Food Product Environmental Footprint Literature Summary:

Food Transportation

State of Oregon
DEQ Department of Environmental Quality

with support from
The Oregon Sustainability Board

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

Martin Heller
September 2017

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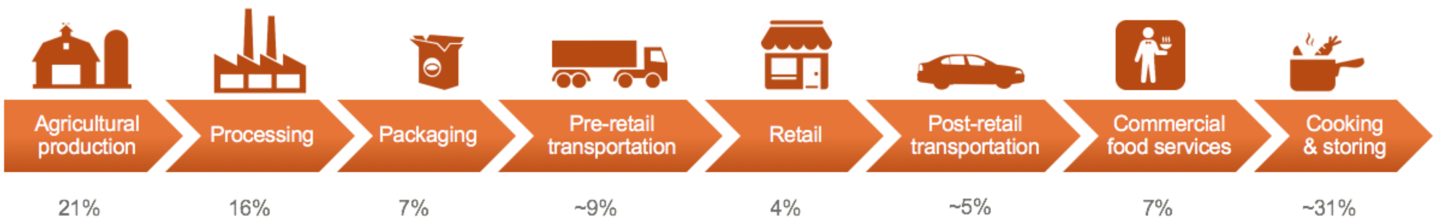
Executive Summary:

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. The graphic below illustrates the distribution of energy used by the food system in the U.S.



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 from an environmental impact perspective. 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 addresses 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 for many foods. Fresh foods transported by air freight can have significant distribution-related carbon impacts, but on average, distribution of finished foods (from farm or factory to retail stores) contributes less than 4%, 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. 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 found that a San Francisco customer driving to a vineyard in Sonoma is even more impactful than distributing wine from Sonoma to a customer in Manhattan using air freight and delivery trucks.

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 on-farm production. 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 impacts 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 U.S. 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.

Overview

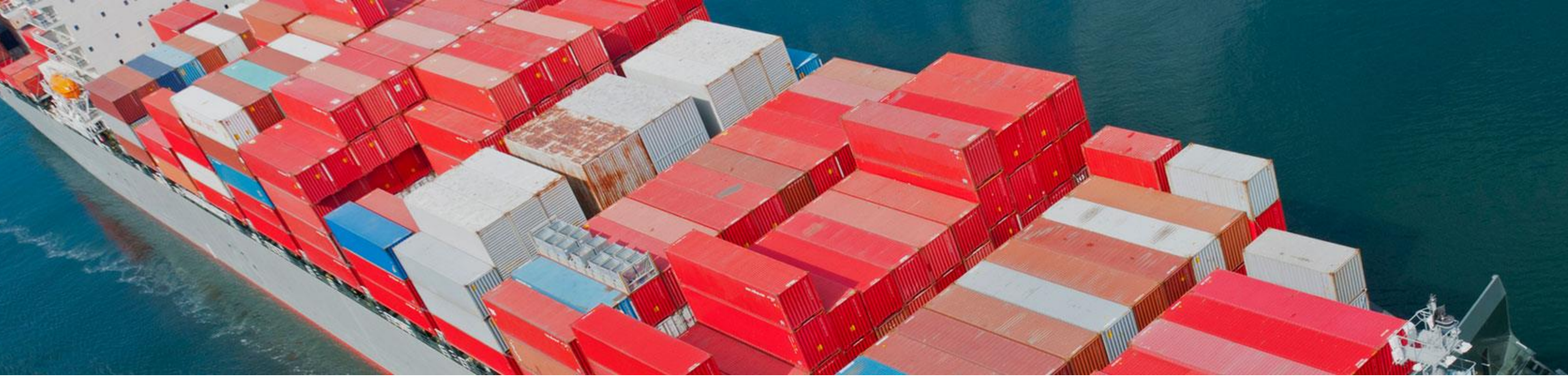
Distribution – the transport of food from producer to consumer – is commonly perceived as a dominant contributor to the overall environmental footprint of foods. The concept of "food miles" is based on the fact that domestic and international transport activities are important users of energy, and hence 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

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



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 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.

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.

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.

[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).

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

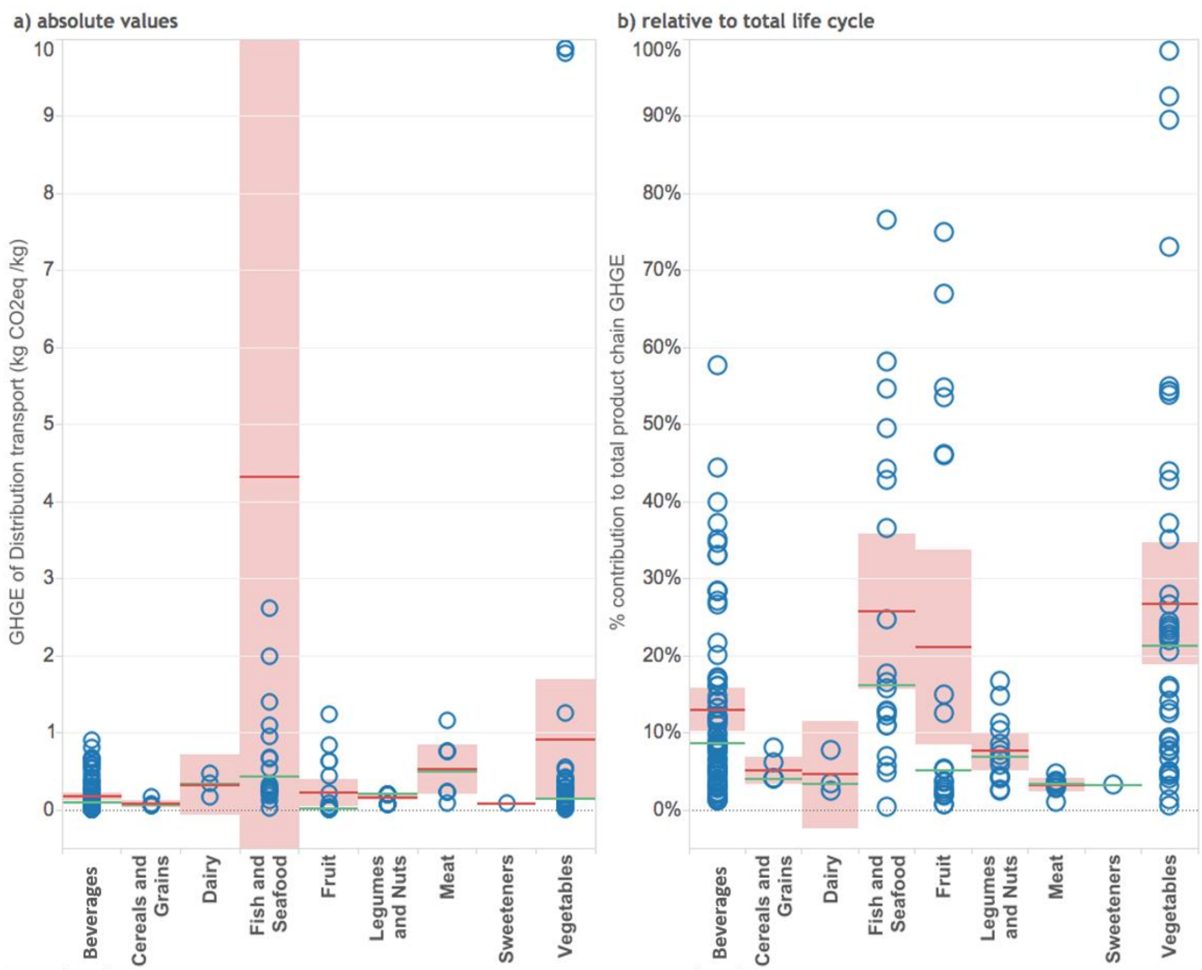


FIGURE 2. Demonstration of the GHGE associated with food distribution (farm to retail transport) in a) absolute values, and b) as a percentage of the total life cycle GHGE for a particular study.

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 2a) 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.

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.

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 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, (for details about tomato product environmental footprinting, view our 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. Emission factors 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.

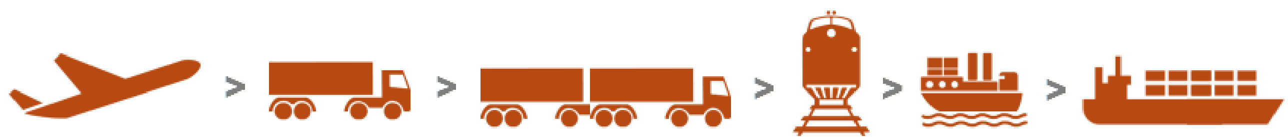


FIGURE 3. Relative carbon footprint of different transport modes and vehicles.

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	Kilograms CO_2eq per metric ton-kilometer (with refrigeration)
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 by mode of transport: air > road > rail > water shipping (depicted in Figure 3). 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 10 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.

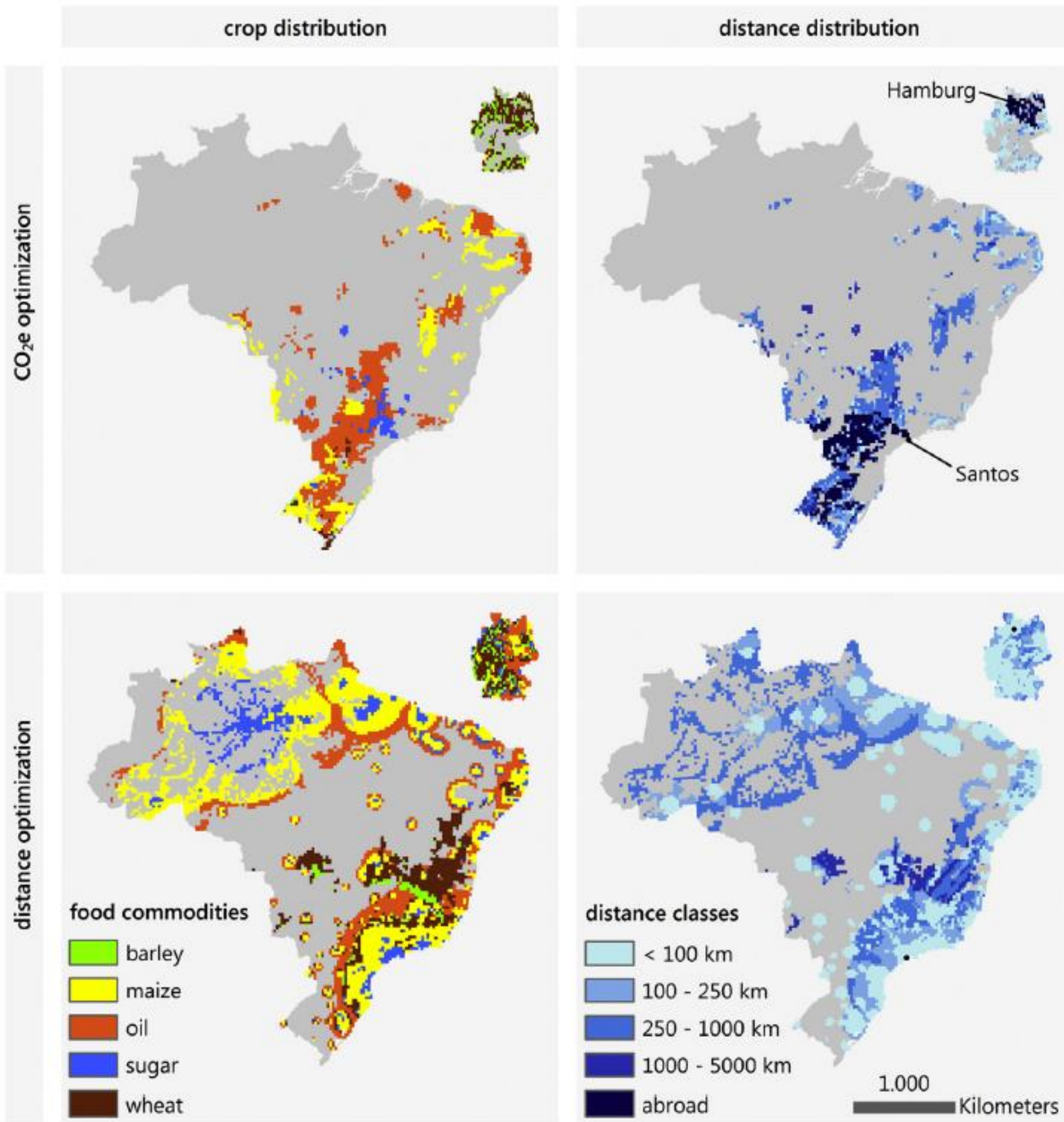


FIGURE 4. Result maps of CO_2 eq and distance optimization from (Kreidenweis et al., 2016).

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 CO_2eq 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.

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.

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 U.S. 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.

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