THE BANANA CARBON FOOTPRINT CASE STUDY

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SUMMARY: *This document describes in detail the process of estimating the carbon footprint of a banana. The case study estimated a total footprint of 121g of CO_2-equivalents, with transportation and farming being the largest share of emissions (36% and 29% respectively). A description of the breadth, depth and precision of the estimation is included in the document, as well as an illustrative assessment on the level of uncertainty of the carbon footprint calculation.*

Introduction

This case 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. The initial phase of this research has involved interviews with key personnel, mapping of the supply chain, visits to a distribution center and retail store, and collection of relevant data. Working with the partner companies the activities associated with the supply chain were examined for any greenhouse gas emissions that might be produced (measured in CO_2 equivalents or CO2e). For each emissions generating activity data was collected regarding the amount of emissions generated and the quantity of bananas involved in the activity. In this manner the emissions can be allocated to the product in order to determine the carbon footprint of a pound of bananas sold at a retail outlet. For data that is not available from the partner companies estimates have been made from secondary data sources. The current work has focused on materials that are consumed and used during the handling process, and capital goods have been excluded.

The Banana Supply Chain

Bananas sold in the United States are typically grown in Central America. CBI works with a network of owned plantations, independent growers, and wholesalers at more than 200 locations, primarily in Guatemala, Nicaragua, and Costa Rica. Though practices may vary from farm to farm banana cultivation often involves the application of fertilizers, pesticides, and fungicides. Once the bananas approach ripeness they are picked at the plantation and packaged for transportation. The bananas are shipped from the packing locations by truck in refrigerated containers to one of three outbound ports. Once they arrive at port the bananas remain in the refrigerated containers and are loaded on ocean vessels for shipment to one of five ports in the US.

After arriving in the US the containers are unloaded from the ship and the bananas are moved from the containers to refrigerated warehouses located near the port. From the warehouse bananas are shipped either to CBI distribution centers or taken to customers DCs. This transportation can be arranged by CBI or by the customer. Upon reaching the DC the bananas undergo a chemical ripening process using ethylene gas that lasts 3-4 days. At the end of this process the bananas are ready for sale and are immediately shipped to retail outlets. At the retail outlet bananas require no special handling or care such as refrigeration. Bananas are a fast moving product, with most bananas typically being sold within a day of arriving at the store.

In addition to the bananas themselves a number of additional materials are used to package the bananas for transport and sale. From the packing station to the DC bananas are normally shipped in container quantities. Each container holds 20 pallets of 48 banana boxes, for a total of 960 boxes per container. Each box contains approximately 40 pounds (18 kgs) of bananas wrapped in a plastic liner and placed in a cardboard banana box. The banana boxes and liners are procured by CBI and sent from the US to Central America during the backhaul portion of the ocean voyage. The materials are sent to the packing stations in the trucks that will be used to transport the bananas from the packing station to the port. Additional packing materials include reusable wooden pallets, cardboard pieces used to help secure boxes of bananas on pallets, and plastic shrink wrap used when transporting pallets of bananas from the DC to the store. Though Chiquita supplies the cardboard and plastic used in packing bananas these materials are eventually disposed of by retailers who purchase bananas from CBI. At Shaw's grocery stores the cardboard used in packing is saved and sent to a recycler, while the plastic lining and shrink wrap are thrown out as waste.

Beyond the bananas and the packaging materials the only other product consumed during the banana supply chain is the ethylene fluid used in the ripening process. This fluid is purchased from the producer and shipped to the DC through a parcel delivery service. The fluid is packaged inside a plastic bottle. One 32 oz. bottle of ethylene fluid is used to ripen one truckload of bananas. After use in the ripening process the empty bottles are discarded as waste. A map of the supply chain is shown in Figure 1.

Emissions and Data Sources

The emissions considered in this analysis can generally be placed in one of three categories: emissions from mobile combustion, emissions from energy use and electricity consumed in facilities, and emissions related to production and disposal of materials used throughout the supply chain. The materials include not only packaging materials such as cardboard and plastic, but also emissions related to the chemicals used in the growing of bananas and production of ethylene fluid. In theory each of these materials can themselves be traced back through the supply chain to quantify their emissions, however, this requires information not available to the partner companies. In this case these emissions can be quantified using available Life-cycle Assessment (LCA) data.

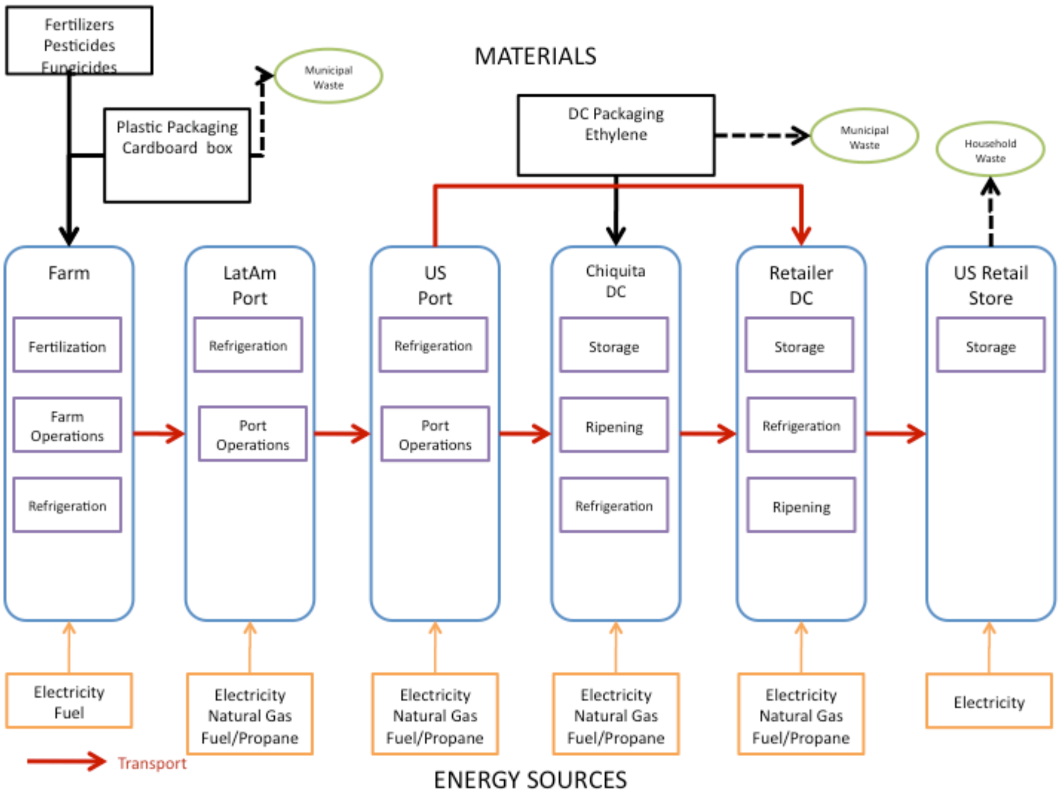

Figure 1. Banana Supply Chain Map

Mobile Combustion

The primary emissions contributions for mobile combustion come from ground transportation of the bananas by truck and ocean transportation of the bananas from Central America to the U.S. Secondary contributions include ocean transportation of cardboard boxes from the U.S. to Central America, ground transportation of ethylene fluid and packing materials to the DC, and transportation of chemicals to the banana farms.

Ground Transportation

Ground transportation of the bananas includes shipping from the grower to the outbound Central American port; inbound from the U.S. port to the DC; and outbound from the DC to the retail store. Shipping distance from the grower to port can vary based on where the grower is located and which shipping port was used, therefore an average distance to port was used based on logistics data provide by CBI's operations in the tropics. This data included the total kilometers traveled, the number of equivalent containers moved, and data regarding fuel consumption from the *genset* units that provided refrigeration in transit.

Shipping distances at the destination side similarly can vary depending on the exact path traveled by the banana. For this study an "average" New England banana was used. This average banana was assumed to travel by ocean to the port of Wilmington, DE. From there it traveled by truck to a Boston area DC and finally to a retail store. The distance from the DC to the store was based on information provided by Shaw's from their transportation management system. Total round trip kilometers for all shipments from the DC to stores was reported, less any backhaul trips, along with the total cases of bananas shipped to determine an average distance from DC to retail store. Additional information regarding fuel consumption of the reefer unit used to provide refrigeration was also provided. This was based on an average consumption of one gallon of diesel per hour of use. Average speed was estimated at 36 mph, and combined with the distance of the shipment this provided an estimate of the total fuel consumption required by the reefer.

Additional ground transportation emissions were calculated for shipment of the ethylene fluid from the distributor to the DC and for chemicals from a distributor to the banana farm. For the ethylene fluid a travel distance was estimated using Google maps functionality to calculate the driving distance from the distributor's city to the DC. Chemical shipments to the banana farms will vary depending on the location of the farm and the source of the chemicals. This distance was assumed to be 100 km for the purpose of this study.

Greenhouse gas emissions were calculated for the ground transportation using SimaPro LCA software. For each shipment the weight and distance were used to calculate the total tonne-kilometers (tkm) of the shipment. SimaPro offers a variety of different road transportation options, but for consistency a 32 tonne lorry was assumed to handle all ground transportation. SimaPro is a Life-cycle Assessment tool, and as such the greenhouse gas emissions are based on the full life-cycle required for road transportation. This includes construction of the lorry, maintenance of the vehicle, road construction, as well as the full life-cycle emissions for the diesel fuel consumed by the vehicle. For the 32 tonne lorry the estimated emissions are 165 grams of CO2e per tkm. The majority of these emissions, approximately 86%, come from the production and consumption of the diesel fuel. In total the ground transportation accounts for approximately 36 grams of CO2e per banana. The breakdown of ground transportation emissions by source is shown in Figure 2.

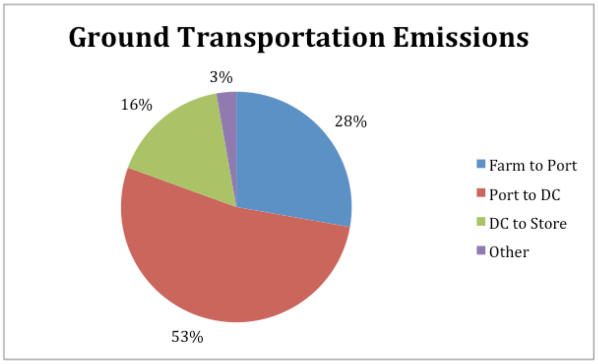

Figure 2. Ground Transportation Emissions by Source

Ocean Transportation

Emissions from ocean transportation were calculated based on the shipping distance from Puerto Moin, Costa Rica to Wilmington, DE. Wilmington was chosen as the destination port because it is the port used to serve the New England market for shipments made by CBI. Puerto Moin was chosen as the origin port because more than 80% of bananas shipped by CBI to Wilmington use Puerto Moin as the origin port. A smaller number of bananas are shipped from Almirante, Puerto Barrios, and Puerto Cortes. The shipping distance was determined based on information provided by dataloy.com, a service that provides shipping distances based on the most heavily traveled shipping lanes. The total distance was calculated based on a trip originating in Puerto Moin, making intermediate stops at Puerto Barrios and Puerto Cortes, and eventually arriving at Wilmington.

An estimation of the emissions related to shipping the cardboard packing boxes by ocean from the US to Central America was also performed. Based on information from CBI the boxes are typically shipped out of New Orleans to the tropics on the backhaul portion of the banana ocean shipments. Again using information from dataloy.com the distance was calculated for a shipment originating in Gulfport, LA and arriving in Puerto Moin with intermediate stops at Puerto Cortes and Puerto Barrios.

Greenhouse gas emissions for ocean transportation were calculated in SimaPro using a similar method to ground transportation. For each shipment the weight and distance were used to calculate the total tonne-kilometers (tkm) of the shipment. The transoceanic freight shipment transport process was chosen to model the ocean shipments. In addition to emissions from the operation of the vessel SimaPro includes emissions from the construction of the vessel, maintenance of the vessel, operation of the port, construction of the port, and maintenance at the port. SimaPro estimates the contribution from transoceanic freight to be 10.6 grams of CO2e per tkm. Almost 86% of the emissions are the result of production and consumption of heavy fuel oil, while 13% comes from operations at the port. Overall, ocean transportation accounts for only 8 grams of CO2e per banana. Nearly 7 of those grams come from the actual transportation, and just over 1 gram is contributed by port operations.

Direct Energy Consumption

Non-transportation energy consumption can be broken down to three sources: distribution facilities such as the DC and retail store, electricity usage by reefer containers waiting at the port, and energy use at the farm.

Distribution Facilities

Electricity is the primary energy consumed at facilities used in the distribution of bananas to the consumer. This includes a Distribution Center where bananas undergo the ripening process and a retail outlet where they are sold to the end consumer. Operations at the DC requiring energy include heating, cooling, and lighting of the facility; electricity to power cargo handling equipment; and electricity to power the banana ripening rooms. Bananas typically require no special handling at the retail outlet, but electricity is consumed at the store for heating, lighting, office equipment, checkout registers, and other activities required to run the store. In addition to electricity a smaller amount of energy is used in the form of natural gas to provide heat.

Energy consumption at facilities was calculated based on actual utility bills. These were provided by Shaw's for their DC that handles bananas and a retail outlet selected to be representative of typical operations. Once total energy for the facilities was calculated the energy needed to be allocated to bananas in some manner. Each facility handles many different products, but no information was tracked that breaks down electricity usage by product. At the DC energy was first allocated to bananas based on the percentage of square footage of the facility occupied by the banana room. Bananas are a high volume product, and have their own separate space for storage and ripening within the facility. While this method is easily calculated it likely overestimates the amount of energy truly required for bananas. This particular DC handles frozen and refrigerated products. Bananas are kept slightly below room temperature, but this requires less energy than other areas of the DC which must be kept below freezing.

Energy at the retail store also required some method of allocating the energy consumption to bananas. For this phase an allocation based on economic factors was used. A retail grocery outlet sells thousands of different products, and allocating based on other means requires significant amounts of information that are typically not available. Sales information is readily available, however, and energy was allocated based on the percentage of total store sales represented by bananas. The energy consumption was then determined at an individual banana level by dividing the allocated energy by the total pounds of bananas sold at the store during the time period.

Carbon emissions from the consumption of electricity were calculated in SimaPro based on the average fuel mix within the United

States. This estimates total emission from electricity consumption at 741 grams of CO2e per kWh. Of the 741 grams more than 90% comes from emissions released during the combustion of fuels to provide the electricity. The remaining emissions come mainly from the extraction and processing of the fuel and the creation of infrastructure. Emissions from natural gas are likewise based on the average U.S. case, with an estimated value of 65 grams of CO2e per cubic foot.

The energy use at the DC and retail store combines to produce only 14 grams of CO2e per banana. Nearly all of these emissions come from the electricity, with the contribution of natural gas consumption being less than 1 gram. While the DC facility as a whole uses more energy than the retail store it makes a much smaller contribution to the carbon footprint of the banana due to the high volume of products handled. Of the 14 grams of CO2e about only 1 gram is contributed by the DC, with the remaining 13 coming from the retail store.

Electricity at the Port

Bananas are shipped from farms in the tropics to the US in refrigerated reefer containers. During transportation these reefers consume power from the ship or a generating unit on the truck. Once they arrive at the port there is typically a wait until they are ready to be loaded on the ocean vessel. During this time the reefers draw electric power from the grid to power the refrigeration unit. Based on an interview with the logistics manager for Latin America it was determined that the bananas spend no more than three days waiting at the port, with an average of two days. The power rating for the units is 10 kW. Given an approximate 48 hour wait time the reefers will consume approximately 480 kWh of electricity, with a full reefer holding 960 boxes of bananas. No electricity factors are available in SimaPro for the countries in the tropics that CBI ships bananas from; instead the average U.S. electricity mix was substituted.

Farms

In addition to the energy consumption at the distribution facilities energy is also used by the farms where bananas are grown. Though banana farming still relies heavily on manual labor energy is needed to power farm equipment, spray chemicals, and power buildings. Practices vary between farms, and at this time good data regarding the energy consumption at farms was not available. Instead this information was estimated using a generic fruit farming process within SimaPro. Emissions were estimated for the energy use required to farm one hectare, and data provided by CBI regarding average farm yields was used to allocate this to individual bananas. This process estimates the emissions required to produce one banana at 12 grams of CO2e, the majority of which comes from diesel fuel consumed in farm equipment.

Materials

Carbon emissions related to the production of materials used in the supply chain can be placed into two categories: packaging materials and chemicals. Packaging materials included in the analysis were the cardboard banana box, the plastic shroud used to wrap bananas inside the banana box, plastic wrap used during outbound transportation from the DC, and cardboard cornerboard used to help stabilize the boxes of bananas for transport. The chemicals used in the supply chain include the pesticides, fertilizers, and fungicides used at the banana farms along with the ethylene fluid used to ripen the bananas at the DC.

Packaging

The most significant aspect of the banana packaging is the cardboard box in which the bananas are shipped. Based on information provided by CBI regarding packaging specification each box is estimated to be about 2.5 pounds of cardboard. The emissions related to producing the box are estimated using SimaPro for a mixed fiber, single wall, corrugated cardboard. The emissions factor for production of the cardboard is approximately 432 grams of CO2e per pound of cardboard. In addition to the production of the box emissions related to its disposal are calculated in SimaPro as well. The empty box is typically collected at the retail outlet for disposal. In this specific case the disposal was modeled as being sent to a standard municipal waste in the U.S. where it's final disposal is based on a mix of landfill and incineration. The emissions related to disposal of the box are approximately 18 grams of CO2e.

The plastic shroud was based on packaging specification provided by CBI. It was modeled in SimaPro as plastic packaging film and used the same municipal waste disposal scenario as the cardboard box. The overall contribution of the shroud, including production and disposal, was about 1 gram of CO2e per banana. The remaining materials used during distribution, including the shrinkwrap and cardboard cornerboard, were modeled in a manner similar to the box and shroud. Due to the limited quantities used of these materials the total contribution was well below 1 gram of CO2e per banana.

Chemicals

Data regarding the chemicals used to help grow the bananas at the farm is based on recommended doses provided by CBI. Actual usage will vary from farm to farm based on specific conditions and management. In order to account for this whenever a range of values was provided the upper end was used in order to provide a conservative estimate of the actual emissions. Typically the guidelines from CBI are based on a recommended amount of the active ingredient in the chemical, such as N, P, or K. SimaPro uses a similar classification, where several different types of fertilizers may be available, but they are measured by the quantity of the active ingredient. Without knowledge of which specific chemical may have been used one of the choices was made from the list. Many of the chemicals used were not available in SimaPro or could not be identified. In this case a similar quantity of an available chemical was chosen from the SimaPro database as a substitute. Future work may involve refining the choice of chemicals or providing a sensitivity analysis based on the choice of different chemicals.

The chemical usage was based on recommended doses per hectare per year. The emissions from these chemicals were then allocated to the bananas based on the average annual yield per hectare. Based on the data from SimaPro the average emissions from the production of these chemicals was 3100 g of CO2e per kg of chemical. This contributed approximately 23 g of CO2 per banana. The largest single contributor was Nitrogen in the form of Ammonium Nitrate. Included in the emissions estimate for the chemicals was truck transportation of 100 km to account for transport of the chemicals from a regional vendor to the farm.

In addition to chemicals used to grow the bananas a small amount of ethylene fluid was used to chemically ripen the bananas just before sale. One 32 oz bottle of ethylene fluid is capable of ripening a full container (960 boxes) of bananas. This was modeled in SimaPro as production of 32 oz of ethylene, production of a HDPE plastic bottle to contain it, and truck transportation from the vendor's location to the Shaw's DC. In addition the plastic bottle was disposed of using the standard U.S. municipal waste scenario. Due to the relatively small amounts of plastic and ethylene used to ripen an entire container of bananas the total contribution amounted to less than 1 gram of CO2e per banana.

Results

The end result of this case study was an estimated carbon footprint of approximately 121 g of CO2e per banana. This is based on an "average" New England banana. Ocean and road distances were all based on data required to get the bananas to Shaw's Boston area DC, and distance to stores was based on Shaw's operations in New England. Figure 3 shows a breakdown of the supply chain along with the relative contribution of each piece in grams of CO2e per banana. Figure 4 provides a relative breakdown of the emissions by source.

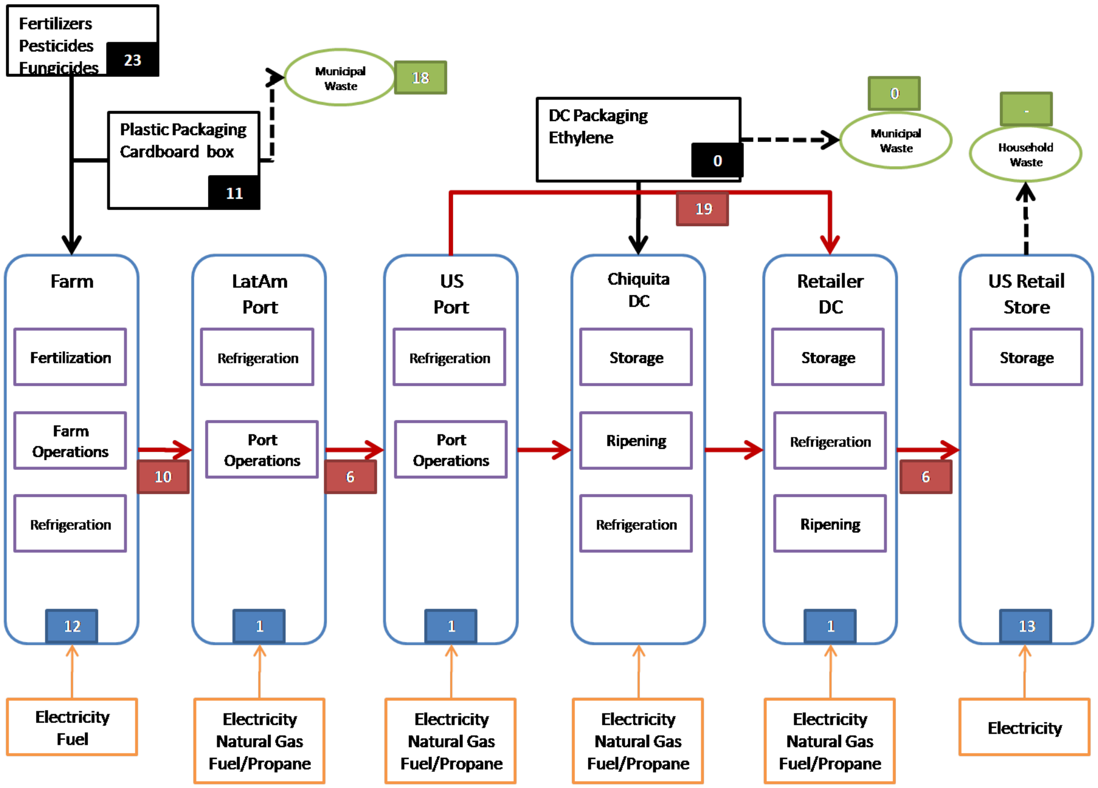

Figure 3. Banana Carbon Footprint by Supply Chain Element

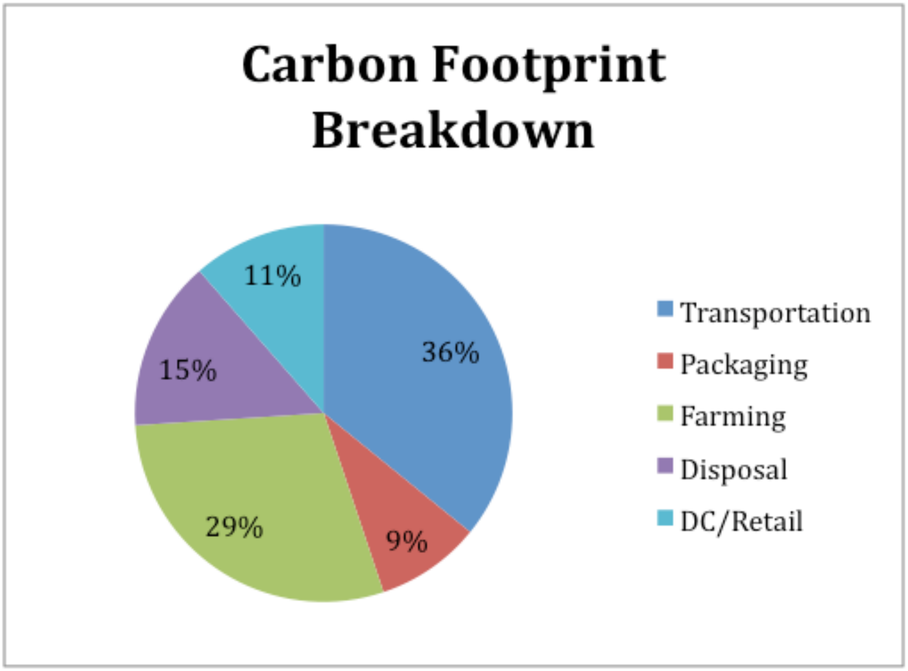

Figure 4. Banana Carbon Footprint Contribution by Source

Carbon Footprint Uncertainty

Several factors impacted the accuracy of the carbon footprint estimation. First, and most important, is the difficulty in gathering all necessary data. These problems can arise from several different issues. In some cases, such as power consumption of the banana ripening rooms, it is data that is not specifically tracked, and therefore difficult to separate from the aggregate power consumption for the whole facility. The use of aggregate data creates further issues with how to allocate the emissions to different products. If the emissions can not be directly tracked at the product level some method must be used to determine which share goes to which products, and in many cases it is not clear that there is a single best answer for how this should be done.

In other cases the data needs to come from sources outside of the partner companies. Often this data was not available. Receiving data from multiple sources also creates issues of consistency. For example, when reporting miles driven or gallons burned during shipping it must be clear whether this includes the return trip or backhaul for other products. When specific data was not available it had to be estimated based on secondary sources. In the case of this study much of the secondary data was taken from databases available in the SimaPro LCA tool. When data is not available, as was the case for several of the chemicals used during the banana farming operations, a substitute chemical was used. The accuracy of these substitutions adds a layer of uncertainty that is difficult to estimate without additional information.

Finally, the necessity of producing a single number requires the use of average data and certain assumptions. In many instances the actual carbon footprint of a specific banana may vary significantly from this single number. The chemical use, farming techniques, travel distances, facility energy efficiency, and electricity generation mix can be different for each banana. With hundreds of farms and thousands of end destinations a single number cannot accurately represent a true carbon footprint of any specific product. Depending on the way this carbon footprint information is used these differences may or may not prove relevant.

Quantifying Uncertainty

The case study used detailed information of the retail distribution network to the New England Area. Approximately 36% of the banana footprint is associated with the transportation network, the largest share of the emissions. However, bananas are shipped all through the continental United States using a variety of distribution networks. In order to illustrate the impact of the distribution network on the carbon footprint, we analyzed a variety of distribution networks to different regions in the United States as well as a variety of underlying transportation network. Figure 5. Shows selected cities in the United States and their associated carbon footprint. We can see that banana carbon footprints vary from 97g to 168g depending on the final retail destination, a large range heavily dependent on the underlying structure of the supply chain.

Similar analysis should be performed to estimate the impact of farming practices, the second larges source of emissions in the banana carbon footprint.

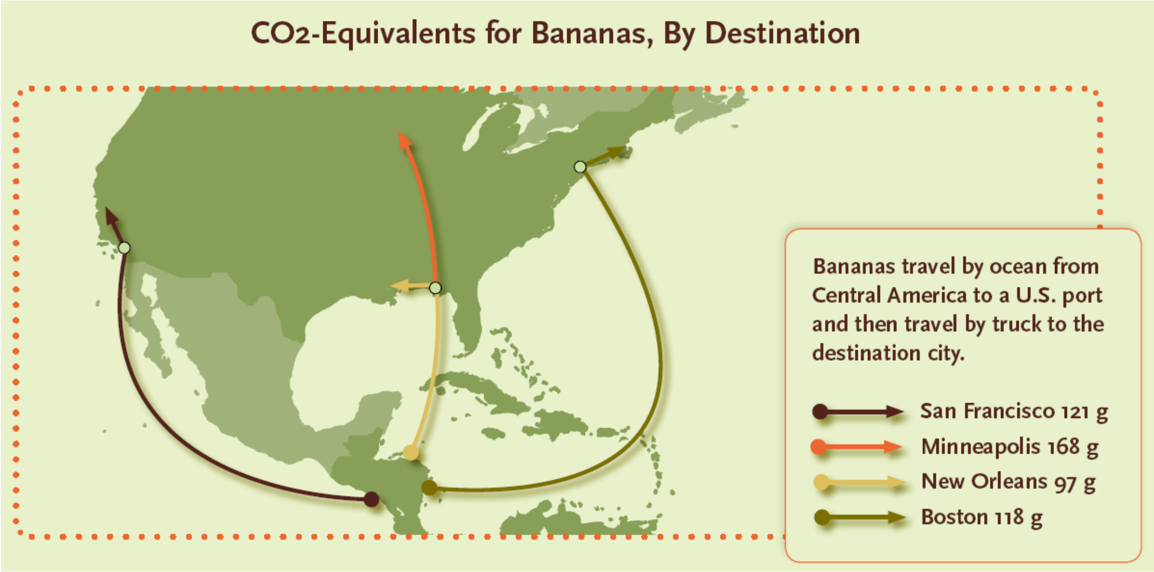

Figure 5. – Carbon Footprint Variation by Destination

NEXT STEPS

For further information, contact Dr. Edgar Blanco, Director of the MIT CTL Carbon Efficient Supply Chains project at: eblanco@mit.edu, or tel: +1 617 253 3630

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