Food Product Environmental Footprint Literature Summary:

Wine

State of Oregon
DEQ Department of Environmental Quality

with support from

The Oregon Sustainability Board

A report by: Center for Sustainable Systems, University of Michigan

Martin Heller
September 2017

This page is intentionally left blank.

Executive Summary:

Wine

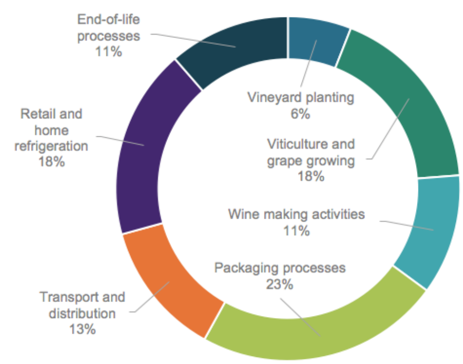
Wine, like anything we consume, requires natural resources and generates environmental emissions, and therefore, understanding the processes that contribute the most impact can aid in efforts to reduce our overall footprint. Oregon is both a significant producer and consumer of wine. Oregon's more than 27,000 acres of vineyards are spread across 18 designated wine growing areas and produced 78,000 tons of wine grapes in 2014, placing it at #10 in dollar value among Oregon's agricultural commodities, and making Oregon the 4th ranked wine producer nationally. According to the Oregon Consumption Based Greenhouse Gas Emissions Inventory for 2014, producing and supplying all wine consumed by Oregonians (not including restaurant sales) contributed an estimated 84,500 metric tons CO_2 equivalents annually. That's equivalent to about 17,800 average passenger vehicles operated for a year.

This summary highlights results from life cycle assessment (LCA) studies of the life cycle of wine production depicted above. Such studies, while not specific to wineries in the Pacific Northwest, can help viticulturists, vintners and wine drinkers focus efforts on activities that can have the greatest reduction on the environmental footprint of wine production.

Key Findings

A critical review of carbon footprint (CF) analyses of wine production reveals that on average:

- Planting and growing grapes contribute about 24% to the total CF for wine.
- Wine making itself contributes about 11% to the total CF for wine.
- The production of packaging materials contributes another 23%, while also contributing to additional impacts of transport and distribution.
- Packaging options exist that have the potential of significantly reducing the overall wine carbon footprint.
- Transporting bottled wine to retailers through a combination of trains and trucks accounts for 13% of total CF of wine, on average.
- Transport from point-of-sale to home and refrigeration in the home contributes about 18%.
- Disposal (mainly packaging) contributes about 11% to the total CF for wine.



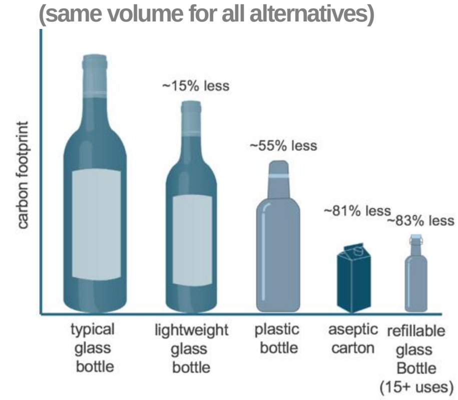
Carbon footprint by life cycle phase of wine

Conclusions

The LCA literature on wine production and consumption offers the following conclusions:

- The impacts of fertilizer production and application are often important to the overall impacts of viticulture, along with growing practices and local climate.
- Significant variability in the environmental impact of a bottle of wine can be seen depending on vintage year, due to the impact of weather on grape growing conditions.
- The typical 750 milliliter glass bottle used to package wine stands out as an important contributor to overall life cycle greenhouse gas emissions. Lightweight glass, alternative packaging options, and shipping in bulk all can offer notable reductions.
- How wine is transported (e.g. road vs rail) can have a far greater influence on the overall carbon footprint than how far it is transported.

Relative carbon footprint of wine packaging alternatives in relation to the typical single use glass bottle (same volume for all alternatives)



This page is intentionally left blank.

Overview

As an integral part of human culture for thousands of years, wine often seems more “art” than “food industry.” Yet, like anything we consume as a society, wine production requires natural resources and generates environmental emissions, and therefore, understanding the processes that contribute the most impact can aid in efforts to reduce our overall footprint. With more than 27,000 acres of vineyards and 78,000 tons of production in 2014, Oregon’s wine grape industry ranks #10 in dollar value among Oregon’s agricultural commodities, making Oregon the 4th ranked wine producer nationally. According to the Oregon Consumption Based Greenhouse Gas Emissions Inventory for 2014[1], producing and supplying *all* wine directly purchased by Oregon households (i.e., not including restaurant sales) contributes an estimated 84,500 metric tons CO_2 eq. annually (1.1% of household non-restaurant food and beverage total, 0.1% of Oregon grand total). Only about 6% of these emissions occur inside Oregon; another 57% occurred elsewhere in the U.S., with the remainder occurring in other countries.

Wine aficionados know that location is an important determinant in the unique qualities of a given wine, and Oregon, with its 18 designated wine growing areas across four diverse regions, is overflowing with uniqueness. While differences in climate and soil can also influence agricultural input needs, and therefore environmental footprint, the goal of this summary is *not* to compare wines or wine regions but instead highlight findings from the academic literature that are broadly applicable to wine production in general. Of course, all generalities have exceptions, and specific studies would be required to provide more accurate information. The following insights, however, can help viticulturists, vintners and wine drinkers focus efforts on activities that can have the greatest reduction on the environmental footprint of wine production.

FIGURE 1. Generic life cycle of wine production.

This literature summary is one of a series commissioned by the Oregon Department of Environmental Quality. For additional information on the background and objectives of these summaries, as well as on LCA methods and definitions of terms, please refer to the Food Product Environmental Footprint Foreword.

[1] http://www.oregon.gov/deq/mm/Pages/Consumption-based-GHG.aspx

Available LCA Research

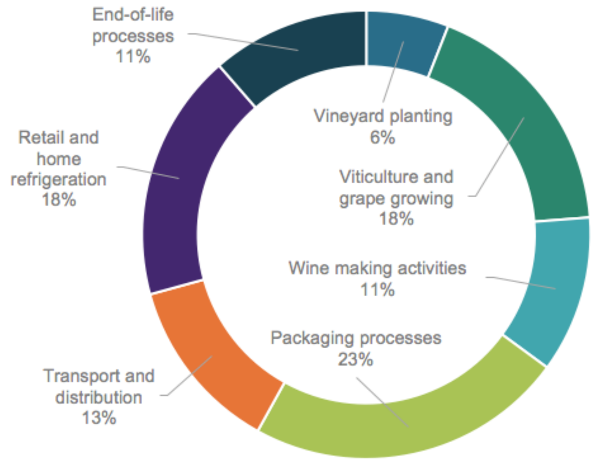


FIGURE 2. Average contribution of each life cycle phase to the overall CF of winemaking.

A critical review of carbon footprint analyses of wine production published in 2013 identified 35 studies; 24 of these were based on LCAs (Rugani *et al*. 2013). We have identified 11 additional studies published since this review, or that were not included in the review. Of these roughly 35 wine LCA studies, only six consider a North American produced wine (four California studies, one in Nova Scotia, and one considering a generic North American scenario). Carbon footprint (CF) or greenhouse gas emissions (GHGE), was the dominant environmental impact category considered, while 19 studies also reported on impact categories *other than* GHGE. Figure 2 shows the average contribution of each life cycle phase to the overall CF of winemaking found in literature.

Key Findings

Carbon Footprint Across the Life Cycle

To summarize results, we compiled reported GHGE values at major life cycle stages, and averaged those values at life cycle stages (Figure 3). While recognizing the variability in technological, geographical and viticulture conditions at play across the world's wine producing regions, Figure 3 offers a global proxy of the CF distribution for the life cycle stages of wine production. Although the variability is large as one might expect for such a global average, Figure 3 helps in pointing to the stages in a typical wine product chain with disproportionately high environmental burdens. This information can help focus improvement efforts where they are likely to have the most bearing.

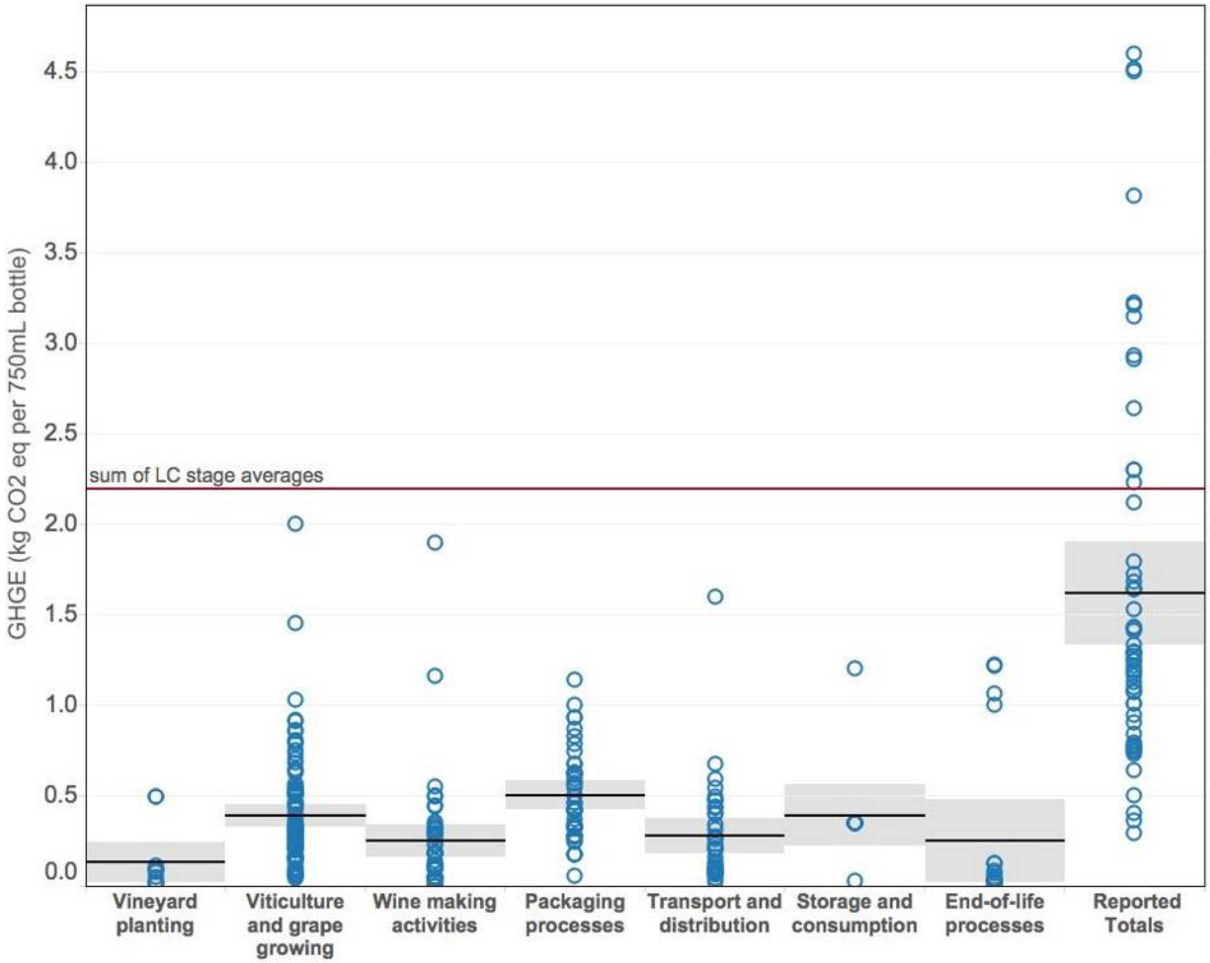


FIGURE 3. Life cycle greenhouse gas emission results from all studies reviewed, distributed across major life cycle stages.

Circles represent individual study results, offering a sense of the data spread or cluster. Horizontal black bars represent averages for each stage, and grey blocks are 95% confidence intervals around the averages. The "Reported Totals" column shows totals from each study, although it is important to recognize that not all studies include the full life cycle stages represented here. The red bar indicates the sum of the averages from each life cycle stage.

On average, viticulture (including vineyard planting) contributes 24% to the total CF, while wine-making processes contribute 11%, and packaging processes contribute 23%. Transport and distribution average 13% of the total, although the relevance of transport is highly dependent on specific transport distances, modes and packaging configurations modeled in individual studies. Uncertainty increases for the remaining "downstream" stages of the life cycle, as they are included in only a few studies. Storage and consumption, which typically includes transport from point-of-sale to home and refrigeration in the home, averages to an 18% contribution (95% confidence interval = 3.7% - 22%). End of life processes, which usually include disposal of packaging but in some studies also includes disposal of winemaking wastes, contributes an average of 11%.

Note that the relatively high outlier in the "storage and consumption" stage is from a study that included driving an average car 5 kilometers for the sole purpose of buying a bottle of wine. Results from this study also show up as the sole "storage and consumption" stage data point for the indicators in Figure 3, and highlight the relative importance of personal shopping trips.

A cradle-to-retail CF assessment of the California wine industry, conducted in 2011 by a respectable consulting firm, found similar results to the global proxy in Figure 3, although incorporation of a carbon and nitrogen bio-geochemistry modeling tool elevated the importance of field emissions[2]. This study found that glass bottles accounted for 29% of the CF up through distribution to U.S. retail facilities; bio-geochemical field emissions, driven primarily by application of nitrogen fertilizers, contributed an additional 17%; transport of bottled wine through a combination of trains and trucks to retailers in the U.S. accounted for 13%; 10% was due to manufacture and shipment of raw materials (fertilizer, pesticides) used at the vineyard; fuel consumed at wineries and electricity at wineries added 7% each; and smaller contributions from fuel and electricity used in the vineyard, additional packaging and other winery contributions made up the balance.

The Beverage Industry Environmental Roundtable (2012) conducted a cradle-to-grave CF of wine, developing scenarios for a European and a North American format. The study found the North American format to have 39% greater GHGE per bottle than the European format, attributable to higher electricity grid emission factors for energy use. The major contributors to the overall CF for each format are shown in Table 1. Sources that contributed less than 1% (each) to the total CF included: label, label adhesive, cork, yeast, nitrogen, fining agent, preservation additives, shrink wrap, wood, water, warehousing, retail, and domestic use.

One point of potential confusion in the CF of wine involves carbon dioxide (CO_2) emissions during fermentation. Winemakers are certainly familiar with the fact that the fermentation process releases large quantities of CO_2, and it might come as a surprise that these emissions do not represent a significant contribution to wine's CF. This CO_2 results from the digestion by yeast of sugars that were built up in the grapes through photosynthesis, which draws CO_2 out of the atmosphere. In other words, this "carbon cycle," similar to the digestion of foods by humans, is considered short-term and a net-zero emission from a global warming perspective, and therefore should not be accounted for in CF calculations.

[2]Field emissions: Nitrous oxide (N_2O), a greenhouse gas 265 times as powerful as CO_2, can be released from nitrifying and denitrifying activities in the soil when nitrogen fertilizers are added to agricultural soils. Estimating these direct field emissions is extremely difficult, and most LCA studies rely on constant emission factors or simple empirical relationships that do not account for vineyard-specific interactions. Process based bio-geochemistry models, such as the one employed in the California wine industry study, are considered to be more accurate.

	European bottle format	North American bottle format
Glass bottle (750 mL)	45%	33%
Grape growing	24%	17%
Energy use for crushing, bottling and maturation	10%	12%
Corrugated cardboard packaging	9%	3%
Fermentation energy use	4%	28%
Transportation	5%	4%

TABLE 1. Largest contributors to the wine carbon footprint as reported by the Beverage Industry Environmental Roundtable, for each of two generic formats.

Other Environmental Indicators Across the Life Cycle

As mentioned earlier, about half of the identified wine LCAs consider environmental indicators beyond GHGE. An even smaller number consider full life cycle impacts and report results in a way that allows comparisons with other studies. Despite this, the results presented in Figure 4 offer some guidance toward life cycle stages with disproportionate eutrophication and acidification impacts. As may be expected, Figure 4 suggests that eutrophication is dominated by the viticulture stage; this is driven primarily by fertilizer application and the potential for field-level nutrient losses. Acidification potential impacts are more evenly distributed across the life cycle; acidification is typically driven by combustion of fossil fuels, either as transportation fuels or in the generation of electricity.

We might expect water use impacts across the wine production life cycle to be dominated by the viticulture/grape growing stage, and the two studies that consider water use across the life cycle confirm this. The magnitude of water use, primarily through irrigation demand, as well as the impact of water use on the local environment, is highly location dependent. While toxicity impacts – both human and ecological – are an interesting and relevant impact category, limited data and uncertainty in characterization factors make it difficult to draw general conclusions.

Volatilization of ethanol to the atmosphere can contribute to photochemical oxidation (summer smog), and some volatilization of ethanol during the wine fermentation process is inevitable. Studies that consider its impact demonstrate that it is not particularly large, making contributions to the wine production life cycle’s overall photochemical oxidation potential that are on the same order as emissions during glass bottle production (primarily tied to electricity generation) and transport fuel use during viticulture activities and transportation.

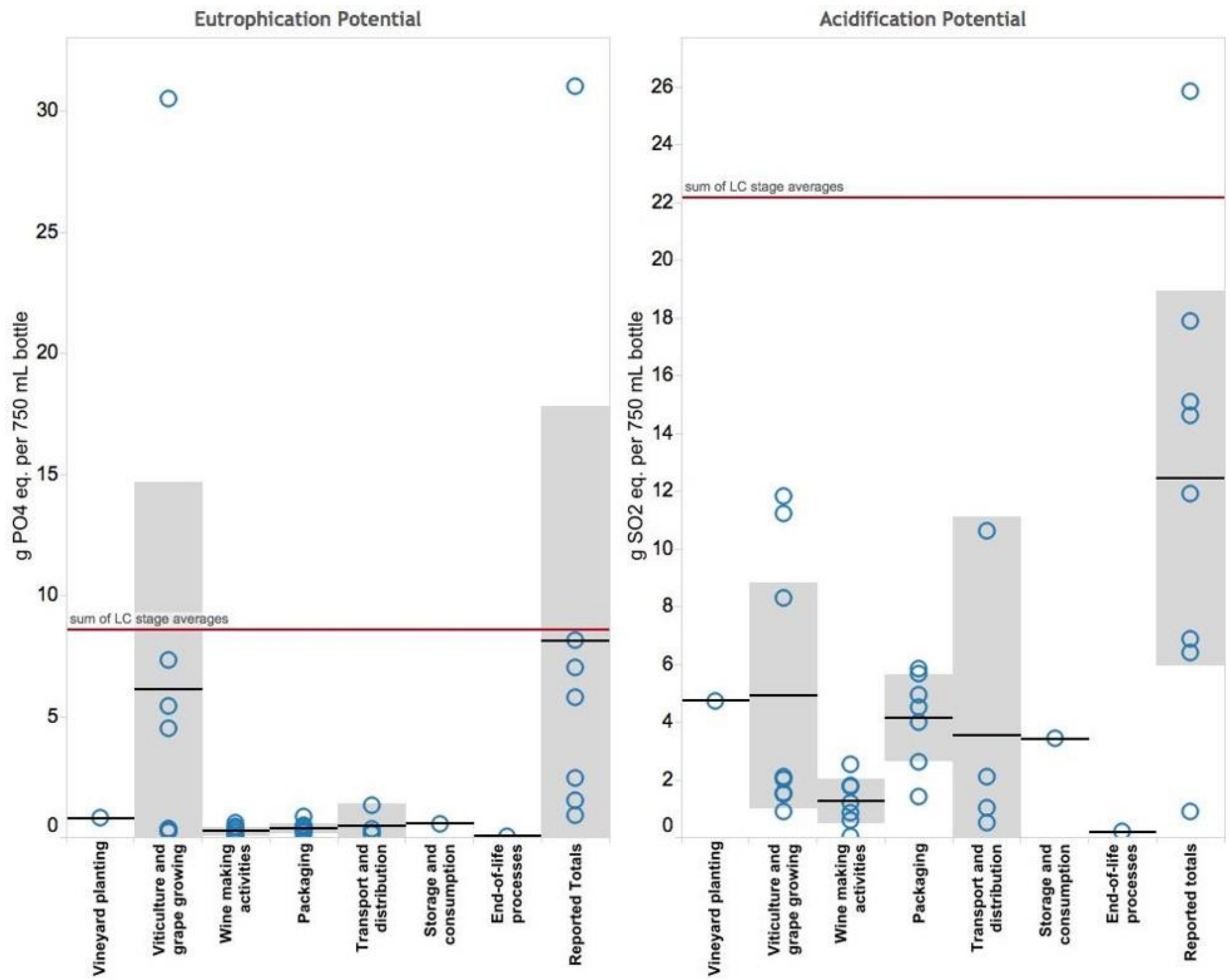


FIGURE 4. Distribution of eutrophication potential and acidification potential across wine life cycle stages.

Circles represent individual study results, offering a sense of the data spread or cluster. Horizontal black bars represent averages for each stage, and grey blocks are 95% confidence intervals around the averages. The reported totals columns show totals for each study: seven values contribute to the average total for eutrophication, eight for acidification. The red bars give the sum of the averages from each life cycle stage.

Viticulture

Grape growing remains an important stage in many LCAs of wine production. The dominant contributor to the viticulture stage varies depending on local climatic conditions, growing practices and how grape growing is modeled, but the impacts of fertilizer production and application (N_2O emissions, nutrient leaching) are often important. Some LCAs of organically managed vineyards or viticulture with very small quantities of fertilizer input demonstrate relatively low GHGE for grape production (Petti *et al.* 2006, Pizzigallo *et al.* 2008, Bosco *et al.* 2011). However, other comparisons between conventional and organic grape growing suggest that a shift to organic production is not a sure-bet way of reducing GHG impacts per unit of wine produced, as composting processes, increased tractor operations, yield differences, and other factors all play a role (Steenwerth et al. 2015, Vázquez-Rowe *et al.* 2013).

One study (Vázquez-Rowe *et al.* 2012) that conducted an LCA over four years of production at the same vineyard and winery identified vintage year variability on the order of 20% across a wide range of environmental indicators (global warming potential, acidification potential, eutrophication potential, others). This is particularly interesting in light of environmental labeling efforts, and the authors suggest the use of an "environmental vintage" grading system to accompany and complement wine quality vintage.

Packaging

In most of the studies reviewed, packaging, and in particular glass bottles, stands out as an important contributor to the CF of wine production. This is largely due to the mass of glass required and the energy needs to produce it.

An LCA study focused on packaging options for wine considered a number of 1 liter packaging options (Cleary, 2013). Relative to a "common single use" glass bottle (weighing 543 grams), see Figure 5, the life cycle CF of only the packaging decreased by 15% for a lightweight single use glass bottle (weighing 434 grams), by 55% for a PET bottle, by 81% for an aseptic carton, and by 83% for a refillable glass bottle (cleaned and filled 15 times). Similar reductions were seen across a host of other environmental impact categories. Note that this study looked only at the packaging and did *not* include wine production.

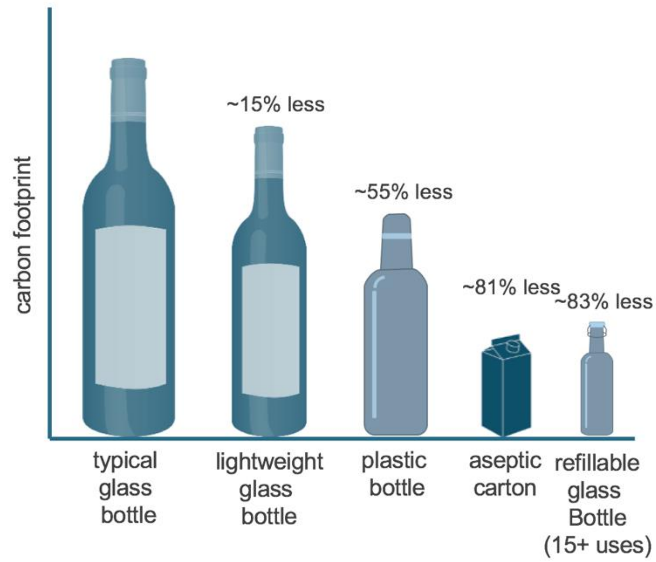


FIGURE 5. Relative carbon footprint of various wine packaging formats compared to the typical single use glass bottle (left).

Lightweighting of bottles affects emissions from packaging manufacturing, but also emissions from transportation. A UK-based study considered the impact of lightweighting bottles shipped from Australia to the UK (WRAP, 2007). Reducing bottle weight from a "business as usual" 502 grams to the current lightest glass bottle, 300 grams, lowered the GHGE of producing and importing a bottle of wine by 15%. A more typical light bottle weighing 400 grams reduces the overall CF by 6.6% The California wine industry study also demonstrated that lightweight glass bottles can decrease the overall CF by 10%, whereas 3 liter bag-in-box packaging decreases overall CF by 40% from the typical 750 milliliter glass bottle.

While life cycle studies of wine indicate that closures (corks, aluminum caps, etc.) have very minimal overall impact, wine producers and consumers may nonetheless be interested in the relative merits of closure options. An LCA study conducted for Corticeira Amorim (largest cork producer in the world) by PricewaterhouseCoopers/ Ecobilan (2008), carefully following international standards including independent critical review, found that cork stoppers performed better than typical aluminum and plastic closures of 750 milliliter bottles in all environmental indicators considered (non-renewable energy consumption, greenhouse gas emissions, atmospheric acidification, photochemical oxidants, eutrophication of surface water, production of solid waste) *except* water consumption, where aluminum stoppers performed better. It is important to note, however, that this study did *not* take into account failure rates of the closures, which can strongly influence the impact per unit of wine actually consumed.

Transportation Logistics

Distribution can be a significant contribution to the overall environmental footprint of wine. In 2009, researchers publishing in the *Journal of Wine Research* suggested that transportation was the most significant part of a wine's lifecycle GHGE, and proposed a "wine line" across the central U.S., indicating that east of this line, wine from France would carry less of a transportation burden than wine from California (Colman and Päster, 2009). However, this study included many simplifying assumptions, and many more nuanced conclusions on the environmental impact of wine transport have emerged since. In fact, a follow-up study by the same author suggested that the transport break-even line between California and French produced wines could be anywhere from a line running through Kansas to one completely off the Eastern seaboard, depending on emission factors chosen (Reich-Weiser *et al.* 2010). If rail transport were chosen rather than truck, this theoretical "break-even" line would range from running through central Missouri to 2000 km into the Atlantic!

A more sophisticated transportation logistics modeling exercise revealed a number of interesting conclusions about the energy and carbon intensity of wine distribution (Cholette and Venkat, 2009). Distribution logistics of alcohol in the U.S. can be complex for historical and regulatory reasons. A number of realistic scenarios utilizing existing distribution echelons were considered for the case of a Sonoma, CA winery attempting to deliver specialty wine to consumers in San Francisco and Manhattan. The impacts of cooled storage at intermediary warehouses were also included. Table 2 offers a summary of some of these scenarios.

One conclusion drawn from this study is that wineries interested in reducing the carbon footprint of distribution should focus more on transit rather than storage, as cooled storage contributes little to overall emissions. Warehousing at aggregation points and taking advantage of the greater efficiencies of larger trucks can therefore lead to reductions in distribution impacts. The study also found that direct-to-consumer sales supported by 3rd party logistics providers can be very efficient for local delivery, and comparable to typical 3-tier distribution for long distance delivery. As shown in Table 2, comparing results from this distribution-focused study with the average CF for wine production up to the point of distribution from Figure 3 gives a sense of the importance of distribution in the overall life cycle.

Sonoma winery to…	Via…	Using… (Transport mode)	GHGE relative to best scenario
San Francisco	3PL direct delivery to consumer	mid-sized trucks, winery →warehouse sorting center; parcel truck delivery to consumer	1 (relative basis)
San Francisco	Local 3-tier system, no consumer driving	mid-sized truck, winery →dist'r & dist'r→retail; consumer walks or takes public transit to retailer	1.2
San Francisco	Consumer makes consolidated run to winery	Midsized pickup (carrying 33 ½-case capacity)	3.4
San Francisco	Winery self-distribution	mid-sized truck (344 case capacity), winery→retail; consumer drives car to retailer solely for wine	4.5
San Francisco	Local 3-tier system, consumer drives to store	mid-sized truck, winery →dist'r & dist'r→retail; consumer drives car to retailer solely for wine	5.2
Manhattan	3PL direct delivery to consumer (rail)	mid-sized trucks, winery →warehouse; Long distance via **rail** (in temp regulating package); parcel truck delivery to consumer	5.2
San Francisco	Winery self-distribution	Light truck (33 case capacity), winery→retail; consumer drives car to retailer solely for wine	6.3
Manhattan	3-tier distribution	mid-sized truck, winery →dist'r; heavy duty truck, cross country; mid-sized truck, dist'r→retail; consumer walks to store, takes cab 0.8 km home	8.6
Manhattan	3PL direct delivery to consumer (truck)	mid-sized trucks, winery →warehouse, Long distance via **truck** (in temp regulating package); parcel truck delivery to consumer	8.7
"global average" viticulture + wine making + packaging from Figure 3 (x6 bottles, for comparison)			16.3
San Francisco	Consumer drives to winery	Hybrid car	34.5
Manhattan	3PL direct delivery to consumer (air)	mid-sized trucks, winery →warehouse; Long distance via **air freight**; parcel truck delivery to consumer	62.3
San Francisco	Consumer drives to winery	Honda Accord (6 bottles, 144 km round-trip)	80.3

TABLE 2. Summary of the relative carbon footprint of transportation for various distribution options available for a Sonoma, CA winery delivering to customers in San Francisco, CA and Manhattan, NY.

All calculations are based on a purchase of a ½ case of wine (six 750 milliliter bottles). Data from Cholette and Venkat, 2009. Note that the "average" for wine production up until transport from Figure 3 is included for comparison. 3PL = "3rd party logistics provider."

Interestingly, the scenario in Table 2 with the greatest impact is the one often considered the most “local” and direct: the consumer driving to the winery. This merely emphasizes the importance of transport mode – how things are shipped – over the distance they travel in determining the GHGE associated with distribution. It is worth noting that the other environmental impacts for which transportation makes a notable contribution – acidification potential, ozone depletion potential, particulate matter air pollution – track fairly closely with GHGE, as they are all related to the combustion of fossil fuels.

This insight – that how things are transported matters more than how far – is echoed in other studies. A LCA of a winery in Nova Scotia showed that impacts decreased across a number of environmental indicators when shipping 18,000 kilometers to Australia via trans-oceanic freight ship and high capacity truck, when compared to a small delivery truck travelling 400 kilometers to Halifax (Point *et al*. 2012).

Shipping wine in bulk (24,000 liter flexitanks) from Australia to the UK decreased GHGE by 38% when compared against bottling at the source; the bulk shipping benefit was also seen for shorter distances (France to the UK) where the dominant emissions are from road transport (WRAP, 2007). This certainly is *not* to say that distance doesn’t matter, but that the mode of transport plays a more important role in determining the environmental impacts of transportation logistics.

Research Gaps

Relative to other food products, wine has been studied quite extensively with LCA. However, gaps in the research still exist. First, no LCA study (that we’re aware of) has been conducted on wines produced in Oregon. This would be an important step in understanding the unique opportunities for improvement available to the Oregon wine industry. Available literature suggests that the “downstream” impacts of personal transport for shopping, refrigeration in the home, and disposal at end of life can be important, but additional work is needed to confirm this. On the other hand, these downstream impacts certainly aren’t unique to wine, and ultimately efforts to reduce their impact will come from choices by individuals.

More robust investigation of environmental impact categories beyond GHGE is also needed. Again, this is not unique to wine and is currently a research gap for LCAs of foods in general. Of particular importance to wine, however, may be a better understanding of water use impacts – not just how much water is used, but how that use impacts local water availability – as this likely varies significantly across wine producing regions.

Finally, inclusion of the impact of food waste appears to be absent from studies of wine. While wastage of wine at the consumer level – say, bottles opened but not completely consumed – certainly adds to overall environmental impact, perhaps a more relevant consideration is wastage in storage or at retail, either due to lost quality through storage or breakage. This is especially important when considering alternative packaging options that may have differences in shelf lives or damage rates.

Conclusions

A fairly extensive collection of life cycle assessment studies of wine offer some broadly applicable conclusions:

- The impacts of fertilizer production and application (N_2O emissions, nutrient leaching) are often important to the overall impacts of viticulture, along with growing practices and local climatic conditions.
- The typical 750 milliliter glass bottle used to package wine stands out as an important contributor to overall life cycle greenhouse gas emissions. Lightweight glass, alternative packaging options, and shipping in bulk all can offer notable reductions.
- Significant variability in the environmental impact of a bottle of wine can be seen depending on vintage year.
- The impacts of wine distribution vary significantly by the mode of transportation. How wine is transported can have a far greater influence on the overall carbon footprint than how far it is transported.

References

Amienyo, D., C. Camilleri and A. Azapagic. 2014. Environmental impacts of consumption of Australian red wine in the UK. Journal of Cleaner Production 72: 110-119.

Arcese, G., M. C. Lucchetti and O. Martucci. 2012. Analysis of sustainability based on Life Cycle Assessment: an empirical study of wine production. Journal of Environmental Science and Engineering. B 1(5B).

Benedetto, G. 2013. The environmental impact of a Sardinian wine by partial life cycle assessment. Wine Economics and Policy 2(1): 33-41.

Beverage Industry Environmental Roundtable. 2012. Research on the Carbon Footprint of Wine. Available from http://media.wix.com/ugd/49d7a0_4d74ddfdfbd64d3a8c1b27c17f460e36.pdf.

Bonamente, E., F. Scrucca, S. Rinaldi, M. C. Merico, F. Asdrubali and L. Lamastra. 2016. Environmental impact of an Italian wine bottle: Carbon and water footprint assessment. Science of The Total Environment 560: 274-283.

Bosco, S., C. Di Bene, M. Galli, D. Remorini, R. Massai and E. Bonari. 2011. Greenhouse gas emissions in the agricultural phase of wine production in the Maremma rural district in Tuscany, Italy. Italian Journal of Agronomy 6(2): 15.

California Sustainable Winegrowing Alliance. California Wine's Carbon Footprint: Executive Summary. Available from http://www.sustainablewinegrowing.org/docs/California_Wine_Executive_Summary.pdf.

Cholette, S. and K. Venkat. 2009. The energy and carbon intensity of wine distribution: A study of logistical options for delivering wine to consumers. Journal of Cleaner Production 17(16): 1401-1413.

Cleary, J. 2013. Life cycle assessments of wine and spirit packaging at the product and the municipal scale: a Toronto, Canada case study. Journal of Cleaner Production 44: 143-151.

Colman, T. and P. Päster. 2009. Red, white, and 'green': the cost of greenhouse gas emissions in the global wine trade. Journal of Wine Research 20(1): 15-26.

Falcone, G., A. Strano, T. Stillitano, A. De Luca, N. Iofrida and G. Gulisano. 2015. Integrated sustainability appraisal of wine-growing management systems through LCA and LCC methodologies. Chem. Eng. Trans 44: 223-228.

FIVS. 2016 International Wine Greenhouse Gas Protocol, Version 2.0. Available from http://www.wineinstitute.org/files/FIVS_Intl_Wine_GHG_v2-2016-02-16.pdf.

Fusi, A., R. Guidetti and G. Benedetto. 2014. Delving into the environmental aspect of a Sardinian white wine: from partial to total life cycle assessment. Science of the Total Environment 472: 989-1000.

Gonzalez, A., A. Klimchuk and M. Martin. 2006. Life cycle assessment of wine production process: finding relevant process efficiency and comparison to eco-wine production.

Iannone, R., S. Miranda, S. Riemma and I. De Marco. 2016. Improving environmental performances in wine production by a life cycle assessment analysis. Journal of Cleaner Production 111: 172-180.

Neto, B., A. C. Dias and M. Machado. 2013. Life cycle assessment of the supply chain of a Portuguese wine: from viticulture to distribution. The International Journal of Life Cycle Assessment 18(3): 590-602.

Petti, L., A. Raggi and C. D. Camillis. 2006. Life cycle approach in an organic wine-making firm: an Italian case-study. Fifth Australian Conference on Life Cycle Assessment, Melbourne, Australia. Available from https://www.researchgate.net/publication/228811696_Life_cycle_approach_in_an_organic_wine-making_firm_an_Italian_case-study

Pizzigallo, A., C. Granai and S. Borsa. 2008. The joint use of LCA and emergy evaluation for the analysis of two Italian wine farms. Journal of Environmental Management 86(2): 396-406.

Point, E., P. Tyedmers and C. Naugler. 2012. Life cycle environmental impacts of wine production and consumption in Nova Scotia, Canada. Journal of Cleaner Production 27: 11-20.

PricewaterhouseCoopers/ECOBILAN. 2008. Evaluation of the environmental impacts of Cork Stoppers versus Aluminium and Plastic Closures. Available from http://www.amorimcork.com/media/cms_page_media/228/Amorim_LCA_Final_Report.pdf.

Reich-Weiser, C., P. Paster, C. Erickson and D. Dornfeld. 2010. The role of transportation on the GHG emissions of wine. Journal of Wine Research 21(2-3): 197-206.

Rugani, B., I. Vazquez-Rowe, G. Benedetto and E. Benetto. 2013. A comprehensive review of carbon footprint analysis as an extended environmental indicator in the wine sector. Journal of Cleaner Production 54: 61-77.

Smyth, M. and J. Russell. 2009. 'From graft to bottle'—Analysis of energy use in viticulture and wine production and the potential for solar renewable technologies. Renewable and Sustainable Energy Reviews 13(8): 1985-1993.

Steenwerth, K. L., E. B. Strong, R. F. Greenhut, L. Williams and A. Kendall. 2015. Life cycle greenhouse gas, energy, and water assessment of wine grape production in California. The International Journal of Life Cycle Assessment 20(9): 1243-1253.

Vázquez-Rowe, I., B. Rugani and E. Benetto. 2013. Tapping carbon footprint variations in the European wine sector. Journal of Cleaner Production 43: 146-155.

Vázquez-Rowe, I., P. Villanueva-Rey, M. T. Moreira and G. Feijoo. 2012. Environmental analysis of Ribeiro wine from a timeline perspective: harvest year matters when reporting environmental impacts. Journal of environmental management 98: 73-83.

Villanueva-Rey, P., I. Vázquez-Rowe, M. T. Moreira and G. Feijoo. 2014. Comparative life cycle assessment in the wine sector: biodynamic vs. conventional viticulture activities in NW Spain. Journal of Cleaner Production 65: 330-341.

WRAP. 2007. The life cycle emissions of wine imported to the UK. Available from https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&ved=0ahUKEwj55LDQnfPNAhWDRiYKHY8eBRkQFggeMAA&url=http%3A%2F%2Fwww.wrap.org.uk%2Fcontent%2Freport-emissions-wine-imported-uk-july-07&usg=AFQjCNFCjBWuTOi-yA4skDIN__FiFIBl-w&sig2=eCvSUycFtC2ohrpadC3iew.