OUTREACH PLAN
PRODUCT ENVIRONMENTAL FOOTPRINT: FOODS

DRAFT – 26 APRIL 2017

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BACKGROUND

The Product Environmental Footprint (PEF) is a multi-criteria measure of the environmental performance of a good or service throughout its life cycle. PEF information is produced for the overarching purpose of seeking to reduce the environmental impacts of goods and services taking into account the full "life cycle" including supply chain activities such as extraction of raw materials, production, use, and final waste management. PEF is used to understand materials and topics that have inherently complex life cycles or high environmental burdens, to understand opportunities for improvement and to help businesses and other stakeholders make informed changes to their operating procedures.

The Food Product Environmental Footprint project was identified by the Oregon Department of Environmental Quality (DEQ) and the Oregon Sustainability Board (OSB) as an effort that might help businesses better manage the environmental impacts of foods by improving understanding of where and how those impacts occur. Considerable research has been conducted into the environmental impacts of foods using life cycle assessment (product footprint analysis), but much of this information has not been communicated in a format or style that is accessible to non-specialists. The DEQ engaged the Center for Sustainable Systems at the University of Michigan to conduct a scientific literature review and produce a synthesis report for each of seven food products and two cross cutting topics – packaging and transportation – in a succinct and more accessible format. Each summary is accompanied by an executive summary that further increases the accessibility of the findings for a wider audience.

The final reports are in the process of being reformatted for better presentation and will be available mid-year (2017). They will be used as one of the tools in our tool kit as DEQ's Materials Management engages with businesses in voluntary initiatives aimed at reducing their environmental impacts. Drafts of three reports (beer, wine and transportation) are attached to this outreach plan as examples.

PROJECT PURPOSE AND GOALS

The purpose of this project is twofold:

1. First, to review existing literature, and where possible, summarize conclusions in "categorical footprint assessments" (short, plain English, summaries), for a variety of food types.
2. Second, to share this information with businesses and other organizations who may find it useful in reducing the impacts of food production as well as purchasing.

The literature review and summaries may identify:

- Those activities in the life cycle of foods that contribute significantly to environmental impacts (e.g., are most of the impacts associated with fertilizer use, packaging, transportation, cold storage, or some other aspect of production or consumption?). This may aid in the prioritization of voluntary environmental initiatives.
- Relative environmental impacts of different practices (e.g., how different production, transport, processing or packaging methods compare). This may aid in the evaluation of alternatives.
- Limitations in the available literature. This may help users to avoid drawing conclusions that are incorrect, as well as to identify knowledge gaps that might benefit from further research.

The objective of this project is not to:

- Conduct original life cycle analyses;
- Evaluate production conditions specific to the Pacific Northwest;

- Compare Pacific Northwest foods against foods produced elsewhere;
- Inform, propose, or promulgate regulations.

COMMODITIES AND TOPICS

Seven food items and two cross cutting topics were selected for detailed meta-analysis via literature review of available life cycle assessment studies. The topics include:

1. Land-based aquaculture
2. Beer
3. Citrus
4. Coffee
5. Packaging's influence on food waste prevention
6. Pork
7. Tomato
8. Transport as a factor of the food life cycle
9. Wine

AUDIENCE

Each Food PEF report provides a detailed summary of the life cycle impacts currently reported in publically available LCA literature, identifies research gaps, and provides overarching conclusions where possible. These report may be useful to businesses and individuals that import, purchase, produce or distribute the products and topics covered. Additionally, these summaries may also serve to direct future research to further understand specific life cycle stages identified as gaps in data during this review.

Though the primary audience is companies and people involved in food production, packaging, transporting or purchasing, these reports also hold pedagogical and research value. In addition, the simplified Executive Summaries for each report could serve as educational content and engagement avenues for residents of Oregon with regards to the impacts of food items commonly purchased, consumed and discarded.

THE MESSAGE

FROM OREGON SUSTAINABILITY BOARD

The Oregon Sustainability Board encourages activities that best sustain, protect and enhance the environment, economy and communities for the present and future benefit of Oregonians. Food is an important topic of interest for both producers and consumers. There are many actors in the food supply chain from farm to table, many of whom are interested in making the correct decisions related to reducing environmental impacts, but scientific information on this topic can be difficult to access. The Oregon Department of Environmental Quality, working in coordination with the OSB, has produced a set of summaries of the environmental footprint of various food items and topics. These summaries condense and explain the findings in the current scientific literature. This information can help food producers and purchasers make informed decisions about reducing the environmental impacts of food. This effort is part of a broader set of business initiatives supported by the OSB to encourage Oregon businesses to improve the environmental profile of their product and service portfolios. We encourage you to leverage the various resources developed by DEQ to produce and market more environmentally responsible products and services.

FROM DEQ

Food as a material is very important to society for a variety of obvious reasons, but the production of food products also has an assortment of environmental burdens. As an environmental agency, the DEQ is interested in identifying places where high impacts occur in the life cycle of products – both for production and consumption. Understanding where the high impacts occur in any given type of food can help producers and purchasers prioritize their environmental efforts. By conducting a food product environmental footprint or PEF for food products, we are able to identify and analyze the best available information from scientific journals to inform production, purchasing, distribution, use and disposal choices. The food PEF project, supported by the Oregon Sustainability Board, reviewed seven food products and two related topics and developed summary papers for each. Each paper contains a brief executive summary along with detailed descriptions of the findings, gaps in information, and overarching conclusions from the literature.

This information can help food producers and purchasers make informed investments in efforts to reduce the environmental impacts of food. This effort is part of a broader set of business initiatives supported by the OSB to encourage Oregon businesses to improve the environmental profile of their product and service portfolios. We encourage you to leverage these and other resources from DEQ to produce and market more environmentally responsible products and services.

OUTREACH METHOD

This Outreach Plan is an internal document to help identify appropriate channels where the PEF approach and content is useful, and to disseminate the resources as broadly as possible. The DEQ is actively engaging with the business community, collaborating with academia, participating in professional conference and initiatives, and engaging a variety of entities to improve environmental outcomes on a voluntary basis. Additionally, there is significant learning opportunity within the findings of this project that may have educational value for partner entities and individual alike.

Outreach efforts will likely take multiple forms including in person presentations and webinars, discussions with local business community and consultants, dissemination via newsletter, professional connections and social media and more.

The following entities have been initially identified as candidates for outreach for the Food PEF summaries. DEQ expects to add to this list in the coming weeks, and invites suggestions from the OSB. Note, since the summaries are food product and topic specific, they are likely to be interesting to different entities within a category.

Outlet	Summary of interest	Incentive to use resource
Higher education – leverage contacts at various schools with sustainability, engineering and design programs		
1. University of Oregon 2. Oregon State University 3. Portland State University 4. University of Michigan 5. Michigan State 6. Association of Sustainability in Higher Education (ASHE) 7. Bainbridge Graduate Institute 8. Others from case studies plan?	1. All 2. All 3. All 4. Packaging, Transport 5. Packaging, Transport 6. All 7. All 8. All	Provides detailed literature reviews that serve a variety of pedagogical uses.

Agriculture/Food		
9. Oregon Dept. of Agriculture 10. Northwest Food Processors Association (NWFPA) 11. Oregon Aquaculture Association 12. Oregon Brewers Guild 13. Oregon Winegrowers Association 14. Oregon Pork Producers 15. Sustainable Food Trade Association 16. OSU Food Innovation Center	9. All 10. All 11. Land based aquaculture 12. Beer 13. Wine 14. Pork 15. All 16. All	Clearly presents relevant life cycle information that isn't readily available to this audience.
Regional environmental / business supporting entities		
17. Environmental Quality Commission (OR) 18. Pollution Prevention Resource Center (PPRC) 19. Oregon Environmental Council 20. Climate Solutions 21. Oregon Global Warming Commission	17. All 18. All 19. All 20. All 21. All	Aligns with their mission to reduce environmental damage, material responsibility, product stewardship, etc.
Professional associations and events		
22. American Council for Life Cycle Assessment (ACLCA) 23. Urban Sustainability Directors Network (USDN) 24. Sustainable Purchasing Leadership Council (SPLC) 25. Responsible Purchasing Network (RPN) 26. Healthcare Without Harm 27. International Safe Transport Association (ISTA) 28. Sustainable Packaging Coalition (SPC) 29. LinkedIn – staff personal and groups 30. Oregon Environmental Professionals Association (OEPA) 31. AMERIPEN	22. All 23. All 24. All 25. All 26. All 27. Transport, Packaging 28. Packaging, Transport 29. All 30. All 31. Packaging, Transport	Highlights the PEF framework and life cycle assessment as tools to inform production, distribution, purchasing, and retail.
Social media		
32. DEQ Facebook 33. DEQ Twitter 34. DEQ Newsletters 35. DEQ Webpages	All as appropriate	Self-serving.
Media outlets		
36. Portland Business Journal 37. Resource Recycling 38. GreenBiz 39. Sustainable Brands	36. Executive summaries 37. Packaging 38. All 39. All	Provides content to report on that is relevant to their diverse audience.

TIMING

DEQ is currently in the process of formatting/designing the technical reports and developing executive summaries and graphics for ease of dissemination. This work should be completed in May or June. Because of some overlap with the PEF case studies project, DEQ recommends delaying outreach on these food summaries until the case studies have been promoted and several weeks have passed.

PROJECT SPOKESPERSONS

DEQ: David Allaway and Minal Mistry

EXECUTIVE SUMMARY: BEER

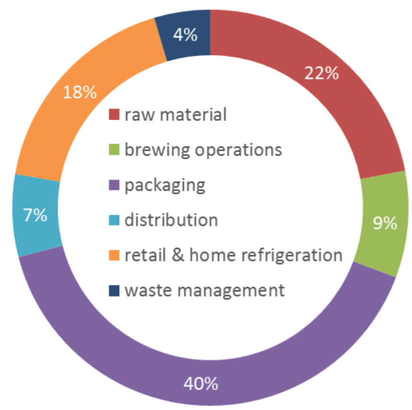
Oregon's booming craft beer industry had the 6th most permitted breweries (281) in the nation in 2015. Oregonians consume 36% of the craft beer production in-state, the highest level in the country. But all of that beer drinking adds up; according to the Oregon Consumption Based Greenhouse Gas Emissions Inventory, the upstream (i.e., raw materials through retail in the flow diagram below) emissions of beer consumption in Oregon (in-state beers plus imports) amount to 202,700 metric tons of CO_2 equivalence annually. That's about the same as 42,800 average passenger vehicles operated for a year.

The life cycle of beer is depicted above. Understanding the life cycle of beer can help focus attention on areas with the greatest potential for reducing environmental burdens. This summary highlights results from life cycle assessment (LCA) studies of beer. Such studies, while not specific to breweries in the Pacific Northwest, can help guide improvement efforts to those parts of the beer value chain where they are likely to have the most bearing, while also identifying potential trade-offs or unintended consequences.

KEY FINDINGS

Barley-based beers are the main type of beer represented in the LCA literature. Greenhouse gas emissions (GHGE), also known as carbon footprint, are the dominant environmental impact examined in these studies, although energy and water use are also considered, and a handful of studies evaluate a full suite of environmental impacts spanning environmental and human health indicators.

An overview of the reviewed beer LCA studies reveals that the packaging format typically contributes the most to environmental impacts. The chart to the right shows the average contribution to the carbon footprint of beer for each life cycle phase represented in the literature. In general, production of raw materials (dominated by malted barley), packaging and refrigerated storage emerge as the most important life cycle stages for a variety of environmental impact categories.



CONCLUSIONS

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

- Raw material production, specifically malted barley, is consistently an important contributor to most environmental impact categories considered.
- Opportunities may exist to reduce the carbon footprint of raw material production by brewing with un-malted barley and industrial enzyme.
- The GHGE from brewery operations are largely driven by energy use, and account for 2 - 28 percent of the impact. Efficiency efforts can lead to reduced impacts.
- Distribution transport was not a standout contributor in the LCA studies reviewed.
- Retail and home refrigeration of beer can be a notable contributor to the carbon footprint, and is dependent on how long the beer kept cold.
- Producers can reduce the carbon footprint of beer by changing packaging formats with lower carbon footprint as shown below.

The full report created by Center for Sustainable Systems - University of Michigan can be downloaded from: [insert URL here]

State of Oregon Department of Environmental Quality

Food Product Environmental Footprint Literature Summary: Beer

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

Martin Heller

4-14-2017

OVERVIEW

Beer, an ancient beverage that has been alluring and intoxicating humans throughout our history, is presently the most produced food commodity in the world on a weight basis. 189 million metric tons of beer (from barley) were produced globally in 2013. The U.S. is the second largest global producer at 22.4 million metric tons. U.S. beer production steadily increased from the 1960s, plateaued in the late 80s and early 90s and actually has been slowly decreasing since a peak in 1991[1]. If total production volume has decreased slightly, you certainly wouldn't know it by looking around the U.S. In 1983 there were 49 breweries in the U.S. and by 2015 the U.S. Alcohol and Tobacco Tax and Trade Bureau permitted more than 6,000 breweries. Between 2009 and 2015, 7% of the total beer market shifted from larger brewers and importers to smaller brewers, although the top five brewery companies still control 82.5% of the total market share. Beer remains the alcoholic beverage of choice for Americans, according to a 2015 Gallup poll[2].

Oregon has a booming craft beer industry, with 281 permitted breweries in 2015, the 6th highest in the nation. 36% of Oregon craft beer production is consumed by Oregonians themselves, the highest level in the country. At present, Oregon's craft beer brewing industry contributes $1.8 billion to the state's economy annually[3]. But all of that beer drinking adds up; according to the Oregon Consumption Based Greenhouse Gas Emissions Inventory[4], the upstream (i.e., beer brewing plus supply chain) emissions of beer consumption in Oregon (in-state beers plus imports) amount to 202,700 metric tons CO_2 eq. annually, equivalent to 42,817 average passenger vehicles operated for a year[5].

Diversification of the U.S. beer market creates ample opportunity for innovation. What can your favorite brewery do to reduce the environmental impact of your beer of choice? In this summary, we highlight results from life cycle assessment (LCA) studies of beer. Such studies, while not specific to breweries in the Pacific Northwest, can help guide improvement efforts to those parts of the beer value chain where they are likely to have the most bearing, while also identifying potential trade-offs or unintended consequences.

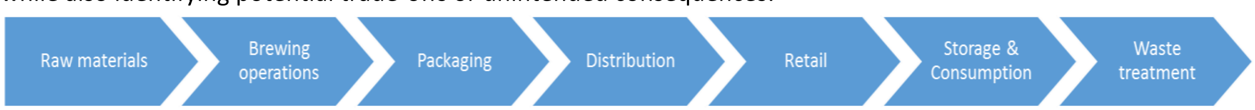


Figure 1 Generic life cycle of beer production

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 [here].

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[1] Food and Agriculture Organization of the United Nations: faostat.fao.org

[2] https://www.nbwa.org/resources/industry-fast-facts

[3] http://www.worldatlas.com/articles/top-us-craft-beer-producing-states.html

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

[5] https://www.epa.gov/energy/greenhouse-gas-equivalencies-calculator

AVAILABLE LCA RESEARCH

We have identified 15 LCA studies dating back to 2005 that consider the environmental impacts of the beer life cycle (see Figure 1). Three of these studies evaluate U.S. breweries or consider North American formats. Others consider beer production in the UK, Denmark, Greece, Italy, Spain, Thailand and West Australia. The available studies consider beers that are predominantly barley based. Greenhouse gas emissions (GHGE), also known as carbon footprint, is the dominant environmental impact examined in these studies, although energy and water use are also considered, and a handful of studies evaluate a full suite of environmental impacts including eutrophication potential, acidification potential, ozone depletion potential, and human and ecotoxicity.

KEY FINDINGS

An overview of the reviewed beer LCA studies reveals inconsistencies about which life cycle stage makes the greatest contribution to environmental impacts. This variability appears to be largely dependent on what packaging/delivery format is being used. In general, production of raw materials (dominated by malted barley) and packaging emerge as the two most important life cycle stages for a variety of environmental impact categories. One U.S. study shows that if beer is refrigerated by the retailer and then kept in refrigeration by the consumer for a long period, retail and home refrigeration can also be an important contributor to the carbon footprint of beer; however, not all studies include these stages in their assessment. Figure 2 shows the average contribution of each life cycle phase to the overall carbon footprint (CF) of beer production found in literature.

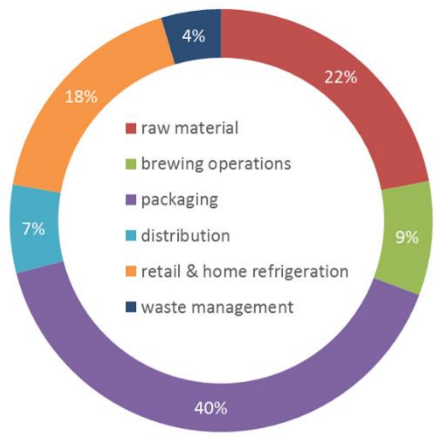


Figure 2 Average contribution of each life cycle phase to the overall CF of beer production

Figure 3 provides an aggregated look at the distribution of greenhouse gas emissions across major life cycle stages for the production and consumption of one liter of beer. Color-coding of the packaging format in Figure 3 demonstrates a distinguishing trend in the packaging stage. Most single-use glass and aluminum can scenarios have larger carbon footprints than average for the stage, whereas steel can and keg delivery scenarios are below the average. The glass bottle scenarios below the average are return/refill glass scenarios; the one high return/refill scenario assumes only a 51% return, meaning every other filled bottle is newly made glass. In the following sections, we provide more information on the environmentally important stages in the beer life cycle.

RAW MATERIAL PRODUCTION

The dominant ingredient in most beer recipes is malted barley. Agricultural production of barley is a significant contributor to the carbon footprint of beer, and also the dominant source of eutrophying emissions. Barley yields can vary significantly with growing region and production practices, with corresponding variability in environmental impact. A study of the Italian lager, *Peroni*, estimated that use of Italian-grown organic barley in place of conventionally grown Italian barley would reduce the beer carbon footprint by 11%, whereas importing conventional barley from 1500 kilometers away (with transport via truck) would increase the beer GHGE by 9%. Importing organic barley, also from 1500 kilometers, decreases the beer GHGE 6% (note that in these cases, differences are due to regional production differences *and* transport) (Cimini and Moresi, 2016). Malting of barley requires additional energy: in one detailed study, the malting process represented 28% of the GHGEs associated with the malted barley ingredient, whereas agricultural production was 66%, and the remainder was due to transport of barley and malt (The Climate Conservancy, 2008). Hops are also an important ingredient in beer, but typically used in small quantities relative to malt, and do not contribute significantly to the beer environmental footprint. For New Belgium Brewery's Fat Tire ale, hops production represents only 0.2% of the total beer carbon footprint (The Climate Conservancy, 2008).

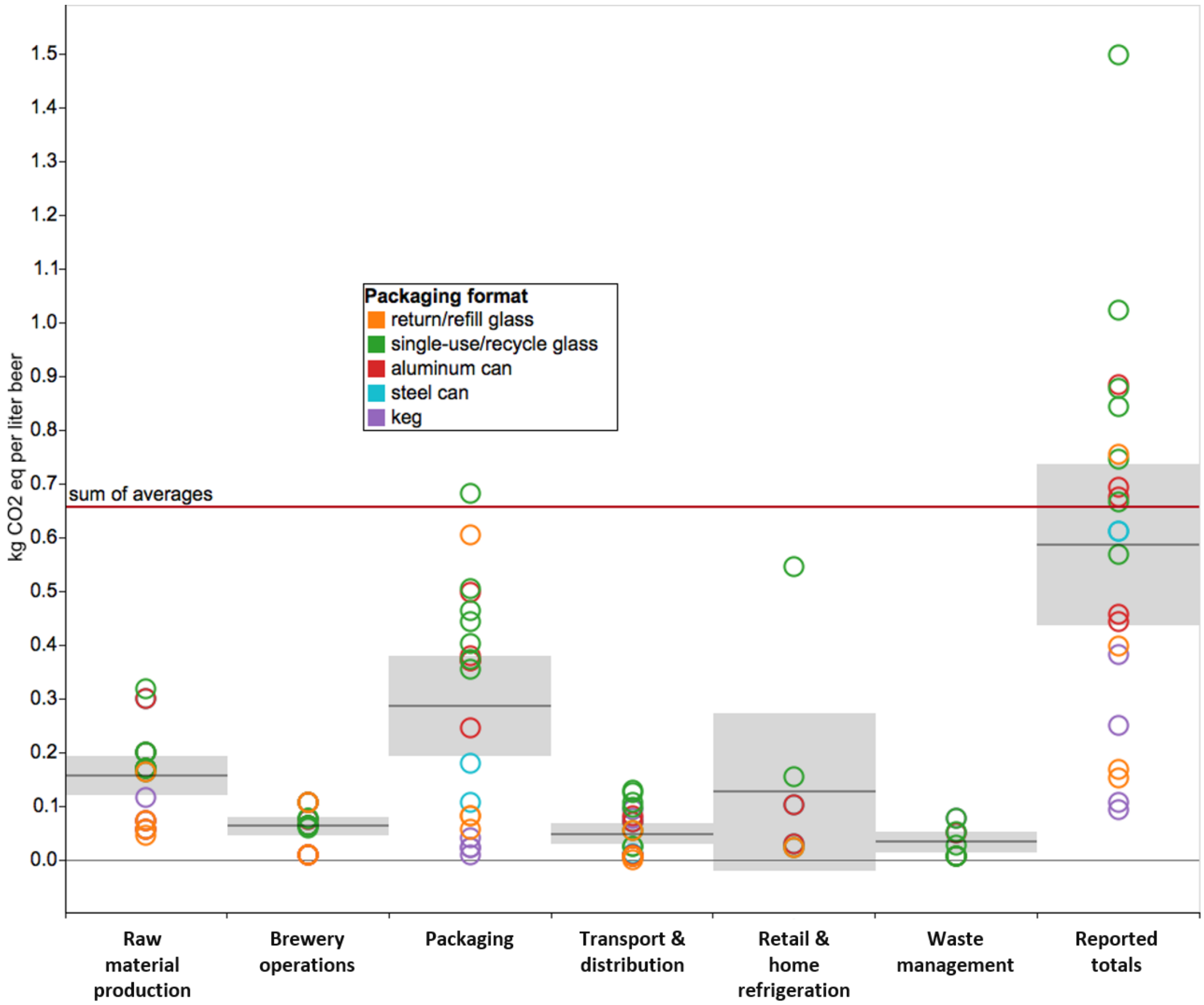


Figure 3. Life cycle greenhouse gas emission results from seven reviewed beer LCA studies, some with multiple scenarios, displayed across life cycle stages. Circles represent individual scenario results, offering a sense of the data spread or cluster. Horizontal grey bars represent averages for each stage, and grey blocks are 95% confidence intervals around the averages. The "Reported totals" column shows totals for a given scenario, 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.

One interesting study compares conventional brewing using malted barley vs. the use of a novel enzyme that allows brewing directly from 100% un-malted barley (Kløverpris et al., 2009). Avoiding the malting process saves energy, and somewhat less barley is needed to brew in this way, but the addition of the industrial enzyme adds an environmental burden. While the study was conducted in a Danish context, a conservative estimate thought to be more widely applicable was also given. This estimate found that brewing with 100% barley (no malting) reduced GHGE by 162 kilograms CO_2 eq. per ton of malt replaced, or 2.4 kilograms CO_2 eq. per 100 liters of beer produced, which amounted to about an 8% reduction in the carbon footprint of a can of beer. The study also included a sensory analysis conducted by a professional tasting panel at the Technical University of Berlin that found no significant differences between the beers when brewed at full scale by the Danish brewery, Harboes Bryggeri.

BREWING

Operations at the brewery – the actual brewing process – represent between 2 and 28% of the total life cycle GHGE of beer in the scenarios in Figure 3. The primary GHGE contribution from the beer brewing stage comes in the form of energy use[6] – electricity, natural gas, etc. It should come as no surprise, therefore, that improving the energy efficiency of the brewery process can lead to reductions in carbon footprint. While not a LCA, Sturm et al. (2013) identify opportunities and barriers for efficient energy use in medium-sized breweries and estimates that easily applicable efficiency measures such as improving insulation and implementing basic heat recovery could potentially reduce energy demand at the brewery by 20% with payback periods of around 1.3 years. The BIER LCA study gathered brewery energy efficiency data from their members and found that the range resulted in the brewery stage representing 12 to 38% of the total beer LCA in the European format and 5 to 20% of the total in the North American format. A study presented at the 2016 LCA Food conference found that the total carbon footprint per liter of beer was more than double from craft breweries compared to industrial production in an Italian context (Gavinelli et al., 2016). This was attributed to more grains used in the brewing recipe but also lower energy efficiencies of the craft breweries.

BEER PACKAGING

The beer delivery system – how beer is packaged – was the most differentiating feature across the environmental assessments reviewed. In general, the environmental impact of common beer packaging decreases in this order: glass bottles, aluminum cans, steel cans, kegs. There are, of course, caveats and exceptions.

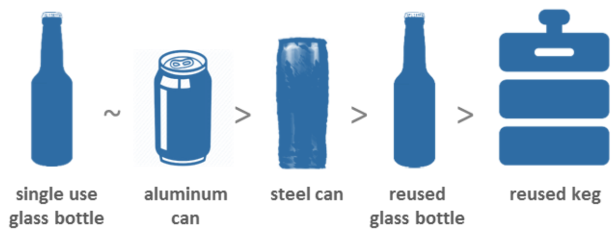


Figure 3 Relative environmental impact of different beer packaging

The Beverage Industry Environmental Roundtable (BIER) (2012) conducted a carbon footprint analysis of two "typical" beers in common packaging formats: European – in 0.33 liter returnable/re-filled glass bottles, distributed in a 24-pack plastic (HDPE) crate, and North American – in 0.355 liter aluminum cans, distributed in a 24-pack fiberboard carton. The full life cycle GHGE associated with the European format was less than half of the North American format, and while there were other differences in the two scenarios, sensitivity analysis points to packaging being the primary driver of this difference (see Table 1). The returnable bottles were modeled as being re-used 30 times; if non-returnable glass were used instead, the carbon footprint (packaging only) per European bottle increased by a factor of 12.5, making the bottle go from 13% of the total carbon footprint to 65%, and resulting in a full life cycle carbon footprint greater than the North American aluminum can format. Increasing the recycled glass content from the assumed 65% to a hypothetical maximum of 100% did not have a big impact on the overall beer carbon footprint. The emissions associated with production of aluminum cans (0.131 kilograms CO_2 eq per can) are significantly greater than those of steel cans (0.034 kilograms CO_2 eq per can), primarily due to the large energy demand necessary for aluminum production. If the North American format switched from aluminum to steel cans, the overall carbon footprint of the beer would be reduced by 29 percent.

[6] While beer brewing emits carbon dioxide during fermentation, this CO_2 results from the digestion by yeast of sugars that were built up in the grains 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 is not accounted for in carbon footprint calculations.

Study	Scenario	GHGE (kilograms CO_2 eq. per liter beer)	
		Primary packaging contribution	Total life cycle
BIER, 2012	Europe, 0.33 liter returnable glass	0.055	0.42
BIER, 2012	Europe, 0.33 liter single-use glass	0.68	1.05
BIER, 2012	N. America, 0.355 liter Al. cans[7]	0.37	0.9
BIER, 2012	N. America, 0.355 liter steel cans	0.096	0.64
Cimini and Moresi, 2016	0.33 liter single-use glass bottle, 24 per carton[8]	0.44	0.67
Cimini and Moresi, 2016	0.33 liter single-use glass bottle, 8 per cluster pack, 3 packs per carton[9]	0.51	0.74
Cimini and Moresi, 2016	0.66 liter single-use glass bottle, 15 per carton[10]	0.36	0.57
Cimini and Moresi, 2016	0.33 liter Al. can, 24 per tray[11]	0.50	0.69
Cimini and Moresi, 2016	30 liter steel keg, re-used 72 times[12]	0.040	0.25

Table 1 Absolute GHGE values for varying packaging scenarios. Note that comparisons within studies are more valid than between studies because modeling approaches and scope can differ between studies.

A thorough examination of the environmental impacts of beer production and consumption in the UK compares different packaging options across a wide array of impact categories (Amienyo and Azapagic, 2016). Results summarized in Table 2 show that beer in steel cans has the lowest impact in seven of the twelve impact categories, per liter of beer delivered. The study also showed that if glass bottles are re-used three times, the GHGE would be comparable to aluminum cans, and that for every 10% increase in recycled glass content in single-use bottles, the GHGE for the beer life cycle decreases by about 3%. Decreasing glass weight by 10% results in a GHGE savings of 5% across the beer life cycle. Such bottle lightweighting efforts have been implemented in the UK[13].

[7] Reported baseline, typical values

[8] 12.5% of Peroni beer

[9] 9.8% of Peroni beer

[10] Most common format for Birra Peroni Srl brewery (Italy), representing 66.6% of Peroni beer

[11] 6.9% of Peroni beer

[12] 4.2% of Peroni beer

[13] http://www.wrap.org.uk/sites/files/wrap/Case%20Study%-20%20GlassRite_16%2010%2008_1230.pdf

Another study of a pale lager in Italy found that the carbon footprint of beer delivered in a 30 liter keg was 2.7 times smaller than in a 0.33 liter glass bottle (Cimini and Moresi, 2016). This same study showed that bottling in larger 0.66 liter bottles decreased the carbon footprint by 15%, but 0.33 liter aluminum cans increased the carbon footprint slightly (relative to the 0.33 liter glass bottle) Absolute values from this study can be found in Table 1.

Environmental impact category	**% change relative to glass bottle w/o secondary packaging**		
	aluminum can	steel can	glass bottle w/ secondary packaging
GHGE	-20%	-29%	17%
primary energy demand	-28%	-34%	11%
water demand	-2%	-1%	0%
abiotic depletion potential	-33%	-45%	1%
acidification potential	-16%	-39%	5%
eutrophication potential	-9%	-10%	2%
human toxicity potential	800%	82%	5%
marine aquatic ecotoxicity potential	95%	-43%	2%
freshwater aquatic ecotoxicity potential	-41%	-49%	11%
terrestrial ecotoxicity potential	-17%	-15%	11%
ozone depletion potential	-52%	-46%	5%
photochemical oxidants creation potential	-37%	-5%	8%

Table 2 Percent change in life cycle impacts of beer (not including retail and home refrigeration) in different packaging options relative to a base case of glass bottles without secondary packaging. The aluminum and steel can scenarios also do not include secondary packaging. Negative percentages represent a decrease in impact from the base case. The best option in each category is highlighted in green. Adapted from Amienyo and Azapagic, 2016.

REFRIGERATION

A very thorough carbon footprint assessment of Fat Tire Amber Ale brewed by New Belgium Brewing Company found retail refrigeration (energy use and fugitive refrigerant emissions) to contribute 28% of the full life cycle GHGE. Refrigeration in the home contributed an additional 8.2% (The Climate Conservancy, 2008). This study assumed that all Fat Tire was sold refrigerated, a one week retail turnover time for each 6-pack, and a 2 week storage in the refrigerator at home. These assumptions are all more conservative than other studies that consider downstream refrigeration and may explain the rather high contribution. The BIER study considered the sensitivity of product cooling by varying parameters as in Table 3. In this study, retail and home refrigeration represented between 2 and 15% of the total beer carbon footprint (2-10% in North American format). It appears that the high value in the Fat Tire study is largely driven by the assumed fraction of product that is refrigerated at retail.

RESEARCH GAPS

The available beer LCA studies provide a fairly good overview of the environmental impacts involved. Consumers or brewers may be interested in differences between beer styles (IPAs, porters, stouts, lagers) but such an assessment would need to be conducted for a particular brewery and specific recipes. A number of other alternatives available to the consumer, such as organic beers, gluten free beers, or beers based largely on other grains, have not received coverage in the existing LCA studies. While not a question for LCA, one area of inquiry raised in this summary, given the potential environmental benefit, would be the reasons for the lack of steel-canned beer in the U.S. marketplace.

	Baseline	High	Low	Fat Tire assumption
Temperature at retail	6.7˚C	10˚C	3.3˚C	not specified
Fraction of production cooled at retail	3%	5%	0%	100%
Retail storage duration	6 days	13 days	2 days	1 week
Domestic storage duration	2 days	10 days	1 day	2 weeks
Resulting GHGE emissions (kilograms CO_2 eq/ liter beer)	0.0214 (EU) 0.0297 (NA)	0.0697 (EU) 0.0958 (NA)	0.0121 (EU) 0.0169 (NA)	0.544

Table 3 Range of product cooling parameters and the resulting effect on retail and home refrigeration GHGE from the BIER LCA study (Beverage Industry Environmental Roundtable, 2012). Values from the study of Fat Tire Amber Ale are included for comparison. GHGE emission results are shown both for the Europe format scenario (EU) and the North American format (NA).

CONCLUSIONS

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

- Raw material production, specifically malted barley, is consistently an important contributor to most environmental impact categories considered.
- Opportunities may exist to reduce the carbon footprint of raw material production by brewing with un-malted barley and industrial enzyme.
- Beer packaging is also an important contributor, but this varies depending on the packaging format. With one exception, the carbon footprint of beer packaging options in the studies reviewed decrease in this order: single-use glass bottles ≈ aluminum cans > steel cans > re-used bottles > re-used kegs.
- The GHGE associated with brewery operations are largely driven by energy use, and contribute 2 - 28 percent of life cycle GHGE for the studies in Figure 3. Efficiency efforts can lead to reduced impacts.
- Retail and home refrigeration of beer can be a notable contributor to the carbon footprint, but this is dependent on how long the beer is cooled in the product chain.
- While certainly important, distribution transport was not a standout contributor in the LCA studies reviewed, averaging 9% of life cycle GHGE for the studies in Figure 3 (standard deviation =±9%, median=5%). This may be partly dependent on the modeling assumptions made. In general, shorter distance, maximizing shipment loading, and, when possible, utilizing rail over truck, will reduce the carbon footprint of beer distribution.

REFERENCES

Amienyo, D. and A. Azapagic. 2016. Life cycle environmental impacts and costs of beer production and consumption in the UK. The International Journal of Life Cycle Assessment 21(4): 492-509.

Beverage Industry Environmental Roundtable. 2012. Research on the carbon footprint of beer. Available from http://media.wix.com/ugd/49d7a0_70726e8dc94c456caf8a10771fc31625.pdf.

Cimini, A. and M. Moresi. 2016. Carbon footprint of a pale lager packed in different formats: assessment and sensitivity analysis based on transparent data. Journal of Cleaner Production 112: 4196-4213.

Gavinelli, C., G. Dotelli and F. Recanati. 2016. Comparing the environmental performances of craft and industrial beer: strengths and weaknesses of Life Cycle Assessment. 10th International Conference on LCA in the Food and Agriculture Sector, Dublin, Ireland.

Kløverpris, J. H., N. Elvig, P. H. Nielsen and A. M. Nielsen. 2009. Comparative Life Cycle Assessment of Malt-based Beer and 100% Barley Beer. Available from https://www.novozymes.com/en/-/media/Novozymes/en/sustainability/customer-benefits/improve-and-document-performance/Documents/Comparative-LCA-of-malt-based-and-barley-based-beer---Full-report.pdf?la=en.

Melon, R. P., V. Wergifosse, R. Renzoni and A. Léonard. 2012. LIFE CYCLE ASSESSMENT OF AN ARTISANAL BELGIAN BLOND BEER. [avniR] 2nd LCA Conference, Lille, France.

Sturm, B., S. Hugenschmidt, S. Joyce, W. Hofacker and A. P. Roskilly. 2013. Opportunities and barriers for efficient energy use in a medium-sized brewery. Applied Thermal Engineering 53(2): 397-404.

The Climate Conservancy. 2008. The Carbon Footprint of Fat Tire® Amber Ale. Available from http://www.newbelgium.com/files/shared/tinkerer/the-carbon-footprint-of-fat-tire-amber-ale-2008-public-dist-rfs.pdf.

EXECUTIVE SUMMARY: WINE

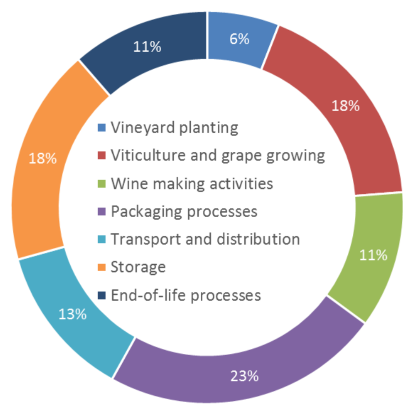
Wine, like anything we consume, requires natural resources and generates environmental emissions, and therefore, understanding the processes that contribute the most impact can aid in efforts to reduce our overall footprint. Oregon is both a significant producer and consumer of wine. Oregon's more than 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 CO2 eq. 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 contribute another 23%, while also contributing to additional impacts of transport and distribution.
- Packaging options exist that have the potential of dramatically reducing the proportional contribution of packaging to the overall wine carbon footprint.
- Transporting bottled wine to retailers through a combination of trains and trucks to accounts for 13% of total CF of wine, on average;
- Consumer behavior, including transport from point-of-sale to home and refrigeration in the home contributes about 18%; and
- Disposal (mainly packaging) contributes about 11% to the total CF for 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.

The full report created by Center for Sustainable Systems - University of Michigan can be downloaded from: [insert URL here]

State of Oregon Department of Environmental Quality

Food Product Environmental Footprint Literature Summary: Wine

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

Martin Heller

4-14-2017

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 life cycle assessment, LCA, methods and definitions of terms, please refer to the Food Product Environmental Footprint Foreword [here].

AVAILABLE LCA RESEARCH

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.

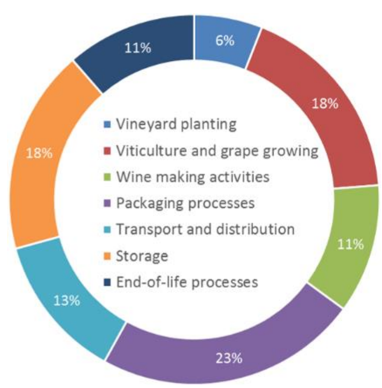


Figure 2 Average contribution of each life cycle phase to the overall CF of winemaking

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

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.

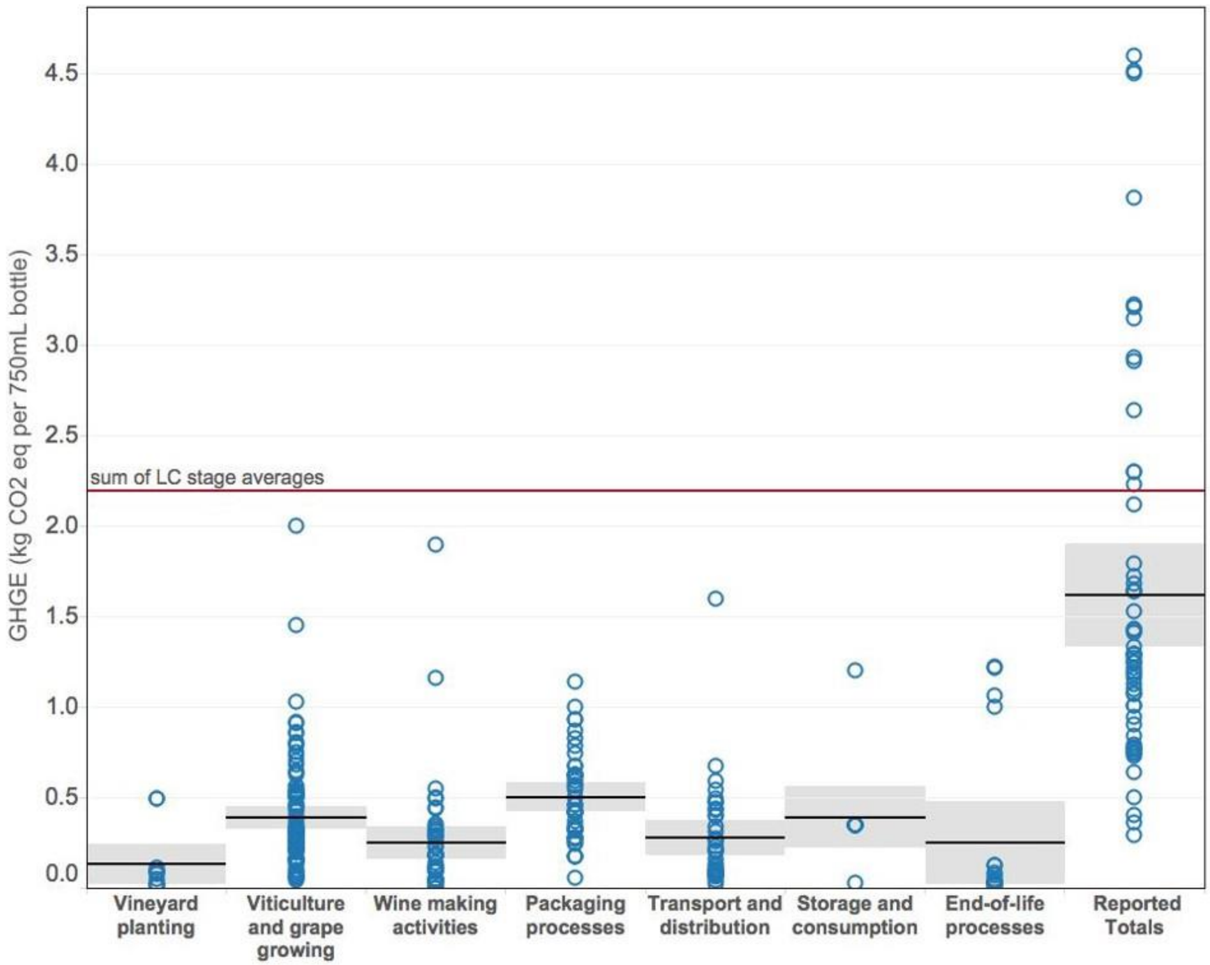


Figure 3 Life cycle greenhouse gas emission results from all studies reviewed, distributed across major life cycle stages. Circles represent individual study results, offering a sense of the data spread or cluster. Horizontal black bars represent averages for each stage, and grey blocks are 95% confidence 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 3 offer some guidance toward life cycle stages with disproportionate eutrophication and acidification impacts. As may be expected, Figure 3 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.

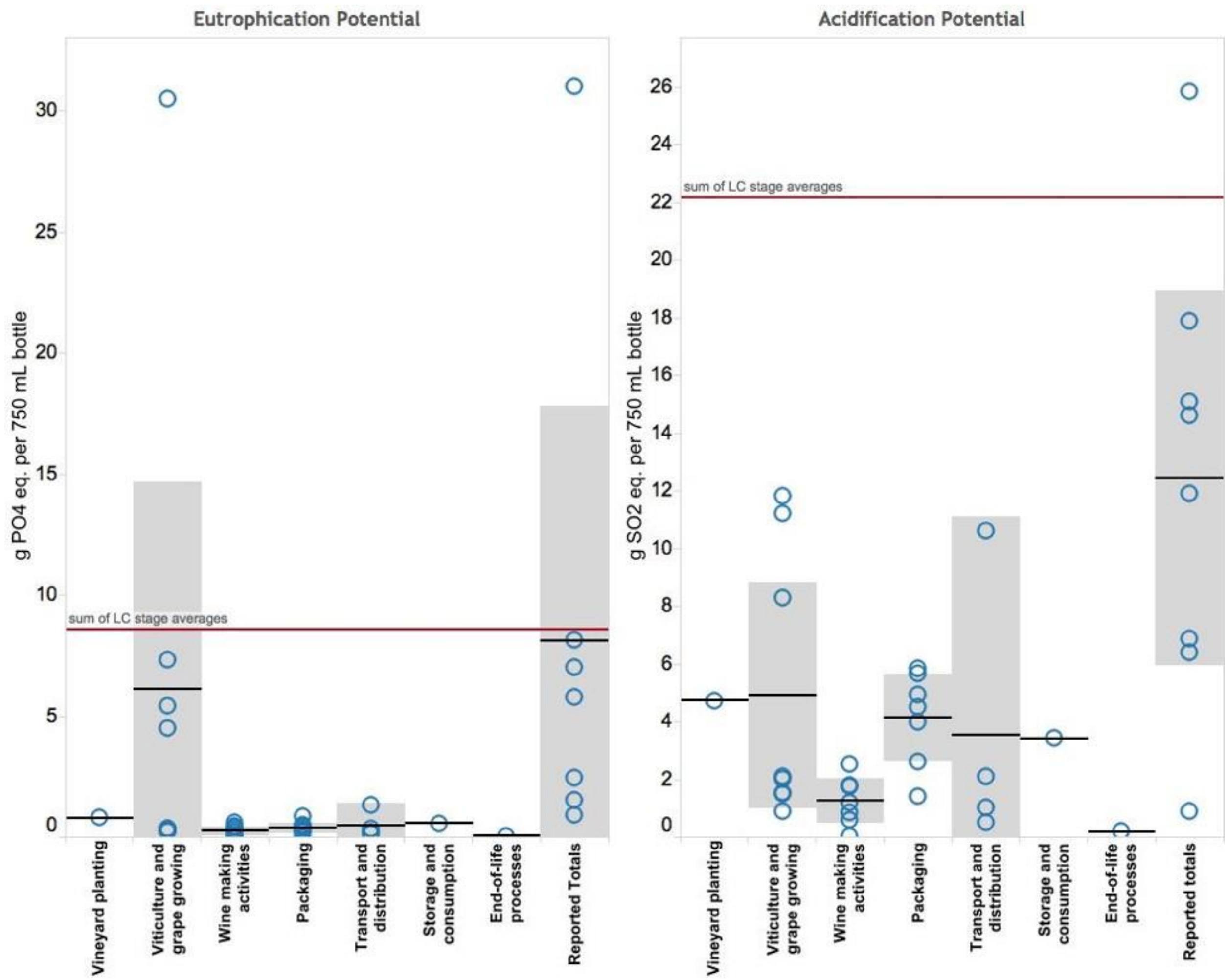


Figure 4 Distribution of eutrophication potential and acidification potential across wine life cycle stages. Circles represent individual study results, offering a sense of the data spread or cluster. Horizontal black bars represent averages for each stage, and grey blocks are 95% confidence intervals 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.

Next we explore a few life cycle stages in more detail: viticulture, packaging and transportation.

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.

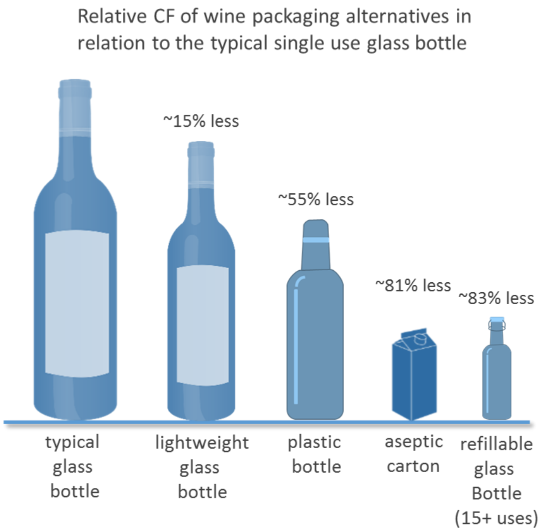


Figure 5 Relative carbon footprint of various wine packaging formats compared to the typical single use glass bottle (left)

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 US, 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.

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.

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."

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.

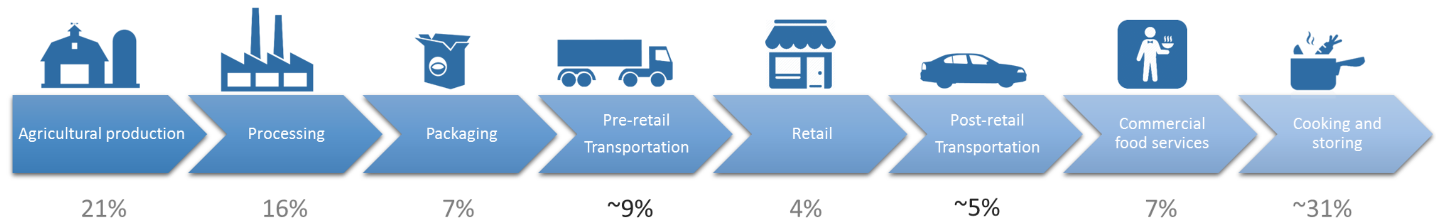
Vázquez-Rowe, I., P. Villanueva-Rey, M. T. Moreira and G. Feijoo. 2012. Environmental analysis of Ribeiro wine from a timeline perspective: harvest year matters when reporting environmental impacts. Journal of environmental management 98: 73-83.

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.

EXECUTIVE SUMMARY: FOOD TRANSPORTATION

Distribution – the transport of food from producer to consumer – is commonly perceived as a dominant contributor to the overall environmental footprint of foods. Because personal and freight transportation account for 28% of the total energy use in the U.S., it is intuitive to reason that the further a product travels to market from the production site, the greater its environmental damage and contribution to global warming. Yet, a closer look at our food system suggests a different story, one where transportation accounts for about 14% of the total energy used by the U.S. food system, about 5% from personal grocery shopping trips and only about 9% from distributing raw and processed food.



While supporting a local food system and minimizing transport are generally useful principles, differences in agricultural production and the realities of transportation impacts may favor sourcing from other regions. A systems approach to considering the environmental footprint of foods and the food system, through tools such as life cycle assessment, LCA, can offer perspective on the relative importance of food transport. Indeed, repeated studies demonstrate that “food miles”, the distance food travels from producer to consumer, is of very little value in predicting the carbon footprint or environmental impact of a food item. Often, the carbon footprint is dominated by variability in production and processing stages of the food life cycle, and can easily overwhelm any differences brought about by transportation distances. This summary highlights results from LCA studies to clarify the role that transportation plays in the food system, and address the deceptively simple question: is “local” more sustainable than “global”?

KEY FINDINGS

Relevance of transportation in food LCAs: In general, the contribution of food transportation relative to the total greenhouse gas emissions of a given food product represents a small percentage of the carbon footprint of many foods. Highly perishable foods such as fish and seafood, as well as foods transported by air, demonstrate significant distribution-related carbon footprints. But on average, distribution of finished foods (from farm or factory to retail stores) contributes less than 4 percent, on average, of the greenhouse gas emissions of foods consumed in the U.S.

Implications of transport mode: Another challenge with relying on “food miles” as an indicator of greenhouse gas emissions or other environmental impacts is that often, the mode of transport (air, road, rail, and water) is a much more important determinant than the distance traveled. The graphic below shows the relative impacts of food transportation options:

Of course, such values are dependent on how efficiently the vehicle is loaded and will be different for products where packing into a vehicle or freight container is volume- rather than weight-limited. It should be noted that other environmental impacts that are relevant to transport such as acidification potential (causing acid rain) or particulate emissions (affecting the respiratory system) associated with the burning of fuel are typically proportional to energy use and greenhouse gases.

Consumer shopping: Transport can play an important role in other ways in the food life cycle: numerous studies that include the impacts of consumer shopping trips – driving a car to the grocery store or other points of purchase – have shown the rather surprising contribution that this seemingly innocuous act can have on the overall footprint of food. For consumers driving long distances to purchase few items, the contribution from a shopping trip by car can be larger than all other transport, storage and processing energy used in marketing stages combined. For example, one study detailed in the wine product environmental footprint summary where a comparison of wine distribution channels for a vineyard in Sonoma to customers in San Francisco and Manhattan found that the San Francisco customer driving to the vineyard was the most impactful scenario, even more so than airfreight to Manhattan.

Comparing local and regional/global food systems: When considering the question of whether a "local" food system has lower environmental impact than a global food system, we must consider factors *beyond* transportation distance and mode that can come into play. These considerations include emissions due to the use of fertilizers and other chemicals during agricultural production that vary greatly by soil type, climate and management practices, and which can greatly affect the total greenhouse gas emissions of a food. Crop yields, which ultimately have a strong influence on environmental impacts per unit of output, also vary with soil type, climate, and historical and current management practices. In addition, crops in most locations have a seasonality and there is a need to store food in some way between the time of harvest and the time of consumption. Consuming local food year-round requires additional or improved storage, leading to impacts typically in the form of energy consumption for refrigeration or freezing. Identifying a minimally impactful consumption strategy would require balancing this with emissions from transport of non-local foods, and this balance likely will vary by season.

In one study of staple crops, a distance-minimized scenario had greenhouse gas emissions that were 86 percent higher than a scenario where crops were grown in locations chosen to minimize overall greenhouse gas emissions. The advantage of non-local production is explained by the minor importance of transport emissions compared to those caused by the production up to farm gate. On-field emissions are influenced by yield differences, which are in turn a consequence of soil and climate conditions. This study demonstrates that staple crops should be produced where the crops grow best and then traded internationally in order to cause fewer greenhouse gas emissions.

CONCLUSIONS

Transportation is an integral part of our modern food system, yet it represents a relatively small contribution to the life cycle impacts of food production. The conclusions listed below however do not suggest that food transport impacts should simply be ignored or tolerated, but instead highlight the need to consider individual food commodity life cycle behaviors and, and when warranted, focus initial abatement strategies on stages and processes with the greatest impact.

- Transportation represents a relatively small contribution to the energy use and associated greenhouse gas emissions of the US food system.
- Meta-analysis of existing food LCAs suggests that for most foods, distribution is not a dominant contributor of greenhouse gas emissions, yet exceptions exist.
- Not all miles traveled are equal in terms of greenhouse gas emissions. Modes of transportation can have a much stronger influence on emissions than transportation distance per se.
- Consumer shopping trips can be a surprisingly large source of greenhouse gas emissions in the cradle-to-grave life cycle of foods. Clearly, this is influenced by consumer behavior, including mode of transport (walking, biking, public transit, personal vehicle), vehicle fuel efficiencies, the quantity of food purchased per trip, and whether shopping trips are combined with other tasks.

The full report created by Center for Sustainable Systems - University of Michigan can be downloaded from: [insert URL here]

State of Oregon Department of Environmental Quality

Food Product Environmental Footprint Literature Summary: Food Transportation

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

Martin Heller

4-14-2017

OVERVIEW

Distribution – the transport of food from producer to consumer – is commonly perceived as a dominant contributor to the overall environmental footprint of foods. The concept of "food miles" is based on the fact that domestic and international transport activities are important users of energy, and hence sources of greenhouse gas emissions. After all, freight and personal transportation account for 28% of the total energy use in the U.S.[1] It is intuitive to reason that the farther a product travels to market from the production site, the greater its environmental damage and contribution to global warming. While a great number of factors have driven the growth of local food movements across the country and around the world, the perception that local food inherently has a lower environmental footprint is a central conceptual argument for many "localists."

Yet, a closer look at our food system suggests a different story. Figure 1 shows that transportation accounts for an estimated 14% of the total energy used by the U.S. food system, about 5% from personal grocery shopping trips and only about 9% from distributing raw and processed food. While the data in Figure 1 are from the 1990s, more recent assessments confirm the general conclusion. An input-output material flow analysis of energy use in the U.S. food system conducted by USDA found that transportation represented only 4% of the total food system energy use in 2002, not including consumer shopping trips (Canning et al., 2010). An often cited input-output life cycle assessment study of supplying food for U.S. households (up until retail outlets) found that direct distribution of foods (from farm or production facility to retail stores) represented only 4% of the total greenhouse gas emissions (GHGE), with indirect transportation (e.g., delivery of fertilizer to farms) adding an additional 7%. Food production (on-farm and processing), on the other hand, represents 83% of the total GHGE (Weber and Matthews, 2008).

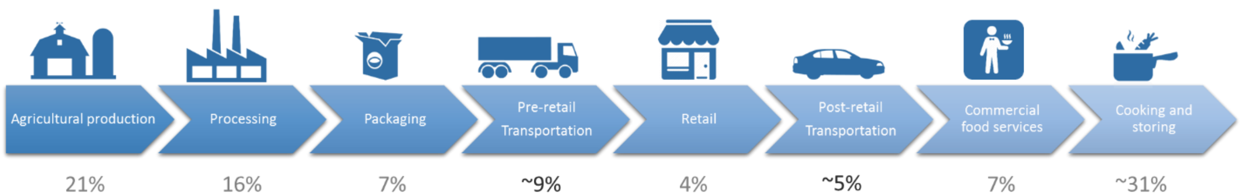


Figure 1 Generic life cycle of food production with the distribution of the estimated 10.8 EJ of energy used annually by the US food system based on data from the early to mid-1990s. Adapted from (Heller and Keoleian, 2003). (EJ = 10^{18} J)

While supporting a local food system and minimizing transport are in general useful principles, differences in agricultural production and the realities of transportation impacts may favor sourcing from other regions. A systems approach to considering the environmental footprint of foods and the food system, through tools such as life cycle assessment, can offer perspective on the relative importance of food transport. Indeed, repeated studies demonstrate that "food miles" – the distance food travels from producer to consumer – is of very little value in predicting the carbon footprint or environmental impact of a food. Often, the carbon footprint is dominated by other life cycle stages, such as production, and variability in these life cycle stages can easily overwhelm any differences brought about by transportation distances. In addition, as we'll see below, the mode of transport – whether truck or train or plane – matters much more than the distance alone. In this summary, we utilize available life cycle assessment (LCA) research to demonstrate the role that transportation plays in the food system and the fallacy of using food miles as a measure of environmental sustainability.

Any consideration of the importance of transportation, and, by extension, the relevance of "local" to the sustainability of foods and food systems must first acknowledge that sustainability encompasses multiple

[1] http://www.eia.gov/totalenergy/data/annual/#consumption

dimensions. Sustainability is also *not* a status to achieve, but a never-ending process of reflection, management and improvement. A recent European-wide project called GLAMUR (Global and Local food chain Assessment: a Multidimensional performance-based approach[2]) includes environmental, economic, social, health and ethical sustainability dimensions in addressing the deceptively simple question: is "local" more sustainable than "global"? While acknowledging the importance of these other dimensions, in this summary, we will focus on environmental aspects, specifically those investigated through a LCA framework, for the Product Environmental Footprint of Food Transportation.

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 [here].

AVAILABLE LCA RESEARCH

We compiled GHGE results from 116 food LCA studies that included product distribution within their system boundaries in order to demonstrate the relative importance of distribution in the life cycle of foods. This meta-analysis included over 300 scenario data points representing all food types including, but not limited to, the food commodities covered in other Product Environmental Footprint Summaries. In addition, a collection of studies that address the question of "local" vs. "global" food systems were reviewed.

KEY FINDINGS

RELEVANCE OF TRANSPORTATION: META-ANALYSIS OF FOOD LCA

Figure 2 offers a compelling demonstration of the influence of distribution transport on the carbon footprint of foods. Note that while the functional unit (denominator in Figure 2a) for all results was adjusted to 1 kilogram *edible* food, and available studies were filtered to show only those that included a farm- or processor-to-wholesale/retail distribution stage, no other adjustments to scenario parameters or boundary conditions were made. Thus, Figure 2 represents a vast array of food types, transport distances and transport modes. While other transportation burdens certainly are included in most if not all of these studies, Figure 2 focuses on the producer-to-consumer distribution transport most commonly associated with "food miles."

One conclusion to be drawn from Figure 2a is that while there are a number of higher outliers (many of these representing air-freighted products) that raise the averages, the median values for all food types are below 0.5 kilograms CO_2eq per kilogram of food delivered. To put this in perspective, the full cradle-to-grave emissions associated with consuming a quart of milk are about 2 kilograms CO_2eq; for 8 ounces of beef, it's about 12 kilograms CO_2eq. Thus, while there are exceptions, the GHGE *per unit of food delivered* associated with "food miles" are typically small.

[2] The main findings of the GLAMUR project were summarized in an open access article in a special issue of the journal, *Sustainability* (http://www.mdpi.com/2071-1050/8/5/449). It is an excellent read for those interested in a thorough (albeit academic) consideration of the local vs. global food system question. The remainder of the special issue contains additional articles covering specific case studies from the GLAMUR project (http://www.mdpi.com/journal/sustainability/special_issues/conventional-and-alternative-food-chains).

Figure 2b shows the contribution of food distribution transport relative to the total GHGE of a given food product scenario. Note that some scenarios in Figure 2 include full cradle-to-grave stages (production, processing, packaging, distribution, retail, consumption, disposal) while others may only go to the distribution stage (scenarios that do not include distribution were excluded from Figure 2). This has the effect of drawing the averages in 2b upward (when fewer stages are included, distribution will be a larger percentage of the whole). Yet, the conclusion from Figure 2b is convincing: in general, distribution represents a small percentage of the carbon footprint of most foods. The fact that the median (green bar) is below the average (red bar) for all food types indicates that there are

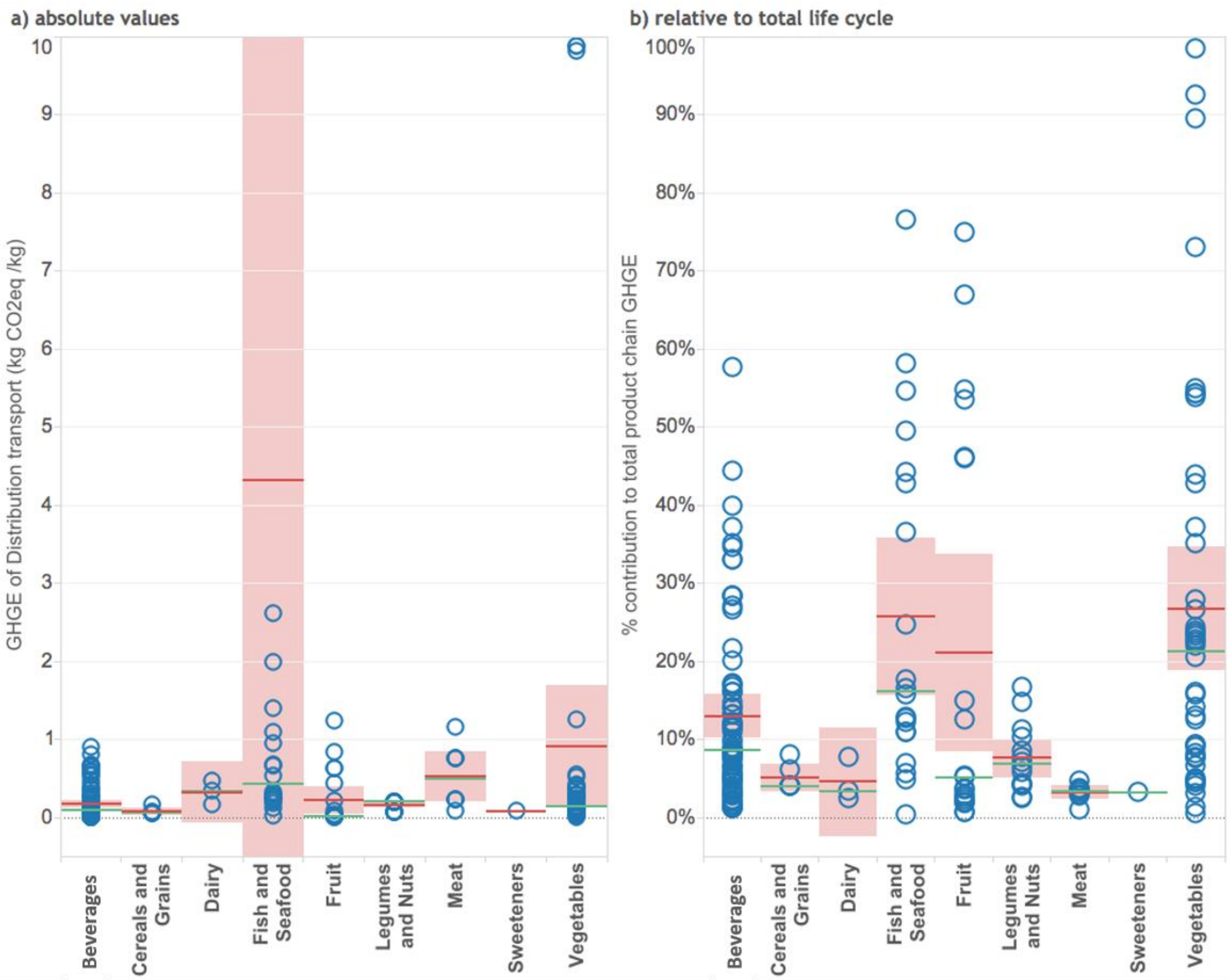


Figure 2. Demonstration of the GHGE associated with food distribution (farm to retail transport) in a) absolute values, and b) as a percentage of the total life cycle GHGE for a particular study. Red horizontal bars are averages for the food category and pink boxes are 95% confidence intervals around that average. Green bars are median values for the food category. Two out-of-scale "Fish and Seafood" data points are not shown in Figure a) but significantly affect the average: one was air freight of live Tasmanian southern rock lobster to Beijing (58 kilograms CO_2eq per kilogram when adjusted to edible portion), the other air freight of live American lobster from Nova Scotia to Las Vegas (16 kilograms CO_2eq per kilogram when adjusted to edible portion). The "vegetables" data points at ~10 kilograms CO_2eq per kilogram in a) also represent air-freighted produce, in this case fresh green beans from Uganda and Kenya to the UK.

more data points below the average than above. Indeed, given the influence of extreme outliers, the median may be more generally representative here than the average. To put these percentages in perspective, we can consider the same meta-analysis applied to other life cycle stages. The average percent contribution for on-farm agricultural production ranges from a low of 34% for beverages to a high of 91% for meats. The average packaging contribution ranges from a high of 30% for both beverages and fruit to a low of 1% for meats. Of course, there are exceptions – foods or distribution scenarios where transportation *is* a dominant contributor to GHGE. Often these are either foods with very low impacts from production, or highly perishable, high-value foods that require air freight. In general, however, the common *a priori* assumption that transportation dominates the GHGE of a food's life cycle does not hold up to further scrutiny. Consider, for example, the case of out-of-season tomatoes produced locally in a heated greenhouse versus tomatoes imported from warmer regions, as discussed in the tomato product environmental footprint summary. One study found that production of fresh tomatoes in heated glass houses in the UK required four times the energy and resulted in three times the GHGE per kilogram delivered to a regional distribution center in the UK than tomatoes grown in Spain and shipped 2300 km via truck (Webb *et al*. 2013). This is despite tomato yield in the UK greenhouses being 2-3 times that in Spain.

EMISSION INTENSITIES OF TRANSPORT MODES

Another challenge with relying on "food miles" as an indicator of GHGE or other environmental impacts is that often, the mode of transport is a much more important determinant than the distance. Table 1 shows energy and GHGE per metric ton-kilometer for different modes of transport. A metric ton-kilometer is a unit of freight carriage equal to the transportation of one metric ton of freight a distance of one kilometer. It is used to conveniently distribute the impacts of hauling a large quantity of freight to individual quantities of that freight (say, one kilogram of oranges). Figure 3 summarizes the emission factors in Table 1 are commonly generated by taking average fuel efficiencies and emissions per distance traveled for the various forms of transportation and dividing them by the load capacity (total tons) of freight at a given loading rate.

Figure 3 Relative carbon footprint of different transport modes and vehicles

Of course, such values are dependent on the loading rate and will be different for products where packing into a truck or freight container is volume- rather than weight-limited. It should be noted that other environmental impacts that are relevant to transport such as acidification potential or particulate emissions are typically proportional to energy use and GHGE.

Transport mode (with refrigeration)	kilograms CO_2eq per metric ton-kilometer
truck, 3.5-7.5 metric tons	0.519 (0.665)
truck, 7.5-16 metric tons	0.217 (0.302)
truck, 16-32 metric tons	0.167
truck, >32 metric tons	0.091
freight train	0.051 (0.058)
inland waterways barge, freight	0.048 (0.062)
transoceanic ship, freight	0.011 (0.022)
air freight	1.119 (1.120)

Table 1 GHGE per metric ton-km for different modes of transport. Adapted from Ecoinvent 3 database

From Table 1, we see that impacts of transport decrease in the order: van > air > truck > rail > transoceanic shipping. Impacts still increase linearly with distance, so shortening transport distance certainly can lower impact, but this is only *a priori* true if comparing the same mode. Rail shipments can go two to ten times farther than truck shipments and result in the same GHGE. In addition, food loaded to the maximum weight capacity of a truck will have a lower transport burden *per kilogram of food shipped* than if the truck were at less than capacity. Thus, tracking only the food miles traveled without knowledge of the mode of transport or packing efficiency offers very little information on environmental impact.

CONSUMER SHOPPING

Transport efficiency can play an important role in other ways in the food life cycle: numerous studies that include the impacts of consumer shopping trips – driving a car to the grocery store or other points of purchase – have shown the rather surprising contribution that this seemingly innocuous act can have on the overall footprint of food. Often, the contribution from a shopping trip by car can be larger than all other transport, storage and processing energy used in marketing stages combined.

Lampert et al., 2016, consider the GHGE of different distribution channels, including packaging, distribution and consumer shopping trips, for asparagus in Germany from both the producer and the consumer side. When considering only the impacts on the producer side, sales from a farm shop are associated with lower emissions than from a sales booth (think: farmers' market) which requires some transport, or through a supermarket supply chain which requires additional wholesale packaging, refrigerated warehousing, and multiple transport steps. When the consumer side is included, based on transport modes and distances identified in a consumer survey, the sales booth option has the lowest carbon footprint because consumers travel shorter distances and more consumers bike or walk. But the consumer shopping trip dominates the distribution impacts in all three channels.

Another study evaluating the distribution of organic vegetables in the UK compared the GHGE of purchasing from a small, local on-farm shop with those of a "box system" of large-scale mass distribution and home delivery (Coley et al., 2009). The actual vegetable production was assumed to be comparable in both cases, but the box system included the impacts of cold storage, transport to a distribution hub, and then delivery to homes by van (80 boxes per van load, averaging 360 kilometers per box). The study found that if a customer drives a round-trip distance of more than 7.4 kilometers (4.6 miles) to the farm to purchase their vegetables, their carbon emissions are likely to be greater than the emissions associated with the home-delivery box system. Another example of the relevance of personal shopping trips is detailed in the wine product environmental footprint summary where a comparison of wine distribution channels for a vineyard in Sonoma to customers in San Francisco and Manhattan found that the San Francisco customer driving to the vineyard was the most impactful scenario, even more so than airfreight to Manhattan (Cholette and Venkat, 2009).

COMPARING LOCAL AND REGIONAL/GLOBAL FOOD SYSTEMS

A number of studies have directly addressed the question of whether a "local" food system has lower environmental impact than a mainstream/regional/global food system (Avetisyan et al., 2014; Brunori et al., 2016; Edwards-Jones et al., 2008; Kreidenweis et al., 2016; Rothwell et al., 2016; Van Hauwermeiren et al., 2007). This question has also been considered in the nutrition science literature where one author concluded that a review of the literature "does not identify any generalizable or systematic benefits to the environment or human health that arise from the consumption of local food in preference to non-local food" (Edwards-Jones, 2010). Of course, all studies frame this question somewhat differently and consider different comparative scenarios, and the particulars and caveats of each approach are far too cumbersome to detail here. It is, however, informative to consider the factors *beyond* transportation distance that can come into play in considering this question.

A number of field-level production factors vary spatially and can therefore influence the relative impacts of foods produced in different locations. Nitrous oxide is a powerful greenhouse gas that is released at elevated levels from soils when nitrogen is added (i.e., during agricultural production). These emissions are notoriously difficult to estimate and vary greatly by soil type, climate and management practices, but can greatly affect the total GHGE of a food. Crop yields, which ultimately have a strong influence on environmental impacts per unit of output, also vary with soil type, climate, and historical and current management practices.

In addition, crops in most locations have a seasonality and there is a need to store food in some way between the time of harvest and the time of consumption. Consuming local food year-round requires additional or improved storage, leading to impacts typically in the form of energy consumption for refrigeration or freezing. Identifying a minimally impactful consumption strategy would require balancing this with emissions from transport of non-local foods, and this balance likely will vary by season. Such a trade-off was demonstrated for apples consumed in the UK; eating domestic apples in-season resulted in the lowest energy use, but later in the year (European spring & summer), apples from the Southern Hemisphere likely would be the low energy option (although variability in the data was too large to say this definitively) (Milà i Canals et al., 2007).

An interesting spatial optimization modeling exercise demonstrates the advantages of non-local production (Kreidenweis et al., 2016). In this study, a linear programming model was created that spatially allocated the production of five important food commodities (barley, maize, vegetable oil, sugar, wheat) based on actual food demand, potential yield levels, and currently used crop land. The model was run with two optimization objectives: one minimizing transport distance (local food production), the other minimizing the GHGE from production and transport. To simplify the complex trade relationships of food transport, the study focused on an idealized example of a world consisting of only two countries: Brazil and Germany. This simplification was sufficient to study the evolving crop distribution while also allowing high spatial resolution. Brazil and Germany offered a strong case as the two countries are in different climates and therefore have differing crop suitability, trade between them requires long-distance overseas transport allowing analysis of different modes of transport and the influence of distance, and a high number of agricultural LCAs have been conducted in the two countries, offering sufficient input data. Demand was based on actual per capita food availability in the two countries, and demand centers were determined by cities over 100,000 inhabitants (all country inhabitants were assigned to the closest demand center). Production was based on potential production capacity data. In this study, oil from soybean (Brazil) and rapeseed (Germany), and sugar from sugarcane (Brazil) and sugar beet (Germany) were treated as perfect substitutes, and only the demand for their processed goods (oil and sugar) was considered. The physical locations of existing sugar refineries and oil mills in each country were utilized.

Figure 4 shows the results of the spatial distribution of the crops in each optimization scenario. The distance-minimized scenario had 86% higher CO_2 eq. emissions than did the CO_2 eq. optimization scenario. In addition, the distance optimized scenario required 49% more total land area. The advantage of non-local production is explained by the minor importance of transport emissions compared to those caused by the production up to farm gate. On-field emissions are influenced by yield differences, which are in turn a consequence of soil and climate conditions. The authors acknowledge that so far, local food has focused on fresh products like fruits and vegetables, with less attention on staple crops; their results demonstrate that such staple crops should be produced where the crops grow best and then traded internationally in order to cause fewer GHGE.

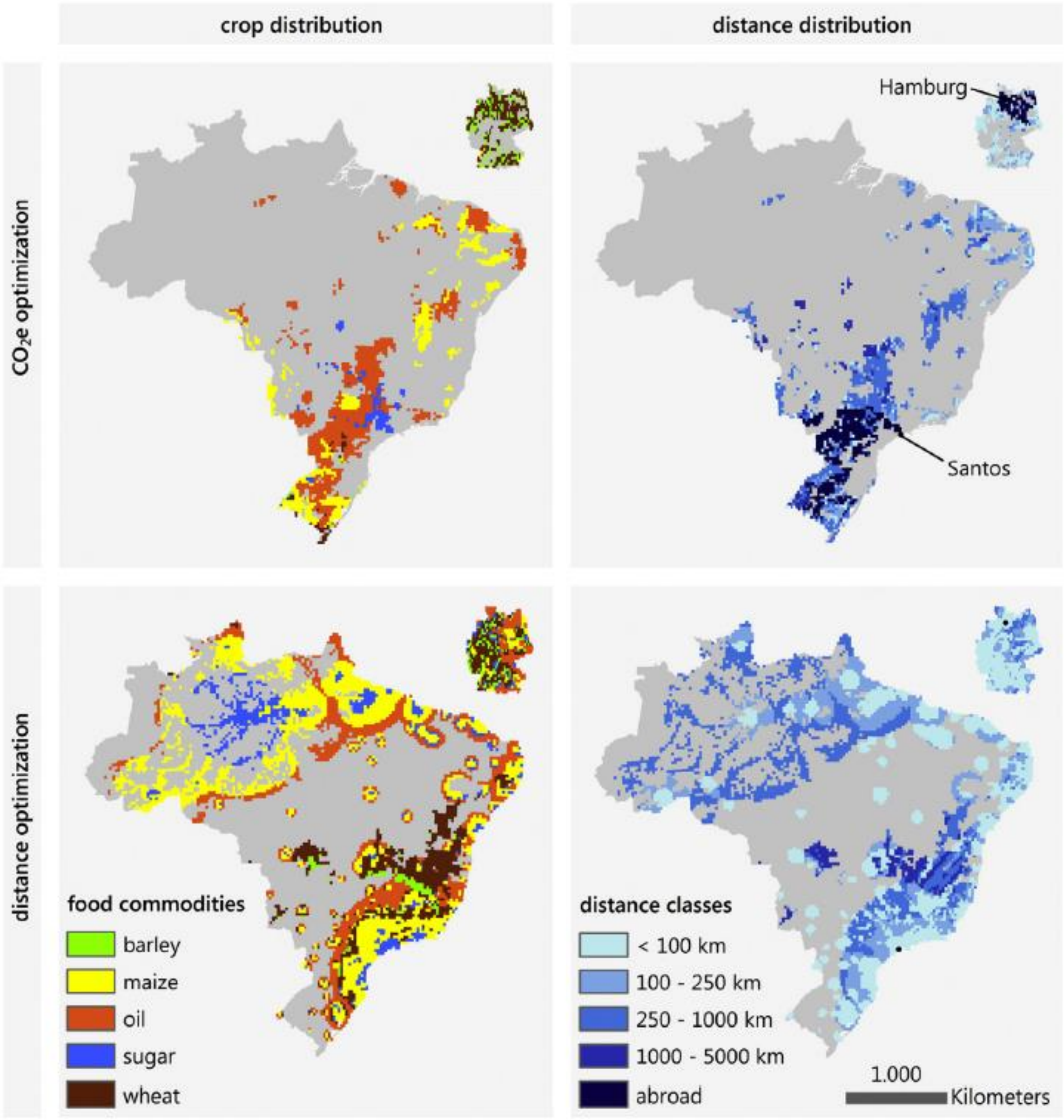


Figure 4 Result maps of CO2 eq and distance optimization from (Kreidenweis et al., 2016). Left column shows the dominant crop of each cell. Right column shows the distance between production and consumption of these crops. Upper row depicts the results of CO2eq optimization, lower row the distance optimization. Oil refers to rapeseed in Germany and soybean in Brazil, sugar to sugar beet and sugarcane, respectively. Maps are projected in Lambert Azimuthal equal-area centered to each country.

RESEARCH GAPS

Existing research clearly demonstrates that reducing transportation distance is not, in general, an effective strategy in minimizing the environmental impact of foods. This does, however, create the need for spatially specific studies of individual food commodities to identify differences in regional production across a wide array of potential environmental impacts – not just GHGE – and the potential for trade-offs with transportation. In addition, balancing environmental aspects with other dimensions of sustainability (social, economic, health) and regional resilience is an ongoing research and governance challenge.

CONCLUSIONS

Transportation is an integral part of our modern food system. Existing LCA literature sheds light on the relatively low contribution of transportation in the overall environmental impact of food production and consumption, and offers some conclusions, listed below. These conclusions do not suggest that food transport should simply be ignored or tolerated, but instead highlight the need to consider individual food commodity life cycle behaviors and, and when warranted, focus initial abatement strategies on stages and processes with the greatest impact.

- Transportation represents a relatively small contribution to the energy use and associated greenhouse gas emissions of the US food system.
- Meta-analysis of existing food LCAs suggests that for most foods, distribution is not a dominant contributor of GHGE, yet exceptions exist.
- Modes of transportation can have a much stronger influence on GHGE than transportation distance *per se*.
- Consumer shopping trips can be a surprisingly large source of GHGE in the cradle-to-grave life cycle of foods. Clearly, this is influenced by consumer behavior, including mode of transport (walking, biking, public transit, personal vehicle), vehicle fuel efficiencies, the quantity of food purchased per trip, and whether shopping trips are combined with other tasks.
- Numerous research examples demonstrate that while local food may have social, economic and ethical advantages, it is not necessarily the preferred option for minimizing energy use and GHGE.

REFERENCES

Avetisyan, M., T. Hertel and G. Sampson. 2014. Is local food more environmentally friendly? The GHG emissions impacts of consuming imported versus domestically produced food. Environmental and Resource Economics 58(3): 415-462.

Brunori, G., F. Galli, D. Barjolle, R. van Broekhuizen, L. Colombo, M. Giampietro, J. Kirwan, T. Lang, E. Mathijs, D. Maye, K. de Roest, C. Rougoor, J. Schwarz, E. Schmitt, J. Smith, Z. Stojanovic, T. Tisenkopfs and J.-M. Touzard. 2016. Are Local Food Chains More Sustainable than Global Food Chains? Considerations for Assessment. Sustainability 8(5): 449.

Canning, P., A. Charles, S. Huang, K. R. Polenske and A. Waters. 2010. Energy use in the US food system. U.S. Dept. of Agri., Econ. Res. Serv., ERR-94.

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.

Coley, D., M. Howard and M. Winter. 2009. Local food, food miles and carbon emissions: A comparison of farm shop and mass distribution approaches. Food policy 34(2): 150-155.

Edwards-Jones, G. 2010. Does eating local food reduce the environmental impact of food production and enhance consumer health? Proceedings of the Nutrition Society 69(04): 582-591.

Edwards-Jones, G., L. M. i Canals, N. Hounsome, M. Truninger, G. Koerber, B. Hounsome, P. Cross, E. H. York, A. Hospido and K. Plassmann. 2008. Testing the assertion that 'local food is best': the challenges of an evidence-based approach. Trends in Food Science & Technology 19(5): 265-274.

Heller, M. C. and G. A. Keoleian. 2003. Assessing the sustainability of the US food system: a life cycle perspective. Agricultural Systems 76(3): 1007-1041.

Kreidenweis, U., S. Lautenbach and T. Koellner. 2016. Regional or global? The question of low-emission food sourcing addressed with spatial optimization modelling. Environmental Modelling & Software 82: 128-141.

Lampert, P., E. Soode, K. Menrad and L. Theuvsen. 2016. Distributing asparagus: a climate perspective considering producer and consumer aspects. Agroecology and Sustainable Food Systems 40(2): 169-186.

Lee, G.-E., S. Miller and S. Loveridge. 2015. Modelling Local Food Policy and Greenhouse Gas Emission due to Transportation. Available from https://www.researchgate.net/profile/Steven_Miller15/publication/283516056_Modelling_Local_Food_Policy_and_Greenhouse_Gas_Emission_due_to_Transportation/links/563cf9a508ae45b5d2899841.pdf.

Milà i Canals, L., S. J. Cowell, S. Sim and L. Basson. 2007. Comparing domestic versus imported apples: a focus on energy use. Environmental science and pollution research international 14(5): 338-344.

Rothwell, A., B. Ridoutt, G. Page and W. Bellotti. 2016. Environmental performance of local food: trade-offs and implications for climate resilience in a developed city. Journal of Cleaner Production 114: 420-430.

Van Hauwermeiren, A., H. Coene, G. Engelen and E. Mathijs. 2007. Energy lifecycle inputs in food systems: a comparison of local versus mainstream cases. Journal of Environmental Policy & Planning 9(1): 31-51.

Webb, J., A. G. Williams, E. Hope, D. Evans, and E. Moorhouse. 2013. Do foods imported into the UK have a greater environmental impact than the same foods produced within the UK? *The International Journal of Life Cycle Assessment* 18(7): 1325-1343.

Weber, C. L. and H. S. Matthews. 2008. Food-miles and the relative climate impacts of food choices in the united states. Environmental Science & Technology 42(10): 3508-3513.