A Supply Chain View of Product Carbon Footprints: Results from the Banana Supply Chain

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Abstract

Interest in the use of Life Cycle Assessment (LCA) to measure the carbon footprint of products has increased in recent years. While issues have been raised regarding the use of LCA to measure carbon footprints, the difficulties of doing so in the context of a modern supply chain have received less attention. In this paper we present a case study of the carbon footprint of bananas done in partnership with a leading importer of bananas and a U.S. retail grocery chain. Issues related to data quality and access represent a significant hurdle in measuring the carbon footprint across a supply chain, and we analyze our results in the context of ownership of the supply chain through the use of the GHG Protocol's concept of emission scopes. Sharing information between supply chain partners has been promoted as one method of resolving data issues, but raises important issues related to supply chain variability. Through an analysis of the impact of transportation we show how the structure of a supply chain introduces significant variability in the carbon footprint required to serve different customers.

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Introduction

Growing interest in the role of consumers in reducing greenhouse gas emissions has led to a number of programs designed to measure the emissions "embedded" in products, known as the product's carbon footprint. In 2007 Wal-Mart announced an initiative to audit the carbon emissions of seven product categories throughout it supply chain (*1*). In 2008, U.K.-based retailer Tesco began a process of labeling more than 100 products with carbon footprints (*2*). The demand for this information has lead a number of government and non-government agencies to set forth proposals for measuring carbon footprints(*3*). As companies work to measure their carbon footprint to support these programs it has the possibility to spur changes throughout the entire supply chain (*4*).

Several recent studies have noted the importance of agriculture to total emissions and applied LCA to measure the carbon footprint of a range of food products (*5–10*). Food represents a significant opportunity for consumers to reduce their carbon footprint given it's large impact, high degree of personal choice, and lack of lock-in effect that prevents making choices (*11*).

This study involves the cooperation of Chiquita Brands International (CBI), a leading international distributor of fruits, and Shaw's, a New England-based grocery store chain, to measure the carbon footprint of bananas. Bananas represent a significant import in the United States, with nearly 10 billion pounds imported in 2010 (*12*), and a challenging supply chain that requires getting the products to market from Central and South America in a timely manner under temperature control. We present the results of this study and discuss implications for measuring the carbon footprint of products for companies in a supply chain.

Methods

Objective and Functional Unit

The objective of this study is to measure the carbon footprint of bananas sold by CBI in North America. The process involved collecting data regarding CBI's supply chain for bananas from the acquisition of materials forward to delivery to customers, typically grocery store chains. An additional partner, Shaw's, was able to provide data regarding supply chain activities for bananas once they have reached retail chains. Together the two companies' supply chains capture the life cycle of the banana from its production at the farm through to final sale to the end consumer. The supply chain data was used to construct a model using the SimaPro LCA software tool with process data provided by the Ecoinvent LCI database.

The primary functional unit for this study was a single box of bananas delivered to a retail outlet. A typical box of bananas delivered to a retail customer consists of a cardboard container box, a plastic shroud wrapping the bananas, and approximately 18.14 kg (40 lbs) of bananas. Boxes were chosen as the functional unit since it is a common measure for quantity throughout the supply chain and represents the individual unit for transactions between CBI and their retail customers. While bananas are sold in box units to retail customers they are usually sold to end consumers by weight. For this reason 1 kg of bananas sold to the end consumer is considered to be a secondary functional unit. This functional unit is based on the assumption of 18.14 kg of bananas per box. When presenting results to consumers this may be the preferred functional unit as it represents the manner in which the product is purchased (*13*).

Description of Supply Chain

Bananas sold in North America by CBI are typically grown in Central and South America. CBI works with a network of owned plantations, independent growers, and wholesalers at more than 200 locations, primarily in Guatemala, Honduras, Panama, and Costa Rica (referred to generally as "the tropics"). Though practices may vary from farm to farm, banana cultivation typically involves the application of fertilizers, pesticides, and fungicides via manual and aircraft spraying. Once the bananas approach ripeness they are picked, inspected, washed, and packaged for transportation primarily through manual labor in packing stations located at the farms. The bananas are shipped from the packing stations by truck to the outbound ocean port. In transit and at port the bananas are kept cool in refrigerated containers or bulk storage until loading on a ship for ocean transportation.

The bananas continue to be refrigerated by container or in bulk refrigerated holds during the ocean voyage. After arriving at the destination port the bananas are unloaded from the ship and stored near the port until pickup. Customers may pick the bananas up at the ports themselves, arrange for CBI to deliver them to their facility, or CBI may take them to their own distribution centers (DCs). Upon reaching the DC the bananas undergo a chemical ripening process in a temperature controlled environment that lasts three to four days. At the end of this process the bananas are ready for sale and have a limited shelf life before over ripening. From the DC, bananas are shipped either directly to retail outlets or first to a customer DC and then to the retail outlets. At the retail outlets bananas require no special handling or care such as refrigeration. They are a fast moving product, with most bananas typically being sold within a day of arriving at the store.

In addition to the primary packing of the cardboard box and plastic shroud, secondary packing materials include cardboard corner board pieces used to help secure boxes of bananas and reusable wooden pallets used to hold the boxes of bananas during distribution. Though CBI supplies the cardboard and plastic shroud used as the primary packaging for the bananas, the retailers who purchase bananas from CBI dispose of these materials.

A number of different chemicals are required to produce and ripen the bananas. Chemical fertilizers, fungicides, and pesticides are applied at the farm to help with cultivation. The bananas are picked before ripening and kept refrigerated during transportation. The refrigeration requires production and use of refrigerant gases, many of which are powerful greenhouse gases. Just before sale the bananas are chemically ripened in ripening rooms using ethylene gas, an organic compound that can be used to force fruits to ripen. The ethylene is purchased in liquid form and then applied to the bananas via air circulation within specially designed ripening rooms.

System Boundary

The system boundary chosen for this project is shown in Figure Figure 1. Sources of emissions considered for analysis include: production of chemicals and packaging materials, production at the farm, transportation and distribution of bananas from the farm through to the retail outlet, disposal of packaging materials, emissions due to leakage of refrigerant gases, and the production of N2O at the farm due to application of nitrogen-based fertilizers. The following activities have been excluded from the system: all activities related to the use phase of the end consumer, including transportation, use, and disposal of any remaining organic matter; infrastructure, capital goods, and durable products such as pallets, roads, ports, buildings, and vehicles used during production and distribution; biogenic emissions from the decay of the organic matter are excluded and likewise no credit is provided for any greenhouse gases sequestered in the product during growth; office buildings and other support activities not involved in production and distribution (estimated to attribute approximately 0.1% to the total carbon footprint); all activities related to employees, including commuting and food provided on site; and price tags, product stickers, and other small items estimated to have an impact of less than 1% of the total. Rejected bananas that do not meet quality standards during the packing process are considered a byproduct. All emissions from production are allocated to the sold bananas, while further processing of the rejected bananas into products such as purees are excluded from the system.

Impact Assessment

All impacts were assessed using the 2007 IPCC 100 year GWP method. This method provides a single measure, the estimated contribution to climate change as represented by the amount of CO_2e attributable to the system. All impacts were calculated using the IPCC 2007 GWP 100a version 1.01 method in SimaPro with the “exclude infrastructure option” selected.

Data Quality

Data for this project was collected from two primary sources, CBI and Shaw’s. Where primary data was not available secondary sources were used, including published reports, specifications, studies, and the Ecoinvent LCI database. Primary data was collected for a significant portion of the supply chain through the involvement of CBI and Shaw’s. The primary data collected consisted of utility records, transportation data, fuel purchase information, sales data, and performance data

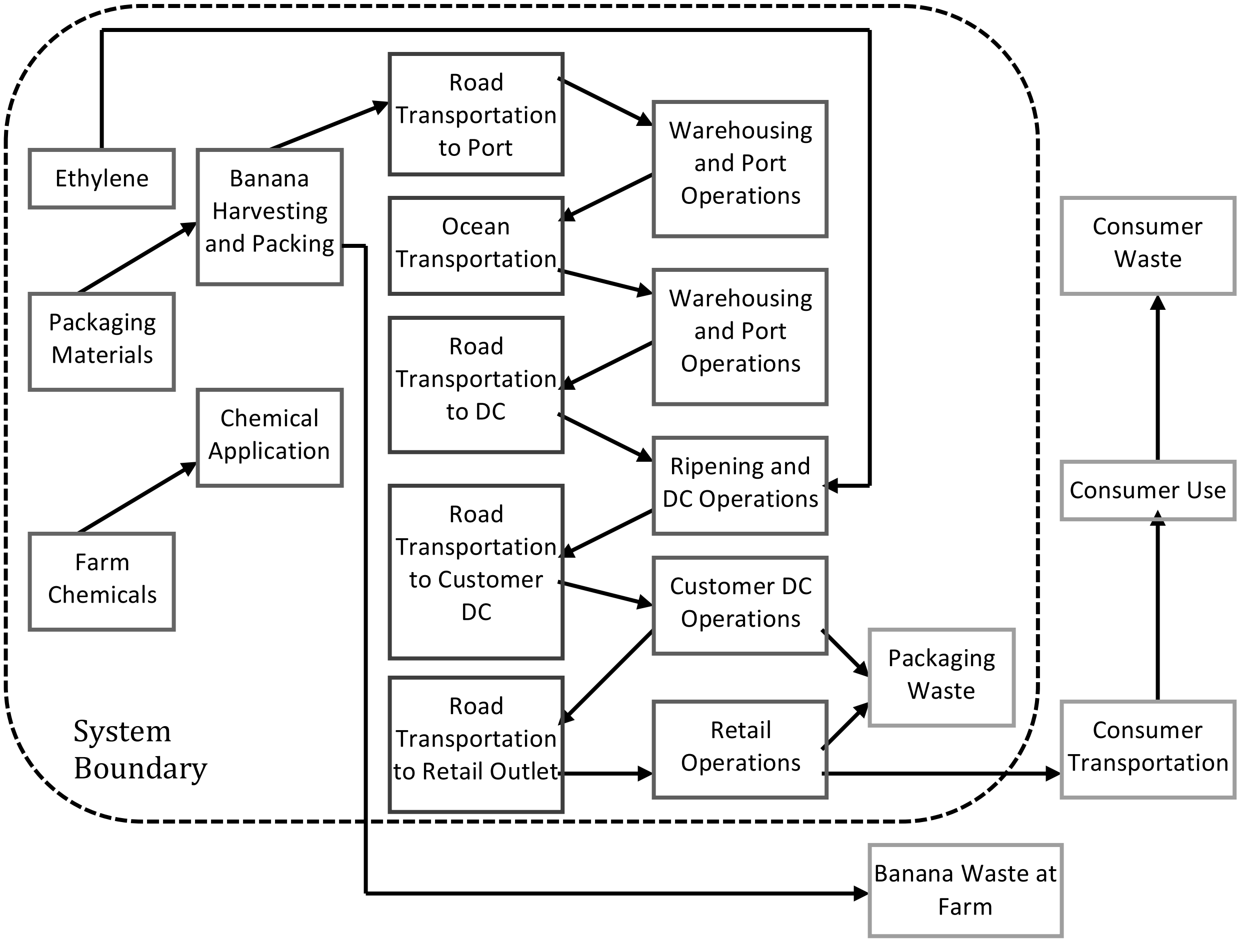

Figure 1: System Boundary

such as farm yields. For packaging materials purchased by CBI, specification regarding the amount and types of materials were provided. For chemical usage, CBI and Shaw's provided information regarding ethylene consumption, and CBI's agricultural division provided recommended quantities per hectare of farm chemicals. CBI provided refrigerant information based on data from maintenance records. Secondary data sources were used for specification on secondary packaging such as cardboard corner board, plastic banana wrappers, and plastic ethylene bottles. All processes were modeled using secondary data from the Ecoinvent database in SimaPro.

The intended time period for data collection was the full calendar year for 2009. Specific cases where the data was not collected for this time period include: Data related to customer transportation and energy consumption is based on the year 2007. Ocean transportation cargo data is based on a set of voyages during 2009, approximately two to three weeks of data. Fuel information and travel distances were collected for the full year and were found to be consistent with the subset of voyages for which cargo data was also available. There were no special circumstances or changes in the supply chain known that would indicate the collected data was not representative of the intended full year 2009 timeframe.

Where possible, data has been collected for all of CBI's operations in order to provide a representative picture of their specific supply chain. The data is intended to model operations where CBI manages transportation and distribution from the port through to the customer DC. Areas where the data collected may not be representative include farm operations, port operations in the tropics, and customer operations. Data for farm operations was gathered for only one of six primary growing regions in the tropics, data regarding port operations was provided for only one of three ports in the tropics region, and data was provided by only one customer in the United States.

Results

The end result of this study was an estimated carbon footprint of approximately 17 kg of CO_2e per banana box. When calculated for the secondary functional unit this results in approximately 1.0

kg of CO_2e per kg of sold bananas. All numbers are based on an average scenario. A breakdown of the carbon footprint is shown in Figure Figure 2.

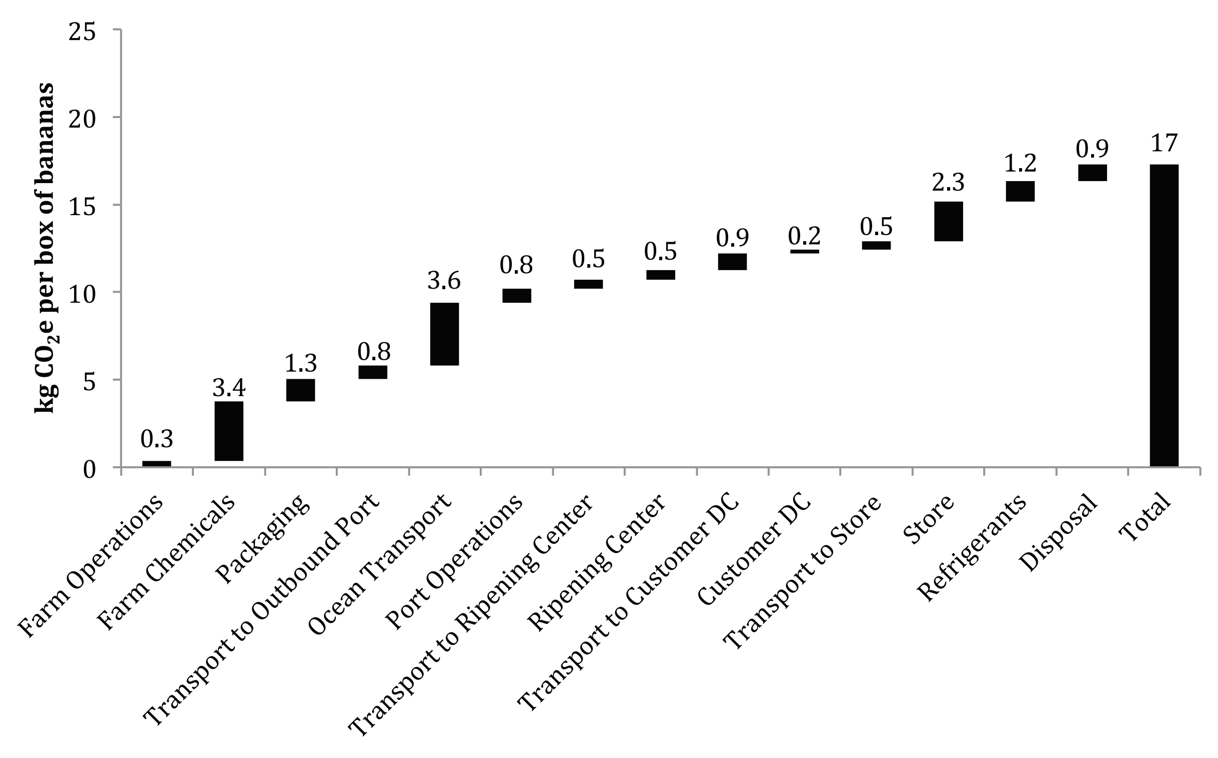

Figure 2: Carbon Footprint Summary

Rather than view the emissions by where they occur in the supply chain, it is also useful to see the types of activities that generate the most emissions. Figure Figure 3 shows the distribution of emissions based on the major activity categories.

Transportation

Transportation as a whole represents the largest share of supply chain emissions, and the single largest source is due to ocean shipping. Bananas are brought to market in dedicated vessels that are smaller than the usual large container ships used for transoceanic freight. The higher emissions of CBI's ocean operations is attributable to a number of factors, including smaller vessels, lower utilization on the backhaul, and higher sailing speeds. Cargo on the backhaul portion of the voyage represents only 22% of total tonnes shipped, and can be as low as 7% for certain rotations. The

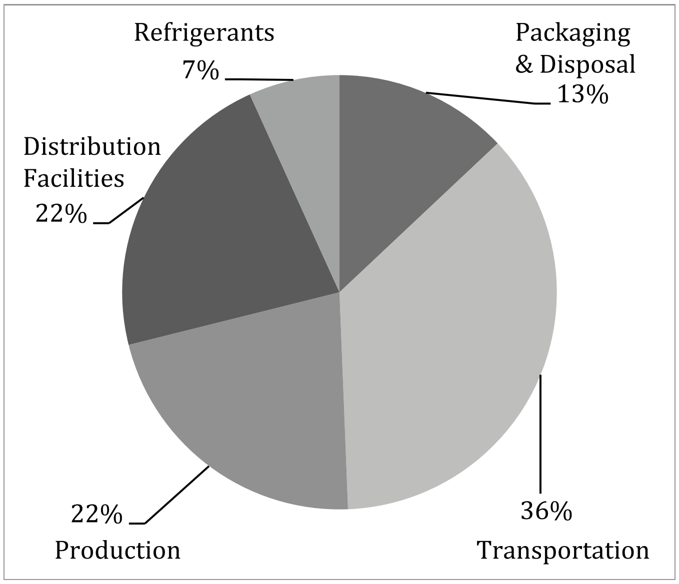

Figure 3: Carbon Footprint by Category

need to get bananas to market as quickly as possible in order to maintain quality and freshness results in higher emissions due to the relationship between vessel speed and fuel consumption. If changes in ocean shipping operations could produce efficiencies similar to the standard Ecoinvent assumptions for transoceanic freight this would produce a large reduction in emissions, reducing the total carbon footprint to 14 kg.

Production

Emissions related to producing bananas are primarily driven by the use of fertilizers, pesticides, and fungicides, and in particular nitrogen-based fertilizers. Production of nitrogen fertilizer accounts for 2.2 kg of the total 3.8 kg when emissions from its production and related N_2O are accounted for. The emissions from operating the packing stations and powering the farms represent only 5% of the total emissions related to production, due in part to the widespread use of manual labor.

Packaging

Emissions from production and disposal of packaging materials accounts for 12% of the total carbon footprint . This is almost entirely due to the production and disposal of the cardboard box, which represents more than 90% of the total emissions from all packaging materials.

Distribution Facilities

The single largest source of emissions among distribution facilities is the retail store. Though total emissions from the store are generally lower than in the various distribution centers, the lower level of efficiency per unit of product leads to higher emissions. Activities at the inbound and outbound port represent only a minor portion of distribution emissions.

Refrigerants

The production and escape of refrigerant gases combine to produce 7% of the total carbon footprint, mostly due to the escape of refrigerant gases in cooling equipment. The results may be surprising given the small amounts of refrigerants lost through leakage–less than one gram per box–but the high GWP of some of the gases produces large amounts of CO_2e. Recent efforts to use less potent greenhouse gases in refrigeration equipment have shown potential for a large reduction in the impact from refrigeration.

Discussion

Two previous studies have attempted to estimate which life cycle emissions fall under various GHG Protocol scopes. Using an input-output analysis for all 491 sectors of the U.S. economy, Matthews et al. (*14*) found that for the average sector only 14% of emissions are scope 1 and 12% are scope 2. Huang et al. (*15*) also apply the EIO-LCA method to estimate the upstream scope 3 emissions for a variety of industry sectors as a percentage of total emissions. Their results show that the share of upstream scope 3 emissions usually falls in the 70-80% range, but can be as little as about 5% in industries such as power generation. Applying a similar concept to the results of this study, but also including the downstream portion of the supply chain, we classify the share of emissions of each scope for CBI as shown in Figure Figure 4.

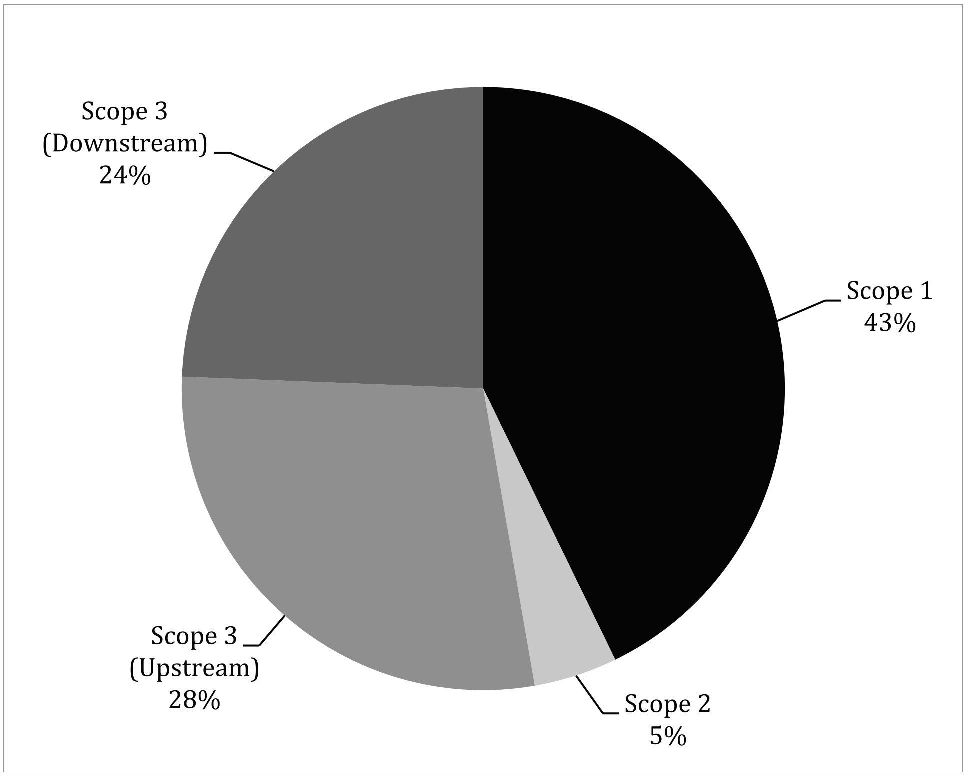

Figure 4: Share of Emissions by Scope

Despite high levels of visibility and control of the supply chain, a large portion of the emissions occur as scope 3 emissions outside of CBI's control. Collecting data across organizational boundaries presents issues with proprietary and confidential information, data accuracy, and a lack of representative data (*16*)(*17*). The accessibility of data is considered a serious issue in LCA (*18*), and the lack of representative data may result in unreliable results (*17*). One possible method for improving the data quality in carbon footprinting is to collect specific process-based data directly from suppliers.

Both the GHG Protocol and Carbon Trust have proposed using a business-to-business (B2B) sharing arrangement to provide information to supply chain partners. The Carbon Trust carbon label program has certified more than £2 billion in consumer products and £1 in B2B products (*19*). B2B labeled products employ a cradle-to-gate system boundary that stops when the product arrives at the customer's door, and downstream emissions are excluded. This is intended to facilitate the sharing of information in the supply chain. By providing the cradle-to-gate carbon footprint to downstream customers, incremental additions to the carbon footprint can be added at each stage of the supply chain until sale to the end consumer (*20*). If the producer of the final product to the end consumer then accounts for the use and end-of-life phases this approach can cover the entire life cycle of the product. The GHG Protocol Scope 3 standard explicitly allows for use of supplier data in both the value chain and product standards (*21*, *22*). The use of actual supplier data has several benefits, including increased transparency, better reflection of changes in emissions due to efforts to reduce emissions, and more effective tracking and reporting of GHG reduction goals (*21*). In their analysis of upstream emissions (*15*) showed that firms can capture a significant portion of their upstream emissions by collecting data from only a limited number of direct suppliers. While sharing carbon footprint information with downstream supply chain customers has the possibility to improve the results of a supply chain carbon footprint measurement, it poses a challenge related to variability within the supply chain.

If carbon footprint data is to be shared between supply chain partners it is important to understand how variability in the supply chain affects the carbon footprint. The importance of variability within the system has been identified in both the supply chain and LCA literature on carbon footprinting. (*23*) identifies variability within the supply chain as one of the problems with trying to calculate product level carbon footprints. (*24*) identifies several types of variability within LCA, including variability between sources, which may arise due to differences in processes. The aggregation of emissions in the inventory analysis of an LCA can cause the loss of certain variability characteristics (*25*). Including these uncertainties in the results of an LCA have been recognized as an important factor in improving the use of LCA as a decision making tool (*26*). If customers plan to use the carbon footprint information shared by suppliers in their sourcing decisions then this variability must be accounted for in the measurement. (*8*) noted that the spatial and temporal uncertainties, including differences in distribution, make measuring the carbon footprint of a food product particularly complex.

To demonstrate this issue we consider the variability within the banana supply chain through an analysis of the role of transportation required to deliver the product to specific customers in the United States. Previous work has shown that a focus on food delivery miles is generally less important in reducing emissions than food choice (*11*). Thus, a focus solely on the emissions from transportation is shortsighted. However, given the high impact of transportation in the supply chain for bananas, delivery distance can represent a key area of variability in the carbon footprint. The variability is introduced in two ways.

First, the bananas are brought to the U.S. on one of three ocean services: dedicated service to the West Coast, dedicated service to Port Everglades, and a combined service that alternates between Wilmington and the Gulf Coast. Each service achieves different levels of efficiency due to differences in average shipment size, backhaul utilization, and distance traveled. As the ocean voyage represents the single largest aspect of the carbon footprint, the variability between the different shipping rotations, due to both distance and relative efficiency, has a significant impact on the calculated carbon footprint. The differences in service efficiency and distances create a range of emissions required to serve each port ranging from 2.2 kg of CO_2e per box at Gulfport to 6.7 kg for service to the West Coast, with an overall 3.6 kg of CO_2e per box average.

Second, once bananas reach port in the United States the bananas must be distributed to customers located throughout the country. To do so the bananas move through a distribution network that includes the five destination ports, ten ripening centers, and finally on to more than 250 retail customer locations. A map showing the locations of the various facilities is shown in Figure Figure 5.

Though emissions from distribution within the United States are on average lower than the ocean voyage they involve a considerably higher amount of variability. Some customers, such as those located near the inbound ports and DCs, require a negligible amount of trucking, while others requires thousands of miles of travel to receive delivery. When combined with the variability required to reach the port, this results in a range of values for the carbon footprint of a box of bananas delivered to different customers, variability that is not captured through the use of average carbon footprint values. To illustrate this variability we have calculated the cradle-to-gate carbon footprint for each customer location that CBI delivers products to. The carbon footprint consists

Figure 5: Map of Facility Locations

of all emissions up to delivery at the customer's DC, as well as the estimated emissions from the disposal of packaging material. We refer to this as the B2B carbon footprint, as calculated in this manner the retail customer would be able to calculate the emissions of their own operations and add them to the value supplied by CBI to get a total carbon footprint. This ability to do incremental additions is at the core of the business-to-business label idea used by the Carbon Trust.

The average B2B carbon footprint calculated in this manner is 14 kg CO_2e per box delivered to the customer. This B2B carbon footprint value includes all of the activities shown in Figure Figure 2, except the activities of the retailer, consisting of the Customer DC, Transport to Store, and Store stages. Though the mean B2B carbon footprint is 14 kg CO_2e, the standard deviation is 1.4 kg CO_2e and the actual value ranges from 11 to 18 kg of CO_2e based on the actual path required to reach a specific retail customer location. When the 3 kg CO_2e contributed by the retailer's operations is added to the B2B carbon footprint this produces a range of 14 to 21 kg CO_2e per box for the full supply chain carbon footprint. This includes variation due to the efficiencies of each ocean shipping service, transportation distances from ports to DCs and DCs to customers, and relative efficiencies of the different ports and DCs.

A visual representation of the B2B carbon footprint serves to highlight the role of location and distance in the calculation. Figure Figure 6 shows the B2B carbon footprint as calculated for any point in the country. The results were generated by first calculating the cradle-to-gate carbon footprint for a box of bananas at each DC. The final B2B carbon footprint for any location was then calculated by first finding the distance from the specific location to the closest DC. The emissions generated by ground transportation for that distance were calculated and added to the cradle-to-gate carbon footprint at the DC. The B2B carbon footprint was calculated in this manner for a grid of destination points throughout the United States and imported to ESRI's arcGIS software. Interpolation was then used to estimate the B2B carbon footprint for all points throughout the country and display the results.

The map clearly shows the effects of differences in trucking distance and the efficiencies of the various ocean services. The port of Gulfport, Mississippi requires the lowest emissions to be reached from the tropics, and combined with the proximity of a DC in New Orleans results in the lowest carbon footprint for products sold in the Southeast. In contrast, the lower efficiency of the West Coast ocean service and the significant trucking distance required to reach the Pacific Northwest results in the highest carbon footprint for customers in this area. Customers on the East Coast have close access to a number of DCs resulting in relatively low carbon footprints, while customers in the Midwest often have significant distance to the closest DC, or require a lengthy haul from the port to the DC near Denver. Thus, the B2B carbon footprint for any particular customer is highly dependent not just on the total food miles, but also on the specific structure of the supply chain.

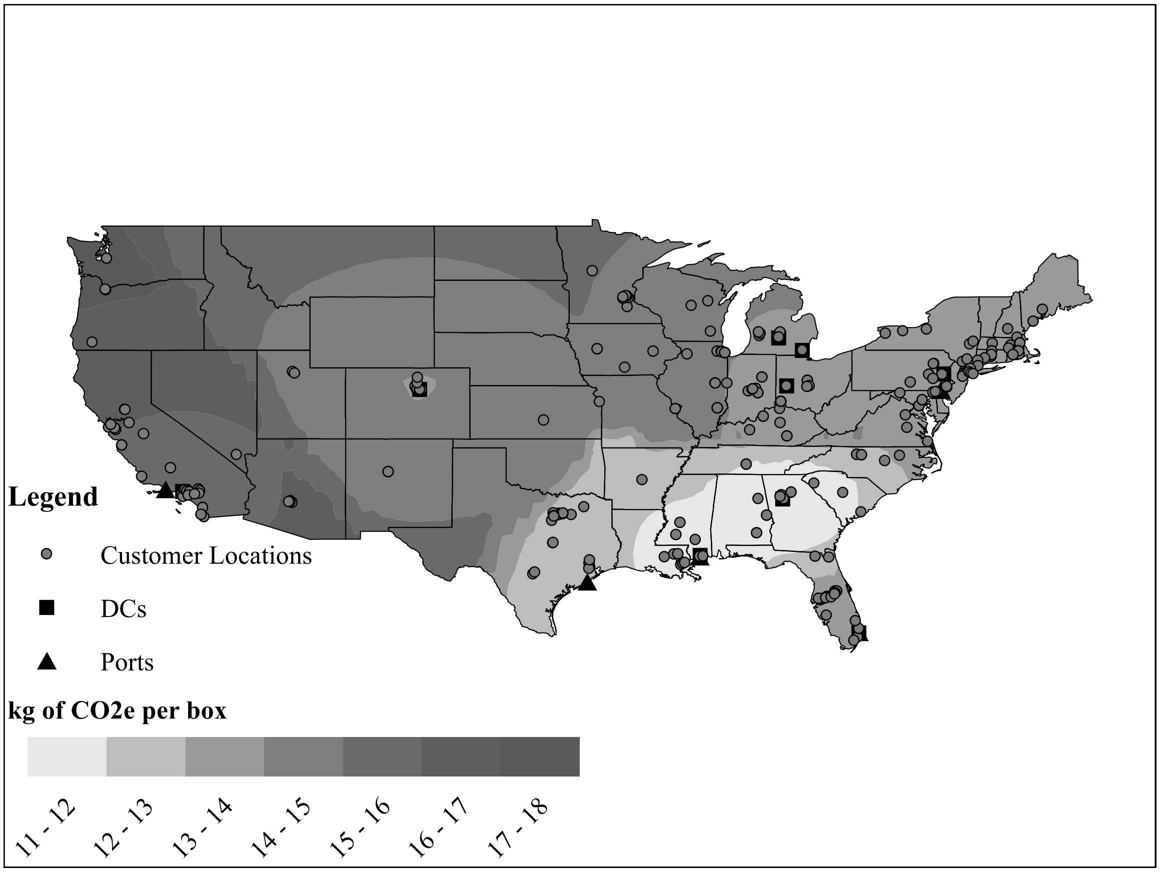

Figure 6: Carbon Footprint by Location

Conclusion

In this paper we have presented the results of a case study regarding the carbon footprint of the banana supply chain. We estimate the carbon footprint of a 40 pound box of bananas sold in the United States to be approximately 17 kg of CO2e, or around 1 kg of CO2e per kg of sold bananas. Our results show transportation to be a significant factor in the final carbon footprint, greater even than the role of production. These results may be attributed to the use of smaller vessels, faster sailing speeds, and the low backhaul utilization during the ocean shipping phase, factors not accounted for in standard estimates of efficiencies for large scale ocean shipping.

We identify sources of uncertainty related to areas upstream and downstream in the supply chain from the fruit production company. In total more than 50% of the carbon footprint occurs as Scope 3 emissions, outside company control. These impacts are driven largely by packaging, production of chemicals used in cultivation, and downstream supply chain activities. While information sharing between supply chain partners has been proposed as a method for reducing uncertainty in the carbon footprint measurement we show that supply chain variability becomes an important issue for these proposed solutions. Our results show that customer location and the structure of the supply chain play a key role in determining the actual carbon footprint. The carbon footprint for products sold to individual customers may vary as much as 30% from average, with the highest carbon footprint being more than 50% greater than the lowest. Accounting for this variability remains an issue for organizations looking to engage in carbon footprint measurements across the supply chain.

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