LIFE CYCLE ENVIRONMENTAL IMPACTS OF WINE PRODUCTION AND CONSUMPTION IN NOVA SCOTIA, CANADA

by

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Table Of Contents

List Of Tables viii

List Of Figures ix

Abstract x

List Of Abbreviations Used xi

Acknowledgements xiii

1.0 CHAPTER ONE: INTRODUCTION 1

1.1 Food Production And The Environment 1

1.2 The Application Of Biophysical Analyses To Food Systems 3

1.3 Overview Of Life Cycle Assessment (LCA) 4

1.3.1 History Of LCA 6

1.3.2 LCA Methodology 8

1.3.2.1 Goal And Scope Definition 8

1.3.2.2 Life Cycle Inventory Analysis (LCI) 8

1.3.2.3 Life Cycle Impact Assessment (LCIA) 9

1.3.2.4 Interpretation Of Results And Improvement Assessment 9

1.3.3 Limitations Of LCA 10

1.4 The Application Of LCA To Food Systems 11

1.4.1 Life Cycle Environmental Impacts Of Food and Beverages 12

1.4.1.1 Organic Agriculture And Food Miles 14

1.5 Life Cycle Environmental Impacts Of Wine 15

1.6 The Wine Industry In Nova Scotia 18

1.6.1 An Emerging Industry, 1980 – 2000 18

1.6.2 Nova Scotia Wine In The New Millennium 19

1.7 Project Rationale And Research Objectives 20
1.8 Organization Of Thesis 22
2.0 CHAPTER TWO: LIFE CYCLE ENVIRONMENTAL IMPACTS OF WINE PRODUCTION AND CONSUMPTION IN NOVA SCOTIA, CANADA 23
2.1 Publication Information 23
2.2 Abstract 23
2.3 Introduction 24
2.4 The Wine Industry In Nova Scotia 26
2.4.1 Grape Growing In Nova Scotia 27
2.4.2 Wine Making In Nova Scotia 28
2.4.3 Post-Winery Stages Of Nova Scotia Wine 29
2.5 Materials And Methods 29
2.5.1 Goal And Scope Definition 30
2.5.2 Life Cycle Inventory (LCI) 32
2.5.2.1 Vineyard Data 37
2.5.2.2 Winery Data 38
2.5.2.3 Bottle Manufacture And Bottle Transport Data 38
2.5.2.4 Transport To Retail Data 38
2.5.2.5 Consumer Transport, Refrigeration And Bottle Recycling Data 39
2.6 Life Cycle Impact Assessment (LCIA) 39
2.7 Interpretation Of Results And Improvement Assessment 40
2.7.1 Scenario Modeling 40
2.7.1.1 Organic Viticulture Scenario 41
2.7.1.2 Lighter Bottle Scenario 42

2.7.1.3 Increased Consumer Transport Distance Scenario 43

2.7.1.4 Increased Transport Distance To Market Scenario..................................43

2.7.2 Sensitivity Analysis 44

2.8 Results..44

2.8.1 Vineyard Life Cycle Inventory Results 44

2.8.2 Post-Vineyard Life Cycle Inventory Results 46

2.9 Life Cycle Impact Assessment Results..48

2.9.1 Scenario Modeling Results 56

2.9.1.1 Organic Viticulture Life Cycle Inventory Results 56

2.9.1.2 Organic Viticulture Life Cycle Impact Assessment Results.....................57

2.9.1.3 Lighter Bottle Life Cycle Impact Assessment Results 60

2.9.1.4 Increased Consumer Transport Distance Life Cycle Impact Assessment Results 61

2.9.1.5 Increased Transport Distance To Market Life Cycle Impact Assessment Results...61

2.9.2 Sensitivity Analysis Results..63

2.10 Discussion 65

2.10.1 Environmental Impacts Of Nova Scotia Wine.......................................65

2.10.2 Nova Scotia Wine In The Context Of Other Wine LCAs..........................65

2.10.3 Improvement Opportunities For Nova Scotia Wine 67

2.10.4 Limitations Of The Organic Scenario Model 69

2.11 Conclusion 70

3.0 CHAPTER THREE: DISCUSSION..73

3.1 Life Cycle Impact Assessment Of Nova Scotia Wine 73

3.2 An Elaboration On The Merits Of Organic Viticulture 74

3.3 Importance Of Wine's Post-production Transport....75

3.4 Limitations Of This Research....76

3.5 Methodological And Conceptual Challenges Of This Research....76

3.6 Recommendations For Future Research....77

Appendix A: Vineyard Life Cycle Inventory Data Collection Survey....80

Appendix B: Winery Life Cycle Inventory Data Collection Survey....91

Appendix C: Calculation Of Emissions From The Application Of Fertilizers....93

Appendix D: Description Of Impact Categories Analyzed In This Study....96

References....98

List Of Tables

Table 2.1 Background process data obtained from peer-reviewed LCA databases 34

Table 2.2 Life cycle inventory results for Nova Scotia viticulture in 2006 45

Table 2.3 Life cycle inventory results for Nova Scotia winery practices in 2006 47

Table 2.4 Detailed contributions (% of total) of sub-systems to wine's life cycle environmental impacts 50

Table 2.5 Inputs, per tonne of grapes produced, to conventional (base case) and two potential organic grape growing scenarios in Nova Scotia 56

Table 2.6 Results of the organic scenario models 59

Table 2.7 Inputs, per tonne of grapes produced, and toxicities associated with fungicides and herbicides used in (actual) conventional and (hypothetical) organic grape growing 60

Table 2.8 LCIA results for the three scenarios: lighter glass bottles, increased consumer transport distance, and increased distance to retail 62

Table 2.9 Sensitivity analysis results testing the relative importance of transport mode for transport of wine to retail in Halifax 64

Table C.1 Calculations of nitrogen and phosphorous losses from synthetic and manure fertilizer application in Nova Scotia vineyards in 2006 92

Table D.1 Information regarding impact categories analyzed in this research and the characterization methodologies used to calculate contributions of LCI data into impact categories 95

List Of Figures

Figure 1.1 The life cycle model 6

Figure 1.2 Nova Scotia grape production, 1981-2006 20

Figure 2.1 Nova Scotia winegrowing regions in 2006 27

Figure 2.2 System flow diagram of Nova Scotia wine's life cycle 32

Figure 2.3 Relative contributions (% of total) of wine's life cycle sub-systems to environmental impact categories 49

Figure 2.4 Detailed contributions (% of total) of vineyard sub-processes to environmental impact categories 53

Figure 2.5 Detailed contributions (% of total) of nutrient management sub-processes to environmental impact categories 54

Figure 2.6 Detailed contributions (% of total) of nitrogen fertilizer manufacture and field level emissions to environmental impact categories 55

Figure 2.7 Life cycle impact assessment results for conventional (base case) and two potential organic grape growing scenarios in Nova Scotia 58

Abstract

Food production and consumption is one of the most resource and energy demanding activities of households in the developed world. Throughout the life cycle of foods, the provision and use of materials and energy result in contributions to a wide range of environmental impacts. Here, life cycle assessment was employed to quantify impacts of, and potential improvement options for viticulture and viniculture, bottle provision, transport, consumer activities and recycling of one bottle of Nova Scotia wine. Results indicate that viticulture, bottle provision, and consumer transport contribute the greatest portion of wine's total impacts. Nutrient management offers the greatest potential source of improvement in the vineyard, and consumer transport distance should be minimized. Modeled scenarios indicate that provision of lighter bottles could reduce contributions to all impacts, whereas organic viticulture offers improvements only to certain impacts. Consuming locally-produced wine may be an effective option for reducing the environmental impacts of wine.

List Of Abbreviations Used

1,4-DCB	1,4-dichlorobenzene
AETP	aquatic eco-toxicity potential
AI	active ingredient
AP	acidification potential
ARDP	abiotic resource depletion potential
BC	British Columbia
CCA	chromium copper arsenate
CED	cumulative energy demand
CFC-11	chlorofluorocarbon-11 (trichlorofluoromethane)
C_2H_4	ethylene gas
CH_4	methane
CO_2	carbon dioxide
EP	eutrophication potential
eq	equivalents
g	grams
GWP	global warming potential
ISO	International Organization for Standardization
kg	kilograms
km	kilometers
kWh	kilowatt hours
l	litres
LCA	life cycle assessment
LCI	life cycle inventory
LCIA	life cycle impact assessment
MJ	megajoules
ml	millilitres
N_2O	nitrous oxide
NH_3	ammonia
NO	nitric oxide
NO_3	nitrate

NO_x	nitrogen oxides
ODP	ozone depletion potential
ON	Ontario
P_2O_5	phosphorous pentoxide
PO_4	phosphate
POP	photo-oxidant formation potential
Sb	antimony
SO_2	sulphur dioxide
TETP	terrestrial eco-toxicity potential
VOC	volatile organic compound

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1.0 CHAPTER ONE: INTRODUCTION

My thesis seeks to communicate the process and results of a life cycle assessment (LCA) of a bottle of wine produced and consumed in Nova Scotia, Canada. My initial interest in this topic was derived from my desire as a consumer to gain a more thorough understanding of the intricacies of food production systems in relation to the notion of environmental sustainability. A heightened recognition of the environmental impacts associated with the industrialization of food systems has stimulated my interest in understanding the factors that determine a food item's relative environmental impact. Recent developments in the field of food sustainability research have suggested that this question may be best addressed by taking a life-cycle perspective (Mattson, 1999a; Mattsson & Sonesson, 2003; Foster *et al*., 2006). Without such a perspective, a narrow view that focuses solely on the production aspect of a food system may omit much of what contributes to that food's total environmental impact, including impacts associated with its processing, packaging, transport, storage, cooking and eventual disposal.

I selected Nova Scotia wine as an industry that could offer insight into the complexities of modern food and agricultural systems. The life cycle of wine contains an agricultural stage, a processing stage, the manufacture of glass packaging, transportation links, refrigeration, and eventual disposal. The application of LCA to Nova Scotia wine also provides an opportunity to gain insight into the perceived benefits of organic grape growing, the relative importance of wine's "food miles", the influence of wine's packaging, and the relative importance of the consumer on wine's total life cycle environmental impacts. At a time when producers of wine have begun to incorporate environmental responsibility as an important criterion of effective management and marketing strategies (California Sustainable Winegrowers Alliance, 2008; Sustainable Winegrowing New Zealand, 2008), an analysis providing insight into the life cycle environmental impacts of wine may prove particularly useful.

1.1 Food Production And The Environment

Throughout much of the history of human civilization, the acquisition of food energy was bound by the capacity of humans to perform work and by the biophysical limits imposed by the surrounding ecosystem (Mead, 2004). Climate and local biodiversity determined the types and abundance of food that were available, and human populations were maintained at levels in accordance with nature's provision of essential inputs of materials and energy, as well as its regenerative and waste assimilative capacity. Only in the past century has the industrialization of our food system vastly altered the physical limits by which food production is bound. With the adoption of fossil energy-dependent technologies, the capacity to grow food has become increasingly less dependent on the seasons, limits of the human body, and soil's natural fertility (Pimentel, 2004). Mechanization and technological innovation since the first "green revolution" in the mid-20th century has led to improved productivity in the primary production of crops and in the production of animal protein per unit of labour and land (Gerbens-Leenes & Nonhebel, 2002; Pimentel, 2004), along with efficiency gains in food processing, transportation, and preservation techniques. The industrial food model, now thoroughly dependent on a finite source of fossil energy, has also enabled the production of enough food to support an ever-increasing global population (Gerbens-Leenes & Nonhebel, 2002).

Industrialization of our food system has not come without costs; food production and consumption has been identified as one of the most resource and energy demanding activities of households in the developed world (Vringer & Blok, 1995; Carlsson-Kanyama *et al*., 2003; Foster *et al*., 2006), responsible for as much as 15% to 20% of total energy consumption (Biesiot & Moll, 1995, as cited in Kramer *et al*., 1999; Pimentel 2004). The resulting impacts are contributing to some of the greatest ecological challenges the world has ever faced - climate change, stratospheric ozone depletion, photo-oxidant formation (the creation of smog), acidification of terrestrial and aquatic ecosystems, eutrophication of groundwater and surface waters, abiotic resource depletion and biodiversity loss. These globally-relevant environmental impacts are manifestations of disruptions to biogeochemical cycles, and to ecosystems and the services they provide. Evidenced by a growing body of climate change (IPCC, 2007) and ecosystem assessment research (Reid *et al*., 2005), the cumulative results of our industrial activities are now exceeding the carrying capacity of the earth's natural resources and cycles.

Many of the environmental impacts associated with the industrialized food model are attributable to a direct or indirect reliance on fossil energy at each stage of food's life cycle (Carlsson-Kanyama, 1998; Horrigan *et al*., 2002). The manufacture of fertilizers and pesticides, farm operations, processing and transport of goods, production of packaging, refrigeration, cooking, and end of life disposal options are all dependent on sources of fossil energy (Kramer *et al*., 1999; Carlsson-Kanyama *et al*., 2003; Wallén *et al*., 2004*)*. Emissions that are released during the combustion of fossil fuels (e.g. CO_2, N_2O, NO_x, SO_2, etc) (IPCC, 2007) contribute to a host of environmental impacts including climate change, the creation of smog, and acidification of terrestrial and aquatic ecosystems (Guinée *et al*., 2001). Not all agricultural impacts stem from the combustion of fossil fuels, however. Globally, enteric fermentation of cattle is estimated to contribute the largest anthropogenic source of CH_4 (Subak, 1999; Bellarby *et al*., 2007), a potent greenhouse gas (Guinée *et al*., 2001). Organic and synthetic fertilizers also contribute to global warming, with field-level emissions of NH_3, NO and N_20 (Brentrup *et al*., 2000), the latter of which has a radiative forcing capacity 310 times that of CO_2 (Guinée *et al*., 2001). Emissions of NO_3 from fertilizers contribute to the eutrophication of fresh water (Kramer *et al*., 1999; Brentrup *et al*., 2000; Guinée *et al*., 2001), and field level emissions from pesticides can have numerous toxicological effects on humans and other forms of life (Audsley, 1997; Milà i Canals *et al*., 2006).

Because the industrial food system contributes disproportionately to many global-scale environmental problems, it is of utmost importance that real improvements are made to its overall environmental performance. The production and consumption of food will always result in some level of environmental impact, yet an appropriate task is to determine how best to grow, process, package, transport, store, cook and dispose of food such that it requires the least possible amount of material and energy and releases a minimal amount of waste back into the environment. Since much of the environmental damage associated with food production systems is not identified by qualitative assessment alone, quantitative analyses based on empirical evidence and biophysical reality, offer a far more rigorous basis of understanding.

1.2 The Application Of Biophysical Analyses To Food Systems

Materials and energy are required, and ultimately emitted at every stage in the life cycle of a food product. Quantification of the biophysically relevant aspects of food production systems allows producers and consumers to make decisions based on far more information than economics alone.

A range of techniques have emerged that seek to assess certain environmental impacts of products and processes. Since many of the environmental burdens associated with food are directly or indirectly related to energy and material consumption (Nieuwlaar, 2004), many of these techniques use quantifications of energy and material exchanges as proxies for overall environmental impact.

Material Flow Analysis (MFA) and Material Intensity per Unit of Service (MIPS) are both measures of the material flows of a system (Brunner & Rechberger, 2004; Baumann & Tillman, 2004). Ecological Footprint Analysis (EF), measures the area of biologically productive land required to sustain a product, process or population (Wackernagel & Rees, 1995). The measure of a system's appropriation of Net Primary Productivity (NPP) is an indicator of that system's use of biologically available energy (Vitousek *et al*., 1986), while emergy and energy analyses use a system's energy requirements as a proxy for environmental impact (Odum, 1996; Nieuwlaar, 2004).

Also in this suite of useful sustainability tools is a process called Life Cycle Assessment (LCA). LCA offers a rigorous framework and standardized methodology for the quantification of several environmentally-relevant material and energetic flows of a product or process (Bauman & Tillman, 2004). In recent decades, LCA has garnered widespread support from the international community (Hertwich *et al*., 2000; Khan *et al*., 2002; United Nations Environment Program, 2006) for its utility to inform strategic environmental programs, monitor progress, and most importantly, lead to a minimization of environmental burdens resulting from the provision and use of products and services (Guinée *et al*., 2001). Although it was developed for the industrial manufacturing sector, the adoption of LCA as a tool to evaluate and improve the environmental aspects of food production and consumption has substantially broadened its methodological capabilities and suitable applications. LCA is the chosen measurement tool for the analysis of the environmental implications of Nova Scotia wine.

1.3 Overview Of Life Cycle Assessment (LCA)

A Code of Practice for LCA developed by the Society of Environmental Toxicology and Chemistry (SETAC) provides the following procedural definition:

> Life-Cycle Assessment is a process to evaluate the environmental burdens associated with a product, process or activity by identifying and quantifying energy and materials used and wastes released into the environment; to assess the impact of those energy and material uses and releases to the environment; and to identify and evaluate opportunities to affect environmental improvements. The assessment includes the entire life-cycle of the product, process or activity, encompassing extracting and processing raw materials; manufacturing; transportation and distribution; use; re-use; maintenance; recycling, and final disposal (Consoli *et al*., 1993, p. 5).

Arguably, LCA's greatest strength is its focus on the entire life cycle of a product or production system – from raw materials acquisition through to post-consumer product disposal. This life-cycle approach, illustrated in Figure 1.1, can provide as complete a picture as possible with regard to the myriad of activities occurring throughout a product's life that may contribute to its total environmental impact. This perspective also ensures that efforts to improve the performance of a product will not unknowingly "shift" the burden to another part of the production chain (Baumann & Tillman, 2004; Curran, 1996). Furthermore, in contrast to other accounting frameworks (e.g. energy analyses or monetary assessments), methodologies have been developed to account for a wide range of potential resource and environmental impacts including, but not limited to: contributions to global warming; stratospheric ozone depletion; smog creation; eutrophication; acidification; toxicological stress on humans and ecosystems; the depletion of natural resources; energy consumption; land use and; water use (Guinée *et al*., 2001; Frischknecht *et al*., 2003). Thus, LCA is comprehensive not only with regard to its inclusion of all processes within a product's life cycle, but with respect to the wide range of globally-significant environmental impacts on which it can report (Guinée *et al*., 2001).

In addition to identifying the impacts and potential improvement options of a product, LCA can inform product development and design, aid in the selection of relevant indicators of environmental performance, and contribute meaningfully to environmental marketing endeavors (ISO, 2006a). The quantification of impacts in an LCA also facilitates the comparison of alternative production techniques and of products with a similar function (ISO, 2006a; Guinée *et al*., 2001; Andersson, 2000). Refinement of the LCA methodology and its applications has been an ongoing process for nearly four decades, as described in the following section.

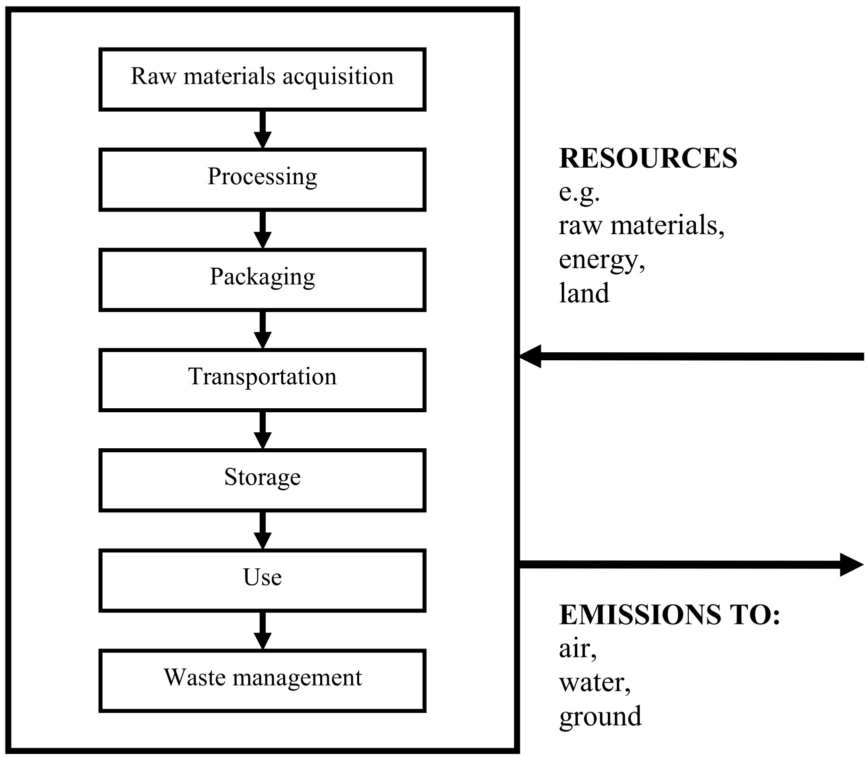

Figure 1.1 The life cycle model. The model illustrates 1) LCA's focus on all stages of a product's life cycle, from raw material extraction, through to post-consumer disposal activities and 2) LCA's quantification of the material, energy and waste flows through a production system. Arrows illustrate the flow of energy and matter (Baumann & Tillman, 2004).

1.3.1 History Of LCA

It is generally accepted that the first commissioned study with a "life cycle" perspective was conducted for the Coca Cola company in the late 1960s (Hunt & Franklin, 1996; Baumann & Tillman, 2004). Fueled by a growing recognition of the environmental implications of disposable packaging, Coca Cola, along with other early life cycle practitioners and commissioners, were interested in learning about the energy, material, and environmental consequences associated with the production and disposal of various packaging options (Baumann & Tillman, 2004). The oil price shocks of the proceeding decade further validated such analyses (Baumann & Tillman, 2004).

Until the early 1990s, studies that undertook an assessment of the material, energy and waste flows of a product's life cycle were conducted under a variety of names including Resource and Environmental Profile Analysis (REPA), Ecobalances, Integral Environmental Analyses, and Environmental Profiles. In 1991, the international LCA community agreed upon its current name and the utility of LCA as an environmental management tool in the public and private sectors was becoming increasingly accepted (Baumann & Tillman, 2004). It had become apparent however, that LCAs carried out by different researchers for similar products were producing conflicting results, attributable in part to the varying methodological choices that were available for LCAs (Russell *et al*., 2005). This, along with criticisms of the ease with which LCAs could be manipulated to produce desired results, sparked the first scientific conferences on LCA where researchers and practitioners began to discuss how best to standardize the methodology (Baumann & Tillman, 2004).

The first guidelines for LCA were published in SETAC's *Code of Practice* (Consoli *et al*., 1993) and within four years, the International Organization for Standardization (ISO) had begun to further develop these methodological standards, the most recent versions of which were published in 2006 (ISO 2006a; ISO 2006b). These ISO documents provided a technically rigorous and repeatable framework for carrying out LCAs (Baumann & Tillman, 2004; Finkbeiner *et al*., 2006). The consolidation of methods and procedures was an important step for LCA as it contributed to an overall acceptance of the tool by the international community (Finkbeiner *et al*., 2006), evidenced by a rapidly growing number of LCA studies that have been published since the introduction of the ISO guidelines, and the establishment of an academic journal devoted to the publication of LCA related materials. More recently, at the World Summit for Sustainable Development in 2002, a call was made by world leaders to develop policies, programs and plans that focus on a movement towards sustainable production and consumption. Remarkably, LCA was identified as the tool that would best help to achieve these sustainability goals (Hertwich, 2005).

1.3.2 LCA Methodology

Technical guidelines for LCA exist to ensure that studies are rigorous and transparent (Consoli *et al*., 1993). According to the ISO 14040 standards (2006a), an LCA should consist of four macro-level methodological stages, performed in the following order: goal and scope definition, life cycle inventory analysis (LCI), life cycle impact assessment (LCIA) and finally, interpretation of results and improvement assessment. An LCA is considered to be an iterative process, however, since new knowledge gained throughout the LCA process often necessitates a revisiting of previously defined assumptions and objectives in order to meet the project's original goals (Baumann & Tillman, 2004).

The four methodological stages of LCA are briefly elaborated below. Greater detail is provided in Chapter Two, in which the application of LCA to the Nova Scotia wine industry facilitates an applied description of these methodological procedures.

1.3.2.1 Goal And Scope Definition

The first component of an LCA involves a clear definition of the project's goal, which consists of stating the intended purpose, application, and audience of the study (ISO, 2006a; Guinée *et al*., 2001). Scope definition entails an elaboration of the functional unit of study (the quantified unit of production to which all resources used and emissions generated by the product system will be referenced), the temporal, geographical and technological boundaries of analysis, the environmental impact categories of concern, as well as any assumptions, data quality requirements and known limitations of the study that may exist (ISO 2006a; Guinée *et al*., 2001).

1.3.2.2 Life Cycle Inventory Analysis (LCI)

The life cycle inventory (LCI) involves a compilation of the inputs and outputs of the system under study, in relation to the chosen functional unit and requirements of the project's goal and scope (Bauman & Tillman, 2004). System inputs consist of environmentally-relevant flows of material and energy resources utilized throughout the life cycle of the functional unit. System outputs are the wastes and emissions that result from the use of these resources. The life cycle inventory is usually the most time-consuming and complicated stage of an LCA. LCI data collection often involves interviews, surveys and other forms of personal communication, the mining of industry reports and grey literature, and accessing process data from LCI databases. Often, emission calculations are required to express material and energy inputs in the form of environmentally relevant emissions. Detailed documentation of this entire process is required (ISO, 2006a).

1.3.2.3 Life Cycle Impact Assessment (LCIA)

In the life cycle impact assessment (LCIA) phase, LCI results are expressed in terms of their contribution to globally significant impact categories such as depletion of abiotic resources, acidification and climate change (Baumann & Tillman, 2004; Consoli *et al*., 1993; Guinée *et al*., 2001). Expression of inventory parameters in this manner facilitates communication of the environmental implications of the functional unit at each stage of its life cycle. Aggregation of emissions into environmental impact categories also enables easier comparison of the functional unit to the environmental profile of other products. (Baumann & Tillman, 2004).

Commonly, LCIA is facilitated with the use of LCA-specific software packages. The software relies on embedded scientific models to sort inventory data according to the type of environmental impact they can cause, and the relative contribution they make to each impact category (Bauman & Tillman, 2004). Use of software vastly reduces the time required to complete the necessary calculations for LCIA. If desired, results can be further aggregated into an even fewer number of impact categories, grouped and weighted according to societal concerns for the various environmental impacts (Guinée *et al*., 2001).

1.3.2.4 Interpretation Of Results And Improvement Assessment

The final phase of an LCA involves a refinement, assessment and presentation of results in order to draw broader conclusions and make recommendations about the system under study (Baumann & Tillman, 2004) in a way that is meaningful within the context of the project's original goal and scope (ISO, 2006a). Potential improvement options to reduce the system's environmental impact are also identified and evaluated (Consoli *et al*., 1993), often with the application of a technique called scenario modeling. Scenario models allow the researcher to test the potential impact of proposed alterations to processes within the product's life cycle. Sensitivity analyses, a technique used to determine the robustness of overall LCA results, evaluate the extent to which the results of the study were influenced by variations and uncertainties in the methods and data used, and by decisions made by the researcher (Guinée *et al*., 2001; ISO, 2006a).

1.3.3 Limitations Of LCA

Decisions regarding the environmental management of food systems should not be made based on LCA results alone. LCAs do not consider the economic or social implications of a product or service (Guinée *et al*., 2001) and thus results of an LCA are best used in conjunction with other assessment tools, monetary analyses and qualitative interpretation of the system's function and resulting impacts. The life cycle perspective offered by LCA is both a strength and a weakness, since simplifying assumptions are often made by the researcher in order to study industrial production systems with such a breadth of analysis (Guinée *et al*., 2001).

Due to the variety of choices and assumptions made by the practitioner throughout the LCA process, (e.g. the selection of system boundaries, impact categories, sources of data, etc), a great deal of subjectivity is inherently introduced into the analysis (Guinée *et al*., 2001). The availability of quality data for the life cycle inventory is also sometimes a challenge. The robustness of an LCA is very dependent on the accuracy of its data and the use of generic unit processes from LCA databases during the LCI may introduce epistemological uncertainties into the study (von Bahr & Steen, 2004).

With regard the analytical capabilities of LCA, it should be noted that the lack of spatial and temporal dimensions available for use in the LCIA phase (ISO, 2006a) limits the subsequent classification of environmental impacts to various impact categories as merely "potential" contributions (Guinée *et al*., 2001). Similarly, the focus of LCA results are on global and regional environmental issues, not on localized environmental effects (Guinée *et al*., 2001). Arguably, the most striking shortcoming of the LCA framework at this time is its weakness for modeling certain environmental impacts such as biodiversity loss (Audsley, 1997; Berlin, 2002; Foster *et al*., 2006) and toxicological effects of emissions on humans and ecosystems (Mattsson, 1999a; Kramer, 2003; Schmidt, 2007) due to lack of appropriate fate pathway models for certain toxic emissions in various ecosystems (Brentrup *et al*., 2004; Schmidt, 2007). Implications of this latter shortcoming are further elaborated in Chapter 2 with reference to the use of fungicides and herbicides in Nova Scotia wine production.

1.4 The Application Of LCA To Food Systems

Although LCA was originally developed to assess the environmental burdens associated with industrial manufacturing (Baumann & Tillman, 2004), methodological developments in recent years have greatly improved the capacity of LCA to adequately assess the environmental impacts of agricultural systems (Cowell & Clift, 1996; Audsley, 1997; Mattsson *et al*., 2000; Weidema & Meeusen, 2000; Brentrup, *et al*., 2000; von Bahr & Steen, 2004; Mourad *et al*., 2007). Consequently, application of LCA to agriculture, and more broadly, food production systems, has become increasingly common since the early 1990s (Andersson *et al*., 1994; Andersson, 2000; Mattson, 1999a; Mattson & Sonesson, 2003). LCA has been applied to fruit and vegetable production (Brentrup *et* al., 2001; Stadig, 2001; Kramer, 2003; Milà i Canals & Polo, 2003; Milà i Canals, *et al*., 2006), dairy products and production systems (Cederberg, 1998; Berlin, 2002; Hospido *et al*., 2003; Cederberg & Flysjo, 2004, Arsenault *et al*., in press), poultry operations (Pelletier, 2008), fisheries (Zeigler & Hansson, 2002; Hospido & Tyedmers, 2005; Boyd & Tyedmers, in prep; Driscoll *et al*., in prep), aquaculture systems (Papatryphon *et al*., 2003; Pelletier & Tyedmers, 2007, Ayer & Tyedmers, in press), processed foods (Pearce, 1997; Andersson *et al*., 1994; Andersson & Ohlsson, 1999; Mattsson, 1999b; Andersson, 2000), beer (Talve, 2001; Hospido *et al*., 2005; Koroneos *et al*., 2005), and wine (Notarnicola *et al*., 2003; Aranda *et al*., 2005). LCA has also been used to compare organic and conventional food production systems (Cederberg, 1998; Mattsson, 1999b; Nicoletti *et al*., 2001; Haas *et al*., 2001; Mattsson & Wallen, 2003; Pelletier & Tyedmers, 2007; Pelletier *et al*., 2008), the relative importance of food's transport distance (Schlich & Fleissner, 2005), alternative production scales (Andersson & Ohlsson, 1999; Schlich & Fleissner, 2005), different processing techniques (Sonesson & Davis, 2005), different cooking techniques (Sonesson *et al*., 2003) and the relative importance of consumer activities in the life cycle environmental impacts of food (Sonesson & Davis, 2005). Although methodological challenges remain, the application of LCA to food has provided a great deal of insight for those wishing to make informed decisions regarding the environmental performance of these production systems (Andersson, 2000; Mattsson & Sonesson, 2003), as will be explored in the following section.

1.4.1 Life Cycle Environmental Impacts Of Food and Beverages

The environmental impact of a food product is dependent on the nature and extent of materials and energy it consumes, and the wastes and emissions it releases throughout its life cycle (Kramer *et al*., 1999; Wallén *et al*., 2004; Neiuwlaar, 2004). Countless variables throughout the life cycle of food products can thus influence environmental performance. These variables include, but are not limited to: farming techniques (Dutilh & Linneman, 2004; Wallen *et al*., 2004), whether a food is of animal or vegetable origin (Carlsson-Kanyama, 1998; Carlsson-Kanyama, *et al*., 2003; Dutilh & Linneman, 2004; Wallen *et al*., 2004), degree of processing (Carlsson-Kanyama, 1998; Dutilh & Linneman, 2004; Sonensson & Davis, 2005; Foster *et al*., 2006), scale of production (Kooijman, 2006; Kramer *et al*., 1999; Andersson & Ohlsson, 1999), packaging requirements (de Leo, 2003; Dutilh & Linneman, 2004; Foster *et al*., 2006), transportation mode (Sonesson & Davis, 2005; Foster *et al*., 2006; Hansen, 2007, as cited in Brodt *et al*., 2007), transportation distance (Carlsson-Kanyama *et al*., 2003; Dutilh & Linneman, 2004), storage requirements (Sonensson *et al*., 2003), cooking method (Uhlin, 1997, as cited in Sonesson *et al*., 2003; Carlsson-Kanyama & Bostrom-Carlsson, 2001; Sonensson *et al*., 2003; Dultilh & Linneman, 2004), the amount of food wasted either in the home, restaurant or processing site (Sonesson, *et al*., 2005), and finally, its end-of-life, or disposal particulars (Dainelli, 2003).

Certain phases of a product's life cycle may contribute disproportionately to the total sum of it environmental impacts and may vary depending on the specific impacts of interest. Life cycle "hot spots", as they are known within the LCA literature, differ among various production systems. Farming is often cited as the most important life cycle stage for meat products (Carlsson-Kanyama, 1998; Cederberg, 2003). The fishing phase is the most environmentally-relevant life cycle stage for seafood products (Ziegler *et al*., 2003) due to intensive fuel use by marine diesel engines (Ziegler, 2003). The agricultural production stage is responsible for a relatively large share of the environmental impacts of fruit and vegetables, driven in particular by the use of pesticides (Kramer, 2003; Milà i Canals & Polo, 2003; Milà i Canals *et al*., 2006). When vegetables are processed however, the use of energy for processing, freezing, and the manufacture of packaging all contribute substantially to total environmental impacts (Kramer, 2003). More than 50% of the total environmental impacts of greenhouse vegetables is attributable to the energy consumed to heat the greenhouse itself (Raaphorst *et al*., 2001, as cited in Kramer, 2003). In addition to crop production (Notarnicola *et al*., 2003), the manufacture of packaging is typically a very important life cycle phase for products packaged in glass, such as beer (Koroneos *et al*., 2005; Hospido *et al*., 2005) and wine (Notarnicola *et al*., 2003; Ardente *et al*., 2006; Pizzigallo *et al*., 2006).

Within each life cycle stage, material, energy, and substance-based analyses (including LCAs) have provided the empirical data to claim environmental superiority for certain product groups and production methods. For instance, at the agricultural level, the production of fruits and vegetables require fewer energy inputs than does livestock production (Carlsson-Kanyama, 1998; Kramer *et al*., 1999; Cederberg, 2003). Similarly, crops grown outdoors require less energetic inputs than those grown in heated greenhouses (Kramer *et al*., 1999; Dutilh & Linneman, 2004). Transportation of food locally, regionally, or globally will consume energy, in the form of fuel, and thus increase a food's environmental impact, as will processing (Sonesson & Davis, 2005), packaging (Kooijman, 2006; Carlsson-Kanyama & Bostrom-Carlsson, 2001; de Leo, 2003; Dutilh & Linneman, 2004) refrigeration, and cooking (Sonesson *et al*., 2003).

While the above generalizations are based on quantitative assessments, they are only relevant to specific stages within a food's life cycle. To assess the overall impact of a food product, its entire life cycle must be analyzed. For instance, Carlsson-Kanyama (1998) has shown that a vegetarian meal composed of imported vegetables produces more greenhouse gas emissions than does a meal made with locally produced meat. Though a food's processing and packaging requirements will contribute to its total impact, substantial refrigeration-based energy costs may be avoided later, and proper packaging may ensure that food spoilage is minimized (de Leo, 2003; Foster *et al*., 2006). The mode by which food is transported is an equally important indicator of environmental impact as transport distance, since some modes of transport are far more fuel efficient per unit of food transported than others (Dutilh & Linneman, 2004; Schlich & Fleissner, 2005; Smith *et al*., 2005; Hansen, 2007, as cited in Brodt *et al*., 2007). For instance, transport by rail is an order of magnitude more fuel efficient than truck transport, per unit of food, and container ships are 2-3 times more efficient than trains. On the other end of the scale, goods that are air freighted, consume 10 times the amount of fuel, per unit of food, than goods that are transported by truck over the same distance (Hansen, 2007, as cited in Brodt, *et al*., 2007). Finally, consumer activities can contribute substantially to a food's total life cycle impacts and thus cannot be excluded from an analysis of environmental performance (Hendrickson, 1996; Andersson & Ohlsson, 1999; Faist *et al*., 2001; Berlin, 2002; Sonesson *et al*., 2005). In part, consumer-related impacts are caused by the use of cars, (also a relatively inefficient mode of transport) for grocery shopping (Sonesson *et al*., 2005; Foster *et al*., 2006), but also by cooking, which is estimated to contribute between 5% and 50% of a food's total life cycle energy requirements (Uhlin 1997, as cited in Sonesson *et al*., 2003; Johannisson & Olsson, 1997, as cited in Sonesson *et al*., 2003; Carlsson-Kanyama & Bostrom-Carlsson, 2001).

1.4.1.1 Organic Agriculture and Food Miles

One of the most controversial illustrations of the importance of considering the entire life cycle of a product, and a suite of environmental impacts, is that of organic agriculture. Depending on the chosen indicator of environmental performance (i.e. land use, energy use, toxicity impacts, etc), and the particular system under study, LCAs and other energy-based analyses have reached varying conclusions with regard to the environmentally preferable method of growing and raising food (Mattsson, 1999b; Cederberg & Mattsson, 2000, Pelletier *et al*. 2008). Organic agriculture is a method of farming in which no synthetic fertilizers and pesticides are permitted (van Zeijts *et al*., 2003) and thus with respect to toxicity impacts, organic agriculture is typically reported as advantageous (Mattsson, 1999b; Cederberg & Mattsson, 2000; Nicoletti *et al*., 2001). Similarly, with regard to biodiversity preservation and landscape aesthetics, organic agriculture is typically favored (Cederberg & Mattsson, 2000; Haas *et al*., 2001; Mäder *et al*., 2002). Regarding other environmental impacts however, conventional and organic agriculture offer competing advantages. In a comparison of conventional and organic carrot production, Mattsson (1999b) found that energy use was 20% higher in the conventional system, whereas the organic system was also responsible for 25% higher eutrophying emissions and required twice the land area per unit of food. An LCA of conventional and organic milk production concluded that the higher input of concentrate feed in the conventional system leads to a higher energy demand, but lower yields in the organic system results in higher land requirements per tonne of milk (Cederberg & Mattsson, 2000).

To a large extent, the poor performance of organic production systems in certain impact categories is a result of lower crop yields that are often reported in organic farming. Reductions in energy use and synthetic fertilizer application may not be enough to offset reduced yields. Organic crop systems which produce yields equivalent to their conventional counterparts however, actually perform substantially better in the impact categories of energy use, global warming emissions and ozone-depleting emissions, as was illustrated by Pelletier *et al*., (2008). Manure-based fertilizers also have higher leaching and volatilization rates than synthetic fertilizers (Intergovernmental Panel on Climate Change, 2006). This can lead to higher rates of NO_3 and P_2O_5 leaching (van Zeijts *et al*., 2003) and N_2O and NH_3 volatilization (Mattsson, 1999b; Brentrup *et al*., 2000; Intergovernmental Panel on Climate Change, 2006) per unit of food. Finally, while certain permitted substances used in organic agriculture to ward off pests are relatively benign in terms of field-level toxicity emissions, they are often relatively high in terms of manufacturing energy requirements (Nicoletti *et al*., 2001; Notarnicola *et al*., 2003).

Evidence to support the concept of "food miles" as a sole proxy for environmental impact is also weak (Foster *et al*., 2006). Certainly, the transportation of food will increase a system's total energy requirements, but this singular index ignores the nuances of transportation-related impacts that may be equally, or even more important than distance alone. For instance, mode of transport, as well as efficiency of transport networks, can strongly influence overall impacts (Sonesson *et al*., 2005; Hansen, 2007, as cited in Brodt *et al*., 2007). Additionally, a focus on "food miles" as the sole indicator of a food's environmental burden may ignore important efficiencies in other phases of its life cycle (Schlich & Fleissner, 2005) or life cycle phases that are responsible for a much greater share of the total burden (Pelletier & Tyedmers, 2007).

1.5 Life Cycle Environmental Impacts Of Wine

Viticulture (grape growing), viniculture (making wine), manufacturing glass bottles, various transportation links, refrigeration and recycling of glass bottles are processes within wine's life cycle that necessitate the transformation of materials and energy and thus result in emissions that contribute to various environmental impacts. Formalized life cycle assessments of wine, as well as other analyses that have employed "life cycle thinking" provide insight into the relative importance of each of these life cycle phases as well as the nature of the associated environmental impacts. In each of the following studies, the functional unit of study was one 750ml bottle of wine.

In Italy, Notarnicola *et al*., (2003) performed an LCA on the viticultural, vinicultural, and bottle production stages of wine with the intent to identify the environmental hotspots for four different bottles of wine – a high quality red and white wine, and a low quality red and white wine. All systems performed similarly whereby the most burdensome phase of wine's life cycle was grape growing, followed by glass bottle production and lastly wine making. On the vineyard, pesticide application contributed the majority of all toxicity-related emissions, while the use of nitrogen and phosphorous fertilizers were important contributors to eutrophication and acidification impact categories. Glass bottle production is an energy-intensive process and this contributed heavily to wine's total energy use, as well as global warming, human toxicity, smog-forming and acidifying emissions. Wine making was shown to be an important process for both ozone depleting and smog-forming emissions due respectively to electricity use at the winery and emissions of volatile organic compounds (VOCs) that are released from wine during fermentation.

A Spanish wine LCA conducted by Aranda *et al*., (2005) encompassing all life stages from the vineyard through to recycling of the glass bottle, indicated a different life cycle hotspot for wine. Unlike Notarnicola *et al*., (2003) this study did not account for field-level pesticide or fertilizer emissions on the vineyard, but did include the transport of wine to retail. The transport phase, which consisted of truck transport within Europe, and container shipping overseas, resulted in the largest contributions to total life cycle impacts. Transport-related impacts were due mainly to the combustion of diesel as a fuel. Vineyard activities were the second most burdensome life cycle phase, resulting from the energy requirements of fertilizer and pesticide manufacture and the use of an electric irrigation system. Winery processes caused the least amount of environmental impact, though impacts within this life cycle stage were dominated by the production of the glass bottle. Recycling was reported to contribute no environmental impacts to wine's total life cycle since these authors interpreted recycling as providing a net energy benefit to the overall system when compared to the alternative of manufacturing glass bottles from virgin materials.

Though not a formalized LCA, Ardente *et al*., (2006) used a life cycle framework to determine the energy use and related emissions associated with all life cycle phases (excluding disposal) of a bottle of red wine in Italy. Bottle production contributed approximately half of total energy consumption and CO_2 emissions, but refrigeration requirements during wine making, as well as the manufacture of fertilizers and pesticides were also identified as important potential improvement options. Interestingly, the modeling of bulk wine transport to domestic markets reduced the resulting energy requirements of the system by more than 50% since glass bottles were excluded from much of the transport distance.

LCA has also been used to compare the environmental impacts of growing grapes and making wine in a small-scale organic and semi-industrial, conventional vineyard in Italy (Pizzigallo *et al*., 2006). Despite lower yields in the organic system (approximately 20% lower), the overall life cycle emissions for organic grapes were lower than for grapes grown conventionally. Due to more mechanized farming practices, fuel and steel consumption were respectively 2 and 6 times greater on the semi-industrial farm, which more than counteracted the benefits of higher yields in this system. Results of this LCA must be viewed with the knowledge however, that production-related emissions for fertilizers were calculated only for the conventional system, and field-level fertilizer emissions in both systems were excluded entirely. Had emissions related to the production and application of organic fertilizers been calculated, a potentially much different environmental profile would have resulted. In both systems, the production of glass bottles was a life cycle hotspot, despite the organic wine's use of lighter bottles. Niccolucci *et al*., (2006) compared these same vineyards using Ecological Footprint Analysis. Per bottle of wine, the Ecological Footprint of the conventional system was nearly double that of the organic wine.

Finally, Nicoletti *et al*., (2001) also compared the life cycle impacts of organic and conventional wine. In contrast to the aforementioned studies, the organic production system was associated with higher environmental emissions in all impact categories except human- and eco-toxicity. To a large extent, this was a function of grape yields since the organic system's yields were 30% lower than its conventional counterpart. In addition, authors note higher rates of acidifying and eutrophying emissions from manure which is used as an organic fertilizer, in comparison to synthetic fertilizers used on the conventional vineyard.

1.6 The Wine Industry In Nova Scotia

Nova Scotia is arguably the oldest grape and wine producing region in North America (Wood, 2006). Documentation suggests that vine cuttings were brought to Acadia by French colonists nearly four hundred years ago and that 17th Century explorers found wild vines in this region (Naugler & Wright, 2006). The first vineyard was established in 1632 by Issac de Razilly, the Governor of a small colony of Acadians near present day LaHave, and grape vines are reported to have been commonly cultivated in the gardens of Acadian settlers through to their expulsion from the region in 1755 (Naugler & Wright, 2006). British settlers continued to cultivate table grapes throughout the 18th and 19th centuries but interest in commercial scale production did not arise until the latter half of the 20th century (Naugler *et al*., 2004). This was spurred in part, by the development of several grape cultivars that could thrive in the Nova Scotia climate (Naugler *et al*., 2004).

1.6.1 An Emerging Industry, 1980 – 2000

Prior to the 1980s, wineries in Nova Scotia were producing either fruit wines or were importing grapes from various established wine regions in Canada and the US (Naugler *et al*., 2004). In 1981, Nova Scotia witnessed the opening of its first winery to process Nova Scotia grown grapes (Wood, 2006; Naugler *et al*., 2004) and in the following decades, vineyards and wineries sprouted up throughout the province. In 1982, the grape growers formed their own industry association (Grape Growers Association of Nova Scotia), and have since lobbied for several changes in the liquor legislation to increase their market access (Naugler & Wright, 2006). The Farm Winery Policy, passed in 1986, effectively licensed estate wineries to sell directly to visiting public, at farmer's markets, restaurants, and private wine and specialty stores (Lewis *et al.*, 2006; Josza Management & Economics, 2006).

1.6.2 Nova Scotia Wine In The New Millennium

Growth and development in the Nova Scotia wine industry has continued into the 21st century (Naugler *et al*., 2004), including the formation of a provincial winery association in 2002 (Naugler *et al*., 2004), and regulatory amendments that have encouraged investment in the production of wine made from Nova Scotia grapes (Anonymous, 2007). In 2005, the establishment of Nova Scotia Wine Standards laid essential ground work for the province to become a nationally recognized, authentic and prosperous wine producing region (Wood, 2006; Lewis *et al*., 2006; Naugler & Wright, 2006). Under the Nova Scotia Wine Standards, wineries are entitled to label their wines with a provincial designation if no less than 85% of a wine's content is derived from Nova Scotia grown grapes (Winery Association of Nova Scotia, 2005). Most recently, the provincial liquor commission, mandated to promote the economic objectives of the province's alcohol industries (Nova Scotia Liquor Commission, 2006), reduced the retail "mark up price" for Nova Scotia wines by 70% (Brooks-Arenburg, 2007). According to a recent economic impact study, the market share of Nova Scotia wine is increasing, accounting for 8.7% of all wine sales in the province in 2006 (Josza Management & Economics, 2006).

Records of the production volumes from Nova Scotia vineyards exist from 1981 through to 2002, as illustrated in Figure 1.2. There is then a paucity of data regarding Nova Scotia grape production until 2006 (*pers. comm*., J. Lewis, June 15, 2008), at which point, the province's 130 hectares of grapes produced approximately 740 tonnes (*pers comm*., J. Ruddick, March 17, 2007). This equated to a production of approximately 900,000 bottles of wine containing at least 85% Nova Scotia grapes by weight. The industry seeks to triple the area of wine grape production in the province by 2020, raising the number of bottles produced (containing 85% Nova Scotia grapes by weight) to approximately 2.5 million (Josza Management & Economics, 2006). An recent economic impact study deemed this target feasible (Josza Management & Economics, 2006).

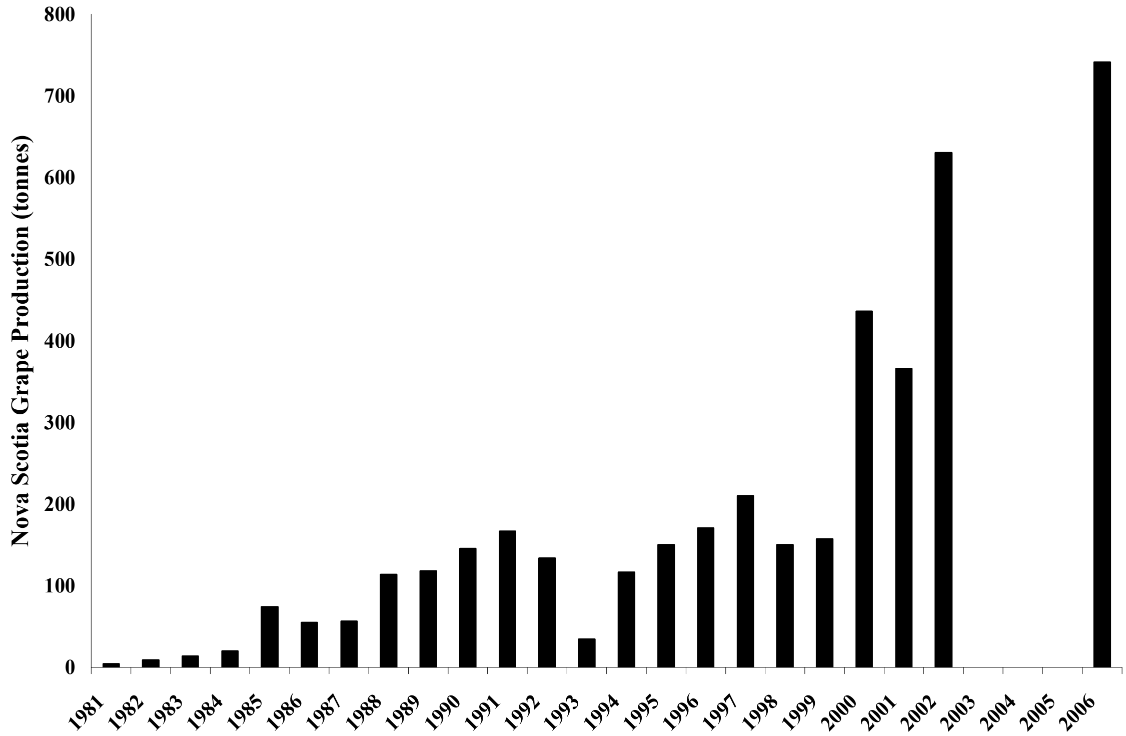

Figure 1.2 Nova Scotia grape production, 1981 – 2006. Data from 1981-2003 compiled by John Lewis, as cited in Naugler *et al*. (2004).

1.7 Project Rationale And Research Objectives

The province of Nova Scotia is attempting to pursue an economic growth strategy congruent with the requirements of environmental, social and economic sustainability (Nova Scotia, 2006). Given the known environmental impacts associated with producing and consuming wine in other regions (Notarnicola *et al*., 2003; Aranda *et al*., 2005), and the expected growth in the province's grape and wine industry (Josza Management & Economics, 2006) Nova Scotia wine offers a unique and practical application of Life Cycle Assessment methodology.

Amidst the growing taste for environmentally-friendly food products (Wandel & Bugge, 1997; Owen *et al*., 2007), from environmentally-committed organizations (Khan *et al*., 2002), there exists a growing demand for wines that have been produced in an environmentally responsible manner. This is evidenced by a number of industry groups and industry standards devoted to this endeavor (California Sustainable Winegrowing

Alliance, 2008; Sustainable Winegrowing New Zealand, 2008). Environmental management strategies for wine that have sought to incorporate life-cycle thinking are also becoming increasingly common (Yalumba, 2007; Anson, 2008a; Anson, 2008b).

The application of LCA to the Nova Scotia wine industry will provide the means with which to assess this industry for its contributions to a variety of environmental impacts and determine the most relevant life cycle phases in which to make improvements. In light of the recent opening of a certified organic vineyard and winery in Nova Scotia, as well as interest from the Canadian wine industry to seek export markets (Madill *et al*., 2003), LCA can provide the means with which to evaluate these and other potential management decisions. This research thus addresses the following six questions.

- What are the life cycle environmental impacts of producing and consuming a bottle of wine in Nova Scotia?
- What are the relative contributions of each phase in wine's life cycle to various environmental impacts?
- How might the adoption of organic viticultural techniques change the life cycle environmental impacts of Nova Scotia wine?
- How might the adoption of lighter glass bottles change the life cycle environmental impacts of Nova Scotia wine?
- How might consumer transport to purchase wine influence the life cycle environmental impacts of Nova Scotia wine?
- How might the life cycle environmental impacts of Nova Scotia wine change if the transport distance to retail increased?

The first two questions are inherent to any product-oriented LCA. The latter four questions were developed to explore potential future developments in Nova Scotia's wine industry, but also speak to a broader set of questions surrounding the current debate on local and organic foods, the consumer's role in food's environmental impact, and new forms of packaging as a means to achieve sustainable production and consumption within the food system.

1.8 Organization Of Thesis

The remainder of this thesis contains two additional chapters and several appendices. Chapter Two contains the project-specific methods and results of the LCA of Nova Scotia wine, along with a discussion of the results in the context of previous wine LCA research, and a discussion of potential improvement opportunities for Nova Scotia wine. Chapter Two was written with intent for submission to an academic journal. Chapter Three contains a summary of the work, a discussion of issues related to organic grape growing and food miles, limitations of the research, encountered challenges, and recommendations for future study. Appendix A contains the vineyard survey used to collect data pertaining to grape growing in Nova Scotia in 2006. Appendix B contains the winery survey used to collect Nova Scotia winery information. Appendix C provides the model used to calculate emissions to air and water from the application of nitrogen and phosphorous fertilizers. Finally, Appendix D presents a description of impact categories quantified in this research, and the methods used to characterize life cycle inventory data.

2.0 CHAPTER TWO: LIFE CYCLE ENVIRONMENTAL IMPACTS OF WINE PRODUCTION AND CONSUMPTION IN NOVA SCOTIA, CANADA

2.1 Publication Information

The publication venue for the following paper has not yet been selected. The study was conducted by Emma Point, who also wrote and researched this paper. A great deal of methodological guidance and editorial advice was provided by Dr. Peter Tyedmers. Insight into the intricacies of the Nova Scotia grape and wine industry, methodological advice, and editorial comments were provided by Dr. Christopher Naugler.

2.2 Abstract

Despite its location at the climatic limit for grape growing, a wine industry has recently emerged in Nova Scotia and current trends suggest this industry will continue to grow. As an agricultural product, the cultivation of grapes require natural, manufactured, and energetic resources, resulting in both proximate and macro-scale environmental emissions. Along the rest of the product chain, wine making, packaging, transport, refrigeration and disposal can further add to the material and energy requirements, and subsequent environmental implications of wine. Here, life cycle assessment (LCA) methodology was employed to quantify the material and energy inputs, and associated environmental emissions of one bottle of wine produced and consumed in Nova Scotia, Canada. The analysis encompassed activities occurring in the vineyard and winery, as well as bottle production, home refrigeration, recycling and all necessary transport links required for the product chain to function. Primary data were obtained from grape growers and wine makers in the province to develop a representative life cycle model of Nova Scotia wine. Results indicate that viticultural (grape growing) activities are responsible for 69% of all eutrophying emissions, 54% of terrestrial eco-toxicity impacts, and 37% of all aquatic eco-toxicity impacts in the life cycle of wine. The manufacture of the glass wine bottle was also shown to be an important life cycle stage, contributing more than 35% of total impacts in five of the nine impact categories quantified. The model also indicates that a consumer can contribute between 7% and 63% of wine's total life cycle impacts depending on the impact category of concern, simply by driving five kilometers to purchase their wine. Interestingly, the transport of Nova Scotia wine from

its place of production to its retail location has a relatively small impact (between 2% and 17%). Four scenarios were also modeled. The adoption of organic viticultural practices would reduce wine's impacts in some impact categories, but increase wine's impact in others. The use of lighter glass bottles resulted in non-trivial improvements to nearly all impact categories. Scenarios also explored increased transport to and by consumers. They provide strong evidence that purchasing wine from a local source may indeed offer environmental advantages over imported wine, but that the mode by which wine is transported is equally important to the distance that it travels and that transport by consumers should be minimized.

2.3 Introduction

We live in a time when consequences of the human experience have reached levels yet unprecedented. The effect of global population size, coupled with a high level of material and energy consumption, have begun to manifest as measurable contributions to various forms of environmental decline, both locally and globally. In particular, food production and consumption has been identified as one of the most resource and energy demanding activities of households in the developed world (Vringer & Blok, 1995; Carlsson-Kanyama *et al*., 2003: Foster *et al*., 2006). The modern food system, characterized by fossil-energy dependent technologies and globalized distribution chains, makes substantial contributions to a range of environmental challenges including climate change, ozone layer depletion, air quality decline, acidification of terrestrial and aquatic ecosystems, eutrophication of groundwater and surface waters, buildup of toxic substances in human and animal tissues, and over-consumption of natural resources. Methods of producing, processing, packaging, distributing, consuming and disposing of food thus offers one of the greatest opportunities to make meaningful improvements to the state of the environment and the sustainability of the human enterprise.

The Nova Scotia wine industry is a small yet growing production system. In 2006, 130 hectares of grape vines produced 700,000 litres of "Nova Scotia wine", (containing at least 85% Nova Scotia grapes by weight) and the industry seeks to nearly triple the number of productive hectares by 2020 (Jozsa Management and Economics, 2006; Naugler & Wright, 2006). As with any agricultural crop, the cultivation of grape vines transform material and energetic resources, and result in certain environmental emissions, as do the necessary life cycle stages of wine making, packaging manufacture, product transport, refrigeration and disposal. To date, no assessment of the environmental implications of the Nova Scotia wine industry has been undertaken, though life cycle impacts of wine have been evaluated elsewhere, including Italy (Nicoletti *et al*., 2001; Notarnicola *et al*., 2003; Ardente *et al*., 2006; Pizzigallo *et al*., 2006), and Spain (Aranda *et al*., 2005). As the industry continues to develop, knowledge of Nova Scotia wine's particular environmental impacts may help to inform decisions that can improve its environmental profile and marketability. This may prove particularly useful in light of Nova Scotia's recent commitment to "achieve international recognition for having one of the cleanest and most sustainable environments in the world by the year 2020" (Environmental Goals and Sustainable Prosperity Act, S.N.S. 2007 s. 4(1)(a)). The Environmental Goals and Sustainable Prosperity Act, legislated in 2007, has committed Nova Scotia to emission reduction standards for greenhouse gases and other environmental pollutants.

Life cycle assessment (LCA) is an internationally recognized environmental accounting tool which offers a standardized framework and methodology for quantifying the environmental impacts of a product or a production system (Consoli *et al*., 1993; ISO, 2006a). As its name suggests, LCA seeks to encompass the entire "life cycle" of a product into its accounting framework, from the extraction of raw materials used to make a product, through to the product's end-of-life activities. Here, LCA methodology was employed to quantify the various material and energetic inputs, wastes and environmental emissions associated with a bottle of wine made in Nova Scotia. Encompassed in this analysis are all of wine's life cycle activities, beginning with viticulture (grape growing) and viniculture (wine making), as well as bottle production, transportation, refrigeration, and disposal of the glass wine bottle. Secondarily, I sought to elucidate which, if any, of these life cycle activities contribute a relatively high proportion of environmental emissions to wine's total life cycle impacts. Additionally, four scenarios were modeled to assess their potential impact:

- a shift to organic grape growing,
- the use of lighter glass bottles,
- the impact of consumer transport to purchase wine, and

- the impact of various transport distances and modes to bring wine to market.

This research is anticipated to be of interest to members of the grape and wine industry, both locally and globally, with an interest in increasing the energy and resource efficiency of wine, for the sake of reduced environmental emissions and improved marketability to environmentally-conscious consumers. In particular, the Nova Scotia wine industry may find utility in gaining an understanding of their current environmental performance in order to compare the associated effect of any potential environmental management decisions in the future. Regulators and funding agencies of the wine industry in Nova Scotia (and beyond) may also find utility in this work to inform decisions about how best to manage the industry and allocate funds designed to improve wine's environmental profile. Finally, as consumers grow increasingly aware of the implications associated with their food and beverage choices, this research provides information with which consumers can make informed decisions about their wine, including the extent to which consumers can influence wine's life cycle impacts.

2.4 The Wine Industry In Nova Scotia

Despite its location at the northern climatic limit for grape growing (Lewis *et al.*, 2006), a small yet growing wine industry has developed in Nova Scotia in recent decades (Figure 2.1). Although grapes have been cultivated in this region since the arrival of French settlers in the early 1600s (Wood, 2006), concerted efforts to establish a commercial wine industry in the province did not begin in earnest until the latter portion of the last century. The first commercial wineries of Nova Scotia opened their doors in the early 1980s and as of 2006, the province's seven grape wineries produced a total of 900,000 bottles of wine (containing at least 85% Nova Scotia grapes, by weight) (*pers comm.*, Jannice Ruddick, March 17, 2008). In 2005, Nova Scotia wine enjoyed 8.7% of total wine sales in the province and winery sales reached $7.16 million. In total, all wine related contributions, including tourist attractions, restaurants, wine tastings and farm tours, are estimated to have contributed as much as $15 million in 2005 to the Nova Scotia economy (Naugler & Wright, 2006). A strategic plan created for the Nova Scotia wine industry seeks to triple the area of wine grape production in the province by 2020, raising the number of bottles produced to approximately 2.5 million (Josza Management

& Economics, 2006). An economic impact study of the Nova Scotia wine industry deemed this target as feasible (Josza Management & Economics, 2006).

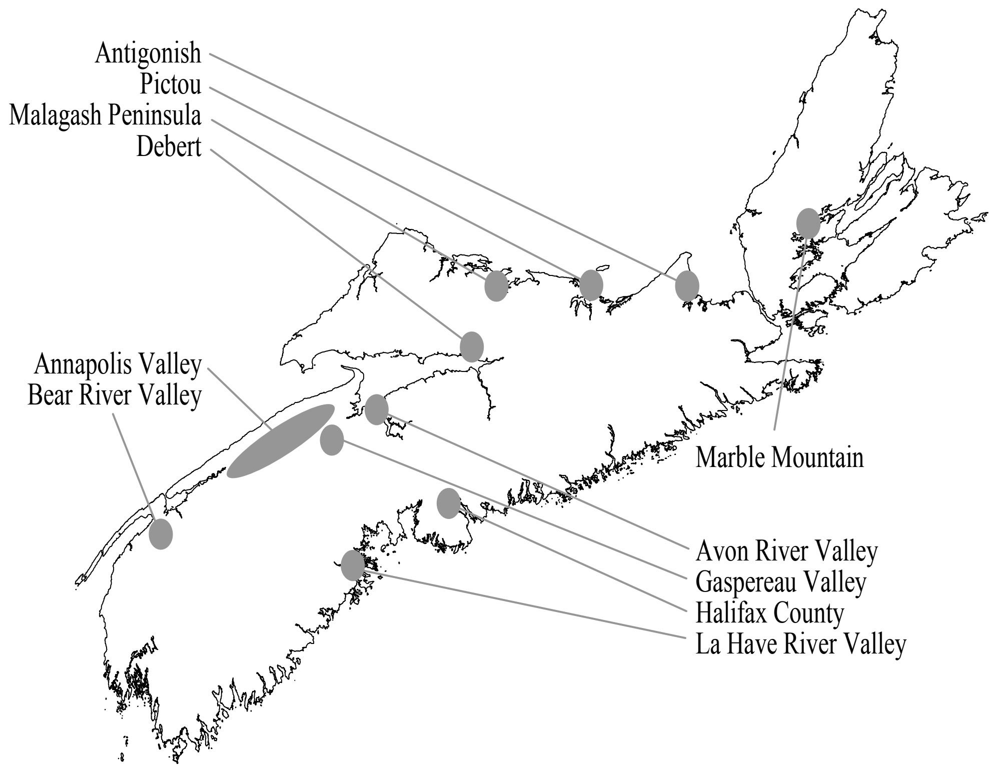

Figure 2.1 Nova Scotia winegrowing regions in 2006. Adapted from Naugler *et al*., 2004, p. 55.

2.4.1 Grape Growing In Nova Scotia

Prior to planting, a vineyard site may require substantial alteration including fertilization, lime inputs to increase soil's pH, the removal of existing groundcover and any large rocks that may impede growth (Naugler & Wright, 2006; Lewis *et al*., 2006). To facilitate drainage, tile drain may be installed, but ripping or sub-soiling the land may be necessary to further aid in the soil's drainage capacity (Lewis *et al*., 2006). Installation of trellis systems, consisting of wooden and steel posts and steel wire on which the vines can climb, are necessary to maintain adequate growth and encourage proper aeration of the fruit. Once plants are established, vineyard soils require regular maintenance and inputs to ensure an adequate pH, content of organic matter and level of soil nutrients.

Fungal pathogens such as powdery mildew, downy mildew and *Botrytis* exist in Nova Scotia vineyards, but can be controlled with chemical sprays (Lewis *et al*., 2006). There are also a number of effective herbicides available for use in the province, used to reduce competition between weeds and grape vines (Naugler & Wright, 2006). Insect pests are not well established in the province and therefore pesticides are currently not required (Lewis *et al*., 2006). Birds, raccoons and deer are deterred with netting and fencing (Lewis *et al*., 2006). Vineyard maintenance is often facilitated with the use of diesel or gasoline powered tractors, mowers, tillers, sprayers, trimmers, hoes, and harvesters. Some Nova Scotia growers have chosen to adopt organic methods on their vineyards (Naugler & Wright, 2006), which may include the use of animal manure in place of synthetic fertilizers, the cultivation of nitrogen-fixing legumes, an exclusion of certain chemical herbicides and fungicides, the application of mulches to suppress weed growth, and omission of wood preservative on trellis posts, amongst many other permutations. In 2006, Nova Scotia's first fully certified organic vineyard produced its first yield. Other vineyards in the province are also undergoing the necessary steps to cultivate grapes organically.

In 2006, Nova Scotia vineyards ranged in size from less than one, to approximately twenty productive hectares. Nova Scotia vineyards also range in age, the oldest of which dates back to the late 1980s, while others have not yet produced a yield. The most commonly grown grapes are 'French hybrid' varieties. Bred for their cold hardiness and disease resistant properties (Naugler *et al*., 2004), these varieties are crosses between classic French and American grapes. Red hybrids, (such as Leon Millot, Lucy Kuhlmann, Maréchal Foch) and white hybrids (L'Acadie, Cayuga White, New York Muscat, Seyval Blanc and Vidal Blanc) form the basis of the cool-climate viticultural regions of eastern North America (Naugler *et al*., 2004). As of late, successful plantings of classic vinifera varieties such as Chardonnay, Riesling and Pinot Noir, are also becoming increasingly common in Nova Scotia vineyards.

2.4.2 Wine Making In Nova Scotia

In 2006, wine was produced at seven grape wineries throughout the province. Wines are produced either entirely from Nova Scotia grapes, or are blended with wine made from imported grape juice. Here, I have only quantified life cycle flows for wines made from 100% Nova Scotia grapes. All estate wineries in Nova Scotia have adjacent vineyards, but most purchase additional grapes from contract growers throughout the province. Most winery equipment is powered by electricity, although some wineries use oil-fired heaters to heat water. Substantial volumes of water are used for cleaning processes in wineries, but exact volumes are unknown as water use is unmetered in Nova Scotia wineries. Fermenting grapes and making wine require various products, including yeasts, sugar, clarifying agents, filtering agents, bacteria, antioxidants and enzymes. Wineries source their wine bottles both locally and internationally.

2.4.3 Post-Winery Stages Of Nova Scotia Wine

The most common retail location for wine made in Nova Scotia is at provincially-regulated liquor stores (*pers comm*., Jannice Ruddick, March 17, 2008), but wine is also sold at estate wineries, farmer's markets, boutique wineries and restaurants. Currently, nearly all wine made from Nova Scotia grapes is sold within the province (Jozsa Management and Economics, 2006), therefore transport distances to market generally do not exceed two hundred kilometers.

In Nova Scotia, residents can access a public recycling system in which to dispose of glass wine bottles. This recycling system is characterized by weekly curbside pickups of glass and other materials, and their subsequent transfer to a recycling facility where materials undergo necessary processing (Resource Recovery Fund Board of Nova Scotia, 2008).

2.5 Materials And Methods

Life cycle assessment (LCA) was chosen to quantify the life cycle environmental implications of Nova Scotia wine. Standardized under ISO guidelines (2006a,b), LCA provides an internationally accepted methodology for quantifying the material and energy inputs, and the wastes and emissions created throughout the entire life cycle of a product (Consoli *et al*., 1993; Guinée *et al*., 2001). In the LCA context, "life cycle" refers to all processes and activities encompassed by raw material extraction and processing, manufacturing, transportation, use and eventual product disposal (Consoli *et al*., 1993; Guinée *et al*., 2001). Although it was developed to assess the environmental impacts of industrial production and manufacturing systems (Baumann & Tillman, 2004), the utility of LCA for use in the environmental management of food products and production systems has also gained widespread acceptance in recent years (Andersson *et al*., 1994; Mattsson, 1999a; Andersson, 2000; Mattsson & Sonesson, 2003; Foster *et al*., 2006).

To the best of my ability, efforts have been made to follow the methodological framework for LCA provided by the ISO guidelines (ISO, 2006a,b) which requires completion of the following four project phases: goal and scope definition, life cycle inventory analysis (LCI), life cycle impact assessment (LCIA) and finally, interpretation of results and improvement assessment.

2.5.1 Goal And Scope Definition

The first step of an LCA involves identification of the intended objectives, audience and application of the study, as well as the functional unit to which all inventory and emissions data will be referenced. An elaboration of the temporal, spatial and technological boundaries of the product system is defined, and environmental impact categories of concern are selected (Consoli *et al*., 1993).

Here, the objectives were to:

- determine the life cycle environmental impacts for the functional unit of one 750 ml bottle of wine (red or white), made entirely from Nova Scotia grapes in 2006, and consumed by a Halifax resident in their home;
- identify particular life cycle stages, or activities, that contribute disproportionately to the sum of wine's environmental burden, and;
- explore how changes in the production chain (organic grape growing, lighter bottles, increased consumer transport, product export,) might impact life cycle results.

Boundaries of analysis included all major material and energetic flows associated with grape growing, wine making and glass bottle production, post-winery transport to retail, consumer transport, refrigeration and bottle recycling (Figure 2.2). Farm buildings and wine-making equipment were excluded from this analysis due to lack of existing data, the assumed low attribution of these elements to a single bottle of wine (Frischknecht *et al*., 2007; Mattsson, 1999a), and the exclusion of these capital goods from previous wine LCAs (Notarnicola *et al*., 2003). Water use, on vineyards and in wineries, was also excluded from this analysis since this flow is not measured in the wineries at this time. Field-level emissions of chemical herbicides and fungicides were excluded from the analysis due to lack of available data concerning the climatic conditions at the time of application (Hauschild, 2000; Schmidt, 2007) and in the absence of site-specific dispersion models to estimate the fate of those emissions through the air, water and soil (Milà i Canals & Polo, 2003). However, emissions related to the provision of fungicides and herbicides were quantified, as was the provision of sugar, corks, paper labels and heat shrink capsules. Following the advice of Notarnicola *et al*. (2003), and Ardente *et al*. (2006), only transport-related emissions for yeasts, filtering and clarifying agents, bacteria, enzymes and antioxidants were quantified in the wine making stage. Also following Notarnicola *et al*. (2003), emissions of CO_2 during the fermentation of wine have been excluded, since they represent carbon that was only temporarily sequestered from the natural carbon cycle. However, emissions of VOCs, principally ethyl alcohol, that occur during wine making were included in this analysis since they have been shown to contribute substantially to wine's depletion of stratospheric ozone (Notarnicola *et al*., 2003). Cleaning products used in the winery were not quantified (Ardente *et al*., 2006). Post winery, pallets on which wine is transported were excluded, as were activities relating to the sale of wine in stores.

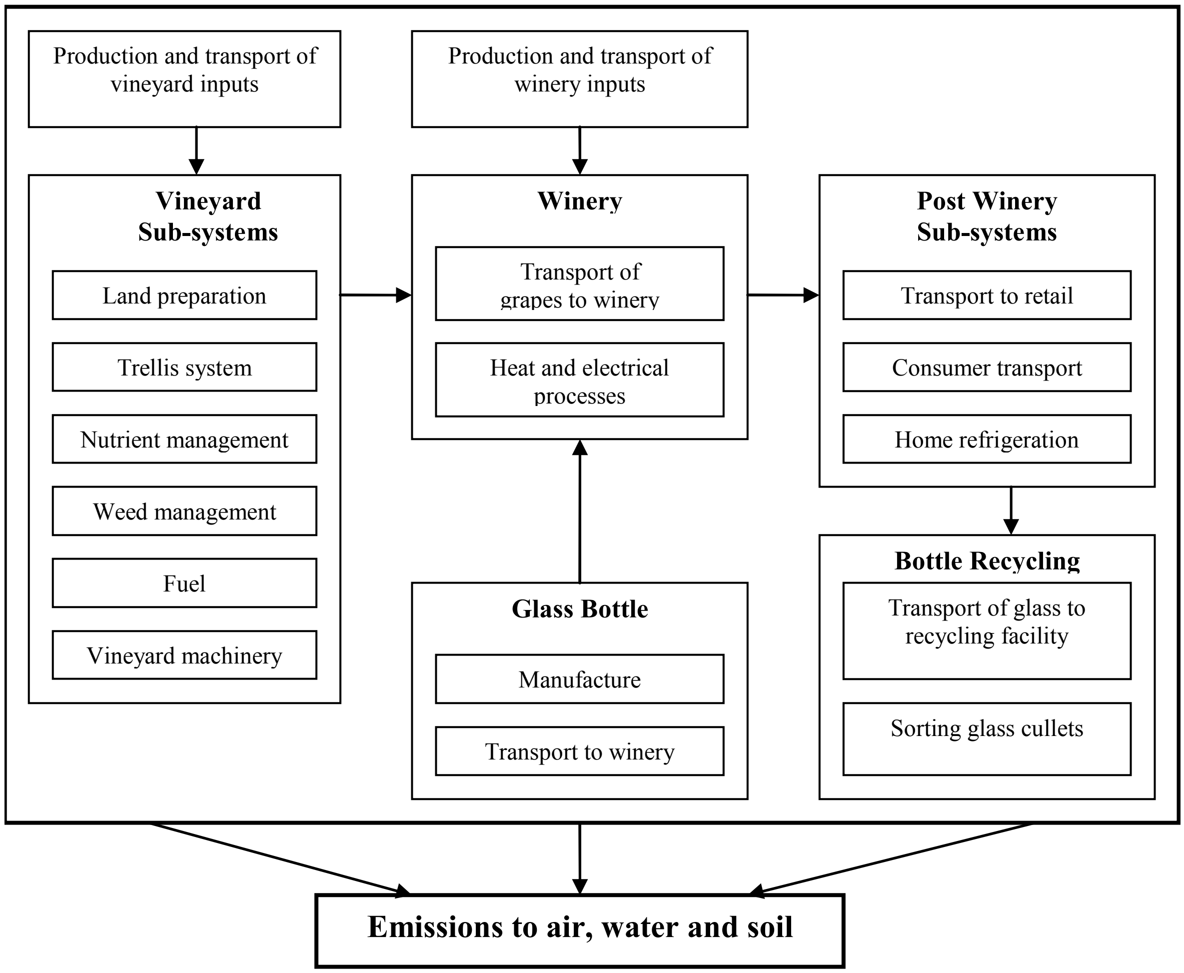

Figure 2.2 System flow diagram of Nova Scotia wine's life cycle. Included are the major life cycle phases and sub-systems associated with Nova Scotia wine.

2.5.2 Life Cycle Inventory

The life cycle inventory (LCI) stage involves the quantification of environmentally-relevant flows of materials and energy required to produce the functional unit of interest (Guinée *et al*., 2001; ISO, 2006a). Whenever possible, primary data were collected through the use of questionnaires and personal communication with industry representatives, crop specialists and other relevant personnel. Secondary data from industry, agricultural, and academic publications were utilized where appropriate. Finally, inputs to background processes (e.g. the provision of steel, plastics, chemical fertilizers, etc.) underpinning Nova Scotia wine's life cycle were obtained from a variety of peer-reviewed LCA databases (Table 2.1). Where possible, background process data representing current, average technologies were used. When information was available, electricity production mixes for geography-specific processes were substituted to reflect actual conditions.

Table 2.1 Background process data obtained from peer-reviewed LCA databases.

Materials and Processes	Relevant Sub-system	Database	Time Period	Geography of Technology
Infrastructure Materials				
High density polyethene	Vineyard	BUWAL 250	1990-1994	Europe
Dolomitic Lime	Vineyard	EcoInvent 2.0	2000	Europe
Diammonium phosphate	Vineyard	EcoInvent 2.0	2000	Europe
Ammonium nitrate	Vineyard	EcoInvent 2.0	2000	Europe
Potassium chloride	Vineyard	EcoInvent 2.0	2000	Germany
Steel, low alloyed	Vineyard	EcoInvent 2.0	2000	World
Reinforcing steel	Vineyard	EcoInvent 2.0	2000	World
Softwood logs	Vineyard	EcoInvent 2.0	2000	Switzerland
Wood preservative	Vineyard	EcoInvent 2.0	2000	Germany
Wood preservative treatment	Vineyard	EcoInvent 2.0	2000	Germany[a]
Organophosphorous-compounds	Vineyard	EcoInvent 2.0	1987	USA
Phtalamide-compounds	Vineyard	EcoInvent 2.0	1987	USA
Bipyridlium-compounds	Vineyard	EcoInvent 2.0	1987	USA
Glyphosate	Vineyard	EcoInvent 2.0	2000	USA
Sulphur	Vineyard	EcoInvent 2.0	2000	Europe
Lubricating oil	Vineyard	EcoInvent 2.0	2000	Europe
Tractor, production	Vineyard	EcoInvent 2.0	2002	Europe
Sugar, from sugar beets	Winery	EcoInvent 2.0	1998-2005	Germany
Glass bottles (recycled)	Bottle	Franklin	1998	USA[a]
Glass bottles (virgin glass)	Bottle	Franklin	1998	USA[a]
Glass bottles (recycled)	Bottle	Franklin	1998	USA[b]
Glass bottles (virgin glass)	Bottle	Franklin	1998	USA[b]
Cork, harvest and transport	Bottle	EcoInvent 2.0	1993	Germany
Cork, processing	Bottle	EcoInvent 2.0	2000	Portugal
Kraft paper, bleached	Bottle	EcoInvent 2.0	early 1990s	Switzerland

Table continued on next page

Table 2.1 continued: Background process data obtained from peer-reviewed LCA databases.

Materials and Processes	Relevant Sub-system	Database	Time Period	Geography of Technology
Infrastructure Materials, continued				
Polyvinylchloride	Bottle	EcoInvent 2.0	2007	Europe
Cardboard	Transport to Retail	BULWAL 250	1993	Switzerland
Refrigerator, efficient	Consumer Storage	LCA Food	2000	Netherlands
Collection of glass bottles	Recycling	EcoInvent 2.0	unspecified	Europe
Sorting of glass cullets	Recycling	EcoInvent 2.0	mid 1990s	Germany
Fuels				
Diesel	Vineyard, Winery	Franklin	1998	USA
Liquid propane gas (LPG)	Vineyard	EcoInvent 2.0	Late 1990s	USA
Gasoline	Vineyard	Franklin	1998	USA
Electricity Generation				
Electricity, hard coal	Winery, Bottle	EcoInvent 2.0	2004	USA
Electricity, natural gas	Winery, Bottle	EcoInvent 2.0	2006	USA
Electricity, hydropower	Winery, Bottle	EcoInvent 2.0	2004-5	Germany
Electricity, industrial gas	Winery, Bottle	EcoInvent 2.0	2001	Northern Europe
Electricity, wind power	Winery, Bottle	EcoInvent 2.0	2002	Europe
Electricity, nuclear	Bottle	EcoInvent 2.0	2006	USA
Transportation				
Operation, lorry (>16 tonnes)	Vineyard	EcoInvent 2.0	2005	Europe
Transport, tractor and trailer	Vineyard	EcoInvent 2.0	1999-2001	Switzerland
Truck (single), diesel	Winery	Franklin	2000	Europe
Operation, lorry (> 28 tonnes)	Vineyard, Winery	EcoInvent 2.0	2005	Switzerland
Transport, lorry (>28 tonnes)	Bottle	EcoInvent 2.0	2000	Switzerland

Table continued on next page

Table 2.1, continued: Background process data obtained from peer-reviewed LCA databases.

Materials and Processes	Relevant Sub-system	Database	Time Period	Geography of Technology
Transportation, continued				
Operation, transoceanic freight ship	Vineyard, Winery, Bottle	EcoInvent 2.0	2000	World
Transport, lorry (3.5-7.5 tonnes)	Transport to Retail	EcoInvent 2.0	unspecified	Switzerland
Operation, passenger car	Consumer Transport	EcoInvent 2.0	2005	Europe

Notes: a. Geography of electricity mix for this process was built to reflect actual conditions in Nova Scotia.
b. Geography of electricity mix for this process was built to reflect actual conditions in France.

2.5.2.1 Vineyard Data

Primary vineyard data were collected through the use of a detailed questionnaire designed to extract relevant information about each vineyard's practices relating to land preparation, trellising systems, nutrient management, weed and pest management, fuel inputs and crop yields in 2006 (Appendix A). Questionnaires were sent either electronically or by mail to every member of the Nova Scotia Grape Growers Association. Once questionnaires were returned, follow-up calls were made in cases where responses required further elaboration. Although primary data collection was not anonymous, confidentiality was assured and all vineyard data were aggregated to protect commercially sensitive data. In addition, information unknown to the grape growers themselves (e.g. industry characteristics, specifications of various vineyard materials, etc.), were obtained from agricultural supply companies, crop specialists, and industry associations. Once vineyard-specific inventory data were compiled, data were weighted using vineyard grape production in 2006, and averaged to provide a representative vineyard model for Nova Scotia. In instances where variability regarding the nature of a material input did not permit averaging, the most common response was used.

In addition to production-related emissions, a significant portion of life cycle impacts in agricultural systems are caused by emissions associated with the application of synthetic and organic fertilizers and soil amendments (Brentrup, *et al*., 2000; Milà i Canals & Polo, 2003; Schmidt, 2007). Methods used to calculate field-level greenhouse gas and nutrient emissions from synthetic and organic fertilizers (manure) were derived from Brentrup *et al*., (2000) and the Intergovernmental Panel on Climate Change Guidelines for National Greenhouse Gas Inventories (Tier 1) (2006). Since manure is essentially a co-product of another economic activity (e.g. meat or dairy production), containing valuable nitrogen and phosphorous, the environmental burdens arising from the transport of manure to the vineyards, plus the additional production-related and field-level emissions associated with an equivalent quantity of nutrients in chemical fertilizers were allocated to the grapes, following Audsley (1997). It is important to note that this analysis did not consider fertilizer application timing, soil characteristics, nor climatic conditions during application, all of which can be important factors for a more detailed analysis of a vineyard's nutrient balance (Brentrup *et al*., 2000; Erisman, 2000; Powers, 2007). CO_2 emissions from propane used on the vineyard, not accounted for in the LCA background process data, were derived from data reported by the United States Environmental Protection Agency (2004).

2.5.2.2 Winery Data

Questionnaires were used to gather data from winemakers processing only Nova Scotia grown grapes. Follow-up phone calls and emails were made when responses required further clarification. Information was sought pertaining to each winery's source of grapes (e.g. distance from winery); type, source and transport mode of bottles; use of electricity; heating oil; wine ingredients (including sugar, yeast and yeast nutrients, clarifying and filtering agents, anti-oxidants and oak chips) and total output of Nova Scotia wine in 2006. Transport distances of grapes to the wineries were modeled as the return trip distance. No inquiry was made into each winery's total water use since none of the province's wineries have water meters. VOC emissions from the fermentation process were calculated based on an emission factor provided by the United States Environmental Protection Agency (1995). Once all inventory data were compiled for each contributing winery, data were weighted, according to litres of wine produced, and averaged to provide a representative model for Nova Scotia wineries. A copy of the winery survey appears in Appendix B.

2.5.2.3 Bottle Manufacture And Bottle Transport Data

Input and emission data for wine bottle production were sourced from well-developed background process data contained in the LCA databases (Table 2.1). Geographically-relevant electricity production mixes for bottle production facilities were obtained from industry websites or from power company employees. Only one-way transport distances were modeled for the delivery of bottles to the wineries.

2.5.2.4 Transport To Retail Data

In 2006, nearly 60% of all wine produced in Nova Scotia was sold at provincial liquor commission outlets throughout the province (Josza Management & Economics, 2006). While it is estimated that a lower percentage of wine made from 100% Nova Scotia grapes is sold at this retail venue, I chose to model the retail location of the functional unit at a provincial liquor commission outlet in Halifax, Nova Scotia's largest and most populated city.

Information regarding the vehicles used to transport wine from its site of production to its place of retail in Halifax were obtained directly from wineries. An assumption was made that trucks delivering wine from a winery to Halifax would drive the round-trip distance (based on the weighted, average distance from all existing wineries to Halifax).

2.5.2.5 Consumer Transport, Refrigeration And Bottle Recycling Data

While it is impossible to characterize an average shopping trip for a bottle of wine, I have modeled a situation in which a Halifax consumer drives a gasoline powered vehicle to a wine retail outlet in Halifax, a round-trip distance of five kilometers, for the sole purpose of purchasing a bottle of wine. Thus, all impacts resulting from the trip are allocated to the functional unit.

Similarly, it is impossible to model a typical storage scenario at a consumer's home, but a conservative estimate was chosen in which one bottle of wine is stored for twenty-four hours in a small, energy efficient household refrigerator.

Finally, to account for the energy and material requirements of wine's end-of-life activities, the model included the requisite vehicle function for collection and transportation of the empty glass bottle to the recycling plant, as well as the energy and material requirements for sorting glass cullets.

2.6 Life Cycle Impact Assessment

Life cycle impact assessment (LCIA) is the stage in which LCI data are expressed in terms of their contribution to globally significant impact categories (Guinée *et al*., 2001; ISO, 2006a). LCI data may consist of hundreds of inputs and emissions and thus in the LCIA, data are organized and quantitatively characterized according to the type of environmental impact they can contribute to (Baumann & Tillman, 2004). LCIA calculations may be undertaken manually, but are commonly facilitated with the use of LCA-specific software. Here, I have used SimaPro (version 7.1.6), a leading LCA software package developed by PRé Consultants in the Netherlands (PRé Consultants, 2008). The impact assessment methodology chosen was CML 2 baseline 2000, developed by the Centre for Environmental Science at Leiden University, which characterizes LCI data into contributions to "problem-oriented" mid-point impact categories (Guinée *et al*., 2001).

Following the path of previous arable crop, beverage, and processed food LCAs (Andersson *et al*., 1998; Andersson & Ohlsson, 1999; Milà i Canals & Polo, 2003; Kramer, 2003; Hospido *et al*., 2003; Notarnicola *et al*., 2003; Milà i Canals *et al*., 2006), and the guidelines provided by Guinée *et al* (2001), the following baseline, and study-specific impact categories were selected for this analysis: abiotic resource depletion potential (ARDP), acidification potential (AP), eutrophication potential (EP), global warming potential (GWP), stratospheric ozone depletion potential (ODP), aquatic eco-toxicity potential (AETP), terrestrial eco-toxicity potential (TETP), photo-oxidant formation potential (POP), and cumulative energy demand (CED). A more detailed description of each impact category appears in Appendix D.

2.7 Interpretation Of Results And Improvement Assessment

In the final stage of an LCA, results are assessed and recommendations about the system under study are made (Baumann & Tillman, 2004) in a way that is meaningful within the context of the project's original goal and scope (ISO, 2006a). Uncertainties and assumptions are addressed through sensitivity analysis and potential improvement options to reduce the system's environmental impact may be explored using scenario modeling (Consoli *et al*., 1993).

2.7.1 Scenario Modeling

Scenario modeling in LCA is a useful practice which allows the researcher to test the potential impact of proposed alterations to processes or stages within a product's life cycle. Here, four scenarios were modeled, each representing a change to a particular stage of wine's life cycle that are perceived, or have been demonstrated to contribute disproportionately to wine's overall life cycle environmental impacts. In the first scenario, a hypothetical organic vineyard was modeled with two different assumed grape yields per hectare. Second, I have modeled the use of lighter glass bottles to illustrate the extent to which this potential management decision might reduce total life cycle environmental costs. Third, a scenario was modeled in which a Halifax-based consumer drives directly to a winery to purchase their wine. Lastly, I have modeled a scenario in which the transport distance from winery to retail location is increased. This final scenario was included to provide insight into the extent to which claims that locally produced food and beverages have lower environmental impacts, holds true for Nova Scotia wine.

2.7.1.1 Organic Viticulture Scenario

Organics is the fastest growing sector in Canadian agriculture, with sales increasing at 20% per year (Canadian Organic Growers, 2008). Organic food production is often cited as environmentally preferable to conventional agriculture (Pimentel & Pimentel, 1996; Refsgaard *et al*., 1998; Stolze *et al*., 2000; Ahlgrimm *et al*., 2000; Haas *et al*., 2001; Pimentel *et al*., 2005a; Pelletier *et al*., 2008) and the human health benefits, both to producers and consumers, are generally accepted in the public sphere (Hendrik *et al*., 1998; Shepherd *et al*., 2005) and academic literature (Pimentel *et al*., 2005b; Milà i Canals *et al*., 2006). A few vineyards in Canada are already practicing organic methods, (Wines of Canada, 2007) including one in Nova Scotia (Naugler and Wright, 2006).

Here, I have modeled a scenario to quantify the potential changes to various environmental impact categories associated with the adoption of organic viticultural practices in Nova Scotia. In 2006, when data for this analysis were collected, Nova Scotia's organic vineyard had not yet reached a fully-productive state and was thus unable to provide the data necessary for this scenario. Similarly, sufficient data were unavailable from any of the other cool-climate viticultural regions in Canada. Instead, a hypothetical model for organic viticultural inputs was designed based on the Canadian Organic Production Systems Permitted Substances List (Canadian General Standards Board, 2006). For yields, I assumed two possible scenarios. In the first, Nova Scotia organic vineyards were assumed to produce 20% fewer grapes (by weight) per hectare compared with existing conventional yields in the province. This assumption was based on conservative estimates from published values for organic grape yields in other wine producing regions (Nicoletti *et al*., 2001; Pizzigallo *et al*., 2006; Niccolucci *et al*., 2006; Delmas & Grant, 2008). In the second organic scenario, Nova Scotia organic vineyards were modeled to produce an equivalent amount of grapes (by weight) per hectare as conventional Nova Scotia vineyards in 2006.

According to Canada's National Organic Standards, the use of most synthetic pesticides and herbicides, all synthetic fertilizers, and all wood preservatives are banned in the cultivation of organic crops (Canadian General Standards Board, 2006). Here, I have modeled a vineyard in which only cow manure is used as a fertilizer, copper sulfate and sulfur are used as fungicides, and no wood pressure treatment substance is used on the vineyard posts. Following Pelletier *et al*., (2008), quantities of elemental nitrogen, phosphorous and potassium inputs on the organic vineyard were assumed to be equivalent to the conventional system on a per-hectare basis. Nitrogen, phosphorous and potassium content of cow manure were obtained from the Atlantic Canada Nutrient Management Planning Guide (Nova Scotia Department of Agriculture and Marketing, 2000) and a simplified system expansion was chosen to allocate an appropriate portion of manure production-related emissions to the grapes, as was articulated in section 2.5.2.1. Field-level emissions from both nitrogen and phosphorous in the manure were calculated following Brentrup *et al*., (2000), Intergovernmental Panel on Climate Change (Tier 1) guidelines (2006) and Dalgaard *et al*., (2006). Copper sulphate and sulphur were modeled in the organic scenario since they are permitted substances that are known to effectively treat Nova Scotia's two most common fungal infections – downy and powdery mildew (Naugler & Wright, 2006). Application rates of organic fungicides were obtained from the Nova Scotia Grape Disease Management Schedule (AgraPoint International Ltd., 2007). For reasons elaborated in section 2.5.1, field-level emissions for fungicides were not modeled in either system. I assumed no differences in machinery-related energy or fuel consumption between the two systems. I also assumed no differences in the amount of wood and steel required for the trellis in the three scenarios, nor did I account for changes in transport-related emissions for vineyard materials.

2.7.1.2 Lighter Bottle Scenario

At a weight of 540 grams, over 40% of the weight of a 750 ml bottle of wine is attributable to the glass bottle itself. A recent study in the UK indicated that a 40% reduction in the weight of glass wine bottles (from 500 to 300 grams) can lead to as much as a 30% reduction in transport- and packaging-related CO_2 emissions per 750 ml bottle of wine (WRAP, 2008a). Research trials have indicated that proper design can produce glass wine bottles that are lighter, yet sufficiently strong for the purposes of containing and transporting wine (Hartley, 2008). Here, I have modeled the potential life cycle environmental benefits of using a glass bottle that weighs 380 grams, or approximately 30% less than the current average weight of wine bottles used in Nova Scotia.

2.7.1.3 Increased Consumer Transport Distance Scenario

Given the recent development by several wineries of tourist-related attractions such as restaurants, wine tastings, and farm tours, it is reasonable to assume that the number of visitors to wineries will continue to increase in the coming years (Jozsa Management & Economics, 2006). In the third scenario, I have modeled a consumer driving a car from Halifax to a Nova Scotia winery to purchase their wine, an average roundtrip distance of 200 km, in order to assess the environmental relevance of this increased transport distance. However, for the purpose of this scenario, it was assumed that the consumer did not solely make this trip to purchase a single bottle of wine and thus only 12.5% or 25 km of the trip is allocated to the functional unit.

2.7.1.4 Increased Transport Distance To Market Scenario

A great deal of attention as of late has been devoted to the concept of "food miles" (Schlich & Fleissner, 2005; Smith *et al*., 2005; Blanke & Burdick, 2005) as a measure of the distance traveled by a food product from its place of origin to its place of consumption (Smith *et al*., 2005). It is a commonly held assumption that the further a food item has traveled, the more environmentally damaging it will be when compared to its local counter-part (Schlich & Fleissner, 2005). Certainly, the transport of a food item will result in increased emissions to the product's life cycle, but evidence exists to suggest that such a myopic view of a product may result in an exaggerated awareness of the relative importance of food's transport distance (Schlich & Fleissner, 2005; Foster *et al*., 2006) and may in fact ignore equally, or more important components of a product's life cycle (Sonesson *et al*., 2005; Hansen, 2007, as cited in Brodt *et al*., 2007).

In the final scenario, the effect of Nova Scotia wine's potential export is modeled. While advocates of developing an export market for Canadian wine exist (Madill *et al*., 2003), it is unlikely in the near future that large quantities of wine produced in Nova Scotia will be exported (*pers comm.*, Christopher Naugler, Feb, 15, 2007). However, shipments to other parts of the country already occur and may increase in volume. Here, I have modeled two potential Canadian retail locations for Nova Scotia wine: Toronto, Ontario and Vancouver, British Columbia, a one-way distance of 1800 and 6000 km, respectively. Though less likely to materialize as a reality, I have also modeled the transport of wine by container ship to Perth, Australia, a distance of 18,000 km, in order to determine the relevance of this transport mode over such a great distance. The delivery of wine to Toronto and Vancouver was modeled in transport trucks (28-tonne capacity). To Perth, a transport truck was modeled to transport wine from the winery to the international port in Halifax, at which point, a fully-loaded shipping container transported the wine by sea for the remainder of the journey. Return trips were excluded from the model as were the use of wooden pallets required to load and unload wine from the truck.

2.7.2 Sensitivity Analysis

While great attempts have been made to create an accurate and detailed model of wine's life cycle in Nova Scotia, I humbly acknowledge that simplifying assumptions and the absence of certain data, do not, nor cannot reflect all possible realities. Sensitivity analyses allow the LCA practitioner to assess the extent to which an assumption, or a data point associated with a degree of uncertainty, has an impact on the overall results of the analysis (Guinée *et al*., 2001). Here, a sensitivity analysis was undertaken to assess the relative importance of truck size modeled to transport Nova Scotia wine from the winery to its place of retail in Halifax. Survey data for wineries indicated that small delivery trucks were used to transport wine in 2006 and I've employed a sensitivity analysis to test the effect of employing a transport truck (28-tonne capacity) for this distance instead.

2.8 Results

2.8.1 Vineyard Life Cycle Inventory Results

Of the 40 surveys sent to grape growers, 10 were completed and returned. Of these 10 surveys, 3 were excluded due to lack of yield data, or because grape growing endeavors were executed for reasons other than wine production. The remaining seven surveys together accounted for fully 60% of all grapes grown in the province in 2006. Table 2.2 summarizes the weighted vineyard LCI data used to characterize typical grape growing activities in the province.

Table 2.2 Life cycle inventory results for Nova Scotia viticulture in 2006.

Material and Energy Inputs	Unit	Per Hectare	Per Tonne of Grapes [a]	Per Bottle of Wine [b]
Land Preparation				
Tile drain[c]	kg	38.41	6.03	7.54 E-03
Lime (dolomitic)[d]	kg	162.37	25.49	3.19 E-02
N-fertilizer (from synthetic source) [e]	kg	0.38	0.06	7.50 E-05
N-fertilizer (from manure source) [e]	kg	2.74	0.43	5.38 E-04
P-fertilizer (from synthetic source) [f]	kg	1.27	0.20	2.50 E-04
P-fertilizer (from manure source) [f]	kg	1.02	0.16	2.00 E-04
K-fertilizer (from synthetic source) [g]	kg	2.23	0.35	4.38 E-04
K-fertilizer (from manure source) [g]	kg	2.89	0.45	5.68 E-04
Glyphosate	kg	0.127	0.20	2.50 E-05
Diesel	l	3.06	0.48	6.00 E-04
Emissions from Land Preparation				
CO_2 (from lime application) [h]	kg	178.36	28.00	3.50 E-02
Trellising System				
Trellis wire [i]	kg	40.07	6.29	7.86 E-03
Grape rod [j]	kg	11.59	1.82	2.23 E-03
Wooden posts [k]	kg	254.80	40.00	5.00 E-02
Wood preservative [l]	kg	6.94	1.09	1.36 E-03
Annual Nutrient Management				
Lime [d]	kg	1154.75	181.28	2.27 E-01
N-fertilizer (from synthetic source) [e]	kg	16.82	2.64	3.30 E-03
N-fertilizer (from manure source) [e]	kg	76.06	11.94	1.49 E-02
P-fertilizer (from synthetic source) [f]	kg	45.67	7.17	8.96 E-03
P-fertilizer (from manure source) [f]	kg	25.16	3.95	4.94 E-03
K-fertilizer (from synthetic source) [g]	kg	79.69	12.51	1.56 E-02
K-fertilizer (from manure source) [g]	kg	82.17	12.90	1.61 E-02
Emissions from Nutrient Management				
CO_2 (from lime application) [h]	kg	550.43	86.41	1.08 E-01
N_2O (from synthetic source) [h]	kg	0.38	0.06	7.50E-05
N_2O (from manure source) [h]	kg	2.99	0.47	5.88 E-04
NO (from synthetic source) [h]	kg	0.45	0.07	8.75E-05
NO (from manure source) [h]	kg	3.25	0.51	6.38 E-04
NH_3 (from synthetic source) [h]	kg	2.93	0.46	5.75E-04
NH_3 (from manure source) [h]	kg	21.53	3.38	4.23E -03
NO_3 (from synthetic source) [h]	kg	10.89	1.72	2.15E-03
NO_3 (from manure source) [h]	kg	80.45	12.63	1.58E-02
P_20_5 (from synthetic source) [h]	kg	1.27	0.20	2.50 E-04
P_2O_5 (from manure source) [h]	kg	0.76	0.12	1.50 E-04
Weed and Pest Management				
Glyphosate[m]	kg	3.06	0.48	6.00 E-04
Gluphosinate [m]	kg	0.25	0.04	5.00 E-05
Paraquat [m]	kg	0.06	0.01	1.25 E-05
Captan [n]	kg	9.17	1.44	1.80 E-03
Folpet [n]	kg	4.40	0.69	8.63 E-04
Sulphur [n]	kg	27.20	4.27	5.34 E-03

Table continued on next page

Table 2.2 continued: Life cycle inventory results for Nova Scotia viticulture in 2006.

Material and Energy Inputs	Unit	Per Hectare	Per Tonne of Grapes [a]	Per Bottle of Wine [b]
Weed and Pest Management, continued				
Propane	l	3.89	0.61	7.63 E-04
Emissions from Weed and Pest Management				
CO_2 (from propane combustion) [o]	kg	13.06	2.05	2.56 E-03
Fuel and Oil				
Diesel	l	236.51	37.13	4.64 E-02
Gasoline	l	3.57	0.56	7.00 E-04
Lubricating oil	l	4.40	0.69	8.63 E-04

Notes: [a] One hectare of Nova Scotia vineyards in 2006, on average, produced 6.37 tonnes of grapes (Nova Scotia vineyard survey).
[b] One tonne of grapes, on average, produces 800 bottles of wine in Nova Scotia (Naugler & Wright, 2006).
[c] Tile drain is made of HDPE plastic and is assumed to last 25 years in a vineyard.
[d] Mostly unburned, dolomitic lime (*pers. comm*., Sonny Murray, March 15, 2008).
[e] Most common source of nitrogen used in Nova Scotia fertilizers is ammonium nitrate, from Russia (*pers. comm*., Sonny Murray, March 15, 2008).
[f] Most common source of potassium used in Nova Scotia fertilizers is di-ammonium phosphate, from Florida, USA (*pers. comm*., Sonny Murray, March 15, 2008).
[g] Most common source of potassium used in Nova Scotia fertilizers is potassium chloride, from Sussex, New Brunswick (*pers. comm*., Sonny Murray, March 15, 2008).
[h] Appendix C
[i] Trellis Wire is made with low-alloyed steel and weighs 0.04 kg/m. It is assumed to last 25 years in a vineyard (pers. comm., Sonny Murray, March 15, 2008).
[j] Grape rods are made from mild, reinforcing steel and weigh 0.1 kg each. They are assumed to last 25 years in a vineyard (*pers. comm*., Sonny Murray, March 15, 2008).
[k] Wooden vineyard posts are made from Nova Scotia spruce wood. Intermediate posts weigh 10 kg each and end posts weigh 30 kg each. They are assumed to last 15 years in a vineyard (*pers. comm*., Tony George, May 7, 2008).
[l] Chromium copper arsenic is the wood preservative used for wooden vineyard posts (pers. comm., Tony George, May 7, 2008).
[m] Glyphosate, gluphosinate and paraquat account for over 90% of the weight of active ingredients of herbicides applied to Nova Scotia vineyards in 2006.
[n] Captan, folpet and sulphur account for over 90% of the weight of active ingredients of fungicides applied to Nova Scotia vineyards in 2006.
[o] United States Environmental Protection Agency, 2004.

2.8.2 Post-Vineyard Life Cycle Inventory Results

Winery, bottle, and transport-related data were obtained from two Nova Scotia wineries that together processed fully 15% of all Nova Scotia grown grapes in 2006 (Table 2.3). I chose to report on data from wineries that process only Nova Scotia grapes, since electricity use of wineries that import a percentage of their grapes and grape juice from out of province would have externalized the requisite energy requirements of crushing and pressing grapes and transporting the juice, or grapes to Nova Scotia. Where bottling services were outsourced, bottling-related electricity consumption was estimated from data in Notarnicola *et al*., (2003) and Aranda *et al*., (2005).

Table 2.3 Life cycle inventory results for Nova Scotia winery practices in 2006.

Material and Energy Inputs	Unit	Per Hectolitre	Per Bottle of Wine
Winery			
Electricity	kWh	50.67	0.38
Heating oil	l	2.67	0.02
Fraction of grapes purchased from contract growers in Nova Scotia	%		45.00
Average distance of contract growers (round trip distance)	km		20.00
Mode of transport			Pick-up truck
Bottle Manufacture and Bottle Transport			
Weight of average bottle	kg		0.54
Origin of bottles			
Halifax, NS	%		50.00
France	%		50.00
Mode of transport for delivery of bottles to wineries			Transport truck
Number of bottles delivered in one shipment			30,000
Transport of Wine to Bottling Facility			
Fraction of wine transported (in bulk) to bottling facility	%		40.00
Average round trip distance of bulk wine to bottling facility	km		300.00
Mode of transport			Small delivery truck
Transport of Wine to Retail			
Average distance to retail (round-trip)	km		400.00
Mode of transport to deliver wine to retail			Small delivery truck
Cardboard box	kg		0.04
Consumer Transport			
Distance traveled (round-trip)	km		5.00
Mode of transport			Passenger car
Consumer Storage			
Small, energy efficient refrigerator	l*day		0.75
Recycling			
Mass of bottles collected and transported to recycling facility	kg		0.54
Mass of glass sorted (as cullets) at recycling facility	kg		0.54

2.9 Life Cycle Impact Assessment Results

Life cycle environmental impacts of a bottle of wine produced and consumed in Nova Scotia are dominated by activities occurring in the vineyard, bottle production, and consumer transport stages (Figure 2.3, Table 2.4).

Vineyard impacts dominate wine's total eutrophication potential (69%), but also make substantial contributions to wine's terrestrial eco-toxicity potential (54%), aquatic eco-toxicity potential (37%), acidification potential (29%), and global warming potential (18%). Vineyard practices contribute relatively less to wine's cumulative energy demand (12%), abiotic resource depletion potential (11%) and ozone depletion potential (9.9%). The vineyard stage of wine's life cycle actually has a negative photo-oxidation potential due to emissions of NO from nitrogen fertilizer application, which have a negative influence on the formation of photo-oxidants in the troposphere (Derwent *et al*., 1996; Guinée *et al*., 2001).

The production of wine bottles and their subsequent transport to wineries contribute a large portion of total potential photo-oxidant creation (66%), acidification (53%), abiotic resource depletion (43%), cumulative energy demand (45%), and global warming (37%). To a lesser extent, wine bottle production contributes to the impact categories of terrestrial eco-toxicity potential (21%), aquatic eco-toxicity potential (21%) and eutrophication potential (18%). Wine bottle production contributes relatively little to ozone depletion potential (7.0%).

As modeled, consumer transport contributes substantially to the impact categories of ozone depletion potential (63%), photo-oxidant formation potential (33%), wine's cumulative energy demand (30%), its potential to deplete abiotic resources (31%), and wine's global warming potential (30%). To a lesser extent, a consumer driving to purchase their wine contributes to its terrestrial and aquatic eco-toxicity potential (16% and 14%, respectively), as well as wine's acidification (8.4%) and eutrophication (7.2%) potential.

Less important to wine's life cycle are winery activities, the transport of wine to its retail location in Halifax, the recycling of the glass bottle, and the refrigeration of wine in the consumer's home (Figure 2.3, Table 2.4). Both winery activities and transport of wine to retail only contribute between 1% to 17% across impact categories (Table 2.4).

Winery impacts are driven by the use of electricity and in particular, by Nova Scotia's coal-fired electricity generation. Impacts arising from the transport of wine are overwhelmingly dominated by the use of a truck (and combustion of diesel fuel), but interestingly, provision of the cardboard box in which wine in shipped makes non-trivial contributions to this life cycle stage in some impact categories (Table 2.4). Recycling of the glass bottle contributes less than 2% to all impact categories except for aquatic eco-toxicity potential to which recycling contributed 6% of total impacts. Finally, contributions to wine's overall environmental impact from refrigeration is so small, its relative contribution is not even visible in Figure 2.3.

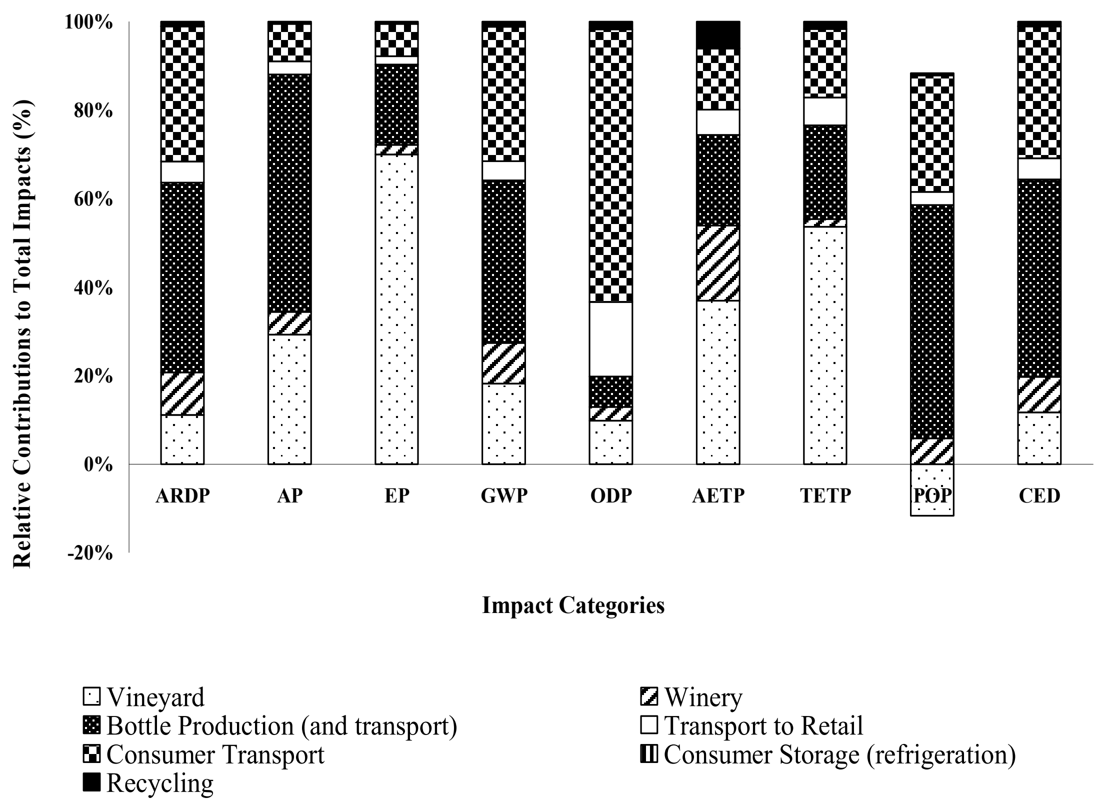

Figure 2.3 Relative contributions (% of total) of wine's life cycle sub-systems to environmental impact categories. Functional unit = 1 bottle of wine made with 100% Nova Scotia grapes. Note: ARDP = abiotic resource depletion potential, AP = acidification potential, EP = eutrophication potential, GWP = global warming potential, ODP = ozone depletion potential, AETP = aquatic eco-toxicity potential, TETP = terrestrial eco-toxicity potential, POP = photo-oxidant formation potential, and CED = cumulative energy demand.

Table 2.4 Detailed contributions (% of total) of sub-systems to wine's life cycle environmental impacts. Functional unit = 1 (750ml) bottle of wine produced and consumed in Nova Scotia in 2006.

	ARDP (kg Sb eq)	**AP** (kg SO_2 eq)	**EP** (kg PO_4 eq)	**GWP** (kg CO_2 eq)	**ODP** (kg CFC-11 eq)	**AETP** (kg 1,4-DCB eq)	**TETP** (kg 1,4-DCB eq)	**POP** (kg C_2H_4)	**CED** (MJ)
Vineyard									
Land Prep	3.34E-04	1.63E-04	4.36E-05	6.29E-02	6.7E-09	6.40E-04	4.84E-05	4.81E-06	6.83E-01
Trellis	1.89E-04	1.27E-04	1.83E-05	-4.78E-02	1.22E-09	1.62E-02	1.73E-03	1.16E-05	1.17
Nutrient management	9.18E-04	9.34E-03	4.98E-03	5.23E-01	1.35E-08	1.34E-02	9.39E-04	-2.61E-04	2.07
Weed and fungus management	2.02E-04	3.05E-04	8.23E-06	1.99E-02	2.58E-09	1.58E-03	2.42E-04	1.26E-05	4.95E-01
Fuel	9.42E-04	1.72E-03	3.47E-04	1.46E-01	1.37E-10	3.50E-04	4.39E-05	6.11E-05	1.98
Vineyard machinery	1.55E-04	6.52E-05	7.42E-06	1.51E-02	2.14E-09	3.09E-03	9.14E-05	5.13E-06	3.87E-01
Sub-total	**2.74E-03**	**1.17E-02**	**5.40E-03**	**7.18E-01**	**2.63E-08**	**3.53E-02**	**3.10E-03**	**-1.66E-04**	**6.78**
Percent of system total (%)	**11.12%**	**28.94%**	**69.10%**	**18.20%**	**9.88%**	**37.08%**	**53.75%**	**-14.57%**	**11.73%**
Winery									
Transport of grapes	2.34E-04	3.27E-04	5.82E-05	3.61E-02	3.18E-11	5.89E-06	1.70E-06	1.57E-05	4.89E-01
Wine ingredients	2.49E-05	4.36E-05	2.06E-05	-5.71E-03	4.40E-10	-1.05E-04	-1.52E-04	8.80E-07	2.34E-01
Electricity	1.79E-03	1.69E-03	7.88E-05	2.85E-01	1.98E-09	1.59E-02	2.26E-04	6.25E-05	3.26
Heating oil	2.98E-04	5.48E-04	1.11E-04	4.62E-02	4.06E-11	1.11E-04	1.39E-05	1.66E-05	6.24E-01
Ethanol emissions	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.62E-05	0.00
Sub-total	**2.35E-03**	**2.52E-03**	**2.67E-04**	**3.62E-01**	**2.36E-09**	**1.59E-02**	**8.91E-05**	**1.31E-04**	**4.62**
Percent of system total (%)	**9.53%**	**6.22%**	**3.41%**	**9.18%**	**0.89%**	**16.72%**	**1.55%**	**11.52%**	**7.99%**
Glass Bottle									
Glass bottle production	9.60E-03	2.10E-02	1.34E-03	1.42	1.20E-08	1.62E-02	9.66E-04	7.27E-04	23.21
Cork, label and cap production	7.84E-04	2.11E-04	2.43E-05	2.10E-03	3.00E-09	2.49E-03	2.12E-04	1.21E-05	2.21
Glass bottle transport	1.73E-04	3.24E-04	3.76E-05	2.45E-02	3.66E-09	7.98E-04	4.88E-05	1.05E-05	3.99E-01
Sub-total	**1.06E-02**	**2.15E-02**	**1.40E-03**	**1.45**	**1.87E-08**	**1.95E-02**	**1.22E-03**	**7.49E-04**	**25.81**
Percent of system total (%)	**43.00%**	**53.08%**	**17.90%**	**36.75%**	**7.03%**	**20.51%**	**21.19%**	**65.85%**	**44.67%**

Table continued on next page

Table 2.4 continued: Detailed contributions (% of total) of sub-systems to wine's life cycle environmental impacts. Functional unit = 1 (750ml) bottle of wine produced and consumed in Nova Scotia in 2006.

	ARDP (kg Sb eq)	**AP** (kg SO_2 eq)	**EP** (kg PO_4 eq)	**GWP** (kg CO_2 eq)	**ODP** (kg CFC-11 eq)	**AETP** (kg 1,4-DCB eq)	**TETP** (kg 1,4-DCB eq)	**POP** (kg C_2H_4)	**CED** (MJ)
Transport to Retail									
Cardboard box	1.87E-04	5.18E-04	1.37E-05	2.94E-02	2.43E-08	5.90E-04	8.94E-05	1.96E-05	4.09E-01
Wine transport	9.77E-04	6.57E-04	1.37E-04	1.42E-01	2.16E-08	4.89E-03	2.74E-04	2.22E-05	2.34
Sub-total	**1.16E-03**	**1.17E-03**	**1.50E-04**	**1.71E-01**	**4.59E-08**	**5.49E-03**	**3.64E-04**	**4.18E-05**	**2.75**
Percent of system total (%)	**4.71%**	**2.89%**	**1.92%**	**4.33%**	**17.26%**	**5.77%**	**6.32%**	**3.68%**	**4.76%**
Consumer Transport									
Passenger car, 5km	7.54E-03	3.41E-03	5.62E-04	1.20	1.68E-07	1.32E-02	8.95E-04	3.75E-04	17.21
Percent of system total (%)	**30.59%**	**8.42%**	**7.19%**	**30.42%**	**63.16%**	**13.88%**	**15.54%**	**32.97%**	**29.78%**
Consumer Storage									
Fridge (energy efficient)	1.85E-05	1.91E-06	4.64E-07	2.65E-03	5.38E-11	5.18E-05	3.83E-07	1.07E-07	3.46E-02
Percent of system total (%)	**0.08%**	**0.00%**	**0.01%**	**0.07%**	**0.02%**	**0.05%**	**0.01%**	**0.01%**	**0.06%**
Recycling									
Public collection of glass	1.06E-04	7.91E-05	1.58E-05	1.45E-02	2.10E-09	8.40E-04	3.86E-05	2.70E-06	2.55E-01
Glass cullets, sorted	1.36E-04	1.01E-04	2.12E-05	2.71E-02	2.59E-09	4.84E-03	5.57E-05	3.51E-06	3.29E-01
Sub-total	**2.41E-04**	**1.80E-04**	**3.70E-05**	**4.16E-02**	**4.69E-09**	**5.69E-03**	**9.43E-05**	**6.21E-06**	**5.84E-01**
Percent of system total (%)	**0.98%**	**0.44%**	**0.47%**	**1.05%**	**1.76%**	**5.98%**	**1.64%**	**0.55%**	**1.01%**
System Total	**2.46E-02**	**4.05E-02**	**7.82E-03**	**3.95**	**2.66E-07**	**9.51E-02**	**5.76E-03**	**1.14E-03**	**57.78**

Given that viticulture, the glass bottle and consumer transport are the most environmentally-relevant life cycle phases of wine, it is useful to take a closer look in order to determine the reason for their disproportionate contributions. In the case of consumer transport, no further resolution is necessary, as these impacts are overwhelmingly associated with the combustion of fuel in a car's engine. With respect to the bottle sub-system, impacts arising from the generation of electricity used to manufacture the bottle dominate in this life cycle stage (Table 2.4).

However numerous vineyard materials and activities contribute to the total emissions associated with grape growing, including land preparation, trellising, nutrient management, weed and fungus management, fuel, and vineyard machinery (Table 2.4). The relative contributions that these activities make to vineyard impacts are illustrated in Figure 2.4. Nutrient management inputs dominate vineyard level impacts, contributing most to the impact categories of acidification, eutrophication, global warming, and ozone depletion potential. Fuel use on the vineyard is also a reasonably important material input to the impact categories of abiotic resource depletion, acidification, global warming, photo oxidant creation, and cumulative energy demand. More than half of potential aquatic and terrestrial eco-toxicity related impacts are derived from a vineyard's trellising system, due to the manufacture of steel posts, and the use of chromium-copper arsenate as a wood preservative on trellis posts, respectively. The provision of tile drain, installed during the land preparation phase and made of high density polyethene, makes non-trivial contributions to the ozone depletion potential and abiotic resource depletion at the level of the vineyard. The manufacture of weed and fungus management inputs contribute relatively little to total vineyard impacts, though recall that since chemical emissions from these substances were not modeled, their contributions illustrated here are likely highly conservative. The provision of vineyard machinery contributes very little to total vineyard impacts. Trellis materials have a negative global warming potential due to the carbon sequestration of wooden posts over the time period modeled here (Figure 2.4).

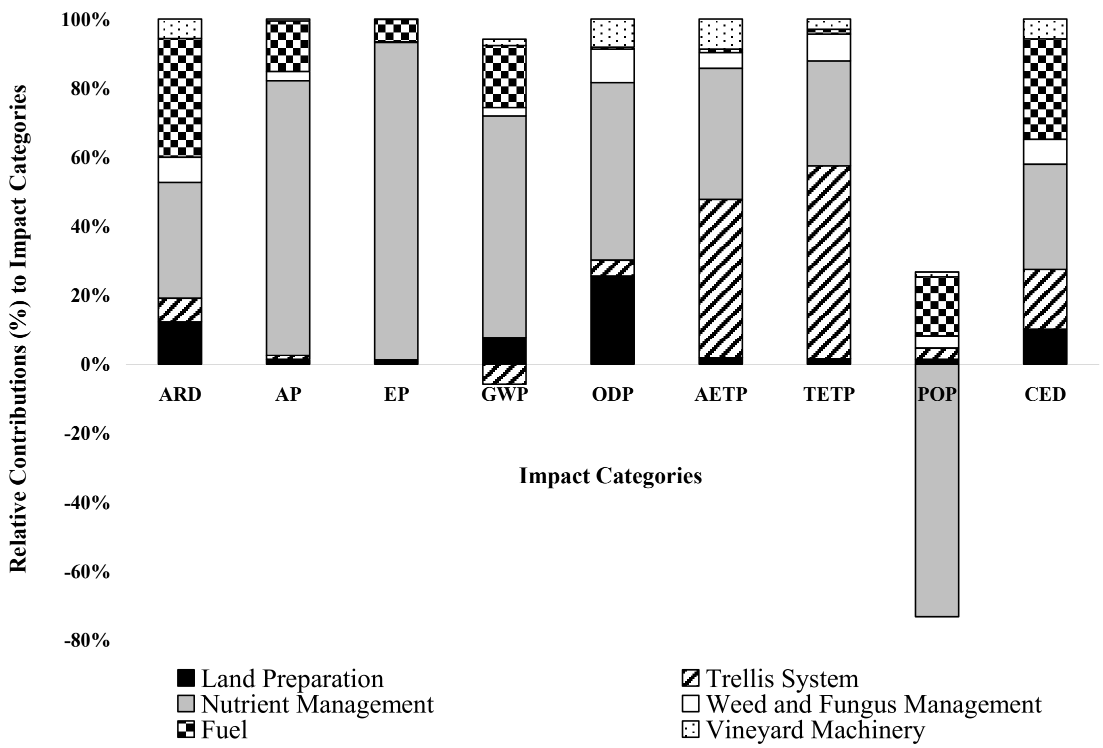

Figure 2.4 Detailed contributions (% of total) of vineyard sub-processes to environmental impact categories.

Within the context of nutrient management, the provision of nitrogen and its associated emissions to air and water make the most important contributions across almost all impact categories (Figure 2.5). Also noteworthy is the use and associated emissions of phosphatic fertilizer to the impact categories of abiotic resource depletion, eutrophication, aquatic and terrestrial eco-toxicity, photo-oxidant formation and cumulative energy demand. Potassium fertilizer contributes to impact categories of abiotic resource depletion, aquatic eco-toxicity and cumulative energy demand. The manufacture of dolomitic lime and its associated field-level emissions of CO_2 make liming an important vineyard practice with respect to global warming potential. Again, nutrient management counteracts the formation of photo-oxidants due to emissions of NO from nitrogen fertilizer.

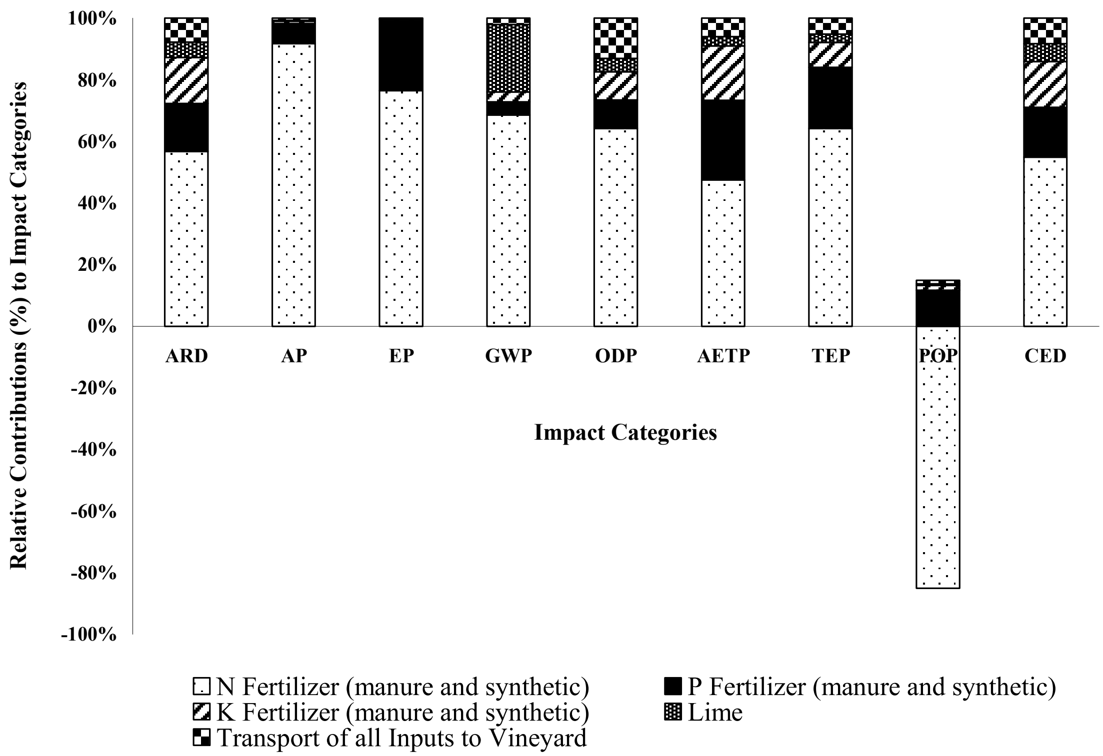

Figure 2.5 Detailed contributions (% of total) of nutrient management sub-processes to environmental impact categories.

Finally, Figure 2.6 illustrates the relative contributions of impacts resulting from the manufacture and application of nitrogen fertilizers. Acidifying, eutrophying, and (negative) photo-oxidant contributions are almost entirely caused by volatilization and leaching of nitrogenous compounds on the vineyard to air and water, respectively. In the remaining impact categories, it is the manufacture of nitrogen fertilizers that contribute solely to these impacts. Potential impacts to global warming are split almost equally between impacts from manufacture and from field-level emissions. Interestingly, 82% of all nitrogen applied to Nova Scotia vineyards in 2006 was applied in the form of manure (Table 2.2).

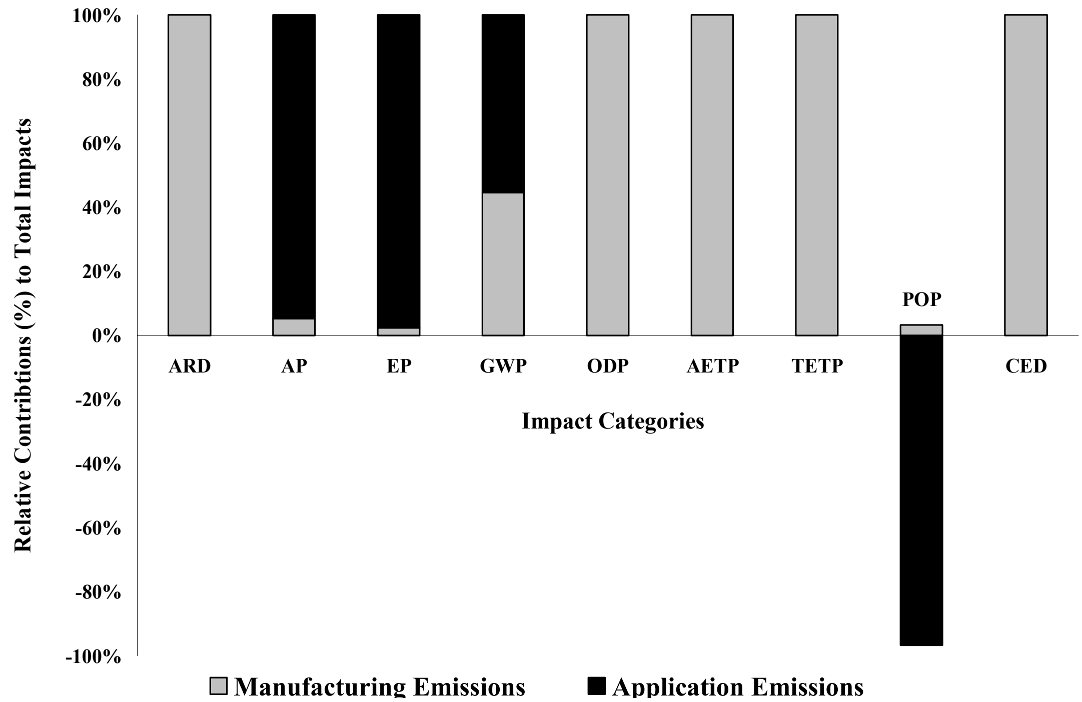

Figure 2.6 Detailed contributions (% of total) of nitrogen fertilizer manufacture and field-level emissions to environmental impact categories.

2.9.1 Scenario Modeling Results

2.9.1.1 Organic Viticulture Life Cycle Inventory Results

Differences in the life cycle inventories for conventional and modeled organic grape production (per tonne of grapes grown) appear in Table 2.5.

Table 2.5 Inputs, per tonne of grapes produced, to conventional (base case) and two potential organic grape growing scenarios in Nova Scotia.

	Unit	**Conventional Viticulture [a]**	**Organic Viticulture: Low Yield [b]**	**Organic Viticulture: Same Yield [c]**
Fertilizers				
N-fertilizer	kg	14.58	18.21	14.58
P-fertilizer	kg	11.11	13.88	11.11
K-fertilizer	kg	25.41	31.74	25.41
Fungicides				
Glyphosate	kg	0.48	0.00	0.00
Gluphosinate	kg	0.45	0.00	0.00
Paraquat	kg	5.40E-03	0.00	0.00
Sulphur	kg	4.27	5.33	4.27
Copper sulphate	kg	0.00	0.06	0.05
Herbicides				
Maestro	kg	1.44	0.00	0.00
Folpet	kg	0.69	0.00	0.00
Wood Preservative				
CCA (kg)	kg	1.09	0.00	0.00
Fertilizer Emissions				
N_2O (to air)	kg	0.54	0.59	0.58
NH_3 (to air)	kg	3.84	4.36	4.12
NO (to air)	kg	0.57	0.62	0.62
NO_3 (to water)	kg	14.35	14.48	13.96
P_2O_5 (to water)	kg	0.32	0.33	0.33
Yield	tonnes/ha	6.37	5.10	6.37

Notes: [a] Conventional viticultural data obtained from Nova Scotia grape growers survey.
[b] Assumes organic yields in Nova Scotia are 20% lower than conventional grape yields in vineyards in Nova Scotia in 2006.
[c] Assumes organic yields in Nova Scotia are equivalent to conventional grape yields in Nova Scotia in 2006.

2.9.1.2 Organic Viticulture Life Cycle Impact Assessment Results

Substituting hypothetical organic grape production inventories into the model yielded varying results (Figure 2.7, Table 2.6). In the first organic scenario, where yields were modeled to be 20% lower than conventional yields, impacts resulting from organic grape production were highest in the impact categories of acidification and eutrophication (Figure 2.7, Table 2.6). In all other impact categories, organic grape growing resulted in improvements, albeit marginal in most. The exception is contributions to terrestrial eco-toxicity potential, in which organic grape production results in a reduction of 29%, due to the exclusion of wood preservatives on organic farms. To a large extent, the higher impacts associated with organic viticulture in this scenario are a result of reduced grape yields. Furthermore, nitrogen in manure is associated with higher farm-level emissions of N_2O, NH_3 and NO than an equivalent amount of nitrogen in synthetic fertilizer, due to higher rates of volatilization and leaching (Brentrup *et al*., 2000; Intergovernmental Panel on Climate Change, 2006) and since nitrogen in manure is absorbed less readily by crops (Bussink & Oenema, 1998). Despite reductions in the use of certain fungicides, permitted substances in the organic scenario (Table 2.5), including manure, are still associated with manufacturing emissions.

The second organic scenario, which assumed equivalent yields to conventional vineyards in Nova Scotia in 2006, results in greater reductions in contributions to all measured impacts, again with the exception of the acidification and eutrophication impact categories (Figure 2.7, Table 2.6). Most striking are the reduced contributions to the impact category of terrestrial eco-toxicity (Figure 2.7, Table 2.6). Recall however that herbicide and fungicide field-level emissions were not modeled, and thus reductions in eco-toxic emissions in both organic scenarios are likely to be conservative. The differences in the two organic scenarios (Figure 2.7, Table 2.6) are illustrative of the fact that life cycle environmental impacts are heavily influenced by crop yields.

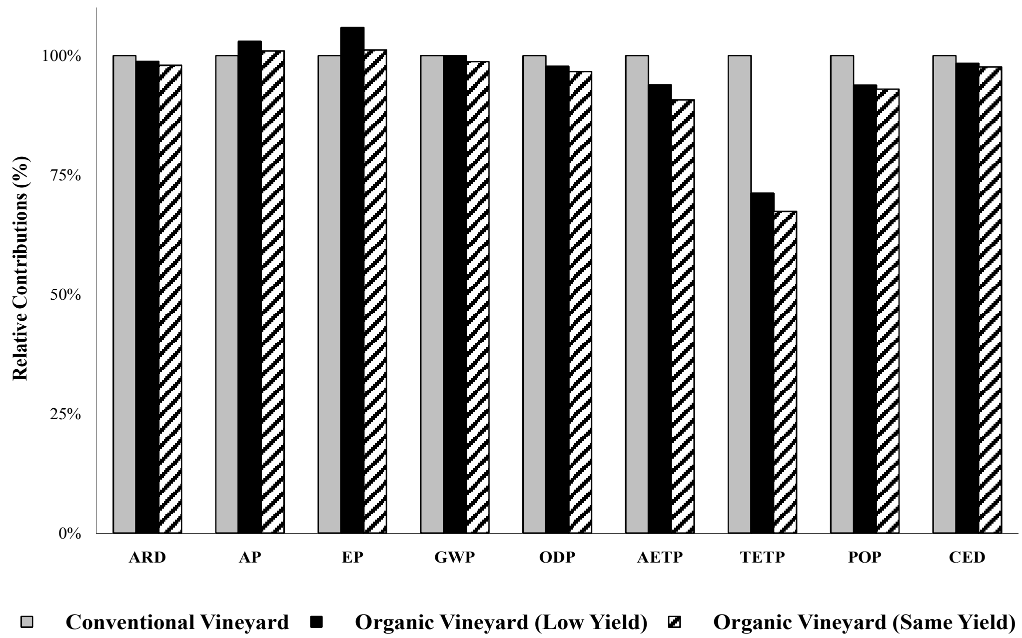

Figure 2.7 Life cycle impact assessment results for conventional (base case) and two potential organic grape growing scenarios in Nova Scotia. For each impact category, conventional grape growing impacts are set at 100% and contributions of the two organic scenarios are shown relative to 100%.

Table 2.6 Results of the organic scenario models. Functional unit = 1 (750ml) bottle of wine produced and consumed in Nova Scotia in 2006. A percent change that is positive reflects a potential increase in contributions to an impact category. A negative percent change indicates reduced contributions to an impact category, and thus reflects the potential for an improved environmental profile for wine.

	ARD (kg Sb eq)	**AP** (kg SO_2 eq)	**EP** (kg PO_4 eq)	**GWP** (kg CO_2 eq)	**ODP** (kg CFC-11 eq)	**AETP** (kg 1,4-DCB eq)	**TETP** (kg 1,4-DCB eq)	**POP** (kg C_2H_4 eq)	**CED** (MJ)
Total life cycle emissions (base case)	2.46E-02	4.05E-02	7.82E-03	3.95	2.66E-07	9.51E-02	5.76E-03	1.14E-03	57.78
Organic scenario (low yield)	2.43E-02	4.17E-02	8.28E-03	3.95	2.60E-07	8.93E-02	4.10E-03	1.07E-03	56.84
Percent change to life cycle emissions	**-1.22%**	**+2.96%**	**+5.88%**	**0.00%**	**-2.26%**	**-6.10%**	**-28.82%**	**-6.14%**	**-1.63%**
Organic scenario (same yield)	2.41E-02	4.09E-02	7.91E-03	3.90	2.57E-07	8.63E-02	3.88E-03	1.06E-03	56.40
Percent change to life cycle emissions	**-2.03%**	**+0.99%**	**+1.15%**	**-1.27%**	**-3.38%**	**-9.25%**	**-32.64%**	**-7.02%**	**-2.39%**

Since field-level emissions for fungicides and herbicides were not modeled in the base case, or either organic scenario, I have followed the practice of Milà i Canals & Polo (2003) and have qualitatively described the relative toxicities of these chemicals used in each system (Table 2.7).

Table 2.7 Inputs, per tonne of grapes produced, and toxicities associated with fungicides and herbicides used in (actual) conventional and (hypothetical) organic grape growing.

Active Ingredient (AI)	Grams of AI/ tonne of grapes	US EPA Toxicity Class	Description
Conventional Viticulture			
Paraquat	5.40[1]	I	Highly toxic [2]
Glyphosate	477.00 [1]	II	Moderately toxic [2]
Folpet	685.50 [1]	II	Moderately toxic [2]
Gluohosinate	46.60 [1]	III	Moderately toxic [2]
Captan	1444.90 [1]	IV	Practically non-toxic [2]
Sulphur	4272.50 [1]	IV	Practically non-toxic [2]
Organic Viticulture			
Copper sulphate	471.00 [3]	I	Highly toxic [2]
Sulphur	5300.00 [4]	IV	Practically non-toxic [2]

Notes: [1] Nova Scotia vineyard survey data
[2] *pers comm*., National Pesticide Information Centre, June 15, 2008
[3] Grape Disease Management Schedule for Nova Scotia (AgraPoint International Ltd., 2007)
[4] Based on practices of Nova Scotia growers in 2006 and assuming organic yield is 20% lower for organic grapes

2.9.1.3 Lighter Bottle Life Cycle Impact Assessment Results

The adoption of glass bottles 30% lighter than bottles currently used by Nova Scotia wineries could result in important reductions to overall impacts associated with the provision and consumption of a bottle of Nova Scotian wine (Table 2.8). In all impact categories, the use of a lighter glass bottle could reduce wine's total contributions between 4% and 23%. The most substantial reductions occur in the impact categories of global warming (12%), abiotic resource depletion (13%), cumulative energy demand (13%), acidification (16%) and photo-oxidant formation (23%) Most of these improvements result from lower impacts associated with bottle manufacture, and to a much lesser extent, bottle transport to the winery and transport of wine to retail.

2.9.1.4 Increased Consumer Transport Distance Life Cycle Impact Assessment Results

Increasing consumer transport distance from 5 to 25km, results in substantial increases – ranging from 28% to 250% – in the total life cycle impacts of a bottle of wine (Table 2.8).

2.9.1.5 Increased Transport Distance To Market Life Cycle Impact Assessment Results

Increasing wine's distance to market could have varying influences on wine's life cycle environmental costs (Table 2.8). When wine is transported to Toronto in a transport truck, contributions to impact categories show very small changes, both positive and negative, from the base case scenario. When wine is transported to Vancouver, contributions to all impact categories increase from the base case model (between 2% and 20%) (Table 2.8). Interestingly, when Nova Scotia wine is modeled to travel 18,000 km by container ship across the ocean to Perth, Australia, only small changes occur in impact categories (between -3% and 4%) (Table 2.8). It seems that ocean travel is a far more efficient mode of transporting wine, and this efficiency thus negates the substantially longer transport distance of wine in this scenario with regard to most environmental impacts measured here.

Table 2.8 LCIA results for three scenarios: lighter glass bottles, increased consumer transport distance, and increased distance to retail. Functional unit = 1 (750ml) bottle of wine produced and consumed in Nova Scotia in 2006. A percent change that is positive reflects a potential increase in contributions to an impact category. A negative percent change indicates reduced contributions to an impact category, and thus reflects the potential for an improved environmental profile of wine.

	ARD (kg Sb eq)	**AP** (kg SO_2 eq)	**EP** (kg PO_4 eq)	**GWP** (kg CO_2 eq)	**ODP** (kg CFC-11 eq)	**AETP** (1,4-DB eq)	**TETP** (1,4-DB eq)	**POP** (C_2H_4 eq)	**CED** (MJ)
Total life cycle emissions [a] (base case)	2.46E-02	4.05E-02	7.82E-03	3.95	2.66E-07	9.51E-02	5.76E-03	1.14E-03	57.78
Lighter bottle (380 g)	2.14E-02	3.41E-02	7.38E-03	3.47	2.55E-07	8.87E-02	5.39E-03	8.81E-04	50.20
Change to life cycle emissions (%)	**-13.01%**	**-15.81%**	**-5.64%**	**-12.05%**	**-4.13%**	**-6.72%**	**-6.38%**	**-22.54%**	**-13.12%**
Increased consumer transport (25 km)	5.45E-02	5.39E-02	1.00E-02	8.70	9.32E-07	1.44E-01	9.12E-03	2.59E-03	126.22
Change to life cycle emissions (%)	**121.54%**	**33.08%**	**27.86%**	**120.51%**	**250.40%**	**51.43%**	**58.40%**	**127.72%**	**118.45%**
Increased transport to retail (1800 km to Toronto, ON) [b]	2.46E-02	4.05E-02	7.83E-03	3.93	2.66E-07	9.62E-02	5.78E-03	1.11E-03	57.74
Change to life cycle emissions (%)	**0.00%**	**-0.01%**	**0.11%**	**-0.39%**	**0.01%**	**1.17%**	**0.39%**	**-2.41%**	**-0.07%**
Increased transport to retail (6000 km to Vancouver, BC) [c]	2.69E-02	4.22E-02	8.18E-03	4.24	3.18E-07	1.10E-01	6.47E-03	1.16E-03	63.07
Change to life cycle emissions (%)	**9.35%**	**4.19%**	**4.59%**	**7.47%**	**19.56%**	**15.68%**	**12.38%**	**1.99%**	**9.16%**
Increased transport to retail (18000 km to Perth, Australia) [d]	2.43E-02	4.21E-02	7.89E-03	3.90	2.58E-07	9.21E-02	5.67E-03	1.15E-03	57.03
Change to life cycle emissions (%)	**-1.22%**	**3.94%**	**0.88%**	**-1.15%**	**-3.00%**	**-3.15%**	**-1.52%**	**1.11%**	**1.30%**

Notes: [a] Mode of transport (to retail) is a small delivery truck (Nova Scotia winery survey, 2006)
[b] Mode of transport (to retail) is a transport truck
[c] Mode of transport (to retail) is a transport truck
[d] Modes of transport (to retail) are a transport truck, and a trans-oceanic freight ship

2.9.2 Sensitivity Analysis Results

Results of the sensitivity analysis for truck size used to transport Nova Scotia wine to market are presented in Table 2.9. The substitution of a transport truck for a small delivery truck results in modestly decreased contributions to nearly all impact categories (between 1% and 6%) as a result of increased transport-related efficiency per bottle of wine.

Table 2.9 Sensitivity analysis results testing the relative importance of transport mode for transport of wine to retail in Halifax. A percent change that is positive reflects a potential increase in contributions to an impact category. A negative percent change indicates reduced contributions to an impact category, and thus reflects the potential for an improved environmental profile of wine.

	ARD (kg Sb eq)	**AP** (kg SO_2 eq)	**EP** (kg PO_4 eq)	**GWP** (kg CO_2 eq)	**ODP** (kg CFC-11 eq)	**AETP** (1,4-DCB eq)	**TETP** (1,4-DCB eq)	**POP** (C_2H_4 eq)	**CED** (MJ)
Total life cycle emissions (base case) **(Small delivery truck)**	2.46E-02	4.05E-02	7.82E-03	3.95	2.66E-07	9.51E-02	5.76E-03	1.14E-03	57.78
Total life cycle emissions (sensitivity analysis) **(Transport truck)**	2.39E-02	4.00E-02	7.72E-03	3.83	2.49E-07	9.16E-02	5.55E-03	1.12E-03	55.90
Change to life cycle emissions (%)	**-2.85%**	**-1.24%**	**-1.29%**	**-3.04%**	**-6.38%**	**-3.67%**	**-3.65%**	**-1.75%**	**-3.25%**

2.10 Discussion

2.10.1 Environmental Impacts Of Nova Scotia Wine

Climate change, energy crises, and general environmental degradation are issues becoming increasingly embedded in political, social and economic agendas. Food production systems, including wine, will face increasing pressure to respond appropriately. Though it is a small and regionally based industry, Nova Scotia wine contributes to a variety of environmental impacts throughout its life cycle and thus will not be exempt from this reality. As Nova Scotia strives to meet emission reduction targets set forth in the Sustainable Prosperity Act (Environmental Goals and Sustainable Prosperity Act, 2007), minimizing the environmental impacts associated with wine's life cycle may become an imperative for the industry and for those who enjoy Nova Scotia wine.

The life cycle assessment of Nova Scotia wine indicated that vineyard activities, particularly the provision and application of nitrogen fertilizers, cause the greatest proportion of Nova Scotia wine's eutrophying and toxifying emissions. Electricity used for the manufacture of glass bottles is the biggest contributor to wine's abiotic resource depletion, acidification potential, global warming potential, photo-oxidant creation potential and cumulative energy demand. Finally, emissions arising from the combustion of gasoline from car-based consumer transport is the largest contributor to wine's ozone depleting emissions.

LCAs completed for other wine production systems offer contextualization of these results and also aid in an assessment of how best to improve the environmental profile of wine made in Nova Scotia and in other wine producing regions.

2.10.2 Nova Scotia Wine In The Context Of Other Wine LCAs

Life cycle assessments, and analyses that employed life cycle perspectives, have been applied to wine in other jurisdictions, most commonly in Italy (Nicoletti *et al*., 2001; Notarnicola *et al*., 2003; Ardente *et al*., 2006; Pizzigallo *et al*., 2006) and Spain (Aranda *et al*., 2005). Due to differences in reporting, only qualitative comparisons with Nova Scotia wine are possible, though results of these studies generally support our identification of viticulture and bottle production as pre-consumer environmental hot spots (Notarnicola *et al*., 2003; Pizzigallo *et al*., 2006; Ardente *et al*., 2006). In these studies, provision of, and field-level emissions from pesticides and fertilizers are cited as the driving activities behind viticulture's environmental relevance, whereas energy consumption is responsible for most impacts associated with glass bottle provision. Interestingly however, energy inputs to grape growing, wine making and bottle manufacture for a 750 ml bottle of Italian wine was reported as 28.1 MJ (Ardente *et al*., 2006). Similar activities associated with the production of a bottle of Nova Scotia wine results in a slightly higher cumulative energy demand of 37.21 MJ (Table 2.4).

The same Italian study found that export of wine, to other EU countries (via truck) and to North and Central American countries (via freighter ship), was a life cycle hotspot (Aranda *et al*., 2005). Transport of wine to retail was also cited as the life cycle stage causing the most greenhouse gas emissions in a study that modeled the transport of wine over varying distances by road, and by sea (Coleman & Päster, 2007). In both of these analyses, distances to markets modeled were far greater than that which Nova Scotia wine undergoes at present. However when Nova Scotia wine was modeled as being exported to Vancouver, BC (6000km), contributions to impact categories increased between 2% and 20% (Table 2.8). Collectively, these findings provide strong evidence to suggest that wine is a commodity for which post-production transport can contribute non-trivial impacts. Thus, if we assume for a moment that all other factors are equal (vineyard practices, crop yields, winery practices, bottle weights, etc), wine imported to Nova Scotia from British Columbia or Ontario (or other distant production centres in North America) using truck transport, will be associated with higher environmental emissions than wine that was produced in the province. Drinking locally produced wine may offer important environmental benefits over wine produced far from its place of consumption.

Coleman & Päster (2007) also offer interesting commentary on the "food miles" debate and the relative importance of wine's transport mode, citing that it is less carbon intensive to transport a bottle of wine 5500km in a container ship, than it is to transport a bottle of wine 4000 km in a truck. Similarly, when we modeled Nova Scotia wine with a transport distance of 18,000 km to Perth, Australia (nearly all of which was ocean transport), the relative efficiency of transport by container ship outweighed the lengthy transport distance and contributions to nearly all impact categories were substantially less than when wine was transported by truck, 6000 km to Vancouver (Table 2.8). Sensitivity analysis revealed that even over a short distance, mode of transport for wine matters with respect to its total impact (Table 2.9). Clearly, while "food miles" may offer important information about wine's environmental impact, it is best reported alongside information about wine's mode of transport (Smith *et al*., 2005; Schlich & Fleissner, 2005).

2.10.3 Improvement Opportunities For Nova Scotia Wine

Wine, and food production in general, will always result in some level of environmental impact. However, numerous opportunities exist for environmental improvements to materialize throughout Nova Scotia wine's life cycle. As life cycle "hotspots", vineyard activities, bottle provision and consumer transport offer the greatest potential improvements to Nova Scotia wine's life cycle. In the vineyard, the provision and subsequent emissions of nitrogen fertilizers were shown to be of great import with respect to vineyard level environmental impacts of wine. Vineyard managers have influence over the type and quantity of fertilizers used, as well as the nature and timing of fertilizer applications. Grapes have a relatively low nutrient uptake efficiency (*pers comm*., John Lewis, April 15, 2008), and thus there will always be some level of nutrient loss from vineyards. However, in addition to selecting grape varieties with high nutrient uptake efficiencies (Northwest Berry & Grape Information Network, 1997), effective management of fertilizer inputs can substantially decrease emissions of nitrogenous and phosphatic compounds to air and water. Management techniques may include: a reduction in the total volume of fertilizer used; application of fertilizer in smaller volumes (Canadian General Standards Board, 2006); using composted manure (Pattey, *et al*., 2005; Monteny *et al*., 2006); incorporating manure-based fertilizer into the soil soon after it is applied (Bussink & Oenema, 1998); and sourcing manure with a low nitrogen content (Bussink & Oenema, 1998; Monteny *et al*., 2006). A vineyard manager wishing to improve a vineyard's environmental performance should also be aware that manure, while an important source of nutrients, is not benign with respect to field-level emissions, and is actually associated with higher rates of greenhouse gas and eutrophying emissions, per tonne, than synthetic fertilizers (Intergovernmental Panel on Climate Change, 2006, Brentrup *et al*., 2000).

Organic viticultural techniques, as they were modeled here, also offered potential improvements to certain impact categories, particularly when organic yields are modeled as equivalent to conventional yields (Table 2.6). Notably, organic agriculture offers substantial reductions to the impact category of terrestrial eco-toxicity, as a result of an exclusion of wood preservative chemicals. This relatively simple option provides one of the greatest potential improvements to wine's toxicity-related life cycle impacts.

Although the winery stage of wine's life cycle makes relatively small contributions to total impacts, a winery manager does have influence with respect to the provision of glass bottles. While it was beyond the scope of this research to determine the availability of lighter glass bottles to Nova Scotia wineries, results indicated that such a decision would result in important reductions to wine's overall impacts (Table 2.8), even greater than those offered by the adoption of organic viticultural techniques in many of the measured impact categories. That lighter glass bottles can offer substantial environmental benefits is a finding consistent with the work of Aranda *et al* (2006) and the Waste Resource Action Program (2008a) in the UK.

Looking to the future, should the Nova Scotia wine industry begin to export its product out of the province in substantial volumes, this analysis demonstrates that this decision will increase wine's environmental impacts, although the nature and extent of this increase is highly dependant on distance and mode of transport used (Table 2.8). As results have illustrated, a small delivery truck is a less fuel-efficient mode of transport, per bottle of wine, than a large transport truck (Table 2.9). Wine transported 1800 km to Toronto in a transport truck contributed equally, or less, to nearly all impact categories than wine transported 400 km in a small delivery truck to Halifax (Table 2.8). The inefficiency of regional operations relying on small-sized vehicles was a conclusion also made by Schlich & Fleissner (2005). On the other hand, transporting wine by containerized shipping was illustrated as a very efficient mode of transport, compared to trucking, per bottle (Table 2.8). This conclusion is supported Hansen (2007, as cited in Brodt *et al*., 2007) who cites that sea transport is the most fuel efficient mode, followed by rail transport, truck transport, and finally, air freight. Because of the Nova Scotia wine industry's close proximity to an international shipping yard in Halifax, a decision to export wine by boat to Europe would likely be associated with far fewer impacts than if Nova Scotia wine was transported by truck within North America.

In addition to choosing locally made wine, consumers who wish to make improvements to the overall life cycle impacts of their food and beverage purchases can rest assured that they have substantial influence over wine's environmental profile. Driving a mere round-trip distance of 5 km contributed between 7% and 65% to wine's life cycle environmental impacts, depending on the impact category. For the impact categories of abiotic resource depletion, global warming potential, and cumulative energy demand, the result of driving 5 km to purchase a bottle of wine is larger than all the impacts arising from grape growing and wine making combined. With respect to ozone depletion potential, a 5 kilometer trip is more harmful than all impacts arising from grape growing, wine making, bottle production and wine's transport to retail. A scenario modeling a 25 km drive to purchase wine indicated increases from the base case between 28% and 250% to impact categories. The relative importance of consumer transport is supported by work undertaken in the UK which suggests that the environmental impacts of car-based shopping and other consumer activities are of greater import than transport in the entire distribution system (Foster *et al*., 2006). Clearly, consumers wishing to minimize wine's environmental impact should walk to the store next time they wish to purchase a bottle. Consumer education programs that provide information on the relative importance of consumer transport may influence consumer behaviour (Owen *et al*., 2007).

2.10.4 Limitations Of The Organic Scenario Model

In reality, organic grape production is far more nuanced than the simplified scenario modeled here. The animal which produces the manure, its diet, and management of manure before and after application will greatly influence the associated environmental emissions to soil, water and air (Nova Scotia Department of Agriculture and Marketing, 2000; Bussink & Oenema, 1998; Monteny *et al*., 2006). Furthermore, Canadian national organic standards mandate the use of organic manure (preferably composted), regulate the timing of application, and require buffer zones between application sites and surface water bodies (Canadian General Standards Board, 2006), none of which was reflected in this coarse scenario. Inclusion of these specifications would likely provide a more conservative estimate with respect to field-level emissions, but may be negated if manure was sourced from a more distant location and transported with a tractor, or a similarly inefficient transport mode. Increased energy use from heat and chemical processing of manure during composting would also influence overall results.

Additionally, the lack of site-specific fate-pathway and emission models for herbicides and fungicides in this analysis means that toxicological emissions from these inputs were not encompassed in the comparison of organic and conventional grape growing. I acknowledge this as a limitation in my analysis, and to LCA methodology at this time, but note that the analysis did encompass impacts arising from manufacture of herbicides and fungicides, which is often a significant source of energy consumption in crop production systems (Milà i Canals *et al*., 2003; Milà i Canals *et al*., 2006).

Despite these limitations, I think that this scenario illustrates the importance of quantifying a range of environmental impacts and taking a product-oriented approach with respect to food systems. In agreement with previous food LCAs, this scenario has demonstrated that per unit of production, organic practices do not offer an automatic solution with respect to certain environmental impacts, due to smaller yields in certain organic systems (Nicoletti *et al*., 2001; Mattsson 1999b), and the associated emissions of permitted substances, such as manure. Arguably, there is an even bigger picture which my analysis has left out entirely, including organic agriculture's proven health benefits to farm workers (Pimentel *et al*., 2005b) and to local biodiversity (Mäder *et al*., 2002; Bengtsson *et al*., 2005), as well as potential access to a rapidly growing market, enjoyed only by those growing grapes, or other crops, organically.

2.11 Conclusion

As producers and consumers become increasingly aware of impacts associated with their food and beverage choices, analyses to quantify environmental emissions from these product chains will help to inform decisions to reduce burdens. Here, I have employed life cycle assessment methodology to quantify the material and energy inputs, and environmental impacts associated with one bottle of wine, produced and consumed in

Nova Scotia, Canada in 2006. The Nova Scotia wine industry is, at present, a relatively small player on the national scale, but is an important contributor to the Nova Scotia tourism, food, and beverage economy, and seeks to triple its production by the year 2020 (Josza Management & Economics, 2006).

Results indicate that grape growing, bottle manufacture and consumer transport, as they were modeled in this analysis, were the largest contributing phases to the impact categories measure here. Additionally, four scenarios were modeled to determine the nature and extent of changes to environmental impacts from the adoption of organic viticultural practices, the provision of lighter glass bottles, increased consumer transport distance, and increased transport distance of wine to its retail location. Improvements resulted in several impact categories when grapes were modeled to have been grown organically, but these improvements were strongly dependent on organic yields being equivalent to current conventional yields in Nova Scotia vineyards (Table 2.6). In some impact categories, organic grape growing actually resulted in increased impacts when compared to conventional viticulture. Reduced contributions to impact categories were also illustrated through the provision of lighter bottles. A 30% reduction in bottle weight resulted in overall reductions between 4% and 23% to total life cycle emissions. In contrast, increasing consumer transport, from 5 to 25 km round-trip driving distance, resulted in increases to impact categories between 28% and 250%. Finally, when Nova Scotia wine was modeled to be transported to Toronto, the relative fuel efficiency of the modeled transport mode offset increased emissions due to transport. Transported further to Vancouver, efficiency gained as a result of transport mode was not sufficient to offset the impacts of food miles. When wine was modeled with a transport distance of 18,000 km to Perth, Australia, the efficiency of containerized ocean transport far outweighed the long transport distance, resulting in reduced contributions to several of the analyzed impact categories from the base case analysis.

Given these results, grape growers, wine makers and wine consumers who wish to reduce environmental impacts associated with Nova Scotia wine should focus on making improvements to the phases of wine's life cycle that are currently associated with the greatest burdens. Rising energy costs and increasingly savvy consumers are likely to soon necessitate the adoption of food production practices that reduce material and energy requirements and resulting environmental implications. Since wine is by no means a physiological requirement for anyone, this industry, perhaps more than others must not disproportionately contribute to environmental decline. This research, I believe, has offered a rigorous assessment of the Nova Scotia wine industry's current life cycle environmental profile, as well as its potential to both increase and decrease its contributions to a variety of global-scale environmental impacts.

3.0 CHAPTER THREE: DISCUSSION

3.1 Life Cycle Impact Assessment Of Nova Scotia Wine

Earnest Hemingway once referred to wine as "the most civilized thing in the world" (1932, p.10). As one of the oldest beverages known to modern man, wine has remained an important thread in the cultural fabric of society since Paleolithic humans accidentally discovered that grapes could naturally ferment into wine (McGovern, 2003). Today, global demand for wine is increasing, with more than 240 million hectolitres having been consumed globally in 2007 (International Organization of Vine and Wine, 2007). Despite its devoted following, humans have no physiological requirement to drink wine and thus this industry, perhaps even more than other food and beverages, may need to defend its existence in the face of food, energy, and land scarcities to which we have already befallen (Pimentel, *et al*., 1999; Heinberg, 2004; Food and Agricultural Organization of the United Nations, 2008). For the global wine industry to align itself with the goals of sustainability and sustainable development (United Nations General Assembly, 1987) the production and consumption of wine must use material and energy resources efficiently, and avoid unnecessary environmental emissions that may contribute to irreparable ecological damage.

In Nova Scotia, demand for wine is also increasing (Nova Scotia Liquor Commission, 2007), and in particular, wine made from Nova Scotia grapes is gaining market share (Josza Management & Economics, 2006). In 2007, provincial legislation committed Nova Scotia to a quality of economic growth that will achieve it "international recognition for having one of the cleanest and most sustainable environments in the world by the year 2020" (Environmental Goals and Sustainable Prosperity Act, S.N.S. 2007 s. 4(1)(a)). In this regulatory context, the rising cost of energy, and the growing share of environmentally-conscious consumers may stimulate the Nova Scotia wine industry to pursue production practices and industry standards that are aligned with the province's goals for sustainable growth and prosperity.

Chapter 2 of this thesis presented the methods and results of a life cycle assessment for a bottle of wine produced and consumed in Nova Scotia. The objectives of the study were to quantify the material and energy inputs, associated environmental emissions, and resulting potential contributions to a variety of globally-relevant environmental impact categories for the life cycle stages of a 750 ml bottle of wine made from Nova Scotia grapes. The analysis encompassed grape growing, wine making, bottle production, home refrigeration and recycling of the glass bottle, as well as any existing transport links necessary for the product chain to function. In addition, scenarios were modeled to determine the nature and extent of changes to environmental impact categories that might result from the adoption of organic grape growing practices, the use of lighter glass bottles, an increased distance driven by the consumer to purchase wine, and finally, an increased transport distance to bring wine to its place of retail. Results appear in Table 2.4, 2.6 and 2.8 in Chapter 2.

3.2 An Elaboration On The Merits Of Organic Viticulture

Results have indicated that organic grape growing techniques can offer improvements to certain life cycle impacts of Nova Scotia wine (Table 2.6, Figure 2.7). These improvements however, are dependent on organic vineyards yielding an equivalent amount of grapes per hectare as conventional vineyards in Nova Scotia. With respect to the impact categories of acidification and eutrophication potential, our organic model actually resulted in increased impacts, due to higher volatilization and leaching rates associated with organic fertilizers. Similar conclusions were made by Nicoletti *et al* (2001), though Pizzigallo *et al* (2006) found that organic grape growing could offer substantial benefits if fuel and steel consumption were substantially reduced in the organic system. Importantly, as has been previously mentioned, the LCA framework as it was applied to Nova Scotia wine, did not quantify toxicological impacts associated with field-level fungicide and herbicide emissions and inclusion of this would certainly have influenced the results of the organic vineyard scenario.

Consumers typically cite personal health and taste, not environmental benefits, as their motivation for purchasing organic foods (Wandel & Bugge, 1997; Miles & Frewer, 2001; Zanoli & Naspetti, 2002; Shepherd *et al*., 2005; Owen *et al*., 2007). There is a paucity of data however, with respect to health benefits of organic wine, and virtually no relationship between wine quality and organic certification (Delmas & Grant, 2008). Consumers surveyed in 2008 reported an unwillingness to pay a price premium for ecolabeled wine but a willingness to pay higher prices for a certified organic, yet unlabeled wine (Delmas & Grant, 2008). The market for organic wine in Nova Scotia is yet untested (Naugler & Wright, 2006), but these studies provide insight into market forces that may exist with respect to organic wine. Producers of organic grapes, and those considering a conversion of their operations to meet organic standards, thus find themselves facing a difficult decision. With no guarantee for environmental improvements with respect to certain impacts measured by LCA, and no assurance that their product will fetch an appropriate price at retail, the host of potential gains from growing grapes organically may remain an elusive prize at this time.

By no means does this preclude, nor do I wish to suggest, that the development of organic vineyards is a senseless endeavor. On the contrary, and as has been previously noted, there are many important potential benefits of organic agriculture (Mäder *et al*., 2002; Milà i Canals & Polo, 2003; Bengtsson *et al*., 2005; Pimentel *et al*., 2005a) that were not captured by the LCA framework applied here (e.g. increased species richness and local biodiversity, soil conservation and carbon storage capacity, landscape aesthetics, farm worker health, etc). Furthermore, an organic vineyard which effectively manages its fertilizer applications and produces a relatively high yield may well produce a product with reduced emissions in many life cycle impact categories.

3.3 Importance Of Wine's Post-production Transport

A great deal of attention has been paid as of late, to the concept of food miles – the distance a food travels from it place of production to its place of consumption (Smith *et al*., 2005). For certain products, food miles have been illustrated to contribute a great deal to total environmental impacts (Andersson & Ohlsson 1999; Blanke & Burdick, 2005). For others, the post-production transport phase is relatively less important (Schlich & Fleissner, 2005). The extent to which transport matters is a function of distance, transport mode, and the relative contributions from other life cycle stages. The commercial transport phase of Nova Scotia wine consumed in the province contributed relatively little to each impact category (Table 2.4 in Chapter 2). However, when Nova Scotia wine was modeled to be transported 6000 km to Vancouver in a truck, contributions to wine's life cycle impacts increased between 2% and 23% depending on the impact category (Table 2.8 in Chapter 2). Similarly, transport of wine was cited as the most important life cycle phase for wine produced in Spain (Aranda *et al*., 2005) and in a study that modeled wine traveling from Europe and the southwestern US, to a northeastern US state (Coleman & Päster, 2007). The results of the scenario model, along with this previous research, provide evidence to suggest that post-production transport is an environmentally-relevant stage for wine. Drinking locally produced wine thus offers an effective way to minimize the associated environmental impacts.

3.4 Limitations Of This Research

Data for this analysis were obtained for the 2006 production and harvest of Nova Scotia grapes. Similarly, modeling assumptions with respect to transport distances were based on the industry as it existed in that year. As the Nova Scotia wine industry grows, the relative contributions to total grape and wine production represented by the vineyards and wineries who participated in this research will decrease and thus this analysis may not adequately reflect future vineyard, winery and consumer-related practices in the province if substantial changes to the life cycle of wine occur.

As previously mentioned, an important limitation of this analysis was the lack of inclusion of field-level herbicide and fungicide emissions from vineyards. The absence of site-specific models to quantify the release of these chemicals to air, water and soil and the associated toxicological effects was not only an unfortunate omission from the Nova Scotia wine LCA, but also from the analysis of the potential benefits of organic grape growing in the province.

3.5 Methodological And Conceptual Challenges Of This Research

The life cycle inventory phase of this research was not only the most time-consuming, but also the most challenging. Grape growers and wine makers in the province who participated in this research were not only data providers, but are the very individuals to whom this research is most relevant. This potential conflict of interest, combined with the fact that LCA is a methodology completely unknown to the majority of the population, warranted that communication of the project's methods, objectives and data requirements were as transparent as possible. Furthermore, as a fledgling LCA practitioner, finding the correct level of detail with respect to inventory survey questions was also a challenge. Many, if not all of the research participants in this study are busy people and can thus devote only a reasonable amount of time to answer questions. Their required time commitment should be kept to a minimum, as much as possible. In hindsight, the questions asked with respect to grape growing, and to some extent wine making for this research (Appendices A and B) were more detailed than necessary and may well have been an understandable source of irritation to data providers. However, this is a lesson that is likely learned more frequently in hindsight, after one has completed their first LCA and has a better sense of the most important material and energy inputs with respect to environmental impact categories measured by LCA.

The application of LCA to a product system involves creating a representative model of that particular system. At times this posed a conceptual challenge as the very concept of modeling requires making simplifying assumptions about the system under study. Creating a representative model of Nova Scotia wine's life cycle required an abstract visualization of wine's life cycle stages and often an acceptance that there is no "right answer". There are a seeming infinite number of permutations to each and every stage of wine's life cycle and the act of learning to incorporate survey data, while providing adequate justification for any necessary assumptions was a new, yet interesting challenge.

3.6 Recommendations For Future Research

The LCA of Nova Scotia wine has provided the baseline data necessary for the industry to understand their most environmentally-relevant life cycle stages, and also to compare the results of future research, should any come to fruition. If and when the Nova Scotia wine industry is able to implement an official environmental management program, a re-analysis of the resulting life cycle impacts of Nova Scotia wine would be of great utility. Such an analysis would not only offer the industry quantified and conclusive data pertaining to the associated environmental effects (positive or negative) of these management decisions, but would provide the data necessary to communicate the benefits of these management decisions to wine consumers via the development of an eco-label, or similar consumer engagement strategy.

Existing vineyard sites in Nova Scotia range in size from less than 1 to approximately 20 hectares. Certainly, an enormous range of vineyard sizes exist in wine producing regions in Canada, and abroad. A comparative analysis of the life cycle impacts of small and large vineyards in the province (and beyond) might also be of utility. Comparison of the material and energy efficiency (and resulting environmental impacts), per unit of production, for vineyards of different sizes (and with varying levels of mechanization) might offer insight into whether there are any benefits associated with scale.

As we have learned from existing research comparing conventional and organic products, and from the Nova Scotia organic viticulture scenario model, crop yields are of tremendous relevance with respect to a product's environmental performance (Figure 2.7, Table 2.6; Mattsson, 1999b; Nicoletti *et al*., 2001; Pelletier *et al*., 2008). Once actual yield data are available from Nova Scotia organic vineyards in a fully-productive year, a re-analysis of the organic grape growing scenario would be of great utility. Furthermore, the simplified organic scenario currently modeled in this analysis would be well complemented with further analyses that encompass a wider range of potential and existing organic grape growing techniques. The modeling of vineyards that cultivate green manure, use various, and potentially composted animal manures, and rely on different permitted substances than were modeled in the Nova Scotia organic scenario, would offer far greater insight into the potential changes associated with organic grape production.

Various endeavors to reduce wine's environmental impact have begun to take form in wine regions across the world. These include organic vineyards (Winery Association of Nova Scotia, 2008; California Sustainable Winegrowers Alliance, 2008; Wines of Canada, 2007) and biodynamic vineyards (Ellison, 2008), energy efficient wineries (Cole, 2006; Schreiner, 2005), the adoption of lighter bottles (Waste Resource Action Programme, 2008a), bulk exportations schemes (Waste Resource Action Programme, 2008b), and the implementation of vineyard and winery-based environmental sustainability programs (Sustainable Winegrowing New Zealand, 2008; California Sustainable Winegrowers Alliance, 2008). Thus, a final recommendation for future research is to determine the extent to which these existing, and potential environmental management decisions address wine's most important life cycle stages and actually reduce total life cycle emissions. Ideally, wine industries will undertake LCAs of their own operations, since countless variables throughout wine's life cycle can impact its environmental hotspots and total environmental impacts. However, in the absence of site specific studies, a rigorous sustainability management program for wine should encompass lessons learned from the Nova Scotia wine LCA and other existing wine life cycle studies. For instance, with the exception of Ardente *et al*., (2006), materials and energy used at the winery have not typically emerged as particularly damaging to wine's total life cycle impacts (Table 2.4, Figure 2.3; Notarnicola *et al*., 2003; Aranda *et al*., 2005; Pizzigallo *et al*., 2006). Thus, environmental management decisions that focus on the winery may not offer a particularly effective option for reducing wine's total impact. On the other hand, the provision of glass bottles, field-level emissions from fertilizers, and consumer transport are life cycle stages evidenced to cause much of wine's total impact (Table 2.4; Notarnicola *et al*., 2003; Aranda *et al*., 2005; Pizzigallo *et al*., 2006; Ardente *et al*., 2006). Environmental management programs which focus on these life cycle stages have a greater potential to result in substantial improvements to wine's environmental profile. In particular, continued research into the potential benefits of bulk transport, bulk packaging, alternative packaging materials, and potentially bottle re-use systems, may elucidate important environmental improvement options for wine, as evidenced by research in the UK (Waste Resource Action Programme, 2008a,b).

Appendix A: Vineyard Life Cycle Inventory Data Collection Survey

In August of 2007, the following survey was emailed to all members of the Nova Scotia Grape Growers Association. Participants were given information about the project's objectives, methodology, and intended utility. They were asked to provide data pertaining to the 2006 production year, except for sections 2 and 3 which pertained to the years in which they prepared the land for planting and initially planted the majority of their vines. Grape growers were assured that any information they provided would be treated as confidential, and that their data would be weighted and averaged in the analysis phase of the research and thus not recognizable as coming from any one particular vineyard. Grape growers were asked to return the survey by email, or mail, at their earliest convenience. My contact phone and email address were provided should any questions or concerns have arisen about the survey or the project in general.

Section One: This section relates to the *size, age and output* of your vineyard

1.1 What is the total area of your vineyard in hectares? (*including buffer zone, if one exists*) ______________________________

1.2 How many hectares of vines were grown on your vineyard in 2006?

White _____ Red _____

1.3 How many tonnes of grapes were harvested for wine in 2006?

White _____ Red _____

1.4 How many years has your vineyard been producing grapes? __________________

Section Two: These questions pertain to *land preparation*

2.1 Has tile drainage been installed on your vineyard? ☐yes ☐no

2.1.1 If *yes*, what is the area of coverage? ______________________

2.1.2 What is the spacing of the tile drainage? ______________________

2.1.3 What material are the tiles made from? ______________________________
(*Please provide a brand name if possible)*

2.1.4 What is the diameter of the pipe? ___________________________________

2.2 Did you grade, cultivate or furrow the land prior to planting vines? ☐yes ☐no

2.2.1 If *yes,* what machinery did you use? (Make/Model) ____________________

2.2.2 Did the machine run on ☐Gasoline? ☐Diesel?

2.2.3 Approximately how many hours did it take to grade/cultivate/furrow the land prior to planting?) ____

2.3 Did you bring in new top soil? ☐yes ☐no

2.3.1 If *yes,* how many cubic metres of topsoil did you import? _______________

2.3.2 From where did you import the soil? ________________________________

2.4 Did you add any nutrients, fertilizers or organic matter to the soil while prepping the land? ☐yes ☐no

2.4.1 If *yes*, what was added to the soil?

name of product ________________ kg/ha _____
name of product ________________ kg/ha _____
name of product ________________ kg/ha _____

2.5 Did you sow a green manure crop in the season prior to planting? ☐yes ☐no

2.5.1 If *yes*, what crop(s)? ____

2.5.2 On how many hectares did you sow these crops? ______________________

2.6 What existed on your vineyard site prior to grape vines? ____________________

2.7 Did you apply a herbicide prior to planting? ☐yes ☐no

2.7.1 If *yes*, what is the name of the herbicide? ______________________________
(Please provide a brand name if possible)

2.7.2 How many litres/hectare of herbicide did you apply to your vineyard in the year before planting?______________________________

2.8 Did you correct the soil pH before planting? ☐yes ☐no

2.8.1 Did you hire a contractor to complete this job?☐yes ☐no

2.8.1.a If *yes*, what is the name of the contractor you hired? ____________

2.8.2 If you corrected the soil pH yourself, what did you add to the soil? ________

2.8.2 If you corrected the soil pH yourself, how many tonnes/hectare of compound was used? ______________________________

Section Three: The following questions pertain to *planting*

3.2 Did you add any of the following soil enhancers in the year you planted the vineyard?

☐bone meal	name of product _____	kg/ha _____
☐super phosphate	name of product _____	kg/ha _____
☐compost	name of product _____	kg/ha _____
☐other	name of product _____	kg/ha _____

3.3 Did you apply a fertilizer starting solution to the soil in the year of planting?
☐yes ☐no

3.3.1 If *yes*, what was the name of the product? ______________________________

3.3.2 How many litres/hectare were applied? ______________________________

3.3.3 Did you fertigate? ☐yes ☐no

3.3.3.1 If *yes*, what was the total length of your drip irrigation lines?
____

3.3.3.2 From where did you purchase/rent your irrigation equipment?
____

Section Four: The following questions pertain to *yearly vine propagation*

4.1 How many new cuttings did you start in 2006? ______________________________

4.2 From where did you get your grape cuttings?

☐Own cuttings
☐Purchased from ____

If you purchase your cuttings from a nursery, please proceed to question 4.4

4.3 Did you cover the cuttings with any material? ☐yes ☐no

4.3.1 If *yes*, what material did you use?

☐landscape fabric ☐plastic ☐other (please explain) _________________

4.3.2 How many years do you reuse the same material? _______________________

4.4 Did you spray your vine propagations for mildew? ☐yes ☐no

4.4.1 If *yes,* how many litres of mildew spray did you use in 2006? _____________

4.4.2 What is the name of the mildew spray? ________________________________

4.5 Do you cover the propagated vines over the winter? ☐yes ☐no

4.5.1 If *yes,* what material did you use? ___________________________________
(*Please provide brand name if applicable*)

4.5.2 How many kilograms of this material did you use? ______________________

Section Five: This section contains questions about your *trellising system*

5.1 What is the spacing of your vines? ______________________

5.2 What is the spacing of your rows? ______________________

5.3 What is the length of your rows? ______________________

5.4 Do you use vine stakes? ☐yes ☐no

5.4.1 If *yes*, what is the spacing of your vines stakes?

☐at every vine ☐other (*please explain*) ______________________

5.4.2 What are your vine stakes made of? ______________________

5.5 Do you use intermediate posts? ☐yes ☐no

5.5.1 If *yes*, what is the spacing of your intermediate posts? ____________

5.5.2 What are your intermediate posts made of? ______________________

5.5.3 Are the intermediate posts pressure treated? ______________________

5.6 What are your end posts made of? ______________________

5.6.1 Are your end posts pressure treated? ☐yes ☐no

5.7 What are your trellis wires made of? Bottom __________ Top __________

5.8 What are the gauges of the wires? Bottom __________ Top __________

5.9 How many wires are on the trellis? Bottom __________ Top __________

5.10 What holds the wire onto the trellis? ______________________

Section Six: The following questions refer to *pruning and canopy management*

6.1 Do you use a hand tying machine? ☐yes ☐no

6.1.1 If *yes,* what is the brand name of your hand tying machine? ______________

6.2 How many boxes of tying tape did you use in 2006? ________________________

6.3 How many boxes of staples did you use in 2006? ____________________________

6.4 What do you do with your vine prunings?

% removed ____________ % burned ___________________
% disked into soil __________ % used for propagation _________

6.4.1 How many kilograms of vine prunings were removed from your vines in 2006? ____

6.5 What is allowed to grow in between your vine rows?
☐ nothing (bare soil) ☐ native plants and grasses
☐seeded grass ☐ cover crop

6.5 If you allow plants to grow in between rows, what is the width of the "weed free zone" underneath your vines? ____

Section Seven: These questions pertain to *nutrient management*

7.1 Did you apply lime to your fields in 2006? ☐yes ☐no

7.1.1 Did you hire a contractor to complete this job? ☐yes ☐no

7.1.1.1 If *yes*, what is the name of the contractor you hired? _____________

7.2 If you did not hire a contractor to complete this job, what is the brand name of the lime product you applied?____

7.2.1 How many tonnes/hectare of lime did you apply? ______________________

7.3 How often do you apply lime to your vineyard? ______________________________

7.4 Did you fertilize your fields in 2006? ☐yes ☐no

7.4.1 If *yes*, what is the brand name of the fertilizer you applied? _______________

7.4.2 How many litres/hectare were applied to your fields in 2006? _____________

7.4.3 How many times did you apply fertilizer in 2006? _______________________

7.5 Did you apply a nitrogen-foliar spray to your fields in 2006? ☐yes ☐no

7.5.1 What is the brand name of the spray you used? _________________________

7.5.2 How many litres/hectare were applied to your fields in 2006? _____________

7.5.3 How many times did you apply foliar-nitrogen spray to your vineyard in 2006? ____

7.6 Did you add compost to your grape fields in 2006? ☐yes ☐no

7.6.1 If *yes*, what is the compost made of? (*Please provide brand name of compost product, if applicable*) ____

7.6.2 How many kilograms/hectare of compost was applied? __________________

7.6.3 How many times did you apply compost to your fields in 2006? __________

7.7 Which of the following micronutrients did you apply to your fields in 2006 and how often?

☐Iron	_____(ml/ha)	_____(times/year)
☐Sulphur	_____(ml/ha)	_____(times/year)
☐Manganese	_____(ml/ha)	_____(times/year)
☐Copper	_____(ml/ha)	_____(times/year)
☐Zinc	_____(ml/ha)	_____(times/year)
☐Boron	_____(ml/ha)	_____(times/year)

Section Eight: The following section contains questions related to *weed and pest management*

8.1 Did you apply herbicide to your grape vines in 2006? ☐yes ☐no

8.1.1 If *yes,* what is the brand name of the herbicide? ________________________

8.1.2 How many litres/hectare of herbicide was applied to your fields in 2006?
____

8.1.3 How many times did you apply herbicide to your vineyard in 2006? _______

8.2 Did you apply a fungicide to you vineyards in 2006? ☐yes ☐no

8.2.1 If *yes,* what is the brand name of the fungicide? ________________________

8.2.2 How many grams/hectare of fungicide was applied to your fields in 2006?
____

8.2.3 How many times did you apply fungicide to your vineyard in 2006? _______

8.3 Did you apply a mulch material to curtail weed growth in 2006? ☐yes ☐no

8.3.1 If *yes*, what did you use?

☐straw ☐woodchips ☐other (*please specify)* ____________________________

8.3.2 How many kilograms/hectare of this mulch material was applied to your vineyard in 2006? ____

8.4 Do you use netting to exclude certain pests? ☐yes ☐no

8.4.1 What percent of your vineyard was netted in 2006? _____________________

8.4.2 What is the type of net used on your vineyard? ________________________

8.5 Did you use propane cannons on your farm in 2006? ☐yes ☐no

8.5.1 How many tanks of propane did you use in 2006? ______________________

Section Nine: These questions relate to *harvesting*

9.1 What percent of your harvesting is done:

Mechanically: _____ By hand: _____

9.2 What is the material of the buckets in which the grapes are harvested into? ______

9.2.1 What are the approximate dimensions of the buckets? ___________________

9.2.2 How many buckets are used on your vineyard? ________________________

9.3 What is the material of the bins used to transport the grapes to the winery? ______

9.3.1 What are the dimensions of these bins? ______________________________

9.3.2 How many bins are used on your vineyard? ___________________________

9.4 How are the bins of grapes transferred from the vineyard to the winery?

☐tractor ☐road vehicle

9.5 If you transport your grapes to the winery in a road vehicle, how many kilometers do they travel? ____

9.5.1 What is the make and model of the road vehicle that is used to transport your grapes to the winery? ____

Section Ten: This section pertains to your *vineyard equipment and human labour requirements*

10.1 Please indicate which of the following machinery/equipment are utilized on your vineyard:

☐Tractor Make/Model: ________________________________
Litres of fuel used/year: _______________________
☐Diesel ☐Gasoline

☐ Sprayer

Make/Model: ______________________________
Pulled by tractor? ☐ yes ☐ no
If it is not powered by the tractor…
Make/Model of machine used to power it: ________
Litres of fuel used/year: ______________________
☐ Diesel ☐ Gasoline

☐ Mower

Make/Model: ______________________________
Pulled by tractor? ☐ yes ☐ no
If it is not powered by the tractor…
Make/Model of machine used to power it: ________
Litres of fuel used/year: ______________________
☐ Diesel ☐ Gasoline

☐ Mechanical Harvester

Make/Model: ______________________________
Pulled by tractor? ☐ yes ☐ no
If it is not powered by the tractor…
Make/Model of machine used to power it: ________
Litres of fuel used/year: ______________________
☐ Diesel ☐ Gasoline

☐ Subsoiler/Ripper

Make/Model: ______________________________
Pulled by tractor? ☐ yes ☐ no
If it is not powered by the tractor…
Make/Model of machine used to power it: ________
Litres of fuel used/year: ______________________
☐ Diesel ☐ Gasoline

☐ Foliage Trimmer

Make/Model: ______________________________
Pulled by tractor? ☐ yes ☐ no
If it is not powered by the tractor…
Make/Model of machine used to power it: ________
Litres of fuel used/year: ______________________
☐ Diesel ☐ Gasoline

☐ Mechanical Pruner

Make/Model: ______________________________
Pulled by tractor? ☐ yes ☐ no
If it is not powered by the tractor…
Make/Model of machine used to power it: ________
Litres of fuel used/year: ______________________
☐ Diesel ☐ Gasoline

☐ Tiller

Make/Model: ______________________________
Pulled by tractor? ☐ yes ☐ no
If it is not powered by the tractor…
Make/Model of machine used to power it: ________
Litres of fuel used/year: ______________________
☐ Diesel ☐ Gasoline

☐ Grape Hoe

Make/Model: ______________________________
Pulled by tractor? ☐ yes ☐ no
If it is not powered by the tractor…
Make/Model of machine used to power it: ________
Litres of fuel used/year: ______________________
☐ Diesel ☐ Gasoline

10.2 How many people worked on your vineyard in 2006? ______________________

10.2.1 What was the approximate number of "people hours" employed on your vineyard in 2006? ____

Section Eleven: Please use this section to provide any additional information regarding your vineyard's operations that you feel necessary

____
____
____
____
____
____

Appendix B: Winery Life Cycle Inventory Data Collection Survey

In the fall of 2007, the following survey was emailed, or delivered in person to Nova Scotia wine makers in the province who had indicated a willingness and ability to provide data pertaining to their winery's operations. Participants were given information about the project's objectives, methodology, and intended utility. They were asked to provide data pertaining to the 2006 production year. Winemakers were assured that any information they provided would be treated as confidential, and that their data would be weighted and averaged in the analysis phase of the research and thus not recognizable as coming from any one particular winery. Wine makers were asked to return the survey by email, or mail, at their earliest convenience. My contact phone and email address were provided should any questions or concerns have arisen about the survey or the project in general.

---

1. How many tons of grapes were processed in 2006? ______________________________

2. What percentage of the grapes you processed are Nova Scotia grown? ______________

3. What percentage of the grapes you processed are purchased from contract growers? ___

4. How are the grapes brought to the winery (including transport mode and vehicle used? _
____

5. What was the total amount of diesel fuel used to power equipment/machinery in the winery in 2006? ____

6. What was the total amount of gasoline used to power equipment/machinery in the winery in 2006? ____

7. How many litres of water were used in the winery's operations in 2006? ____________

8. What was the total electricity use (kWh) of the winery in 2006? ___________________

9. How many litres of heating oil were used in your winery's operations in 2006? _______

10. What products are added to your wines throughout various stages of the wine making process and in what amounts? Please provide as much detail about these products as possible, including the brand name, as well as the name of your main supplier, if possible. If you are unsure of the volumes added to the wines, please provide an estimation, or an indication of where I might find this information.

Example:
Clarifying Agents: Bentonite, 1gram per litre of wine ______________________________

Yeast ______________________________
Yeast Nutrients ______________________________
Sugar ______________________________
Clarifying Agents ______________________________
De-filtering Agent ______________________________
Malolactic Bacteria ______________________________
Anti-oxidants ______________________________
Other ______________________________
Other ______________________________
Other ______________________________

11. What was the winery's total output of wine in 2006? ______________________________

12. From whom do you purchase your:
- glass bottles? ______________________________
- corks? ______________________________
- screwcaps? ______________________________
- labels? ______________________________
- heat-shrink capsules? ______________________________

13. In what vehicle do you transport your grapes to Halifax for retail? ________________

14. What do you do with leftover:
Pomace? ______________________________
Lees? ______________________________

15. What cleaning products are used in the winery and how much of each product was used in 2006? Please provide brand names of products when possible. ________________
____

16. Please provide any additional information regarding your winery's material and energy use that you feel necessary. ______________________________
____

17. Please provide any additional comments, suggestions, concerns, etc. ______________
____

Appendix C: Calculation Of Emissions From The Application Of Fertilizers

Emissions from fertilizer application were calculated using a model developed by Arsenault (2006) and further developed by Pelletier (2006). Calculation steps in the model were derived from Brentrup *et al.*, (2000), Intergovernmental Panel on Climate Change (2006) and Dalgaard *et al.*, (2006). Table C1 illustrates the calculations made to quantify N_2O, NH_3, NO, NO_3 and P_2O_5.

Table C.1 Calculations of nitrogen and phosphorous losses, per tonne of grapes, from synthetic and manure fertilizer application in Nova Scotia vineyards in 2006.

Calculation Step	Unit	Mass
NITROGEN EMISSIONS		
N from Fertilizer	kg	2.64
Percent Fertilizer N lost as NH_3 [a]	%	9.00
NH_3-N lost to atmosphere	kg	0.24
Percent Fertilizer N lost as NO [a,b]	%	1.00
NO-N lost to atmosphere	kg	0.03
Percent Fertilizer N lost as N_2O [a]	%	1.00
N_2O-N lost to the atmosphere	kg	0.03
Percent N_2-N lost to the Atmosphere [b]	%	9.00
N_2-N lost to the Atmosphere	kg	0.24
N from Manure	kg	11.94
Percent Fertilizer N lost as NH_3 [a]	%	18.00
NH_3-N lost to atmosphere	kg	2.15
Percent Fertilizer N lost as NO [a,b]	%	2.00
NO-N lost to atmosphere	kg	0.24
Percent Fertilizer N lost as N_2O [a]	%	2.00
N_2O-N lost to the atmosphere	kg	0.24
Percent N_2-N lost to the Atmosphere	%	9.00
N_2-N lost to the Atmosphere [b]	kg	1.08
Mass of Crop Residues [c]	kg	500.00
Total Nitrogen in Crop Residues [d]	kg	2.16
Percent Crop Residue N lost as N_2O [a]	%	1.00
N_2O-N lost to the atmosphere	kg	0.02
Remaining Crop Residue N	kg	2.14
NH_3-N Emissions per Hectare [e]	kg/ha	5.00
Yield Per Hectare	tonnes/ha	6.37
Total Additional NH_3-N Emissions	kg/tonne	0.79

Table continued on next page

Table C.1 continued: Calculations of nitrogen and phosphorous losses, per tonne of grapes, from synthetic and manure fertilizer application in Nova Scotia vineyards in 2006.

Calculation Step	Unit	Mass	
NITROGEN EMISSIONS, continued			
N Inputs			
Fertilizer N	kg	2.64	
Manure N	kg	11.94	
Atmospheric N Deposition	kg/ha	15.00	
Crop Yield	tonnes/ha	6.37	
N Deposition/tonne of Crop	kg/tonne	2.36	
Total N Inputs	kg	16.94	
N Outputs			
Fertilizer N lost as NH_3-N	kg	0.24	
Fertilizer N lost as NO-N	kg	0.03	
Fertilizer N lost as N_20-N	kg	0.03	
Fertilizer N lost as N_2-N	kg	0.24	
Manure N lost as NH_3-N	kg	2.15	
Manure N lost as NO-N	kg	0.24	
Manure N lost as N_2O-N	kg	0.24	
Manure N lost as N_2-N	kg	1.08	
Crop Residue N as N_2O-N	kg	0.02	
Additional NH_3-N lost from Crops	kg	0.79	
Nitrogen Removed with Crop [d]	kg/tonne	1.10	
Total N Outputs	kg	6.14	
Total N Surplus	kg	10.80	
% Leached as NO_3 [a,b]	%	30.00	
Nitrogen Surplus for NO_3 Loss	kg	3.24	
Indirect Nitrogen Emissions			
Total NH_3-N	kg	3.17	
% Indirect N_2O Emissions from NH_3-N	%	1.00	
Indirect N_2O Emissions from NH_3-N	kg	0.03	
NO_3 Emissions	kg	3.24	
% Indirect N_2O Emissions from NO_3	%	0.75	
Indirect N_2O Emissions from NO_3	kg	0.02	
TOTAL NITROGEN EMISSIONS			
TOTAL N_2O TO AIR [a]	kg	0.34 * (44/28)	**0.53** [f]
TOTAL NH_3 TO AIR [a]	kg	3.17 * (1.21)	**3.84** [f]
TOTAL NO TO AIR [a]	kg	0.27 * (30/14)	**0.58** [f]
TOTAL NO_3 TO WATER [a]	kg	3.24 * (62/14)	**14.35** [f]

Table continued on next page

Table C1 continued: Calculations of nitrogen and phosphorous losses, per tonne of grapes, from synthetic and manure fertilizer application in Nova Scotia vineyards in 2006.

Calculation Step	**Unit**	**Mass**	
PHOSPHOROUS EMISSIONS			
Total Phosphorous Applied as Fertilizer	kg	7.17	
Total Phosphorous in Phosphate Fertilizer	kg	3.13	
Total Phosphorous Applied as Manure	kg	3.93	
Total Phosphorous in Manure	kg	1.82	
Phosphorous Content of Crop [d]	%	0.01	
Phosphorous Removed/Tonne of Crop	kg	0.10	
Total Remaining Phosphorous	kg	4.85	
Leaching Rate of Phosphorous [g]	%	2.90	
TOTAL PHOSPHOROUS EMISSIONS			
TOTAL P_2O_5 TO WATER [h]	kg	0.141 * 2.29	**0.32** [i]

Notes:

[a] Intergovernmental Panel on Climate Change (2006)
[b] Brentrup *et al*., (2000)
[c] *Pers comm*., Lewis, J. April 15, 2008.
[d] National Resources Conservation Service (2007)
[e] Andersson *et al*., 2001, as cited in Schmidt, 2007
[f] Nitrogen emissions are split 18% from synthetic fertilizers and 82% from manure fertilizer as per initial input ratio (Table 2.2).
[g] Dalgaard *et al*., 2006
[h] Nova Scotia Agricultural College, 2003
[i] Phosphate emissions are split 62% from synthetic fertilizers and 38% from manure fertilizers as per initial input ratio (Table 2.2)

Appendix D: Description Of Impact Categories Analyzed In This Study

Table D.1 provides a list of impact categories defined in this research and a description of the characterization methods used to quantify the impact of flows of materials and energy to a particular impact category. In this study, I have reported on the CML 2 baseline 2000 impact categories, recommended by the Handbook on Life Cycle Assessment (Guinée *et al*., 2001), and cumulative energy demand (CED). Characterization methods are comprised of category indicators, characterization models, and characterization factors. Category indicators are quantifiable representations of an impact category. Characterization models are mathematical models used to calculate the impact of LCI data with respect to a particular category indicator. Characterization factors are used to express LCI data in terms of the common unit of the category indicator. Characterization factors for substances are listed in Part 2b of Guinée *et al*., (2001). Guinée *et al*., (2001) also provide detailed qualitative descriptions of each impact category, in terms of relevant substances, chemical reactions and processes that contribute to each impact category.

Table D.1 Information regarding impact categories analyzed in this research and the characterization methodologies used to calculate contributions of LCI data into impact categories (Guinée *et al*., 2001; Frischknecht *et al*., 2003).

Impact Category	LCI Results	Characterization Model	Category Indicator	Characterization Factor	Unit
Abiotic Resource Depletion	Extraction of minerals and fossil fuels (in kg)	Based on concentration-based reserves and rate of de-accumulation	Depletion of the ultimate reserve in relation to annual use	Abiotic Resource Depletion Potential (ARDP) for each extraction of minerals and fossil fuels (in kg antimony (Sb) equivalents/kg extraction)	kg (Sb equivalents)
Acidification	Emissions of acidifying substances to the air (in kg)	RAINS10 model, developed at IIASA, describing the fate and deposition of acidifying substances	Deposition/acid-ification critical load	Acidification Potential (AP) for each acidifying emission to the air (in kg SO_2 equivalents/kg emission)	kg (SO_2 equivalents)

Table continued on next page

Impact Category	LCI Results	Characterization Model	Category Indicator	Characterization Factor	Unit
Eutrophication	Emissions of nutrients to air, water and soil (in kg)	The stoichiometric procedure, which identifies the equivalence between N and P for terrestrial and aquatic systems	Deposition/N/P equivalents in biomass	Eutrophication Potential (EP) for each eutrophying emission to air, water and soil (in kg PO_4 equivalents/kg emission)	kg (PO_4 equivalents)
Global Warming	Emissions of greenhouse gases to the air (in kg)	The model developed by the IPCC defining the global warming potential of different greenhouse gases	Infrared radiative forcing (W/m^2)	Global Warming Potential (GWP) for a 100-year time horizon (GWP 100) for each greenhouse gas emission to the air (in kg CO_2 equivalents/kg emission)	kg (CO_2 equivalents)
StratosphericOzone Depletion	Emissions of ozone-depleting gases to the air (in kg)	The model developed by the World Meteorological Organization, defining the ozone depletion potential of different gases	Stratospheric ozone breakdown	Ozone Depletion Potential (ODP) in the steady state, for each emission to the air (in CFC-11 equivalents/kg emission)	kg (CFC-11 equivalants)
Terrestrial Eco-toxicity	Emissions of toxic substances to air, water and soil (in kg)	USES 2.0 model developed as RIVM, describing fate, exposure and effects of toxic substances	Predicted environmental concentration/predicted no-effect concentration	Terrestrial Eco-toxicity Potential (TETP) for each emission of a toxic substance to air, water and/or soil (in kg 1,4-dichlorobenzene equivalents/kg emission)	kg (1,4-DCB equivalents)
Aquatic Eco-toxicity (freshwater)	Emissions of toxic substances to air, water and soil (in kg)	USES 2.0 model developed as RIVM, describing fate, exposure and effects of toxic substances	Predicted environmental concentration/predicted no-effect concentration	Aquatic Eco-toxicity Potential (AETP) for each emission of a toxic substance to air, water and/or soil (in kg 1,4-dichlorobenzene equivalents/kg emission)	kg (1,4-DCB equivalents)
Photo-oxidant Formation	Emissions of substances (VOC, CO) to air (in kg)	UNECE Trajectory Model	Tropospheric ozone formation (aka: smog formation)	Photochemical Ozone Creation Potential (POCP) for each emission of VOC and CO to air (in kg ethylene equivalents/kg emission)	kg (C_2H_4 equivalents)
Cumulative Energy Demand	Direct and indirect consumption of energy (in MJ)	Based on method published by ecoinvent 1.0 and expanded by PRé Consultants	Direct and indirect consumption of energy	Based on upper heating value/energy content of each energy carrier (fossil nuclear, biomass), or the rotation energy transmitted to turbines (hydro)	MJ-equivalents

References

AgraPoint International Ltd. 2007. Grape Disease Management Schedule for Nova Scotia: Revised Edition. Retrieved October 31, 2008 from: http://www.extensioncentral.com/index2.php?option=com_docman&task=doc_view&gid=391&Itemid=32

Ahlgrimm, H., Bockisch, F., Böhme, H., Bramm, A., Dämmgen, U., Flachowsky, G., *et al*., 2000. Evaluation of Conventional and Organic Agricultural Production in Relation to Primary Energy Inputs and Certain Pollution Gas Emissions. Federal Research Centre of Agriculture.

Andersson, K., Ohlsson, T. & P. Olsson. 1994. Life Cycle Assessment (LCA) of Food Products and Production Systems. *Trends in Food Science and Technology*, 5(5): 134-138.

Andersson, K. 2000. LCA of Food Products and Production Systems. *International Journal of Life Cycle Assessment, 5*(4): 239-248.

Andersson, K. & T. Ohlsson. 1999. Life Cycle Assessment of Bread Produced at Different Scales. *International Journal of Life Cycle Assessment*, 4: 25-40.

Andersson, K., Ohlsson, T. & P. Olsson. 1998. Screening Life Cycle Assessment (LCA) of Tomato Ketchup: A case study. *Journal of Cleaner Production*, 6(3-4): 277-288.

Anonymous. 2007. Nova Scotia Farm Winery Policy. Retrieved November 4, 2008 from: http://www.gov.ns.ca/agri/mbd/WineryPolicy.pdf.

Anson, J. 2008a. *Champagne Announces Carbon Dioxide Emissions Strategy*. Retrieved October 31, 2008 from: http://www.decanter.com/news/181263.html.

Anson, J. 2008b. *Bordeaux to Study Carbon Emissions*. Retrieved October 31, 2008 from: http://www.decanter.com/news/175396.html.

Aranda, A., Zabalza, I. & S. Scarpellini. 2005. Economic and Environmental Analysis of the Wine Bottle Production in Spain by Means of Life Cycle Assessment. *International Journal of Agricultural Resources, Governance and Ecology*, 4(2): 178-191.

Ardente, F., Beccali, G., Cellura, M. & A. Marvuglia. 2006. POEMS: A case study of an Italian wine-producing firm. *Environmental Management*, 38(3): 350-364.

Arseneault, J. N. 2006. Comparing the Environmental Impacts of Pasture-Based and Confinement-Based Dairy Systems in Nova Scotia Using Life Cycle Assessment. Master's Thesis, Dalhousie University.

Arsenault, N., Tyedmers, P., & A. Fredeen (in press). Comparing the Environmental Impacts of Pasture-based and Confinement-based Dairy Systems in Nova Scotia (Canada) Using Life Cycle Assessment. *International Journal of Agricultural Sustainability*.

Audsley, E. 1997. Harmonization of Environmental Life Cycle Assessment for Agriculture. European Commission DG VI Agriculture.

Ayer, N. & P. Tyedmers (in press). Assessing Alternative Aquaculture Technologies: life cycle assessment of alternative aquaculture technologies in Canada. *Journal of Cleaner Production*.

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

Bellarby, J., Foereid, B., Hastings, A. & P. Smith. 2007. Cool Farming: climate impacts of agriculture and mitigation potential. University of Aberdeen. Retrieved October 31, 2008 from: http://www.greenpeace.org/international/press/reports/cool-farming-full-report.

Bengtsson, J., Ahnström, J. & A. Weibull. 2005. The Effects of Organic Agriculture on Biodiversity and Abundance: a meta-analysis. *Journal of Applied Ecology*, 42(2): 261-269.

Berlin, J. 2002. Environmental Life Cycle Assessment (LCA) of Semi-hard Cheese. *International Dairy Journal*, 12: 939-953.

Blanke, M.M. & B. Burdick. 2005. Food (Miles) for Thought. *Environmental Science and Pollution Research*, 12(3):125-127.

Boyd, C. & P. Tyedmers (in prep). From Ocean to Market: the life cycle biophysical impacts of the southwest Nova Scotia live lobster industry.

Brentrup, F., Küsters, J., Lammel, J., & H. Kuhlmann. 2000. Methods to Estimate On-field Nitrogen Emissions from Crop Production as an Input to LCA Studies in the Agricultural Sector. *International Journal of Life Cycle Assessment*, 5: 349-357.

Brentrup, F., Küsters, J., Kuhlmann, H., & J. Lammel. 2001. Application of the Life Cycle Assessment Methodology to Agricultural Production: An example of sugar beet production with different forms of nitrogen fertilizers. *European Journal of Agronomy*, 14(3): 221-233.

Brentrup, F., Küsters, J., Kuhlmann, H., & J. Lammel. 2004. Environmental Impact Assessment of Agricultural Production Systems Using the Life Cycle Assessment Methodology: I. theoretical concept of a LCA method tailored to crop production. *European Journal of Agronomy*, 20(3): 247-264.

Brodt, S., Chernoh, E. & G. Feenstra. Assessment of Energy Use and Greenhouse Gas Emissions in the Food System: a literature review. 2007. Agricultural Sustainability Institute, University of California, Davis. Retrieved October 31, 2008 from: http://asi.ucdavis.edu/Research/Literature_Review_-_Assessment_of_Energy_Use_and_Greenhouse_Gas_Emissions_in_the_Food_System_Nov_2007.pdf.

Brooks-Arenburg, P. 2007. Nov 15. Grape Expectations: Nova Scotia winemakers in good cheer; liquor corp. lowers markup. *The Chronicle Herald*, p. 1.

Brunner, P.H. & H. Rechberger. 2004. *Practical Handbook of Material Flow Analysis*. Boca Ranton, Florida: CRC Press. 318 pages.

Bussink, D.W. & O. Oenema. 1998. Ammonia Volatilization from Dairy Farming Systems in Temperate Areas: a review. *Nutrient Cycling in Agroecosystems*, 51:19-33.

California Sustainable Winegrowers Alliance (CSWA). 2008. *California Sustainable Winegrowing Program*. Retrieved November 4, 2008 from: http://www.sustainablewinegrowing.org/.

Canadian General Standards Board. 2006. *Organic Production Systems Permitted Substances List*. ICS 67.040. Retrieved November 4, 2008 from: http://www.cog.ca/documents/311.pdf.

Canadian Organic Growers. 2008. *Quick Facts About Canada's Organic Sector*. Retrieved November 4, 2008 from: http://www.cog.ca/orgquickfacts.htm.

Carlsson-Kanyama, A. 1998. Climate Change and Dietary Choices: how can emissions of greenhouse gases from food consumption be reduced? *Food Policy*, 23(3-4): 277-293.

Carlsson-Kanyama, A., Ekström, M. P. & H. Shanahan. 2003. Food and Life Cycle Energy Inputs: consequences of diet and ways to increase efficiency. *Ecological Economics*, 44(2-3): 293-307.

Carlsson-Kanyama, A. & K. Bostrom-Carlsson, 2001. Energy Use for Cooking and Other Stages in the Life Cycle of Food: a study of wheat, spaghetti, pasta, barley, rice, potatoes, couscous and mashed potatoes. Stockholm University fms Report No. 160. Retrieved November 4, 2008 from: http://www.infra.kth.se/fms/pdf/Report160.pdf.

Cederberg, C. 1998. Life Cycle Assessment of Milk Production: a comparison of conventional and organic farming. SIK report No. 643. Göteburg, Sweden: The Swedish Institute for Food and Biotechnology.

Cederberg, C. 2003. Life Cycle Assessment of Animal Products. In: *Environmentally-friendly Food Processing*. Mattsson, B. & U. Sonesson (eds.), pp. 54-69. Cambridge, England: Woodhead Publishing Limited.

Cederberg, C. & B. Mattsson. 2000. Life Cycle Assessment of Milk Production: a comparison of conventional and organic farming. *Journal of Cleaner Production*, 8: 49-60.

Cederberg, C. & A. Flysjo. 2004. Life Cycle Inventory of 23 Dairy Farms in South-western Sweden. SIK report No. 728. Göteburg, Sweden: The Swedish Institute for Food and Biotechnology.

Cole, E. 2006. *Canada's Stratus Wins Plaudits for Massive Energy Cuts.* Retrieved October 31, 2008 from: http://www.decanter.com/news/86372.html.

Coleman, T. & P. Päster. 2007. Red, White and "Green": The cost of carbon in the global wine trade. American Association of Wine Economists, Working Paper No. 9. Retrieved September 15, 2008 from: http://www.wine-economics.org/workingpapers/.

Consoli, F., Allen, D., Boustead, I., Fava, J. Franklin, W., Jensen, A.A., de Oude, *et al*., (eds). 1993. Guidelines for Life-Cycle Assessment: A "Code of Practice", Edition 1. From the SETAC Workshop held at Sesimbra, Portugal 31 March – 3 April 1993. Society for Environmental Toxicology and Chemistry (SETAC).

Cowell, S.J. & R. Clift. 1996. Impact Assessments for LCAs Involving Agricultural Production. *International Journal of Life Cycle Assessment*, 2(2): 99-103.

Curran, M.A. (ed.) 1996. *Environmental Life Cycle Assessment*, Toronto: McGraw Hill Companies, Inc.

Dainelli, D. 2003. Recycling of Packaging Materials. In: *Environmentally-friendly food processing*. Mattsson, B. & U. Sonesson (eds.), pp. 154-179. Cambridge, England: Woodhead Publishing Limited.

Dalgaard, R., Halberg, N., Kristensen, I. S. & I. Larsen. 2006. Modeling Representative and Coherent Danish Farm Types Based on Farm Accountancy Data for Use in Environmental Assessments. *Agriculture, Ecosystems and Environment*, 117: 223-237.

De Leo, F. 2003. The Environmental Management of Packaging: an overview. In: *Environmentally-friendly food processing*. Mattsson, B. & U. Sonesson (eds.), pp. 130-153. Cambridge, England: Woodhead Publishing Limited.

Delmas, M.A. & L.E. Grant. 2008. Eco-Labeling Strategies: the eco-premium puzzle in the wine industry. 2008. American Association of Wine Economists, Working Paper No. 13. Retrieved September 15, 2008 from: http://www.wineeconomics.org/working papers/.

Derwent, R.G., Jenkin, M.E. & S.M. Saunders. 1996. Photochemical Ozone Creation Potentials for a Large Number of Reactive Hydrocarbons Under European Conditions. *Atmospheric Environment*, 30(2): 181-199.

Driscoll, J.D. & P. Tyedmers (in prep). Life Cycle Environmental Impacts of Gulf of Maine Lobster and Herring Fisheries Management Decisions.

Dutilh, C. E. & A.R. Linneman. 2004. Food system, Energy Use in. *Encyclopedia of Energy*, 2: 719-726.

Ellison, K. 2008. The Science of Sustainable Wine. *The Ecological Society of America.*

Environmental Goals and Sustainable Prosperity Act. 2007. Bill No. 146. 1st Session, 60th General Assembly, Nova Scotia, 56 Elizabeth II. Retrieved: September 15, 2008 from: http://www.gov.ns.ca/legislature/legc/bills/60th_1st/1st_read/b146.htm.

Erisman, J. 2000. Key Factors Necessary to Determine the Impact on the Nitrogen Cycle and the Resulting Environmental Effects as part of LCA for Agricultural Products. *In: Agricultural Data for Life Cycle Assessments*. Weidema, B.P. & M.J.G Meeusen (eds.), Volume 1., Agricultural Economics Research Institute (LEI), The Hague.

Faist, M., Kytzia, S. & P. Baccini. 2001. The Impact of Household Food Consumption on Resource and Energy Management. *International Journal of Environment and Pollution*, 15(2): 183-199.

Finkbeiner, M., Inaba, A., Tan, R. B. H., Christiansen, K. & H. Klüppen. 2006. The New International Standards for Life Cycle Assessment: ISO 14040 and ISO 14044. *International Journal of Life Cycle Assessment*, 11(2): 80-85.

Food and Agricultural Organization of the United Nations. 2008. Food Outlook: global market analysis. Retrieved October 31, 2008 from: ftp://ftp.fao.org/docrep/fao/011/ai474e/ai474e00.pdf.

Foster, C., Green, K., Belda, M., Dewick, P., Evans, B., Flynn, A. & J. Mylan. 2006. Environmental Impacts of Food Production and Consumption: a report to the Department for Environment, Food and Rural Affairs. Manchester Business School. Defra, London.

Frischknecht, R., Jungbluth, N., Althaus, H., Bauer, C., Doka, G. & R. Dones. 2003. Implementation of Life Cycle Impact Assessment Methods, Final Report. Ecoinvent Report No. 3. Dübendorf.

Frischknecht, R., Althaus, H., Bauer, C., Doka, G., Heck, T., Jungbluth, N., *et al*. 2007. The Environmental Relevance of Capital Goods in Life Cycle Assessments of Products and Service. *International Journal of Life Cycle Assessment*, DOI: http://dx.doi.org/10.1065/lca2007.02.308.

Gerbens-Leenes, P. W. & S. Nonhebel. 2002. Consumption Patterns and their Effects on Land Required for Food. *Ecological Economics*, 42(1-2): 185-199.

Guinée J. B., Gorée, M., Heijungs, R., Huppes, G., Kleijn, R. & A. De Koning., *et al*. 2001. An Operational Guide to the ISO Standards, Final Report. The Netherlands: Ministry of Housing, Spatial Planning and the Environment (VROM) and the Centre for Environmental Studies, Leiden University.

Haas, G., Wetterich, F. & U. Köpke. 2001. Comparing Intensive, Extensified and Organic Grassland Farming in Southern Germany by Process Life Cycle Assessment. *Agriculture, Ecosystems & Environment*, 83(1-2): 43-53.

Hartley, A. 2008. Lightweight Wine Bottles: Strength as an issue in the manufacture of lightweight wine bottles. Final Report: GlassRite: Wine. MSG009. Retrieved: November 4, 2008 from: http://www.wrap.org.uk/downloads/Wine_bottle_strength-_May_08.b294276b.5393.pdf.

Hauschild, M. 2000. Estimating Pesticide Emissions for LCA of Agricultural Products. *In: Agricultural Data for Life Cycle Assessments*. Weidema, B.P. & M.J.G Meeusen (eds.), Volume 1., Agricultural Economics Research Institute (LEI), The Hague.

Heinberg, R. 2004. *Powerdown: options and actions for a post-carbon world.* Gabriola Island, BC: New Society Publishers. 208 pages.

Hemingway, E. 1932. *Death in the Afternoon*. Charles Scribner Sons. New York, New York. 517 pages.

Hendrickson, J. 1996. Energy Use in the U.S. Food System: a summary of existing research and analysis. Madison, WI: University of Wisconsin, Centre for Integrated Agricultural Systems.

Hendrik N., Schifferstein, J. & P. A. M. Oude Ophuis. 1998. Health-related Determinants of Organic Food Consumption in the Netherlands. *Food Quality Preference*, 9(3): 119-133.

Hertwich, E.G. 2005. Life Cycle Approaches to Sustainable Consumption: a critical review. *Environmental Science and Technology*, 39(13): 4673-4684.

Hertwich, E. G., Hammitt, J. K. & W.S. Pease. 2000. A Theoretical Foundation for Life-Cycle Assessment: recognizing the role of values in environmental decision making. *Journal of Industrial Ecology*, *4*(1): 13-28.

Horrigan, L., Lawrence, R. S. & P. Walker. 2002. How Sustainable Agriculture can Address the Environmental and Human Health Harms of Industrial Agriculture. *Environmental Health Perspectives*, 110(5): 445-456.

Hospido, A., Moreira, M. T. & G. Feijoo. 2003. Simplified Life Cycle Assessment of Galician Milk Production. *International Dairy Journal*, 13(10): 783-796.

Hospido, A., Moreira, M. T. & G. Feijoo, G. 2005. Environmental Analysis of Beer Production. *International Journal of Agricultural Resources, Governance and Ecology*, 4(2): 152-162.

Hospido, A. & P. Tyedmers, P. 2005. Life Cycle Environmental Impacts of Spanish Tuna Fisheries. *Fisheries Research*, 76(2): 174-186.

Hunt, R.G. & W.E. Franklin. 1996. LCA – How it Came About: personal reflections on the origin and the development of LCA in the USA, *International Journal of Life Cycle Assessment*, 1(1): 4–7.

International Organization of Vine and Wine. 2007. *State of the Viniviticultural World Report*, Retrieved October 31, 2008 from: http://news.reseau-concept.net/pls/news/p_entree?i_sid=&i_type_edition_id=20508&i_section_id=20510&i_lang=33.

Intergovernmental Panel on Climate Change. 2006. 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Volume 4 - Agriculture, Forestry and Other Land Use, Chapter 11: N2O Emissions fro Managed Soils, and CO2 Emissions from Lime and Urea Application. Retrieved: November 4, 2008 from: http://www.ipcc-nggip.iges.or.jp/public/2006gl/index.html.

Intergovernmental Panel on Climate Change. 2007. Climate Change 2007 – The Physical Science Basis - Contribution of Working Group I to the Fourth Assessment Report of the IPCC. Retrieved: November 4, 2008 from: http://www.ipcc.ch/ipccreports/assessments-reports.htm.

ISO. 2006a. *ISO 14040 Environmental Management - Life Cycle Assessment - Principles and Framework*. Geneva, Switzerland.

ISO. 2006b. *ISO 14044 Environmental Management - Life Cycle Assessment – Requirements and Guidelines*. Geneva, Switzerland.

Jozsa Management and Economics. 2006. Economic Impact Study of the Nova Scotia Wine Industry. Prepared for: Nova Scotia Liquor Corporation; Winery Association of Nova Scotia; Grape Growers Association of Nova Scotia.

Khan, F. I., Raveender, V. & T. Husain. 2002. Effective Environmental Management through Life Cycle Assessment. *Journal of Loss Prevention in the Process Industries*, 15(6): 455-466.

Kooijman, J.M. 2006. Environmental Assessment of Food Packaging: impact and improvement. *Packaging, Technology and Science*, Published online: DOI 10.1002/pts.2770070302, June 26, 2006.

Koroneos, C., Roumbas, G., Gabari, Z., Papagiannidou, E. & N. Moussiopoulos. 2005. Life Cycle Assessment of Beer Production in Greece. *Journal of Cleaner Production*, 13: 433-439.

Kramer, K. J. 2003. Life cycle Assessment of Vegetable Products. In: *Environmentally-friendly food processing*.Mattsson, B. & U. Sonesson (eds.), pp. 16-28. Cambridge, England: Woodhead Publishing Limited.

Kramer, K. J., Moll, H. C., Nonhebel, S. & H.C. Wilting. 1999. Greenhouse Gas Emissions Related to Dutch Food Consumption. *Energy Policy*, 27(4): 203-216.

Lewis, J.C., Jamieson, A., Gordon, R. & G. Patterson. 2006. Opportunities and Challenges for Wine Grape Production in Nova Scotia. Retrieved October 31, 2008 from:http://www.extensioncentral.com/index2.php?option=com_docman&task=doc_view&gid=19&Itemid=32.

Mäder, P. Fleissbach, A. Dubois, D. Gunst, L., Fried, P. & U. Niggli. 2002. Soil Fertility and Biodiversity in Organic Farming. *Science*, 296(5573): 1694-1697.

Madill, J. J., Riding, A. L., & G. H. J. Haines. 2003. “Strategic Dilemmas of a Small Market Player: The Canadian wine industry” in Proceedings of the International Colloquium in Wine Marketing. Adelaide, Australia; Wine Marketing Group, University of South Australia. Retrieved November 4, 2008 from: http://www.unisa.edu.au/winemarketing/conferences/proceedings.asp.

Mattsson, B. 1999a. Environmental Life Cycle Assessment (LCA) of Agricultural Food Production, Doctoral Thesis, Swedish University of Agricultural Sciences. Agraria 187, 298 pages.

Mattsson, B. 1999b. Life Cycle Assessment (LCA) of Carrot Purée: case studies of organic and integrated production. SIK report No. 653. Göteburg, Sweden: The Swedish Institute for Food and Biotechnology.

Mattsson, B., Cederberg, C. & L. Blix. 2000. Agricultural Land Use in Life Cycle Assessment (LCA): case studies of three vegetable oil crops. *Journal of Cleaner Production*, 8: 283-292.

Mattsson, B. & E. Wallén. 2003. Environmental LCA of Organic Potatoes. In: Proceedings of the 26th International Horticultural Congress, ISHS, Acta Horticulturae 691.

Mattsson B. & U. Sonesson. (eds). 2003. Introduction. In: *Environmentally-Friendly Food Processing*, Cambridge, England: Woodhead Publishing Limited, 337 pages.

McGovern, P. 2003. *Ancient Wine: the search for the origins of viniculture*. Princeton University Press, New Jersey, USA. 400 pages.

Mead, J. V. 2004. Food Capture, Energy Costs of. *Encyclopedia of Energy,* 2: 705-717.

Milà i Canals, L. & G. C. Polo. 2003. Life Cycle Assessment of Fruit Production. In: Mattson, B. & U. Sonesson. (eds.), *Environmentally-friendly food processing*, pp. 29-53. Cambridge, England: Woodhead Publishing Limited.

Milà i Canals, L., Burnip, G., Suckling, D.M. & S.J. Cowell. 2003. Sources of Site-Dependency and Importance of Energy Consumption in Agricultural LCA: apple production in New Zealand. In: Life Cycle Assessment in the Agri-Foods Sector, DIAS Report: Proceedings from the 4th International Conference – Oct 6-8, 2003, Bygholm, Denmark.

Milà i Canals, L., Burnip, G.M. & S.J. Cowell. 2006. Evaluation of the Environmental Impacts of Apple Production Using Life Cycle Assessment (LCA): case study in New Zealand. *Agriculture, Ecosystems and Environment*, 114: 226-238

Miles, S. & L.J. Frewer. 2001. Investigating Specific Concerns about Different Food Hazards. *Food Quality Preference*, 12: 47-61.

Monteny, G., Bannink, A. & D. Chadwick. 2006. Greenhouse Gas Abatement Strategy for Animal Husbandry. *Agriculture, Ecosystems and Environment*, 112(2-3): 163-170.

Mourad, A.L., Coltro, L., Oliveira, P.A.P.L.V., Kletecke, R.M. & J.P.O.A. Baddini. 2007. A Simple Methodology for Elaborating the Life Cycle Inventory of Agricultural Products. *International Journal of Life Cycle Assessment*, 12(6): 408-413.

National Resources Conservation Service. 2007. *Nutrient Content of Crops: Nutrients Removed by Harvest*. Retrieved: November 8, 2008 from: http://npk.nrcs.usda.gov.

Naugler, C. & B. Wright. 2006. *Wamboldt's Nova Scotia Winegrowers' Guide 2006 Edition*. Bridewater, Nova Scotia: Blue Frog Inc. 139 pages.

Naugler, C., Wright, B. & R. Murray. 2004. *The Tangled Vine: Winegrowing in Nova Scotia*. Bridewater, Nova Scotia: Blue Frog Inc. 148 pages.

Nicoletti, G.M., Notarnicola, B. & G. Tassielli. 2001. Comparison of Conventional and Organic Wine. *Proceedings: International Conference on LCA in Foods*. Gothenburg, Sweden, 26-27 April, 2001. SIK Document 143.

Niccolucci, V., Galli, A., Kitzes, J., Pulselli, R.M., Borsa, S. & S. Bastianoni. 2006. The Ecological Footprint Analysis Applied to Two Different Italian Wine Productions. Report No. A0001-95. The ESRC Centre for Business Relationships, Accountability, Sustainability and Society. Retrieved: November 4, 2008 from: http://www.brass.cf.ac.uk/uploads/Niccolucci_et_al_A95.pdf.

Nieuwlaar, E. 2004. Life Cycle Assessment and Energy Systems. *Encyclopedia of Energy*. 3: 647-654.

Northwest Berry & Grape Information Network. 1997. Grape Rootstocks and Nutrient Uptake Efficiency. Retrieved November 4, 2008 from: http://www.berrygrape.oregonstate.edu/grape-rootstocks-and-nutrient-uptake-efficiency/.

Notarnicola, B., Tassielli, G. & G. M. Nicoletti. 2003. Life Cycle Assessment (LCA) of Wine Production. In: Mattson, B. & U. Sonesson (eds.), *Environmentally-friendly food processing*, pp. 306-326. Cambridge, England: Woodhead Publishing Limited.

Nova Scotia Agricultural College. 2003. Atlantic Canada Nutrient Management Planning: Study Guide, Revised First Edition.

Nova Scotia Department of Agriculture and Marketing. 2000. Guidelines for the Management and Use of Animal Manure in Nova Scotia. Publication No. R-91-2000.

Nova Scotia Liquor Commission. 2006. Annual Report, 2005-2006. Retrieved October 31, 2008 from: http://nslcweb.thenslc.com/portal/page?_pageid=33,2893846&_dad=portal&_schema=PORTAL.

Nova Scotia Liquor Commission. 2007. Annual Report, 2006-2007. Retrieved October 31, 2008 from: http://nslcweb.thenslc.com/portal/page?_pageid=33,2893846&_dad=portal&_schema=PORTAL.

Nova Scotia. 2006. Opportunities for Sustainable Prosperity 2006: an updated economic growth strategy for Nova Scotia. Retrieved September 15, 2008 from: www.gov.ns.ca/econ/ofsp/.

Odum, H.T. 1996. *Environmental Accounting: emergy and environmental decision making*. New York, New York: Wiley-Interscience. 370 pages.

Owen, L., Seaman, H. & S. Prince. 2007. Public Understanding of Sustainable Consumption of Food: a report to the Department for Environment, Food and Rural Affairs. Opinion Leader. Defra, London.

Papatryphon, E., Petit, J., Van der Werf, H. & S. Kaushik. 2003. Life Cycle Assessment of Trout Farming in France: a farm level approach. Life Cycle Assessment in the Agrifood sector. Proceedings from the 4th International Conference DIAS Report 61: 71-77.

Pattey, E., Trzcinski, M.K. & R.L. Desjardins. 2005. Quantifying the Reduction of Greenhouse Gas Emissions as a Result of Composting Dairy and Beef Cattle Manure. *Nutrient Cycling in Agroecosystems*, 72: 173-187.

Pearce, F. 1997. White Bread is Green. *New Scientist*, 156(2111): 10.

Pelletier, N.L. 2006. Life Cycle Measures of Biophysical Sustainability in Feed Production for Conventional and Organic Salmon Aquaculture in the Northeast Pacific. Master's Thesis, Dalhousie University.

Pelletier, N. & P.H. Tyedmers. 2007. Feeding Farmed Salmon: is organic better? *Aquaculture*, 272: 399-416.

Pelletier, N. 2008. Environmental Performance in the US Broiler Poultry Sector: life cycle energy use and greenhouse gas, ozone depleting, acidifying and eutrophying emissions. *Agricultural Systems*, 98(2): 67-73.

Pelletier, N. Arsenault, N. & P. Tyedmers. 2008. Scenario Modeling Potential Eco-Efficiency Gains from a Transition to Organic Agriculture: life cycle perspectives on Canadian canola, corn, soy and wheat production. *Journal of Environmental Management*, Published online: DOI10.1007/s00267-008-9155-x, June 24, 2008.

Pimentel, D. Bailey, O., Kim, P. Mullaney, E. Calabrese, J. Walman, L., Nelson, F. & X. Yao. 1999. Will Limits of the Earth's Resources Control Human Numbers? *Environment, Development and Sustainability*, 1:19-39.

Pimentel, D. 2004. Industrial Agriculture, Energy Flows in. *Encyclopedia of Energy*, 3: 365-371.

Pimentel D. & M. Pimentel. 1996. *Food, Energy and Society*. University Press of Colorado, Colorado, USA. 363 pages.

Pimentel, D. Hepperly, P. Hanson, J., Douds, D. & R. Seidel. 2005a. Environmental, Energetic, and Economic Comparisons of Organic and Conventional Farming Systems. *Bioscience*, 55(7): 573-582.

Pimentel, D., Hepperly, P., Hanson, J., Siedel, R. & D. Douds. 2005b. Organic and Conventional Farming Systems: Environmental and Economic Issues. Ecology and Evolutionary Biology Reports, Report 05-1. Accessed Oct 31, 2008 from: http://hdl.handle.net/1813/2101.

Pizzigallo, A.C.I., Granai, C. & S. Borsa. 2006. The Joint Use of LCA and Emergy Evaluation for the Analysis of Two Italian Wine Farms. *Journal of Environmental Management*, 86(2): 396-406.

Powers, S. 2007. Nutrient Loads to Surface Water from Row Crop Production. *International Journal of Life Cycle Assessment*, 12(6): 399-407.

Pré Consultants. 2008. Life Cycle Consultancy and Software Solutions. Retrieved November 4, 2008 from: http://www.pre.nl.

Refsgaard, K. Halberg, N. & E.K. Steen Kristensen. 1998. Energy Utilization in Crop and Dairy Production in Organic and Conventional Livestock Productions Systems. *Agricultural Systems*, 57(4): 599-630.

Reid, W.V., Mooney, H.A.., Cropper, A., Capistrano, D., Carpenter, S.A. & K. Chopra. 2005. Ecosystems and Human Well-being: General Synthesis. Millennium Ecosystem Assessment. Retrieved November 4, 2008 from: http://www.millenniumassessment.org/en/Synthesis.aspx.

Resource Recovery Fund Board (of Nova Scotia). 2008. Beverage Container Recycling Program. Retrieved November 4 2008, from: http://www.rrfb.com/default.htm.

Russell, A., Ekvall, T. & H. Baumann. 2005. Life Cycle Assessment: introduction and overview. *Journal of Cleaner Production*, 13(13-14): 1207-1210.

Schlich, E. H., & U. Fleissner. 2005. The Ecology of Scale: assessment of regional energy turnover and comparison with global food. *International Journal of Life Cycle Assessment*, 10(3): 219-223.

Schmidt, J.H. 2007. Life Cycle Assessment of Rapeseed Oil and Palm Oil. Ph.D. thesis, Part 3: Life Cycle Inventory of Rapeseed Oil and Palm Oil. Department of Development and Planning, Aalborg University.

Schreiner, J. 2005. *Orofino Vineyards: Canada's first strawbale winery opens in Similkameen Valley*. Retrieved October 31, 2008 from: http://wine.appellationamerica.com/wine-review/28/Orofino-Vineyards.html.

Shepherd, R. Magnusson, M. & P. Sjödén. 2005. Determinants of Consumer Behaviour Related to Organic Foods. *Ambio*, 34(4): 352-359.

Smith, A., Watkiss, P. Tweddle, G., McKinnon, A., Browne, M. & A. Hunt., *et al*. 2005. The Validity of Food Miles as an Indicator of Sustainable Development: Final Report. DEFRA

Sonesson, U., Janestad, H. & B. Raaholt. 2003. Energy for Preparation and Storing of Food: models for calculation of energy use for cooking and cold storage in households. SIK report No. 709. Göteburg, Sweden: The Swedish Institute for Food and Biotechnology.

Sonesson, U. & J. Davis. 2005. Environmental Systems Analysis of Two Meals: model description and data used for two different meals. SIK report No. 735. Göteburg, Sweden: The Swedish Institute for Food and Biotechnology.

Sonesson, U., Anteson, F., Davis, J. & P. Sjödén. 2005. Home Transport and Wasteage: environmentally relevant household activities in the life cycle of food. *Ambio*, 34(4): 371-375.

Stadig, M. 2001. Life Cycle Assessment of Apple Production: case studies for Sweden, New Zealand and France. SIK report No. 683. Göteburg, Sweden: The Swedish Institute for Food and Biotechnology.

Stolze, M., Piorr, A., Häring, A. & S. Dabbert. 2000. The Environmental Impacts of Organic Farming in Europe. Organic farming in Europe: economics and policy; 6. University of Hohenheim, Germany. Retrieved October 15, 2008 from http://www.uni-hohenheim.de/i410a/ofeurope.organicfarmingineurope-vol6.pdf.

Subak, S. 1999. Global Environmental Costs of Beef Production. *Ecological Economics*, 30: 79-91.

Sustainable Winegrowing New Zealand. 2008. *Introduction*. Retrieved October 31, 2008 from: http://www.nzwine.com/swnz/.

Talve, S. 2001. Life Cycle Assessment of a Basic Lager Beer. *International Journal of Life Cycle Assessment*, 6(5): 293-298.

United Nations Environment Program. 2006. Life Cycle Management: a business guide to sustainability. Retrieved: November 4 2008 from: http://lcinitiative.unep.fr/.

United Nations General Assembly. 1987. World Commission on Environment and Development. Report of the World Commission on Environment and Development. 42/187. 96th Plenary Meeting, 11th December, 1987. Retrieved October 31, 2008 from: http://www.un.org/documents/ga/res/42/ares42-187.htm

United States Environmental Protection Agency. 1995. Emission Factor Documentation for AP-42, Section 9.12.2 - Wines and Brandy. Final Report for U. S. Environmental Protection Agency, Office of Air Quality Planning and Standards; Emission Factor and Inventory Group. Table 4-3. Summary of Candidate Emission Factors for Fermentation in Wine Production.

United States Environmental Protection Agency. 2004. Unit Conversions, Emissions Factors, and Other Reference Data. Retrieved: November 4, 2008 from: http://www.epa.gov/appdstar/pdf/brochure.pdf.

Van Zeijts, H., van den Born, G.J. & M.W. van Schijndel. 2003. Comparing Integrated Crop Management and Organic Production. In: *Environmentally-friendly food processing*. Mattsson, B. & U. Sonensson (eds.), pp. 70-92. Cambridge, England: Woodhead Publishing Limited.

Vitousek, P.M., Ehrlich, P.R., Ehrlich, A.H. & P.A. Matson. 1986. Human Appropriation of the Products of Photosynthesis. *Bioscience*, 36(6): 368-373.

Von Bahr, B. & B. Steen, 2004. Reducing Epistemological Uncertainty in Life Cycle Inventory. *Journal of Cleaner Production*, 12: 369-388.

Vringer, K. & K. Blok. 1995. The Direct and Indirect Energy Requirements of Households in the Netherlands. *Energy Policy*, 23(10): 893-910.

Wackernagel, M. & W. Rees. 1995. *Our Ecological Footprint: reducing human impact on the earth*. Gabriola Island, BC: New Society Publishers. 176 pages.

Wallén, A., Brandt, N. & R. Wennersten. 2004. Does the Swedish Consumer's Choice of Food Influence Greenhouse Gas Emissions? *Environmental Science & Policy*, 7(6): 525-535.

Wandel, M. & A. Bugge. 1997. Environmental Concern in Consumer Evaluation of Food Quality. *Food Quality Preference*, 8: 19-26.

Waste Resource Action Programme. 2008a. Lightweight Bottles: less is more. Retrieved October 31, 2008 from : http://www.wrap.org.uk/downloads/GlassRite_Wine_lightweighting_-_web_version.d52d1615.5381.pdf.

Waste Resource Action Programme. 2008b. Benefits of Importing Wine in Bulk. Retrieved October 31, 2008 from: http://www.wrap.org.uk/downloads/GlassRite_Wine_lightweighting_-_web_version.140c420e.5382.pdf.

Weidema, B.P & M.J.G. Meeusen (eds). 2000. Agricultural Data for Life Cycle Assessments, Volume 1 and 2, Agricultural Economics Research Institute (LEI), The Hague.

Winery Association of Nova Scotia. 2005. *Nova Scotia Grape Wine Standards.* Retrieved October 31, 2008 from: http://www.winesofnovascotia.ca/images/pdfs/Nova_Scotia_Wine_Standards.pdf.

Winery Association of Nova Scotia. 2008. *Wineries*. Retrieved October 31, 2008 from: http://www.winesofnovascotia.ca/wineries/index.php.

Wines of Canada. 2007. *Organic Wines*. Retrieved November 4, 2007 from: http://www.winesof Canada.com/organic_wines.html.

Wood, S. 2006. *Wineries and Wine Country of Nova Scotia*. Halifax, Nova Scotia: Nimbus Publishing. 108 pages.

Yalumba. 2007. *Yalumba and the Environment: Share Yalumba, Share the Future*. Retrieved November 4, 2008 from: http://yalumba.com/library/EPA_May_1.pdf.

Zanoli, R. & S. Naspetti. 2002. Consumer Motivations in the Purchase of Organic Food: a means-end approach. *British Food Journal*, 104: 643-653.

Ziegler, F. 2003. Environmental Impact Assessment of Seafood Products. In: *Environmentally-friendly food processing*, Mattsson, B. & U. Sonesson (eds.), pp. 70-92. Cambridge, England: Woodhead Publishing Limited.

Ziegler, F. & P. Hansson. 2002. Emissions from Fuel Combustion in Swedish Cod Fishery. *Journal of Cleaner Production*, 11: 303-314.

Ziegler, F., Nilsson, P., Mattsson, B. & Y. Walther. 2003. Life Cycle Assessment of Frozen Cod Fillets Including Fishery-specific Environmental Impacts. *International Journal of Life Cycle Assessment*, 8(1): 39-47.