Chapter 9
Food transportation issues and reducing carbon footprint

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9.1 Introduction

Transportation is the largest end-use contributor toward global warming in the United States and many other developed countries. The U.S. Department of Energy (DOE 2009) calculates that CO_2 emissions from transportation surpassed two billion metric tons in 2007. Yet a survey by Golicic et al.(2010) finds that fewer than 10% of Fortune 500 companies have addressed the environmental impacts of transportation, and even fewer are actively implementing improvements, despite the fact that such initiatives would also tend to reduce fuel usage and costs in the long run.

Transportation has a significant impact within the food and beverage sector because food is often shipped long distances and not infrequently via air. Heller and Keoleian (2000) estimate that diesel fuel use accounts for 25% of the total energy consumed within the U.S. food system. Pirog et al. (2001) report that nearly half of all fruit sold in the United States is imported, and that produce grown in North America travels an average of 2,000 km from source to point of sale.

Although the impact of transportation is important, full life cycle analyses indicate that for most foods transportation does not have the largest environmental impact. Some analysts, such as Weber and Matthews (2008), estimate that given the

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typical household food basket, aggregate transportation accounts for just 11% of total carbon emissions associated with food production. We show in Sect. 9.5 that freight transport accounts for just 6% of overall emissions in the U.S. food sector, but its life cycle impact is greater in the case of plant-based foods that have relatively low production emissions. Therefore, it is still worthwhile to consider improving the food distribution system. There are often many options for delivering food to consumers, and these supply chain configurations can result in vastly differing energy and emissions profiles. In this chapter, we provide the background and tools for analyzing the energy intensity and resultant emissions of a food distribution system, evaluating tradeoffs and identifying opportunities for significant improvement. Note that we use the terms “carbon emissions” and “greenhouse gas emissions” interchangeably in this chapter, implying in both cases that all significant greenhouse gases emitted in a process are counted and reported as a single “carbon dioxide equivalent” figure.

9.2 Supply chain basics

Before we can further investigate transportation impacts, we must first introduce the concept of the supply chain: the sequenced network of facilities and activities that support the production and delivery of a good or service. Given the obvious importance of the supply chain, this field is rife with terminology and buzzwords, many of which are synonymous. For instance, supply chains are sometimes referred to as “demand chains” or “value chains.” A supply chain starts with basic suppliers and extends all the way to consumers via stages. These stages may include such facilities as suppliers, factories, warehouses and other storage facilities, distribution centers, and retail outlets.

Figure 9.1 shows a sample supply chain, where the arrows denote the flow of a product toward the consumer. This figure depicts both inbound logistics (the delivery of raw materials and packaging to the manufacturer) as well as outbound logistics (the transportation and storage of the finished good to the end consumer). This chapter focuses on outbound logistics, colloquially known as “gate-to-kitchen” and “farm-to-fork” in the food and beverage industry. The emissions associated with outbound logistics vary by origin and type of food. Weber and Matthews (2008) estimate that food transportation may account for 50% of total carbon emissions for many fruits and vegetables, but less than 10% for red meat products. Although

Fig. 9.1 A simple supply chain

inbound logistics can require substantial energy use, it is considered part of the production process and is discussed in earlier chapters.

Although the interrelationships between supply chain stages may be quite complex, all supply chains have one aspect in common—they end with a consumer. Supply chains for different products may be interlinked; one supply chain's end consumer may represent an intermediate node for another supply chain. Examples include a firm that buys components and assembles them into consumer items, and a soft drink producer that buys cylinders of compressed CO_2 to carbonate its products.

Much supply chain complexity results from the fact that few supply chains are completely controlled by one firm or vertically integrated. For example, producers and retailers are not typically owned by the same firm. Companies may outsource supply chain activities, especially transport and storage activities, which are handled more effectively by third party logistic (3PL) providers. Outside firms that form a part of a company's supply chain are channel partners. These partnerships require collaboration across organizations. We define supply chain management (SCM) as the coordination of business functions within an organization and between the organization and its channel partners. SCM strives to provide goods and services that fulfill customer demand responsively, efficiently, and sustainably.

SCM includes such functions as demand forecasting, purchasing (also known as sourcing), customer relationship management (CRM), and logistics. Logistics concerns the movement and storage of goods, services, and information. It is an umbrella term for such important functions as transportation, inventory management, packaging, and returns/reverse logistics. Some terminology will be helpful to understand who is doing what. The shipper initiates the movement of the product forward into the supply chain, the carrier is the party that does the actual moving of the product, and the consignee receives the product.

9.2.1 Transport modes

Within the developed world there are four basic transport modes for shipping large quantities of packaged products: water, rail, truck, and air. Trucking dominates, comprising more than 75% of the total U.S. freight transit bill. Trucking variables include truck type, ownership model (such as 3PL or company-owned fleet), and loading option (less-than-truckload or full-truckload). The dominant transport mode has shifted over time. The first transport revolution occurred when inland water transport replaced animal caravans. In the mid-1800s railroads displaced inland water as the dominant form of cargo transport, and in the mid-1900s trucking displaced railroads. Air cargo is a more recent and growing transport mode popular for short life cycle products such as flowers and luxury foods. The U.S. DOE (2009) estimates that air transport accounts for 9% of U.S. transportation fuel usage. Interestingly, water transport has started to make a comeback. In the United Kingdom (UK), for example, Tesco is relying on inland waterway barges for transporting

Table 9.1 Energy and emissions per ton-km

	MegaJoules per ton-km	kg CO_2e per ton-km
International water-container	0.2	0.14
Inland water	0.3	0.21
Rail[a]	0.3	0.18[a]
Truck[b]	2.7	1.8
Air[c]	10	6.8

Note that utilization and backhaul rates will affect all figures
[a]May depend on whether diesel or electric power is used
[b]Depends on size and type of truck, power source
[c]Includes effects from radiative forcing
Source: Based on data from Weber and Matthews (2008)

more of their beverage products. Short sea shipping, using ocean-going vessels for delivering cargo domestically, is popular in Europe and also holds promise for replacing many truck deliveries in the United States.

To compare transport modes with regard to energy usage and resultant emissions, we define a ton-km as the movement of 1 metric ton of cargo over 1 km. Table 9.1 shows that these modes have very different energy and emissions profiles. Caveats abound regarding the accuracy of these figures, but clearly air freighting is much more energy and emission intensive compared to other modes, especially water and rail. Of course, water and rail transport modes are contingent upon the availability of navigable water and established railroad tracks. An additional consideration is the potential need for supply chain responsiveness: air freight may be the only viable option for long-distance transport when customer orders require immediate fulfillment.

9.2.2 Intermodal transport

Before we choose one mode over another, we should consider intermodal transport. Defined as using more than one transportation mode to move a shipment between two points, an intermodal route might involve shipping cargo by water, then by rail, then by truck. Intermodal transport became practical with the advent of containerization, where products stay in the same container throughout their entire journey. Containerization was made possible through global standardization of container size and features, which dramatically reduced intermodal transfer times and significantly increased cost efficiency. From a sustainability viewpoint, the advantage of intermodal transport is that we can utilize more efficient modes for major transport corridors, and then shift to trucks for transport to remote destinations. Shippers can also use a 3PL provider to oversee the entire shipping process. One disadvantage of intermodal transport is its inherent complexity of coordination and the information technology support required to address that complexity. Another issue is the movement and repositioning of empty containers.

9.2.3 Utilization and backhaul

Many carbon analyzers base calculations on only transport mode and shipping distance. In our analysis, we will take into account additional factors, including vehicle utilization (how full the vehicle is) and backhaul (whether or not the vehicle carries freight on its return journey). Although fully laden vehicles use more fuel than nearly empty ones, most of the energy expended during a trip is used to move the vehicle and not its cargo. Underutilized vehicles waste energy, as do vehicles that return empty. Also, weight and volume limits must be respected, and all but the lightest and bulkiest cargo loads tend to "weigh out" rather than "cube out."

It can be difficult to determine utilization fractions and backhaul percentages, as these are likely to vary with each trip. Such information is even more challenging to obtain when transportation functions have been outsourced. However, some assumptions can be made. For example, vehicles chartered by 3PL providers are likely to have higher utilization fractions because they often carry cargo from multiple companies. Third party logistic providers are also likely to have higher backhaul rates, because they have more opportunities for obtaining return freight owing to their broader customer base.

9.2.4 Warehousing

Logistics involves not only the movement of goods, but their storage. Unless a product is custom ordered by an onsite client, it is likely that the product will enter storage at some point in its journey to the consumer. Such storage can occur at any supply chain stage: at the producer, distributor warehouse, and/or retailer stockroom. Intermediate supply chain stages range from pure storage centers to dedicated cross-dock facilities, in which cargo from upstream supplier trucks/railcars is transferred directly to outbound trucks/railcars destined for downstream stages. In addition to storage, warehouses can provide additional services: pick and pack (repackaging palletized products to smaller quantities destined for either retailers or end consumers), customs clearance, or even house product-finishing functions such as customizing goods to the local marketplace.

9.2.5 Packaging

Packaging decisions are inherently linked to the supply chain. Goods are frequently shipped in bulk and broken into consumer-sized quantities at a warehouse or other facility, and individual commodities are sometimes bundled into larger end-items, such as multipacks, and palletized. Packaging materials (pallets, boxes, totes, slipsheets, etc.) for both finished goods and intermediate support functions may be designed to be recyclable, compostable, or reusable. Non-landfilled packaging is highly desirable, but creates other challenges, such as the impact of reusable packaging in the reverse supply chain.

Packaging can often be reengineered to reduce package weight or bulk, which can translate into savings in raw materials, landfill impacts, and transport/storage energy use; but extra costs may be incurred elsewhere. For example, Safeway is working with Kimberly-Clark to pilot palletless deliveries of paper products. Although this may allow trucks to be packed with more products, labor costs are likely to increase in receiving, and pallets would still not have been totally eliminated from the supply chain because pallets would continue to be used at local warehouses.

9.3 What makes food supply chains special?

We have shown that supply chains can be long and complex. Food supply chains are some of the most difficult to manage as they must often address time constraints to avoid spoilage, as well as concerns about contamination, high weight-to-value ratios, fragility, unique packaging requirements, and the potential impact of food being wasted rather than consumed. We show here how these considerations affect outbound logistics.

One challenge relates to food production being inherently dependent on nature. Not only is the cultivation of many foods restricted geographically, but also temporally. Fruits, vegetables, and grains typically have fixed growing cycles with short and specific annual harvest periods. However, North American and European demand for many of these items is year round. There are three options for supplying fresh produce that is out of season locally: sourcing from distant growing areas, using long-term storage, or cultivating in a protected environment such as a greenhouse. Importing produce often results in lower overall emissions than harvesting and storing local produce for several months, as Hospido et al. (2009) and Milà i Canals et al. (2007) show for lettuce and apples, respectively. Indeed, energy needed for long-term cold storage can dominate a product's overall emissions profile. Carlsson-Kanyama (1998) shows, for example, that storage accounts for 60% of the carbon emissions associated with carrots. Higher emissions can result not only from the energy needed for climate control, but also from the inherent yield losses that occur during storage. Protected cultivation is even more energy intensive. Carlsson-Kanyama et al. (2003) show that tomatoes produced locally in Swedish greenhouses require ten times the energy as field-grown tomatoes imported from Southern Europe. Thus, long-distance supply chains, even though they are energy intensive, may yield the lowest overall footprint for providing out-of-season product to consumers.

A second challenge is related to situations where similar food commodities are produced locally as well as imported from distant locations, the emissions intensity of the production methods must be considered in any comparison of overall supply chain emissions. For example, Saunders and Barber (2007) find that milk solids produced locally in the United Kingdom generate 34% more emissions than the same product imported from New Zealand, even with transport included. This result reflects the more energy-intensive dairy production system in the United Kingdom.

A third challenge is that highly perishable foods require special handling to avoid yield loss and potential health issues. These foods often require cooling, refrigeration, or freezing during transport and/or storage. It may also be necessary to control other conditions, such as humidity, exposure to air, or contact with other items. These requirements increase energy usage and emissions.

A fourth challenge is that the location of facilities within a food supply chain can also affect emissions. For example, Sim et al. (2007) find that overall carbon emissions can be significantly reduced by locating processing and storage facilities in countries where more electricity is generated from renewable fuels or cleaner energy.

Fifth, when time is of the essence, as in the transport of highly perishable produce such as berries, air freight may be the only viable transport option. Air freighting may also be necessary in regions such as Africa where no other viable alternative exists for transporting produce to market. As previously shown, air freighting is highly energy intensive. Scholz et al. (2009) report that fresh salmon air freighted from overseas has about twice the environmental impact as frozen salmon transported by container ships over the same distance. The difference owing to transport modes is far more significant in this case than production choices such as wild versus farmed or organic versus conventional.

A sixth challenge is that safe food storage not only requires climate controls, but also a high degree of sanitation. In most developed countries, warehouses must be built and maintained to stringent guidelines to be certified as "food grade." In the United States, wood pallets may not be reused and may soon be phased out as unsanitary.

The process of packaging food is yet another challenge. Twede et al. (2000) emphasize that packaging beverage products is a high-speed automated process involving expensive equipment. Such capital investment and the need for a controlled environment favors centralizing packaging at the point of production, even if it might be more energy efficient to ship product in bulk. Food and beverage products typically require extensive packaging, which adds both weight and volume to the product. Additional energy and materials are required to create the packaging and transport it to the production site. Point (2008) performs a life cycle assessment of the Nova Scotia wine industry and finds that the largest contribution to emissions is owing to the production and transport of wine bottles.

9.4 Measuring transportation-related carbon emissions

This section presents the basics of performing a carbon audit and concludes with some examples from practice. Although other gases such as methane and nitrous oxide may contribute to global warming, aggregate greenhouse gas measures are typically reported in CO_2 equivalents (CO_2e), which is kgs of CO_2 emitted per kg of product. Carbon dioxide dominates, comprising 95% of total greenhouse gas emissions by volume (World Resources Institute 2004). Some points of confusion in carbon measures exist. For instance, U.S. documents report tons emitted, where most of the world measures in the SI (metric) units and reports in tons, as will we. Emissions are colloquially called "carbon emissions," which can lead to confusion as some older studies only weigh the carbon component of the gas, which is 30% of the total mass of CO_2. It is also now standard practice to report all significant greenhouse gas emissions as a single carbon emissions figure. The scope of the analysis depends on the purpose of the study. Scope 1 includes only direct emissions, whereas Scope 2 also includes indirect emissions from any consumption of purchased electricity, heat, or steam. Scope 3 is the broadest, including all other indirect emissions, such as the extraction and production of purchased materials and fuels, all outsourced activities, and waste disposal. Scope 3 can also include the substantial impact of radiative forcing from the contrails in tallying airplane emissions.

Scope must be carefully considered because incomplete framing (inappropriate scope) may lead to incorrect conclusions. For example, food miles are defined as the distance between the production source and the retail store, or "farm-to-fork." This metric has received substantial attention in the popular press and has been adopted by the business community. For example, the UK supermarket chain Tesco now provides food mile information. However, there is often no consideration of the energy used to transport supplies to the farm or the energy used for processing or storage. For example, Saunders et al. (2006) estimate that grass-fed lamb from New Zealand produces lower emissions overall than locally raised lamb fattened in a feedlot. Transport modes such as ocean and rail may actually be more efficient on a per-weight basis, even over long distances. Considering another dimension of sustainability, some African and South American farmers derive their livelihood from the service export markets. Tradeoffs between different facets of sustainability (environment, economics, equity; or planet, profits, people) can mean that carbon-based metrics may be misleading, especially in the context of incomplete framing.

Now that we understand supply chain basics and special logistical issues faced in food distribution, it would seem we are ready to collect data and enter this data into an analysis tool to derive the definitive answer to the question: How much carbon does our supply chain emit? Before we start broadcasting results with conviction and certainty, however, let us consider the following scenario. A person travels from San Francisco to New York and desires to purchase carbon offsets for the round-trip flight. The Internet has many free online carbon calculators, often with donation links for offsetting one's carbon footprint. Table 9.2 shows results from several calculators that target the typical U.S. consumer and report results in tons (the unit used in the United States). Even for a well-defined trip, the emissions reported and the recommended amount of carbon offsets to purchase vary widely. The amounts vary for both logical reasons (such as whether radiative forcing is included or not) and for obscure reasons (such as JetBlue's claim to being almost twice as carbon efficient as United Airlines). Note also that there are many other factors that may or may not have been considered by these carbon calculators, such as plane age and

Table 9.2 Divergent results of online carbon calculators—round trip from San Francisco to New York

	Tons CO_2e	Recommended offset	Implied $ per ton
Carbonfund.org	0.93	$9.34	$10.04
Adding radiative forcing	2.52	$25.22	$10.01
Terrapass.com			
Via JetBlue	1.462	$11.90	$8.14
Via Virgin	1.584		
Via United Airlines	2.215	$11.73	$5.30
Sustainabletravelinternational.org	1.86	$47.31	$25.44
Nativeenergy.com	2.055	$42.00	$20.44
Bonneville Education Foundation			
www.b-e-f.org	4.192	$56.00	$13.36

model, weather, utilization, and backhaul. Table 9.2 also shows that even when the amount of emissions being offset is about the same, the suggested donation is different. Different carbon calculators make different assumptions about the price per unit of offset.

So what lessons can be learned? First, it may not be realistic to expect highly accurate estimates of carbon emissions. It may be more important to strive for consistency and to avoid using different tools or techniques when comparing across scenarios. Johnson (2008) recommends that carbon footprints be defined sensibly and transparently because definitive standards have not yet emerged. It is also important to consider who will use the analyses and for what purpose. When providing consumers with recommendations for assessing personal transportation footprints, it may be appropriate to acknowledge the disparities between calculators and to provide a range of recommended offsets. There is a risk of backlash when savvy Internet users survey websites and discover how divergent the results can be. As an example of consumer skepticism, Rosenthal (2009) reports that in Sweden, where carbon labeling is starting to appear, the typical consumer reaction to carbon labels is bemusement.

In addition to providing consumers with information, carbon audits can provide useful insights for companies evaluating their operations. However, we believe that the figures from carbon audits should be viewed as guidelines rather than as precise and absolute truths. Given these caveats, we are now ready to consider some results from actual carbon audits performed for companies.

Case study: wine delivery to consumers

To illustrate the impact that supply chain design and implementation can have on carbon emissions, our first case considers the delivery of wine to the consumer. Energy usage associated with postproduction logistics is high for wine because the standard consumer packaging (a 750 mL glass bottle) is fragile, heavy, and bulky. Wine comprises 50% of the weight and less than 40% of the volume of a case of 12 bottles. Wine is also sensitive to temperature and must be stored in a controlled

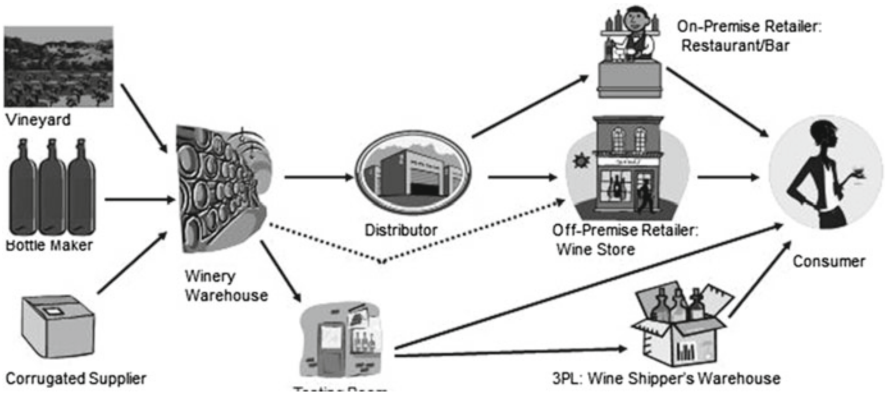

Fig. 9.2 An outbound logistics network for a winery

climate for all but the shortest periods. The outbound logistics network, depicted in Fig. 9.2, depicts paths with differing numbers of intermediary stages and several retail channels. The majority of wine sold in the United States is delivered within the framework of the 3-tier system, with product flowing from the winery to a distributor/wholesaler, then to a retailer before reaching the end consumer. However, in most states, wine can also be sold directly to the end consumer, either through tasting room sales, or through wine clubs and mailing lists where delivery is typically supported through a 3PL provider such as IBG or ShipCompliant, Inc. A few states such as California and Oregon allow wineries to self-distribute directly to both on-premise and off-premise retailers.

Cholette and Venkat (2009) use an online carbon calculator to model each of these options and provide a stage-by-stage view of resulting emissions for shipping a half case of wine to both local and cross-country consumers. The tool utilized, CargoScope (Venkat 2008), considers transportation distances, mode, temperature control, utilization, and backhaul rates for each link within the supply chain. Figure 9.3 provides a comparison of some of the different options investigated both for small and long-distance consumers. Not surprisingly, cross-country transport by rail (scenario D4) is more efficient than trucking (D1), which in turn is better than air freight (D2). Direct-to-consumer small package local delivery (L4) is the most efficient, in part because the overall transportation distance is minimized and the vehicles servicing the delivery area are highly utilized because of its compactness. Making a dedicated trip to the winery in a typical gasoline-powered car (L5a) results in 80 times more emissions than the least carbon-intensive method (L4). Most local commercial delivery configurations result in lower emissions than their long-distance counterparts, but there is a notable exception: long-distance delivery via rail (D4) is effectively equivalent to the standard, local 3-tier distribution scenario (L1).

Figure 9.3 also shows that the most energy-intensive transit link is often the last one–driving to the store. This is not surprising, because other studies, such as those by Browne et al. (2005) and Van Hauwermeiren et al. (2007), find that this link can

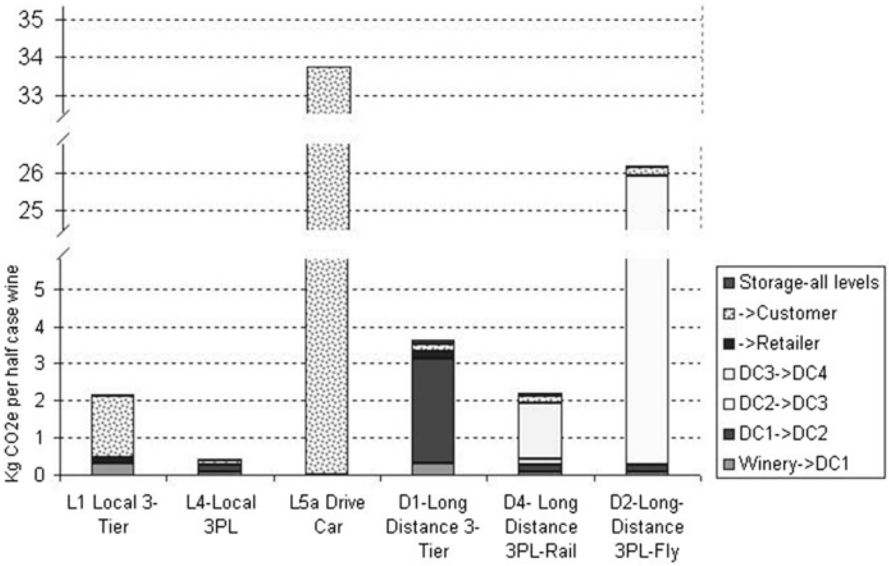

Fig. 9.3 Carbon emissions for local and long distance delivery scenario (Based on Cholette and Venkat 2009)

be the most carbon intensive even in European countries where consumers are traditionally more energy conscious than their U.S. counterparts. Because it is the least measurable and the most difficult to control, the retail-to-consumer link is typically outside the system boundary of most analyses. However, it may be worth considering the retail-to-consumer link when options include home delivery or when it may be possible to influence consumer shopping behavior. For example, if wine producers or retailers could provide incentives for consumers either to make larger purchases less often or to visit the store by bicycle, foot, or public transport, then the energy intensity of this last segment could be reduced. However, for supply chains involving multiple stages, such incentives may be impractical or difficult to implement and monitor.

Cholette and Venkat (2009) also find that no single supply chain configuration is ideal for all wineries. Large wineries that sell in volume to retailers, whereby a typical delivery would fill a reasonably efficient midsized truck, could consider self-distribution. For small wineries, where a typical delivery would fill a less-efficient light truck, 3-tier distribution would be more efficient than self-distribution. For retail store chains, the key to reducing carbon emissions can be to design their supply chain to maintain high vehicle utilization rates. For example, if a store chain moves sufficient volumes to be able to keep their fleet of delivery trucks fully utilized transporting goods to and from their distributors' warehouses, the third tier of the 3-tier distribution channel (a central warehouse for the retailer) may not be necessary, thereby saving considerable cost and reducing carbon emissions.

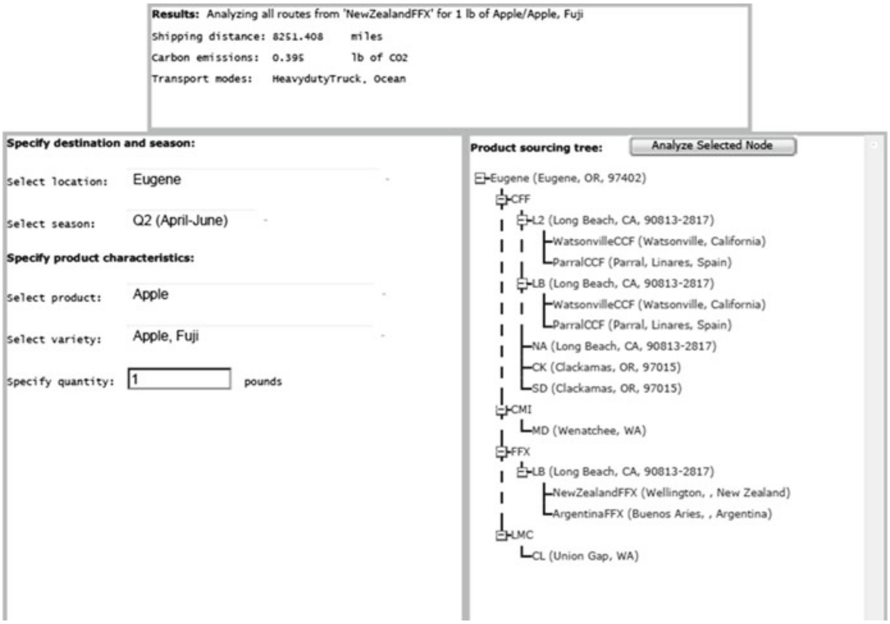

Fig. 9.4 Analysis of a supply chain for apples

Case study: an online supply chain emissions calculator

Organically Grown Co. (OGC), an Oregon-based regional distributor of organically produced fruits and vegetables, undertook a major initiative in 2008 to track the transport of every product that reached one of their three distribution centers located in northwestern United States. The company wanted to be responsive to customer requests for information about the environmental impacts of their products and to be a part of the sustainability discussion in the region.

About one third of the company's products are sourced from regional growers; the remainder are transported long distances from other states such as California and Hawaii, as well as from South America and other distant locations such as New Zealand. Transport modes include air, ocean, and land, as well as multimodal transport. Many products require temperature control during transit and storage. Products that have very short shelf lives often must be transported by air, whereas others can be sent refrigerated by ocean or land.

A web-based greenhouse gas emissions analyzer developed by CleanMetrics Corp. (2010) made use of OGC's database of thousands of suppliers and products, to compare the transport impacts of products sourced from different suppliers and locations. Figure 9.4 shows a typical result from the analysis of an international supply chain for apples, a typical crop that has a fixed harvesting cycle, which necessitates diverse sourcing in order to meet year-round demand. The destination

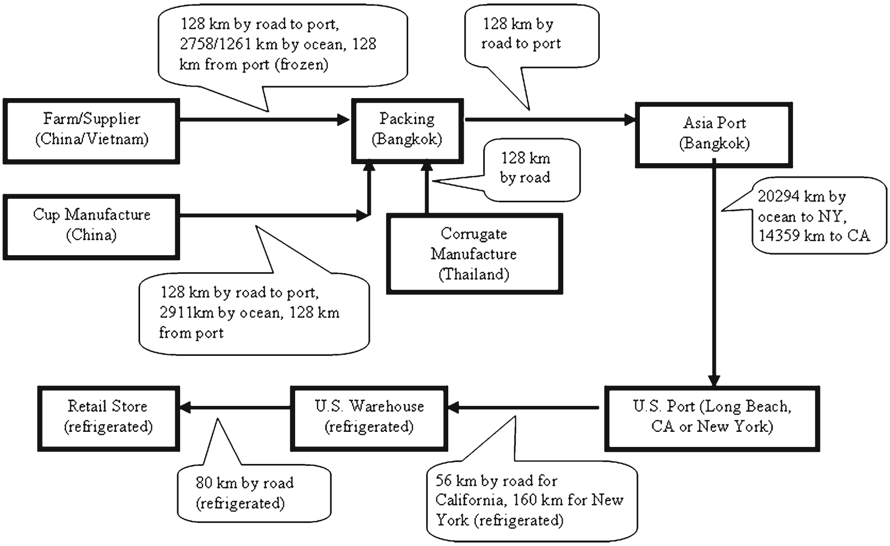

Fig. 9.5 A packaged fruit product supply chain

is a warehouse located in Eugene, Oregon, and the product is sourced from a variety of producers, ranging from growers that are local (Oregon) and regional (California and Washington) to international (Argentina and New Zealand). Results from these analyses provide OGC with visibility into product supply chains and information needed to incorporate transportation-related carbon footprint as one component of their food purchasing decisions.

Case study: an international supply chain for packaged fruit products

Sundia Corporation, based in Oakland, California, produces and distributes fresh fruits cut and packaged in plastic cups. Once packaged, the products do not require refrigeration until they are placed on supermarket shelves. This process allows the company to procure tropical fruits in Asian countries such as Vietnam and Thailand where they are grown, process the fruits close to the source location, and then ship the packaged products by ocean to stores in New York and California at a relatively low carbon cost. Figure 9.5 depicts the entire supply chain. A carbon footprint analysis of the supply chain shows that only about 30% of total emissions could be attributed to transport. The longest transport leg, the ocean segment from an Asian port to the United States, spanning 14,000–20,000 km, was responsible for just half of the transport-related emissions. The remaining 70% of total emissions came from growing, processing, and packaging the product. This is one of many recent industry examples where transport distances have not been good indicators of overall life cycle greenhouse gas emissions.

Case study: home delivery of groceries versus consumers driving to stores

Many national and regional grocery chains now offer convenient home delivery services. An example of this is the service provided by New Seasons Market in the Portland, Oregon metropolitan area. The company uses a fleet of delivery vans with the capacity to make up to ten deliveries on a single route. The vans are fueled with a blend consisting of 20% biodiesel, and they have separate cargo areas for unrefrigerated, refrigerated, and frozen goods. Deliveries are made directly from each of the company's retail stores to customers within a certain distance from that store. Customers typically place their grocery orders online and receive an estimated delivery time. Store employees shop for each customer and then load the filled shopping bags into a designated van. Delivery routes are calculated and mapped in advance using mapping and routing software such as MapPoint.

A carbon footprint study conducted by CleanMetrics (2010) for New Seasons Market compared the emissions produced by the delivery vans with the emissions that would have been generated had the customers driven from their homes to the nearest store. Using delivery data that included street addresses and delivery routes, the study calculated carbon emissions for both scenarios using actual driving distances and found that the delivery vans were more efficient by a factor of almost two. This result suggests that there may be significant potential for emissions reductions in the last leg of most supply chains where the product is finally delivered to consumers.

9.5 Putting transport emissions in context

Although transportation generally does not have the largest environmental impact in food supply chains, it can play a significant role depending on the specific supply chain and the modes of transport used. In this section, we put transportation-related greenhouse gas emissions in context by considering the major life cycle phases of food products in the U.S. food sector.

Based on food consumption and food waste data published by the United States Department of Agriculture (USDA 2008), we analyzed the typical life cycles of major food categories consumed in the United States, including meats, dairy, eggs, seafood, grains, nuts, vegetables, and fruits. This data set includes quantities of raw and processed food products delivered to retail locations, as well as percentages of food wasted at the retail and consumer levels. The analysis was conducted using the CarbonScope analytical tool (Venkat 2009). Typical cooking and waste disposal processes were assumed for the various food categories, with a standard freight transport distance of 1,500 miles by semi-trailer truck from the farm or processing facility to a typical retail location. Packaging, transport from retail stores to consumers' homes, and home refrigeration were not included in this analysis.

The results showed that freight transportation accounts for just 6% of the total carbon emissions (in millions of metric tons of CO_2e) for the food categories analyzed, indicated by the short bar in Fig. 9.6. Considering both animal-based and

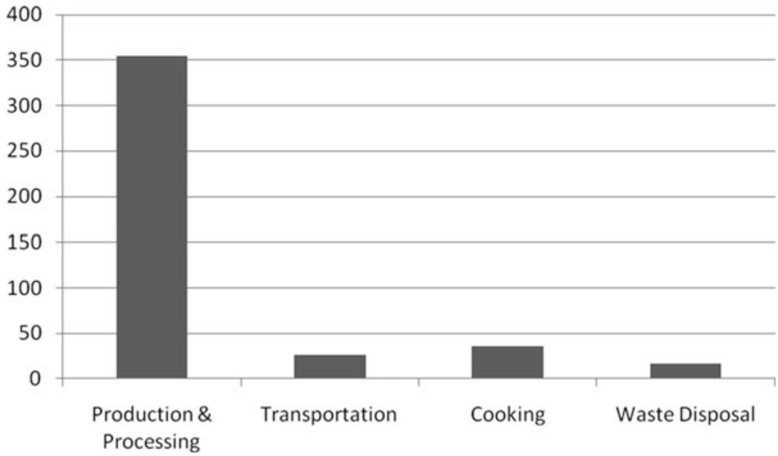

Fig. 9.6 Life cycle carbon emissions (millions of metric tones of CO_2e) for major food categories in the United States

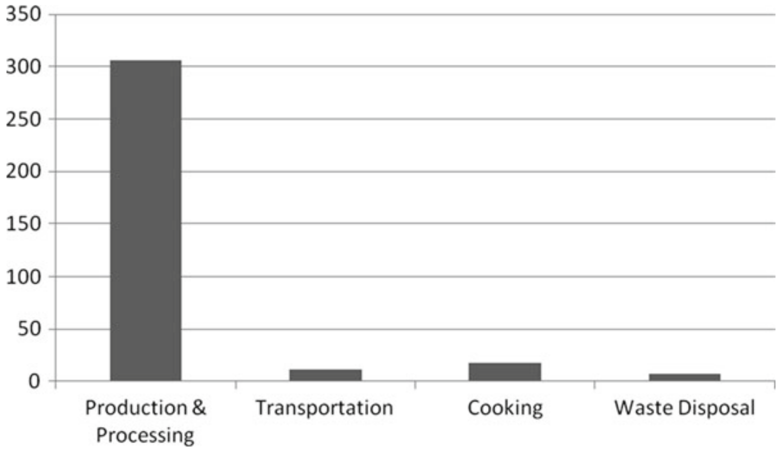

Fig. 9.7 Life cycle carbon emissions (millions of metric tons of CO_2e) for animal-based foods

plant-based foods, production and processing dominate with 81.6% of the emissions, followed by cooking, with 8.3%. Only waste disposal produces fewer emissions than transport, primarily because of the fact that more than 44% of the methane emissions from landfills are typically flared or converted to useful energy.

If we examine only the food products derived from animals (Fig. 9.7)—including meat, seafood, dairy and eggs—transportation contributes even less: just slightly more than 3% of total carbon emissions. For animal products, the high production-related carbon emissions dwarf emissions from all other factors.

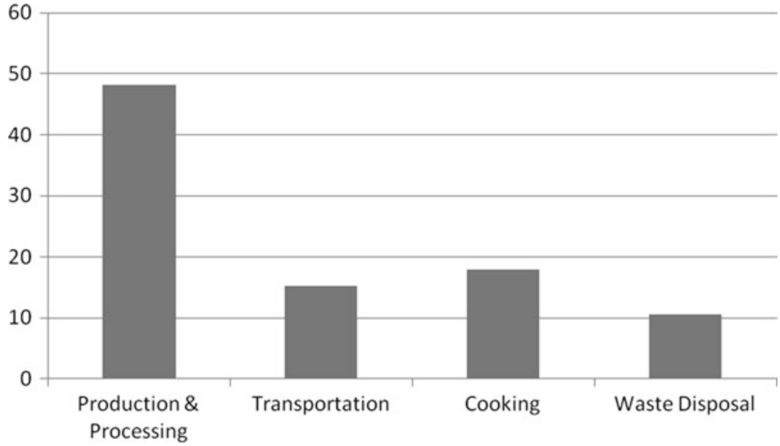

Fig. 9.8 Life cycle carbon emissions (millions of metric tones of CO_2e) for plant-based foods

On the other hand, if we consider only the plant-based products (Fig. 9.8)—including grains, nuts, fruits and vegetables—transportation contributes more than 16% of the life cycle emissions, because of the relatively low emissions from production. The preceding results indicate that the degree to which carbon emissions can be reduced by optimizing the distribution network depends on whether the food items are plant-based or animal-based.

If we replace our assumption of long-distance road transport with other distances and transport modes, the results will change significantly. For example, if air transport is used to deliver fresh imported foods from distant production locations, transportation will be a major contributor to the total life cycle emissions, regardless of production emissions. Ocean transport, on the other hand, generally produces low transport emissions per unit of freight. For foods that are imported via ocean, the road transport to and from the sending and receiving ports often generates emissions comparable to the [much longer] ocean segment, and therefore the total transport carbon emissions for ocean-related segments are likely to end up being comparable to the emissions associated with domestic truck transport for long distances.

9.6 Interactions and trade-offs

A classic challenge for supply chain managers is to strike the right balance between transportation and storage costs. Because costs and carbon emissions are correlated, Venkat and Wakeland (2006) examined the transportation and storage-related emission characteristics of a food supply chain that was adapted from Simons and Mason (2002). Figure 9.9 shows the carbon emissions per unit of final product. Venkat and Wakeland (2006) also determined the sensitivity of the total transportation and storage

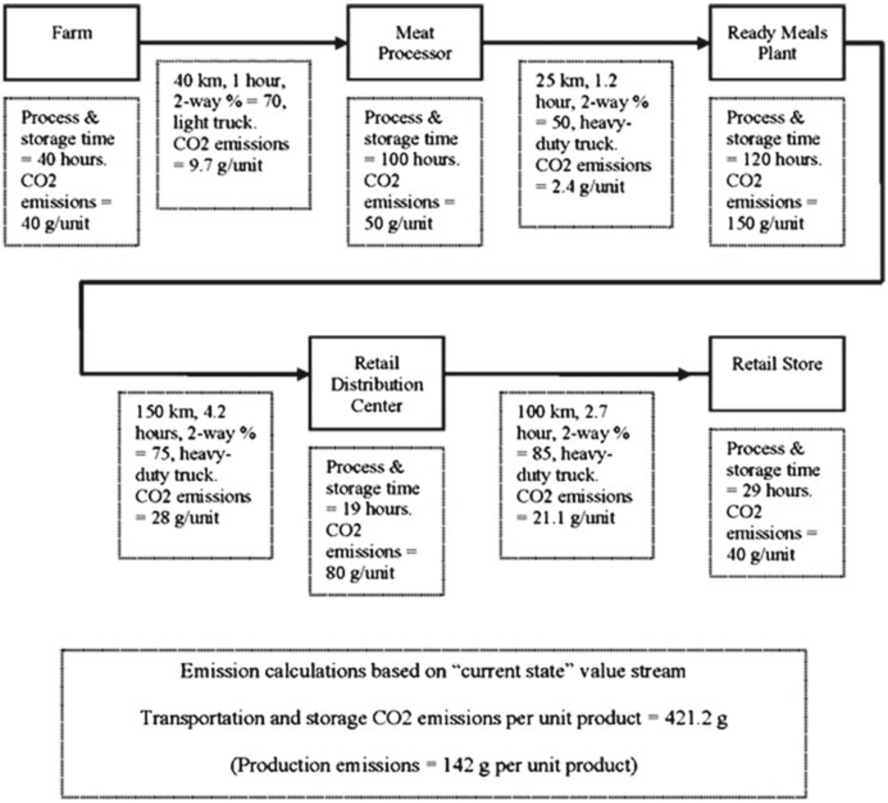

Fig. 9.9 Food supply chain-related carbon emissions (From Venkat and Wakeland 2006, adapted from Simons and Mason 2002)

emissions to the maximum distance between points in the supply chain. The total emissions would change by about 20% per 1,000 km (excluding any cold storage that might be required during transportation). Next, the impact of using a lean supply chain philosophy that emphasized small and frequent deliveries was analyzed. Results showed that for distances greater than 200 km, the increase in transportation-related carbon emissions would be greater than the reduction in storage-related carbon emissions.

Packaging design, production methods, and distribution are inherently interdependent. For example, the wine distribution scenarios explored in Sect. 9.4 consider wines bottled at the winery in standard 750 mL bottles. A case of 750 mL bottles is, by weight and volume, only about 50% product. As some wine producers shift to packaging in polyethylene terephthalate (PET) bottles, Tetra Pak, or Bag-in-Box formats, they realize energy and emissions savings by avoiding the transport of excess packaging. Recent carbon footprint analyses done for a packaging manufacturer show that from a carbon emissions standpoint, plastic is often a better material for making bottles than glass. For example, considering their full life cycle, a 360 mL PET bottle generates 41% fewer greenhouse gas emissions than a comparable glass bottle (Constar 2010). Full lifecycle includes the carbon emissions associated with transporting filled bottles to retail locations. Other winemakers have started to experiment with light-weighting (decreasing the amount of glass used in a bottle), although this can necessitate more careful handling in transport and storage. Furthermore, some wine companies have started to ship wine in bulk from Australia and bottle it in the United Kingdom, closer to the consumer market. Bulk shipping requires a firm to geographically distribute its operations and to be able to address preservation and contamination concerns. Of course, all alternative packaging formats are dependent on consumer acceptance.

9.7 Taking action

We consider what companies can do to cost-effectively reduce logistics-related carbon emissions without compromising quality and service levels. Sometimes a single project can provide a huge improvement opportunity. Jackson Family Wines recently consolidated its ten warehouses into a single energy-efficient distribution center (DC) with a rail spur connecting it to the Union Pacific Railroad. According to Bradley (2010), the new facility allowed the wine producer to stop shuttling inventory between storage locations and enabled increased usage of rail to transport its five million cases produced annually. Locating the DC near a key supplier supported the company's backhaul initiative as well: after transporting wine from the production facility to the DC, vehicles were able to pick up bottles from their nearby supplier on the return journey.

In other situations, a series of separate initiatives may be more appropriate than one large project. According to their website, by 2012 the UK-based retailer Tesco intends to reduce by half the emissions associated with delivering a case of goods. They plan to reach this goal through a variety of logistics improvements for moving goods, including switching to larger vehicles, partnering for backhaul opportunities, relying on rail for transport between DCs, and using barges to a greater extent.

A unifying factor in these initiatives is that they start with an initial study to benchmark the current system performance and to discover potential opportunities. Sometimes the results can be quite surprising, as seen in the following study. Recent research sponsored by the Oregon Transportation Research and Education Consortium (Pullman et al. 2009) compared a variety of packaging, food waste, and transportation scenarios for three food items: fresh or frozen chicken, raw potatoes, and processed diced tomatoes. These items were selected based on surveys and interviews of institutional food purchasers. Packaging alternatives consisted of waxed cardboard box versus plastic bag for chicken, cardboard versus reusable plastic container (RPC) for potatoes, and can versus plastic bag (in box) for tomatoes. Food waste scenarios considered uncooked and cooked waste that was either

Table 9.3 Example life cycle analysis of food waste, packaging, and distance

Processed tomatoes #10 can or equivalent		Transportation			
		Local (within 100 miles)		Major distributor	
		Packaging		Packaging	
		A	B	A	B
		Can (recycled)	Bag-in-box	Can (recycled)	Bag-in-box
Food waste (disposed before or after cooking)	None	1.56	1.39	1.61	1.44
	50% Compost, before cooking	2.22	1.89	2.38	2.00
	50% Landfill, after cooking	4.09	3.76	4.20	3.86

From Pullman et al. (2009)

partially composted or 100% landfilled. Transportation alternatives included local versus long distance and fresh versus frozen.

For each scenario, full life cycle carbon assessments were done to determine the embodied carbon (the total greenhouse gas emissions generated by the product life cycle within a system boundary of interest and reported in kg of CO_2e). The CarbonScope analytical tool (Venkat 2009) was employed to do the analysis. The primary standard used for the product life cycle greenhouse gas emissions calculations was PAS 2050 (BSI Group 2008). PAS 2050 relies on the ISO 14040 series of standards (International Standards Organization 2009) and the 2006 IPCC Guidelines for National Greenhouse Gas Inventories (Intergovernmental Panel on Climate Change 2009).

Pullman et al. (2009) conclude that food waste has a large adverse impact on the environment (especially if landfilled, as is often the case with cooked vegetables and meats); an unexpected finding that can be easily acted upon. Even raw vegetables that are composted rather than consumed increase carbon impact (see Table 9.3). Institutions may want to consider policies to encourage the use of packaging that reduces food waste (both before and after cooking). Similarly, “buy local” efforts for the three products evaluated earlier would make sense and would contribute to carbon reduction. Transportation-related carbon impacts were the most significant for frozen meat items.

Overall, “food miles” do not matter as much as other considerations when determining the carbon impact of food production, consumption, and disposal (except perhaps for fresh food that is air freighted). Minimizing food waste and composting the unavoidable food waste could have a much larger benefit than switching from a distant supplier to a local supplier. Also, when analyzed carefully, one must conclude that plastic packaging generally has a smaller environmental footprint than steel, paper, or glass, because of its low volume (thinness) and light weight. Considerations may, however, be required on other health impacts of plastic packaging (e.g., physiological impacts on animals who consume plastics in landfills, etc.).

As we have seen from previous examples, items transported by highly utilized larger trucks result in lower emissions per unit than when transported in smaller vehicles. Such operational realities have led some analysts to posit a natural ecology of scale must exist. Schlich and Fleissner (2005) provide examples of how the international sourcing of juices and lamb is less energy intensive on a per-unit basis than the local (German) equivalent. They calculate that energy and cost savings arise from large-scale production and distribution, as well as from the comparative natural advantages some countries have in growing or raising food. For example, Brazil's climate is naturally more conducive to growing fruit than the climate in most of Europe, and Brazilian juice production typically occurs on a much large scale than European producers are able to support. Consequently, Schlich and Fleissner (2005) found that the lower emissions owing to producing juice in Brazil rather than Europe more than offset the transportation-related emissions associated with transporting the juice from Brazil to Europe. Such analyses tend to be controversial, in part because the answer is not what many people expect. Also, these results do not mean that local production can never compete with long distance sourcing regarding energy use and carbon emissions. The key is for local operations to find ways to be efficient and to achieve the economies that tend to be associated with large scale operations. Local production also provides other benefits that are not as easily incorporated into analyses, such as local employment, rural conservation, and consumer trust in origin and local brands.

It is not necessarily the case that only giant conglomerates can be highly efficient. It is possible for smaller firms to mimic the efficiency of larger entities. For example, farmers in European wine regions have often formed cooperatives for the production and marketing of their products. Indeed, Schlich (2010) documents the Hessische Bergstraße cooperative within the Rhine Valley, which is comprised of more than 500 family-owned vineyards. Despite the small size of these individual winemakers, the Hessische Bergstraße cooperative coordinates production and distribution in a way that allows these farmers to capture efficiencies of scale normally associated with a much larger producer.

When aggregation occurs even further downstream in the supply chain, producer collectivism is not required. The following example explores how the logistics needed to support California farmers' markets could be improved, while preserving the small scale and independent nature of both the farms and the markets. Such improvements will not only yield financial benefits, but will also improve the energy intensity associated with bringing these products to consumers.

The proliferation of farmers' markets in the last few years has been a boon to consumers looking to purchase fresh, locally grown fruits and vegetables. Worthen (2010) documents that California now has more than 500 markets, which are attended by nearly 3,000 farmers. However, this growth in the number of markets has negatively impacted many farmers, who report having to make multiple trips to visit more markets in order to sell the same amount of produce. Jog (2010) profiles Schletewitz Farms, one such fruit producer located near Fresno, California, that sells year round to nine greater Bay Area markets, each 200–350 km away. Such distances are typical, as many of the certified market suppliers are located in the Central Valley, whereas most markets are found in population centers closer to the coast, as seen in Fig. 9.10, which depicts a representative subset of farmers' markets and the farms that service them. Likewise, a map of vendors found at the Jack

Fig. 9.10 Subset of farmers' markets, farms and candidate DCs (From Jog 2010). The Northern DC belongs to Safeway. The other DC represents a plausible consolidation point for Central Valley Farmers

London Square Farmers Market in Oakland shows that farmers come from as far north as Yuba City and as far south as San Diego, almost 800 km away (Jog 2010).

On a per unit basis, supply chains relying on extensive use of small capacity vehicles are likely to be less energy efficient than their larger-scale counterparts. To illustrate this, we consider Sanger Farm, a regular vendor at the San Francisco Ferry Market. We assume that they nearly fill (90%) a large pickup truck with produce and that they are able to completely sell the produce at the market (a best-case scenario). Using CargoScope, we calculate that the round-trip journey to transport the produce from Sanger Farm to San Francisco results in .45 kg CO_2e emitted per kg of produce.

We next consider a neighboring farm that may sell high volumes of produce through a supermarket such as Safeway. In this supply chain scenario, a midsized commercial truck (which has about ten times the capacity of a pickup truck) would

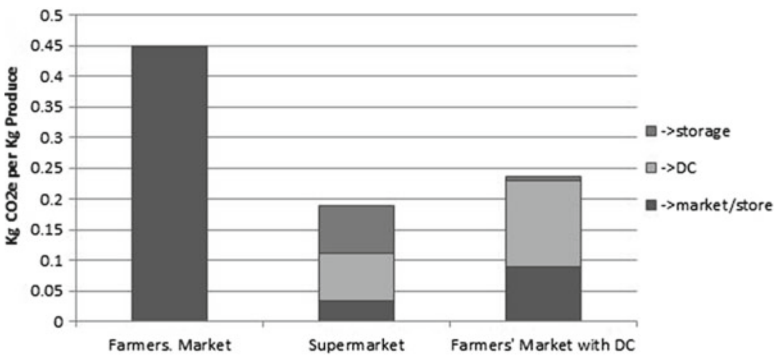

Fig. 9.11 Emissions from farm to retail for different sales channels (calculations performed using CargoScope)

transport produce from the farm to the Safeway DC in Tracy, where it could be placed in cold storage for a period of time. The produce would then be transported by a similar truck to a Safeway store in San Francisco, where it could take up to a week to be sold. Considering typical supermarket volumes and dwell times, we assume 90% utilization rates for both trucking links, and determine that .19 kg of CO_2e is emitted for the transport and storage of 1 kg of produce from farm to retail gate. The farmers' market produce may be fresher and have other ecological benefits, but its carbon footprint is more than twice that of the comparable supermarket produce. This difference would be even greater if the dwell time at the DC were reduced for the supermarket-bound produce, because refrigerated storage contributes significantly to emissions. Figure 9.11 compares the transport and storage-related carbon emissions for the two preceding distribution scenarios and a third scenario discussed next.

We finally consider modifying the farmers' market supply chain to include a consolidation DC that is near an interstate highway, but still relatively close to many Central Valley farms (such as in the vicinity of the small town of Cantua Creek). Rather than individually driving their produce across the state to farmers' markets in the Bay Area, participating farmers would deliver produce to the DC, where it would be stored for a period of a few days and then consolidated into midsized commercial trucks, each destined for a particular farmers' market. Market stalls could be staffed by employees of the DC or individuals hired at the local markets Assuming the same high utilization rates would hold, Fig. 9.11 shows that this newly designed supply chain would be much less carbon emissions intensive, approaching the relatively low levels of emissions provided by the supermarket supply chain.

Jog (2010) explores the potential for a farmers' market consolidation DC at a regional level. Although it would be impractical to gather historical sales data for every farmer at every market, Jog creates a simplified approximation by modeling the underlying network, which includes 135 Bay Area markets and more than 1,000 farms that sell produce at these markets. Jog's analysis treats the farms within a given zip code as a single larger farm that is equivalent in volume. The result is slightly more than 200 equivalent farms. Using this approximation tends to slightly underestimate the total travel distances. Considering one type of undifferentiated produce, assuming uniform production rates for each of the equivalent farms, and classifying each market into one of three sizes, Jog models this network as a transportation problem. The optimization problem was to find the minimum total travel distance that could meet the market demand.

Without a consolidation DC, nearly 400 trucks would be needed to supply the markets over the course of a week, with an average round trip of slightly more than 200 km and a total travel distance of 84,000 km. It should be noted that this optimal solution greatly understates actual transit, as farmers typically travel more than 300 km per trip and visit several markets per week. In this minimized solution, farmers would visit only two or three markets per week, and markets would have at most a few vendors. Of course, such a lack of diversity would be counter to the mission of a farmers' market.

Next, Jog adds the Cantua Creek consolidation DC to the model and finds that the optimum in this case occurs when nearly 60% of the produce is routed through the DC, which reduces the overall distance traveled by 20%. Furthermore, market diversity would be supported, because trucks arriving to the market from the consolidation DC would carry produce from multiple farmers, a benefit for small-scale farmers who produce specialized products. Such farmers would be able to reach more consumers than is currently possible, because it would be economically feasible to ship fractional truckloads of their goods to different markets by consolidating them with goods from other small-scale farmers.

Of course, the reality of funding and implementing such a consolidation DC, supporting transport from the DC to the markets, and arranging for staffing would be much more complex than building models and calculating potential benefits. Perhaps the DC could be created by the farmers as a cooperative, with collaborative staffing and support, as well as partnerships with organizations such as the California Federation of Certified Farmers' Markets. Alternatively, the DC could be created as a joint venture funded by a major reseller. Another option might be to allow produce to be sold at the DC or the market on a consignment basis. At present, California farmers' markets allow only direct producers. The concepts described above would tend to reduce consumer contact with growers, which has been one of the primary benefits of farmers' markets. However, the current trend toward more and more farmers' markets, without corresponding improvements to the underlying support structures, will not be sustainable in the long run for most small family farms and could ultimately deter participation of just the sort of vendors these markets were created to showcase.

9.8 Conclusion

The transportation-related carbon footprint varies from a few percent to more than half of the total carbon footprint associated with food production, distribution, and storage. Supply chains are complex and varied, and food supply chains are especially challenging because of seasonality, freshness, spoilage, and sanitary considerations. Measuring transportation-related carbon footprint involves careful choice of the scope of the analysis, and there is much uncertainty in the results. Caution is warranted regarding the absolute numbers from carbon assessments, so it may be best to focus primarily on relative comparisons.

The winemaker case study showed that a local 3PL approach had the lowest carbon footprint, and that the highest carbon footprint resulted from consumers driving to the winery. This does not mean, however, that local 3PL would be the best solution for all wineries. The case study involving organic fruit and vegetable supply showed how food carbon data can be provided to consumers in order to support their food purchasing choices, and the case study regarding packaged fruit indicated that transportation distances are not always a good indicator of total carbon footprint. Another case study indicated that home delivery can cut the transportation-related carbon footprint almost in half compared to consumers driving to the store individually.

Supply chain planners must carefully consider the trade-off between transportation-related energy cost & carbon footprint and storage-related energy cost & carbon footprint. Also, the frequent small deliveries called for by lean manufacturing practices, although optimizing efficiency within a facility, can increase overall carbon footprint. Packaging is another important consideration, and the use of plastics rather than glass tends to lower carbon footprint. Benefits for the environment and health are further accrued by plastic recycling.

To reduce carbon footprint, suppliers are consolidating their operations, increasing their use of rail and water transit, and increasing transport efficiency by filling trucks and considering backhaul opportunities. Food waste is another potentially significant contributor to carbon emissions, which could potentially be reduced via alternative packaging options. Our research also indicates that food-miles, a metric that many consider to be of primary importance, do not actually correlate very well with overall carbon footprint. Finally, although farmers' markets have many desirable attributes, they unfortunately tend to have a much higher carbon footprint than conventional food distribution. This differential could be lessened considerably by using consolidation DCs close to the farms.

Whether comprising a large or small share of a product's total emissions, transportation is an unavoidable step in the supply chain for nearly every food product. However, the economic and environmental impacts of food transportation can be moderated. We reiterate that although food transportation decisions can sometimes be considered separately from other issues, this is not always appropriate. Food transportation and storage involves trade-offs that necessitate taking an overall system perspective.

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