electricity Consumption in the Winery Electricity is required throughout the year to maintain the fermentation tanks at the required temperature. Consumption data were downloaded from the websites of the two power companies, with the usage period covering the six months from harvest to when the first wine went to bottle.

Yeasts and Wine Additives During the wine making process a number of yeasts and other additives are added to the tanks. Yeast is the catalyst as the sugars are converted to alcohol and CO_2. A range of additional acidifying, filtering, anti-bacterial, fining, clarifying and stabilising agents are also added, depending on the desired quality, taste and composition of the wine and the preferences of the wine maker.

There is little data available on the embodied energy associated with manufacturing yeasts and wine additives. However, some data are provided by MAF (2008) which are largely taken from EcoInvent v.2. 2007 and the LCA Food Database (LCAFD, 2010). Where data are not available for general additives or non-yeast products, a default (estimate) value of 0.5 kg CO_2-e kg and 0.729[16] kg CO_2-e per kg of product respectively is used (MAF, 2008).

Given that a large number of yeasts and additives can be used, it is not feasible to include each individual product in this study. Nonetheless, the manufacture and distribution of a majority of products used (based on mass) were included; 94% and 91% of all products used in the SI and NI wineries respectively.

Casual Staff International Travel To assist with the harvest and wine making process, two expert wine makers were flown in from Germany and Spain (NI) and three from Australia, Italy and Spain (SI). The environmental impact of this travel was allocated based on the percentage of Sauvignon Blanc produced at each winery.

Gases Various gases are used in the winery for a range of purposes. Nitrogen, argon and CO_2 are used for adjusting dissolved gases and blanketing ullaged tanks[17]. Pestigas is used to kill fruit fly, SO_2 is used as a preservative and LPG is used to power the forklift. The manufacture of these gases, along with the air

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[16] Based on data from a factory in Ireland, includes materials, energy uses, infrastructure, and emissions.
[17] Ullage refers to the space in the tank above the liquid wine, where the gases are injected.

emissions associated with their use is not included in this study, though the transportation of the gas bottles to and from the local supplier is included.

Fermentation Tank Cleaning After finished wine is taken from the tank it is cleaned and sanitised using three chemicals: Fermabriet, Citric and Proxitane. The manufacture of these products is not included in this study, although the transportation of each product from the country of origin is included.

Refrigerants As both wineries have relatively new wine making equipment there was no need for a top up of any HFCs in the refrigeration system. Thus, there are no fugitive HFC emissions relevant to this study.

Winery Waste Products

The main organic wastes produced in a modern winery include grape marc, lees and waste water (Ruggieri et al., 2009). Each of these three waste products is included in the analysis.

Lees Waste Wine lees are made up of dead yeast cells, grape seeds, pulp, tartrates, stem and skin fragments that are deposited during ageing of the wine. The wine is separated from the lees through a rotary drum vacuum system soon after fermentation and taken to a local landfill that flares methane. An accurate landfill emission factor specific to lees was not found in the literature. For example, the lees emission factor provided in the IWCC is considered by the authors to be "inadequate" and of low quality (Provisor, 2008, p. 85). For this reason average New Zealand emissions data is used instead (MfE, 2008)[18].

The quality of the data used to determine the environmental impact of lees waste is lower than for the other processes. This is for a number of reasons. Firstly, it was difficult to derive an exact weight quantity that relates to the reference flow, as the lees is also constantly being produced from other white wines. Secondly, lees contains clay-based products[19] that will not degrade further in a landfill. To account for this an estimate was made on the average quantity of clay products added to the tanks, and this figure (20% by mass) was deducted from the final weight. A third source of uncertainty arises from the use of a national average waste emission factor for food and garden waste.

[18] National average; land filling of garden and food waste (with landfill gas recovery) 0.572 kg CO_2-e/kg waste
[19] These products are used to filter the wine in the tanks

Lees is the only winery waste stream modelled in this study that crosses the system boundary from the technosphere into the ecosphere. In other words, it is the only waste stream for which air emissions – arising from its decomposition in landfill – is estimated.

Waste Water Winery wastewater stems largely from washing floors and equipment such as the fermentation tanks, hoses and barrels. Effluent waste water quantities are included in this study, but as for irrigation water, are only presented in this LCI and not carried through to impact assessment. Each discharge is passed to a sump tank where it is aerated and then pumped onto the vineyards. As the waste water is aerated, the GHG emissions associated with its treatment are considered to be minimal.

An estimate on the electricity consumption of the aerator is included in this study. While the pumps run continuously throughout the year, it cannot be assumed they are always running on maximum load. To account for this, the kWh figure used to estimate consumption was lower than the stated maximum output; reduced from 1.4 to 1.2 kWh (NI) and from 2.2 to 2.0 kWh (SI). This method was considered sufficiently accurate by the manufacturer of the aerators (pers. Comm.).

Grape Marc After the juice is pressed, a waste by-product called marc (or pomace) is produced. Marc consists of the skins, pulp, seeds, and stems of the grapes. At NI the marc is composted on the vineyard and then returned to some of these blocks as compost (though not any of the Sauvignon Blanc blocks). According to the Principal Viticulturalist, the nitrogen content of the marc does not displace the need for nitrogen fertilisers. Thus, the return of these nutrients back into the soil is considered a steady state system and are not modeled in this study. As the marc is aerobically composted, any emissions associated with its decomposition are considered to be minimal. However, the GHG emissions associated with turning the compost are included.

At SI the marc is transported to a nearby dairy farm (1 km away) where it is spread out over several fields and fed to the cows. As the marc is considered more of a sweet treat for the cows rather than a solid food, it is not considered to displace the need for any cow feed. Thus, only the transportation of the marc to the local dairy farm is modelled for SI.

Waste Cardboard and Glass This waste is mostly from wine deliveries and barrel packaging. The quantity of cardboard and glass recycled, and its transportation to the local recycling station, is included in this study, though the environmental impact or benefit associated with this recycling is not modelled.

The following tables provide the relevant inputs and outputs of the studied system during the wine making stage. The inputs and outputs in table 6 are relevant to the entire Sauvignon Blanc production at each winery for the 2010 vintage, while those for table 7 relate to quantities of wine additives used in one fermentation tank only. The data sources for all the flows listed in the following two tables are the winery staff, apart from the electricity consumption, which is taken from power company's websites.

Table 6: Inventory table for entire Sauvignon Blanc production during the wine making life cycle stage

Flow	**Unit**	**Quantity for Vintage**	
		NI	**SI**
Inputs			
Grapes	tonnes	203.06	1079.43
Electricity for winery	kWh	60,148	143,350
Electricity for waste water	kWh	2,568	6,806
Staff international travel	km	18,533	32,849
Filled gas bottles to winery	tonne km	82.12	96.53
Water for tank cleaning	kg or litres	742	1180
Outputs			
Wine – Sauvignon Blanc	litres	146,651	777,333
Lees	kg	3,694	7,520
Marc	tonnes	30	159
Cardboard waste	kg	102	545
Glass waste	kg	84	443
Waste water	m^3	651	2,226
Empty gas bottles to supplier	tonne km	61.47	46.5

Table 7: Inventory table for wine additives used in the wine making life cycle stage

Wine additives[20]	Unit	Quantity for one tank	
		NI	SI
Potassium Metabisulphite	kg	46.84	19.90
Cream of tartar	kg	87.79	60.33
Lafazym CL	kg	0.38	0.37
Perlite	kg	87.16	66.07
Supervit	kg	0.24	0.62
Nutristart	kg	7.70	-
Diammonium phosphate	kg	8.16	4.82
Dynastart	kg	3.15	7.52
Activit	kg	4.63	85.46
Celluflux	kg	-	55.58
Nacalit bentonite	kg	87.18	-

5.2.3 Packaging

The bulk wine from both wineries is bottled in the Hawke's Bay.

Glass Bottle Production The bottles are manufactured in Adelaide, Australia. They are shipped to Auckland then brought to the Hawke's Bay by truck. The bottles contain 68% recycled content and weigh 515 g. Box 2 discusses the variability of GHG emissions factors available in the literature.

[20] Figures shown here for wine additives are those used in one fermentation tank at each winery.

Box 2: Emissions Factors for Glass Production

Current data relating to emissions from glass production is not well known (Provisor, 2008) and the figures used in the literature are highly varied. Table 8 lists a range of studies and reports, with the respective GHG emissions factors used. Obviously, various non-GHG related emissions are also associated with glass bottle production. However, given that the quantity of GHG emissions (measured in CO_2-e) is an indicator used in most studies, it is used here to compare alternative data sources for this study.

This data variation is an interesting feature of the wine LCA literature, given the relative importance of the glass bottle in the wine life cycle. It is not evident why such a range exists, though likely reasons include differences in countries' electricity mixes, the level of recycled content in the bottle, the type and quality of furnaces used, variations in methodology, and data quality.

Table 8: Various greenhouse gas emission factors used for glass bottle production in the literature

	Franklin (2006)	**Franklin (2006)** **Transport removed**	**GaBi**	**EcoInvent v.2, 2007**	**Australian LCI**	**Ardente, et al. (2006)**	**IWCC**	**Point (2008)**
kg CO_2-e per bottle	0.651	0.574	0.308 (green)* 0.395 (white)*	0.322 (green)* 0.339 (white)*	1.2*	0.44	1.13	1.42
Bottle weight (g)	527	527	515	515	515	Unknown	515	Unknown

* Denotes where the emissions figure relates to general glass

The GHG emissions factor used in this thesis is taken from (Franklin, 2006) with *transport removed* (second column in Table 8). The Franklin study provides a LCI for 101 atmospheric and 72 waterborne emissions associated with the manufacture of a 527 g glass wine bottle and associated cardboard carton packaging. The peer-reviewed LCI study is based on ISO 14040 and 14041 and extends from the production of raw materials through to postconsumer disposal; the recycling scenario assumes a glass recycling rate of 15%.

The study appears to be the most comprehensive and well documented LCA on this subject available in the literature. The authors' goals for data quality were to "to use the best available and most representative data for the materials used and processes performed in terms of time, geographic and technology coverage" (Franklin, 2006, pp. A-9) and the study results "are believed to be as accurate and reasonable as possible" (Franklin, 2006, pp. A-10). For these and the following reasons, this study was selected as the data source:

- Emission data is provided for a range of pollutants that contribute to a wide range of CML 2001 impact categories[21];
- The derived figure of 0.574 kg CO_2.e per bottle sits in the middle of the range when compared with other data sources;
- The weight of the bottle assessed was 527 g, similar to the weight of the bottles used by the case study wineries (515 g);
- The inventory is largely based on actual industry data;
- This study relates specifically to the production of wine glass bottles;
- The emissions figure incorporates an end-of-life scenario, which means an additional life cycle stage did not have to be modelled in this study.

The original figures for air emissions provided in this study (far left column in table 8) include the road transportation of the filled glass bottle to a hypothetical distribution centre, at a distance of 2,414 km. As this activity is not relevant to this New Zealand study, its contribution to air

[21] These figures were entered into GaBi, and characterized using the CML 2001 method.

emissions has been removed. This was done by modelling a hypothetical truck movement in GaBi, using the stated distance and filled bottle weights provided in the LCI, and subtracting the resulting 85 air emissions associated with this activity from the bottle inventory.

Transportation to Bottling Finished wine from the NI winery is transported by truck to the bottling facility, which is located nearby. Wine from the SI winery is transported as follows. It is placed in a 20,000 litre ISO tank, loaded onto a truck, and taken to a nearby railhead. The tank is then placed on rolling stock, shipped to Wellington on the Interislander ferry, then taken by rail to Napier railhead. From there it is placed on a truck and taken to the bottling facility.

Secondary Packaging The screw caps are made in West Auckland and composed of 100% virgin aluminium. Emissions data for the manufacture of screw caps is taken from a LCA study on wine closures by (PWC, 2008). The manufacture of paper labels and shrink wrap is taken from the GaBi database. The distribution of all packaging materials, from place of manufacture to the Hawke's Bay bottling facility, is included in this study.

Table 9 lists the relevant inputs and outputs of the studied system during the packaging stage. The 'weight or quantity' column refers to the amount of product or material associated with one bottle of packaged wine that is ready for shipment. Data sources are staff at the winery and bottling facility.

Table 9: Inventory table for the packaging life cycle stage

Flow	**Unit**	**Weight or Quantity**
Inputs		
Wine from winery	ml	750
Electricity	kWh	0.0302
LPG forklift	kg	0.00093
Petrol	litres	0.00009
Diesel	litres	0.00075
Glass bottle	g	515
Screw cap	g	4.53
Label	g	1.34

Cardboard carton	g	38.17
Shrink wrap	g	0.86
Wooden pallet	g	29.76
Output		
One bottle of packaged Sauvignon Blanc wine	kg	1.34

5.2.4 Distribution to Consumer

Shipping to the UK The bottled and packaged wine is taken by truck to the Port of Napier and transported by container ship to the Port of Tilbury, London. It is then transported by truck to a supermarket in London. Box 3 discusses the uncertainty surrounding shipping emissions factors.

Box 3: Emissions Factors for Shipping

The emissions factor used in shipping is expressed in terms of the amount of CO_2e that is emitted for transporting one tonne of freight a distance of one kilometre (Greenhalgh et al., 2008).

While there appears to be some degree of consistency in the emissions factors from various data sources (table 10) it is worth noting the high degree of uncertainty associated with determining the emission intensity of a given shipping voyage. This uncertainty is due to variants such as: how well the available cargo space is utilised (freight packing density), the fuel efficiency of the ship, the length of ballast voyages (where no cargo is carried), ship speed, and weather and currents (DELFT, 2006). For example, a recent study by MAF (2010b) reviewed emissions factors for international shipping, and reported that figures vary by a factor of 30 for bulk cargo vessels, 10 for refrigerated vessels, and 3 to 5 for container ships.

Table 10: A range of data sources and their respective shipping emissions factors for container ships

	GaBi container ship	CE Delft[1]	Defra[2]	(WRAP, 2007)[3]	(MAF, 2010b)[4]
kg CO_2-e/tonne km	0.01363	0.01454	0.0153	0.014	0.022 (Range = 0.0054 to 0.038)

[1] Container ship average, taken from (Provisor, 2008); [2] Large container ship; [3] Large container vessel; [4] Based on an average of 16 container ships.

In this thesis the GaBi figure is used; a figure which seems to fit reasonably well with the literature. The fact that wine from the studied wineries is shipped to the UK on container ships implies at least some degree of uncertainty is reduced, given the findings by (MAF, 2010b).

Car trip to supermarket At this final stage of the studied life cycle, a typical UK consumer to retailer scenario will be taken from (DEFRA, 2005). The DEFRA study assumes the typical consumer trip to the supermarket involves a distance travelled of 5.5 km and the purchase of an average of 11 kg of groceries. In order to allocate the environmental burden of this activity, it is assumed the bottle of wine makes up 12% of the weight of groceries (1.3 kg divided by 11 kg). Therefore, 12% of the car journey (equating to 0.65 km) is allocated to wine. Table 11 shows the absolute distances modelled for this life cycle stage, which were subsequently normalised to the functional unit. Note, as 100% backhauling is assumed for shipping and trucking movements, the distances shown represent the one-way journey for each activity.

Table 11: Transportation distances for the distribution to consumer life cycle stage

Distribution Activity	Unit	Distance	Data Source
Truck: Bottling facility to Port of Napier	km	Undisclosed[22]	
Shipping to UK: Napier to Port of Tilbury, London, UK	km	20,692	www.searates.com
Truck: Port of Tilbury to supermarket	km	43	
Car trip to supermarket	km	5.5	(DEFRA, 2005)

[22] This distance is not given as to keep the identity of the bottling company confidential

5.3 Life Cycle Impact Assessment (LCIA)

The LCIA is where the inputs and outputs reported in the LCI are assessed with respect to their contribution to various environmental impact categories (Guinée, 2002). This section provides a general overview of the results, followed by a closer look at each impact category. It concludes with a normalisation of the study results.

For each impact category a graph is provided showing the relative contribution of each life cycle stage to that particular category. For clarity of understanding, the following summarises the boundaries for each life cycle stage:

- Grape Growing – from winter pruning to delivering grapes to the winery;
- Wine Making – from grape delivery to when wine is about to leave the winery;
- Packaging – from wine leaving the winery to when it is fully packaged ready for shipment;
- Distribution – from wine leaving the bottling facility to when it reaches the consumer's household.

For most impact categories a table is provided showing all activities that contribute at least three per cent[23] to the result for that impact category.

5.3.1 General Findings

Figure 13 provides a compilation of the LCIA results for the different impact categories, showing the relative contribution that each life cycle stage makes to each impact category. It can be seen that packaging (red) is the most environmentally significant life cycle stage, followed by distribution to consumer (blue). The only impact category in which grape growing is the most dominant life cycle stage is FAETP. Interestingly, wine making itself makes a notably minor contribution among all impact categories.

[23] Three percent was chosen as the cut-off for practical reasons in terms of presenting the data, because it enables identification of a small number of activities that make the biggest contribution.

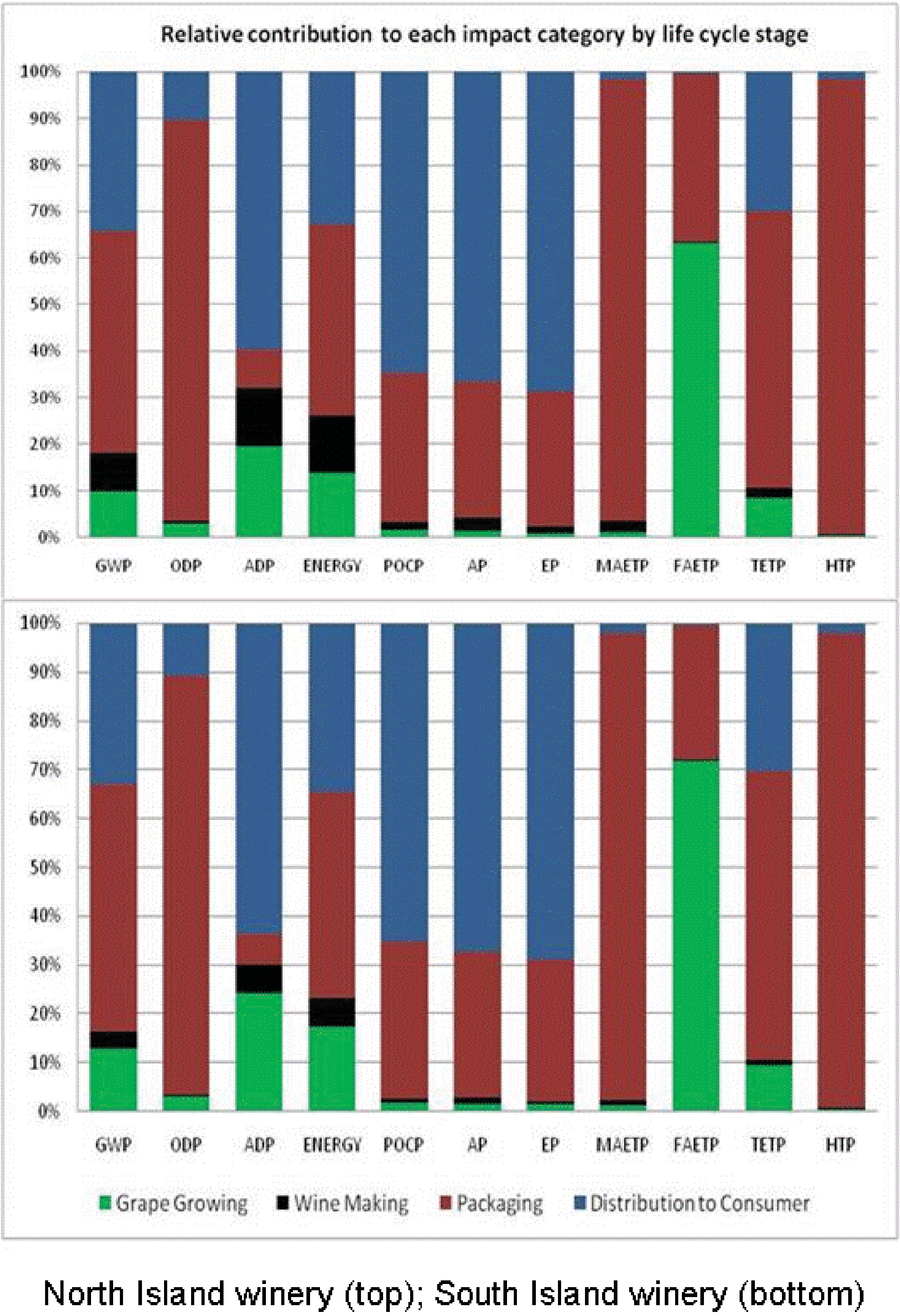

Figure 13: Relative contribution of each life cycle stage to the eleven impact categories

5.3.2 Results by Impact Category

Global Warming Potential

Greenhouse gases (GHGs) are substances with the ability to absorb infrared radiation from the earth (radiative forcing) which cause the temperature at the earth's surface to rise (Guinée, 2002). This impact category indicates the contribution of wine to global warming. The GWP results for each winery by life cycle stage are shown in figure 14. It can be seen that packaging and distribution to consumer are the main contributors to GWP.

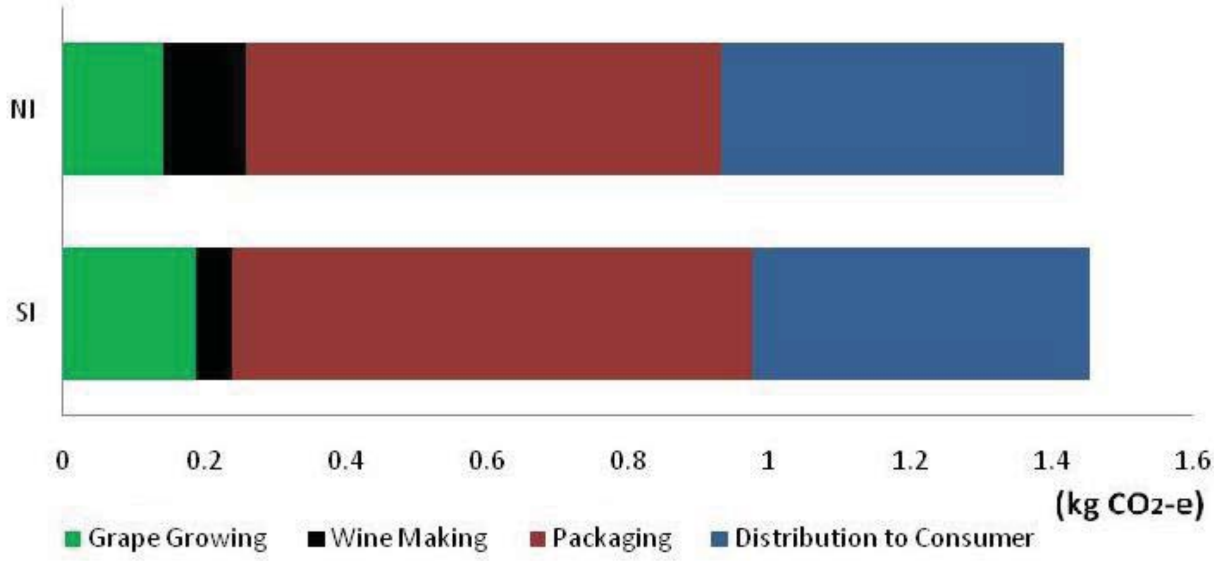

Figure 14: Contribution of each life cycle stage to Global Warming Potential in both wineries

Table 12 shows the main contributors to GWP throughout the wine life cycle. The main sources of GHGs are the CO_2 emissions associated with electricity generation, glass bottle production, and the burning of fuels for transport and frost protection.

Table 12: Main contributing activities to Global Warming Potential in both wineries

Life Cycle Stage	Grape Growing	Wine Making	Packaging				Distribution to Consumer		Other
Activity	Frost protection	Electricity	Transport to Bottling	Glass bottle production	Transport bottle from manufacturer	Screw cap production	Shipping to UK	Car trip to supermarket	
% contribution to total GWP (NI)	5	7	-	42	3	3	27	8	5
% contribution to total GWP (SI)	6	3	5	41	3	3	26	7	6

Ozone Layer Depletion Potential

This category relates to the ability of emissions to contribute to the depletion of the stratospheric ozone layer (ILCD, 2010a). Figure 15 shows that packaging is the main contributor to this impact category, followed by distribution to consumer.

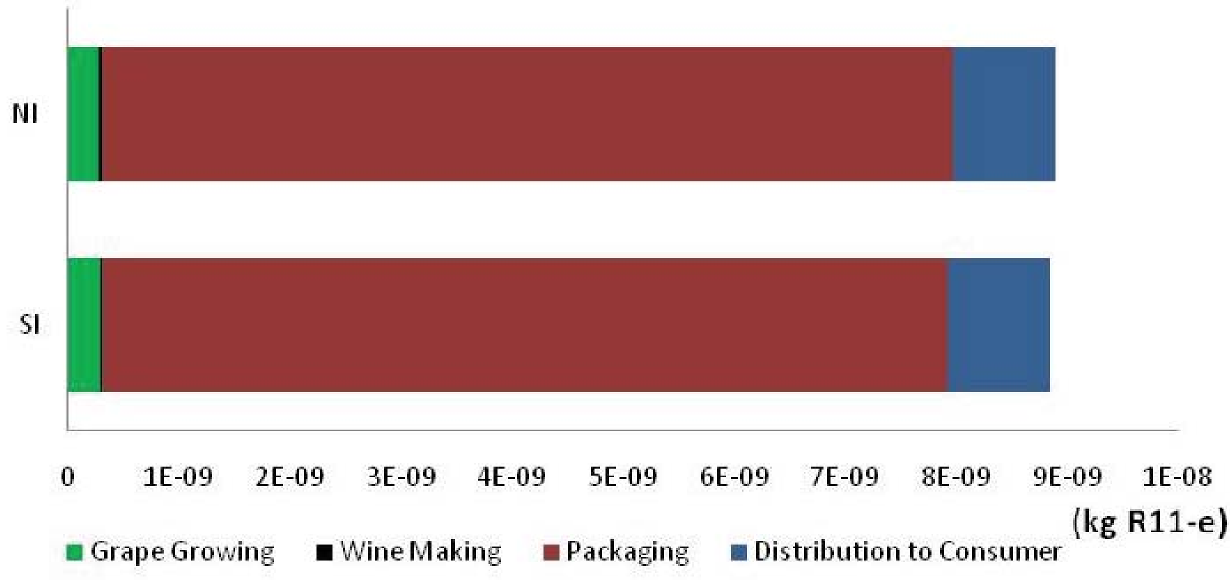

Figure 15: Contribution of each life cycle stage towards Ozone Depletion Potential in both wineries

Table 13 shows the main contributing activities to ODP. The most relevant emissions from glass production are the release of carbon tetrachloride and methyl bromide, while those from shipping are chlorofluorocarbons associated with the refining of crude oil (Koroneos, Dompros, Roumbas, & Moussiopoulos, 2005).

Table 13: Main contributing activities to Ozone Depletion Potential in both wineries

Life Cycle Stage	Packaging		Distribution to Consumer	Other
Activity	Glass bottle production	Paper label production	Shipping fuel supply chain	
% contribution to total ODP (NI)	81	4	9	6
% contribution to total ODP (SI)	81	4	9	6

Abiotic Depletion Potential

ADP refers to the consumption of non-living finite resources, such as minerals and fossil fuels (ILCD, 2010a). The main contributors to ADP are the distribution to consumer stage, followed grape growing (figure 16). The difference between the two wineries is due, at least in part, to the higher electricity requirement of the NI winery.

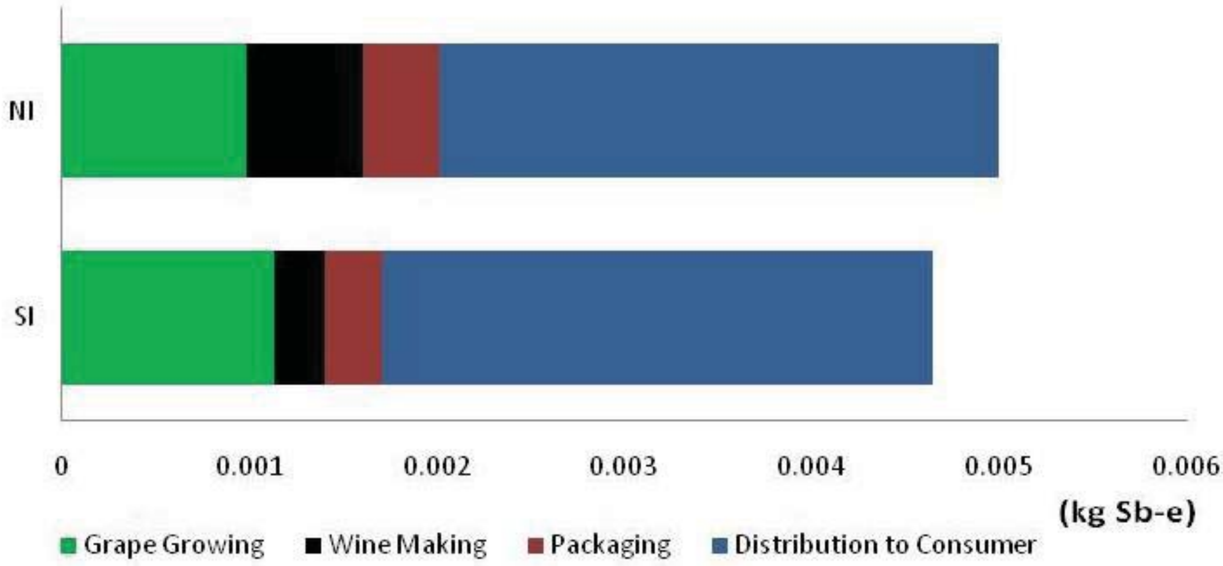

Figure 16: Contribution of each life cycle stage towards Abiotic Depletion Potential in both wineries

Table 14 shows the main activities that influence the ADP. Apart from electricity use in the winery (which involves the use of natural gas) all other activities appear in this impact category due to the consumption of oil.

Table 14: Main contributing activities to Abiotic Depletion Potential in both wineries

Life Cycle Stage	**Grape Growing**	**Packaging**	**Wine Making**	**Distribution to Consumer**		**Other**
Activity	Frost protection	Transport bottle from manufacturer	Electricity in winery	Shipping to UK	Car trip to supermarket	
% contribution to total ADP (NI)	11	3	11	45	14	16
% contribution to total ADP (SI)	13	3	5	48	15	16

Primary Energy Consumption

Primary Energy Consumption is essentially a measure of the energy required for each process or activity throughout the life cycle. Figure 17 shows that this impact category is relatively more evenly spread across the life cycle stages than the other impact categories.

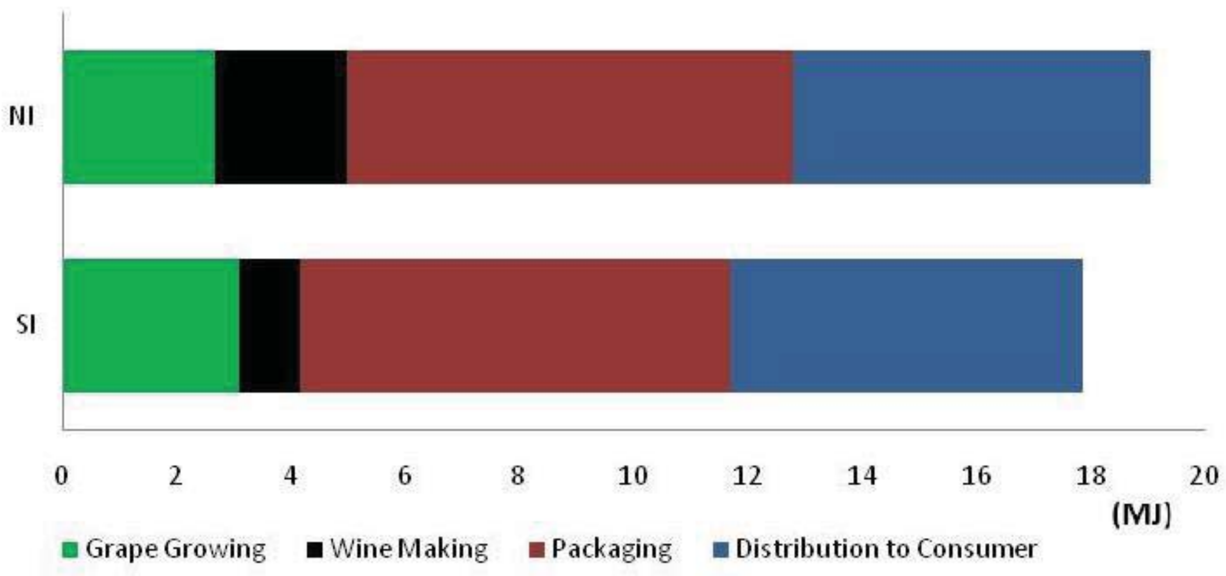

Figure 17: Contribution of each life cycle stage towards Primary Energy Consumption in both wineries

The most energy intensive activity is glass bottle production, making up around one-third of all energy requirements. The main contributions from the two distribution to consumer activities are associated with the supply chain of fuels and the transportation process. Note, the 'use of agrichemicals' in table 15 refers to their manufacture, distribution and application.

Table 15: Main contributing activities to Primary Energy Consumption in both wineries

Life Cycle Stage	Grape Growing		Wine Making	Packaging	Distribution to Consumer		Other
Activity	Use of agrichemicals	Frost protection	Electricity in winery	Glass bottle production	Shipping oil supply chain	Petrol supply chain	
% contribution to total MJ (NI)	3	6	11	33	25	8	14
% contribution to total MJ (SI)	4	7	5	35	26	8	15

Photochemical Ozone Creation Potential

Photo-oxidant formation is the forming of chemical compounds through a reaction between sunlight and certain air pollutants, also commonly known as summer smog. These reactive compounds can harm, among other things, respiratory tracts in animals and attack the surfaces of plants (Guinée, 2002). The main contributing life cycle stages to POCP are distribution to consumer and packaging (figure 18).

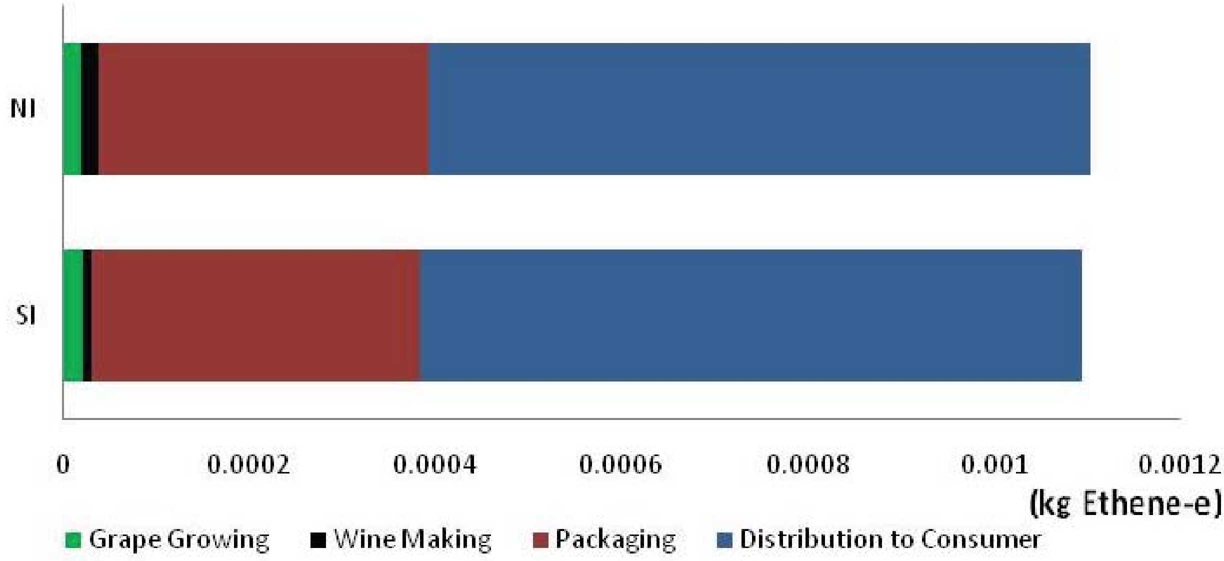

Figure 18: Contribution of each life cycle stage towards Photochemical Ozone Creation Potential in both wineries

A majority of emissions relating to POCP are associated with shipping to the UK and glass bottle production (table 16). For both these activities the most significant emissions are releases of sulphur dioxide (SO_2) and nitrogen oxides (NO_x).

Table 16: Main contributing activities to Photochemical Ozone Creation Potential in both wineries

Life Cycle Stage	Packaging		Distribution to Consumer		Other
Activity	Glass bottle production	Transport bottle from manufacturer	Shipping to UK	Car trip to supermarket	
% contribution to total POCP (NI)	26	4	62	3	5
% contribution to total POCP (SI)	26	4	62	3	5

Acidification Potential

AP relates to impacts caused by atmospheric deposits of acidifying substances (ILCD, 2010a). Figure 19 shows the life cycle stages contributing most to AP are distribution to consumer, followed by packaging. Both the grape growing and winemaking stages make relatively minor contributions.

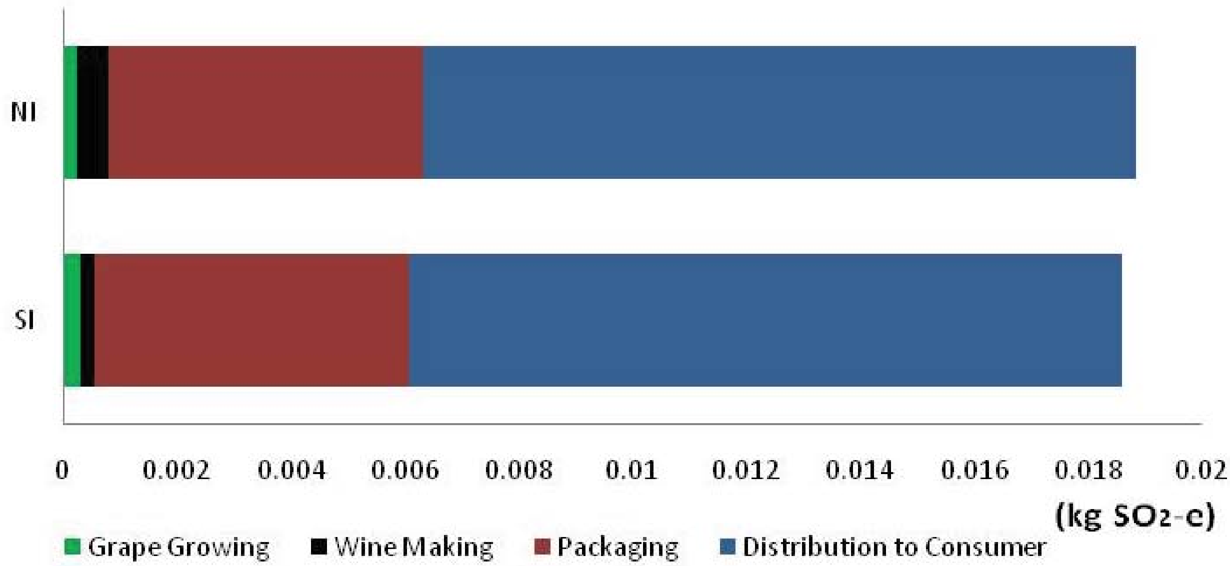

Figure 19: Contribution of each life cycle stage towards Acidification Potential in both wineries

Table 17 shows the largest contribution within packaging comes from the production and distribution of the glass bottle. The major contributor within distribution to consumer is shipping the wine to the UK. For both bottle production and shipping activities, the key contributors towards AP are air emissions of NO_x and SO_2.

Table 17: Main contributing activities to Acidification Potential in both wineries

Life Cycle Stage	Packaging		Distribution to Consumer	Other
Activity	Glass bottle production	Transport bottle from manufacturer	Shipping to UK	
% contribution to total AP (NI)	24	5	66	5
% contribution to total AP (SI)	24	5	67	4

Eutrophication Potential

EP is a measure of the impacts associated with increased nutrient flows (nitrogen and phosphorus) and associated depleted oxygen levels on aquatic and terrestrial systems (Guinée, 2002). Figure 20 shows an almost identical pattern of results as for AP, with the main contributors being packaging and distribution to consumer.

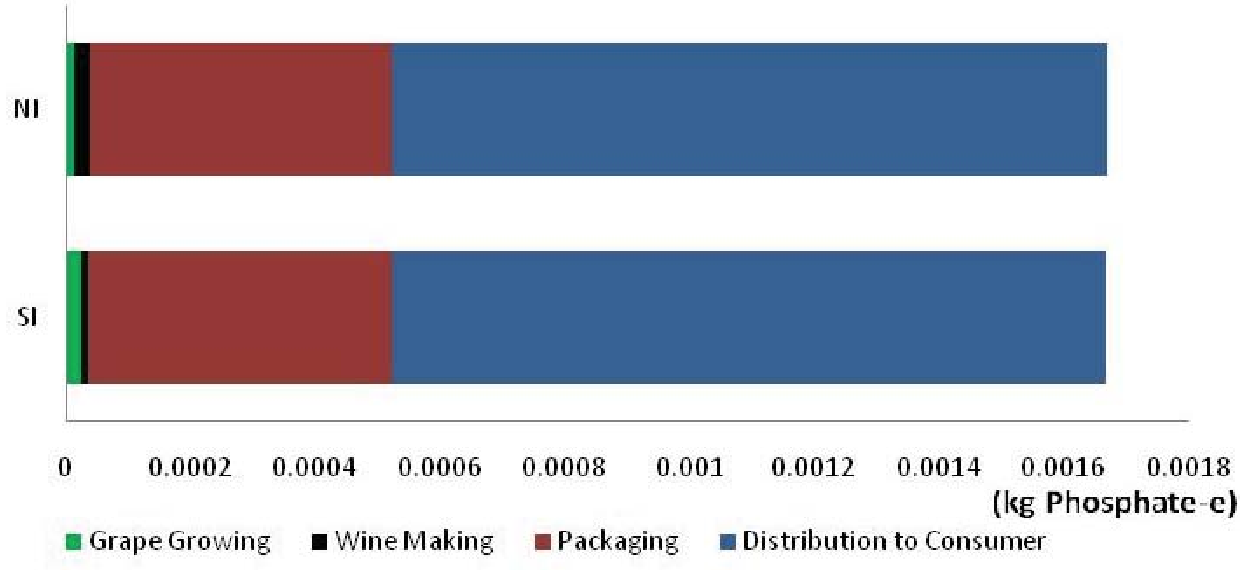

Figure 20: Contribution of each life cycle stage towards Eutrophication Potential in both wineries

Table 18 also shows a similar pattern to AP, with glass bottle production and shipping to the UK being the most dominant activities. The pollutant mostly responsible for EP during both life cycle stages is NO_x.

Table 18: Main contributing activities to Eutrophication Potential in both wineries

Life Cycle Stage	**Packaging**		**Distribution to Consumer**	**Other**
Activity	Glass bottle production	Transport bottle from manufacturer	Shipping to UK	
% contribution to total EP (NI)	23	5	67	5
% contribution to total EP (SI)	23	5	67	5

Marine Aquatic Ecotoxicity

This impact category deals with emissions of toxic substances on marine aquatic ecosystems (Guinée, 2002). Figure 21 shows this impact category is dominated by packaging.

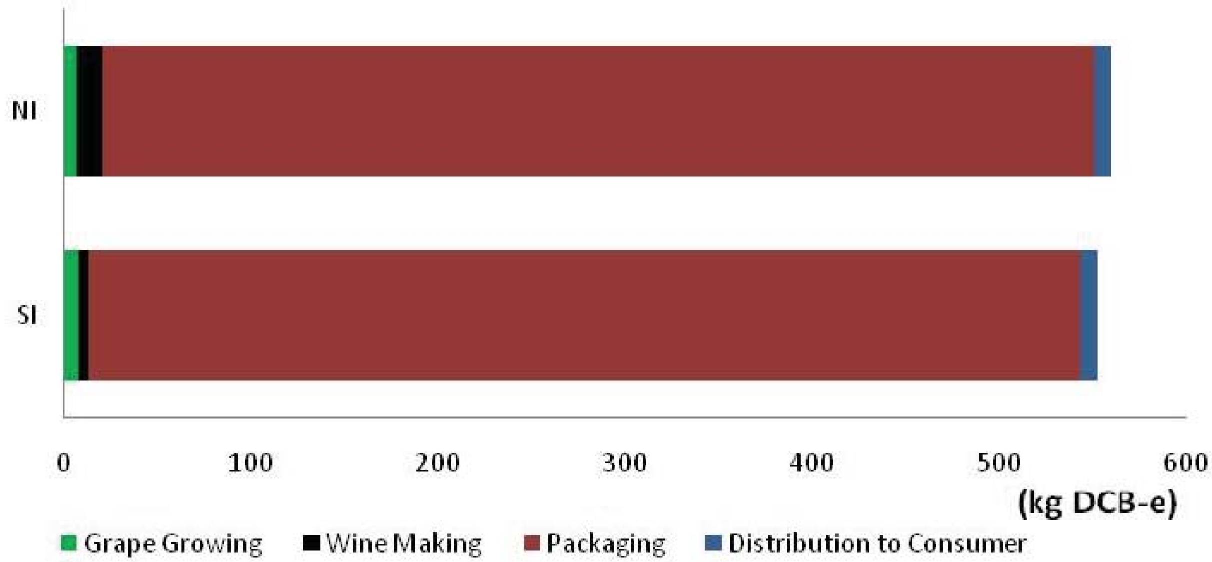

Figure 21: Contribution of each life cycle stage towards Marine Aquatic Ecotoxicity Potential in both wineries

The main contributors to MAETP are releases of barium, selenium and hydrogen fluoride, which are toxic by-products of glass production (IFC, 2007). The contributing pollutants associated with distribution to consumer are mostly related to activities in the shipping fuel supply chain.

Freshwater Aquatic Ecotoxicity

This impact category deals with emissions of toxic substances reaching freshwater aquatic ecosystems (Guinée, 2002). Figure 22 shows the main contributing life cycle stages are grape growing and packaging, with negligible contributions from the other two stages. The difference between the two wineries is due to the use of agrichemicals on the vineyard.

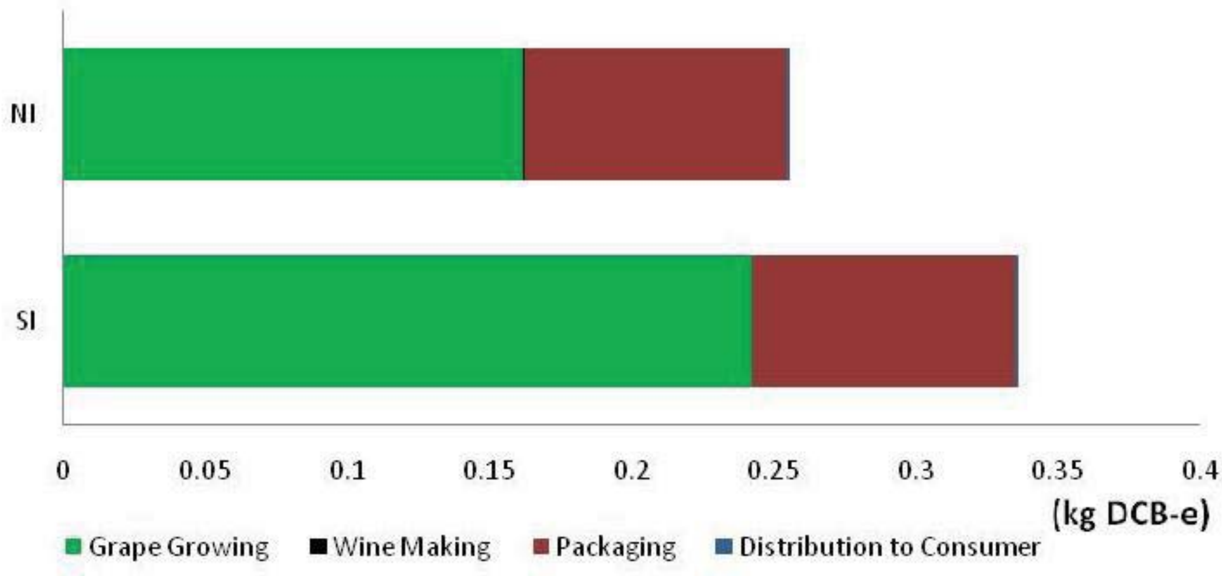

Figure 22: Contribution of each life cycle stage towards Fresh Water Aquatic Ecotoxicity Potential in both wineries

The primary contributor at the grape growing stage is the field-based emissions of pesticides, fungicides and herbicides (table 19). More minor contributions to FAETP include the airborne release of vanadium from the burning of diesel, and emissions of polychlorinated dibenzodioxins associated with production of the polyvinyl chloride irrigation pipe (EPA, 2005). Glass bottle production is the main contributor within packaging, due to emissions of barium, acrolein, nickel and various dioxins.

Table 19: Main contributing activities to Fresh Water Aquatic Ecotoxicity Potential in both wineries

Life Cycle Stage	Grape Growing		Packaging	Other
Activity	Pesticide and fungicide application	Herbicide application	Glass bottle production	
% contribution to total FAETP (NI)	54	9	36	1
% contribution to total FAETP (SI)	67	6	26	1

Terrestric Ecotoxicity Potential

This impact category deals with emissions of toxic substances on terrestrial ecosystems (Guinée, 2002). TETP is dominated by the packaging and distribution to consumer stages (figure 23).

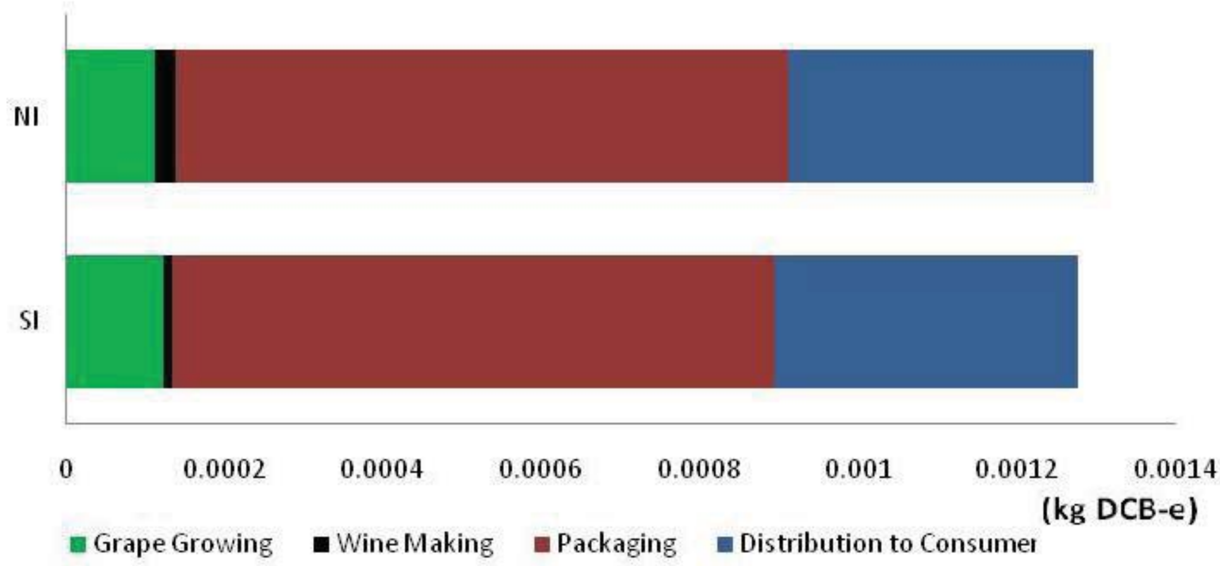

Figure 23: Contribution of each life cycle stage towards Terrestric Ecotoxicity Potential in both wineries

Table 20 shows that glass bottle production is the dominant activity influencing FETP. Most relevant pollutants from this process include air emissions of mercury, chromium and arsenic. The main contributors from the other three activities shown are vanadium emissions associated with the extraction and combustion of fossil fuels.

Table 20: Main contributing activities to Terrestric Ecotoxicity Potential in both wineries

Life Cycle Stage	Grape Growing	Packaging	Distribution to Consumer		Other
Activity	Frost protection	Glass bottle production	Shipping to UK	Car trip to supermarket	
% contribution to total TETP (NI)	4	56	25	4	11
% contribution to total TETP (SI)	5	57	25	4	9

Human Toxicity Potential

This category addresses the impacts on human health of toxic substances in the environment (Guinée, 2002). The packaging stage almost entirely dominates this impact category, largely due to water and airborne emissions of gases such as chromium, selenium, barium and various dioxins, all associated with glass making. There are almost negligible contributions from the other life cycle stage (figure 24).

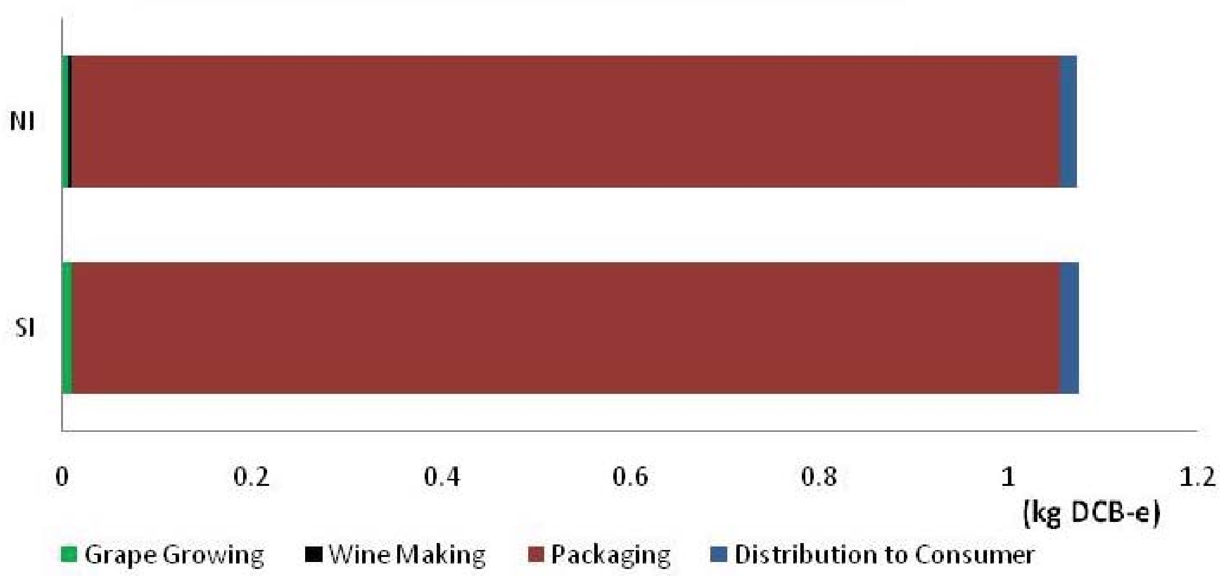

Figure 24: Contribution of each life cycle stage towards Human Toxicity Potential in both wineries

5.3.3 Normalisation

Normalising the LCI results provides a way of understanding the relative magnitude or significance of each impact category compared with the other impact categories. Normalised results are calculated relative to reference data; they are calculated by dividing the LCIA results by a common selected reference value (ISO, 2006). The reference value used in this thesis is CML 2001 OECD[24], which is an average-based estimate of the magnitude of the total impact for each impact category for all OECD countries over a year. This is chosen because it is considered more meaningful in the context of this study. All major stakeholders throughout the value supply chain are OECD countries: New Zealand (the location of the study), the UK (destination market), Australia (where the glass bottle is made), and the United States and Western Europe (where most of the agrichemicals and wine making additives are made).

Figure 25 provides a normalised profile of the LCIA results. It shows the relative contribution of the studied wine products to the total impact for each impact category in the OECD. The most significant impact categories after normalisation are AP, followed by FAETP, GWP, ADP, HTP and POCP.

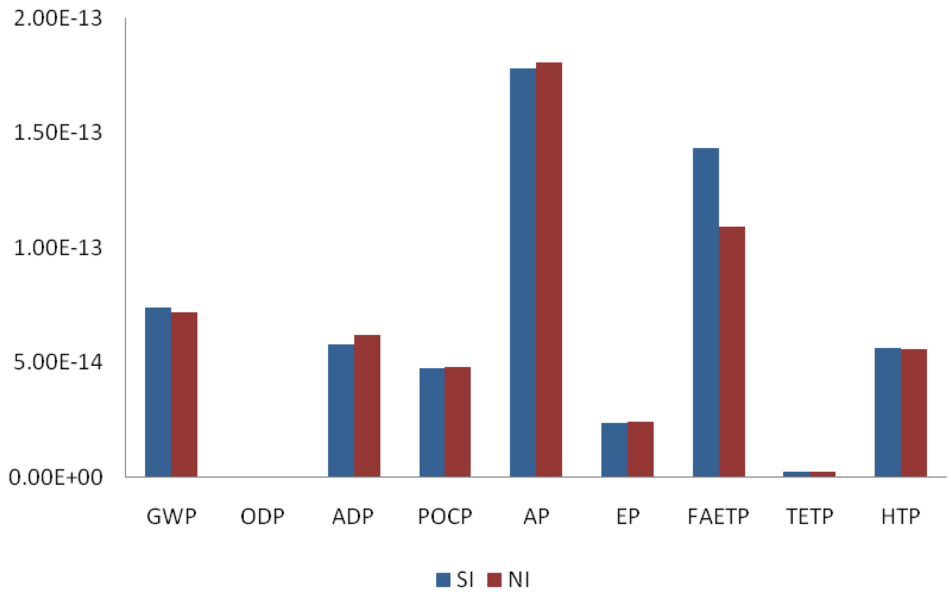

Figure 25: Normalised data results for both wineries against the CML 2001 OECD reference index value

[24] Organsiation for Economic Co-Operation and Development

When undertaking the normalisation step, it was found that MAETP was considerably higher than all other impact categories (by more than 8 times). The literature suggests this high figure may be erroneous, due to certain uncertainties and inaccuracies associated with normalising this impact category. More specifically, it is a result of modelling long residence times for cause-effect pathways in oceans (Sim et al., 2007).

The characterisation factor used for hydrogen chloride (released during glass production) may also be overstated in normalising MAETP (Heijungs, Guinée, Kleijn, & Rovers, 2007). A recent LCA study on glass production also reported an unusually high impact score for normalised MAETP results due to hydrogen fluoride emissions (Pulselli, Ridolfi, Rugani, & Tiezzi, 2009). For these reasons, the results for MAETP are omitted from this analysis, because the methodology used for assessment is questionable.

5.4 Sensitivity Analysis

This section presents results of sensitivity analysis performed on a number of activities throughout the wine life cycle. ISO defines sensitivity analysis in LCA as a procedure to determine how changes in data and methodological choices affect the results of the LCI (ISO, 2006, p. 22).

Sensitivity results are presented in terms of the percentage change of each impact category relative to the baseline results, either for: the respective life cycle stage, the product-at-gate (PAG), or for the total life cycle.

In some cases it is more suitable to present the results in terms of the respective life cycle stage or the PAG, rather than for the total life cycle.

This is for three main reasons;

- Due to the environmental significance of activities within the packaging and distribution life cycle stages, scenario analysis on many activities in other life cycle stages make a relatively small changes over the whole life cycle. has the effect of understating the relative changes in activities within other life cycle activities. While some of these sensitivity analyses are seemingly insignificant over the entire life cycle, it is nonetheless useful from an environmental management point of view to also target such activities, particularly where improvements can be made for minimal effort
- By removing the distribution stage, the results would also be relevant for all wine companies who do not export

Note the only impact categories shown are those for which a change of more than one per cent in the overall result was observed.

For ease of presentation, and given the general similarity between the two wineries, sensitivity analysis results are only shown for one of the case study wineries (NI winery). These sensitivity analyses form the basis for much of the discussion in the following chapter.

5.4.1 Grape Growing

Analysis One: Variation in Frost Events In this analysis the number of frost events during the vintage is assumed to double, which means the quantity of diesel required for the wind machine and frost pots is twice that of the baseline scenario. Figure 26 shows the resultant percentage increase compared with the baseline for all the impact categories. A significant change can be seen in a number of impact categories.

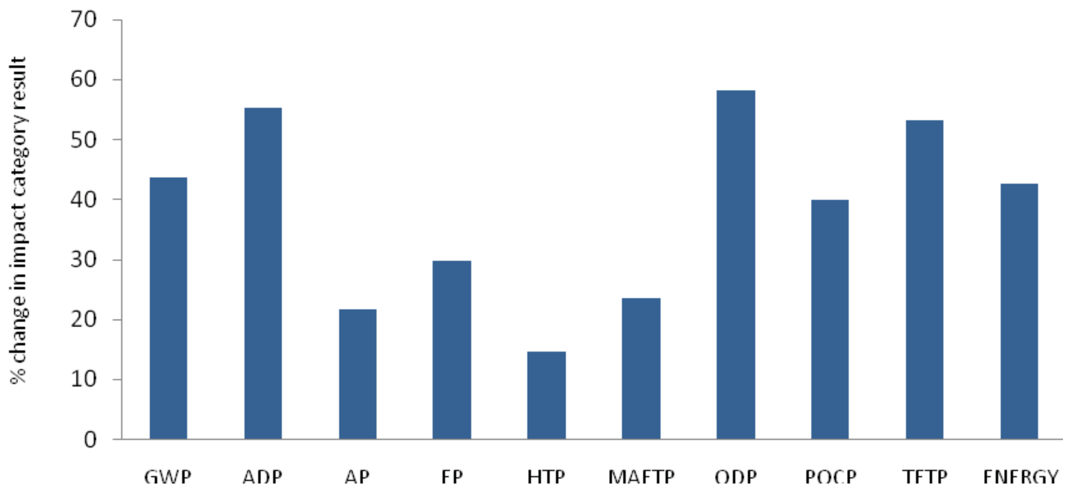

Figure 26: Sensitivity to a doubling of frost events in various impact category values for the grape growing life cycle stage

Analysis Two: Field-based Spray Emissions In this analysis the sensitivity to changes in modelled emissions to the environment is tested (figure 27). The baseline assumes that 10% of agrichemicals applied in the vineyard are released to the air as emissions, with 5% released to the groundwater and soil. The alternative scenario assumes a 50% increase in emissions, with 15% released to air and 7.5% released to the groundwater and soil. The only two impact categories for which a change of more than one per cent in the overall life cycle results was observed is FAETP and TETP.

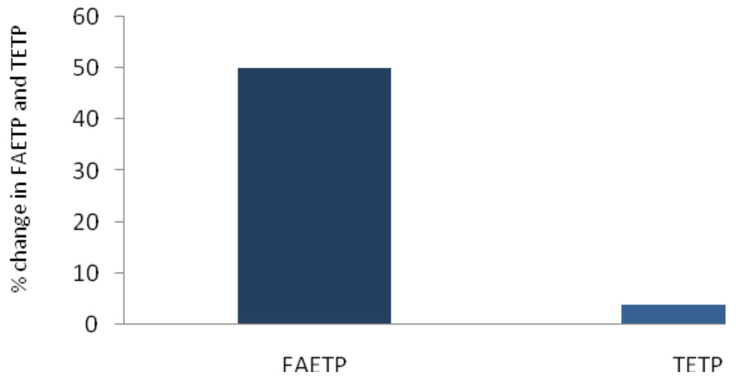

Figure 27: Sensitivity of Freshwater Aquatic Ecotoxicity Potential and Terrestric Ecotoxicity Potential in the grape growing stage to a 50% increase in field spray emissions

Analysis Three: Grazing Sheep This analysis includes the grazing of sheep in the system boundaries. It considers both the environmental impact of sheep methane emissions, and the associated environmental savings from the reduced need for grass mowing and herbicides.

The left bar in figure 28 includes both sheep methane emissions and the displaced need for herbicides and mowing in the model. This is a positive change, showing the environmental impact of the sheep emissions is greater than the savings associated with less herbicides and mowing. The right bar also includes the displaced need for herbicides and mowing, but here the sheep emissions are attributed to another product system. The fact that, at least in this model, sheep emissions are greater than the environmental savings they provide, raises the question of how sheep emissions should be modelled in the wine industry.

Note only GWP is pictured as this is the only impact category relevant to this activity; eutrophication impacts from sheep manure were not modelled due to a lack of suitable data.

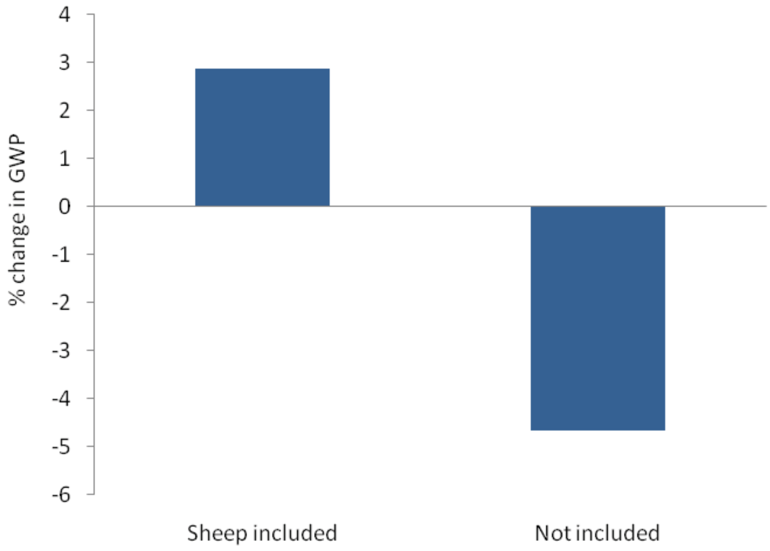

Figure 28: Sensitivity of Global Warming Potential in the grape growing stage to the inclusion and exclusion of the GHG impacts associated with sheep grazing in the system boundary

Analysis Four: Halving the Yield In this analysis the sensitivity to a 50% reduction in harvest yield is tested (figure 29). Given that the impact category values for the grape growing stage are obvious (i.e. all the results are doubled because the yield has halved), it is considered more useful to present these results for the PAG. It can be seen that a reduction in yield has a significant influence on FAETP, ADP and Primary Energy Consumption.

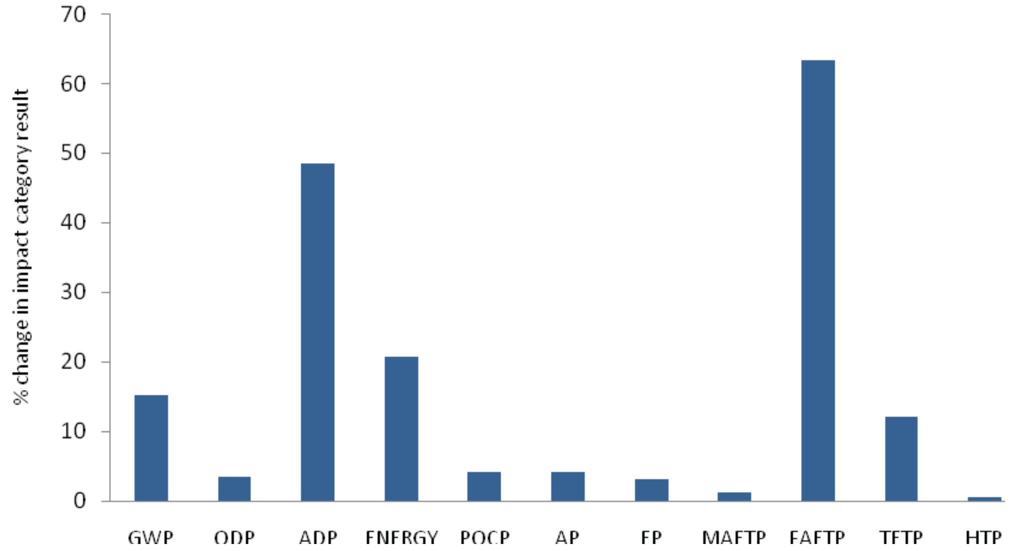

Figure 29: Sensitivity to a 50% reduction in harvest yield in various impact category values for the product-at-gate

5.4.2 Wine Making

Analysis Five: Energy Efficiency in the Winery This analysis tests the sensitivity of the wine making stage results to a 15% increase in electricity consumption in the winery (figure 30).

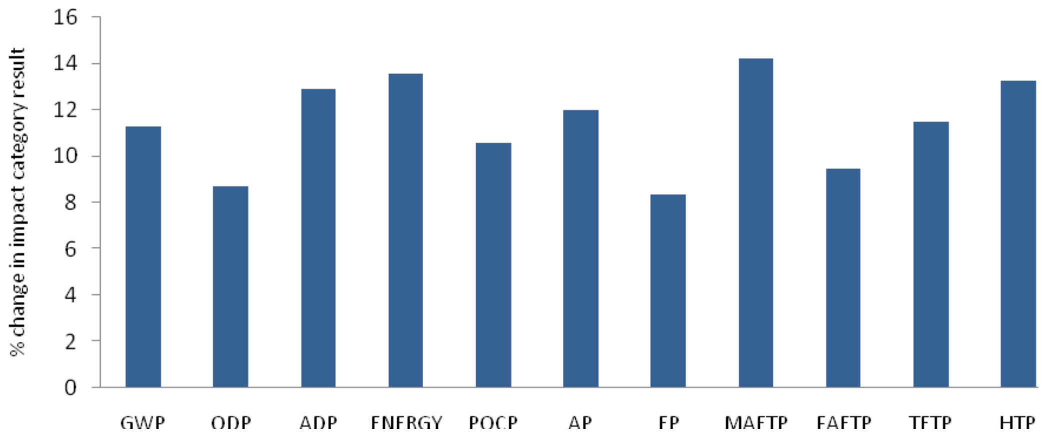

Figure 30: Sensitivity to a 15% increase in electricity consumption in the winery in impact category values for the wine making stage

Analysis Six: Composting of Lees Waste Figure 31 provides the change in GWP for an alternative option for lees waste management. The baseline study modelled landfilling the waste, while the alternative option involves transporting the waste to a local composting facility. This scenario uses an estimated figure from the USA Environmental Protection Authority (EPA), that the amount of diesel required to turn industrial-scale piles of compost generates 4.4 kg of CO_2 emissions for each tonne of compost waste (EPA, 2006). It can be seen that composting - which avoids methane emissions associated with decomposition in the landfill - provides a GWP reduction of nearly 10% in the wine making stage. Note this scenario also assumes the lees is composted properly, that is, any methane emissions associated with its decomposition are considered to be negligible.

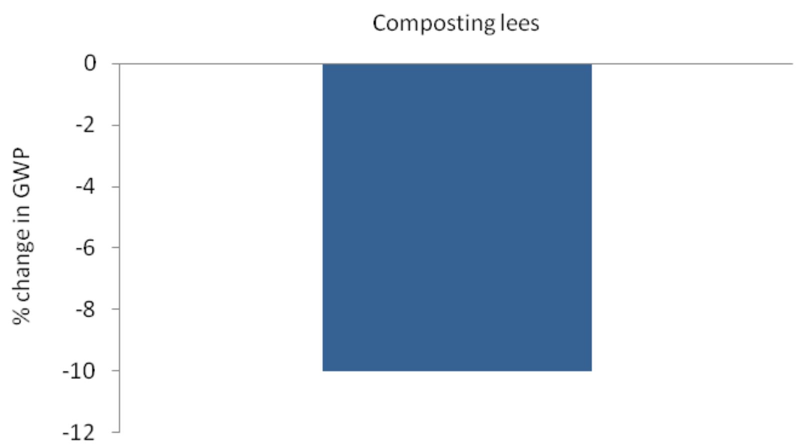

Figure 31: Sensitivity of Global Warming Potential in the wine making stage to composting lees waste

5.4.3 Packaging

Analysis Seven: Emissions Factor for Bottle Production This analysis tests the sensitivity of total GWP to changes in the GHG emissions factor for glass bottle production (figure 32). A highly sensitive response can be seen, where increasing the emissions factor from 0.3 to 0.7 kg CO_2-e causes a rise in GWP of around 35%. Changes in total GWP are shown rather than for the packaging stage, as this best demonstrates the significance of the glass bottle in the wine life cycle.

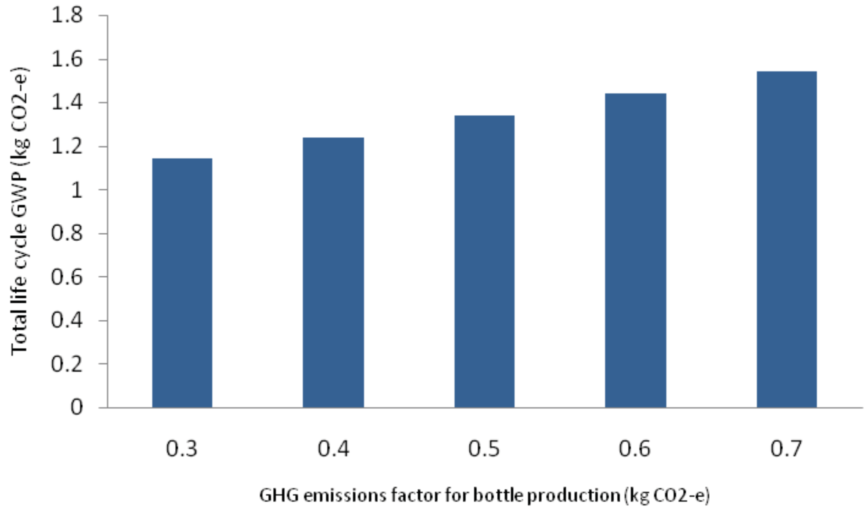

Figure 32: Sensitivity of Global Warming Potential over the total life cycle to changes in the greenhouse gas emissions factor for glass bottle production

5.4.4 Packaging and Distribution to Consumer

Changes in packaging systems also affect the distribution to consumer stage, because lighter packaging reduces the energy required to transport the wine product. For this reason, the following three sensitivity analyses are presented in terms of the changes in impact categories over the total life cycle, rather than by individual life cycle stage.

Analysis Eight: PET Bottles In this analysis the exported wine is assumed to be shipped to the UK in polyethylene terephthalate (PET) bottles (figure 33). PET bottles are environmentally advantageous over glass bottles because they require less energy and release fewer GHGs during manufacturing, while also requiring less energy to transport.

The GWP associated with production of a PET bottle is 0.208 kg CO_2-e per bottle, using data from the same Franklin study from which glass production figures were taken (Franklin, 2006). Using the same source provides the potential advantage of achieving a higher degree of comparability between glass and PET. However, it should be noted this value is around 20% lower than the 0.253

kg[25] CO_2-e per bottle figure used in a 2008 study by WRAP (2008). A significant change can be seen in a number of impact categories.

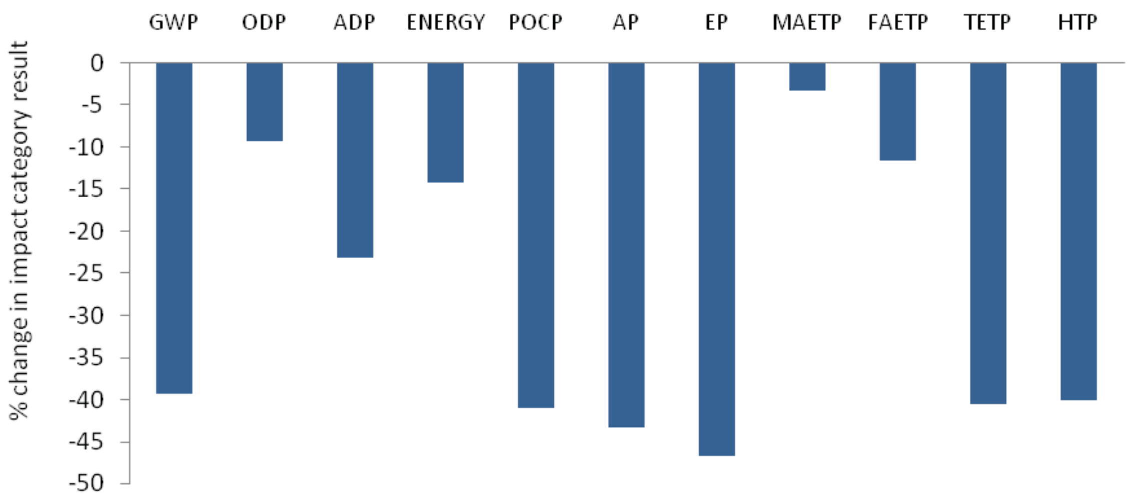

Figure 33: Sensitivity of using the PET bottle in the impact category values over the total life cycle

Analysis Nine: Bulk Shipping In this analysis the wine leaves the winery in a 24,000 litre flexitank (which is stored inside a standard shipping container) and then shipped to the UK (figure 34). On arrival to the UK the wine is bottled in a locally-made standard glass bottles and taken by truck to London. The GWP associated with bulk shipping from Napier to London is 0.212 kg CO_2-e, which is comparable with the figure of 0.235 kg CO_2-e used in the WRAP (2008) study. However, note this WRAP study examined bulk shipping from Adelaide, Australia.

[25] WRAP used data from Boustead, I. (2005) Eco-Profiles of the European Plastics Industry-PET bottles

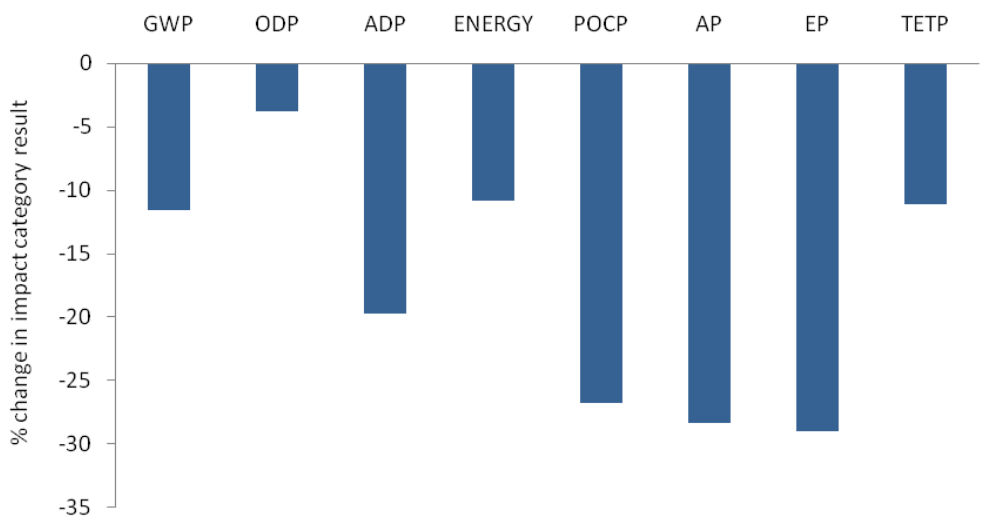

Figure 34: Sensitivity of bulk shipping in various impact category values over the total life cycle

Analysis Ten: Bottle Lightweighting In this analysis the exported wine is assumed to be shipped to the UK in lightweight glass bottles (figure 35). Lighter bottles are environmentally advantageous because they require less energy and release fewer GHGs during manufacture, while also requiring less energy to transport. The reduction in embodied GHG emissions was estimated using the same assumption adopted by WRAP, that assumes the CO_2 savings (in grams) in switching from a standard bottle to a lightweight bottle, equates to around 78% of the reduction of the bottle weight (in grams) (WRAP, 2010a).

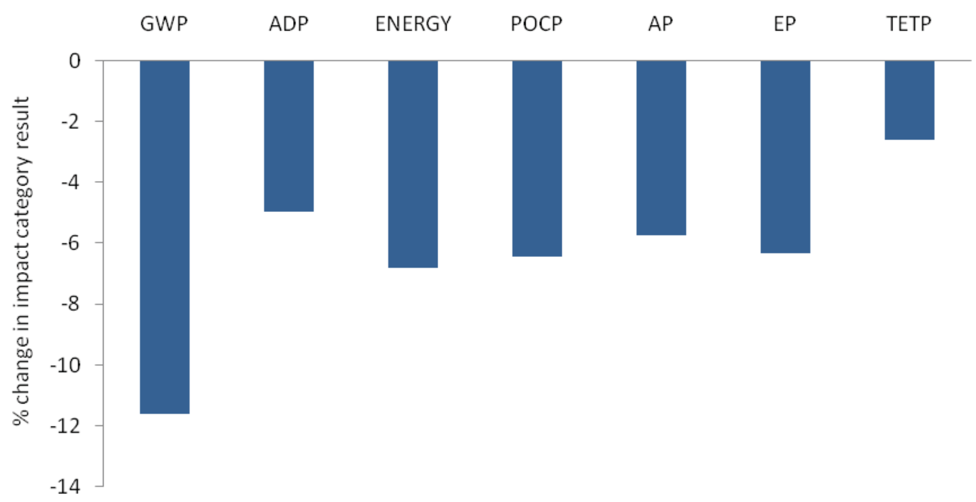

Figure 35: Sensitivity of using lightweight glass bottles in various impact category values over the total life cycle

5.4.5 Distribution to Consumer

Analysis Eleven: Changing Export Markets This analysis tests the sensitivity of halving the original shipping distance (figure 36). Half of the distance to the Port of Tilbury is around 10,346 km, which is approximate to the distance of many Asian markets. The responsiveness of POCP, AP and EP highlight the extent to which shipping contributes to these impact categories.

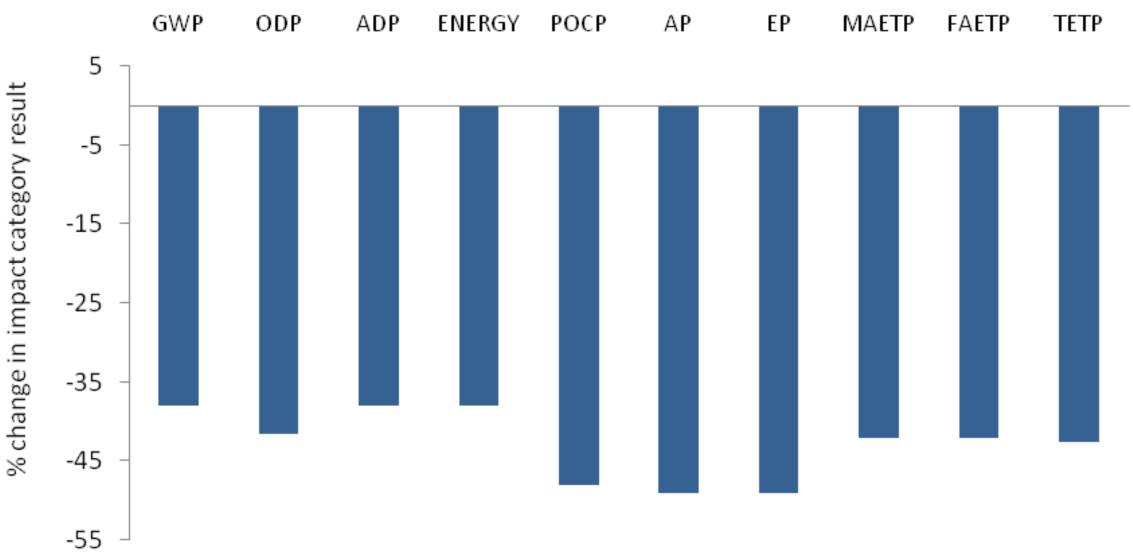

Figure 36: Sensitivity to a 50% reduction in shipping distance in the impact category values for the distribution to consumer stage

5.5 Interpretation

Interpretation is the final phase of the LCA, in which the results of a LCI or LCIA, or both, are interpreted as a basis for conclusions and recommendations in accordance with the goal and scope definition (ISO, 2006, p. vi).

5.5.1 The Vineyard

Frost Protection This activity was identified as the main contributor to GWP during grape growing in both case study wineries. While in many cases frost protection using diesel cannot be avoided, these results suggest that frost management techniques may be an effective carbon mitigation measure in certain regions. In regions that are prone to frost events, investment in carbon intensive management options - such as frost cloths, sprinkler systems or solar water heated mulches – may be one of the most practical and feasible ways to reduce the GWP of the vineyard.

Sensitivity analysis highlights the vulnerability of the GWP to environmental conditions. The top row in Table 21 provides the number of frost events that occurred during the 2010 vintage in the main wine growing regions throughout New Zealand. It can be seen that frost events are highly regionally variable. Frost events are defined here as when the minimum temperature at grass level reaches -1^{o}C or less (Trought et al., 1999).

The second row in this table provides an estimated annual diesel requirement per hectare for a hypothetical vineyard in each region. This estimate is based on the LCI data for the case study wineries, but applying a slightly more conservative estimate of five litres per hectare per frost event. The bottom row shows a resultant hypothetical GWP for the PAG in each region. It shows, assuming all else being equal, a regional variation of GWP of up to 10% may exist due to differences in frost alone.

Table 21: Number of frost events in different wine growing regions of New Zealand, with a corresponding hypothetical Global Warming Potential for the product-at-gate.

	Northland	Auckland	Gisborne	Hawke's Bay	Wairarapa	Nelson	Marlborough	Canterbury	Otago
No. frost events	1	24	48	34	47	79	40	53	103
Diesel use (litres/ha)	5	120	240	170	235	395	200	265	515
GWP for PAG	0.94	0.96	0.99	0.98	0.99	1.03	0.98	1.00	1.05

Source (NIWA, 2010)[26]

These findings suggest frost management is more of an issue in terms of carbon management in frost prone regions. It should be noted that frost events are highly dependent on microclimatic conditions, such as topography, aspect and altitude. For this reason the figures shown in table 21 are not intended to represent all wineries in each region that use diesel for frost protection. Rather, the intent is to illustrate the regional variation in GWP that could potentially occur as a result of frost.

Agrichemical Field Emissions At normalisation, FAETP was one of the most significant impact categories, which underlines the importance of field-based spray emissions in the wine life cycle. Vineyard activities are the main contributors to FAETP, specifically emissions from the spraying of pesticides, fungicides and herbicides. In most vineyards, reduction opportunities for FAETP will not likely result from spraying less agrichemicals, as this may jeopordise the quantity and quality of the harvest. Therefore, viticulturalists will likely look elsewhere for reduction opportunities.

Harvest Yield Sensitivity analysis found that a number of impact categories, including ADP, FAETP and GWP, are sensitive to changes in harvest yield. The size of the yield is typically controlled by the viticulturalist through crop regulation, where the crop size is manipulated to achieve the desired quantity and/or quality. The near 50% increase of ADP (seen in halving the yield scenario) suggests that poor crop regulation effectively leads to an inefficient use of natural resources, while

[26] Data were taken from the following weather stations: *Northland*, Kaitaia Observatory; *Auckland,*Henderson, River Park; *Gisborne*, Gisborne Aws; *Hawke's Bay,* Hastings Aws; *Wairarapa,*Martinborough Ews; *Nelson,* Motueka, Riwaka Ews; *Marlborough*, Awatere Valley, Dashwood Ews; *Canterbury*, Waipara West Ews; *Otago,* Alexandra.

the more than 60% rise in FAETP highlights that poor crop regulation also causes a considerable and possibly unnecessary release of toxins into the environment.

This possible relationship between yield and the carbon footprint is illustrated in table 22, showing how the changing of yield quantities in the GaBi model affects the GWP of the PAG.

Table 22: Various hypothetical harvest yields with its effect on Global Warming Potential in the modelled wine product

Harvest yield (tonnes per hectare)	5	10	14.25 (baseline)	20
Total GWP (CO_2-e per functional unit)	1.68	1.47	1.42	1.37
Change against baseline GWP for the PAG (%)	+28	+6.5	0	-4.4

This relationship might prove to have a varying degree of impact depending on the grape type. For some wines, such as Cabernet Sauvignon, Pinot and Merlot, the quality of the wine is more dependent on the size of yield than, say Sauvignon Blanc (Anon, 2010b). This suggests there may be a relationship between wine type and environmental impact, though research relating to this topic was not found in the published literature.

Sheep Grazing Interestingly, the LCA method for modelling sheep grazing can either increase or decrease the GWP result for the vineyard. If the methane and nitrous oxide emissions associated with the sheep are attributed to another product (such as meat or wool) then the GWP is reduced to below the baseline results. If these emissions are attributed to the wine product, the vineyard's GWP is increased. This implies, at least in this case, that the environmental impact of the sheep emissions is greater than the environmental savings they provide (reduced mowing and herbicide application).

5.5.2 The Winery

Electricity Consumption The findings in this study are consistent with the literature; electricity consumption is the most environmentally burdensome process during the wine making stage.

Electricity consumption in the case study wineries was 0.40 (NI) and 0.48 (SI) kWh per litre of wine, which is comparable with the average benchmark figure of 0.58 kWh per litre[27] (SWNZ, 2008). Specific opportunities to improve energy efficiency in wineries have been adequately covered elsewhere in the literature (CEC, 2005; Deurer, Clothier, Pickering, McDonald, & Pique, 2009) and will not be provided here.

By international standards, New Zealand's electricity generation mix has a relatively low GHG intensity, with a majority of power coming from hydro, geothermal and wind sources (MED, 2007). This provides a potential competitive advantage for the local wine industry, while also offering a way of compensating for the relatively longer shipping distance to the UK market.

Figure 37 provides various hypothetical scenarios, where two input parameters (electricity grid mix and shipping distance) are changed in the GaBi model. The blue bars assume a change in the electricity grid mix only, with the inclusion of each country's respective grid mix in the model. All blue bars are positive, indicating that the same wine produced in each of these countries may result in a higher GWP than the baseline New Zealand figure, solely on the basis of using more thermally intensive electricity. The red bars assume the same wine produced, but with the shipping distance changed to represent each country's actual shipping distance to London. The net change (brown bars) shows the change due to assuming each country's respective grid mix and shipping distance to London.

[27] This was an energy use data survey of twenty two New Zealand wineries that represented 53% of the harvest volume in 2005

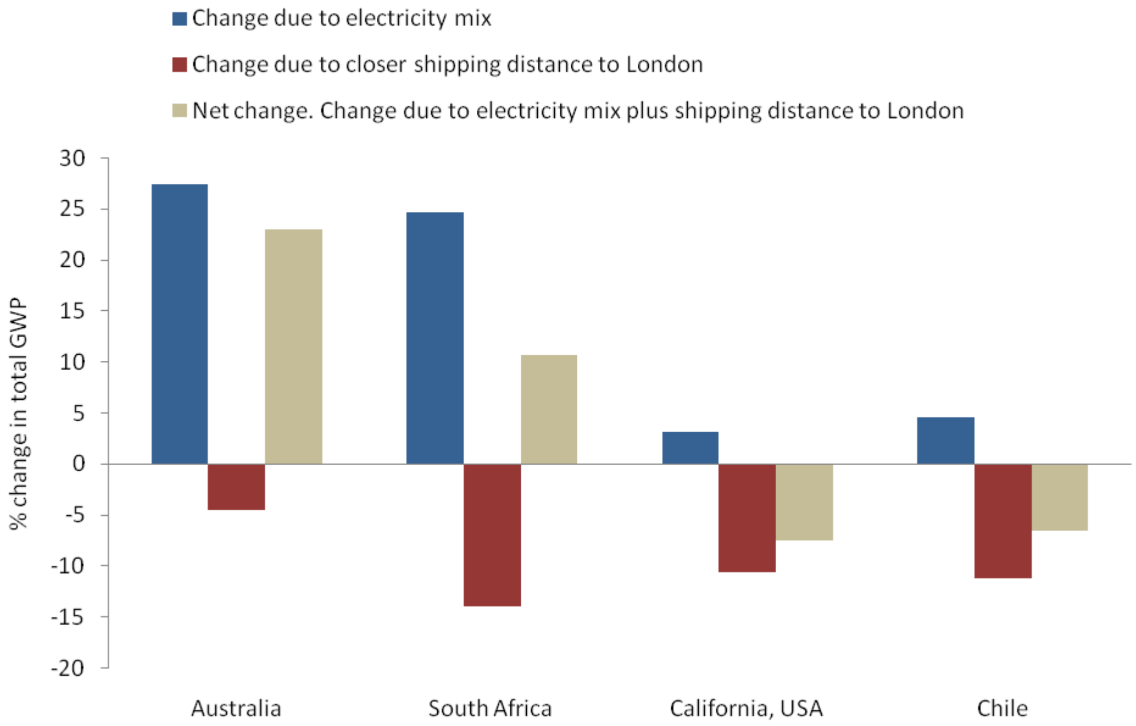

Figure 37: Change in total Global Warming Potential that would hypothetically result from the same studied wine product being produced in different countries

To illustrate, in the case of Australia and South Africa, modelling with the local grid mix increases total GWP compared with baseline by around 27% and 24% respectively (blue bars). The closer shipping distance reduces the GWP by around 5% and 15% respectively (red bars). The net change, which takes both electricity mix and distance into account, results in a higher GWP than the baseline of around 23% and 10% respectively (brown bars). This suggests that New Zealand's cleaner electricity mix may help compensate wine exporters for the extra shipping distance compared with their South African and Australian counterparts. It also suggests that New Zealand wine exporters, all else being equal, may be in a good position to compete with certain other countries in the UK market on the grounds of the PCF.

However, in the case of California and Chile, while assuming the local grid mix results in a slightly higher GWP, this difference is negated when the shorter shipping distance is modelled. This suggests that in these cases New Zealand's electricity mix cannot compensate exporters for the greater shipping distance.

5.5.3 Packaging

In agreement with most other wine LCA studies, packaging is the most dominant life cycle stage in the case study wineries, with glass bottle production being the most significant individual activity. While a range of packaging options are available in the wine industry, this study focuses on three options: the PET bottle, bulk shipping, and lightweighting of the glass bottle.

Of all the reduction opportunities presented in this thesis, the greatest environmental savings can be achieved with the PET bottle. Compared with the baseline study, the PET bottle provides reductions of between 3 and 40% in GWP, AP, EP, HTP, POCP and TETP. Given that many of these impact categories have relatively high normalised values in the baseline data, the PET bottles provides an option to significantly reduce the overall environmental profile of the wine product. Further reductions in many of these categories will be achieved through shipping the wine in bulk and bottling (in PET) at the destination.

Despite these advantages, a number of issues exist relating to the use of PET. Firstly, PET allows the diffusion of oxygen into the wine, affecting the shelf life and freshness of the product (Spangenberg & Vennemann, 2008). For this reason, shipping PET bottles over long distances may not be suitable, implying that if the PET bottling of New Zealand wine becomes more common in the UK market then the wine will more likely be shipped there in bulk. Secondly, there is concern that under certain conditions (such as prolonged storage and high temperatures) that PET bottles leach toxic substances such as phthalates[28] into the bottle contents, though this still debated. The amount of leaching is also dependent on the type of contents inside the bottle (Sax, 2010). Thirdly there is a question about image: Do consumers perceive the quality of wine from a PET bottle as being the same as wine from a glass bottle?

A second packaging option for New Zealand wine exporters is bulk shipping. Between March 2008 and late 2009, the percentage of wine imported in the UK in bulk rose from 17.5% to around 24% (WRAP, 2010a). If we assume the wine is bottled at destination in the standard bottle, then bulk shipping reduces the GWP of the distribution to consumer life cycle stage by around 33%. This is in line with WRAP's figure of 38%, which modelled bulk shipping from Australia (WRAP, 2007). The increased use of locally made glass in the UK wine market has the added benefits of increasing the

[28] Phthalates are known endocrine disruptors, that can interfere with the natural hormonal balance in the body

demand for UK green glass cullet, thereby helping the local glass recycling infrastructure (WRAP, 2010a).

Wine that is shipped in bulk and bottled at destination is an obvious potential issue for winery managers in terms of quality control. Wine exporters will likely need assurance that wine put into bottles that bear their company label is the same wine product that left the winery. In other words, there needs to be a quality assurance process to ensure that the bottled product has not been mixed with other brands or had its quality impaired in any way. Other issues associated with bulk shipping include the need to maintain a cool and stable temperature, preventing oxidisation from occurring, and reducing risk of breakage and associated major spillages to occur.

A third packaging option is that of the lightweight glass bottle. Of the three options, lightweighting may be considered by most wine managers to be the most feasible option. The wine is still packaged in glass, so does not face the same potential quality, health or consumer perception issues as PET bottles. Also, bottling the wine locally (as opposed to bulk shipping) means the company retains a greater degree of assurance and control over its quality.

The lightweighting of wine bottles has become increasingly popular in recent years and will undoubtedly become more mainstream into the future. For example, between 2006 and 2008 more than 300 different wine labels in the UK alone converted to lighter bottles (WRAP, 2009).

In 2006 WRAP conducted a survey of the average glass bottle weight from eleven of the main countries from where the UK imports its wine. It found the average weight of New Zealand bottles was the third highest (around 520 g) (WRAP, 2006) which suggests there is significant opportunity for New Zealand exporters to lightweight their bottles.

5.5.4 Summary of Activities

Tables 23, 24 and 25 show the percentage change in GWP, AP and ADP for a range of environmental improvement options. These three impact categories are chosen because they have the highest normalised values. Data is presented in the form of dominance analysis, in terms of the ability of various improvement options to reduce the value of each impact category. The figures shown in each table are the percentage change in the result for each impact category at the individual life cycle stage level, the PAG, and the total GWP. These tables underline that fact that the most significant environmental improvement opportunities lie in the packaging and distribution stages of the wine life cycle.

Table 23: Percentage reduction in Global Warming Potential for a range of environmental improvement options

Activity or Process	% reduction life cycle stage	% reduction PAG	% reduction total GWP
Grape Growing			
Frost protection	43.7	6.6	4.4
3 less spraying runs	3	0.5	0.3
Sheep grazing (not including impact within system boundary)	4.6	0.7	0.5
Wine Making			
Composting lees	10	1.2	0.8
15% increase in energy efficiency	11.3	1.4	0.8
Using local wine makers	6.4	0.8	0.7
Packaging			
Buying NZ made glass	4	3	1.9
PET bottle	60.4	54.6	40
Lightweight glass bottle	20.7	15	0.08
Distribution			
Shipping to China	38	N/A	13.3
Standard glass with bulk shipping	34	0.08	11.6

Table 24: Percentage reduction in Acidification Potential for a range of environmental improvement options

Activity or Process	% reduction life cycle stage	% reduction PAG	% reduction total AP
Grape Growing			
Frost protection	**22**	**1**	**0.4**
3 less spraying runs	**1.1**	**0.25**	**0.07**
Wine Making			
15% increase in energy efficiency	**12**	**1.3**	**0.5**
Using local wine makers	**5.3**	**0.25**	**0.1**
Packaging			
PET bottle	**60.1**	**52.5**	**43.3**
Lightweight glass bottle	**5.7**	**0.05**	**5.7**
Distribution			
Shipping to China	**50**	N/A	**33**
Standard glass with bulk shipping	**42.7**	**N/A**	**28.3**

Table 25: Percentage reduction in Abiotic Depletion Potential for a range of environmental improvement options

Activity or Process	% reduction life cycle stage	% reduction PAG	% reduction total ADP
Grape Growing			
Frost protection	55	26.7	11
3 less spraying runs	3	1.1	0.3
Wine Making			
15% increase in energy efficiency	13	3.7	1.3
Using local wine makers	8.2	3	1.4
Packaging			
PET bottle	63.6	13	23
Lightweight glass bottle	23.4	4.8	5
Distribution			
Shipping to China	37.5	N/A	22.6
Standard glass with bulk shipping	33	N/A	20

KEY

< 3	3 – 9	10 – 20	21 – 39	40 +	**(% reduction)**

CHAPTER 6: DISCUSSION AND CONCLUSION

The previous chapter showed how LCA can be used to identify hotspots and generate ideas for improvement options in the life cycle of wine. In this chapter, the LCA results are interpreted at the level of the New Zealand wine industry. In particular, the discussion addresses Research Questions 2 and 3 in Section 1.2: "What is the role of LCA in measuring and improving environmental management in the New Zealand wine industry?" and "How can LCA contribute to the New Zealand wine industry's environmental labelling programmes?"

To reiterate the limitation stated earlier, the LCA results from the case study wineries are not intended to be representative of the entire New Zealand wine industry. Nonetheless, this research identifies where environmental improvement opportunities might lie for the industry. This is the first study of its kind in the local wine industry and further research is needed to validate and confirm these findings.

6.1 Implications for Environmental Management in the Wine Industry

The results of the LCA case studies have a number of specific implications for environmental management in the New Zealand wine industry. They are discussed in Sections 6.1.1 to 6.1.9 below with particular reference to how the SWNZ programme can be improved.

6.1.1 Frost Management

SWNZ might consider a specific category for diesel requirements for frost protection on its score card. This may improve the industry's understanding of the environmental relevance of frost protection and incentivise managers to invest in less carbon intensive frost protection measures. Findings from this research also suggest that more information could be provided to the industry regarding less carbon intensive frost protection measures, particularly in the more frost-prone regions.

6.1.2 Use of Agrichemicals

Scenario analysis identified the high sensitivity of FAETP to changes in emission rates, which highlights the importance of ensuring that more of the chemical reaches its intended target. This suggests the importance of providing the industry with information on measures to reduce spray drift, such as through using more accurate spraying technologies or ensuring optimal weather conditions before spraying.

Another option for SWNZ to address FAETP is to promote EIQ as a tool for developing spray programmes. Through EIQ, vineyard managers can make more informed decisions about the toxicity of the sprays that are being used, while having a quantitative measure to gauge future improvements. Also, if EIQ was incorporated into the SWNZ score card, performance benchmarks could be established from which managers can compare their practices with others in the industry. So while LCA is a useful method to identify the relative significance of FAETP related emissions, EIQ may be a more practical and feasible way of managing these emissions.

6.1.3 Sheep Grazing

In a practical sense, it seems sensible that sheep emissions should not be attributed to the wine product because the sheep exist regardless of whether they are grazing on pasture or in a vineyard. In many cases, this is likely to be a relatively easy and cost effective way of reducing the carbon footprint of the vineyard by avoiding some mowing and herbicide use. Therefore the grazing of sheep should be encouraged in the industry.

6.1.4 Management of Yields

This study has identified the potential relationship between crop regulation and environmental impact. Poor crop regulation, which for example leads to excessive dumping of fruit, has the inadvertent effect of increasing the environmental impact of the finished product from a life cycle perspective. At an industry level, if the current overabundance of grapes continues to worsen into the future then it could be argued the industry is not operating efficiently - both in terms of resource and energy consumption, and management of its overall environmental impact.

6.1.5 Energy Efficiency in the Winery

Given the significance of electricity use in the wine life cycle and the ready availability of more energy efficient technology, there is opportunity for SWNZ to promote the importance of energy efficiency to its members. One option for SWNZ might be to lease electricity meters out to its members to install on various wine making machinery and equipment. Consumption data could be compiled to improve understanding on where electricity is consumed in New Zealand wineries, from which point targeted energy efficiency improvement options can be identified.

6.1.6 Lees Waste Management

While the composting of lees waste offers a relatively modest reduction opportunity, it is nonetheless a relatively easy management practice to adopt. In some cases composting is actually cheaper than land filling. For example, BioRich, a composting operation in Hastings charge $35 per tonne for disposal, while the local City Council's landfill costs around $75 per tonne (Anon, 2010a).

Returning the compost to the soil offers the additional benefits of improved water retention, weed control and increased soil organic content.

According to SWNZ data, around 19% of member wineries compost their lees waste while 12% send it to the local landfill[29]. This implies there is room for the industry to raise its environmental standards at this life cycle stage. SWNZ might consider offering information aimed at promoting composting in the industry, either at the vineyard or at commercial composting operations. This may involve researching the potential GWP savings that might be realised if the composting of lees was practiced more widely throughout the industry.

Supporting the market for large-scale composting operations would also demonstrate to stakeholders that the wine industry is actively addressing its environmental standards. The market would likely develop at a faster rate if the wine industry were to engage with other agricultural industries to promote the practice of composting organic agricultural waste.

6.1.7 Packaging Systems

It may be worthwhile for the industry to conduct research into how the PET bottle is perceived among wine consumers, whether leaching is an issue for wine, and which types of wine are better suited to this type of bottle. Researching these areas would not only provide clarity over some the issues mentioned earlier, but might also help accelerate the uptake of PET bottles in certain markets.

Regarding bulk shipping, one option for SWNZ might be to administer a cooperative of New Zealand wine companies interested in investing in a small bottling facility in the UK. While this option would incur high initial capital costs, it may prove to be a viable investment in the longer term, particularly if bulk shipping continues to increase in popularity. It is worth noting nearly half (48%) of all still white wine exported from Australia and South Africa is shipped in bulk (AWBC, 2009; Woodward, 2010).

[29] At the remaining wineries, lees is either mixed with waste water, spread straight onto the vineyard or some other disposal method is employed.

Reducing the environmental impact associated with packaging and distribution presents an opportunity for the New Zealand wine industry to demonstrate its environmental responsibility to UK importers and consumers. Exporting wine in lighter packaging provides an easy way for British retailers that are signatories to the Courtauld Commitment to meet their packaging reduction targets. A number of major retailers, such as Sainsbury's, Tescos and Kingsland Wines and Spirits are already actively marketing their wine products with lighter packaging (WRAP, 2008). It may eventuate at some point in the future that wine with a smaller packaging footprint gets priority access to supermarket shelves over similar wine products using the standard glass bottle. It therefore makes sense from a risk management perspective, for New Zealand exporters to consider lighter packaging options if they want to retain access to certain UK markets.

Table 26 shows the potential GWP reductions the industry could achieve through changing the way it delivers its product to the British market. The GWP savings shown are derived from assuming that half of the 28.86 million litres[30] of Sauvignon Blanc exported from New Zealand to the UK in 2009 was packaged using each of the scenarios discussed above. It is assumed that all of this wine was previously packaged in the standard glass bottle.

Table 26: Potential greenhouse gas reductions the industry might achieve under a range of packaging scenarios

	Bulk shipping - standard glass	**Lightweight glass**	**PET bottles**
Potential CO_2-e saving (tonnes) per year	3,164	3,165	10,704

This study confirms that while distance is a key determinant of the GWP of wine, this footprint can, at least partly, be mitigated through a range of packaging options. This need to address packaging is more likely to be an issue for countries that are distant from their key markets, such as New Zealand.

[30] This is based on sales data from (NZWINE, 2009).

6.1.8 Export Markets

Another option for New Zealand wine exporters to reduce their environmental footprint is to expand their export markets nearer to home. While many of the largest wine importing countries are European, a significant volume of wine is imported into Asia. China and Japan are the largest consumers of wine in Asia, together importing around two-thirds of all wine imported into Asia in 2007. At that time Japan and China were the 13^{th} and 14^{th} largest wine importers in the world, while China's imports have increased significantly over recent years (OIV, 2010b). Given the favourable "clean and green" image that New Zealand has in these countries, it may be useful to market wine with environmental credentials in these markets. The Japanese market is particularly relevant to producers of Sauvignon Blanc, as around 45% of all wine exported to Japan during 2009 was of this variety (NZWINE, 2009).

6.1.9 SWNZ and Carbon Footprinting

Finally, given the increasing relevance of the PCF as a point of difference in the market, it may be desirable from a competitive advantage point of view for SWNZ to develop a PCF option for its members. One option might be to integrate a streamlined LCA, based only on GWP from certain activities, with a multi-tiered certification scheme. The tiers might take the following structure: less than 700g CO_2-e; between 700-1000g CO_2-e; and more than 1000g CO_2-e.

Based on the LCA results, the following activities might be included:

- Fuel requirements for frost protection;
- Mobile fuel use;
- Manufacture and application of agrichemicals;
- Electricity consumption for irrigation and the winery;
- Emissions from lees waste;
- Glass bottle production and distribution;
- Shipping to market.

Activities of lesser environmental significance might be excluded from the system boundary, such as transportation of gas bottles to and from the winery, transportation of recycling waste to the recycling station, and the distribution of agrichemicals, wine additives and tank cleaning products, though these might be included at a later stage. Note these suggestions are based on this LCA case study, and further research is needed to test the strength of these recommendations.

Taking such a proactive stance would incentivise SWNZ members to better measure, manage and reduce their carbon emissions, while also sending a positive message to consumers and retailers that New Zealand wine industry is actively involved in carbon management.

In terms of GHG accounting, it is evident from this research and the literature that Scope 3 emissions make a significant contribution to the life cycle GWP of the wine product. A company measuring its emissions according to the GHG Protocol is not required to measure Scope 3 emissions, indicating the Protocol is not an entirely adequate assessment method for the wine industry. However, the new draft Scope 3 reporting standard does require measuring emissions throughout the supply chain, and in the case of the wine industry, is a more appropriate method to apply for company-level accounting.

Therefore, a product-oriented life cycle approach is more suitable approach for company-level GHG accounting in the wine industry. This suggests that carboNZero's method in terms of boundary setting, which accounts for all the activities listed above, is appropriate, and that the most significant activities associated with the wine product (at least those relating to GWP) are being accounted for. One minor exception exists though, in the exclusion of waste to landfill emissions in one of the company's carbon disclosure statements, on the grounds these emissions "are likely to be of limited significance with respect to the total inventory" (carboNZero, 2009). Based on the LCA case study results, which show that landfilling lees waste contributes around 10% towards the GWP of the wine making stage, it would seem fair to suggest these emissions should be included in any calculations of the carbon footprint at a product-level.

Finally, should assessment methods such as the IWCC and MAF's GHG Accounting Guidelines be expanded to include non-GHG related activities, then these might include: AP associated with manufacturing the packaging system, and the FAETP impacts from agrichemical emissions.

6.2 Implications for Environmental Labelling in the Wine Industry

In this section, five recommendations for environmental labelling in the wine industry are discussed based on the LCA case studies: the need for more research into non-GHG related impacts, the need for a standardised assessment methodology, disclosure of the packaging GHG emissions factor, communication of the environmental benefits of PET bottles, and the integration of carbon footprinting with SWNZ.

Firstly, the normalised results, in line with findings reported by Petti (2006), show that use of a carbon label is not an entirely adequate indicator of the full environmental impacts associated with the wine product. GWP only had the third highest normalised value, with AP and FAETP identified as being of greater environmental significance and having different activities contributing to their results. This highlights that one of the main criticisms of the PCF, its single-indicator approach, may be valid in the case of wine. However, development of a better understanding of this issue requires more LCA research.

Secondly, given the relatively high sensitivity of activities such as mobile and stationary fuel combustion, glass bottle production and shipping, there is a good case for developing a more standardised assessment methodology to be used in labelling programmes. This would apply at both company- and product-level. This research has also identified that activities of lesser environmental significance, such as sheep grazing and waste treatment, also require definition of a standardised approach. While the IWCC represents a solid first step in this direction, the tool still fails to address a number of methodological issues, particularly those relating to data quality.

Of all the activities in the wine life cycle, the need for a standardised emissions factor is arguably greatest for bottle production. This activity has a significant influence on total GWP, yet a wide range of emissions factors are available in the literature. One option might be to develop an industry-wide data set, in which changeable parameters such as bottle weight, level of recycled content and country of origin can be entered. This would provide greater transparency and fairer competition in the marketplace, as it would lessen the ability of wine companies to make misleading claims, by reducing the ability to use emissions figures that are either inaccurate or based on data sources that are of poorer quality.

There is also a need for a set of more standard emissions figures for shipping, which could be developed in line with each of the wine packaging options available. It would be fair to suggest this need also exists for most exporting industries in New Zealand.

Thirdly, given the environmental importance of packaging, it could be argued the embodied GHG emissions associated with packaging should be more obviously disclosed in environmental labelling. In terms of product carbon labelling, this might take the form of a Type III environmental label, with the emissions figure stated alongside the carbon footprint. For company-level carbon reporting, the emissions figure might be stated in the carbon disclosure statement.

Fourthly, with regard to the PET bottle, this segment of the market might develop at a faster rate if the environmental benefits of PET bottles are more clearly communicated to the public. A form of Type II label may be appropriate, using phrases such as "around a 33% smaller carbon footprint than glass". While there are non-GWP related environmental benefits with PET bottles, it is more likely the carbon footprint will be the most relevant environmental indicator, at least in the short term. While this study identified a life cycle GWP saving of 38%, there is an obvious need for further research to test and validate this figure.

Fifthly, the integration of carbon footprinting into SWNZ (as discussed in Section 6.1.9) would represent a form of Type I labelling scheme for the industry. This might involve developing a new logo that would indicate the carbon footprint has been independently verified by a third party.

Finally, it will be interesting to observe how well the new Mobius wine brand (the first to bear the Carbon Reduction Label) is received in the UK market. This will provide a better indication of how wine consumers respond to carbon labelling, and if successful, may encourage other New Zealand wineries to engage with this kind of marketing.

CHAPTER 7: CONCLUSION

Through the identification of environmental hotspots, use of sensitivity analysis, and normalisation of results, all using a product life cycle framework, this thesis shows LCA to be a potentially useful environmental management tool for the New Zealand wine industry. The LCA case study results provide the industry with some direction as to how to better measure, manage and reduce its environmental impacts, and have led to identification of various ways of improving the quality of information being conveyed to the consumer through environmental labelling schemes.

It seems sensible that SWNZ – which is already well established and widely used - incorporate these results into its certification scheme. Given the complexity and time consuming nature of LCA, it would not be practical for every wine company to employ this method, but there is opportunity for the wider industry to be guided by these LCA results. This sector-based approach to Life Cycle Management echoes the approach taken in MAF's GHG Footprinting Strategy where different primary sectors in New Zealand have been encouraged to develop sector-based reduction programmes based on carbon footprinting studies. In terms of its future strategic direction, the New Zealand wine industry would clearly benefit from incorporating life cycle thinking into its environmental management; as a means for raising its environmental standards, driving continuous improvement and remaining internationally competitive.

AREAS FOR FUTURE RESEARCH

- Accurately determine the carbon balance, in terms of how much carbon is sequestered by grapevines in relation to the amount of carbon released during fermentation
- Establish an industry wide tool to estimate the embodied GHG emissions associated with glass bottle production
- Establish an industry wide figure for the shipping emissions of bottled and bulk wine
- Determine an emissions factor specific to the land filling of lees waste
- Develop embodied GHG emissions factors for the most common wine additives
- To better understand the significance of non-GHG related environmental impacts associated with the wine life cycle
- To define a method for how sheep emissions should be modelled in the wine industry

APPENDIX I- DESCRIPTION OF THE IMPACT CATEGORIES USED

This appendix provides a brief description of each impact category used in this LCA study. To understand the terms used in table 27, the following definitions are provided:

- *Environmental mechanism* - A system of physical, chemical and biological processes for a given impact category, that link the LCI results to their respective category indicators;
- *Characterisation model* - A model that describes the relationship between the LCI results and the category indicators, and is used to derive the characterisation factors;
- *Characterisation factor* - Derived from the characterisation model, which is applied to convert LCI results into the category indicator;
- *Category indicator* - A quantifiable representation of a given impact category.

Table 27: Description of the various impact categories used in this LCA study. Based on Guinée (2002).

Impact Category	Environmental Mechanism	Characterisation Model	Characterisation Factor	Category Indicator	Unit (e=equivalents)
Global Warming Potential (GWP)	Release of airborne GHG emissions	Developed by the IPCC, which defines the GWP of various gases	GWP of each gas over a 100-year time horizon	Infrared radiative forcing (W/m^2)	Kg (CO_2-e)
Ozone Depletion Potential (ODP)	Release of ozone-depleting substances into air	Developed by the World Meteorological Organisation, which defines the ODP of various gases	ODP in the steady state, for each emission to the air	Stratospheric ozone breakdown	kg (CFC-11-e)
Abiotic Depletion Potential (ADP)	Extraction of minerals and fossil fuels	Based on concentration- based reserves and rate of de-accumulation approach	ADP for each extraction of minerals and fossil fuels	Depletion of the ultimate reserve in relation to annual use	(in kg antimony (Sb) equivalents/kg

					extraction)
Primary Energy Consumption	Consumption of energy			Measures net calorific, or lower heating value	MJ-e
Photochemical Ozone Creation Potential (POCP)	Emissions of substances (volatile organic compounds or carbon monoxide) to the air	UNECE Trajectory Model	POCP for each emission of VOC and CO to air	Tropospheric ozone formation	kg (C2H4, or ethylene-e)
Acidification Potential (AP)	Emissions of acidifying substances to the air	RAINS10 model, developed at IIASA, which describes the fate and deposition of acidifying substances	AP for each acidifying emission to the air	Deposition / acidification critical load	kg (SO_2-e)
Eutrophication Potential (EP)	Emissions of nutrients to air, water and soil	Stoichiometric procedure, which identifies the equivalence between N and P for terrestrial and aquatic systems	EP for each eutrophying emission to air, water and soil	Deposits of nitrogen or phosphorus, equivalents in biomass	kg (PO_4-e)
Marine Aquatic Ecotoxicity Potential (MAETP)	Emissions of toxic substances to air, water and soil	USES 2.0 model developed as RIVM, which describes fate, exposure and effects of toxic substances	MAETP for each emission of a toxic substance to air, water and soil	Predicted environmental concentration / predicted no-effect concentration	kg (1,4-DCB, or dichlorobenzene-e)
Freshwater Aquatic Ecotoxicity Potential (FAETP)	Same as above	Same as above	FAETP for each emission of a toxic substance to air, water and soil	Predicted environmental concentration / predicted no-effect concentration	kg (1,4-DCB, or dichlorobenzene-e)
Terrestric Ecotoxicity Potential (TETP)	Same as above	Same as above	TETP for each emission of a toxic substance to air, water and soil	Predicted environmental concentration / predicted no-effect concentration	kg (1,4-DCB, or dichlorobenzene-e)
Human Toxicity Potential (HTP)	Same as above	Same as above	HTP for each emission of a toxic substance to air, water and soil	Acceptable daily intake / predicted daily intake	kg (1,4-DCB, or dichlorobenzene-e)

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