Life Cycle Environmental Impact Assessment of Local Wine Production and Consumption in Texas: Using LCA to Inspire Environmental Improvements

Life Cycle Environmental Impact Assessment of Local Wine Production and Consumption in Texas: Using LCA to Inspire Environmental Improvements

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A Thesis in the Field of Sustainability

for the Degree of Master of Liberal Arts in Extension Studies

Harvard University

May 2017

Abstract

The future viability of wine production is directly linked to its environmental impacts and conditions in which it is required to operate. The environmental impacts related to the production of a food product are directly influenced by the amount of materials, energy, waste and the emissions the product releases throughout the products life cycle. A life cycle assessment (LCA) provides a framework that can identify a food products relative environmental impacts and provides insights into the complexities of our modern food production activities. This research employed an LCA to quantify the impacts and potential improvement scenarios for the wine production industry in Texas. To quantify these impacts, the LCA examined all life cycle phases of the wine industry: viticulture agricultural practices (conventional or organic), the type of grapes cultivated, scope of processing activities (viniculture), use of packaging materials (bottles, corks, labeling), transportation links, consumption, and final disposal. Evaluating these processes addressed the primary research question: Which factors contribute to the relative environmental impacts associated with the production of a 750ml bottle of wine produced and consumed in Texas?

In order to carry out this research I followed the 14040 standardized framework as a first step. This framework helped identify how the Texas wine industry contributes to the environmental impacts associated with the production of a 750ml bottle of wine. The LCA quantified these impacts and identified how the industry could benefit from switching from the business as usual approach by tackling the most impactful areas associated with the wine production. By modeling different scenarios, I tested the

hypotheses that both organic farming techniques, and the use of lighter bottles, would reduce the impact categories. The results for the organic farming scenarios showed that restrictions on the use of synthetic pesticides, herbicides and fertilizers lowered environmental impacts associated with eutrophication, ecotoxicity and global warming potential. Results for the lighter bottle scenario demonstrated that a reduction in the weight of the glass bottles will reduce both packaging and transport related CO_2 emissions associated with the production processes of the bottle. A sensitivity analysis also determined if the study was influenced by any uncertainties.

These results suggest recommendations to increase sustainability in the Texas wine industry based on the LCA. Based on the cultural and economic importance attached to wine production in Texas, it is vital that quantification and mitigation of the environmental impacts associated with this industry takes place. Utilizing an LCA ensured that any efforts to improve upon the performance of the Texas wine industry will not unknowingly "shift" the burden to another aspect of the production chain (Baumann & Tillman, 2004). The results help inform future decisions that can improve upon the industry's environmental profile and marketability, and provide a foundation that helps Texas continue to pursue an economic growth strategy that is not only economically sustainable, but environmentally and socially acceptable as well.

Acknowledgments

I thank Gregory Norris greatly for his willingness to help me at odd hours of the day, providing key insights, a calming demeanor and generous guidance throughout the thesis process.

In regards to the vineyard owners whom participated in the study, I want to thank Gabe Parker, Bobby Cox, Gene Estes, and the other Texas vineyard owner who wished to remain anonymous, for assisting me throughout this process. I also want to thank Debbie Reynolds from the Texas Wine and Grape Growers Association, for taking the time to meet with me and helping me network within the Texas wine industry. I cannot thank them enough for donating their time, knowledge, expertise and the data that helped me complete my thesis.

Finally, I thank everyone who stood by me throughout this process by encouraging and supporting me. Especially, Karen who knows me better than anyone and is always there for me every step of the way.

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Definition of Terms

AVA	At least 85% of the volume of wine must come from grapes grown in that designated region
Ecotoxicity	Potential for biological, chemical, and or physical stressors that affect the ecosystem
Enology	The study of wines
Eutrophication	Enrichment of an ecosystem with chemical nutrients (usually contains nitrogen and or phosphorus)
LCA	Life cycle assessment
LCI	Life cycle inventory
LCIA	Life cycle impact assessment
Mesoclimate	Climate of a particular vineyard site (restricted to a small space. Usually, tens or hundreds of meters)
Terroir	The complete natural environment where wine is produced, including the soil, topography and the climate
Oenology	The science of viniculture
Viticulture	growing grape processes
Viniculture	Wine processing activities

Chapter I

Introduction

The production of wine is one of the world's oldest industries (Pretorius, 2000). Quantifying the environmental impact associated with wine production and cultivation is not a widely studied subject (Barber, 2009; Marshall, 2005). Although the wine industry generally has a reputation for being environmentally safe, prior research of viniculture (processing wine) and viticulture (grape growing) processes exposed a large number of environmental concerns (Christ & Burritt, 2013). The wine production industry inadvertently influences the physical environment where it operates and its future viability is linked to these environmental impacts and conditions in which it operates (Schaltegger & Burritt, 2000).

The economic impact of the grape and wine industry in Texas directly employs around 8,000 people and contributes more than $1.88 billion to the Texas annually (USDA, 2010). Therefore, based on the relative economic importance of the wine industry in Texas, it is vital to understand how this industry can continue to be a part of a successful economic growth strategy that is not only economically, but environmentally and socially sustainable as well.

Research Significance and Objectives

This research addresses the environmental burdens of wine production in Texas throughout its entire lifecycle. Quantifying these impacts will assist local industries in identifying potential opportunities that will improve their environmental performance within various aspects of the wine productions life cycle (ISO, 2006a). Based on the cultural and economic importance attached to the production of wine in Texas, it is vital to understand and help minimize the negative environmental burdens and impacts associated with this industry's activities (IVO, 2015). Current practices within the wine industry are largely unexplored and inadequate in terms of qualitative environmental data. Without viable quantitative data, there can be no means to push towards more sustainable or proactive actions, track progress within the industry, and or identify the environmental impact areas that need improvement efforts.

Based on limited case studies some known environmental impacts associated with producing and consuming wine in other regions around the world and the expected growth rate in the wine industry, studying Texas wine offers a constructive and unique application of using the Life Cycle Assessment (LCA) methodology. The practical application of this methodology is a necessary element that can help existing and potential grape growers comprehend the associated environmental impacts of this industry to continue to safeguard the future wellbeing and profitability of cultivating winegrapes in the Texas region (Appel, 2016). The results will provide an array of qualitative data that will lead to an in-depth understanding of these processes which can bring about lasting environmental improvements for operational practices, products, and push towards economically and environmentally improved performance (Gabzdylova, Raffensperger & Castka, 2009). Therefore, my primary objectives were:

1) To perform an LCA to quantify the impacts for the functional unit of one 750ml bottle of wine made entirely from Texas AVA grapes in 2015 and consumed by a

Texas resident in their home. (The term AVA means that at least 85% of the volume of wine must come from grapes grown in that designated region).

2) To evaluate the advantages of reducing the associated life cycle impact categories by comparing two hypothesized sustainability improvements, organic viticulture techniques and lighter bottles, to the business as usual approach.

Background

The burdens associated with our modern food systems often generate larger environmental micro and macro-scale environmental emissions that are generally not accounted for. The use of a life cycle assessment methodology can help quantify how the wine industry's processes affect the environment and identifies that areas of possible improvements.

The Industrialization of Food Systems and its Environmental Consequences

Before the industrialization of our food systems, the climate, length of the growing season, soil fertility and presence of local biodiversity were major determinants of the amount of food that could be produced annually. Originally, human populations were heavily influenced by the amount of directly available energy, materials and the ecosystems' ability to handle waste inputs (Carlsson-Kanyama, 1998; Foster, Green, Blenda, & Dewik, 2007). Only within this past century has the industrialization of our food systems in developed countries reduced the limitations associated with the lack of food resources. Research done from the 1960-1970s indicated that agriculture only accounted for around a third of the total energy that was used in the U.S. food system

(Robertson, Paul, & Harwood, 2000). Within the past ten years, the world's food production rates have increased by 24% (USDA, 2010). The adoption of new technologies (highly dependent on fossil fuel use), use of fertilizers, less manual labor, and the ability to grow food for longer time frames, has increasingly reduced the physical limits in which food production was originally bound (Foster, Green, Blenda, & Dewik, 2007).

Within developed countries, advancements in the food industry have created a foundation in which this industry is now one of the most energy and resource intensive activities that consumers participate in (Foster, Green, Blenda, & Dewik, 2007; Carlsson-Kanymana, 2003). In 2010, 15.7% of the total national energy budget stemmed from food related energy activities and is increasing every year (USDA, 2010). This dramatic increase in resource and energy use in the food industry is directly contributing to some of the world's most difficult challenges. Some of these challenges include: climate change, ozone depletion, acidification, resource depletion, ecotoxicity, ozone depletion, etc. (Robertson, Paul, & Harwood, 2000; Foster, Green, Blenda, & Dewik, 2007). The cumulative effects of these environmental impacts encourage extensive pressures on our ecosystem services in which we depend upon for our continued existence. Therefore, we must explore the application of LCA to the wine industry's activities to identify possible management strategies that reduce these environmental impacts.

Based on previous case studies, many of the associated environmental impacts are directly or indirectly related to our reliance on fossil fuel energy sources at each of the wine productions life cycles (Carlsson-Kanyama, 1998; Horrigan, Lawrence, & Walker, 2002). Some of these fossil fuel energy intensive activities are related to farm operations:

fertilizer and pesticide production, acquisition and applications, processing the wine (viniculture activities), manufacturing the bottles (electricity production, materials needed to make the bottle, transporting the materials), transportation links, refrigeration, and end of life disposal (Carlsson-Kanyama, 1998). Due to the complexity surrounding the analysis of a food production system, it is necessary to perform a more quantitative analysis. The impacts related to a food or a beverage product are directly influenced by the amount of energy, materials, waste and the emissions the product releases throughout the products life cycle (Kramer, Mattsson, & Sonesson, 2003; Wallén, Brandt, & Wennersten. 2004; Neiuwallar, 2004). Thus, the LCA approach provides a more in-depth assessment of these environmental impacts.

Organic and Conventional Agriculture

An enlightening application of life cycle assessment to food production systems is comparing conventional and organic agriculture methods. In the United States, the term organic viticulture is defined as a farming system that produces grapes that follow regulations of the National Organic Program (NOP) (USDA, 2014). In practice, organic agriculture utilizes a wide range of farming systems, including the use of crop protectants and fertilizers that are derived from natural sources (botanicals, mined minerals, animal, and plant byproducts). Based on these stipulations, in regards to toxicity impacts, organic viticulture is typically reported as more auspicious than conventional viniculture farming (De Backer, Aertsens, Vergucht, & Steurbaut, 2009). However, these results are typically dependent upon which environmental performances indicators were selected and the parameters associated to the area of study for the LCA. In reference to the wine making processes, organic and conventional agriculture have numerous competing merits. Thus, determining which technique is environmentally advantageous is a complex process.

There are several obstacles which can arise from the use of organic farming techniques. These complications are based on the acquisition and application of naturally derived fertilizers and pesticides. The use of manure based fertilizers can release higher rates of N_2O and NH_3 into the air and leach NO_3 and P_2O_5 into the soil (IPPCC, 2006; Mattsson, 2000). Similarly, although the application of organic pesticides may lead to lower toxicity related emissions, organic pesticides typically have a higher environmental impact due to the amount of energy that is required in their manufacture (Notarnicola, Tassielli, & Nicoletti, 2003). These examples indicate how the results of comparing these two techniques in an LCA are dependent upon the parameters examined, the assumptions that are made, the type of products that will be analyzed, and the geographical differences (climate, pests present, temperature, humidity levels, etc.). Results may not be the same for every vineyard analyzed.

An example of such a case study was performed by Mattsson (2000) who performed an LCA that focused on the comparison of both organic and conventional carrot cultivation techniques. The energy use in conventional systems for carrot production was 20% higher than organic agricultural cultivation techniques. However, the organic system recorded a eutrophication emission rating 25% higher than conventional farming and required double the land area per unit of carrot production (Mattsson, 2000). Another comprehensive case study was performed comparing the benefits of organic versus conventional farming. Mondelares assessed 10 farms in developed countries and determined that the crop yields for organic farms are on average

17% lower than farms that use conventional methods, but the use of organic pesticides also reduced the toxicity related emissions (1999b). However, in other case studies in which organic agriculture yields were equivalent, then the organic systems tend to outperform the traditional viniculture vineyards in multiple impact categories (J. Steinhart, & C. Steinhart, 1974). Some of these impact category improvements were related to a decrease in energy use, green house gas emissions (GHGs), and ozone-depleting emissions (J. Steinhart, & C. Steinhart, 1974). Therefore, the large variances in these results reiterates the need to evaluate each LCA case on an individual basis. In summary, proper analysis must be performed before a preference for organic or conventional farming can be established.

Packaging Options and its Relative Importance in the Wine Industry

Within the wine industry there are several alternative forms of packing materials that can be employed to bottle or package wine: glass, liquid cartons, aluminum, Polyethylene Terephthalate (PET), bag-in-box, or pouches. Some of these packaging materials which weigh significantly less, and produce fewer emissions per pound than traditional glass bottles. However, wine typically oxidizes at accelerated rates in a majority of these alternative packaging materials.

In the case of glass bottles, an average case holds twelve 750 ml glass bottles and weighs anywhere from 33 to 42 pounds. These cases can contribute to around a 1.8% increase of CO_2 emissions, as opposed to a PET bottle traveling equal distances (Colman & Paster, 2007). In the case of PET wine bottles, an average case of wine weighs around 22 pounds with a weight savings of around 40% (Thompson, 2010). While these diminished weights can help minimize transportation costs, reduce associated CO_2 emissions, decrease the risk of breakage, and offer flexibility in design, PET does not provide similar levels of protection from oxidation. Based on the nature of PET materials, plastics are much more porous and allow the wine to oxidize at an accelerated rate (Thompson, 2010). Oxidation of the wine significantly reduces the quality of the wine, so wineries prefer to use glass bottles.

Another alternative form of packaging is the bag in a box design. Boxed wine offers several advantages over using a glass bottle. These advantages include more economically minded packaging, minimizing transportation costs and using an easy open and pour system. However, examination of the enological characteristics of wine packaged in these types of containers indicates that the internal packaging system (known as a bladder) that contains the wine is not hermitically sealed and can oxidize the wine even when the package remains unopened (Fusi, Guidetti, & Benedetto, 2014). Based on these findings and higher oxidation rates of the bladder, wineries and consumers typically prefer the use of a glass bottle.

The packaging choice of a vineyard owner is highly influenced by the purchasing preference of the consumer, which is typically a glass bottle. Glass bottles preform an important function. Glass bottles protect the quality of the wine produced by reducing the oxygen penetration through the non-porous glass bottle. While there are many other alternative bottling mechanisms that might be both economical and less dense than the traditional glass bottle, these alternative containers fail to preserve the nature of the wine, unlike glass bottles. Within the past decade, wine bottles have gradually increased in weight based on consumer association of the heaviness of a bottle with a higher quality of wine (Waste Resource Action Programme, 2008).

Based on a recent shift of the consumer's preference for more environmentally friendly products, however, consumers and winery owners alike are beginning to shift to more economical and more ecologically minded packaging options. These demands have lead glass manufactures to develop an alternative method called "light weighting" which decreases the amount of materials needed to manufacture a glass wine bottle (Gannon, 2009). Light weighting focuses on trimming the wall layers down and eliminating the punt (indention) usually located on the base of the wine bottle (Gannon, 2009) without compromising the quality of the wine. By incorporating this technique, glass manufactures have observed that these processes diminish the amount of glass used by up to 16% with a cost savings of up to 10% (Thompson, 2010).

These consumer preferences, preserving the enological characteristics of the wine, and the winery owner's preference for more economically produced packaging materials, provides incentives to explore improvement opportunities to ameliorate the environmental profile of Texas wine. This reiterates the need to evaluate the use of a lighter bottle through LCA to address these knowledge gaps through proper analysis before a preference of the type of glass bottle and its associated benefits can be established.

Life Cycle Assessments of Wine Production

Researchers in a few countries around the world have begun to quantify the environmental impacts associated with wine production through application of LCA.

Two such case studies are from Portugal and in Nova Scotia, Canada. In wine production, environmental impacts can stem from numerous activities, which can include, but are not limited to, agricultural practices, type of grape cultivated, scope of the processing activities, use of packaging materials, transportation links, storage conditions, use and the disposal route taken (Nieuwlaar, 2004). In each of the following case studies I review, the functional unit of study was one 750ml bottle of wine. This comparison demonstrates that, despite similarities in the processes analyzed, the environmental impact categories vary. While these studies may be comprehensive and offer an insight into some of the issues within the wine industry, no LCAs exist which assess the wine production processes in Texas.

Life Cycle Assessment of Portuguese Wine Production

A study conducted in northern Portugal, in Leiro and San Amaro, aimed to identify which environmental impacts occur during the life cycle processes for the production of a bottle of white vinho verdes (Neto, Dias, Machado, 2012). The life cycle assessment considered the following: the viticulture techniques utilized; viticulture processes needed from vinification (wine production) through the storages processes; wine distribution (transportation links); and processes associated with bottle production (Figure 1) (Neto, Dias, & Machado, 2012).

Primary data were collected through a set of detailed questionnaires that were distributed to the wine-growers who participated in the study. Other primary data were collected at the cultivation sites to account for fuel usage, pesticide and fertilizer applications, field operations utilized, use of machinery or trellis, labor data (working

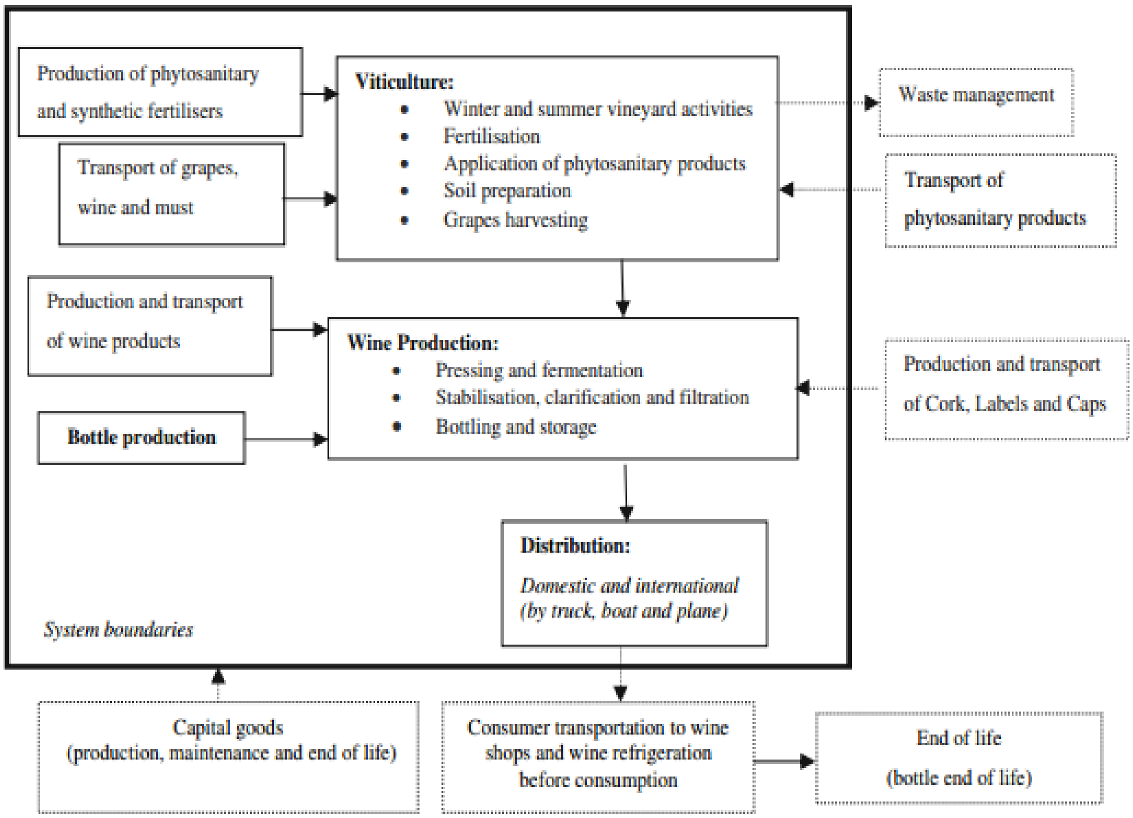

Figure 1. Life cycle stages for white vinho verde production. Bolded square delineates system boundaries and the dotted square shows potential inputs and outputs of the systems that are present, but, were not accounted for during the study.

hours of employs), electricity needed to produce the bottles, etc. Secondary data collection stemmed from the Ecoinvent database for the production of plant protection products, trellis and or diesel usage. Once the data had been collected, the researchers utilized the SimaPro (version 7.3.2) to model the life cycle assessment of wine using midpoint indicators of the environmental impact (CML 2001 impact assessment method) to perform the LCIA analysis and interpret the results (Neto, Dias, & Machado, 2013).

Overall, the results indicated that the most burdensome phases of the wines life cycle in Portugal stemmed from viticulture (grape growing) processes (Table 1). The contribution of viticulture for each of the impact categories selected for the study were larger than 50%. Bottle production was the second highest contributor for each of the selected environmental impact categories, ranging from about 4% (eutrophication) to 26% (acidification) (Neto, Dias, & Machado, 2013). Based on the two most burdensome environmental activities stemming from the viticulture processes incorporated into the wine making processes and bottle production activities, these results establish a decent foundation for further research, and future mitigation strategies that could be devised and tested in order to improve upon the processes in this country.

Table 1. Life cycle impact assessment results for white vinho verde wine.

							Distribution		
Impact category	Viticulture	%	Bottle production	%	Wine production	%	Domestic	Worldwide	%
Eutrophication (kg PO_4^{3-} eq)	7.3E-03	89.9	2.9E-04	3.6	3.7E-04	4.5	1.2E-04	4.5E-05	2.0
Land competition (m^2a)	1.1E+00	88.7	1.3E-01	10.7	7.4E-03	0.6	1.6E-05	2.0E-05	0.0
Ozone layer depletion steady state (kg CFC-11 eq)	3.3E-07	77.3	4.8E-08	11.1	1.5E-08	3.6	2.7E-08	7.6E-09	8.0
Terrestrial ecotoxicity 100a (kg 1.4-dB eq)	6.8E-04	70.0	1.9E-04	19.7	7.3E-05	7.5	2.4E-05	3.0E-06	2.8
Global warming 100a (kg CO_2 eq)	2.0E+00	68.6	4.4E-01	15.3	2.4E-01	8.1	1.8E-01	5.2E-02	8.0
Freshwater aquatic ecotoxicity 100a (kg 1.4-dB eq)	1.4E-02	67.4	4.4E-03	21.5	9.5E-04	4.7	1.0E-03	2.9E-04	6.4
Human toxicity 100a (kg 1.4-dB eq)	2.0E-01	65.5	5.4E-02	17.4	3.3E-02	10.4	1.2E-02	8.4E-03	6.7
Marine sediment ecotoxicity 100a (kg 1.4-dB eq)	2.6E-01	65.2	4.7E-02	11.9	5.2E-02	13.2	1.7E-02	2.2E-02	9.7
Freshwater sediment ecotoxicity 100a (kg 1.4-dB eq)	2.4E-02	64.1	8.5E-03	22.5	2.1E-03	5.6	2.3E-03	7.3E-04	7.8
Abiotic depletion (kg Sb eq)	1.1E-02	63.7	3.3E-03	18.9	1.6E-03	9.0	1.1E-03	3.3E-04	8.4
Marine aquatic ecotoxicity 100a (kg 1.4-dB eq)	2.3E-01	63.3	5.7E-02	15.6	4.7E-02	13.0	1.4E-02	1.6E-02	8.1
Acidification (kg SO_2 eq)	8.3E-03	55.1	4.0E-03	26.4	1.8E-03	11.9	6.1E-04	3.9E-04	6.6
Photochemical oxidation (kg C_2H_4 eq)	3.1E-04	50.6	1.4E-04	23.7	7.0E-05	11.7	7.1E-05	1.3E-05	14.0

These results are expressed in absolute values and in percentages of contribution from the life cycle stages that were analyzed and presented for each impact category above.

Life Cycle Assessment of Nova Scotia, Canada Wine Production

A study conducted in Nova Scotia, Canada aimed to quantify the associated impacts of and any potential improvement options for viticulture, viniculture, bottle provision, transportation links, consumer activities and recycling one bottle of Nova Scotia wine (Figure 2) (Point, 2008). The case study also focused on addressing the current debate surrounding locally produced organic foods, the consumer's role in the environmental impacts, and if lighter bottles would reduce environmental impacts associated the Nova Scotia wine industry (Point, 2008).

The primary vineyard data were collected through the use of a questionnaire that asked for relevant 2006 data on local Nova Scotia vineyards that only used grapes grown in that region to produce the wine. The questions covered land preparations tactics, what trellising system they used, nutriment applications, weed and pest management, fuel inputs, and crop yields (Point, 2008). Any sort of input and emissions data that were used in this LCA were derived from background processing data located in the LCA database.

The results in Table 2 indicated that the viticulture, heavier bottles and consumer transport were responsible for the highest contribution of the wines total LCA impacts. Viticulture (grape growing) accounted for at least 69% of all eutrophication environmental impact emissions, 54% of terrestrial ecotoxicity impact emissions and 37% of aquatic ecotoxicity impact emissions in the life cycle (Point, 2008). These emissions are primary impacted by the purchase and application of nitrogen fertilizers. The manufacturing processes associated with the production of the wine bottle also contributed to more than 35% of five of the nine impact categories examined in the study (abiotic resource depletion, acidification, global warming potential, cumulative energy

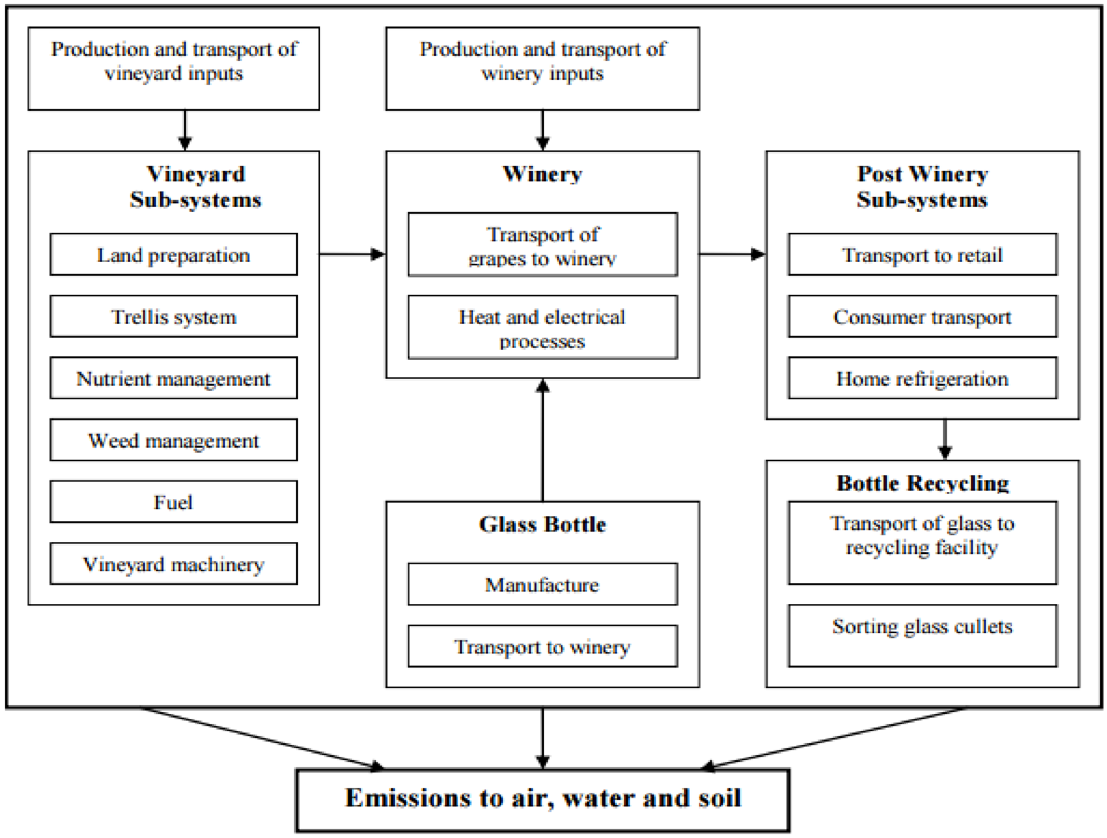

Figure 2. Life cycle system flow diagram of Nova Scotia Wine production in 2006 (Point, 2008). Includes all the major life cycle phases and sub-systems.

demand, photo-oxidant creation potential) (Point, 2008). The largest contributing factor to the higher emission rates of manufacturing the glass bottles stemmed from electricity use.

Based on these results, four additional models were assessed of possible management improvement options that would reduce environmental impacts in the Nova Scotia wine industry. These four models examined the potential of reducing the weight of the glass bottles by 30%, applying organic agricultural practices, decreasing the distance of transportation activities, and purchasing the wine from more local sources (Point, 2008). The results indicated that the lighter bottle would reduce the environmental impact emissions in all impact categories ranging from 4 to 23% (Point, 2008). The use of organic agricultural techniques offered minor improvements in a few impact categories, but also increased emissions in other categories (Figure 3). The last two scenarios modeled included transportation and purchasing wine from local sources. These scenarios provided strong evidence that purchasing wine locally is environmentally advantageous, but the mode of transportation (and distance traveled) strongly influences the results (Point, 2008).

Together these case studies help highlight the various sources of environmental impacts associated within the wine production industry. They provide two strong examples of how one of the world's oldest industries has yet to fully transition to more sustainable practices.

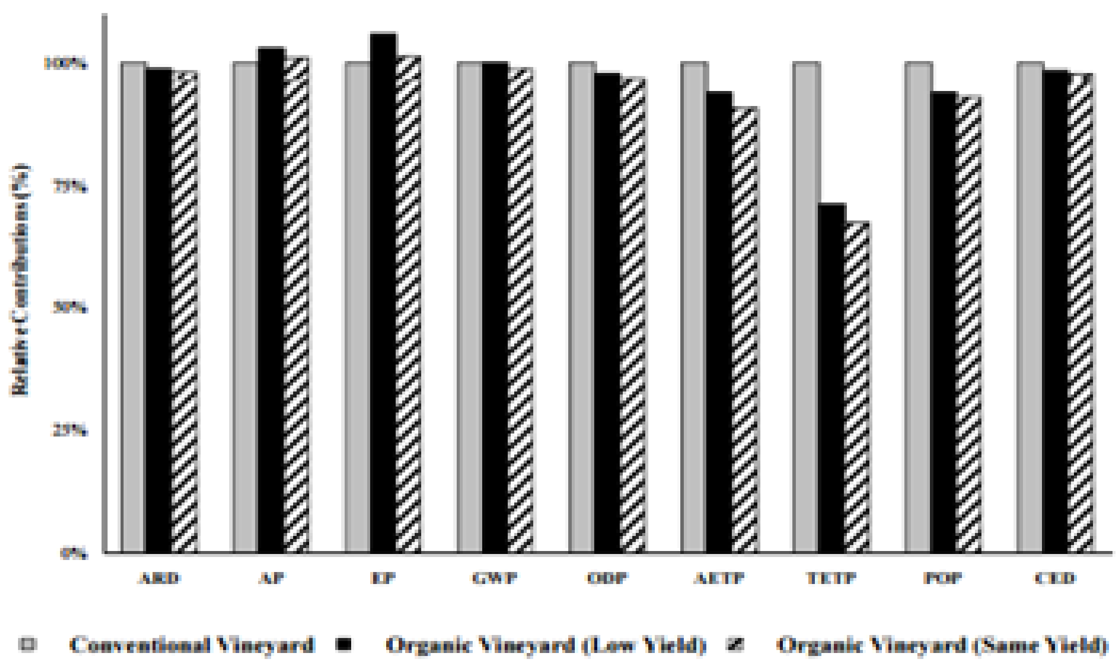

Figure 3. LCIA results for conventional (base case) and two organic grape growing scenarios in Nova Scotia (Point, 2008). For each of the impact categories analyzed, the conventional grape growing impacts are set at 100% and contributions of the two organic scenarios are shown relative to 100%.

Table 2. Life cycle inventory results for Nova Scotia viticulture in 2006 (Point, 2008).

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
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

The Texas Wine and Grape Industry

The International Organization of Vine and Wine established that the United States is the top fourth largest wine producer with 2015 production rate of 22,140 hectoliters. Grapes are one of the highest grossing fruit crops within the United States with an estimated value of around five billion dollars (National Grape & Wine Initiative, 2012). Wine production occurs in several locations throughout the United States, including California, Oregon, New York and Texas. Texas has a long history associated with wine production and is one of the oldest wine growing states. Documentation hints that the first vineyard planted within North America was planted in Texas by Franciscan priests in the 1650s (The Texas Wine & Grape Industry, 2013). Texas is now home to more than 4,000 acres of vineyards and is America's fifth top wine producer and top seven wine grape producer (Texas Wine and Grape Growers Association, 2015). Recent trends in grape production are shown in Figure 4.

The U.S. Department of Treasury through the Alcohol and Tobacco Tax and Trade Bureau officially designates America's viticulture (grape growing) areas, or AVAs. For a wine to mention an AVA on its label, 85% of the volume of wine must come from grapes grown in that designated region (Texas Wine and Grape Growers Association, 2015). Texas has eight official AVAs. These eight AVAs in Texas are divided in five regional growing regions that host a variety of microclimates that allow a large variety of different grapes to grow (Figure 5).

Despite the recent tendency for the economy to dip downwards, numerous wineries have opened throughout the state and have expanded the market for Texas grown grapes (Texas Wine & Grape Industry, 2015). Despite The economic impact of the grape and wine industry in Texas directly employs around 8,000 people and provides more than $1.88 billion to Texas annually (USDA, 2010). With an increase in the acreage of grapes cultivated, exposure and risk of losses to biotic and environmental factors significantly increases.

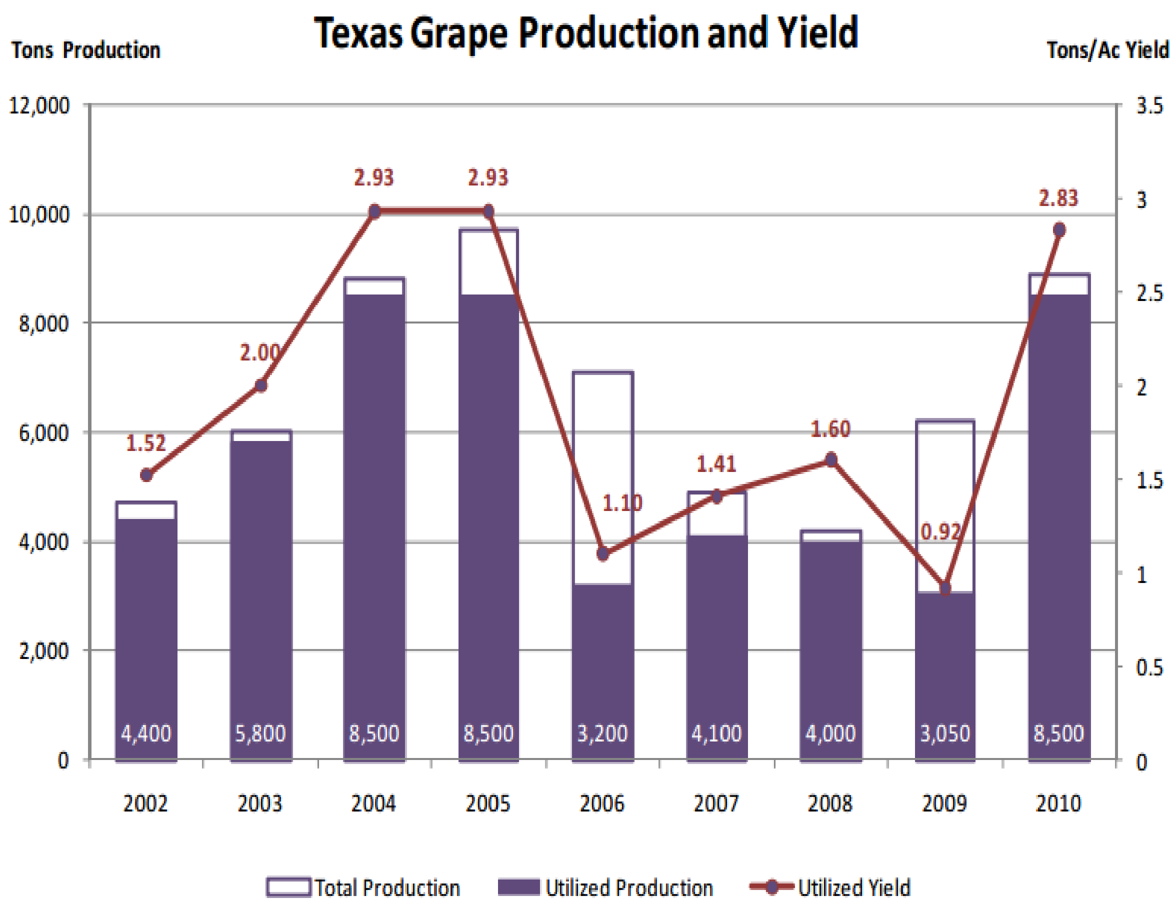

Figure 4. Texas grape production from 2002-2010. Data were compiled by the Texas Field Office of USDA-NASS (Texas Field Office of the National Agricultural Statistics Service of the USDA, 2010).

Texas Grape Variety Acreage by Region [1]

Region and Leading Varieties	Acres	Region and Leading Varieties	Acres
High Plains	1,040	**North Texas**	280
Cabernet Sauvignon	260	Syrah	50
Chardonnay	110	Cabernet Sauvignon	40
Merlot	110	Blanc du Bois	30
Muscat Canelli	80		
Tempranillo	60	**Central Texas**	610
Viognier	50	Cabernet Sauvignon	100
		Merlot	90
West Texas	900	Syrah	70
Chenin Blanc	*	Chardonnay	40
Chardonnay	*		
Cabernet Sauvignon	170	**Gulf Coast and South Texas**	170
Merlot	*	Black Spanish	40
Zinfandel	*	Blanc du Bois	40

[1] Only varieties with highest acreage in each region reported, they will not sum to region total. * Did not meet publication standards for disclosure.

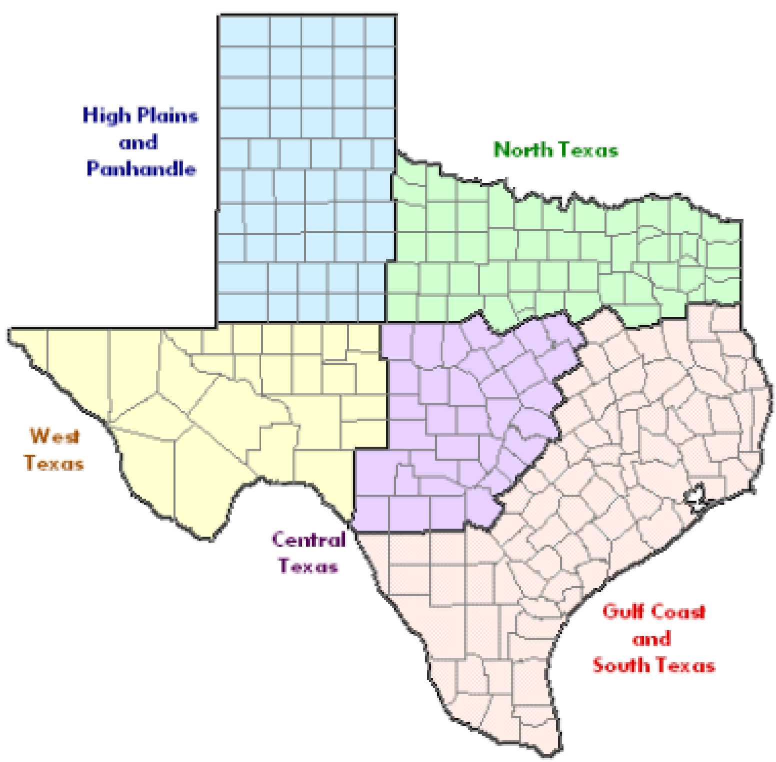

Figure 5. 2010 Texas grape production and variety survey by region (Texas Field Office of the National Agricultural Statics Service of the USDA, 2010).

Disease Prevalence and Susceptibility of Texas Grown Cultivars

Even with incorporating top management practices, there are numerous environmental and biotic stressors that make the cultivation of grapes in Texas exceptionally arduous. In relation to environmental factors, hail, early and late freezes, disease vectors, extreme wind, blowing sand, drought, excessive rainfall and severe heat waves are already limiting factors for cultivating both reliable and high quality grapes (Texas Wine & Grape Industry, 2013). Thus, to mitigate these associated risks, superior growing sites are a necessity.

For biotic stressors, the presence of disease vectors, fungal pathogens, insects and wildlife all make the cultivation of high-quality grapes in Texas very difficult. Diseases are particularly problematic (Table 3). Pierce's disease (PD) is arguably the most restrictive factor limiting cultivation of higher quality wine grapes within the Texas region (USDA, 2015). PD is precipitated by the presence of a bacterium known as *Xylella fastidosa* (Xf), which obstructs the water conductive tissues in the xylem of susceptible grapevine varieties. There is currently no cure for PD and current research indicates that up to 22 assorted species are able to transmit PD, with the highest transmission rates from the sharpshooter, leafhopper, and spittlebug insects (Texas Wine and Grape Growers Association, 2013).

Phylloexera, cotton root rot, Armillaria root rot and nematodes are all biological agents that affect the root systems of vines and if present, make it extremely difficult to cultivate wine grapes in Texas. *Phylloxera* are native microscopic insects that consume the rootstock and leaves of a grapevine, making the vine susceptible to secondary fungal infections which halt the movement of nutrients and water to the vine (McEacher, 2003).

Table 3. Relative disease susceptibility and development among Texas grape cultivars.

	Disease Susceptibility							
Variety	Black Rot	Downy Mildew	Powdery Mildew	Pierce's Disease	Phylloexera	Cotton Root Rot	Armillaria Root Rot	Phomopsis Cane and Leafspot
Black Spanish	+++	++	?	-	-	+	+	+
Blan de Bois	+++	++	?	-	?	+	++	+
Cabernet Sauvignon	+++	+++	++	+++	++	++	+	+++
Chardonnay	++	+++	+++	+	+	++	+	+++
Chenin Blanc	+	+	+++	+	+	+	N/A	N/A
Merlot	++	+++	+	+	?	++	+	+++
Muscat Canelli	++	++	+++	N/A	+	?	+	++
Tempranillo	?	+	++	N/A	+	+	+	+++
Syrah	+	+	++	+	?	++	++	++
Viognier	+	++	++	N/A	+	+	?	?
Zinfandel	?	?	++	N/A	+	+	?	?

The relative ratings of the chart are applicable to the typical growing conditions favorable for disease development. Thus, any given variety may be more severely affected or resistant. Ratings indicate: + mildly susceptible; ++ moderately susceptible; +++ highly susceptible; - Resistant; N/A indicates that information was limited.;? indicates conflicting data. Data were sourced from McEacher (2003), Baumgartner (2004), Ghorbani (2008), Texas Wine and Grape Growers Association (2013) and Poling, & Barclay (2015).

Grafting the rootstock with resistant strains is one of the few measures to guard against *Phylloxera*. Cotton root rot is a fungus endemic to Texas that targets the root system of the grapevines and is caused by *Phymatrotrichopsis omnivoa* (Ghorbani, Wilcockson, Koocheki, & Leifert, 2008). To control these fungal pressures, management decisions range from chemical applications (anhydrous ammonia, halogenated hydrocarbons, fungicides), to altering the pH of soil with Sulphur by adding ammonium sulfate, and using green manure with deep tillage tactics (Texas Grape Growers Association, 2013).

Armillaria root rot is another fungal pathogen that targets the grapevines root system and can be mitigated by root collar excavation tactics (exposing the roots to air), and or employing fumigation tactics as a means of fungal control (Poling & Spayd, 2015). Grape nematodes are microscopic parasitic roundworms that both target and consume the roots of a grapevine. Once established, nematodes are permanent and although applications of fumigant pesticides can reduce the presence of nematodes, they will also kill many beneficial organisms within the soil (Poling & Spayd, 2015).

Important insects that primarily impact grape production include the grape berry moth, leafhoppers, leafrollers, the metallic June beetle and the climbing cutworms (Texas Wine and Grape Growers Association, 2013). These insects consume the foliage and fruit of the grapevine and the fruit openings rapidly encourage fruit rot. These insects can be extremely destructive and result in significant yield reductions for the vineyard. Reoccurring monitoring for the presence of these insects is encouraged to assess the level of threat and discern a suitable means for treatment. In addition to the numerous soil borne pathogens, environmental factors and presence of insects, there are numerous fungi that directly affect the foliage and fruit throughout the entire state. These fungal diseases include downy mildew, powdery mildew, black rot, phomopsis, leafspot and cane leaf (McEacher, 2003). Based on Texas's climatic factors, understanding the general biology of these diseases, pathogens, and insects dictates that there are numerous measures that must be employed to protect the cultivated grapevines in the Texas region. Many of these management practices and control methods can have severe environmental impacts.

Research Question, Hypotheses and Specific Aims

Currently, there is no assessment of the environmental implications of the Texas Wine industry. Based on Texas being a large producer of wine and given other international LCA results, preforming an LCA with local data will help identify which significant impact categories have the greatest environmental implications of the designated functional unit at each aspect of the wine productions lifecycle (Baumann & Tillman, 2004). The primary research question addressed is: Which factors contribute to the relative environmental impacts associated with the production of a 750ml bottle of wine produced and consumed in Texas? The research especially focuses on comparing LCA results for the business as usual approach versus organic farming methods and the benefits of reducing the weight of glass bottles.

For organic farming, the research hypothesizes that the restrictions on the use of synthetic pesticides, herbicides and synthetic fertilizers will lower environmental impacts associated with eutrophication, ecotoxicity and global warming potential. As a second hypothesis, I expect that reducing the weight of the glass bottles reduces both packaging and transport related CO_2 emissions associated with bottle production.

Specific Aims

The hypotheses stated above articulate five specific research aims and indicates the corresponding methods to address these specific aims:

1. The first step focused on gathering the necessary data needed to evaluate the environmental burdens associated with the production of a 750-ml bottle of wine. This was done by identifying and quantifying the energy used, materials needed, and the waste

outputs that are released into the environment by utilizing the ISO 14040 framework to perform an LCA for this industry (Consoli, Allen, Bousted, Fav, Franklin et al., 1993).

2. A study sample of four vineyards located within the two of the eight recognized American Viticultural Areas (AVA) in Texas was identified. The areas included in the research are the Texas High Plains AVA (located west of Lubbock in the Panhandle) and the Texas Hill country AVA (located in central Texas). As per request for the vineyard owners, primary data were aggregated and weighted to protect the privacy of the vineyards.

3. Data for the four vineyards that agreed to participate in the study were collected by using the appended surveys (Appendices 1 & 2) and site visits. These surveys provided the data necessary to analyze the cradle to grave processes for the production of the wine. These processes included: viticulture (grape growing), viniculture (making the wine), glass manufacturing (bottle making), transportation and distribution, use, re-use, recycling, and final disposal (Figure 7, below).

4. The ISO 14040 standardized framework was incorporated to perform the LCA for the aggregated data from the four wine vineyards. The results were then analyzed to determine the most environmental burdensome activities associated with the cradle to grave life cycle stages of the production of the wine.

5. Three additional scenarios were modeled in order to compare the proposed alternative production techniques (organic viticulture) and products with similar functions (using lighter bottles) to determine if this improves the environmental burdens associated with the production of wine in Texas (ISOb, 2006; Andersson, 2000).

Chapter II

Methods

The methods section addresses the necessary aspects of performing the thesis research and highlights how to apply a life-cycle perspective of a complex food production system.

ISO 14040 Standardized Framework to Perform an LCA

Recently, methodological developments have improved upon the ability to apply an LCA to assess the environmental impacts associated with agricultural systems (Cowell & Clift, 1996; Audsley, 1997; Mattsson, Cederber, & Blix, 2000; Weidema & Meeusen, 2000; Brentrup, Küsters, Lammel, & Kuhlmann, 2000; von Bahr & Steen, 2004; Simon, Amor, & Földényi, 2016).

The first step for completing this LCA for the Texas wine industry focuses on following the ISO 14040 standardized framework. According to the ISO 14040 framework, an LCA should be comprised of four different methodological stages (2006). These four stages should be completed in the following order: goal and scope definition, life cycle inventory analysis (LCI), life cycle impact assessment (LCIA) with interpretation of the results, and improvement assessments that should be made (Baumann & Tillman, 2004). These methodologies help quantify the environmental energy and material flows that are either directly or indirectly, related to the material and energy consumption of the wine production processes (Baunman & Tilman, 2004).

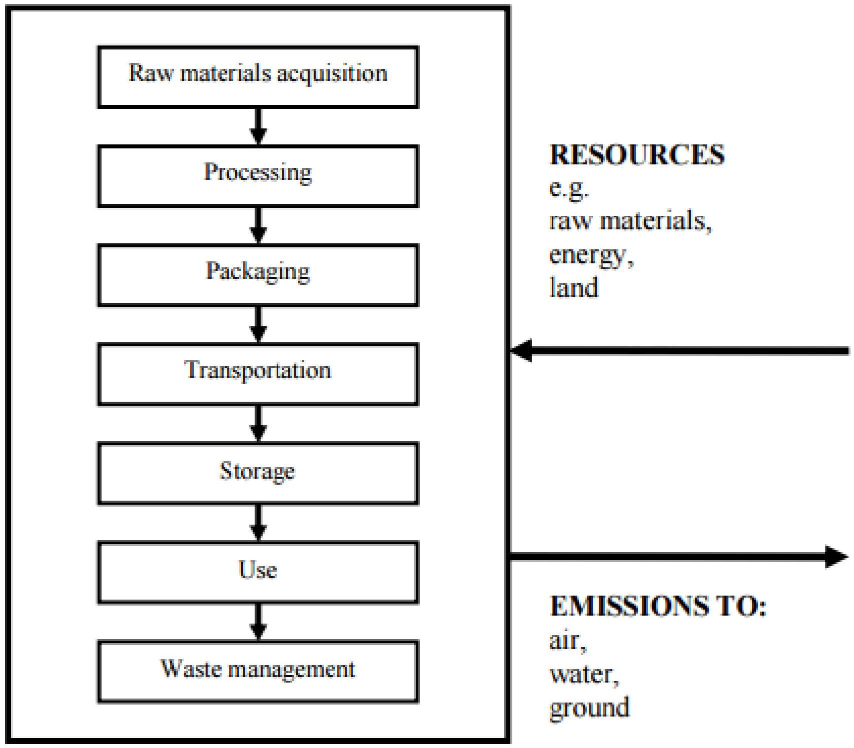

Figure 6. Model of the basic processes of a product life cycle. An LCA is a technique that assesses environmental impacts associated with all stages of a product's life cycle processes by compiling an inventory of all relevant energy and material inputs and is associated environmental releases to land, air, and or water sources.

Goal and Scope Definition

The goal and scope defines the following: all of the products and or services that will be assessed, a functional basis for comparison is chosen (functional unit), the unit system boundaries, the environmental impact categories of interest, and the required level of detail (limitations of the study) (ISOb, 2006; Baumann & Tillman, 2004).

The defined functional unit is one 750ml bottle of wine made entirely from Texas AVA grapes and consumed by a local resident. The bolded square accounts for the system boundaries under study (Figure 7). The green squares include all of the essential energy and material inputs/outputs that are associated with the processes of producing wine.

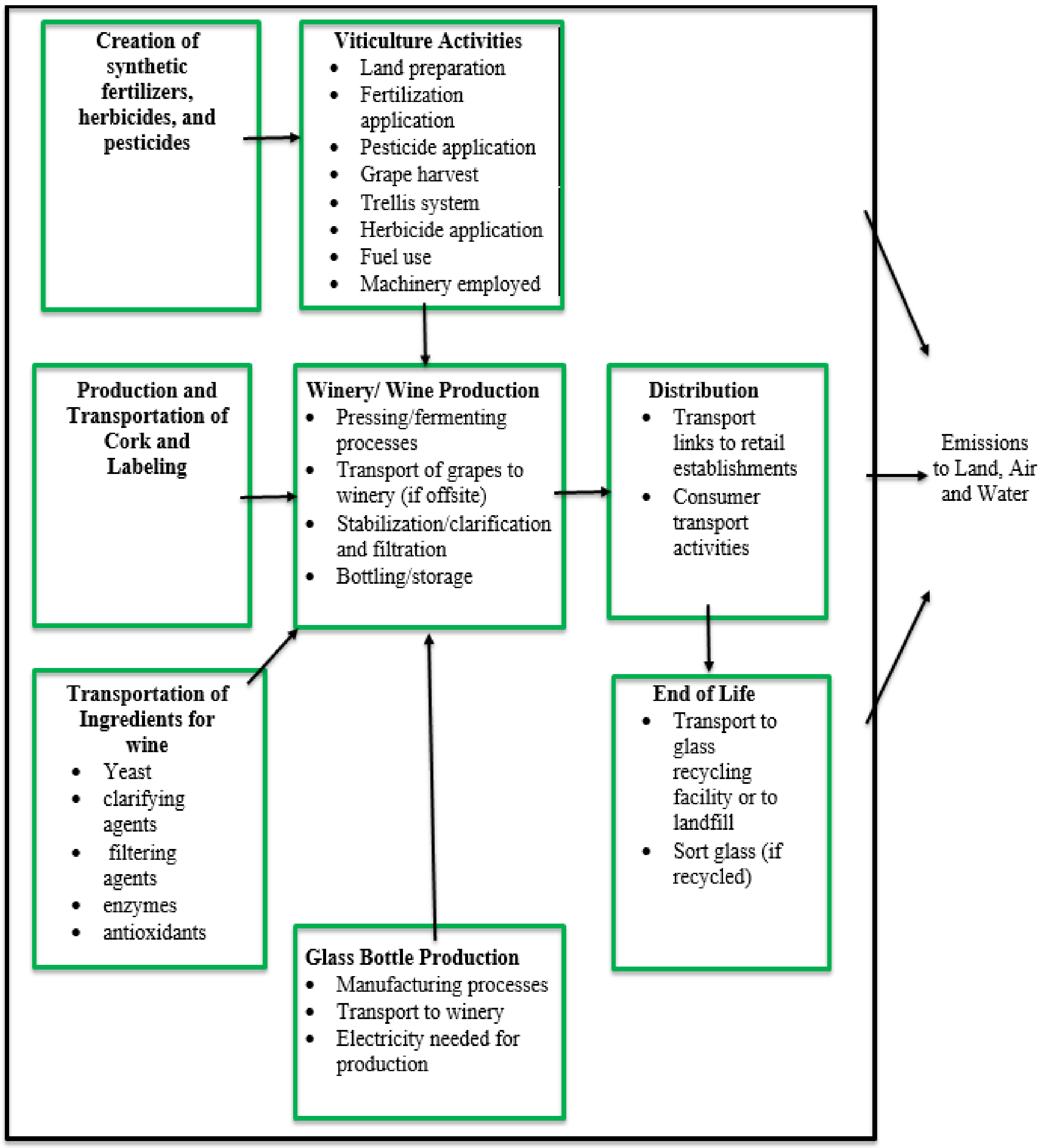

Figure 7. The LCA stages of Texas wine production. This system flow diagram includes all the major life cycle phases and sub-system phases associated with the wine industry (by author, 2017).

Life Cycle Inventory

The life cycle inventory (LCI) process involves accounting for all of the relevant input and output flows that are related to the wine production processes in the system under study. These inputs and outputs should relate directly to the defined functional unit and any requirements related to the goal and scope of the research (Baumann & Tillman, 2004). The system inputs for this research contain the associated energy and raw materials that are used to manufacture the product. The outputs are documented as all of the wastes and emissions that result from the use of the energy and material resources required to produce the functional unit. Once the input and output data were collected, they were incorporated into the OpenLCA software and then combined to create the necessary process flow charts and the product systems for analysis. Detailed documentation of this entire process is required (ISO, 2006a).

Vineyard Data Collection

Primary vineyard data were collected through the use of detailed questionnaires, meetings with experienced industry representatives, qualified crop specialists, the Texas Grape Growers Association, and other pertinent associates. The finalized draft of this questionnaire for vineyard life cycle inventory data and winery life cycle inventory data is attached as Appendix 1. This questionnaire collected 2015 vineyard data in relation to land preparation tactics, the use of trellising systems, nutrient management, weed and pest management, fertilizer inputs, fuel inputs, crop yields, etc. (Point, 2008). The collection of vineyard data took place during site visits to the participating vineyards while the questions were directed to pertinent personnel; data were recorded on site. In order to account for viniculture and viticulture phases that contribute to the vinification, bottling, packaging distribution phases, and disposal processes (Bosco, Bene, Galli, Remorini, Massai, & Bonari, 2011), some vineyard owners directed me to contact additional sources to fill data gaps in the survey. Thus, any data unavailable directly from the vineyard owners was acquired from additional sources who work with the vineyard owners including: bottle suppliers, fertilizer, herbicide and fungicide suppliers, horticultural specialists, and other relevant industry associates. Obtaining additional data from these sources supplied a more robust and incisive evaluation of the environmental performance of the Texas wine sector and accounted for potential burdensome activities, that if excluded, could have potentially altered the LCA finalized results.

Primary data collection was aggregated in order to help protect any commercially sensitive data in order to assure confidentiality for the participating vineyards. Once the specified vineyard data were accumulated, that datasets were combined and weighted using associated 2015 vineyard grape production to generate an ideal model for the Texas region.

Secondary data inputs stemmed directly from industry, farming, academic peer-reviewed publications, and LCA databases. The background processes contain peer-reviewed OpenLCA databases (EcoInvent, Franklin, Openio lcia normalization) that accounted for data sets that were not available directly from the vineyards under study (e.g. adhesive materials utilized for wine labels, lack of site specific wooden post materials, and other associated vineyard supplies).

Winery Data Collection

Primary data were collected through the use of detailed questionnaires that addressed these winemaking facilities, which are only responsible for processing Texas grown grapes. All associated vineyards that participated in the study contained winemaking and processing facilities that are located on the vineyard premises. This questionnaire for the winery life cycle inventory data is attached as Appendix 2. This questionnaire collected information on the sources of the grapes (round trip distance from the winery to the retailers), the type, source and the transportation links associated with obtaining the bottles, use of electricity to run machines, wine ingredients (yeast, sugar, yeast nutrients, filtering/clarifying agents, antioxidants, etc.), water use (via metering data), and the total output of Texas produced wine in 2015 (in gallons and number of cases produced). Data were combined and weighted in association with the number of gallons of wine that was produced in 2015 to generate an ideal and representative model for the Texas wineries.

Bottle Manufacturing, Retail and Transportation Data

The associated input and emission data for wine bottle production was highly dependent upon the data that was available from the questionnaires. Any insufficient bottle production data, electricity sources and transportation data, was supplemented with background process data in the LCA databases to fulfill these data gaps. Round trip transportation distances were established and modeled for the delivery of the bottles to the wineries and the trip back to the bottle production facility.

Based on the results from the questionnaires, nearly all the wine produced in Texas is sold mainly to local and nearby regional stores throughout Texas. Associated transportation models in the Ecoinvent database indicated that the retail locations affiliated with the associated functional unit have an average transport distance corresponding to the most populated areas near the participating vineyards, located in Fort Worth, Southlake, Grapevine, Lubbock and Dallas, in Texas. Transportation vehicles utilized in the delivery of wine to local and regional retailers was obtained directly from the wineries questionnaires. Based on the associated pattern of low density of population, and automobile dependent infrastructure associated with many Texas cities, it was assumed that the associated transportation vehicles that are used for wine deliveries, drove a round-trip average distance of 29.1 miles to the retailer and back to the winery.

Due to the impracticalities associated with determining a consumer’s intent to solely leave their house to only purchase a bottle of Texas made wine, several assumptions about consumer travel distance to purchase wine were made. The average transportation distance was calculated from the travel distance to a store within the heavily populated areas where the wine is sold to consumers. The cities considered included Fort Worth, Southlake, Grapevine, Lubbock and Dallas, Texas. Several assumptions had to be made about this average distance since each individual lives at varying distances to the store. Based on these stipulations a model scenario was constructed in which a Texas resident drove a regular gasoline powered sedan to a retailer to purchase wine with an average round trip distance of 12.94 miles.

Lastly, to quantity the associated material and energy emissions for the end-of-life of a 750ml bottle of Texas wine, the LCA model contains all of the activities and processes for the municipal solid waste and recycling vehicle collection and pickup of the empty wine bottles to the two separate facilities. In addition, the energy and material requirements associated with sorting the glass culets, paper waste, and cork for the wine bottles at both facilities were included. While glass containers are one hundred percent recyclable, the Texas Recycling Data Initiative indicates that out of 137,222 tons of glass that is processed, only 2.2% of the glass materials are recycled (2015). Thus, an assumption was made that since the data does not account for all regions of Texas (some with higher recycling rates), 5% of the glass bottles consumed by a Texas resident are recycled in the LCA model (with the remaining 95% being landfilled).

Life Cycle Impact Assessment

After the data were collected and aggregated, they were input in the OpenLCA software to perform an LCIA assessment. All of the data inputs were utilized in order to create all of the necessary process flows (inputs and outputs for each life cycle stage) and generate the product systems (the process flows are connected to the activity as a whole unit). After these process flow charts and product systems were created, the OpenLCA software was consulted in order to produce the LCIA results. The OpenLCA software provides numerous scientific models that sort through the inventory data and identify which type of environmental impact is caused by the wine processes activities. Once identified, the software provides an impact assessment which shows all of the effects of the resources and emissions generated during the wine making process.

These results are expressed as the percentage contribution each process activity makes in each of the identified impact categories (Baumann & Tillman, 2004). The data were then normalized and weighed in order to interpret the results (ISO, 2006). Based on previous LCA studies performed on other agricultural studies, the impact assessment method TRACI 2.1 was selected for this analysis. This method examined impact categories stemming from Acidification, Eco toxicity, Eutrophication, Global Warming, Human Health- carcinogenic, Human Health – non-carcinogenic, Ozone Depletion, Photochemical Ozone Formation, Resource Depletion- fossil fuels, and Respiratory Effects (Figure 8).

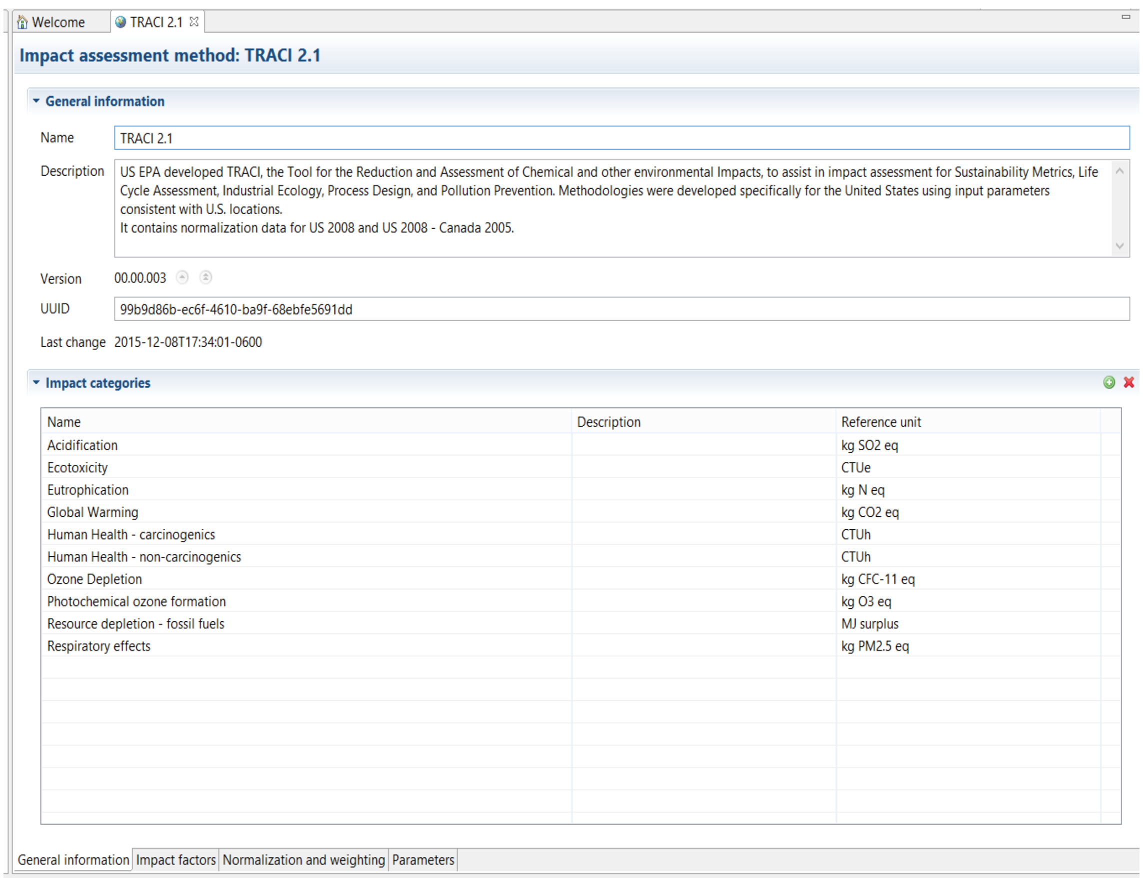

Figure 8. TRACI 2.1 method used in OpenLCA and associated impact categories that were measured (OpenLCA, 2013).

Interpreting Results and Improvement Assessments

Once the product systems emissions were calculated, results were interpreted and improvement assessments were preformed (Baumann & Tillman, 2004). The results indicate and highlight the areas of opportunity where reduction of the impact of the product and or service on the environment can be evaluated and retested in a way that is useful within the context of the studies original goal and scope (ISO, 2006). The stated hypothesis was then tested and three additional improvement scenarios, including assessing the potential of organic viticulture (same yield and twenty percent reduced yield) and using lighter bottles, were modeled. Scenario modeling allows for testing these two alternative scenarios to assess the potential impact of these alternations within the Texas wine productions life cycle. These improvement scenarios were selected based on other life cycle assessment case studies indicating where the highest levels of environmental impacts stem from in the wines life cycle. Thus, scenario modeling examined these proposed alternatives to see if altering these parameters improves or exacerbates the products life cycle environmental impacts.

A sensitivity analysis was also incorporated to determine which results of the study were influenced by any uncertainties, if these improvement options will reduce the system's environmental impacts, if the variations in the methods used influenced the results, if decisions made by the researcher affected the results, and/or if the data employed during the thesis research affected the results (ISOa, 2006; Guinee, Gorée, Heijungs, Huppes, Kleijn, & De Koning, 2001). This analysis allows justification measures to be made during the analysis and rationalizes the suggested recommendations and conclusions at the end of the study.

Alternative Organic Viticulture Scenarios

Organic grape production can provide a moderately improved return on one's investment in the irrigated arid regions of West Texas. In all other regions but West Texas, fungal, insect, and other disease vectors make the possibility of organic grape production extremely challenging (Texas Wine and Grape Growers Association, 2013). Based on these findings, organic viticulture is not a widely-practiced technique and acquiring data for the organic scenario requires data collection from multiple organic vineyards located only in the West Texas region. Based on the USDA organic standards, the land in which viticulture takes place cannot have had any synthetic substances applied to it within the last three years prior to the harvest of an organic crop (USDA, 2008). Pests, weeds, fungal pathogens, and other disease pressures should also be mitigated by the use of approved physical, mechanical and or biological controls. If these measures fail, then incorporating some approved synthetic substances found on the National List may be incorporated (USDA,2008).

Vineyards located within the West Texas region are grown in desert like conditions where disease pressures are significantly less than other AVA regions in Texas. These vineyards have their own set of unique management practices that make organic viticulture probable. Many west Texas vineyards whom practiced organic farming techniques were contacted and declined to participate in the study. To avoid biases associated with producing organic grapes, and comparing those methods to other regions whom cannot successfully compete without severe economic and crop losses, hypothetical models were constructed, based on the laws surrounding the USDA organic agricultural guidelines (Appendix 3).

The first hypothetical scenario accounts for a 20% lower yield (by weight) per acre compared with existing conventional yields in Texas. The second scenario accounts for the equivalent number of grapes (by weight) per acre as the conventional Texas vineyards in 2015. Based on Texas's use of the USDA organic agricultural guidelines, the use of most synthetic pesticides, herbicides and fungicides are banned and would not be accounted for. Instead, quantities of organic alternatives of fertilizers, herbicides, and fungicides were assumed to be equivalent to the conventional systems on a per-acre basis (Point, 2008). Since mechanical, physical and biological controls are preferred, a lack of site-specific models to quantity the use of these alternatives and any potential benefits of organic grape production associated with these activities, were an unfortunate omission from the Texas wine LCA. This limitation allowed me to make an assumption that the application rates of the use of organic fungicides, herbicides and pesticides were modeled based on the traditional use of regular application of non-organic materials. Any absence of site-specific models that did not have an alternative form of organic herbicide and fungicide emissions, were significantly reduced. No additional differences were made between the two organic scenarios. Assumptions were made to account for similar inputs associated with the business as usual approach, for machinery, fuel use, and energy, trellising systems (use of steel and wooden posts), other associated agricultural processes and transport-related emissions for vineyard goods.

Alternative Lighter Bottle Scenario

Within the wine industry there are a variety of packing materials that can be employed to bottle or package the wine (glass, liquid cartons, aluminum, PET, bag-in-box, or pouches). However, a majority of wineries choose to employ glass bottles. The use of the packaging materials for the wine can influence numerous benefits and or burdens associated with the materials utilized. Each packaging material has its merits and can protect and or minimize product damage, is recyclable, minimizes CO_2 emissions, reduces the materials needed for manufacturing the packaging, and can lessen the associated weight of the materials that are required for transport. In the case of glass wine bottles, one such case study was performed by the UK by a program known as WRAP. WRAP determined that the use of lighter weight wine bottles can be a difficult, but an achievable scenario if proper bottle design and packaging requirements are incorporated (WRAP, 2008). WRAP estimated that a 40% reduction in the weight of the glass wine bottle (from 1.1- 0.66 pounds) can have up to a 30% reduction in transport and packaging related CO2 emissions per 750 ml bottle of wine (WRAP, 2008).

A typical wine bottle (including the liquid) weights around 3.34 lbs. and an empty bottle weights approximately around 1.65 lbs. (ranges from 0.66-1.98 lbs.). About 40% of the weight of a 750 ml bottle of wine is credited to the weight of the glass bottle itself. In this study, the lighter bottle scenario used a glass bottle weighing 0.82 lbs., or an estimated 20% reduction in the weight of the bottle that is typically used in a Texas winery.

Sensitivity Analysis

Incorporating a sensitivity analysis within an LCA allows the researcher to evaluate how manipulating a set of parameters within the datasets can affect the modeled results for the system under study. While every attempt has been made to secure accurate datasets and generate appropriate process systems to model the Texas wines life cycle processes, any simplifications, assumptions, or lack of pertinent datasets, do not and cannot possibly reflect all facets of the system under study. A sensitivity analysis helps address these degrees of uncertainty in assumptions and parameter values, and indicates to what extent the results are influenced by these uncertainties. Based on previous LCA studies undertaken by Neto, Dias, & Machado (2013) and Fusi, Guidetti, & Benedetto. (2014), a sensitive analysis was initiated within the agricultural aspect of the LCA to determine the significance of the parameters that are associated with nitrogen fertilizer use and its associated emissions. Adjusting these parameters within the agricultural phase examined the effects of the related emissions of nitrogen compounds and its influence on the impact categories.

Chapter III

Results

The results section addresses the inventoried data and showcases the impact assessment outcomes for the business as usual approach and compares it to the three proposed alternative scenarios. Quantification of these results provided evidence for the associated emissions from wine industry activities, and where the largest improvements to reduce environmental impacts could occur. The alternative scenarios highlight areas of feasibility and improvement options to increase the sustainability profile of Texas produced wine.

Life Cycle Inventory Data for Regular Vineyard Activities

Based on the numerous vineyards located within the Texas region (over 220 vineyards), seventy-six vineyards were contacted and four responded with interest. Based on the designated eight American Viticulture Areas (AVA) within the Texas region, the surveys account for vineyards located within the West, High Plains, and North and Central Texas AVA regions. Table 4 presents the weighted life cycle inventory data that were incorporated into the software to indicate average grape growing activities within the Texas.

Table 4. Life cycle inventory results for Texas viticulture activities in 2015.

Materials And Energy Inputs	Unit	Per Acre	Per Ton of Grapes[a]	Per Bottle of Wine[b]
Land Preparation and Nutrient Management				
Ammonium nitrate phosphate, as N2O5 (synthetic source)[e]	kg	22.65	1.74	.49
Ammonium nitrate as N (from compost)[c]	kg	208.404	16.0312	4.53
Potassium Chloride, as K2O (synthetic source)[d]	kg	25.86	1.989	.5622
Potassium Chloride, as K2O (from compost)[c]	kg	12.58	.9677	.2734
20-20-20 NPK (fertilizer)[e]	kg	45.3592	3.489	.0758
Awaken (nitrogen foliar spray)[f]	kg	10.466	.8051	.2275
Lime	kg	907.185	69.7834	19.72
Elemental Sulfur	kg	1.9159	.1473	.0032
Magnesium Oxide	kg	27.06	2.081	.58827
Diesel	kg	104.896	8.0689	2.2803
Land Prep Activities				
Grade/Cultivate/Furrow:				
Rotary Tillers/ Loyal Drag Harrow	Hours of operation	1.078	.083	.023
R56 Plow/D11T Bulldozer	Hours of operation	.15	.43	.003
Allis Chalmers 200 Plow	Hours of operation	2	.61	.17
Trellising System				
Vine Stakes	kg	175.96	13.5353	3.825
Trellis Wire[i]	kg	38.008	2.9236	.8262
Wooden Posts[h]	kg	261.18	20.0907	5.6778
Fiberglass Posts[h]	kg	104.37	8.028461	2.2689
Steel Posts[h]	kg	208.254	16.0195	4.527
Tying Tape	# of Boxes	8.23	.63	.17
Staples	lbs.	3.665	.28	.08
Bird netting	Feet	98,000	7538.46	2130.43
Weed and Pest Management				
Trifluralin (herbicide)	kg	38.9522	2.9963	.8468
Nova (fungicide)	kg	.226796	.017445	.0049
Dithane (fungicide)	kg	1.0773	.08287	.02341
Intrepid (fungicide/insecticide)	kg	11.2268	.8636	.24406
Pristine (fungicide)	kg	2.1263	.16356	.04622
Sulphur	kg	22.679	1.7445	.49302
Glyphosate (Roundup- herbicide)[g]	kg	.95	.073	.0015
Rally 40WSP (fungicide)	kg	4.904	.3804	.0082

Additional Notes:

[a] One acre of Texas vineyards produced, on average, 13 tons of grapes (Texas vineyards survey).
[b] One acre, on average, produces 46 bottles of wine (Texas vineyard survey).
[c] The most common source of compost that is used in Texas Vineyards is manure and cotton burr from local sources (pers. comm., Lubbock vineyard owner, September, 15, 2016).

[d] The most common source of potassium that is used in Texas vineyards for fertilization is sulfur and lime/sulfur sprays sourced from Missouri (Miller, & Krusekopf, 1920)
[e] The most common source of nitrogen and sulfur that are used in Texas vineyards for fertilization is 120026 and or 20-20-20 NPK, from Home Depot, Lowes, and local agricultural supply retailers (person. comm., vineyard owners, 2016).
[f] The most common nitrogen-foliar spray that is used in Texas vineyards is Awaken 3fold which is imported to local stores from UAP Canada (UAP, 2012).
[g] The most common herbicide that is applied in Texas vineyards is glyphosate and trifluralin which are sourced from Dow AgroSciences in Indianapolis (Ruiz, McGahan, Ganjegunte, Girisha, & Wittie, 2013).
[h] Vineyard posts are comprised of maclura pomifera (bodark tree), fiber glass, non-specified 4-inch wooden posts, and bamboo (pers. Comm., vineyard owners, 2016).
[i] Trellis Wires are comprised of steel regular wire #5, 12.5 inch gauge steel wire, 30 inch cordon wire, 14 inch gauge steel wire, and 18 inch gauge high tensile steel wire (pers. Comm., vineyard owners, 2016). Weight approximations are determined by lbs. per lineal foot=2.6729xD^2. D=size in inches (Cromwell, 2014).

All relevant input flows for the winery operations, bottle manufacturing, cork manufacturing, electricity use and all related transportation data, were obtained directly from the four wineries that processed only Texas grown grapes (Table 5). All wineries were located on property so all of the energy usage required for grape processing (crushing, pressing, fermenting, bottling, labeling), are directly tied to producing Texas sourced wine.

Life Cycle Impact Assessment Results Texas Wine Base Case Scenario

Based on the life cycle environmental impacts associated with the production of a 750 ml bottle of wine that is produced and consumed in Texas, the results indicate that the Texas wine industry could benefit from switching from the business as usual approach to improve upon their environmental profile. LCIA results were modeled by using OpenLCA software (version 1.4.2) and the following impact categories were evaluated to generate the environmental impact of the Texas wine industry: acidification, ecotoxicity, eutrophication, global warming, human health- carcinogenic, human health – non-carcinogenic, ozone depletion, photochemical ozone formation, resource depletion- fossil

Table 5. Winery life cycle inventory input data for Texas wine activities in 2015.

Materials And Energy Inputs	Unit	Per Bottle of Wine
Winery		
Electricity	kWh	11.78
Average distance traveled for contract growers in Texas	miles	15.7
Percentage of grapes purchased from contract growers in Texas	%	59
Mode of transport		Pick-up truck
Cork, Label, and Bottle Manufacture and Transport		
Weight of Average Bottle	kg	.5
Origin of Bottle Illinois	%	100
Mode of Transportation for Delivery to Winery		Transport lorry 20-28t
Number of Bottles Delivered		1992
Weight of Average Cork	kg	.0033
Origin of Cork: Portugal	%	100
Number of Corks Delivered		1992
Cardboard Case	kg	.17
Weight of Average Label	kg	.021
Origin of Label		
California	%	6.3
Texas	%	93.7
Transport of Wine to Retail		
Average Distance to Retail (roundtrip)	miles	29.12
Cardboard Box	kg	.684
Mode of Transport to Deliver Wine		Small delivery truck
Consumer Transport		
Distance Traveled (roundtrip)	miles	25.87
Mode of Transport		Passenger car
Disposal		
Mass of Bottles Collected and Recycled	kg	.5
Mass of Glass sorted (as cullet's) at recycling facility	kg	.5
Mass of Bottles Collected and Landfilled	kg	.5
Mass of Corrugated Board Collected and Recycled	kg	.0017
Mass of Corrugated Board Landfilled	kg	.0187
Mass of Paper Collected and Recycled	kg	.0025
Mass of Paper Collected and Landfilled	kg	.0025

fuels, and respiratory effects. The LCIA results demonstrated that the processes that take place primarily within the bottle production, transportation, and viticulture stages are strongly influencing the associated environmental impacts within this system under study (Figure 9).

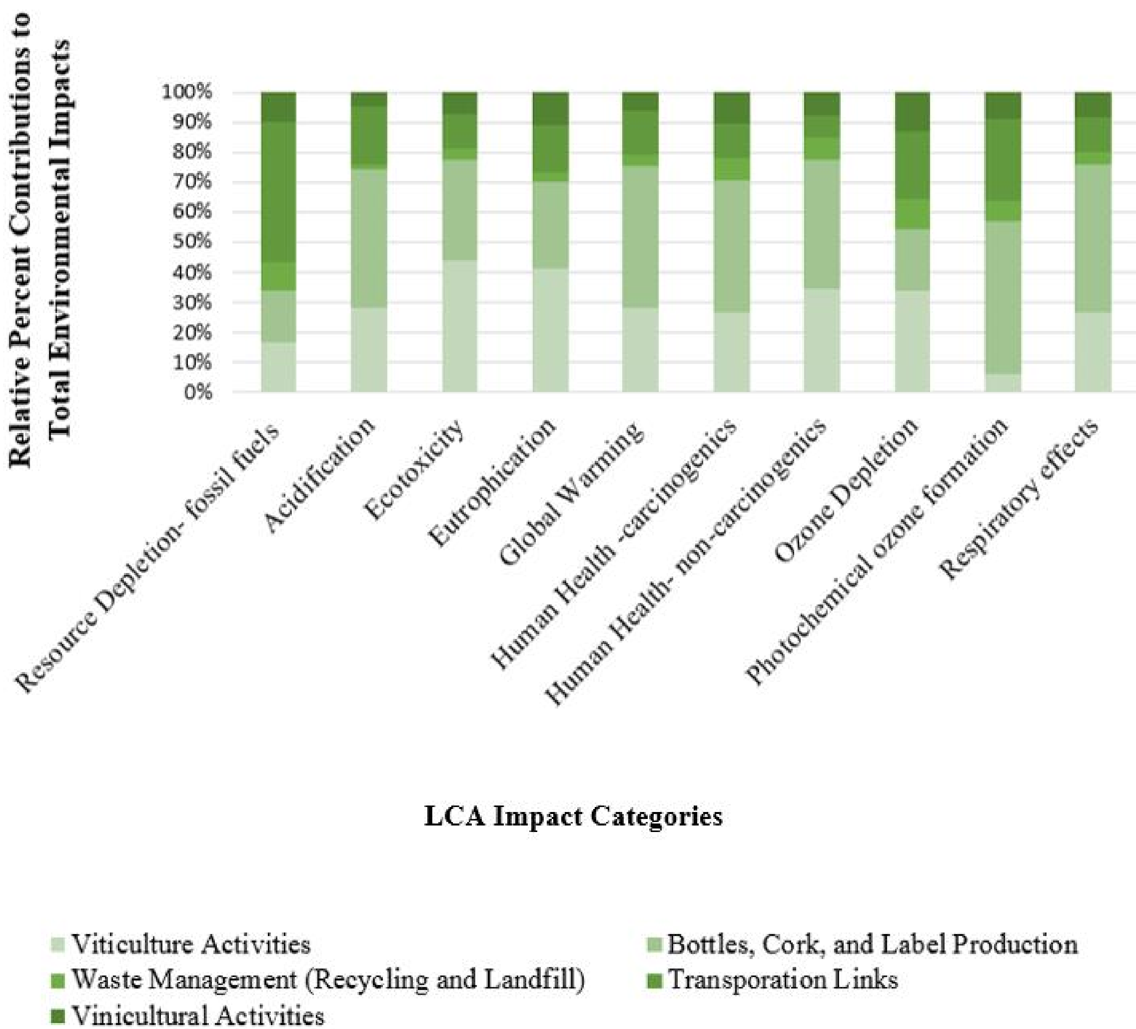

Figure 9. Relative percent of the total contributions of the Texas wine's life cycle processes to the selected environmental impact categories (base case scenario). The defined function unit is one 750ml bottle of wine made entirely from Texas AVA grapes and consumed by a local resident.

Viticulture activities have significant implications for a wine's total eutrophication potential (51%), acidification (30%), ecotoxicity potential (63.7%), human health-non-carcinogenic (44%) and global warming potential (28%). Viticulture practices contribute relatively less to respiratory effect potential (26.4%), resource depletion potential (22.6%), photochemical ozone formation (6.2%), human health – carcinogenics (26.6%), and ozone depletion (18.5%) (Figure 9). Basic viticulture activities and materials required to cultivate Texas grapes denotes that the total emissions associated with these processes originates from numerous actions, such as, nutrient management, pesticide application, grape harvest, the trellising system employed, herbicide application, fuel use, machinery employed and land preparation activities. Nutrient management, fertilizer, herbicide, and fungicide applications, contribute predominantly to impact categories such as, acidification, ecotoxicity, eutrophication, global warming, ozone depletion, respiratory effects, resource depletion, and photochemical ozone formation. Fuel usage for machinery operations and transportation links associated with viticulture activities also contribute to acidification, global warming, photo oxidant creation, resource depletion and respiratory effects (Point, 2008).

The production of wine bottles, corks, labels and their associated transportation links, contribute to a large percentage of photochemical ozone formation (50.8%), acidification (49%), global warming potential (46.3%), and respiratory effect potential (49.3%) (Figure 9). The production of wine bottles contributed relatively less to the impact categories associated with, ecotoxicity potential (13.9%), eutrophication potential (18.9%), human health non-cargionenics potential (33%), ozone depletion potential (16.5%) and resource depletion potential (11.4%) (Figure 9). The use of glass bottle packing impacts the wine industry at the manufacturing, bottling, supply, distribution, and at the end-of-life of the life cycle stages. The acidification and photochemical oxidation environmental impacts are mainly influenced by the manufacturing at the facility and transportation links for delivery.

Wine bottles were assumed to be delivered within the Texas border via road transportation. Some assumptions were made in order to perform the transportation analysis and achieve and estimation of the transportation processes and its associated impacts in the wines life cycle assessment. Transportation routes were assumed to take place by road transport from the vineyards to nearby retailers in major cities including, but not limited to, Dallas, Fort Worth, Lubbock, Grapevine, and Sherman. It should be noted that online orders do take place and are shipped elsewhere in Texas, but, information regarding data availability was limited. While alternative transportation scenarios were not modeled, consumer and other transportation links associated with the Texas wine industry contributes notable sums in the impact categories resource depletion potential (46.8%), ozone depletion potential (45.6%), and photochemical ozone formation potential (27%) (Figure 9). To a smaller degree, these transportation links contribute to the wines impacts acidification potential (20.8%), global warming potential (11.49%), respiratory effect potential (11.23%), human health- non-carcinogenics (7.3%) and ecotoxicity (11.4%) (Figure 9). Transportation impacts are a result from the combustion of fuel sources (gasoline and diesel) from the trucks, cars, and Lorries used to deliver the wine to retailers and consumers to purchase the wine.

Less influential to the Texas wine life cycle industry are the viniculture processes and their associated activities, and the waste management processes (refer to Table 5 and

Figure 9). Vinicultural activities contribute much smaller sums to the associated impact categories such as, eutrophication potential (10.9%), Ozone depletion (10.6%), Human Health carcinogenic potential (10.5%), resource depletion potential (9.87%), photochemical ozone formation potential (8.9%), respiratory effects potential (8.4%), human health- non-carcinogenic potential (7.92%), ecotoxicity potential (7.43%), global warming (5.9%) and acidification potential (4.7%). Vinicultural environmental impacts are predominantly influenced by the use of purchased electricity and its associated energy sources from natural gas and coal. The use of solar and other renewable energy sources to provide energy for winemaking processes in Texas, remains rather small. Waste management processes contribute to relatively small portions of the Texas wine industries environmental footprint, with the highest impact related to resource depletion-fossil fuel potential (9.3%). Remaining percent contribution to the associated impact categories for waste disposal, range from 1.2% to 8.2% and can be seen in Figure 9. Resource depletion for fossil fuel potential is highest among the impact categories, because of the associated emissions from curbside pickup from the consumer and is either taken to a recycling facility or to a landfill for final disposal.

In summary, based on the LCIA results, viticulture, glass bottle and transportation processes are the most environmentally impactful life cycle processes within the Texas wine industry. Transportation does have a high environmental impact on the wine industry. The location of the vineyards, current use of a smaller transport vehicle, and limited infrastructure options for alternative transport currently create few feasible options to help address these impacts. Based on the LCIA results for the base case scenario, alternatives to conventional grape production methods and using lighter bottles should also be explored to improve upon the life cycle inventory results. Thus, three additional scenarios were assessed and compared as possible alternatives to improve upon the Texas wine industries environmental profile within the viticulture and bottling stage processes.

Life Cycle Impact Assessment Results for a Lighter Bottle Scenario

The use of glass packaging affects the processes associated with manufacturing, bottling, supply, distribution, and the end-of-life of the life cycle phases for Texas wine. Wine bottles are the largest contributor to the waste stream, and this impacts the environmental burdens that stem from these stages of the industry's LCA. The use of a lighter glass bottle helps minimize the associated emissions with packaging and greatly improves upon the resource efficiency of this system (Table 6). Under normal circumstances, a typical empty wine bottle weights approximately 1.2 lbs. The use of a wine bottle that is 20% lighter than the bottles currently used within the Texas wineries helps reduce all of the associated environmental impact categories, as can be seen in Table 6 and Figure 10. In all impact categories, the use of a lighter wine bottle can reduce the wine's total contribution to these emissions (between 11.0% and 25.7%). The most substantial changes occur with acidification (25.1%), global warming (20.2%), photochemical ozone formation (25.7%), and resource depletion- fossil fuels (17.6%).

The acidification and photochemical ozone formation impacts are mostly affected by the bottle manufacturing processes at the facility. The glass bottle making industry generally works towards melting together glass cullet's, silica sand, soda ash, limestone, and coloring materials to dye the glass. Glass containers are melted together in a furnace at a temperature of 2350 degrees Fahrenheit and cooled to a temperate to 2150 degrees Fahrenheit (Cattaneo, 2010). Once through with the cooling process, the glass materials go through a two stage molding processes known as blow molding to shape the final mold of the container (Cattaneo, 2010). Using recycled glass cullet's and or reducing the weight of the bottles helps save on the need for virgin raw materials, melting costs, and helps divert glass from landfills which leads to a decrease in energy use and reduced global warming potential. Based on Texas's poor glass recycling rates, the use of lightweight glass containers also reduced raw material usage, associated production emissions, energy used and the overall weight of the bottle. Lighter bottles help production lines operate at a much faster pace, because there is less glass per container and less energy needed for the cooling processes (Cattaneo, 2010). Thus, lightweight containers can be more economical, much more competitively priced, while still reducing environmental impacts. Most of these reductions of the LCA are a result of lower impacts associated with bottle manufacture. Since cumulative energy demand is lower, it improved upon resource efficiencies. It decreased load transport of bottle shipments to and from winery to retailer. Also, the use of lighter bottles would help minimize the waste impacts that are associated with recycling and or landfilling the glass bottles. To summarize, substantial reductions associated with environmental impacts occur when lighter bottles are utilized. The efficiencies gained as a result of using them would dramatically reduce the associated impacts of current Texas wine production activities (Table 6 and Figure 10).

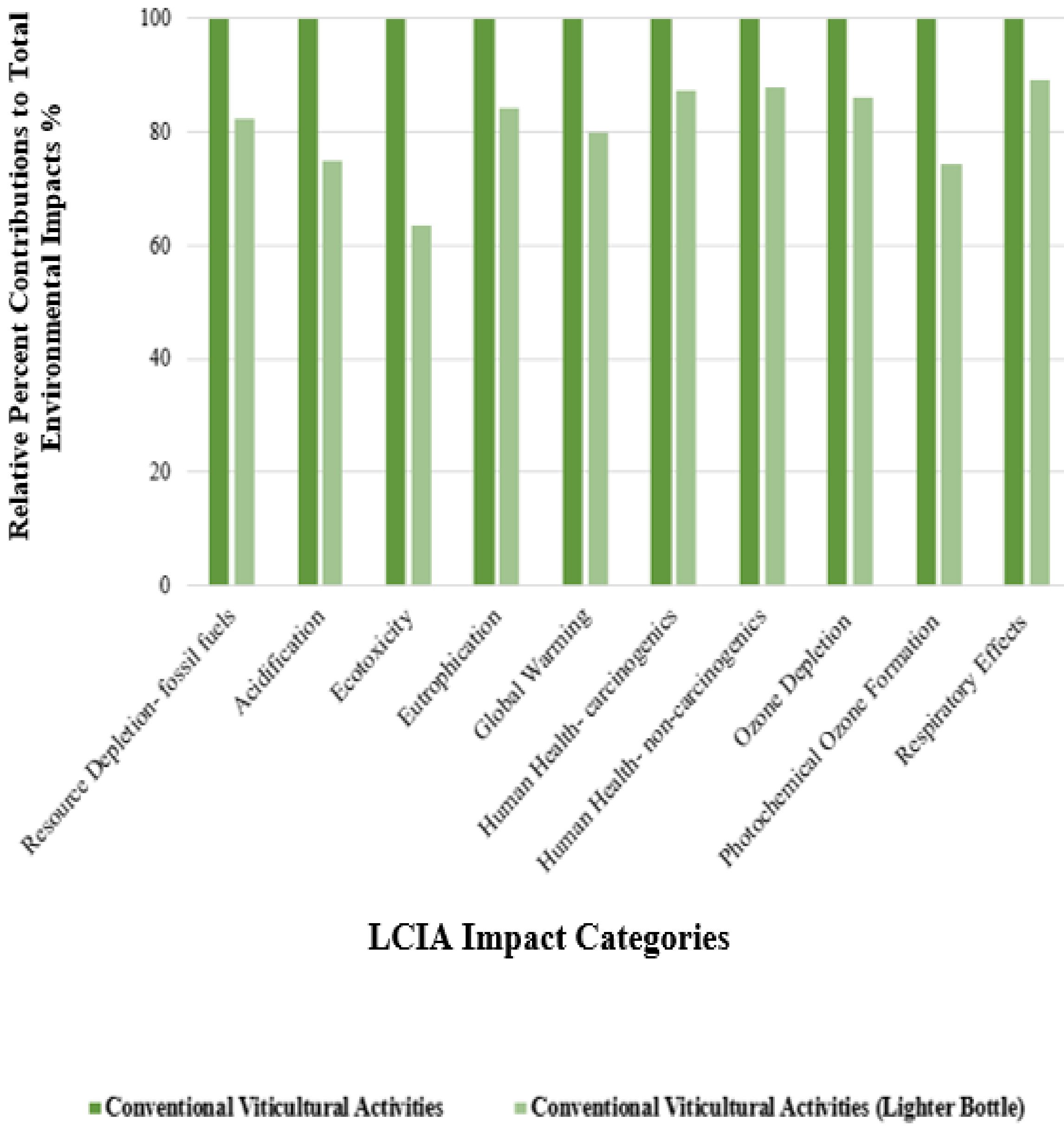

Figure 10. LCIA comparison results for the base case scenario and the proposed 20% ligher bottle scenario. Each impact category for the base case scenario are set at 100% and the contibutions of the two additoinal organic scenarios are presented relative to 100%.

Table 6. LCIA Results for incorporating a 20% lighter glass bottle.

Impact Category	Lighter Bottle Scenario	Regular Scenario (Base Case)
Acidification	3.50061e-3	4.675948e-3
Percent change of life cycle emissions %	**-25.14%**	
Ecotoxicity	2.800101e-3	3.14598e-3
Percent change of life cycle emissions %	**-10.99%**	
Eutrophication	2.9758e-3	3.53939e-3
Percent change of life cycle emissions %	**-15.64%**	
Global Warming	2.51982e-2	3.15874e-2
Percent change of life cycle emissions %	**-20.22%**	
Human Health -carcinogenics	3.17457e-5	3.8938755e-5
Percent change of life cycle emissions %	**-12.79%**	
Human Health- non-carcinogenics	3.477175e-4	3.9871265e-5
Percent change of life cycle emissions %	**-12.2%**	
Ozone Depletion	4.98520e-5	5.79431e-5
Percent change of life cycle emissions %	**-13.96%**	
Photochemical ozone formation	3.708848e-3	4.99354e-3
Percent change of life cycle emissions %	**-25.73%**	
Resource depletion- fossil fuels	2.90510e-4	3.527235e-4
Percent change of life cycle emissions %	**-17.64%**	
Respiratory effects	2.464270e-4	2.768227e-4
Percent change of life cycle emissions %	**-10.98%**	

A percent change that is negative indicates a reduction in the contributions to the associated impact category (compared to the base case scenario), indicating potential to improve the environmental profile; positive indicates a potential increase in contributions to the associated impact category.

Life Cycle Impact Assessment Results for the Organic Viticulture Scenarios

In regards to viticulture processes, copious amounts of materials and activities generate emissions associated with horticultural activities, land preparation, nutrient management, trellising systems, machinery employed, pesticide management, fungicide management, herbicide management, and the use of fuel sources at the vineyards.

It is well understood that nutrient management is an area has significant potential impacts on agriculturally related emissions. Thus, identifying this area of concern provides an area of opportunity to evaluate its relative context within the Texas wine's life cycle and potentially focus on improvement initiatives for this sector. Related GHG emissions that are derived from viticulture processes originate mainly from the percent of surface-applied fertilizer volatilized as nitrous oxide (N_2O) emissions. Nitrous oxide emissions from synthetic fertilizers, manure applications and crop residues can account for over 40% of total agricultural emissions (Maraseni, Tek, & Qu, 2016). N_2O emissions are heavily influenced by the soils pH, local climate, and the nutrient management application timeline in which the fertilizer was present on the soil surface (Maraseni, Tek, & Qu, 2016). Higher impacts associated with viticulture activities for acidification and ecotoxicity emissions are also caused by vitalization and the leaching of the fertilizers to the atmosphere, surrounding land and to water sources. These associated manufacturing and application emissions derived from nutrient management applications of fertilizers to the vineyards, indicate that alternations to these practices may improve upon the life cycle inventories for grape production activities in Texas (Table 7).

Table 7. Associated inputs measured in per ton of grapes produced in Texas for the conventional and two additional organic grape growing scenarios.

Materials And Energy Inputs	Unit	Traditional Viticulture Activities [a]	Organic Viticulture Activities Lower Yield [b]	Organic Viticulture Activities Same Yield [c]
Yields	tons/acre	13	2.6	13
Fertilizers [d]				
Nitrogen (N)	kg	13.4	18.03	13.4
Phosphorous (P)	kg	9.42	13.19	9.42
Potassium (K)	kg	14.33	22.66	14.33
Herbicides				
Trifluralin	kg	2.99	0.00	0.00
Glyphosate	kg	.073	0.00	0.00
Fungicides				
Nova	kg	.018	0.00	0.00
Dithane	kg	.083	0.00	0.00
Pristine	kg	.164	0.00	0.00
Rally 40WSP	kg	.380	0.00	0.00
Sulphur	kg	1.74	2.84	1.74
Copper Fungicide	kg	0.00	.7	.7
Pesticides				
Intrepid	kg	.8636	0.00	0.00
Fertilizer Emissions [e]				
N_2O	kg	.531	.57	.56
NH_3	kg	2.59	3.82	3.32
NO	kg	.514	.64	.62
NO_3	kg	8.87	9.71	9.35

Additional Notes: [a] Traditional viticulture data were obtained from Texas grape grower's survey the year 2015.
[b] Organic yields are assumed to be 20% lower than the traditional viticulture grape yields in Texas vineyards from the year 2015.
[c] Organic yields are assumed to be equivalent to the traditional viticulture grape yield in Texas vineyards from the year 2015.
[d] NPK inputs averaged around 498.95 kg per acre. Compost inputs averaged around 362.74 to 9071.85 kg per acre
[e] Fertilizer emissions were modified within the range defined in the Intergovernmental Panel on Climate Change (IPCC, 2006). Calculations for fertilizer emissions can be seen in Table 8.

Table 8 shows the calculations used to quantify emission factors from fertilizer usage on the vineyards under study for N_2O, NH_3, NO, NO_3 and P_2O_5. The calculations used to generate this table were derived from Point (2008), Intergovernmental Panel on Climate Change (2006), United States Department of Agriculture (1998), Schmidt JH (2007) and Brentrup, Küsters, Lammel, & Kuhlmann (2000).

Table 8. Fertilizer application calculations for synthetic, manure nitrogen, and phosphorous losses, per ton of grapes produced in Texas vineyards in 2015.

Calculations	Unit	Mass
Nitrogen Emissions		
N from Fertilizer	kg	2.948
Percent of Fertilizer lost as NH_3 [a]	%	9.00
NH3 lost to air	kg	0.26
Percent Fertilizer N lost as NO [a,b]	%	1.00
NO lost to air	kg	0.03
Percent Fertilizer N lost as N_2O[a]	%	1.00
N2O Lost to air	kg	0.03
Percent N2 Lost to air [b]	%	9.00
N2 Lost to Air	kg	0.26
N from Manure	kg	10.45
Percent of Fertilizer lost as NH_3[a]	%	18.00
NH3 lost to air	kg	1.88
Percent Fertilizer N lost as NO [a,b]	%	2.00
NO lost to air	kg	0.21
Percent Fertilizer N lost as N_2Oa	%	2.00
N2O Lost to air	kg	0.20904
Percent N2 Lost to air	%	9
N2 Lost to Air [b]	kg	0.94068
Weight of Crop Residues [c]	kg	1437.888
Nitrogen Content in Crop Residues [c]	kg	6.21
Percent of Crop Residue lost as N2O [a]	%	1
N2O lost to air	kg	0.0621
Remaining Crop Residue as N	kg	6.15
NH3 Emissions per Acre [d]	kg per acre	2.023
Yield Per Acre	ton per acre	13
Nitrogen Inputs		

Fertilizer	kg	2.948
Manure	kg	10.45
Atmospheric Nitrogen Deposition	kg/acre	14.03
Crop Yield	tons per acre	13
Atmospheric Nitrogen Deposition/ton of Grapes	kg/tons	4.81
Total N Inputs	kg	21.788
Nitrogen Outputs		
Fertilizer lost as NH_3	kg	0.26
Fertilizer lost as NO	kg	0.03
Fertilizer lost as N_2O	kg	0.03
Fertilizer lost as N_2	kg	0.26
Manure lost as NH_3	kg	1.88
Manure lost as NO	kg	0.21
Manure lost as N_2O	kg	0.209
Manure lost as N_2	kg	0.94
Crop Residue as N_2O	kg	0.0621
Nitrogen Removed with Crop [c]	kg per ton	0.71
Total N Outputs	kg	4.5911
Total Nitrogen Surplus	kg	11.125
Percent Leached as NO_3 [a,b]	%	18
Nitrogen Surplus for NO_3 Loss	kg	2.0025
Indirect Nitrogen Emissions		
Total NH3	kg	2.14
Percent of Indirect N2O emissions from NH3	%	1
N2O emissions from NH3	kg	0.0214
Total NO3 Emissions	kg	2.025
Percent of indirect N2O Emissions from NO3	%	0.75
N2O Emissions from NO3	kg	0.0152
Total Nitrogen Emissions		
N2O emissions to Air [a]	0.3377*(44/28)	**0.5306714**[e]
NH3 to Air [a]	2.14*(1.21)	**2.5894**[e]
NO to Air [a]	0.24*(30/14)	**0.5142857**[e]
NO3 to Water [a]	2.0025*(62/14)	**8.8682143**[e]

Additional Notes: [a] Intergovernmental Panel on Climate Change (2006)
[b] Brentrup, Küsters, Lammel, & Kuhlmann, (2000)
[c] National Resources Conservation Service (2007)
[d] Anderson (2000) cited from Schmidt (2007)
[e] Nitrogen emissions are divided into 20% synthetic fertilizer inputs and 80% manure fertilizer inputs as per the base case scenario inputs in Table 7.

By proposing alterations to the base case scenario, the two hypothetical organic grape production scenarios focus on incorporating the USDA organic agricultural guidelines into the viticulture processes. The 20% lower yield organic scenario and the organic same yield scenario use similar processes to the base case scenario, but the use of most synthetic pesticides, herbicides and fungicides are banned and were eliminated from the analysis. Instead, quantities of alternative organic fertilizers, herbicides, and fungicides were assumed to be equivalent to the conventional systems on a per-acre basis for both scenarios. If these alternatives were not found in the software, then the assumptions were based on reducing some of these inputs to include some form of field-level fungicide, herbicide, and pesticide emissions from the vineyards. The differences in these quantities for the base case and organic grape production scenarios can be seen in Table 9.

In the first hypothetical organic production scenario, production yields were generated with a 20% lower yield than the conventional base case scenario in Texas in 2015. The corresponding environmental impact results for organic grape production with a 20% lower yield can be seen in Figure 11 and Table 9. Environmental impact results were marginally higher than the base case scenario with mild increases for eutrophication (2.1%) and acidification (3.7%). In all impact categories except eutrophication and acidification, results for organic grape production with a 20% lower yield reduced the wine's total contribution to GHG emissions (between 2.8% and 26.9% for different categories). The most substantial changes occurred with ecotoxicity (26.9%) and photochemical ozone formation (10.1%). All other impact categories experienced minimal improvements for the environmental footprint: human health- carcinogenic

(4.6%), human health-non-carcinogenic (4.5%), ozone depletion (8.4%), resource depletion- fossil fuels (8.9%), and respiratory effects (2.8%).

Following the USDA organic agricultural guidelines and substituting the use of prohibited fungicides, herbicides, pesticides and fertilizers with permitted materials into the organic scenarios, shows that even the permitted materials are linked to manufacturing emissions (Point, 2008). Despite the hypothetical applications of compost and manure materials as a fertilizer to reduce environmental impacts, when compared to equal quantities of nitrogen content in synthetic fertilizers, these organic alternatives often lead to elevated farm level emissions for N_2O, NO, and NH_3 (Bussink & Oenema, 1998; Monteny, Bannink, & Chadwick, 2006) (Table 7). Since the nitrogen content in manure is not readily absorbed by cultivated crops (Bussink & Oenema, 1998), a higher percentage of N_2O, NO, and NH_3 in manure results in elevated LCA emissions due to volatizing and leaching from the surface (Brentrup, Küsters, Lammel, & Kuhlmann, 2000); Intergovernmental Panel on Climate Change, 2006; Point, 2008). The elevated emissions linked to eutrophication, acidification and global warming impacts also correspond with diminished grape yields, because emissions per ton of grapes produced are allocated to a smaller batch of wine produced. In fact, due to the restrictions and preferred methods employed for organic viticulture, a 20% crop loss is rather conservative, and the prevalence of disease pressures indicates that this would likely be higher without some form of synthetic disease controlling mechanisms.

In the second hypothetical organic scenario, production yields were assumed to be equal to the yields from the conventional base case scenario in Texas in 2015. The corresponding environmental impact results for organic grape production with equal yields, compared to the conventional base case, resulted in reductions in resource depletion-fossil fuels (8.9%), global warming (3.3%), human health- carcinogenc (9.9%), human health- non- carcinogenic (5.8%), ozone depletion (11.5%), and photochemical ozone formation (10.1%) (Figure 11). Results for two impacts were higher than the base case: acidification (0.7%) and eutrophication (1.66%). These were marginally smaller than the organic 20% reduced yield scenario (Figure 11). However, ecotoxicity experienced significant impact reductions by 27.9%. Since ecotoxicity measures relevant emissions of toxic substances to air, water and soil, a reduction in this impact category recapitulates that the life cycle environmental impacts are substantially affected by crop yields. Complete comparative results are depicted in Figure 11 and Table 9.

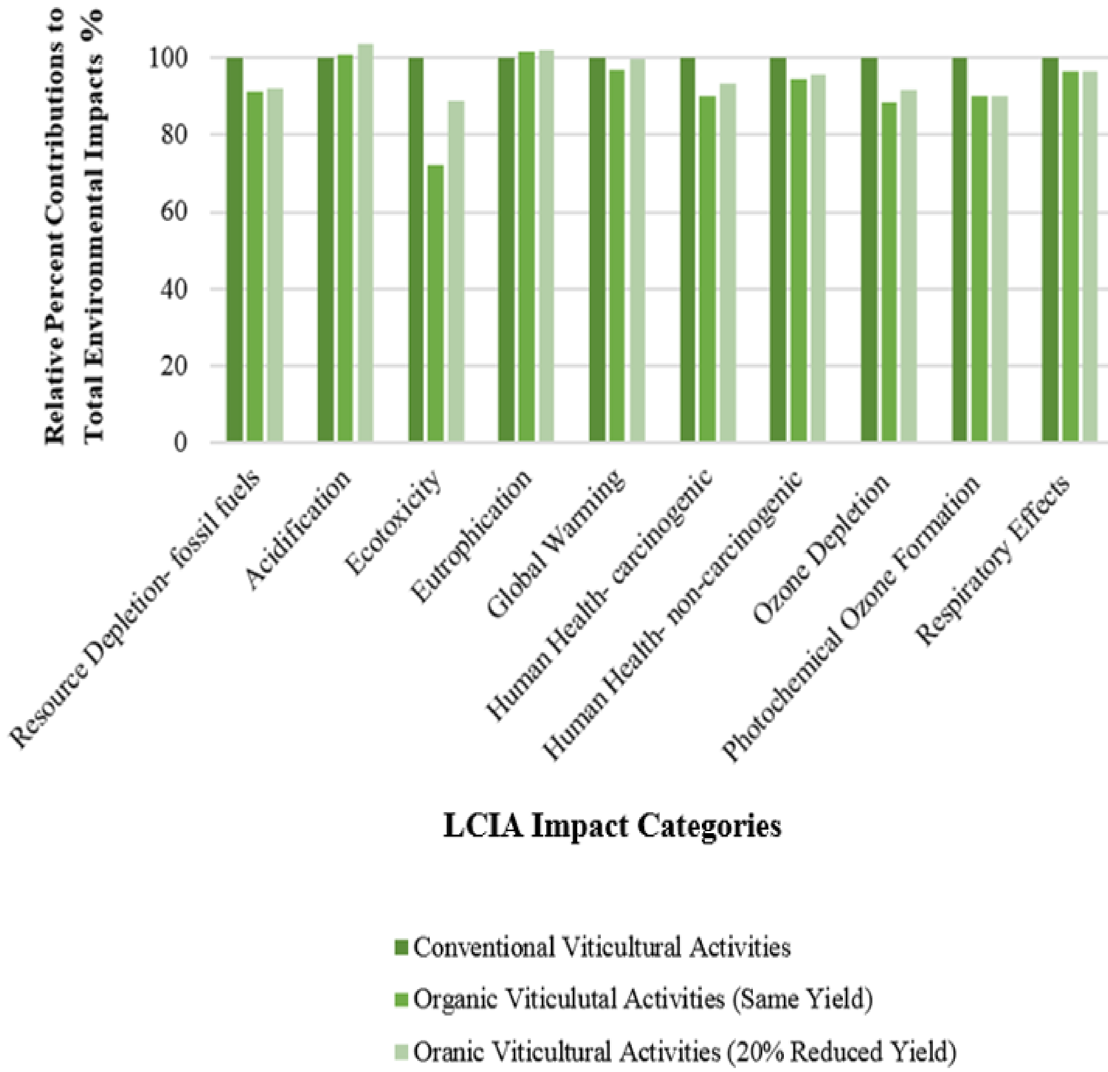

Figure 11. LCIA results for the base case scenario and the two proposed organic viticultural scenarios. Each impact category for the base case scenario are set at 100% and the contibutions of the two additoinal organic scenarios are presented relative to 100%.

Table 9. Life cycle impact assessment results for base case and organic modeled scenarios.

Impact Category	20% Reduced Yield Organic Scenario	Same Yield Organic Scenario	Regular Scenario (Base Case)
Acidification	4.85187e-3	4.70872e-3	4.675948e-3
Percent change of life cycle emissions %	**+3.76%**	**+0.70%**	
Ecotoxicity	2.299790e-3	2.269550e-3	3.14598e-3
Percent change of life cycle emissions %	**-26.89%**	**-27.87%**	
Eutrophication	3.61442e-3	3.59818e-3	3.53939e-3
Percent change of life cycle emissions %	**+2.12%**	**+1.66**	
Global Warming	2.00576e-2	3.00575e-2	3.15874e-2
Percent change of life cycle emissions %	**-0.37%**	**-3.34%**	
Human Health -carcinogenics	4.07459e-5	3.509316e-5	3.8938755e-5
Percent change of life cycle emissions %	**-4.64%**	**-9.88%**	
Human Health- non-carcinogenics	3.807459e-5	3.757177e-5	3.9871265e-5
Percent change of life cycle emissions %	**-4.50%**	**-5.77%**	
Ozone Depletion	5.307740e-5	5.126677e-5	5.79431e-5
Percent change of life cycle emissions %	**-8.40%**	**-11.46%**	
Photochemical ozone formation	4.49138e-3	4.44913e-3	4.99354e-3
Percent change of life cycle emissions %	**-10.06%**	**-10.10%**	
Resource depletion- fossil fuels	3.21189e-4	3.21185e-4	3.527235e-4
Percent change of life cycle emissions %	**-8.94%**	**-8.94%**	
Respiratory effects	2.66420e-4	2.645010e-4	2.768227e-4
Percent change of life cycle emissions %	**-2.76%**	**-3.76%**	

A percent change that is negative indicates a reduction in the contributions to the associated impact category (compared to the base case scenario), which indicates where there is potential to improve the environmental profile for Texas wine. A percent change that is positive indicates a potential increase in contributions to the associated impact category.

Sensitivity Analysis Results

Based on the LCIA results, a sensitivity analysis was conducted in order to address key sources of uncertainty. The nutrient management parameters were altered to assess its relative influence on the environmental impact emission results. Identifying these uncertainties and testing their influence increases the level of understanding of the relationship between the associated viniculture activities and the emission output variables for the LCIA modeled results. For viticulture phases, the largest sensitivities can be seen in the application of organic and synthetic fertilizers for nutrient management. Altering the synthetic and organic fertilizer inputs in the model to assess its relative importance and its associated emissions related to nitrogen compounds (both directly and indirectly) produced varying results (Table 10).

In the second column in Table 10, the base case scenario for fertilizer inputs remained the same and represents the original LCIA results. The third column changed the amount of synthetic fertilizer inputs by -15%. The fourth column changed the amount of synthetic fertilizer used in fertilization activities by replacing it with 100% manure compounds. The fifth column changed he amount of synthetic fertilizer used by +/-18% and manure inputs by +/-82%. The associated emissions from fertilizer usage and the variation of the sensitivity parameters that had the largest impact was on eutrophication and acidification impact categories (Table 10). Altering the fertilizer inputs per ton of grapes for conventional and organic grape production (per ton of grapes) model scenarios indicates the relative importance of monitoring nutrient management for viticulture activities in Texas vineyards, and would result in increased or decreased nutrient-related efficiencies per bottle of Texas produced wine.

Table 10. Sensitivity analysis results by altering parameters for fertilizer inputs to testing the relative importance of nutrient management for viticulture activities.

Impact Category	Base Case Scenario for Fertilizer Inputs	Sensitivity Analysis with 15% Reduced Synthetic Fertilizer Inputs	Sensitivity Analysis with Manure Inputs	Sensitivity Analysis with Mixture of 18% Synthetic Fertilizer and 82% Manure Inputs
Acidification	8.89e-03	4.27e-02	5.02e-2	9.48e-03
% Change of life cycle emissions		**+380.32%**	**+464.67%**	**+6.22%**
Ecotoxicity	2.34e-01	1.99e-01	+2.34	+4.22
% Change of life cycle emissions		**-14.95%**	**+900%**	**+1703.42%**
Eutrophication	1.28e-02	1.09e-02	5.02e-02	2.34e-03
% Change of life cycle emissions		**-14.84%**	**+292.19%**	**-81.72%**
Global warming potential	6.99e-01	4.14e-02	1.62e-03	8.6e-01
% Change of life cycle emissions		**-94.07%**	**-99.77%**	**+23.03%**
Human Health-carcinogenic	1.28e-03	9.24e-07	1.08e-6	7.53e-5
% Change of life cycle emissions		**-99.92%**	**-99.91%**	**-94.41%**
Human Health- non-carcinogenic	2.77e-04	1.76e-07	2.06e-6	1.96e-7
% Change of life cycle emissions		**-99.93%**	**-99.45%**	**-94.17%**
Ozone depletion	1.62e-05	7.53e-07	8.89e-07	1.60e-06
% Change of life cycle emissions		**-95.35%**	**-94.51%**	**-99.92%**
Photochemical ozone formation	1.13e-03	5.94e-02	6.99e-02	1.28e-02
% Change of life cycle emissions		**+5156.64%**	**+6085.84%**	**+1032.74%**
Resource depletion-fossil fuels	1.08e-05	9.74e-05	1.14e-04	2.07e-04
% Change of life cycle emissions		**+801.85%**	**+955.56%**	**+1816.67%**
Respiratory effects	2.06e-05	2.36e-04	2.77e-04	5.07e-5
% Change of life cycle emissions		**+91.27%**	**+1244.66%**	**+146.12%**

A percent change that is positive reflects a potential increase in relative contributions to an associated impact category. A negative percent change stipulates a decrease to an associated impact category, and reveals potential options to improve upon the environmental profile of Texas produced wine.

Chapter IV

Discussion

Quantification of the results from the life cycle assessments indicates that the environmental performance of a bottle of Texas AVA produced wine was mostly prompted by glass bottle production and associated viticulture activities. After the base case scenario model was completed, alternations were made so that three additional LCA models could be tested to determine plausible options to reduce the environmental impact of Texas wine production. The results modeled by each of the life cycle assessment analyses permitted a second look into my original hypotheses. In retrospect, some aspects of the hypotheses were supported by my findings while other aspects were not. Finally, a discussion of the studies limitations, suggestions for improvements, and future recommendations for future research is provided.

Improvement Opportunities for the Texas Wine Industry

The future plausibility of wine production is directly affixed to its environmental impacts and the conditions in which it conducts its operational activities. The environmental impacts related to the production of a food product are directly influenced by the amount of materials, energy, waste and the emissions the product releases throughout the products life cycle. As future environmental issues are increasingly ingrained in political, social and economic processes, many food production activities, including wine, may encounter these pressures to respond in a congruous manner. Texas has established itself as the United States top fifth wine producer and is a vast multifaceted regionally based industry that contributes to numerous environmental impacts throughout its life cycle and may face some of these subsequent sustainability challenges. As the Texas wine industry continues to grow, striving to understand the emissions derived from these systems can provide reasonable options to reduce the environmental impact of wine production and employ future decisions that can improve its environmental profile and marketability. Therefore, preforming this LCA for the Texas Wine industry provides an initial foundation that can assist the Texas wine industry to pursue an economic growth strategy that is not only economically sustainable, but environmentally and socially acceptable as well. The study aimed to evaluate the associated environmental impacts associated with: viticulture practices, cultivation techniques, viniculture processes, packaging materials (bottles, corks, and labels), transportation links, use and final disposal for Texas wine. The life cycle assessment methodology was used to quantify the associated energy and material processes that contribute to the environmental impacts associated with the production of a 750 ml bottle of wine that is produced and consumed in Texas in 2015.

The life cycle assessment for Texas AVA produced wine indicates that vineyard activities, and bottle manufacturing activities were the largest contributing phases to the impact categories measured. Reported total relative impact values linked to the wine production processes under study were found to be consistent with earlier published results (Petti, Raggi & Camillis, 2006); Point 2008; Fusi, Guidetti & Bendetto, 2013). Based on these findings, three additional scenarios were modeled to evaluate the life cycle assessments. internal process components and the degree of adjustments to their associated environmental impacts, by modifying the use of a 20% lighter glass bottle and incorporating appropriate organic viticulture operational activities. While wine production will always result in some degree of environmental impact, there are feasible alternatives and opportunities to develop more sustainability minded principles for environmental improvement. Based on the LCA results, viticulture activities and bottle provision provides the most pronounced areas of plausible recourse for environmental improvement for the Texas wine's life cycle (Table 11 and Figure 12).

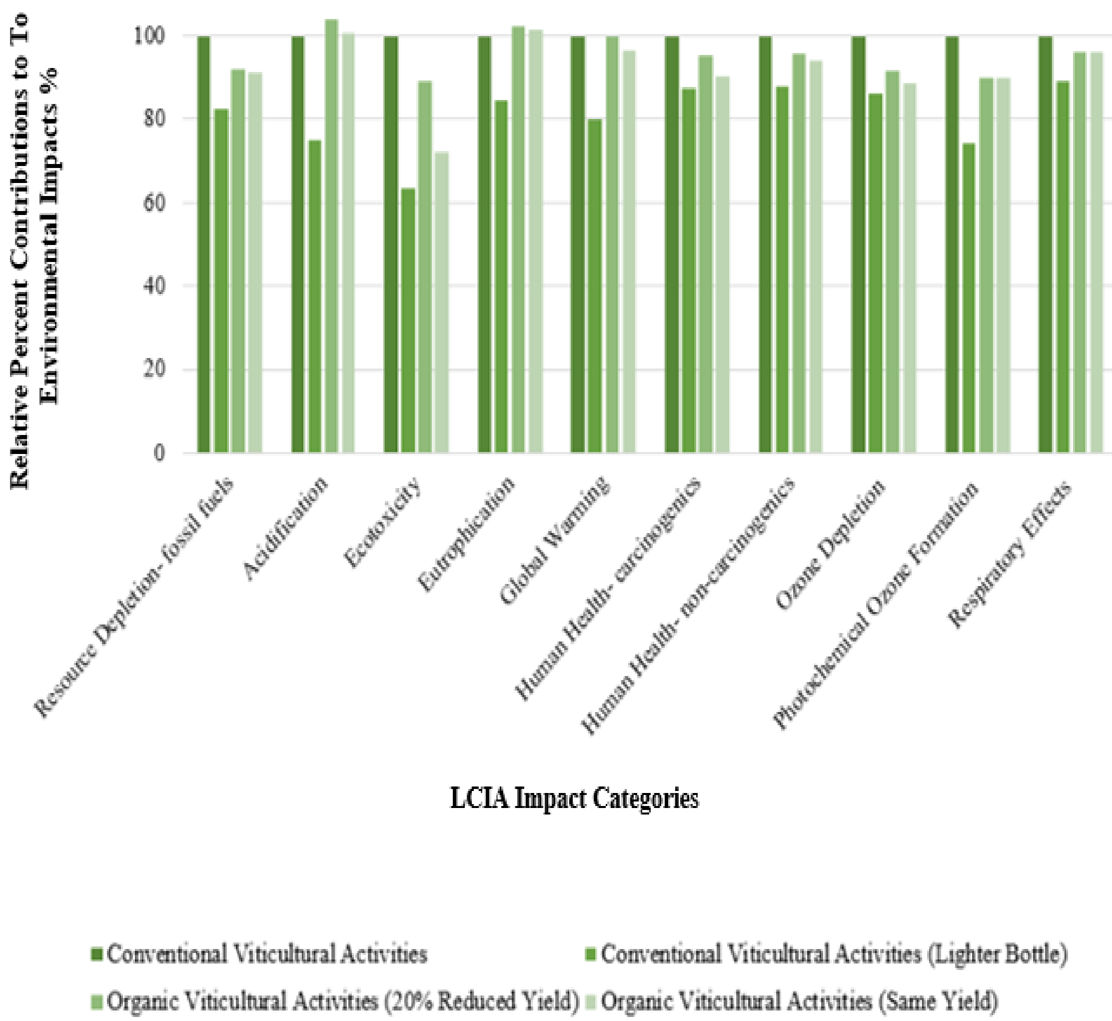

Figure 12. LCIA results for all modled scenarios for Texas wine production. Each impact category for the base case scenario are set at 100% and the contibutions of the two additoinal organic scenarios are presented relative to 100%.

Table 11. Life cycle impact assessment results for all the modeled scenarios.

Impact Category	20% Reduced Yield Organic Scenario	Lighter Bottle Scenario	Same Yield Organic Scenario	Regular Scenario (Base Case)
Acidification	4.85187e-3	3.50061e-3	4.70872e-3	4.675948e-3
Percent change of life cycle emissions %	**+3.76%**	**-25.14%**	**+0.70%**	
Ecotoxicity	2.299790e-3	2.800101e-3	2.269550e-3	3.14598e-3
Percent change of life cycle emissions %	**-26.89%**	**-10.99%**	**-27.87%**	
Eutrophication	3.61442e-3	2.9758e-3	3.59818e-3	3.53939e-3
Percent change of life cycle emissions %	**+2.12%**	**-15.64%**	**+1.66**	
Global Warming	2.00576e-2	2.51982e-2	3.00575e-2	3.15874e-2
Percent change of life cycle emissions %	**-0.37%**	**-20.22%**	**-3.34%**	
Human Health -carcinogenics	4.07459e-5	3.17457e-5	3.509316e-5	3.8938755e-5
Percent change of life cycle emissions %	**-4.64%**	**-12.79%**	**-9.88%**	
Human Health- non-carcinogenics	3.807459e-5	3.477175e-4	3.757177e-5	3.9871265e-5
Percent change of life cycle emissions %	**-4.50%**	**-12.2%**	**-5.77%**	
Ozone Depletion	5.307740e-5	4.98520e-5	5.126677e-5	5.79431e-5
Percent change of life cycle emissions %	**-8.40%**	**-13.96%**	**-11.46%**	
Photochemical ozone formation	4.49138e-3	3.708848e-3	4.44913e-3	4.99354e-3
Percent change of life cycle emissions %	**-10.06%**	**-25.73%**	**-10.10%**	
Resource depletion- fossil fuels	3.21189e-4	2.90510e-4	3.21185e-4	3.527235e-4
Percent change of life cycle emissions %	**-8.94%**	**-17.64%**	**-8.94%**	
Respiratory effects	2.66420e-4	2.464270e-4	2.645010e-4	2.768227e-4
Percent change of life cycle emissions %	**-2.76%**	**-10.98%**	**-3.76%**	

A negative percent change indicates a reduction in the contributions to the associated impact category (compared to the base case scenario), suggesting a potential to improve the environmental profile for Texas wine. A positive percent change indicates a potential increase in contributions to the associated impact category.

Interpreting the Organic Viticulture Activities Hypothesis

Based on the USDA organic agriculture guidelines, the use of many synthetic herbicides, fungicides, and pesticides are banned. Thus, the hypothesis for organic farming I examined presumed that the use of the guidelines is manageable within the West Texas region, and quantities of alternative organic use of fertilizers, herbicides, and fungicides were assumed to be equivalent to the conventional systems on a per-acre basis.

Application rates of the use of organic fungicides, herbicides and pesticides were modeled based on the traditional use of regular application of non-organic materials. Where alternatives were not found in the software, then the assumptions were based on reducing some of these inputs to include some form of field-level fungicide, herbicide, and pesticide emissions from the vineyards. No additional differences were made between the two organic scenarios other than the 20% adjustment of the harvest yield loss for the second organic scenario. Assumptions were made to account for similar inputs associated with the business as usual approach, for machinery, fuel use, and energy, trellising systems (typing tape, staples, use of steel cables, fiberglass and wooden posts etc.), other associated agricultural processes and transport-related emissions for vineyard goods. The restrictions on the use of synthetic pesticides herbicides and synthetic fertilizers predicted that lower environmental impacts associated with eutrophication, ecotoxicity and global warming potential, would transpire in this scenario.

The original hypothesis for organic viticulture activities was based on the key assumption that the use of USDA organic agricultural guidelines and its restrictions on the use of harmful pesticide, fungicide, herbicide, and fertilizers, would substantially remove these toxins from the viticulture activities and thus improve upon the environmental footprint of the Texas wine industry. Limiting the use of these substances would result in lower emissions from nutrient and toxic substance inputs, and would have lower volatilization and leaching rates to air, water and soil and thus improve ecotoxicity, global warming and eutrophication impact categories. But this was not the case.

One explanation for this negative result is that the organic model's acidification and eutrophication potential actually increased impacts due to higher volatization and leaching rates associated with organic fertilizers. It is well understood that nutrient management is an area that has significant potential impacts on viticulture related emissions, thus identifying this hot spot, provided an area of opportunity to evaluate its relative context within the Texas wines life cycle. In the agricultural phase, acquiring, applying and the subsequent emissions for nitrogen fertilizers had visible implications for the environmental impacts associated with Texas wine production.

There are a several elucidations that can delineate these findings:

1) When comparing equivalent volumes of nitrogen content found in synthetic fertilizers, many organic substitutes are connected to higher rates of N_2O, NH_3, and NO emissions (Bussink & Oenema, 1998; Monteny, Bannink, & Chadwick, 2006).
2) For viticulture activities, grapevines have a comparatively minimal nutrient uptake efficiencies and will have higher rates of nutrient losses. These losses result in a higher rate of N_2O, NH_3, NO, other GHG and eutrophying emissions by means of leaching and volatilization from the fertilizer applications, per ton, than using synthetic fertilizers (Intergovernmental Panel on Climate Change, 2006, Brentrup, Küsters, Lammel, & Kuhlmann, 2000, & Schmidt, et al., 2014).

a) N_2O emissions are intricately guided by the fertilizer application technique, a soils pH balance, the mesoclimate and the timeframe in which the nutrients were superficially on the soils surface (Maraseni, Tek, & Qu, 2016).

3) Finally, the elevated emissions linked to eutrophication, acidification and global warming impacts also correspond with diminished grape yields, because emissions per ton of grapes produced are allocated to a smaller batch of wine produced.

While results of the LCA indicate that organic grape viticulture activities can improve upon some of the impacts for the Texas wine industry, maximizing these improvements are centered on the vineyards ability to produce an equivalent yield of grapes per acre as traditional viticulture activities in Texas. This presents a unique problem for Texas vineyard owners, in all other regions but West Texas, because fungal, insect, weather conditions, disease vectors, and other biotic stressors makes the possibility of organic grape production extremely challenging (Texas Department of Agriculture, 2005). Texas is known as the land of extremes for vineyard owners (Texas Department of Agriculture, 2005) and is home to numerous biotic stressors. Without the protection of synthetic fungicide, herbicide, and pesticide applications, many of the grape varieties that are produced in Texas are highly susceptible to numerous biotic stressors, disease vectors, fungal pathogens, and the presence of insects (whom consume the fruit, foliage and spread disease) See Table 3. Based on the USDA agricultural organic guidelines, the ability for vineyard owners (not including AVA regions in West Texas), to appropriately mitigate disease risks would face huge financial risks since regional crop losses would be substantial. Based on the LCA results for organic production and the emissions associated with these activities, emissions are highly dependent on producing similar crop yields per unit when compared to the base case scenario. Thus, with the risk of reduced crop yields coupled with the accelerated emissions from incorporating organic fertilizers, following these standards would significantly increase the environmental footprint for the Texas wine industry.

Based on these findings, following organic standards is not currently a recommended practice for Texas AVA vineyards not located in the West Texas region. Some possible alternatives that Texas vineyards could incorporate would be to focus on more effective fertilizer management practices by using more environmentally friendly application tactics. Improving fertilizer management would involve monitoring the classification, chemical composition, and monitoring the timing of nutrient application to the vines. Incorporating these practices can notably decrease nitrogen and phosphate emissions to other land, air and water sources (Barry, 2011; Fusi, Guidetti, & Benedetto, 2014; Pett, Raggi, & Camillis, 2006; & Point, 2008). Other advantageous fertilizer operations may include: decreasing the total sum of nutrient supplements that are applied to the vineyard; incorporating buffer zones between application sites; sourcing alternative fertilizers such as manure and or composted materials with lower nitrogen contents (Pattey, 2005); incorporating compost or manure based nutrients into the soil shortly after it is applied (Bussink & Oenema, 1998), though application methods differ depending upon the amount applied and the vineyard design; and using manure or composted fertilizer that contain smaller nitrogen contents that still meet the nitrogen needs of the vineyard (Hudson, 2000). However, mitigating the use of synthetic fertilizers by substituting it with manure or composted materials may provide an alternate form of necessary nutrients, but manure is not benign with respect of filed-level emission (Point, 2008). Manure based fertilizer are oftentimes associated with higher ratios of GHG and eutrohphing emissions, per ton, than the use of synthetic fertilizers (Intergovernmental Panel on Climate Change, 2006; Brentrup, Küsters, Lammel, & Kuhlmann, 2000). Based on the sensitivity results (Table 9), continued research into the potential benefits of incorporating the use of some scaled degree of organic processes may exhibit important environmental improvement options for Texas wine.

Interpreting the 20% Lighter Bottle Hypothesis

The second hypothesis focuses on reducing the weight of a wine glass bottle by 20%. The weight of a typical wine bottle (including the liquid) averages around 3.34 lbs and an empty wine bottle weights around 1.025 lbs (ranges from .066-1.984 lbs.). Around 40% of the weight of a 750-ml glass wine bottle is attributed to the mass of the glass bottle itself (Thompson, 2010). Thus, reducing the weight of the bottle by 20% predicted that this will lower both the packaging and transport related CO_2 emissions that are associated with the manufacturing processes of the glass bottle. No additional differences were made between the use of a lighter bottle and the traditional base case scenario. Similar assumptions were made to account for similar inputs associated with the business as usual approach, for vineyard agricultural processes and transport-related emissions for vineyard goods.

The original hypothesis estimated that provisioning a lighter bottle would weight approximately 0.82 lbs., or an estimated 20% reduction in the weight of the bottle that is typically used in a Texas winery. A reduction in the weight of the glass wine bottle would impact the processes associated with both packaging and transport related CO_2 emissions, substantially improving the environmental footprint of the Texas wine industry.

Based on the findings of the LCA model for this scenario, an acute oversimplification of the wine bottles packaging process and its influence on the entirety of the wines LCA took place. The original hypothesis only accounted for the potential emission reduction factors for a small amount of the environmental footprint. For wine bottle production and its associated activities, these processes have noticeable implications on the environmental impacts associated with wine production, see Figure 10. For each impact category, bottles, cork, and label production represented the contributor to all impact categories excluding ecotoxicity, eutrophication and ozone depletion, for which the viticulture processes contributed the most environmental impacts. As can be seen in Table 6 and Figure 10, in all impact categories, the use of a lighter glass bottle can reduce the wine's total contribution to the emission factors considered by 10.98% and 25.73%. These results are fairly consistent with previous results (Petti, Raggi, & Camillis, 2006; Fusi, Guidetti, & Benedetto, 2014; Neto, Dias, & Machato, 2012). However, based on the various techniques used for reporting, only qualitative comparisons with Texas wine is possible.

There are several explanations that can describe these discoveries:

1) Incorporating the use of lighter weight glass bottles helps reduce the amount of virgin materials that must be sourced for manufacturing glass containers. Less material provision per container helps reduce the amount of energy that must be sourced in order to produce a glass bottle. Impacts from packaging are due to the energy requirements of producing the required materials and much of Texas's energy

supplies are sourced from natural gas and coal (U.S. Energy Information Administration, 2015). Thus, dematerialization can help significantly reduce the associated environmental burdens of producing glass packaging materials.

2) Based on the processes associated with the glass bottle manufacturing industry, by using less volume of materials that must be processed per batch to generate similar quotas (compared to a regular weighted bottle), the energy required to melt, cool and process the materials can be reduced as these occur at much faster rates, as there is less glass needed to produce each bottle (Cattaneo, 2010). Based on Texas's reliance on natural gas and coal supplies to source their energy needs, this helps reduce the global warming potential of manufacturing and processing these materials (U.S. Energy Information Administration, 2015).

3) Reducing the overall weight of a glass bottle, cuts down on the mass of the glass materials that must be transported from the manufacturing facility to the winery and from the winery to the retail facility. A lighter load for a transport lorry each trip reduces the burden of distribution and the amount of gas that is needed to transport the materials to these locations.

4) Finally, while glass containers are one hundred percent recyclable, the Glass Packaging Institute indicates that Texas's recycling rate for beverage containers is only around 18% (Glass, 2013). Using a lighter bottle means that this will prevent a larger percentage of glass materials per bottle from ending up in a landfill.

While the results of the LCA indicate that incorporating lightweight containers can significantly improve the environmental performance of the Texas wine industry, using lighter bottles can also be much more competitively priced than its traditional counterpart (Colman, & Paster, 2009). Most of these reductions are a result of lower impacts associated with bottle manufacture since cumulative energy demand is lower, it improved upon resource efficiencies, and the use of lighter bottles helps minimize the waste impacts that are associated with recycling and or landfilling the glass bottles. Glass bottle manufacture and the electricity used for the manufacture of glass bottles is the biggest contributor to wine's, acidification potential, global warming potential, and photochemical ozone formation potential. Thus, by incorporating a lighter glass bottles, substantial reductions occur for the acidification potential (25.14%) and photochemical ozone formation (25.73%) impacts are mostly affected by the bottle manufacturing processes at the facility. The emissions associated with ozone depletion potential arise from the combustion of gasoline and diesel transportation links. The use of a lighter bottle helps decrease the load transport of bottle shipments to the winery and from the winery to the retailer, thus reducing its emissions by 16.5% from the base case scenario. Substantial reductions associated with environmental impacts occur when lighter bottles are utilized and the efficiencies that are gained as a result of using them, dramatically reduces the associated impacts with the Texas wine production activities. Based on these findings, incorporating the use of a lighter glass wine bottle may be a reasonable alternative to reduce the environmental impact of a Texas sourced bottle of wine (Aranda, Zablaza, & Scarpellini, 2005; Point, 2008; Cleary, 2013; Fusi, Guidetti, & Benedetto, 2014).

Research Limitations

When performing an LCA, not all relative environmental impacts are considered. This is due to the limitation associated with defining the scope and system bounders of the area under study. As with most LCAs, the system under study is extremely complex and the research could argue that providing higher levels of detail and collecting more data is necessary to create a more robust and comprehensive model. However, despite the almost infinite number of aspects to each of the stages for the life cycle for wine production, it is necessary to provide the appropriate level of goals, scope and system boundaries for the short time frame of this thesis. A limitation of this methodology choice means that with a limited timeframe, this can restrict the accuracy of the end results. An LCA methodology can always benefit from obtaining more data, incorporating more detail, and broadening the unit system boundary to improve the results.

The finalized results and deductions presented here are subject to a number of additional research limitations:

- A limitation of the study stems from the availability of inventory data that was collected during this thesis. Texas is home to over 220 vineyards in eight of the AVA regions. The initial attempts to entice vineyards to participate in this research was met with much resistance since the vineyard owners were extremely busy and tasked with the time consume processes during the harvest season. Thus, this research only contains data for the four vineyards that agree to participate and all eight AVA regions were not represented in this study. Vineyards are extremely diverse in their management styles, viticulture practices, machinery employed, trellising system, viniculture practices, terroir and mesoclimate. Therefore, the emissions represented by the vineyards and wineries who participate in this thesis may not adequately reflect future vineyard and winery practices in every vineyard located in Texas.

- Based on the hypothetical organic grape production scenario modeled in the study, one can argue that organic grape production is far more intricate than the simplistic scenario modeled in this research. The organic scenarios did not consider the parameters associated with regulating the sources of manure or composted materials, the timing of nutrient application, and requiring buffer zones between the applications sites. The organic scenario also omitted the provision of manure and its associated environmental emissions to the environment based on the type of animal that generates the manure, its diet, and the application practices involved (Bussink & Oenema, 1998; Monteny, Bannink, & Chadwick, 2006; Point, 2008). It is plausible to consider that by incorporating these stipulations into the model, it would likely allocate a more modest estimation for related quantiles of field-level emissions. However, these conservative estimates may be invalidated or dependent upon the source, the transportation link(s) and the delivery distance for the fertilizers.
- Based on the variety of grapes cultivated, the numerous control methods that are incorporated to preserve the quality of the grapes, and the diversity of Texas's climate, it might be beneficial to preform future scenarios and limit the research to evaluate one to two regions at a time. Limiting the analysis system boundaries to one to two regions may provide more pertinent control methods that could be incorporated into the vineyards managed practices to improve upon the environmental footprint of the system. It is impossible to calculate a one size fits all environmental improvement approach based on the infinite number of

management techniques, size, age, output, and types of grapes cultivated all over the region.

- Finally, a limitation that should be noted is that as the wine industry continues to grow in the Texas, the relative contributions to the total life cycle impacts of the viniculture and viticulture production processes may shift. If substantial changes to the wines life cycle do occur, then this may not adequately reflect future vineyards and the winery's practices.

Notwithstanding these limitations, this fieldwork demonstrates the crucial components for employing a life cycle assessment for evaluating the amplitude of environmental impacts associated with a food product system. Based on alternative LCA's that have taken place in other regions around the world, this LCA signifies that embracing a more organic approach is not always associated with a more environmentally friendly footprint for all impact categories and is not a one size fits all solution (Notarnicola, Tassielli, & Nicoletti, 2003; Mattsson, 1999b, Point, 2008).

Suggestions for Further Research

The life cycle assessment for the Texas wine industry has yielded datasets that provide insights into the complexities of our modern food production activities and its relative environmental impacts. Understanding these processes can provide a baseline for comparison purposes for any future research pertaining to the associated environmental impacts of the Texas wine industry. If and when the Texas wine industry purses a more environmentally sustainable management agenda, examining the results from this study would provide quantified and definitive data that identifies the industries relative environmental impacts. Access to such data could provide a foundation that conveys the advantages of altering current management practices to improve upon the environmental profile of Texas produced wine.

While the results that were obtained in this study are similar to other findings, as noted by and Point (2008), Neto, Dias, & Machado (2013), and Amineyo (2014) the outcomes for other wine-related LCA studies are not easily comparable due to the variations of the methodological options employed by the research to estimate the emissions, and the various management decisions that are used to produce the wine (Fusi, Guidetti, & Bendetto, 2014). Other life cycle assessments undertaken for wine production present multiple results from other wine production regions. They offer a frame of reference to determine the optimal course of action to improve upon the environmental profile of wine made in Texas and other wine producing regions. Employing a systematized set of guidelines to compare the outcomes from these various LCA wine studies is needed to create a more robust environmental management program.

When comparing the life cycle assessments business as usual approach to the lighter bottle scenario, the results indicated that for all that all impact categories experienced notable improvements. Decreasing the amount of material needed for glass production by 20% is a conservative approach for light weighting bottles. Studies have indicated that some bottles weight can be reduced by up to 40% (WRAP, 2008) and incorporating additional lighter weight bottles might indicate even further environmental improvement opportunities. Further research should also prioritize the environmental performance aspects of the supply chain by focusing on multiple alternative packaging options and activities associated with the manufacturing areas and to the retailer for consumer purchase. The datasets quantified within the LCA by incorporating the use of lighter bottles could also help the community realize the benefits of utilizing these bottles and promote consumer engagement strategies (Point, 2008) Since the environmental impacts resulting from the consumer behavior are currently neglected in the study, an analysis of the environmental, economic and value of the packaging choices in the life cycle assessment for Texas wine, makes this aspect of the LCA a potential target for further studies.

Existing vineyards in Texas range drastically in scales of less than one acre to approximately two-hundred acres. A comparative analysis of the life cycle impacts associated with both smaller and larger scaled vineyards might also be beneficial. In reference to scale, an investigation of smaller and larger scaled vineyards might present an opportunity to examine potential benefits of comparing the energy efficiencies, materials and processes linked to each unit of production. Future research should also focus on comparing vineyards sizes which may provide an insight into the possibility of any advantages corresponding to the scale of a vineyard (Point, 2008; Neto, Dias & Machado, 2013)

Finally, many wine regions here and abroad have begun pursing more environmentally friendly endeavors to lessen their environmental impacts. Presently, the prevalence of such studies is limited. In its absence, a recommendation for future research is that any knowledge gained from the Texas wine life cycle assessment and other wine LCAs, is incorporated in a thorough sustainability management agenda that vineyards owners could potentially reference and follow. This agenda should incorporate potential environmental management choices that address the most impactful areas of wines life cycle stages that diminish associated impact emissions. Preferably, wine industries will commit to preforming their own LCAs, because there are innumerable variables throughout each wines life cycle that can influence its environmental impacts. Continued research into this industry will document potential opportunities to significantly improve a wines environmental profile and will lead to the development of more robust environmental management programs.

Appendix 1

Sample Survey for Winery Life Cycle Inventory Data Collection

The following survey was presented to the vineyards under study. The survey asked for primary data pertaining to the 2015 production year. However, the second and third section of the survey were relevant to the years in which the land had to be prepped for planting and when the majority of the vines were originally established. The survey questions were compiled by analyzing multiple LCA case studies including 1) LCA of the supply chain of a Portuguese wine: from viticulture to distribution; 2) environmental impacts of consumption of Australian red wine in the UK; and 3) the life cycle environmental impacts of wine production and consumption in Nova Scotia, Canada (Amienyo, 2014; Neto, Dias & Machado, 2013; Point, 2008). These are peer reviewed case studies that performed similar LCAs of their wine industries, and utilized similar questions to gather their data. The questions have been adapted to accurately reflect the differences associated with vineyards located within Texas.

Section One: Relates to the size, age and output of your vineyard

1.1. What is the total area of your vineyard in acres? (including buffer zones if applicable)

____

1.2. How many acres of vines were grown on your vineyard in 2015?
Red _____ White _____

1.3 How many tons of grapes were harvested for wine in 2015?

Red ______White ______

1.4 How many years has your vineyard been producing grapes?

____

Section Two: Relates to Land Preparation

2.1 Did you grade/cultivate/furrow the land before planting the vines?

Yes _____ No ______

2.1.1 If yes, what machinery did you use? (Make/Model)

____

2.1.2 Did the machine run on Gasoline or Diesel?

____

2.1.3 Approximately how many hours did it take to grade/cultivate/furrow the land prior to planting? ________________________________

2.2 Did you bring in new top soil? Yes _____ No _____

2.2.1 If yes, how many cubic meters of the topsoil did you import?

____

2.2.2 If yes, where did you import the soil from?

____

2.3 Did you add any nutrients, fertilizers, or organic matter to the soil when prepping the land? Yes ____ No_____

2.3.1 If yes, what was added to the soil?

Name of Product ________________________ lb/ac ________

Name of Product ________________________ lb/ac ________

Name of Product ________________________ lb/ac ________

Name of Product ________________________ lb/ac ________

2.4 Did you sow a green manure crop in the season prior to planting?

Yes _____ No _____

2.4.1 If yes, what crop(s)? ______________________________________

2.4.2 If yes, on how many acres did you sow these crops? __________

2.5 What existed on your vineyard site prior to grape vines? _________________

2.6 Did you apply an herbicide prior to planting? Yes ____ No _____

2.6.1 If yes, what is the name of the herbicide? (Please provide brand name if possible)

____

2.6.2 If yes, how many gallons/acre of the herbicide did you apply to your vineyard in the year before planting?

____

2.7 Did you correct the soil pH before planting? Yes _____ No _____

2.7.2 Did you hire a contractor to complete the job? Yes _____ No ______

2.7.1 If yes, what is the name of the contractor you hired?

____

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

____

2.7.4 If you corrected the soil pH yourself, how many tons/acre of the compound was used? _______________________________________

Section Three: Refers to planting

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

______ Bone metal name of product _______________ lb/ac ______

______ Super phosphate name of product _______________ lb/ac______

______ Compost name of product _______________ lb/ac ______

______ Other name of product _______________ lb/ac ______

3.3 Did you apply a fertilizer staring solution of 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 gallons/acre 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: This section refers to yearly vine propagation

4.1 How many new cuttings did you start in 2015? _________________________

4.2 From where did you get your grape cuttings? (Check one)

_______ own cuttings

________ Purchased from:____

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

4.3 Did you spray your vine propagations for mildew? 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 gallons of mildew spray did you use in 2015?
____

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 materials did you use? (Please provide brand name if possible). ____

4.5.2 How many pounds of this material did you use? ___________

Section Five: This section refers to 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 vine 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?

____

5.5.2 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 wires? Bottom ___________ Top___________

5.9 How many wires are on the trellis? Bottom ___________ Top___________

5.10 What holds the wires onto the trellis?

____

Section Six: Refers 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 trying machine?

____

6.2 How many boxes of trying tape did you use in 2015?

____

6.3 How many boxes of staples did you use in 2015?

____

6.4 What do you do with your vine prunings?

% Used for propagation ___________ % Disked into soil _____________

% Removed ____________________ % Burned ____________________

6.4.1 How many pounds or tons of vine pruning's were removed from your vines in 2015?

____

6.5 What is allowed to grow in between your vine rows?

Nothing______________________________

Native Plants and grasses________________

Nonnative Grass (seeded) _______________

Cover Crop___________________________

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

Section Seven: Refers to Nutrient Management and Application

7.1 Did you apply lime to your fields in 2015? 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 personally complete this job, what is the brand name of the lime product you applied?
____

7.2.1 How many pounds/acre of lime did you apply?
____

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

7.4 Did you fertilize your fields in 2015? Yes_____ No ______

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

7.4.2 How many liters/hectares were applied to your fields in 2015?
____

7.4.3 How many times did you apply fertilizer in 2015?
____

7.5 Did you apply a nitrogen-foliar spray to your fields in 2015?
____

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

7.5.2 How many liters/hectare were applied to your fields in 2015?
____

7.5.3 How many times did you apply foliar-nitrogen spray to your vineyard in 2015? ____

7.6 Did you add compost to your grape fields in 2015? 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 pounds/acre of compost was applied? ___________

7.6.3 How many times did you apply compost to your fields in 2015?
____

7.7 Which of the following micronutrients did you apply to your fields in 2015 and how often?

_______ Iron __________ lb/ac ___________times/year

_______ Sulphur __________ lb/ac ___________ times/year

_______ Manganese __________ lb/ac ___________ times/year

_______ Copper __________ lb/ac ___________ times/year

_______ Zinc __________ lb/ac ___________ times/year

_______ Boron __________ lb/ac ___________ times/year

Section Eight: Focuses on weed and pest management activities

8.1 Did you apply herbicide to your grape vines in 2015? Yes_____ No_____

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

8.1.2 How many pounds/acre of herbicide was applied to your fields in 2015?

____

8.1.3 How many times did you apply herbicide to your vineyard in 2015?

____

8.2 Did you apply a fungicide to your vineyards in 2015? Yes______ No______

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

____

8.2.2 How many pounds/acre of fungicide was applied to your fields in 2015?

____

8.2.3 How many times did you apply fungicide to your vineyard in 2015?

____

8.3 Did you apply mulch materials to curb weed growth in 2015?

8.3.1 If yes, what did you use?

Straw __________

Woodchips___________

Other (please specify) ____________

8.3.2 If yes, how many pounds/acre of this mulch material was applied to your vineyard in 2015?

____

8.4 Do you use netting to exclude pests? Yes______ No______

8.4.1 What percent of your vineyard was netted in 2015?

____

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

____

Section Nine: Refers to harvesting

9.1 What percent of the harvesting is done:

Mechanically: _________ By hand: ___________

9.2 What is the material of the buckets in which the grapes are placed into during the harvest?

____

9.2.1 What are the approximate dimensions of the buckets?

____

9.2.2 How many buckets are used on you vineyard?

____

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

____

9.3.1 What are the dimensions of the bines?

____

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 ________ Other 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 vehicle that is used to transport the grapes to the winery? ________________________________

Section Ten: Vineyard Equipment and Human Labor Requirements

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

Tractor_________ Make/Model: _____________________________

Liters of fuel used/year: _____________________

Does it use Diesel_____ or ______Gasoline ______

Mower_________ Make/Model: _____________________________

Pulled by a tractor? Yes____ No_____

If it is not powered by the tractor then please list the make/model of machine used to power it:_______________________________________

Liters of fuel used/year: _____________________

Does it use Diesel________ or Gasoline_________

Sprayer_________ Make/Model: _____________________________

Pulled by a tractor? Yes____ No_____

If it is not powered by the tractor then please list the make/model of machine used to power it:_______________________________________

Liters of fuel used/year: ______________________

Does it use Diesel________ or Gasoline_________

Mechanical Harvester_________ Make/Model: ______________________________

Pulled by a tractor? Yes____ No_____

If it is not powered by the tractor then please list the

make/model of machine used to power it:____

Liters of fuel used/year: ______________________

Does it use Diesel________ or Gasoline_________

Subsoiler/Ripper _________ Make/Model: ______________________________

Pulled by a tractor? Yes____ No_____

If it is not powered by the tractor then please list the

make/model of machine used to power it:____

Liters of fuel used/year: ______________________

Does it use Diesel________ or Gasoline________

Foliage Trimmer_________ Make/Model: ______________________________

Pulled by a tractor? Yes____ No_____

If it is not powered by the tractor then please list the

make/model of machine used to power it:____

Liters of fuel used/year: ______________________

Does it use Diesel________ or Gasoline_________

Mechanical Pruner_________ Make/Model: _____________________________

Pulled by a tractor? Yes____ No_____

If it is not powered by the tractor then please list the

make/model of machine used to power it:_______________________________________

Liters of fuel used/year: _____________________

Does it use Diesel________ or Gasoline_________

Tiller_________ Make/Model: _____________________________

Pulled by a tractor? Yes____ No_____

If it is not powered by the tractor then please list the

make/model of machine used to power it:_______________________________________

Liters of fuel used/year: _____________________

Does it use Diesel________ or Gasoline________

Grape Hoe_________ Make/Model: _____________________________

Pulled by a tractor? Yes____ No_____

If it is not powered by the tractor then please list the

make/model of machine used to power it:_______________________________________

Liters of fuel used/year: _____________________

Does it use Diesel________ or Gasoline_________

Appendix 2

Sample Survey for Winery Life Cycle Inventory Data Collection

1. How many tons of grapes were processed in 2015? ______________________
2. What is the winery's total output of the wine in 2015?____________________
3. What percentage of the grapes you processed are Texas Grown?____________
4. What percentage of the grapes you processed are purchased from other contract growers?____
5. How are the grapes brought to the winery, including transport mode and vehicle used?____
6. What was the total amount of diesel fuel used to power the equipment/machinery in the winery in 2015?____________________________
7. What was the total amount of gasoline used to power equipment/machinery in the winery in 2015? ____
8. How many liters of water were used in the winery's operation in 2015?
   ____
9. What was the total electricity utilized (in kWh) to run the winery in 2015?
   ____
10. What products are added to your wines during the various stages of the viniculture processes and the amounts added? Please indicate as much detail about these products as possible (brand name, name of main supplier). However, if unsure about the amount added to the wines, please indicate an estimation or further information about where I might obtain this data.

Clarifying Agents: ____
Yeast: ____
Yeast Nutrients: ____
Antioxidants: ____
De-filtering Agent: ____
Bacteria: ____
Sugar: ____
Other: ____

11. Where are these purchases made?
    - Glass bottles: ____
    - Corks: ____
    - Screwcaps: ____
    - Labels: ____
    - Heat-shrink capsules: ____

12. In what vehicle do you transport your grapes for retail in Texas markets?
____

13. What do you do with the leftover Pomace (solid materials such as the skins, seeds, pulp)? ____
____

14. What do you do with leftover lees (deposits of dead yeast/ other particles that settle to the bottom of the vat after the wine finishes fermenting/aging)?
____
____

15. What cleaning products are used in the winery and how much of each product was used in 2015? Please provide names of products if possible.
____
____

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

17. Please feel free to provide any additional comments, suggestions, concerns, etc.
____
____
____
____
____
____
____
____

Appendix 3

USDA Organic Certification and National Organic Program Standards

Based on the laws in Texas surrounding organic viniculture techniques the vineyard will have to apply to these stated laws which include:

- The land in which viticulture takes place cannot have had any synthetic substances applied for at least three year prior to the harvest of an organic crop (USDA, 2008).
- The use of fertilizers must be comprised of animal and or crop wastes.
- Pests, weeds, and any sort of disease measures should be handled through the use of approved physical, mechanical and biological controls. If these measures fail, then the use of approved synthetic substances found on the National List may be utilized (USDA, 2008).
- The use of organic seeds and planting stock are preferred unless otherwise specified.
- Genetically modified organisms/engineering, ionizing radiation and the use of sewage sludge is prohibited.
- The use of sulfates in 100% organic wines may not be utilized (water and salt are permitted). Therefore, since no added sulfites are present in the finished product, the label may not require a sulfite statement. In these cases, a lab analysis is necessary to verify that the wine contains less than 10 ppm of sulfites (USDA, 2008).

- 95% organic wines allow for 5% of non-organic ingredients. However, the addition of sulfates is still not permitted. Therefore, testing must confirm that the wine contains less than 10 ppm sulfites (USDA, 2008).
- Made with organic grapes: 30% of the wine may be produced with non-organic ingredients when organic ingredients are not available for the producer to utilize during production. These wines could have additional Sulfites, but may not surpass 100 ppm (USDA, 2008).

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