Carbon Footprint of Chiquita's North American and European Bananas

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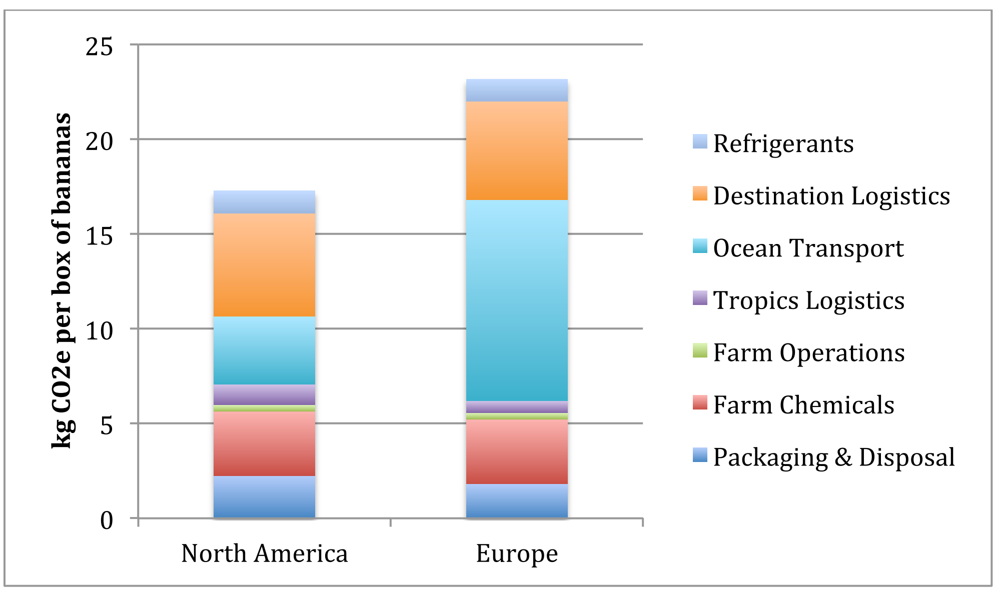
Executive Summary

Growing awareness of the role of consumers in reducing greenhouse gas emissions has led to the introduction of several standards designed to measure a product's carbon footprint. The carbon footprint of a product is defined as the total greenhouse gas equivalent emissions attributable to the product during its lifecycle. This study uses Life Cycle Assessment techniques to measure the carbon footprint of bananas sold in both North America and Europe.

In partnership with Chiquita Brands Inc., a leading supplier of bananas, and Shaw's, a New England based grocery store chain; data has been collected over the entire supply chain of the banana from cultivation in farms located in the tropics to final sale to the consumer at the grocery store. This data includes information related to transportation, energy consumption in distribution facilities, farming operations, chemical usage, and packaging materials. Using a model built in the SimaPro Life Cycle Assessment tool the average carbon footprint of a box of bananas was calculated for North America and Europe.

Results from the analysis show the carbon footprint to be approximately 17 kg of CO2e per box in North America and 23 kg per box in Europe. Each box holds on average 18 kg of bananas, for an estimated 1.0 kg of CO2e per kg of banana sold in North America and 1.3 kg CO2e per kg in Europe. The major individual contributors to the total are the shipment by ocean from the tropics to destination, distribution at the destination market, and chemicals used during cultivation.



Sensitivity analysis was performed on a number of factors used in the model. Results from this analysis show that differences in specific farm chemical usage, transportation distances, and efficiency assumptions can have significant impact on the calculated carbon footprint. The single most important source of emissions is the ocean voyage, and initial data collection for banana specific ocean shipments shows significantly higher fuel consumption that in standard oceanic freight assumptions.

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1. 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. A number of government and non-government agencies have set forth proposals for labeling systems designed to inform consumers of the carbon footprints of the products they purchase. These programs generally call for the use of Life Cycle Assessment (LCA) as a method for measuring carbon footprints. 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 using an LCA methodology.

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. For each activity data was collected regarding the processes responsible for producing emissions. For data that was not available from the partner companies’ estimates have been made from secondary data sources. After collecting data for all activities ranging from growing the bananas at farms in the tropics to sale to the end consumer at retail outlets in North America and Europe an LCA model was constructed to calculate the total carbon footprint for the product. This report provides details on the methods used in building the model, the defined goal and scope of the project, the data collection effort, and the results of the analysis.

2. Life Cycle Assessment

Life Cycle Assessment (LCA) is a quantitative process for evaluating the total environmental impact of a product over its entire life cycle, often referred to as a cradle-to-grave approach. LCA is generally product focused, with emphasis on quantifying the environmental impacts (Heijungs 1996). LCA, as defined by the International Standards Organization (ISO), consist of four phases:

1. Goal Definition and Scope
2. Inventory Analysis
3. Impact Assessment
4. Interpretation

The goal definition and scope phase includes identifying the product or function being studied, the reasons for carrying out the study, defining the system boundary, and identifying the data requirements. Inventory analysis involves identifying the process involved in the system, defining the inputs and outputs of each process, and collecting data to quantify those inputs and outputs. Impact assessment defines impact categories and used the results of the inventory analysis to calculate indicator results in those categories. Finally, in the interpretation phase the results of the inventory analysis and impact assessment are interpreted in terms of the goal and scope definition; the results are checked for completeness, sensitivity, and consistency; and conclusions, limitations, and recommendations are reported (International Standards Organization 2006).

LCAs generally fall in to two categories based on their purpose. An attributional LCA is focused on looking back on a product and determining what environmental burdens can be attributed to it. A consequential LCA is focused on the environmental effects of what will happen due to a decrease or increase in demand for goods and services (Ekvall and Weidema 2004). The types of LCAs are suitable for different purposes and require different types of data. An attributional LCA is appropriate for making specific environmental claims regarding a product, and typically makes use of average data for the product. The consequential category is more suited to performing scenario analysis. It often requires marginal data for the product as it requires making assumptions about economic factors related to changes in product consumption or production (Tillman 2000).

In addition to the types of LCA there are two main LCA methodologies: a process based approach and an Economic Input-Output (EIO) approach. In a process based methodology all phases of a product are examined and their inputs and outputs are mapped. This is typically considered the conventional method of LCA, and is sometimes referred to as the ISO or SETAC method (Lenzen 2001). The EIO-LCA approach uses broad economic categories to provide environmental impacts, but generally only includes the production phase. The two methods can also be combined to form a hybrid approach (Suh, Lenzen et al. 2004).

The goal of this study is to measure the carbon footprint of a product, a goal that is consistent with the attributional approach to LCA. A process based methodology has been followed, consistent with ISO standards for LCA and influenced by leading carbon labeling programs such as the PAS-2050 (British Standards Institute 2008) standard used by the Carbon Trust. Chapter 3 provides a description of the goal and scope selected for the project.

3. Goal and Scope Definition

Objective

The objective of this study is to measure the carbon footprint of bananas sold by CBI. The process involves collecting data regarding CBI's supply chain for bananas from the acquisition of materials forward to delivery to customers. Since a carbon footprint should measure the impact over the product's entire life cycle the supply chain data was used to construct a model using the SimaPro LCA software tool. This allows estimation of life cycle impacts that occur outside of CBI's supply chain, such as impacts related to upstream production of materials and end of life waste scenarios. An additional partner, Shaw's, was able to provide data regarding supply chain activities for bananas once they have reached retail customers. 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 results of this study are by nature backwards looking, measuring the emissions attributable to bananas for operations during the year 2009. The results are not intended to evaluate the impact of specific decisions, but rather provide information about the average impact of bananas that will be useful in three ways:

1. Provide an estimate of the carbon footprint of bananas over their life cycle. This information could be used to develop a product carbon label and help influence future consumer purchases to reduce environmental impact.

2. Develop a process useable by CBI on an ongoing basis to track information necessary for developing performance metrics related to environmental impact.
3. Identify areas of high environmental impact and uncertainty in the CBI supply chain for further exploration of strategies to reduce environmental impact.

Functional Unit

The primary functional unit for this project is 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. When packed at the farm a box of bananas will hold more than 19 kg of bananas, but due to water loss during transit the weight is reduced before delivery to customers. Boxes were chosen as the functional unit since it is a common measure for quantity throughout the supply chain, avoids confusion regarding the difference in beginning and ending weight, and represents the individual unit for transactions between CBI and their retail customers.

Carbon labels are typically developed for a single saleable unit of goods to the end consumer. 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.

The functional unit is further separated between banana boxes sold in North America and Europe. While the supply chains of the two are substantially similar they are managed by different organizations and do include slightly different packaging, different methods of handling, and a significant difference in average transportation distance due to the longer ocean voyage to Europe and the larger geographic area of North America. The specific differences will be discussed in the data inventory and two results will be presented, one for each market.

Description of Supply Chain

Bananas sold in North America and Europe 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 throughout this document 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 locations by truck to the outbound ocean port. In transit and at port the bananas are kept refrigerated in reefer containers (primarily for North America) or bulk storage (primarily for Europe) until loading on a ship for ocean transportation.

The bananas continue to be refrigerated by reefer 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 using ethylene gas in a temperature controlled environment that lasts 3-4 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 outlet 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 bananas themselves a number of additional materials are used to package the bananas for transport and sale. From the packing station to North American DCs bananas are normally shipped in container quantities. Each container holds 20 pallets of 48 banana boxes, for a total of 960 boxes per container. For bulk shipping bananas are typically palletized in 48 box lots, but the number of pallets per shipment varies depending on the size of the vehicle. Each box contains approximately 18 kgs (40 lbs) of bananas wrapped in a plastic shroud and placed in a cardboard banana box. Additional packing materials include cardboard corner board pieces used to help secure boxes of bananas and reusable wooden pallets. 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.

In addition to packaging materials a number of different chemicals are required to produce and ripen the bananas. Chemical fertilizers, fungicides, and pesticides are typically applied at the farm to help with cultivation. These fertilizers are usually applied by aerial spraying or manually by farm workers. 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. 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 1 below. The ideal system boundary for an attributional LCA should include the entire life cycle of the functional unit with every component traced back to its natural state. In practice such a boundary is difficult, if not impossible, to actually achieve and the ISO standards allow for the exclusion of certain stages, processes, inputs, and outputs provided it does not significantly change the conclusions of the study. The popular PAS-2050 standard used in the Carbon Trust label allows exclusions for certain phases of the life cycle that can be difficult to measure, including the use phase of the product; infrastructure and other capital goods with a lifetime of more than one year; and certain other process or facilities with small impacts that represent less than 1% of the total.

In keeping with this definition of the system boundary the following activities are included:

- Upstream production processes for items consumed during production and distribution, including fuel, energy, farm chemicals, ethylene gas, and packaging materials.
- Fuel and energy consumption at the farm used for harvesting, chemical spraying, and packing processes.

- Fuel and energy consumed during transportation operations and in the operation of distribution facilities such as DCs, ports, and retail outlets up to and including the place of final sale to end consumers.
- End of life waste scenarios for packaging materials
- Production and leakage of refrigerant gases
- Production of Nitrous Oxide at the farm due to application of Nitrogen based fertilizer

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. In general bananas require no special handling, storage, cooking, or processing, so in use emissions should be minimal. An estimate of the impact of customer transportation is included in the sensitivity analysis section of this report.
- Infrastructure, capital goods, and durable products such as pallets, roads, ports, buildings, and vehicles used during production and distribution.
- Organic waste from the bananas generated at the farm. This includes stalks and other material separated from the bananas during the packing process. The material is collected at the packing station and returned to the farm to decay. Since bananas are a biogenic product the 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.
- Rejected bananas that do not meet quality standards during the packing process are considered a byproduct. All impacts from the cultivation of these rejected bananas have been allocated to the bananas that do pass quality inspection. All impacts for further processing of the rejected bananas into products such as purees or ingredients are excluded from this system.
- 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.
- Price tags, product stickers, and other small items estimated to have an impact of less than 1% of the total.

Though a number of different configurations of the supply chain may exist, this analysis focuses on the particular configuration where CBI transports the bananas from the port to their DC, performs the ripening, ships the bananas to the customer DC, and the customer distributes them to the retail outlets. This configuration is generally the most complex and should provide an upper bound on the carbon footprint of the product, as other configurations generally omit at least one of the included distributions steps.

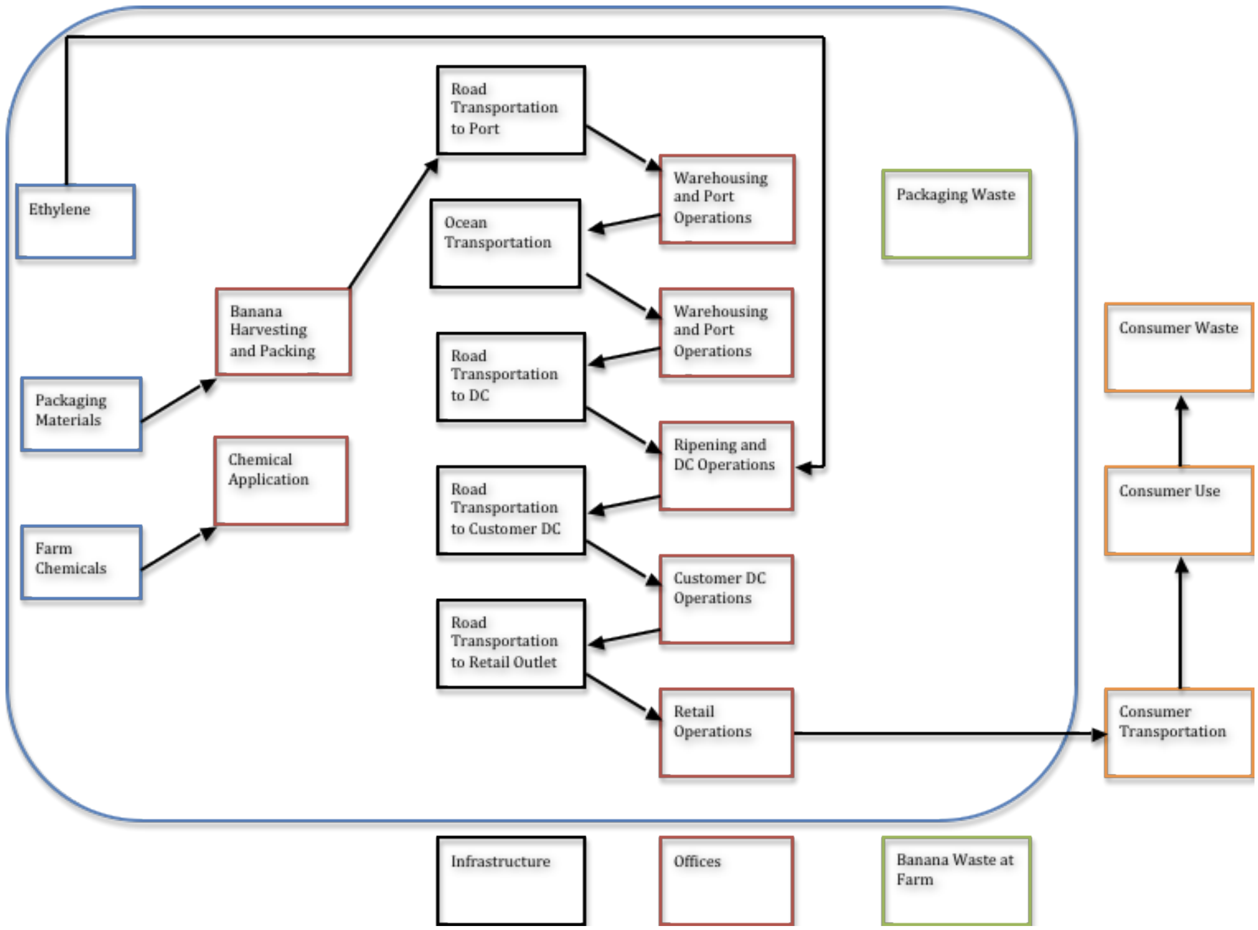

Figure 1: System Boundary

Impact Assessment

This project is intended to provide an estimate of the carbon footprint of the product, and therefore only a single impact assessment has been performed. 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 Carbon Dioxide Equivalent (CO_2e) attributable to the system. CO_2e represents a contribution towards climate change equivalent to that of an expressed mass of carbon dioxide. While the exact definition of a carbon footprint is still subject to debate the total CO_2e of a product is one accepted measure, and the one chosen for this analysis. All impacts were calculated using the IPCC 2007 GWP 100a version 1.01 method in SimaPro with the “exclude infrastructure option” selected.

4. Inventory Analysis and Data

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 LCA database. The quality of the data has been assessed on three criteria:

- Source--primary or secondary

- Temporal--when was the data collected and over what amount of time was it aggregated
- Representativeness—how closely the data collected represents the supply chain of the system, including geographic and operational considerations

Source

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 specific tracked performance data 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 data sources are summarized in the table below, and more detail is given in the relevant sections later in the report.

Stage	Data
Primary Packaging Materials	Primary data regarding specification, types of material, and quantities. Secondary data for upstream extraction and processing
Secondary Packaging	Secondary data from publicly available specification for similar products.
Chemicals	Primary data on recommended types and quantities. Secondary data for modeling of upstream processing.
Farm Operations	Primary data regarding energy consumption and product output.
Origin Port	Primary data regarding transportation distance, product quantities, and energy consumption at ports.
Ocean Transportation	Primary data on distances, fuel consumption, and cargo quantity.
European Ports	Primary data on energy consumption and product quantities.
North American Ports	Primary data on energy consumption and product quantities.
CBI DC	Primary data on energy consumption and product quantities in the USA and Europe.
Customer DC	Primary data on electricity consumption and product quantities for one customer DC in the USA. Secondary data for process modeling.
Retail Outlet	Primary data on sales information and energy consumption for one store in the USA.
Use	Secondary data for consumer transport distances and modeling in sensitivity analysis section.
Disposal	Secondary data for disposal scenarios.

Table 1: Data Sources

Time Period

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.

- Some ports and DCs in Europe reported data for partial periods of 2009. More detail on the time periods used are found later in the report.
- Some transportation data from the CBI DC to customer DC in Europe was provided for a subset of 2009, and was extrapolated to a full year.
- Ocean transportation cargo data is based on a set of voyages during 2009, approximately 2-3 weeks of data per service. 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 are 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.

Representativeness

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 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, transportation to customers within Europe, and customer operations.

- Data for farm operations was gathered for only one of six primary growing regions in the tropics. While this data does include aggregate data for more than thirty farms it does represent only one region.
- Data regarding port operations was provided for only one port in the tropics region.
- CBI handles transportation to customer in four European regions, the U.K., Poland, Belgium, and the Netherlands. Data was only provided for the U.K. and Poland.
- Data was provided by only one customer in the U.S. and none in Europe

Several alternative scenarios are considered in the sensitivity analysis section of this report to attempt to address issues of representativeness.

A summary of the representativeness of data collected at different stages is shown below.

Stage	Data
Chemicals	Average recommended usage across all 6 growing regions.
Farm Operations	Average data for more than 30 farms, but only within 1 growing region.
Origin Port	Data for only 1 of 6 ports in the tropics.
Ocean Transportation	Data for 5 of 6 ocean services, average across services due to limited time horizon of data.
European Ports	Data for all
North American Ports	Data for 4 of 5 ports
European Transportation	All shipments from Port to DC. Data for transportation to customer in 2 of 4 regional markets. Average statistical data for customer transportation.
North American Transportation	All shipments from Port to DC and to customers. Customer transportation for 1 retail customer.
CBI DC	Data for 6 of 9 DCs in the USA. Data for 10 of 11 European DCs.
Customer DC	Data for only 1 customer in the USA, none in Europe.
Retail Outlet	Data for only 1 store of 1 customer in the USA, none in Europe.
Disposal	Average disposal scenarios for USA and England.

Table 2: Data Representativeness

Loss Rates

Data has generally been collected and reported based on production quantities rather than final sales numbers to customers. Since the functional unit chosen for this study was a box of bananas delivered to the retail customers the results must be adjusted to account for loss during operations. Based on an estimate reported by CBI the loss rate was assumed to be 4%. That is, for every 100 boxes produced by CBI only 96 will end up sold to customers, with the other 4 lost, damaged, or rejected by the customer. This is reflected in the reported emissions numbers by first calculating results per box based on production data and then multiplying by 1.0417 (100/96) to account for allocation of the total emissions to only sold bananas. Throughout this report all data is reported per box produced while results are presented per box sold, reflecting the adjustment due to loss.

Transportation

Ground Transportation

Ground transportation of the bananas includes shipping from the farm to the outbound port, inbound from the destination port to the CBI DC, from the CBI DC to the customer DC, and outbound from the customer DC to the retail store. Additional ground transportation includes delivery of chemicals and packaging materials to the farm and ethylene ripening fluid to the CBI DC.

Data

Tropics

Shipping distance from the farm to port can vary based on where the farm is located and which shipping port was used. Transaction level data for each shipment was not available; instead an average distance to port was calculated based on logistics data provided by CBI's operations in the tropics for eight different countries (Guatemala, Honduras, Nicaragua, Costa Rica, Panama, Colombia, and Ecuador). This data included the total kilometers traveled for all shipments (except in Colombia and Ecuador where this data was not provided), the number of equivalent containers moved, and the total number of boxes shipped to North American and Europe for each country. From this data the average distance per shipment for each country was calculated by dividing the total kms by the number of equivalent containers shipped, providing an average distance per equivalent container. The emissions from the operation of the vehicle over this distance were then allocated to the product by dividing the total boxes shipped by the number of equivalent containers to estimate the average number of boxes on each shipment. The average distance and boxes per shipment for North America bound shipments was calculated by averaging the results from the four countries that supplied North America (Guatemala, Honduras, Nicaragua, and Costa Rica). The data for Panama was used as the average distance for Europe bound shipments due to the lack of distance data for the other sourcing countries, Colombia and Ecuador.

	Guatemala	Honduras	Nicaragua	Costa Rica	Panama	Colombia	Ecuador
Total kms traveled	29,554,975	4,411,562	3,829,143	10,710,321	3,669,115	-	-

Equivalent Containers	54,244	26,003	3,528	41,949	16,142	21,572	18,412
Total boxes	28,043,772	11,425,631	1,661,320	24,256,076	15,265,841	17,737,773	17,675,316
To EU boxes	0	0	0	0	15,265,841	17,737,773	17,675,316
To NA boxes	28,043,772	11,425,631	1,661,320	24,256,076	0	0	0
Avg. km per container	545	170	1,085	255	227	-	-
Avg. boxes per container	517	439	471	578	946	822	960

Table 3: Ground Transportation from Farm to Port

North America

Shipping distances at the destination side similarly can vary depending on the exact path traveled by the bananas. Data provided by the North American logistics teams included the total number of shipments, the total number of boxes shipped, the total distance traveled, and the average fuel consumption of the vehicles used. This was further broken down between shipments from the port to DCs and from DCs to customers. The shipping data is based on records from all five ports and nine DCs in North America, and includes shipments to more than 300 customer locations.

Origin	Destination	Total # of Shipments	Total Distance (kms)	Total Boxes
Port	DC	9,991	4,255,568	10,586,392
DC	Customer	6,374	2,806,902	4,036,569

Table 4: Ground Transportation Data, NA Ports and DCs

The average shipment distance was calculated by dividing the total distance by the number of shipments, producing an average distance traveled per shipment of 426 km from the port to the DC and 440 km from the DC to the customer. The average number of boxes per shipment was 1,060 from the port to the DC and 633 from the DC to the customer, and was calculated in a similar manner. Emissions from the shipment were then allocated based on the average number of boxes per shipment.

Data on transportation for customers from the DC to the retail outlet in North America were based on data provided by Shaw's, a New England based grocery store chain. This data included the total distance driven for all shipments in a year, the number of shipments, the total number of banana boxes delivered, and the percentage of all shipments composed of bananas as measured by volume. Using this data the average distance per shipment of 118 km was calculated. Emissions from the shipment were allocated based on the average of 18 boxes of bananas per shipment and 5.4% of the shipment volume being made up of bananas. This is equivalent to a full shipment of bananas alone consisting of 333 boxes.

While data from only a single grocery chain was available previous work has noted that distribution patterns are consistent across firms within regions. Typical distribution radiuses for supermarket chains would be 50-100 miles in the eastern United States and 100-150 miles in the west (Ellickson 2007). The average distance to stores calculated for Shaw's was about 70 miles, consistent with the reported values for the eastern United States. In the sensitivity analysis section of this report the effect of using the maximum distance (218 miles) rather than the average distance is shown, and the midpoint between those values might be more representative of West Coast chains. (Ellickson 2007)

Europe

The European logistics team provided data for shipments from ports to DCs where CBI managed the transportation. This consisted of records for more than 6,000 shipments and 7 million boxes of bananas. Data consisted of the origin port, destination DC, total number of shipments, total number of banana boxes, and distance between the origin and destination. A sample of the data is shown in the table below. The average shipments distance was calculated using the distance of each origin-destination pair weighted by the total number of boxes shipped on that route. The emissions from the shipment were allocated based on the average number of boxes per shipment.

Port	DC	# of Shipments	Total Boxes	Distance
Antwerp	Gdynia	323	372,004	1,226
Antwerp	Katowice	329	378,473	1,218
Antwerp	Kalisz	359	414,056	1,170

Table 5: Ground Transportation Data, EU Port to DC, Sample

CBI operates DCs in five European regions, but only manages transportation from those DCs in four regions: the U.K., the Netherlands, Poland, and Belgium. CBI provided data on shipments from the DC to customers for two of those regions, the U.K. and Poland. The data for the U.K. was based on a sample of one week's shipments while the data for Poland included 6 months of shipments. In each region the data included the total distance of the shipments, the total number of boxes shipped, and the total number of shipments. The average shipment distance was calculated using the total distance and the total number of shipments. The emissions for the shipment as a whole were allocated based on the average number of boxes per shipment.

No data for shipments from the customer DC to the retail outlet was provided. Instead an average shipment distance was calculated based on information supplied by Eurostat, the European statistical office, and sales data provided by CBI. The Eurostat database contains information on the food supply chain for the EU-27 members. This data includes the transport volume for 'potatoes, other fresh or frozen fruits and vegetables' for the EU-27 countries based on the distance which it is shipped within ranges of 0-49 km, 50-149 km, 150-499 km, or greater. Volumes were assumed to be uniformly distributed within a range, while shipments greater than 499 km were assumed to average 700 km per shipment. Using these assumptions and the percentage of shipments within each range an average shipment distance was calculated for each country. CBI provided sales data that included the volume of banana boxes sold within each European country. Using the sales volume for each country along with the calculated shipping distance for that country a weighted average distance of 193 km was calculated across the EU-27 countries. Vehicle utilization was assumed to be equal to North America, 333 boxes per shipment, and emissions from the shipment were allocated to the functional unit based on this assumption.

Refrigeration Equipment

In addition to fuel consumption required for vehicle operation ground transportation of bananas requires refrigerated containers to prevent ripening during transit. The operation of these reefer containers consumes approximately 1 gallon of diesel fuel per hour of operation based on estimates provided by Shaw's and CBI. Speed estimates from Shaw's indicate an average speed of about 36 mph including loading, unloading, and transportation times. Using these estimates fuel consumption due to refrigeration for all ground transportation stages was calculated based on the distance traveled, average speed, and fuel consumption per hour. Emissions from the refrigeration were allocated based on the average number of boxes per shipment.

Packaging and Material Shipments
Additional ground transportation emissions were calculated for shipment of the ethylene fluid from the distributor to the DC, packaging materials delivered to the farm, and for chemicals from a distributor to the banana farm. The ethylene fluid shipment travel distance was estimated using Google maps functionality to calculate the driving distance from the distributor's city to each DC. The average distance was then calculated by weighting the distance by the number of boxes processed at each DC as reported by CBI sales figures. Packaging materials are delivered to the farms on the backhaul leg of journeys from the farm to the port, so the average distance calculated for the farm to port banana shipment was used as the shipping distance of the packing materials as well. Chemical shipments to the banana farms 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, as no data has yet been collected on actual shipping distances.

Modeling
Modeling of ground transportation is based on two pieces of data: the distance traveled and the average number of boxes per truck. Using this information the process is modeled as the operation of an appropriate sized truck from the Ecoinvent 2.0 transport processes database in SimaPro. Since no United States data for trucks was available in Ecoinvent the older EURO 3 emissions standard was chosen to account for older vehicles that may exist in fleets and provide a more conservative estimate of total emissions. A comparison of emissions factors based on US data and some reported fuel efficiency information is found in the sensitivity analysis section of the report.

For ground transportation processes where data on shipment sizes and vehicles are not known, such as delivery of farm chemicals, packaging, and ethylene fluid, the transport is modeled using the Ecoinvent process "transport, lorry 16-32t, EURO3/tkm/Europe" on a tonne-km basis. Using estimated travel distances in km multiplied by the weight of the material in tonnes to determine the appropriate quantity.

North America
Shipments within North America use full size tractor-trailer equipment for all transport stages, and are modeled using 32t and larger trucks.

Europe
Shipments in Europe may vary in size depending on the region and stage of the supply chain involved. This includes a mix of 8t, 15t, and larger trucks. Shipments from the port to the DC average 1,114 boxes per shipment, and are assumed to use 32t or larger trucks. Supplied data for the U.K. indicates 44t trucks are used for shipments between the DC and customers. In Poland a mix of 8t, 15t, and 23t trucks are used. Only 17% of boxes shipped from DCs in Poland use 8t trucks, with the remaining using an unspecified mix of 15t and 23t trucks. A truck size of 23t is assumed for all shipments in Poland to provide an upper range of estimated emissions.

Tropics

Shipments to ports destined for Europe average 945 boxes per shipment, and therefore a 32t or larger truck is assumed for these shipments. Shipments bound for North America average 520 boxes per shipment, and all four sourcing countries fall in the range of 439-578 boxes per shipment. Based on this range a 23t truck is assumed for these shipments, consistent with the reported average of 550 boxes per shipment for the 15t and 23t trucks used in Poland to deliver to customers.

The average distance, boxes per shipment, and the process used within SimaPro for each ground shipment stage are shown in Table 6.

Location	Stage	Avg. Distance	Avg. Boxes	Process
North America	Port to DC	426 km	1060	Operation, lorry >32t, EURO3/Europe
North America	DC to Customer	440 km	633	Operation, lorry >32t, EURO3/Europe
North America	Customer DC to Store	118 km	333	Operation, lorry >32t, EURO3/Europe
Europe	Customer DC to Store	193 km	333	Operation, lorry >32t, EURO3/Europe
Europe	Port to DC	727 km	1,114	Operation, lorry >32t, EURO3/Europe
U.K.	DC to Customer	463 km	443	Operation, lorry >32t, EURO3/Europe
Poland	DC to Customer	140 km	359	Operation, lorry 16-32t, EURO3/Europe
Tropics (NA)	Farm to Port	385 km	520	Operation, lorry 16-32t, EURO3/Europe
Tropics (EU)	Farm to Port	227 km	945	Operation, lorry >32t, EURO3/Europe

Table 6: Ground Transportation Modeling (source: Ecoinvent 2.0)

Refrigeration Equipment

Emissions due to consumption of fuel to power the reefer container were modeled using the Ecoinvent process "Diesel, burned in diesel-electric generating set/Global". After calculating the volume of diesel fuel consumed in the genset this was converted to an equivalent amount of energy in MJ using a conversion calculator published by the Energy Information Agency.[1]

Results

[1] http://www.eia.doe.gov/energyexplained/index.cfm?page=about_energy_conversion_calculator

The results from all ground transportation operations are shown in the table below. The largest contributor to emissions for both the North American and European case was the trip from the DC to the customer. The higher vehicle utilization achieved during full truckload shipments from the port to the CBI DC reduces the overall impact on a per box basis despite similar trip lengths in North America and longer trips in Europe. As distances between ports, DCs, and customers can vary significantly a comparison of the average distance to the minimum and maximum shipment distance is included in the sensitivity analysis.

Stage	North America	Europe
Farm to Port (Lorry)	0.6	0.3
Farm to Port (Genset)	0.2	0.1
Port to DC (Lorry)	0.5	0.7
Port to DC (Genset)	0.1	0.1
DC to Customer (Lorry)	0.8	0.6
DC to Customer (Genset)	0.2	0.1
Customer to Store (Lorry)	0.4	0.6
Customer to Store (Genset)	0.1	0.1
Packaging Shipment	0.1	0.1
Fertilizer Shipment	0.0	0.0
Ethylene Shipment	0.0	0.0
Total	2.8	3.0

Table 7: Emissions from Ground Transportation (kg CO2e/box)

Ocean Transportation

Bananas are shipped between the tropics and destination ports in North America and Europe on a series of ocean shipping rotations. Each shipping rotation visits a regular series of ports on a defined schedule. The primary purpose of the shipments is the delivery of bananas to the destination market, but some cargo is also shipped back to the tropics during the return (backhaul) portion of the voyage.

Data

CBI provided shipment data for one complete shipping rotation for each of the three European services and two full rotations for two of the three North American services. This data included the shipping distance, cargo weight, and fuel consumption during each leg of the voyage. The tonne-km of cargo shipped was calculated by multiplying the distance in kilometers by the cargo in tonnes for each leg of the rotation. The ocean data provided for the Gothenburg-Bremerhaven service is shown in the table below as a sample.

From	To	Cargo (Tonnes)	Distance (Nautical Miles)	Fuel, Propulsion (Tonnes)	Fuel, Auxiliaries (Tonnes)	Tonne-km	Total Fuel Consumption (Tonnes)
Almirante	Moin	6223	65	7.0	1.3	749,125	8.3
Moin	Gothenburg	8301	5410	663.5	46.4	83,170,375	709.9
Gothenburg	Bremerhaven	6211	349	41.8	3.8	4,014,467	45.6
Bremerhaven	Almirante	1850	5149	561.3	41.0	17,641,504	602.3

Table 8: Sample Ocean Data

Using this data the fuel consumption (propulsion and auxiliaries) from the operation of the shipping vessel was calculated per tonne-km of goods shipped adding the results from each leg to calculate the total fuel consumption and tonne-km for the rotation. This process was repeated for each service, and total average fuel consumption per tonne-km was calculated for all services together.

Service	Fuel (tonnes)	Cargo (tonne-km)	Fuel Efficiency (g/tkm)
Wilmington-Gulfport-Freeport	1,054	100,521,756	10.5
Port Everglades	360	35,390,431	10.2
Gothenburg-Bremerhaven	1,366	105,575,471	12.9
Sheerness-Antwerp	1,214	89,041,451	13.6
Southern	1,443	89,586,805	16.1
Average	1,087	84,023,183	12.9

Table 9: Fuel Efficiency by Service

Shipping distance for each destination port was calculated from the first port on the rotation through to the destination port using the data provided by CBI. For ports that were not included on the rotations provided in the data distances were calculated using sailing schedules provided by CBI and distances between ports calculated using www.dataloy.com. Using the data from Gothenburg-Bremerhaven as an example, shipments were assumed to originate in Almirante and distances were calculated as 5,475 nautical miles to Gothenburg and 5,824 to Bremerhaven. This distance was calculated for every destination port and a weighted average for North America and Europe was calculated based on the volumes shipped to each destination port.

Destination Port	Distance (kms)	Share of Volume
Antwerp	9,443	29%
Bremerhaven	10,786	25%
Gothenburg	10,140	13%
Aegion	13,451	7%
Vado	11,958	8%
Civitavecchia	12,342	11%
Setubal	9,666	3%
Sheerness	9,354	4%
Average	10,651	

Table 10: European Ocean Shipping Distances

Destination Port	Distance (kms)	Share of Volume
Hueneme	3,880	22%
Everglades	1,671	12%
Gulfport	1,882	23%
Freeport	2,909	6%
Wilmington	5,593	37%
Average	3,737	

Table 11: North American Ocean Shipping Distances

Fuel consumption for boxes sent to each destination port was calculated by multiplying the distance to the port by the weight of the boxes in tonnes to find the total tonne-km. This figure was multiplied by the average efficiency of 12.9 g/tonne-km to calculate total fuel consumption per box. Average weight per box was provided by CBI as 20.2 kg for North America and 20.9 kg for Europe. This figure is based on the total weight of bananas, their packaging, and pallets divided by the number of boxes.

Modeling

Ocean transportation of bananas from the tropics to market in Europe or North America was modeled using a modification of the Ecoinvent process "transport, transoceanic freight ship/tkm/OCE". The Ecoinvent process is based on data for a vessel assumed to be 50,000 deadweight tons (dwt) with a 65% utilization rate and fuel consumption of 2.5 g/tkm. While these assumptions may be appropriate for larger sized freight vessels the typical banana freight vessel is a much smaller size and operates at higher speeds, resulting in greater fuel consumption. The data provided by CBI showed an average fuel consumption of 12.9 g/tkm, more than five times greater than the value used in the Ecoinvent transoceanic freight process.

A number of factors may contribute to this increased fuel consumption, but the higher speed, smaller size, and lower utilization of the banana vessels are likely causes. The vessels used to haul bananas vary in size, but all are less than 20,000 dwt, significantly smaller than the ocean freighter assumed in Ecoinvent. Further, Chiquita achieves a lower utilization than assumed by Ecoinvent, 43% compared to 65%. Much of this lower utilization is related to the backhaul portion of the voyage, where utilization is quite low.

To compensate for the effect of this increased fuel consumption a new process was created in SimaPro based on the Ecoinvent "Transport, transoceanic freight ship/Ocean" process. This new process was simply a copy of the existing process; however, each tonne-km of ocean transport was changed to require 5.16 tkm of vessel operation. This accounts for the increased fuel consumption and related emissions due to the lesser efficiency reflected in the Chiquita data.

Packaging Estimates

In addition to shipment of bananas to the destination ports the ocean vessels are also used to deliver packaging materials to the tropics. Based on information from CBI the materials are produced in the United States shipped out of Gulfport on the return voyage of the banana vessels for delivery to the farms in the tropics.

Data
The distance for the shipment and the weight of the packaging and pallets are assumed to be identical as for the shipments of bananas to Gulfport. Emissions are allocated to the bananas based on the assumption of one box and shroud per banana box, one set of corner board per pallet, and one pallet for every forty-eight banana boxes.

Modeling
The shipments are modeled using the same oceanic freight process as was used for the banana shipments.

Results
The emissions from the ocean shipping of the bananas represent a significant source of emissions in the supply chain, particularly in the case of Europe. The average distance for shipments destined for Europe is three times as great as for the average shipment to North America, producing the much higher emissions value. Despite the much higher emissions than typical large oceanic freight transport the emissions from ocean shipping are still more efficient than ground transportation by a factor of between 1.5 and 4 times depending on the utilization of the truck. Even achieving a similar level of utilization on the backhaul portion of voyages as on the fronthaul could produce nearly double the current level of efficiency.

Stage	North America	Europe
Banana Shipment	3.6	10.6
Packaging Shipment	0.0	0.0
Total	3.6	10.6

Table 12: Emissions from Ocean Transportation (kg CO2e/box)

Facilities

Four types of facilities are involved with producing and distributing bananas:

- Farms where the bananas are grown and packaged.
- Ports where they are loaded and unloaded from ships and may be stored temporarily.
- Distribution centers that store and ripen the bananas. May be operated by CBI or the retail customer.
- Retail outlets where the bananas are sold to end consumers.

Distribution Centers

Distribution centers are used to store the bananas and provide chemical ripening before shipping to the customer DC or the retail outlet. Operations at the DC requiring energy may include heating, cooling, and lighting of the facility; electricity and propane to power cargo handling equipment; diesel burned in trucks moving containers; and electricity to power the banana ripening rooms. CBI DCs primarily handle bananas, with other products such as plantains and pineapples making up less than 1% of volume. The Shaw’s DC, however, handles all perishable goods sold at their stores. Bananas are high volume products and have a separate room for storage and ripening within the facility. This room is kept chilled, but at a higher temperature than other parts of the facilities which handle other refrigerated products.

Data

North America

CBI operates nine DCs within the United States. Energy consumption was calculated for six of those DCs based on their utility bills and purchase records for a one year period. The total number of banana boxes processed in each facility was calculated based on sales data. An average consumption of each energy source per box was calculated for each DC separately and for the total of all five reporting DCs together.

DC	Boxes	Electricity (kWh)	Propane (lbs)	Diesel (gallons)	Fuel Oil (gallons)	Natural Gas (100 ft^3)
Boston	1,032,947	597,289	2,345	0	0	1,243
Mid Atlantic	2,439,871	1,215,600	0	23,158	10,000	0
Atlanta	1,179,638	432,766	0	0	0	5,669
Miami	4,806,068	3,508,320	4,824	70,856	0	0
Gulfport	978,686	1,117,080	0	0	0	0
Los Angeles	2,922,417	511,280	0	66,040	0	0
Total	13,359,627	7,382,335	7,169	160,054	10,000	6,912

Table 13: North American CBI DC Data

Shaw's provided utility data for electricity consumption and banana sales data for their perishable DC over a one year period. Energy consumption in the DC was allocated to bananas based on the percentage of square footage of the facility occupied by the banana room. The emissions from this share of the facility energy consumption were then allocated based on the total boxes of bananas sold by Shaw's in the year.

Customer DC	
kWh	6,045,000
Allocation %	5.4%
Boxes	1,161,600
kWh/box	0.28

Table 14: North American Customer DC Data

Europe

CBI operates eleven DCs in five different European countries, the U.K., Sweden, Poland, the Netherlands, and Belgium. Electricity and banana sales data were reported for a six month period for ten of the eleven DCs. Average electricity consumption per box was calculated for each DC as well as an overall average using the total kWh consumption and sales data for the ten reporting facilities.

Facility	Electricity Consumption (kWh)		Boxes	Electricity per box (kWh / box)
Dewsbury	1,196,530	718,306	1,196,530	1.67
Sheerness	440,363	584,333	440,363	0.75
Puurs	1,687,074	1,011,781	1,687,074	1.67

Gorinchen	764,305	499,153	764,305	1.53
Meppel	325,400	226,993	325,400	1.43
Helsingborg	674,795	512,367	674,795	1.32
Enkoeping	545,967	371,820	545,967	1.47
Katowice	456,000	426,312	456,000	1.07
Gdynia	533,000	370,303	533,000	1.44
Kalisz	473,000	364,197	473,000	1.30

Table 15: European CBI DC Data

No data was provided for customer DCs in Europe. Electricity consumption was assumed to be the same as the North American data on a per box basis.

Modeling
Electricity consumption was modeled using the Ecoinvent process for medium voltage electricity + imports specific to the country of operation where the facility is located. For example, distribution centers in the United States were modeled using the process "Electricity, medium voltage, at grid/USA" while those in the UK use the process "Electricity, medium voltage, at grid/Great Britain". The customer DC in Europe was modeled using the process "Electricity, medium voltage, production RER, at grid/Europe" to represent the average European electricity system.

Specific knowledge about the equipment used to burn natural gas at different facilities was not known. The Ecoinvent process "Natural gas, burned in boiler atm. low-NOx condensing non-modulating <100kW/Europe" was used to model gas consumption within facilities. Consumption reported in cubic feet of natural gas was converted to megajoules based on the calculator published by the EIA. Other available Ecoinvent processes for consumption of natural gas in boilers or industrial furnaces for heat produce emissions that range from 13% below to 10% above the chosen process, but due to the small impact on the overall life cycle these differences do not produce significant differences in the total carbon footprint.

Fuel oil was modeled using the process "Heat, light fuel oil, at boiler 100kW condensing, non-modulating/Switzerland". Conversion from gallons to MJs was done using the EIA calculator.

Diesel consumption was modeled using the process "Operation, lorry >32t, EURO3/Europe" and converted from gallons of fuel to kilometers of operation based on the assumed fuel efficiency of 34 liters per 100 km.

Finally, no process was available for the consumption of propane in forklifts, so "Operation, passenger car, natural gas/Switzerland", a process for consumption of natural gas in automobiles, was used as a substitute. Pounds of propane were assumed to be equivalent to pounds of natural gas, and consumption was modeled based on the assumed efficiency of .064 kg of natural gas per kilometer of travel.

Results
The results for the DCs are shown below. Emissions are the CBI DC are significantly higher on a per box basis than at the customer DC due to higher utilization of the Shaw's DC. While both Shaw's and individual CBI DCs handle similar volumes of bananas this represents only a small

fraction of the total material handled by the perishable DC, and this higher utilization more than offsets the higher total energy consumption of the facility.

Distribution Center	North America	Europe
CBI DC	0.5	0.8
Customer DC	0.2	0.1
Total	1.2	0.9

Table 16: Emissions from Distribution Centers (kg CO2e/box)

Retail Outlet

Bananas typically require no special handling at the retail outlet, but electricity and natural gas are consumed at the store for heating, lighting, office equipment, checkout registers, and other activities required to run the store. At Shaw's bananas may be delivered to the store on a nearly daily basis. Once they arrive they are usually placed in a storage room with other produce and used to restock the banana display on the sales floor several times per day.

Data

North America

Utility and sales data were collected from one of Shaw's retail store that was considered to be representative of an average store. The energy data included total electricity and natural gas consumption for one year. Sales data included the total store sales volume in dollars, banana sales in dollars, and banana sales in boxes for the year. For this phase an allocation based on the economic value of products sold was used. A retail grocery store 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 allocated to individual banana box level by dividing the allocated energy by the total boxes of bananas sold at the store during the year.

Name	Value
Electricity (kWh)	2,536,490
Natural Gas (cubic ft)	39,867
Allocation %	0.65%
Boxes	5,760
kWh/box	2.86
cubic ft/box	0.04

Table 17: North American Store Data

Europe

No data from a European retailer has been collected yet. Instead it was assumed that per box consumption of electricity and natural gas was the same as in the case of North America.

Modeling

Electricity consumption was modeled in an identical method to that used for DCs. Since no store data was provided for specific countries in Europe the average European electricity process that was used for the customer DC was also used for the retail store. Natural Gas consumption was also modeled in the same manner as for DCs.

Results

Emissions from energy use at the retail store are shown in the table below. Nearly all emissions are the result of electricity usage, as the small amount of natural gas used does not produce significant emissions. Emissions from the store are higher than at the DCs due to the greater efficiency of DCs. A single distribution center may process the same number of bananas as are sold at hundreds of stores, and while energy consumption in total is higher at the DC it is lower on a per box basis. Emissions in Europe are again lower due to the lower emissions intensity of the average European electricity production process.

Store	North America	Europe
Retail Store (Electricity)	2.3	1.5
Retail Store (Natural Gas)	0.0	0.0
Total	2.3	1.5

Table 18: Emissions from the Retail Outlet (kg CO2e/box)

Port Operations

Facilities at the port can include a refrigerated storage building, offices, and a container yard used for storing and powering the reefer containers. Activities that generate emissions may include powering facilities, drayage operations involving trucks moving containers within the yard, and operation of heavy equipment cargo equipment. The exact usage depends on the infrastructure and operations at the ports involved.

Data

North America

The North American logistics team provided electricity and diesel consumption data for one year for all ports except Freeport. Data on the number of boxes handled at each port were based on reported shipments via ocean to each port. Electricity and diesel consumption were calculated per box at each port and then an average for all ports was calculated based on total consumption and boxes handled.

Port	Boxes	Electricity (kWh)	Diesel (gallons)	kWh/box	Gallons/box
Wilmington	23,319,318	8,927,829	31,450	0.383	0.001
Gulfport	14,449,053	8,345,262	1,548	0.578	0.000
Port Everglades	7,352,312	6,981,832	41,226	0.950	0.006
Hueneme	14,087,360	2,620,020	0	0.186	0.000
Total	63,166,010	26,874,943	74,974	0.425	0.001

Table 19: North American Port Data

Europe

The European logistics team provided data for ten destination ports in Europe. This data included the total electricity, natural gas, and diesel fuel consumed as well as the total boxes handled during a given time period. Average energy consumption per box was calculated for each port during the given timeframe, and then an overall average was calculated based on the share of boxes handled by each port during the full year as reported by ocean shipping data.

Port	Weeks of Data	Boxes	Share	Electricity (kWh)	Natural Gas (liters)	Diesel (liters)	Electricity (kWh/box)	Natural Gas (liters/box)	Diesel (liters/box)
Sheerness	20	2,189,338	3%	757,175	0	0	0.35	0.00	0.00
Bremerhaven	25	7,003,378	25%	1,636,000	450,000	0	0.23	0.06	0.00
Antwerp	52	12,938,755	24%	2,239,696	0	83,523	0.17	0.00	0.01
Vado	34	3,571,894	9%	129,500	0	0	0.04	0.00	0.00
Civitavechia	52	4,571,458	11%	945,392	0	0	0.21	0.00	0.00
Setubal	-	2,496,000	3%	210,525	0	7,800	0.08	0.00	0.00
Aegion	34	3,122,265	7%	351,393	0	0	0.11	0.00	0.00
Gothenburg	52	6,240,000	16%	1,594,360	0	84,340	0.26	0.00	0.01

Table 20: European Port Data

Tropics

Energy consumption data was collected for one origin port in the tropics, Puerto Limon in Costa Rica, based on fuel and electricity purchase records for the year. This was separated into fuel consumed for truck operation at the port, operating heavy equipment, powering generators, and electricity used in the container yard. Emissions were allocated per box using the total number of boxes shipped from the port during this time period. Data for other ports was not yet available, and was assumed to be the same as for Costa Rica.

Category	Energy Source	Total Consumption	Total Boxes	Per Box
Heavy Equipment	Diesel (liters)	307,047	12,121,430	0.03
Container Yard	Electricity (kWh)	11,643,348	12,121,430	0.96
Generators	Diesel (liters)	364,412	12,121,430	0.03
Truck Operation	Diesel (liters)	123,766	12,121,430	0.01

Table 21: Costa Rica Port Data

Modeling

North America

For operations at ports in North America electricity consumption is modeled using the Ecoinvent process for medium voltage + imports specific to the United States, “Electricity, medium voltage, at grid/USA”. Diesel consumption reported for use in trucks at the port was modeled using the process “Operation, lorry >32t, EURO3/Europe“. Conversion from gallons to kilometers of operation was done using the assumed efficiency of 34 liters per 100 km of operation. No data for heavy equipment used to unload and move containers was reported; instead consumption of diesel for use in heavy equipment was assumed to be the same as reported in Costa Rica on a per box basis.

Europe

For operations at ports in Europe electricity consumption is modeled using the Ecoinvent process for medium voltage + imports specific to the country where the port is located. Similar to North America, no data for heavy equipment used to unload and move containers was reported, and consumption was assumed to be the same as in Costa Rica. Diesel consumption for truck operation was converted to kilometers of vehicle travel based on the 34 l/100 km fuel consumption of the greater than 32t EURO3 lorry from the Ecoinvent database used as the model for truck operation within SimaPro.

Tropics

Country specific electricity information was not available within the Ecoinvent database for Costa Rica. Instead, a new process was created in SimaPro using processes from the Ecoinvent database and based on the electricity generation mix of Costa Rica. Data regarding the electricity generation mix in Costa Rica was obtained from the IEA[2] for 2007, the most recent year available. From this data the percentage of kWhs produced by each source was calculated in Excel, and a new process created using the percentages of generation and processes shown in Table 22. The electricity production mix in Costa Rica has very low emissions intensity due to the high usage of renewables. A comparison with the electricity production in other regions of the tropics is shown in the sensitivity analysis section of the report.

Source	% of Generation	Process	Note
Oil	8%	Electricity, oil, at power plant/UCTE U	
Biomass	1%	Electricity, bagasse, sugarcane, at fermentation plant/BR U	
Hydro	75%	Electricity, hydropower, at reservoir power plant, non alpine regions/Europe	
Geothermal	14%	Electricity, hydropower, at reservoir power plant, non alpine regions/Europe	Hydro as a substitute for Geothermal, as no geothermal process exists in Ecoinvent
Wind	3%	Electricity, at wind power plant/Europe	

Table 22: Costa Rica Electricity Production Mix (Database Source: Ecoinvent 2.0)

No specific process existed in Ecoinvent for the operation of heavy equipment at the port, such as cranes or loaders, and therefore the operation of a building machine was used as a substitute. Other possible substitutions include operation of a hydraulic digger, skid loader, and chopper, all of which produce emissions within 10% of the operation of a building machine. The specific processes used within SimaPro for port operations are shown in Table 23. For processes that used activity data in MJ the conversion between liters of diesel and MJ was based on the EIA energy conversion calculator.

[2] http://www.iea.org/stats/electricitydata.asp?COUNTRY_CODE=CR

Activity	Process	Notes
Heavy Equipment	Diesel, burned in building machine/Global	Activity data in MJ
Truck Operation at Port	Operation, lorry >32t, EURO3/Europe	Km traveled based on assumed 34 l/100km consumption
Electricity Consumption	Electricity, medium voltage, at grid/Costa Rica	Custom energy production mix for Costa Rica
Electricity Consumption	Electricity, medium voltage, at grid	Country specific electricity process for United States and European ports
Diesel Use in Generators	Diesel, burned in diesel-electric generating set/Global	Activity data in MJ

Table 23: Port Operations (Database Source: Ecoinvent 2.0

Results

Results for port operations from all three regions are shown below. Emissions from Europe are lower primarily due to the reported low energy consumption per box. North American and Costa Rica showed similar electricity consumption per box, but the electricity generation in Costa Rica is significantly lower in emissions intensity than in the United States.

Source	North America	Europe	Costa Rica
Electricity	0.4	0.1	0.1
Heavy Equipment	0.1	0.1	0.1
Truck Operation	0.0	0.0	0.0
Generators	0.0	0.0	0.1
Natural Gas	0.0	0.0	0.0
Total	0.5	0.2	0.3

Table 24: Emissions from Port Operations (kg CO2e/box)

Farms

In addition to the energy consumption at the distribution facilities farms consume energy during the cultivation and packing of bananas. Though banana farming still relies heavily on manual labor energy is needed to power farm equipment, spray chemicals, and power packing stations.

Data

Practices vary between farms, and at this time data regarding the energy consumption at each farm was not available. Instead total data was provided for all farms in one growing region in Costa Rica. This region contains more than 30 farms and produced more than 12 million boxes in 2009. This data includes fuel records for diesel used to run generators and farm equipment; electricity purchased from the grid for powering packing stations and offices; gasoline and diesel used in vehicles; and estimates of fuel consumption by airplanes used to spray chemicals. Total fuel and electricity consumption were allocated per box by dividing the total consumption by the number of boxes produced by the region during the year.

The company that operates the agricultural spraying service provided estimates for the fuel consumption of the airplanes used during the spraying process. This approximation was based on an estimate of the amount of fuel required to spray one hectare of farmland. Total consumption was then calculated by the farm operations team based on total number of hectares sprayed during all spraying operations for the year. Emissions from spraying were allocated per box based on the total production for the year.

Activity	Fuel	Consumption	Boxes Produced	Consumption per box
Building Power	Electricity (kWh)	5,536,529	12,121,430	0.46
Vehicle Operation	Diesel (liters)	15,910	12,121,430	0.00
Vehicle Operation	Gasoline (liters)	12,091	12,121,430	0.00
Aircraft Spraying	Diesel (liters)	847,454	12,121,430	0.07
Generators	Diesel (liters)	63,266	12,121,430	0.01
Generators	Gasoline (liters)	10,415	12,121,430	0.00

Table 25: Data from Farm Operations

Modeling

Electricity was modeled using the custom electricity production mix process created for Costa Rica described in the Port Operations section. Total liters of gasoline and diesel used to run generators were converted to an equivalent amount of MJs of energy, and then modeled as "Diesel, burned in diesel-electric generating set/Global". Fuel consumption in vehicles was modeled as "Operation, lorry 16-32t, EURO3/Europe" for diesel consumption and "Operation, passenger car, petrol, EURO3/Switzerland" for gasoline consumption. Conversions from liters consumed to kilometers of operation were made using the assumed fuel economy within Ecoinvent corresponding to 8 l/100km for passenger cars and 22 l/100km for 16-32t trucks.

The process of spraying the chemicals was modeled in SimaPro using the process "Transport, helicopter/Global" from the Ecoinvent database. This functional unit of this process is 1 hr of flying time in the helicopter. The flying time required for the spraying was calculated using the Ecoinvent assumption of 26.4 kg of kerosene per hour, and converting between liters of fuel consumption and kg of kerosene consumption using the EIA conversion of diesel fuel from liters to kg. Modeling of helicopter operation was used as a substitute as no suitable airplane operations are contained within the Ecoinvent database. Helicopters are sometimes used to provide agricultural services, while the only other types of aircraft operation available are for passenger and cargo planes.

Activity	Process	Notes

Electricity	Electricity, medium voltage, at grid/Costa Rica U	Custom energy production mix
Aircraft Operation	Transport, helicopter/Global	26.4 kg/hr .834 kg/liter
Vehicle Operation (diesel)	Operation, lorry 16-32t, EURO3/Europe	Assumes 22 l/100 km
Vehicle Operation (gasoline)	Operation, passenger car, petrol, EURO3/Switzerland	Assumes 8 l/100 km
Generators	Diesel, burned in diesel-electric generating set/Global	In MJ

Table 26: Farm Operations (Database source: Ecoinvent 2.0)

Results

Emissions from farm operations are shown in the table below. The fuel consumption due to aerial spraying is the primary source of emissions due to operations at the farm. The low emissions intensity of electricity generation in Costa Rica keeps emissions from the packing station low. A comparison of electricity emissions intensities of other growing regions is included in the sensitivity analysis section of this report.

Source	CO2e
Electricity	0.0
Vehicles (gas)	0.0
Vehicles (diesel)	0.0
Generators	0.1
Aircraft	0.2
Total	0.3

Table 27: Emissions from Farm Operations (kg CO2e/box)

Materials

Emissions related to the production of materials used in the supply chain can be placed in to two categories: packaging materials and chemicals. The primary packaging materials included in the analysis were the cardboard banana box, the plastic shroud used to wrap bananas inside the banana box, and the cardboard corner board used to help stabilize the boxes of bananas for transport. In addition to the primary packaging the plastic banana wrapper used to protect the banana bunches during cultivation is included, as well as the plastic bottle used to hold the ethylene fluid used for ripening. 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 primary packaging for the bananas consists of a plastic shroud used to enclose the bananas and a cardboard box that the shroud and bananas are placed within. Boxes of bananas may then be stacked on pallets, typically with 48 boxes per pallet. Cardboard corner board may be placed on the edges of the stacked banana boxes to provide stability during transit. The wooden pallets used during shipping are durable goods that are collected and reused, and their production and disposal is excluded from this study.

Data

Data for the box and shroud is based on specifications provided by CBI to the companies that produce the packaging. This data includes the type of material for the packaging as well as the weight of the product. The banana box has three different models: one for North American container shipment, one for North American bulk shipping, and one for European boxes. Each box is constructed of the same corrugated cardboard, but differ in dimensions and final weight. The plastic shrouds likewise differ between the North American and European markets, with the North American shroud produced from HDPE and the European one from LDPE.

No data was provided regarding the cardboard used in the corner board. Instead an assumption of 0.61 kg of recycled cardboard was used based on published numbers for a similar product.

Object	Weight (kg)	Material	Data Source
Box (NA - underdeck)	1.41	Cardboard	Chiquita specifications, BN_209_Cont_00_B_flute.pdf
Box (NA - container)	1.28	Cardboard	Chiquita specifications, BN_209_GS_UD_00_flute.pdf
Box (EU)	1.26	Cardboard	Chiquita specifications, UF_21A_05.pdf
Shroud (EU)	0.03	LDPE Plastic	Chiquita specifications, Polypack_04_02.pdf
Shroud (NA)	0.03	HDPE Plastic	Chiquita specifications, L_Polypack_312_05_HDPE.pdf
Corner board	0.61	Cardboard	Alliance Plastics, .200 caliper, 2x2 4 ft * 4 * .336 lbs/ft = 1.344 lbs per pallet load

Table 28: Packaging Data

Modeling

The primary packaging materials are modeled in SimaPro as shown in Table 29 below. In two cases the material used in the LCA model required some modification. First, banana boxes are produced from fresh fibre, rather than mixed. However, the Ecoinvent process for fresh fibre corrugated board production gives a negative carbon footprint for the production process due to the inclusion of carbon dioxide sequestered in the wood. Consistent with the system boundary, these emissions are excluded from this study. Instead of fresh fibre the process for mixed fibre corrugated board was used.

Second, the shroud used in North America is specified as HDPE rather than LDPE. No process for creating packaging film from HDPE was included in the Ecoinvent database, so instead the process “Packaging film, LDPE, at plant/Europe” was copied. The process was modified by substituting the material “Polyethylene, HDPE, granulate, at plant/Europe” for the original LDPE material “Polyethylene, LDPE, granulate, at plant/Europe” as the input to the production process. This new material is identical to the LDPE version with the exception of an equal amount of the HDPE granulate material substituting for LDPE granulate.

Name	Material	Notes
Box (All)	Packaging, corrugated board, mixed fibre, single wall, at plant/Europe	Substituted for fresh fibre due to modeling of sequestered CO_2
Shroud (EU)	Packaging film, LDPE, at plant/Europe	

Shroud (NA)	Packaging film, HDPE, at plant/Europe	Modified from LDPE Packaging Film process
Corner board	Corrugated board, recycling fibre, double wall, at plant/Europe	

Table 29: Materials (Database source: Ecoinvent 2.0)

Results

The results from each of the three packaging scenarios are shown below. The plastic shroud is identical between the two North American scenarios, while the corner board is the same across all scenarios. In all cases the production of the banana box is the most significant source of emissions in the primary packaging.

Material	NA - Underdeck	NA - Container	EU
Banana Box	1.1	1.0	1.0
Plastic Shroud	0.1	0.1	0.1
Corner board	0.0	0.0	0.0
Total	1.2	1.1	1.1

Table 30: Emissions from Packaging Materials (kg CO2e/box)

Farm Chemicals

A number of agricultural chemicals are applied during banana cultivation, including fertilizers, pesticides, and fungicides. Exact chemical requirements vary by growing region and based on the specific qualities of the farms in question. Emissions related to the application of the chemicals were covered in the section on farm operations, while emissions of Nitrous Oxide due to application of Nitrogen based fertilizers are covered later in the section on other emissions sources.

Data

Data regarding the chemicals used to help cultivate the bananas at the farm is based on recommended doses provided by CBI. Actual usage varies from farm to farm based on specific conditions and management. For fertilizers CBI's agricultural management group provided a list of recommended applications for eight chemicals in six different growing regions. The average value of the recommended dosage across all regions was used as the base scenario. The active ingredients recommended for use as fertilizers by CBI are N, P_2O_5, K_2O, MgO, B, Zn, S, and CaO. In addition a recommended range of application quantities was provided for three more elements: Fe, Cu, and Mn.

	Division					
	Cobigua	TRRCo	COBAL Sarapiqui	COBAL Matina Limon	BOFCo	Average
N	399	386	385	392	384	389.2
P2O5	88	85	92	92	83	88.0
K2O	763	677	628	710	642	684.0
MgO	0	66	69	0	39	34.8
S	62	82	82	56	47	65.8
CaO	0	0	28	36	58	24.4
B	3.2	2.2	6.7	6.7	4.7	4.7

Zn	1.2	0.6	6.7	6.9	7	4.5
Fe	0-3	0-3	0-3	0-3	0-3	1.5
Cu	0-1	0-1	0-1	0-1	0-1	0.5
Mn	0-2	0-2	0-2	0-2	0-2	1.0

Table 31: Recommended Fertilizer Applications (kg/ha/yr)

In addition to fertilizers CBI provides a similar recommendation for the use of pesticides and fungicides. Recommendations are provided in the form of a range of the number of applications per year and the amount of active ingredient per application. The base scenario for analysis is based on using the midpoint of the recommended applications and amounts of active ingredients. The commercial name, active ingredients, and recommended annual applications are shown in Table 32.

Commercial Name	Active Ingredient	Amount of Active Ingredient (Kgs/ha/yr)
Opal 7.5 E.C	Epoxiconazole	0.2 - 0.3
Sico 25 EC	Difeconazole	0.3 - 0.4
Folicur 25 EW	Tebuconazole	0.3 - 0.4
Silvacur 30 EC	Tebuconazole y Tridiamenol	0.12 - 0.24
Tega 30C	Trifloxytrobin	0.1
Regnum 25 EC	Pyraclostrobin	0.1
Calxin 86OL	Tridemorph	2.15 - 4.30
Siganex 60 SC	Pyrimethanil	0.6 - 1.2
Impulse 80 EC	Spyroxamine	0.96
Dithane 60 SC	Mancozeb	57
Spraytex o Banole		27 - 432

Table 32: Recommended Pesticide Application

All chemical usage is based on recommended doses per hectare per year. The amount of chemical usage per box was then calculated using farm yield data per hectare provided by CBI. Yield information is a key performance indicator for farm productivity, and CBI provided data on total average yield in boxes per hectare from different growing regions.

	Honduras and Guatemala	Costa Rica	Panama	Total

Hectares	5,000	6,400	5,000	16,400
Yield (boxes per ha)	2,550	2,400	2,400	2,446
Production	12,750,000	15,360,000	12,000,000	40,110,000

Table 33: Farm Yield Data

Application of the chemicals is performed manually or by aerial spraying. It is assumed that no additional emissions arise from manual spraying, while emissions from aerial spraying are covered in the section on energy use at the farms. Emissions related to the delivery of chemicals to the farm are covered in the section on transportation.

Modeling

Fertilizer recommendations were based on application of the active ingredient, and the specific fertilizer used in the model is shown in the table below. For N, P2O5, and K2O the Ecoinvent process data is also based on the amount of the active ingredient. Thus 1 kg of "Ammonium Nitrate, as N" includes enough Ammonium Nitrate to supply 1 kg of Nitrogen based on the assumed Nitrogen content of Ammonium Nitrate. For Ecoinvent processes that are not based on an amount of active ingredient the assumed content is shown in the Notes column. For example, Borax is assumed to be 11% Boron, thus 100 kg of Borax would be required to produce 11 kg of Boron as the active ingredient. The specific process data used within SimaPro for these chemicals is shown in the table below. Nutrient concentrations for micronutrients are based on data found at:
http://www.soil.ncsu.edu/publications/Soilfacts/AG-439-18/.

Nutrient	Fertilizer	Note
N	Ammonium nitrate, as N, at regional storehouse/Europe	
P_2O_5	Ammonium nitrate phosphate, as P2O5, at regional storehouse/Europe	
K_2O	Potassium chloride, as K2O, at regional storehouse/Europe	
MgO	Magnesium oxide, at plant/Europe	
S	Secondary sulphur, at refinery/Europe	
CaO	Quicklime, milled, packed, at plant/Switzerland	
B	Borax, anhydrous, powder, at plant/Europe	Assumed 11% B
Zn	Zinc monosulphate, ZnSO4.H2O, at plant/Europe	Assumed 33% Zn
Fe	Iron sulphate, at plant/Europe	Assumed 20% Fe
Cu	Copper oxide, at plant/Europe	Assumed 89% Cu
Mn	Manganese, at regional storage/Europe	

Table 34: Fertilizers (Database Source: Ecoinvent 2.0)

Data on applications of pesticides and fungicides follows similar guidelines to that of fertilizers; however, the specific chemicals used at banana plantations are not found in the Ecoinvent database. Instead, all pesticides and fungicides are modeled using the Ecoinvent process "Pesticide unspecified, at regional storehouse/Europe". A sensitivity analysis examining both the amount and types of chemical use modeled at the farms is available later in this report.

Results

The impact of chemical production under the baseline assumption for usage and average yield per hectare is shown below. Emissions from the application of Nitrogen based fertilizers are high due to the relatively high amounts applied as well as the intensity of the production process.

Chemical	Emissions
N	1.4
P2O5	0.0
K2O	0.1
MgO	0.0
S	0.0
CaO	0.0
B	0.0
Zn	0.0
Fe	0.0
Cu	0.0
Mn	0.0
Pesticides	1.1
Total	2.6

Table 35: Emissions from Farm Chemical Production (kg CO2e/box)

Other Materials

Data

In addition to the primary packaging and chemical use at the farms a limited number of other materials are used throughout the supply chain. This includes the ethylene used to chemically ripen the bananas at the ripening center, the plastic bottle the ethylene is packaged in, and a plastic banana bunch wrapper used to protect the banana bunches on the tree as they mature. Specifications for the plastic ethylene bottle and plastic banana wrap were not provided, instead estimates were created based on publicly available data for similar products:

- Banana Bunch Wrapper – .04 kg of LDPE plastic. Source: http://www.agnet.org/library/pt/2001036/
- Ethylene Bottle - .06 kg of HDPE plastic. Source: http://www.thecompliancecenter.com/store/us/PK-P3200.html

In addition to chemicals used to grow the bananas a small amount of ethylene fluid is used to chemically ripen the bananas just before sale. One 32 oz bottle of ethylene fluid is composed almost entirely of ethanol and is capable of ripening a full container (960 boxes) of bananas. The fluid is used in specially designed banana ripening rooms that catalyze the ethanol and release the ethylene as a gas to circulate it among the banana boxes. This process causes the banana to ripen over a period of 3-4 days, at which point they are ready to sell.

Modeling

The specific processes used to model these materials are shown in the table below. For the ethylene bottle in addition to the HDPE granulate used as the basic material an injection molding process was included for the production process. The amount of ethanol is based on the assumption of a 32 oz bottle of ethanol with a density of .789 g/cm3. Emissions from these materials are allocated based on the assumption of one bottle of ethylene per 960 boxes and one banana bunch wrapper per box. The allocation for the banana bunch wrapper is based on data supplied by the farm operations group in Costa Rica that estimates one bunch of bananas produces enough saleable bananas to supply one box.

Material	Process	Notes
Ethylene Bottle	Polyethylene, HDPE, granulate, at plant/Europe	Includes the process Injection moulding/Europe
Ethylene Fluid	Ethanol from ethylene, at plant/Europe	0.75 kg of ethanol
Banana Bunch Wrapper	Packaging film, LDPE, at plant/Europe	

Table 36: Other Materials (Source: Ecoinvent 2.0)

Results

None of these materials produce significant emissions relative to the overall supply chain. The effect of allocating emissions from the ethylene over an entire container load of bananas reduces the overall impact of producing both the ethanol and the plastic bottle.

Material	Emissions
Ethylene Bottle	0.0
Ethylene Fluid	0.0
Banana Wrapper	0.1
Total	0.1

Table 37: Emissions from Other Materials (kg CO2e/box)

Other Emissions

Two other sources of emissions included in this study are the release of certain refrigerant gases to the atmosphere and the release of nitrous oxide (N_2O) due to the application of nitrogen based fertilizers to soil. Land use changes can also contribute to climate change; however, they are excluded from this study as the farms that produce bananas are generally pre-existing and not the result of recent changes in land use.

Nitrous oxide is produced naturally in soil, and one of the main factors in its production is the amount of nitrogen in the soil. When nitrogen is added to the soil through the application of fertilizers the amount of available nitrogen increases, resulting in increased production of N_2O. N_2O is a greenhouse gas with a global warming potential (GWP) of 298 according the latest report by the IPCC, meaning each kg of N_2O in the atmosphere produces a warming effect equivalent to 298 kg of CO_2. Given its high global warming potential and the use of nitrogen based fertilizers at the banana farm an estimate of the impact from nitrous oxide production is included in this study.

Many of the chemicals used in the refrigeration process are powerful greenhouse gases. Over the course of time some of these gases escape from the refrigeration equipment into the air and contribute to climate change. Since bananas are generally kept in a cooled environment from the time they are packed at the farm until they arrive at the retail store the loss of refrigerant gases to the atmosphere can produce significant emissions.

Nitrous Oxide

Data

The amount of N_2O produced is calculated based on IPCC recommendations of 1% of Nitrogen applied as fertilizer being converted to N_2O (IPCC 2006). The ratio of mass of N_2O to N is 44:28, thus for every 100 kg of N applied as fertilizer 1 kg will be converted to N_2O producing about 1.57 kg N_2O. The amount of N_2O produced is therefore tied to the amount of nitrogen fertilizer applied, and all emissions are derived from the data for application of fertilizers at the farms. Emissions from the N_2O production are then allocated in the same manner as emissions from the production of the nitrogen fertilizer.

Modeling

Emissions from the production of N_2O were modeled in SimaPro as a direct emission to air of .0157 kg dinitrogen monoxide for every 1 kg of nitrogen based fertilizer applied.

Results

The production of nitrous oxide in soil due to application of nitrogen fertilizers leads to 0.8 kg of CO2e per box. When combined with the emissions due to production of the fertilizer this makes the use of nitrogen fertilizers a significant source of emissions in the context of the total carbon footprint.

Source	Amount
Nitrogen (kg/ha)	389
N2O Emissions (kg/ha)	6.1
GWP	298
Assumed Yield (boxes/ha)	2446
CO2e (kg/box)	0.8

Table 38: Emissions from Nitrous Oxide (kg CO2e/box)

Refrigerant Emissions

Data

Data regarding loss of refrigerant gases is based on purchases of gases used to recharge refrigeration equipment during maintenance. It is assumed that the level of gases contained in the tanks is maintained at a consistent level, and therefore any added gases are to replace gases that have escaped to the atmosphere. This 100% fugitive rate assumes that none of the refrigerants are captured during the recharging process, and represents an upper range of possible emissions.

North America

Data for consumption of refrigerants was supplied for all five ports and two DCs. This data consisted of the total kilograms of each type of refrigerant added to the cooling system during maintenance for the year. For some locations sealed refrigerating equipment is used, and so no data on refrigerant recharges was available. Instead the total refrigerant charge capacity was supplied and an annual leakage rate of 2% was assumed based on guidelines supplied by the Green Building Council(Rubenstein, Didion et al. 2004). Refrigerant quantities based on estimated leakage rates are noted with an asterisk in the tables below.

Location	Boxes	R-134A	R-12	R-409A	R-22	R-123
Wilmington	23,319,318	694	125	411	0	0
Gulfport	14,449,053	240	120	210	0	0
Port Everglades	7,352,312	67	6	22	0	0
Hueneme	14,087,360	0	0	0	0	60*
Freeport	3,957,968	29	38	17	0	0
Total	63,166,010	1,030	289	660	0	60

Table 39: Refrigerant Usage at North American Ports (in kgs)

Location	Boxes	R-134A	R-12	R-409A	R-22	R-123
Mid Atlantic	2,439,871	0	0	0	300*	0
Los Angeles	2,922,417	0	0	0	250	0
Total	5,362,288	0	0	0	550	0

Table 40: Refrigerant Usage at North American DCs (in kgs)

Average refrigerant leakage per box was calculated separately for ports and DCs based on total refrigerant usage and boxes processed at each stage.

Europe

No data was provided regarding refrigerant use in Europe. Consumption has been assumed to be identical to that of North America for this report.

Tropics

The provided data shows the total amounts, in tonnes, of four refrigerant gases: R-134a, R-12, R-409a, and foam froth. Based on the quantities and GWP of the gases R-134a and R-12 combine to produce more than 95% of the greenhouse gas emissions. Data regarding the refrigerant usage was provided in total for one growing region, and the emissions were allocated on a per box basis to the total number of boxes produced in that growing region during the time period.

Refrigerant	Amount (tonnes)	GWP	CO2e (tonnes)	Production (Boxes)	Amount Per Box (g/box)	Emissions Per Box (kg CO2e/box)	Share of CO2e
R-134a	1.66	1430	2155.10	12,121,430	0.14	0.2	24%
R-12	0.66	10900	4654.12	12,121,430	0.05	0.6	72%
R-409a	0.29	1548.75	376.78	12,121,430	0.02	0.0	5%
Foam Froth	0.02	286	4.81	12,121,430	0.00	0.0	0%

Table 41: Refrigerant Data, Tropics

The total refrigerant usage per box, including both origin and destination operations, is shown below.

Location	R-134a	R-12	R-409a	Foam Froth	R-22	R-123
GWP	1430	10900	1584.75	286	1700	76
Tropics (g/box)	0.137	0.054	0.024	0.002	0.000	0.000
Destination Port (g/box)	0.016	0.005	0.010	0.000	0.000	0.001
Destination DC (g/box)	0.000	0.000	0.000	0.000	0.103	0.000
Total (g/box)	0.153	0.059	0.034	0.002	0.103	0.001
CO2e (kg/box)	0.219	0.639	0.054	0.000	0.174	0.000

Table 42: Refrigerant Data Per Box

Modeling

The use of refrigerants was modeled in two ways: first as the production of the refrigerants themselves, and second as the release of the fugitive emissions to air. Not all refrigerants were available as production processes or direct emissions to air, and therefore substitutes were required. For production of the refrigerants the total quantity of all refrigerants in kg per box was calculated, and modeled in SimaPro using the process "Refrigerant R134a, at plant/Europe" from the Ecoinvent 2.0 database. Of four available refrigerant production processes in Ecoinvent R134a shows the highest emissions per kg of production, and therefore provides an upper range of possible emissions.

Refrigerant	HFC-152a /USA	R-20 /Europe	R134a /Europe	HCFC-22 /Netherlands
kg CO2e/kg	5.0	10.8	102.8	86.9

Table 43: Emissions from Refrigerant Production

Emissions from the release of fugitive emissions to air were calculated based on the amount of each gas released and the GWP of the gas. Approximately 59% of CO2e emissions were due to R-12 and 20% due to R-134a. Since both of those gases were available in the Ecoinvent database as direct emissions to air they were use to model the emissions of all four refrigerant gases. Using the total CO_2e per box from all gases combined the emissions were assumed to come 3/4 from R-12 and 1/4 from R-134a. Dividing that amount of CO_2e by the associated GWP of each gas (1430 for R-12 and 10,900 for R-134a) produced an estimated amount of each gas leaked to air in kilograms necessary to produce the equivalent total CO2e value for all refrigerants.

Refrigerant	Total CO2e/box (All Refrigerants)	Share	CO2e/box	GWP (kg CO2e/kg)	g/box
R-134a	1.09	25%	0.27	1430	0.19
R-12	1.09	75%	0.82	10900	0.08

Table 44: Calculation of Refrigerant Emissions Quantities

As data on refrigerant leakage was provided only for the tropics total refrigerant usage for the supply chain has been assumed to be double these calculated values. These amounts were then modeled in SimaPro as direct emissions to air of "Ethane, 1,1,1,2-tetrafluoro-, HFC-134a" and "Methane, dichlorodifluoro-, CFC-12" from the Ecoinvent 2.0 database.

Results

The emissions from the production of the refrigerant are low relative to the effects of its release to air due to the high global warming potential of some of the refrigerants.

Process	Emissions
Refrigerant Production	0.0
Refrigerant Leakage	1.1
Total	1.2

Table 45: Emissions from Refrigerants (kg CO2e/box)

End of Life

Disposal of all packaging materials used are considered within the system boundary for the banana carbon footprint. This includes the ethylene bottle, plastic shroud, cardboard corner board, and the banana box.

Data

According to interviews with Shaw's the typical practice at their stores is for all cardboard and plastic materials to be collected and sent to a recycler. As this disposal practice may not be representative of all retailers an average waste disposal scenario was applied rather than assuming 100% recycling. A sensitivity analysis conducted on the end of life results is found later in the report. Emissions for the disposal of packaging materials are allocated to the bananas in the same manner as emissions from the production of the materials.

Modeling

For the North American market all materials were modeled as using the Ecoinvent "Packaging waste scenario/USA" scenario. This process assumes an average recycling rate for different material types, with the non-recycled portion being disposed of 20% by incineration and 80% by landfill. For the European market the process "Packaging waste scenario/Eng U" was applied. Standard waste scenarios were supplied in Ecoinvent for only four European countries: England, France, Switzerland, and the Netherlands. Of these only England has a separate scenario for packaging. Recycling rates for cardboard and plastic in the US and England scenarios were checked against data provided by the EPA and Defra for municipal solid waste, and the comparison is shown in the table below.

	Defra	Packaging waste scenario/Eng U	EPA	Packaging waste scenario/USA
Cardboard	68%	77%	56%	59%
Plastic	19%	22%	7%	11%

Table 46: Comparison of Recycling Rates

Data sources:
http://www.defra.gov.uk/environment/statistics/index.htm
http://www.epa.gov/epawaste/nonhaz/municipal/msw99.htm

Results

Similar to production of the packaging emissions from disposal are driven almost entirely by the cardboard banana box. As actual disposal practices may vary between customers and across countries a sensitivity analysis is included later in this report that examines the effects of different recycling, incineration, and landfilling rates.

Material	NA - Underdeck	NA - Container	Europe
Banana Box	1.0	0.9	0.5
Plastic Shroud	0.0	0.0	0.0
Banana Wrapper	0.0	0.0	0.0
Corner Board	0.0	0.0	0.0
Ethylene Bottle	0.0	0.0	0.0

Total	1.0	0.9	0.5

Table 47: Emissions from Packaging Disposal (kg CO2e/box)

5. Results

The end result of this project was an estimated carbon footprint of approximately 17 kg of CO_2e per banana box in North America and 23 kg of CO_2e per banana box in Europe. When calculated for the secondary functional unit this results in approximately 1.0 kg of CO_2e per kg of sold bananas in North America and 1.3 kg of CO2e in Europe. All numbers are based on an average scenario for each market consisting of:

- Standard EU packaging for Europe and the NA Container packaging for North America
- Identical farming scenarios consisting of average chemical usage and yield per hectare
- Average transportation distance from the farm to the port calculated separately for bananas destined for North America and Europe
- Identical operations at the origin port in the tropics
- Average ocean distances based on shipping distances of each service to the destination ports
- Average ground shipping distances at the destination market
- Average facility energy consumption for all ports, DCs, and stores within the destination market
- US packaging waste scenario for North America and the England packaging waste scenario for Europe

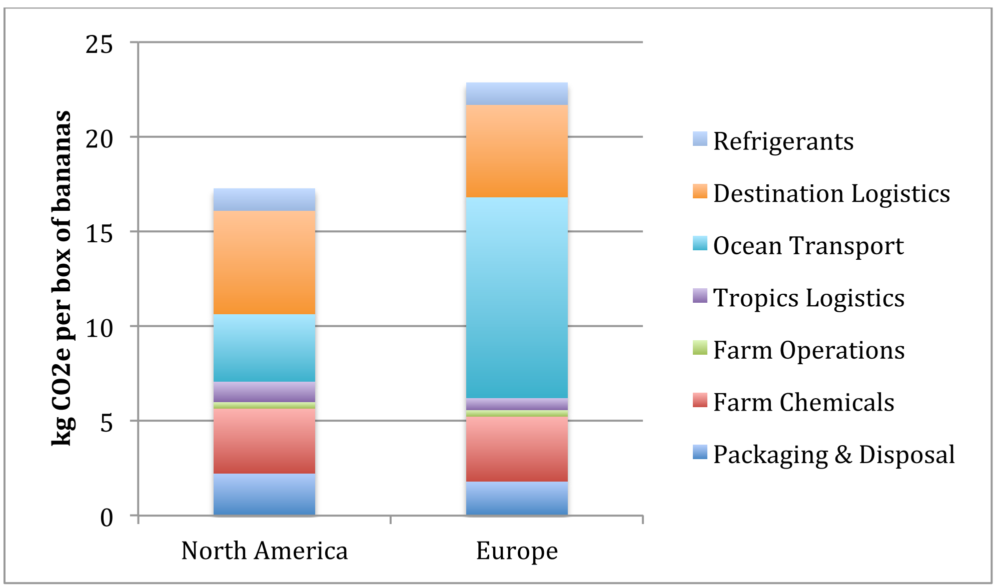

Figure 2: Comparison of Carbon Footprints

In a comparison between the two markets the increased ocean shipping distance tends to dominate the comparison, producing more than three times as much CO_2e in the European scenario than in the North American case. This is only slightly offset by the generally lower emissions from transportation and facility operation due to shorter travel distances, lower energy consumption, and lower emissions intensity of electricity in Europe.

By Supply Chain Stage

An alternative analysis of the carbon footprint of the banana is to view the emissions by supply chain stage, as shown in the figures below. In this representation each stage of the supply chain managed by Chiquita or its retail partner is shown by a blue box. Inputs to the supply chain, in the form of packaging and chemicals, are shown as black boxes. Transportation steps link the supply chain stages through red arrows. Emissions from leaking refrigerant gases are shown in purple. End of life scenarios are represented by the green ovals. The associated CO2e emissions tied to each stage are shown in the numbered boxes in kg CO2e per box. This method allows analysis of the specific steps that represent the largest share of emissions.

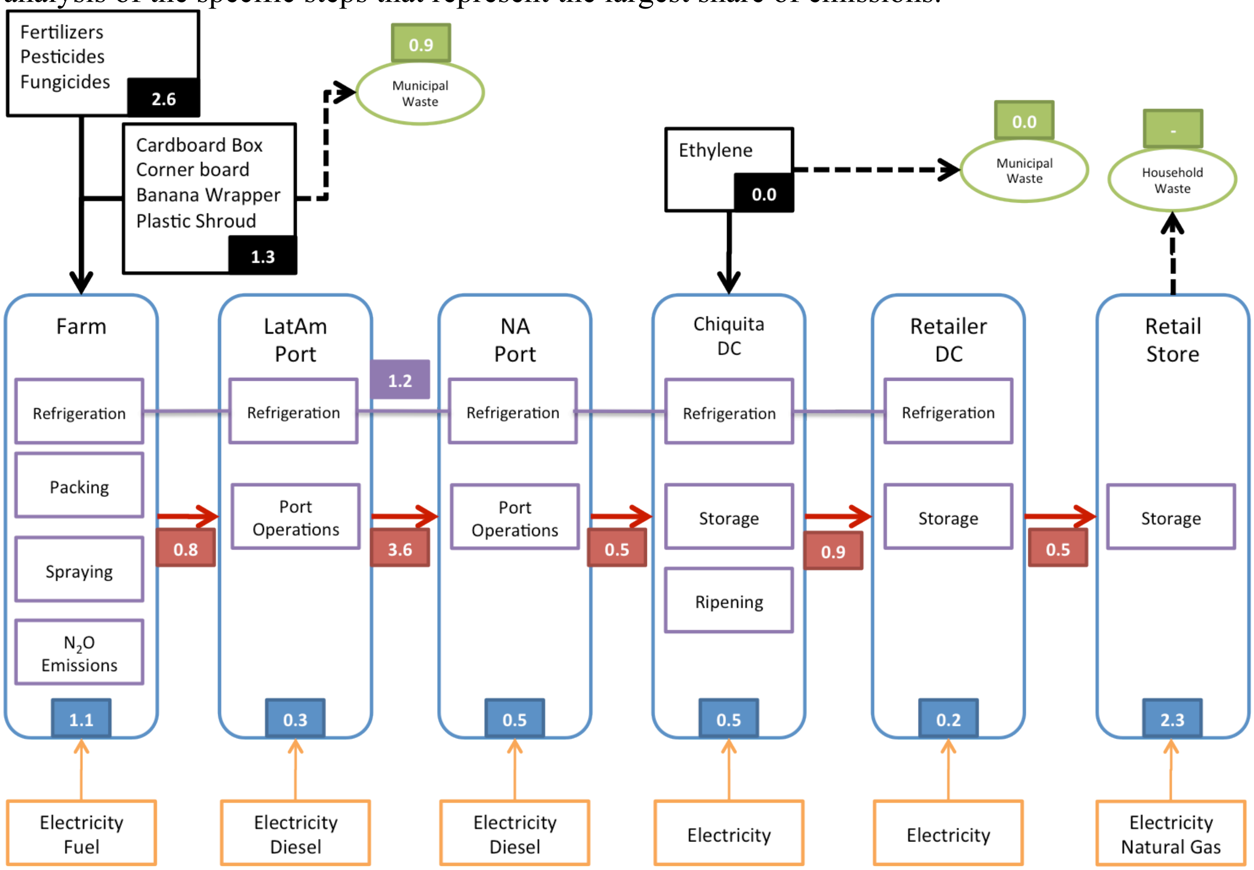

Figure 3: North American Supply Chain Emissions

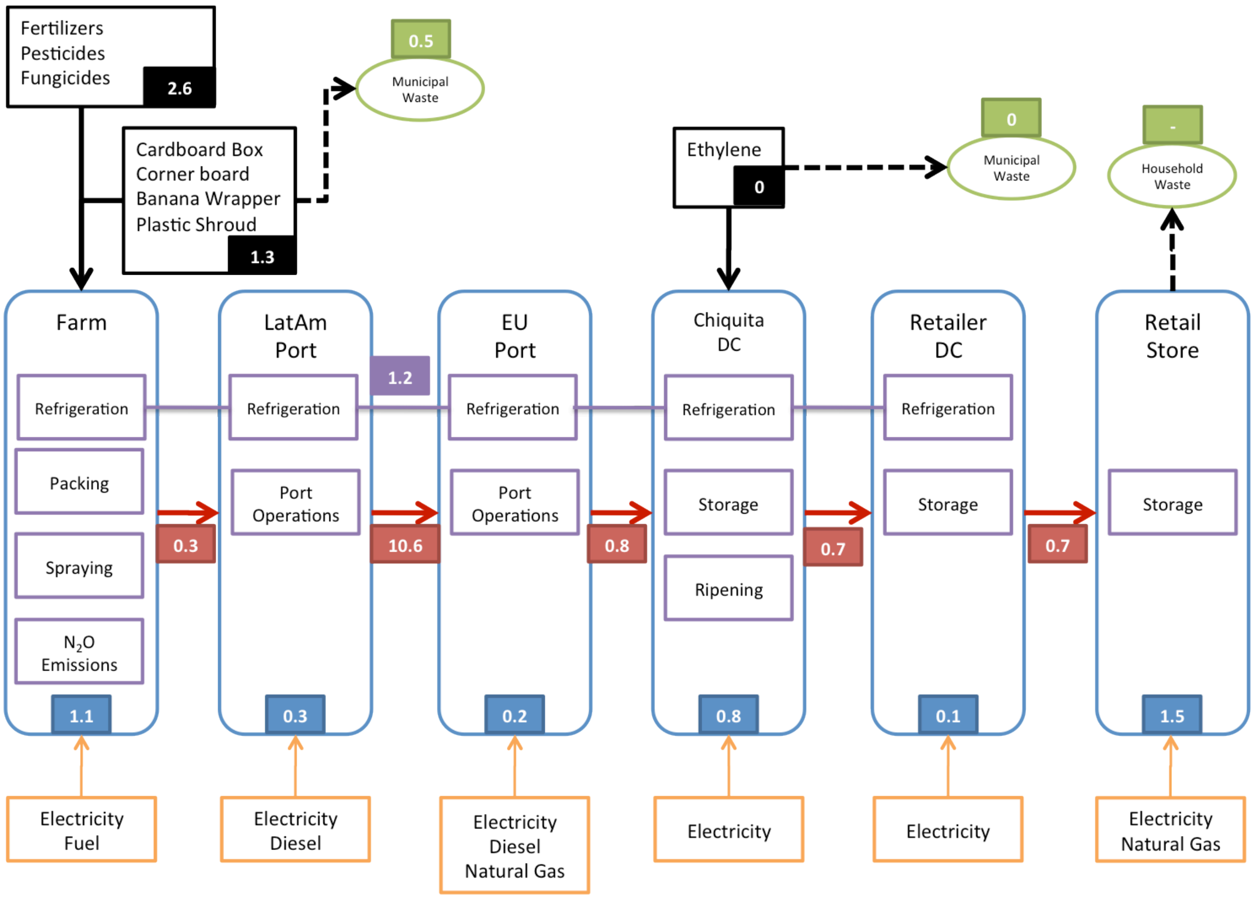

Figure 4: European Supply Chain Emissions

In both scenarios the areas that generate the largest amount of emissions are the production of farm chemicals, the ocean transportation leg, escape of refrigerant gases, and retail store operations. In some cases the cumulative effects of various activities, such as ground transportation, may combine to produce a significant share of emissions even when the individual segments have less impact.

By Activity

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. In this breakdown the emissions are separated into the following categories:

- Transportation—includes all ground and ocean transportation from the time the bananas leave the farm until they arrive at the store. Also included are emissions from running the refrigeration equipment needed to keep the bananas cool during transit.
- Distribution Facilities—All emissions from facilities operated in the distribution channel; including ports, distribution centers, and retail outlets.
- Production—All emissions related to growing and packing the bananas; including emissions due to chemical production, chemical spraying, and nitrous oxide
- Packaging—All emissions from the production and disposal of packaging materials
- Refrigerants—All emissions from producing refrigerants and the fugitive emissions from their release during operation

Error! Reference source not found. shows the respective distribution of emissions for both the North American and European markets for these categories.

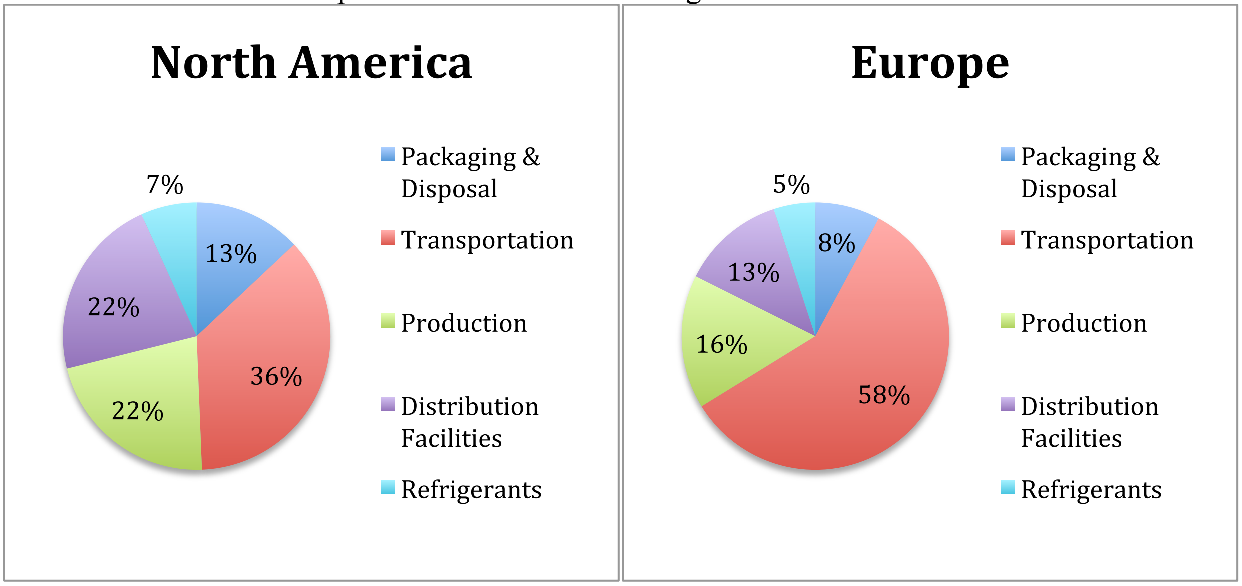

Figure 5: Comparison of Carbon Footprint by Category

Transportation

Transportation as a whole represents the largest share of supply chain emissions, and the single largest source in each case is due to ocean shipping. For Europe the ocean voyage is responsible for 46% of the total carbon footprint, while it is 21% of emissions for North America. Despite the high level of emissions due to ocean shipping it remains more than twice as efficient as road transportation on an average basis, and more than four times as efficient when lower utilization of the truck is achieved. 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 about 15 kg per box in Europe and 14 kg in North America.

Stage	North America	Europe
Farm to Port	0.8	0.3
Port to DC	0.5	0.9
DC to Customer	0.9	0.7
Customer DC to Store	0.5	0.7
Ocean	3.6	10.6
Total	6.3	13.2

Table 48: Emissions from Transportation (kg CO2e/box)

Production

Emissions related to producing bananas are primarily driven by the use of fertilizers, and in particular Nitrogen based fertilizers. The emissions from operating the packing stations and powering the farms represent only 5% of the total emissions related to production. The remaining 95% are due to production of fertilizers, N2O emissions, and aerial spraying of the chemicals. Production of nitrogen fertilizer accounts for 2.2 kg of the total 3.8 kg when emissions from its production and N2O emissions are accounted for.

Source	North America	Europe
Fertilizer, N	1.4	1.4
Fertilizers, Other	0.2	0.2
N2O	0.8	0.8
Pesticides	1.1	1.1
Packing	0.1	0.1
Fertilizer Spraying	0.2	0.2
Total	3.8	3.8

Table 49: Emissions from Production (kg CO2e/box)

Packaging

Emissions from production and disposal of packaging materials are more than 90% due to the cardboard box used to hold the bananas. While the overall impact is only 8% of the total in Europe it represents 12% in the case of North America.

Material	Stage	North America	Europe
Banana Box	Production	1.0	1.0
Banana Box	Disposal	0.9	0.5
Plastic Shroud	Production	0.1	0.1
Plastic Shroud	Disposal	0.0	0.0
Banana Wrapper	Production	0.1	0.1
Banana Wrapper	Disposal	0.0	0.0
Corner Board	Production	0.0	0.0
Corner Board	Disposal	0.0	0.0
Ethylene Bottle	Production	0.0	0.0
Ethylene Bottle	Disposal	0.0	0.0
Total		2.2	1.8

Table 50: Emissions from Packaging Materials (kg CO2e/box)

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.

Facility	North America	Europe
Port, Tropics	0.3	0.3
Port, Destination	0.5	0.2
CBI DC	0.5	0.8
Customer DC	0.2	0.1
Retail Store	2.3	1.5
Total	3.8	2.9

Table 51: Emissions from Distribution Facilities (kg CO2e/box)

Refrigerants

The production and escape of refrigerant gases combine to produce 5% of the total emissions in Europe and 7% in North America. The results may be surprising given the small amounts of refrigerants involved, less than one gram per box, but the high GWP of some of the gases produces large amounts of CO_2e.

6. Sensitivity Analysis

Scenarios

In order to provide a better understanding of the possible environmental impacts from bananas several alternative scenarios were considered beyond the base case. These scenarios focused on areas that contributed significant greenhouse gas emissions to the overall carbon footprint or had high levels of uncertainty or variability. First, a range of possible values for chemical usage at the farm was calculated based on the range of recommended doses and assumptions regarding chemical modeling. Second, an effort was undertaken to survey a large number of farms to compile actual statistics on yield, chemical usage, and energy consumption. The survey has not yet been completed, but responses from a single farm used as a pilot study are available, and the results from this farm are compared to the data estimated in the base scenario. Third, an estimate of the role of consumer transportation to the retail store was made. Fourth, the efficiency of ground transportation used in the modeling was compared to some reported data and secondary sources. Fifth, several end of life scenarios were analyzed for packaging materials. Sixth, an estimate of the sensitivity due to electricity generation was made for the different production regions in the tropics. Finally, a table summarizing the effect of certain variations to the base scenario was included to help identify the key areas of uncertainty.

UNIVEG Data

Though CBI handles transportation and ripening for nearly 6 million boxes of bananas per year in Europe this represents only a fraction of the CBI bananas sold there. Approximately 80% of the bananas are taken over by the customers once they arrive at the port, with those customers handling transportation and ripening themselves. In order to gauge the representativeness of CBI's operations data was collected from UNIVEG, one customer that handles transportation and ripening from the port through to the retailer.

UNIVEG is a worldwide supplier of fresh fruits and vegetables, and purchased nearly 7 million boxes of bananas from Chiquita in 2009. UNIVEG purchases bananas from CBI and arranges transportation via trucks from the ports of Antwerp and Bremerhaven to a network of 13 ripening facilities located within Germany. After ripening the bananas are sold and transported by UNIVEG to their network of customers throughout Germany.

Data was collected from UNIVEG regarding quantities of banana boxes processed, transportation from ports to ripening centers, electricity consumption at ripening centers, and transportation from the ripening centers to customer DCs. This data allows for a comparison to similar data collected from CBI in Europe in order to assess how representative the CBI data may be for the 80% of bananas picked up by customers at the port.

Ripening Center Data

Data was provided in aggregate for all thirteen ripening centers operated by UNIVEG for the full year of 2009. This data included the total electricity consumption of the facilities, the total ethylene gas consumption, total banana boxes handled, and the percentage of total products handled represented by CBI bananas.

Category	Quantity	Unit
% of Chiquita products vs. total products	49.91	%
Total Chiquita production 2009	6,958,000	Boxes
Electricity consumption per year 2009	15,188,774	kWh
Ethylene gas consumption per year 2009	3,319	Nm3

Table 52: UNIVEG Ripening Center Consumption

Consumption per box was calculated by first allocating 49.91% of total consumption to CBI bananas based on the percentage of total products calculated by UNIVEG. This share of the consumption was then allocated on a per box basis by dividing the total by the number of CBI banana boxes processed by the facilities. This results in an estimated consumption of 1.09 kWh per box. This value is consistent with the data reported for CBI ripening centers in Europe given in Table 15 that shows a range of 0.75 to 1.67 kWh per box and an average of 1.39 kWh.

Transportation Data

Transportation data provided by UNIVEG consisted of shipment distances, number of shipments, and total number of boxes shipped for each origin-destination pair. This was divided between green freight, consisting of shipments from ports to ripening centers, and yellow freight, consisting of shipments from UNIVEG ripening centers to customer DCs. A sample of the green freight data is shown in the table below.

Origin Port	Destination	Distance (km)	Shipments	Total distance	Total Boxes
Bremerhaven	Bremen	63	352	22,317	404,884
Bremerhaven	Hamburg	178	511	90,839	587,525
Bremerhaven	Leipzig	423	195	82,471	223,838

Table 53: Sample UNIVEG Green Freight Data

Average shipping distances for green and yellow freight were calculated by dividing the total distance for all shipments by the total number of shipments. The average number of boxes per shipment was similarly calculated by dividing the total boxes shipped by the number of shipments. A comparison of the calculated shipment distances and boxes transported with those of CBI's European operations are shown below.

Source	Stage	Avg. Distance	Avg. Boxes
CBI Europe	Port to DC	727 km	1,114
CBI Europe	DC to Customer (UK)	463 km	443
CBI Europe	DC to Customer (Poland)	249 km	387
UNIVEG	Port to DC	395 km	1,150
UNIVEG	DC to Customer	158 km	442

Table 54: Comparison of UNIVEG and CBI Europe Ground Transportation

UNIVEG transportation operations show similar results to those of CBI Europe, though generally shorter distances possibly due to the focus on one market. Truck utilization rates are similar, with UNIVEG averaging 3% more boxes per shipment from the port and nearly identical average efficiency to CBI's operations in the UK for customer shipments.

Results

Finally, to assess the representativeness of the average CBI European banana carbon footprint a separate calculation was performed for the average UNIVEG banana carbon footprint. This analysis was based on the same baseline scenario used for the European carbon footprint with the following changes:

- Ocean distance was calculated using a weighted average of the shipping distances to Antwerp and Bremerhaven based on the volume shipped from each port by UNIVEG
- Port operation emissions at the European port were based on a weighted average of Antwerp and Bremerhaven using the volume shipped from each port by UNIVEG
- Ground transportation distances and utilization were based on UNIVEG data
- Ripening center electricity consumption was based on UNIVEG data and modeled using the electricity production mix for Germany
- Customer DC and retail store electricity consumption was modeled using the electricity production mix for Germany

The net effect of these changes is a reduction in the average carbon footprint from 22.9 to 22.1 kg of CO2e per box. This represents a reduction of 3% in the total carbon footprint of the product. A table comparing the calculated carbon footprint for the stages that differ between the UNIVEG and CBI EU scenarios is shown below.

Stage	UNIVEG	CBI EU	% Change
Port, Destination	0.2	0.2	10%
Ripening Center	0.7	0.8	-4%
Customer DC	0.2	0.1	31%
Retail Store	1.9	1.5	31%
Ground Transport, Port to DC	0.5	0.8	-45%
Ground Transport, DC to Customer	0.4	0.7	-50%
Ocean Transport	10.1	10.6	-5%
Total	22.1	22.9	-3%

Table 55: Comparison of UNIVEG and Average EU Carbon Footprint (kg CO2e/box)

The reduction is driven primarily by the lower emissions from the ground transportation and the reduced emissions from ocean shipping. The reduced emissions from ground transportation are the result of the lower average shipping distance combined with equal or better truck utilization than achieved in CBI's operations. The reduced emissions from ocean shipping are due to the 5% reduction in average shipping distance required to service only Antwerp and Bremerhaven compared with the overall average of CBI's European shipments. While the reduction is small on a percentage basis the high overall impact of ocean shipping results in a 0.5 kg reduction in the overall carbon footprint.

The increase in emissions from ripening centers, customer DCs, and retail stores is a result of the higher average electricity emissions intensity in Germany compared to the European average. The customer DC and retail outlet are modeled to consume an equivalent amount of electricity as in the CBI case, but the higher emissions from electricity in Germany result in a 31% increase in the carbon footprint of these operations. The UNIVEG ripening centers consume on average 21% less electricity than the average of CBI's facilities, but the higher emissions intensity means this results in only a 4% reduction in emissions.

In summary the data provided by UNIVEG shows similar, though generally better, efficiency numbers when compared to CBI operations. These efficiencies are offset by higher electricity emissions intensities within UNIVEG's operating region of Germany, resulting in only a slight reduction in the overall carbon footprint. Given that the majority of the overall carbon footprint impact occurs before arrival at the destination port customer operations would need to be significantly different from CBI's practices to create a large impact on the calculated carbon footprint.

Farm Chemical Usage

The amount of chemicals applied at each farm varies depending on local conditions at the farm. The base scenario for this report used the average of the values recommended for the six growing regions. In order to estimate the sensitivity of the final carbon footprint value to the amount of chemicals applied at the farm three further scenarios were considered: one using the minimum recommended value, one using the maximum recommendation, and one using the mean of the min and max. The values used in the base scenario, minimum, mean, and the maximum dosage scenarios are shown in Table 56.

	N	P_2O_5	K_2O	MgO	S	CaO	B	Zn	Fe	Cu	Mn
Mean	470	75	625	75	75	1000	3	4	1.5	.5	1
Min	390	0	400	0	0	0	0	0	0	0	0
Max	550	150	850	150	150	2000	6	8	3	1	2
Base Scenario	389.2	88	684	34.8	65.8	24.4	4.7	4.48	0	0	0

Table 56: Fertilizer Application Scenarios (kg/ha/yr)

The recommendations for pesticides and fungicides come in the form of a range of possible values for the number of applications per year and the amount of active ingredient per application per hectare per year. The base scenario uses the average application quantity calculated using the mean number of applications and amount of active ingredient per application. Similarly, the extreme values of each range were used to create a minimum and maximum scenario. The values used for each of the three scenarios are shown in Table 57.

Active Ingredient	Minimum	Mean	Maximum
Epoxiconazole	0.2	0.25	0.3
Difeconazole	0.3	0.35	0.4
Tebuconazole	0.3	0.35	0.4
Tebuconazole y Tridiamenol	0.12	0.18	0.24
Trifloxytrobin	0.1	0.1	0.1
Pyraclostrobin	0.1	0.1	0.1
Tridemorph	2.15	3.225	4.3
Pyrimethanil	0.6	0.9	1.2
Spyroxamine	0.96	0.96	0.96
Mancozeb	57	57	57
Spraytex	32	272.5	513
Fenpropimorf	0	0	0

Table 57: Pesticide and Fungicide Application (kg/ha/yr)

A comparison of the contribution from farm chemical production when using the base, minimum, mean, and maximum scenarios are shown in the figure below. The contribution to the total carbon footprint from the production of chemicals ranges from 27% below the base scenario in the minimum case to 77% higher in the maximum case. These scenarios produce a carbon footprint that is 5% below the North American base case in the minimum application scenario, 5% higher in the median scenario, and 15% above in the maximum application scenario. In the European case the minimum is 4% below the base scenario, the median is 4% above, and the maximum is 11% higher.

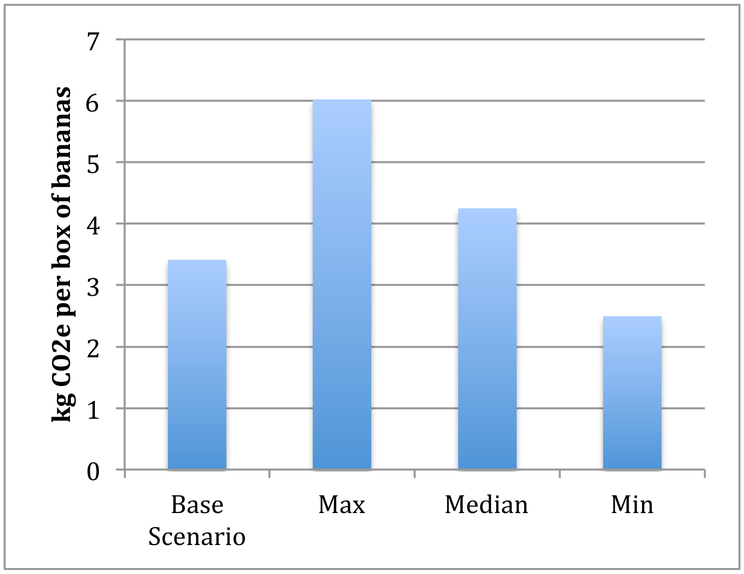

Figure 6: Comparison of Chemical Scenarios

In addition to the sensitivity analysis based on the amount of chemicals applied a second analysis was performed in SimaPro based on the types of chemicals used. Together the production of pesticides, fungicides, and nitrogen based fertilizers represent 90% of the total emissions from chemical production. No other fertilizer or chemical contributes more than 5% to the total. To test the sensitivity to the assumptions regarding these chemicals the emissions from the base scenario were compared with a range of other available chemical choices.

While the recommended quantity of nitrogen fertilizer is known the exact choice of fertilizer is not. In the base scenario Ammonium Nitrate was assumed, but in order to test the sensitivity of the results to that assumption the emissions from this choice were compared to the other available nitrogen based fertilizers. The emissions from production of Ammonium Nitrate are 1.4 kg of CO2e per box, and are represented by the red line in Figure 7. Only one other fertilizer, Potassium Nitrate, produces significantly higher emissions than Ammonium Nitrate. The use of Potassium Nitrate would increase the total carbon footprint by 7% in the North American case and 5% in the European case. The use of the mean value of nitrogen fertilizer production would result in a 2% reduction in total carbon footprint for both North American and Europe, while the median would decrease the carbon footprint by 4% in North America and 3% in Europe.

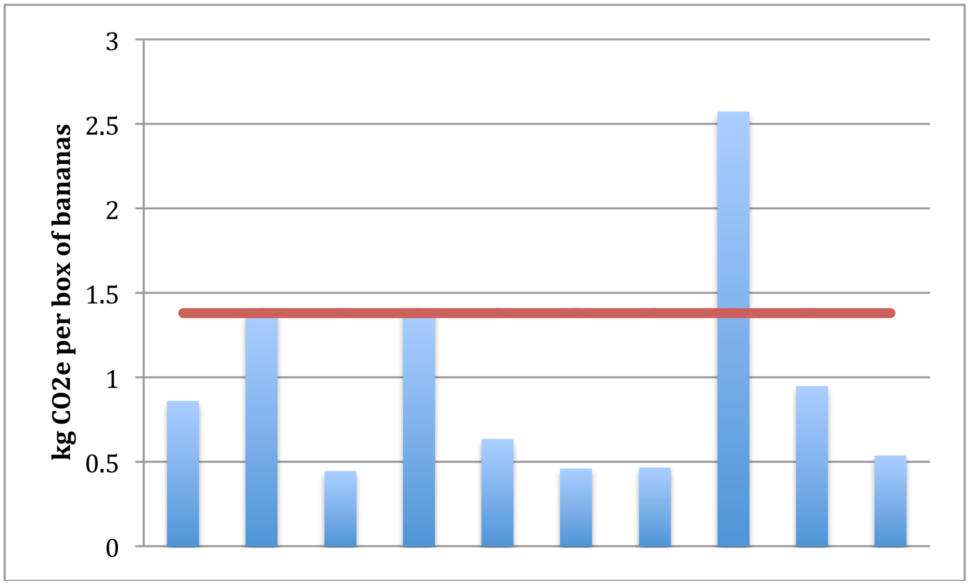

Figure 7: Comparison of Ecoinvent Nitrogen Fertilizer Production Processes

Not all chemicals have LCA data available in the Ecoinvent database, and in the case of those used in banana cultivation none of the specific pesticides or fungicides have data available. The base scenario used the Ecoinvent process "Pesticide unspecified, at regional storehouse/Europe", which produced 1.06 kg of CO2e per box. To estimate the range of possible values for the emissions from pesticide production the emissions per kg for all 37 chemicals available in the Ecoinvent pesticide database were calculated. Figure 8 shows the results when these values are used in place of the value for unspecified pesticides on a per box basis. Each vertical blue bar represents the emissions related to production of a specific chemical, while the horizontal red bar provides a comparison with the level of emissions for the base scenario.

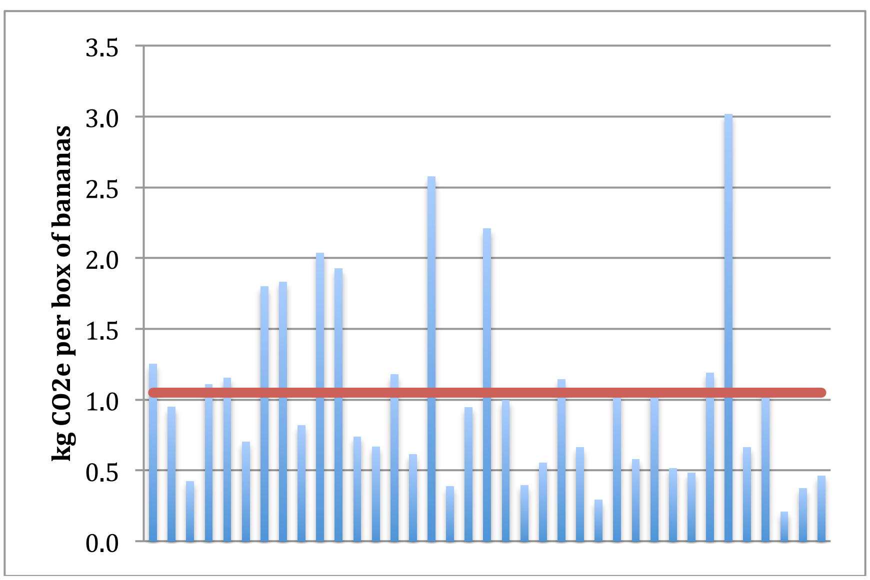

Figure 8: CO_2e Impact of Ecoinvent Pesticide Production Processes

In the case of the mean and median values from the sample of 37 chemicals the effect on the total carbon footprint for both the North American and European scenario is a reduction of less than 1%. Using the minimum and maximum values from the sample produces a decrease of 5% and an increase of 11% respectively for North America. This corresponds to a 4% reduction and an 8% increase for the European case.

Farm Survey Data

In an effort to understand differences between operations at different farms in different regions a survey was developed for farms to report on key performance indicators, such as electricity and fuel consumption, number of hectares, annual yield, and chemical applications. The survey was sent to a single farm as a pilot program, and will be distributed to a number of farms in the future. The response of the initial farm is presented below in comparison with the base scenario utilized in the model, which was based on recommended fertilizers doses and aggregated farm data for one growing region consisting of more than thirty farms.

	Base Scenario	Survey Data
Yield (boxes/ha)	2446	2359
Electricity (kwh/ha)	1117	727
Diesel (l/ha)	13.2	14.8
Gasoline (l/ha)	2.3	1.7
Fertilizers (kg/ha/yr)		
N	389.2	348
P2O5	88	68
K2O	684	445
MgO	34.8	75
S	65.8	76
CaO	24.4	921
B	4.7	6
Zn	4.48	6
Fe	0	0
Cu	0	0
Mn	0	0
Pesticides & Fungicides (kg/ha/yr)		
Epoxiconazole	0.25	0.1
Difeconazole	0.35	0.7
Tebuconazole	0.35	0.2
Tebuconazole y Tridiamenol	0.18	0.36
Trifloxytrobin	0.1	0
Pyraclostrobin	0.1	0.2
Tridemorph	3.225	11.18
Pyrimethanil	0.9	0.3
Spyroxamine	0.96	0
Mancozeb	57	63.45
Spraytex	272.5	0
Fenpropimorf	0	94

Table 58: Farm Survey Comparison

When modeled in SimaPro in the same manner as the base scenario the farm survey data produces emissions that are 9% lower for the farm portion of the supply chain, primarily due to reduced chemical usage. This results in a 0.3 kg reduction the carbon footprint of a box, less than a 2% change in the overall carbon footprint for both North America and Europe.

Consumer Transportation

Though excluded from the system boundary used for this study transportation by the consumer to the store can represent significant emissions for retail products. In order to help provide context for communication to consumers regarding the carbon footprint of bananas an estimate of the emissions for a sample consumer trip to the store have been calculated.

The consumer trip was assumed to be a round trip distance of 6.41 miles, the mean distance of trips reported as shopping/errands by the 2009 National Household Travel Survey[3]. Vehicle operation was modeled using the Ecoinvent process "Operation, passenger car, petrol, fleet average" for Switzerland. This process is based on an assumed fuel consumption of 25.7 miles per gallon. The total trip emissions were allocated to bananas using an economic allocation method based on data provided by Shaw's that showed bananas represented 6.7% of the average total purchase price for consumer purchases that included bananas. This results in an estimated 0.2 kg of CO2e per trip allocated to bananas. Assuming a purchase of 1 kg of bananas (the approximate size of one bunch) this represents a significant contribution to the total life cycle emissions, as this would result in a 20% increase in the estimated impact of 1 kg of CO2e per 1 kg of bananas.

Name	Value
Distance (miles)	6.41
Fuel Efficiency (mpg)	25.7
Trip Emissions (kg CO2e)	2.6
Allocation	7%
Consumer Emissions (kg CO2e)	0.2

Table 59: Emissions from Consumer Transport

Ground Transportation Efficiency

Throughout the report the emissions from ground transportation have been based on the operation of vehicles meeting the EURO3 emissions standards. This assumes certain fuel efficiency for each vehicle, and as such the emissions from ground transportation are highly dependent on this assumption. In order to show the sensitivity to this assumption the fuel efficiency of the EURO3 process from the Ecoinvent database was compared with some initial reported fuel efficiency numbers from CBI and Shaw's operations, as well as average fuel efficiency data reported by the Argonne National Labs GREET model and WRI's Greenhouse Gas Protocol. The results are shown below.

Stage	NA mpg	EU mpg	GREET	GHG Protocol	Ecoinvent >32t, EURO3

[3] http://nhts.ornl.gov/tables09/fatcat/2009/avtl_WHYTRP1S.html

Port to DC	6.0	7.2	6.0	5.9	6.9
DC to Customer	5.6	8.3	6.0	5.9	6.9
Customer to Store	6.4	6.4	6.0	5.9	6.9

Table 60: Comparison of Ground Transportation Efficiency (miles per gallon)

Based on these results the use of the EURO3 transportation model is overstating the efficiency of operations in North America, where the GREET and GHG Protocol estimates are closer to reported values. In Europe the numbers appear to slightly understate emissions from the Port to Customer. The higher efficiency in Europe also indicates that the use of Shaw's data for customer transportation in Europe may be slightly overestimating emissions.

In addition to the fuel efficiency of the vehicles the emissions intensity of the fuel cycle is a key factor in the emissions from transportation. The GREET Fleet Footprint Calculator[4] provides a method for estimating GHG emissions over the full fuel cycle, referred to as the Well-to-Wheel basis. Using the GREET tool a comparison can be made to the similar life cycle emissions estimated by the Ecoinvent transportation process. Using the default GREET estimates of 6.0 mpg and 80,000 vehicle miles the total estimated CO2e emissions are 167.2 short tons. Converting the results to kilograms and the 80,000 miles driven to kilometers gives an amount of CO2e per vehicle kilometer that can be compared to the emissions factor used in Ecoinvent. The table below shows the results of that comparison, along with a comparison of the total emissions per gallon of fuel.

	GREET	Operation, lorry >32t, EURO3/Europe
kg CO2e/km	1.2	1.1
Assumed mpg	6.0	6.9
kg CO2e/gallon	11.4	12.0

Table 61: Comparison of Ground Transportation Emissions

Based on this comparison the overall emissions from using the GREET model are 9% higher than using the Ecoinvent EURO3 assumption. This increase is due to a 13% lower vehicle efficiency in the GREET model being slightly offset by 4% lower emissions from the fuel cycle of diesel fuel. Using the numbers from the GREET model rather than Ecoinvent would increase ground transportation emissions from 1.6 kg CO2e/box to 1.7 kg CO2e in the North American case and from 2.2 kg to 2.3 kg in the European case. While this is a 9% increase in the emissions from ground transportation it causes an increase of less than 1% in the overall carbon footprint for both cases.

End of Life

A number of possible disposal scenarios exist for packaging materials based on the percentage of the materials recycled, incinerated, and landfilled. The primary driver of emissions from packaging disposal is the banana box, and since these are disposed of by the customer practices may vary. In order to show the range of possible emissions values three possible extremes were considered:

- 100% recycled

[4] http://greet.es.anl.gov/fleet_footprint_calculator

- 100% incinerated
- 100% landfilled

The results of disposal of the packaging materials under these three scenarios are shown in comparison with the base scenario used in the report in the table below.

Scenario	NA	EU
Packaging Waste	0.9	0.5
100% Recycled	0.0	0.0
100% Incineration	1.9	1.8
100% Landfilled	2.3	2.3

Table 62: Emissions from Packaging Waste Scenarios (kg CO2e/box)

The impact of the waste scenarios on the total carbon footprint in the North American case ranges from a decrease of 5% for the 100% recycled scenario to an increase of 8% in the 100% landfill scenario. In Europe the difference ranges from a 4% reduction to a 6% increase.

Electricity Generation

CBI operates farms in a number of growing regions in the tropics. Currently data has only been collected for farm and port operations in Costa Rica. While electricity use in Costa Rica at the farms and ports is not a major contributor to emissions this is partly attributable to the low emissions intensity of electricity in Costa Rica. In order to test the sensitivity of the results to the emissions intensity of the electricity in the different growing regions an electricity process was created in SimaPro using data on electricity generation from Ecoinvent and based on the electricity production mix of the other major producing countries in the tropics. The process and data sources used to create this analysis followed the same procedure as outlined earlier in this report for creation of the electricity production mix in Costa Rica. A comparison of the electricity generation mix in each country is shown in the table below.

Electricity Source	Costa Rica (GWh)	Share	Honduras (GWh)	Share	Guatemala (GWh)	Share	Panama (GWh)	Share
Coal	0	0%	0	0%	1131	13%	0	0%
Oil	721	8%	4049	62%	2322	27%	2438	38%
Gas	0	0%	0	0%	0	0%	0	0%
Biomass	79	1%	197	3%	1552	18%	19	0%
Waste	0	0%	0	0%	0	0%	0	0%
Nuclear	0	0%	0	0%	0	0%	0	0%
Hydro	6770	75%	2291	35%	3712	43%	3973	62%
Geothermal	1239	14%	0	0%	0	0%	0	0%
Solar PV	0	0%	0	0%	0	0%	0	0%
Solar Thermal	0	0%	0	0%	0	0%	0	0%
Wind	241	3%	0	0%	0	0%	0	0%
Tide	0	0%	0	0%	0	0%	0	0%
Other	0	0%	0	0%	0	0%	0	0%
Total	9050		6537		8717		6430	

Table 63: Electricity Generation Mix by Country

Using these electricity processes the emissions from packing operations at the farm and port operations were calculated for each country. Table 64 shows the resulting emissions intensity for each country and the impact on packing operations, port operations, and the total carbon footprint when compared with the base scenario for Costa Rica. Though the electricity emissions intensity is much higher in other countries, as much as seven times greater in Honduras, the relatively low consumption of electricity in the tropics leads to small changes in the overall carbon footprint. The largest difference is seen in Honduras where emissions are 3% higher in the European scenario and 4% higher in North America.

	Costa Rica	Guatemala	Honduras	Panama
Electricity Emissions Intensity (kg CO2e/kWh)	0.080	0.384	0.560	0.347
Packing (kg CO2e/box)	0.1	0.3	0.3	0.2
Port Operations (kg CO2e/box)	0.3	0.6	0.8	0.6
Carbon Footprint - EU (kg CO2e)	23.3	23.7	24.0	23.7
Carbon Footprint - NA (kg CO2e)	18.0	18.4	18.7	18.4

Table 64: Comparison of Emissions by Country

Sensitivity Analysis Table

A summary of impact of varying one factor at a time from the sensitivity analysis scenarios is shown in the table below. For each factor the carbon footprint was calculated while letting the factor vary between the minimum and maximum value. The new carbon footprint value was then compared to the base scenario of 17.2 kg CO2e for North American and 23.2 kg for Europe.

	North America				EU			
	Min		Max		Min		Max	
	kg CO2e	% Decrease	kg CO2e	% Increase	kg CO2e	% Decrease	kg CO2e	% Increase
Chemical Quantity	16.3	5%	19.9	16%	22.2	4%	25.8	12%
Pesticide Emissions Factor	16.4	5%	19.2	12%	22.3	3%	25.1	9%
Packing Operations	17.2	0%	17.4	1%	23.1	0%	23.3	1%
Ocean Factor	14.4	16%	17.2	0%	14.6	37%	23.1	0%
Ocean Distance	15.3	11%	19.0	10%	21.8	6%	25.9	12%
Port to DC Distance	16.4	5%	22.0	28%	23.0	0%	23.3	1%
DC to Customer Distance	16.8	2%	17.7	3%	22.4	3%	24.0	4%
Customer DC to Store Distance	16.7	3%	18.2	6%	22.7	2%	24.7	7%
Origin Port Operations	17.2	0%	17.7	3%	23.1	0%	23.6	2%
Destination	17.0	1%	17.6	3%	22.1	4%	24.8	7%

Port Operations								
Chiquita DC Operations	17.0	1%	17.5	2%	22.5	3%	24.9	8%
Waste Scenario	16.3	5%	18.6	8%	22.6	2%	24.9	8%

Table 65: Sensitivity Analysis Results

7. Conclusions

The Goal and Scope Definition for this LCA identified three primary goals for conducting this study:

1. Provide an estimate of the carbon footprint of bananas over their life cycle. This information could be used to develop a product carbon label and help influence future consumer purchases to reduce environmental impact.
2. Develop a process useable by CBI on an ongoing basis to track information necessary for developing performance metrics related to environmental impact.
3. Identify areas of high environmental impact and uncertainty in the CBI supply chain for further exploration of strategies to reduce environmental impact.

With these three goals in mind the results are discussed below in this context.

Estimated Carbon Footprint

The carbon footprint for one box of bananas sold in North America was estimated at 17 kg of CO2e and in Europe as 23 kg of CO2e. The box was used as the primary functional unit as it represented a common internal measurement of production within CBI as well as the unit of sale to customers. The results in this form are thus easily communicated within CBI and to their direct consumers.

A secondary functional unit of 1 kg of bananas sold was defined with the goal of measuring the carbon footprint in a way that could be communicated to end consumers, possibly through a carbon label. The carbon footprint of 1 kg of bananas sold in North America was estimated to be 1.0 kg of CO2e and as 1.3 kg of CO2e for Europe. Though excluded from the boundary used in the PAS-2050 carbon labeling standard the emissions from consumer transport to the store were estimated at 0.2 kg CO2e per kg of bananas, a significant amount relative to the estimated footprint of the bananas themselves.

Additional work may be required to use the results from this study and produce a carbon label certified under a standard such as PAS-2050. The functional unit for this study was defined as bananas sold within North America and Europe, but carbon labels may require country specific values. Given the variability in the carbon footprint due to transportation distances and variations between operations in different countries a further refinement may be needed that differentiates between the U.S. and Canada in North America and between the many countries in Europe. Further, certain assumptions, such as the exclusion of land use effects, may require data gathering to support in the certification process.

Development of an Ongoing Process

This project served as an initial attempt to measure the carbon footprint of its supply chain by CBI. Based on the results of this project similar attempts may be made to measure the carbon footprint of other products sold by CBI such as salads and pineapples. The initial process has served to identify the data requirements from different groups within CBI, methods for data collection and verification; and identify key partners in the supply chain for future collaboration. Building on the lessons learned during this time additional data collection has begun to standardize data reporting methods, coordinate between the three key operating regions of the tropics, North America, and Europe; capture additional data to fill data gaps and uncertainty in the initial study; and with other current and future sustainability projects within CBI.

Identify Areas of High Impact and Uncertainty

The results of this study have identified four areas of high impact within the operations of CBI: the ocean voyage, the use of farm chemicals, the box used for packaging, and the use of refrigerants to keep the bananas cooled during distribution. Together these four areas combine for more than 60% of the total emissions in North America, and more than 75% in the case of Europe. The ocean voyage is particularly high in impact for Europe, representing 46% of all emissions as compared to 21% in North America. Emissions from the farm chemicals are driven primarily by the use of nitrogen based fertilizer due to the large quantities used, the high emissions intensity of production, and the release of nitrous oxide from soil. The high global warming potential of certain refrigerant gases causes significant impacts from the release of only a small amount of gas.

The banana box poses a special challenge to CBI, as all of its emissions occurs either upstream during production or downstream in disposal. Thus changes to the packaging process, such as the current use of returnable plastic containers with one customer, may reduce lifecycle emissions at the expense of increased direct emissions from CBI operations due to extra effort on collection and return. The issue of emissions that occur outside their control is an issue in another area of high impact identified by this study, that of retail operations.

The areas of highest uncertainty found in this study are related to the production of bananas, the transportation distance, customer operations, and final disposal of the banana box. The largest single cause of uncertainty in transportation is due to the ocean voyage. Due to the long distances involved the differences between the longest and shortest voyages can cause significant differences in the total carbon footprint. While the ground transportation stages show lower uncertainty than the ocean voyages individually, in aggregate they can cause large uncertainty between the easiest customers to reach and the most difficult.

The production of bananas is uncertain due to the wide range of types and quantities of chemicals that may be applied during cultivation. Differences in electricity production in the growing regions may also contribute to this uncertainty, but the effects are relatively small due to the low overall use of electricity compared to chemicals. In the future collection of data on actual chemical usage and quantity in the different growing regions will be necessary to help reduce this uncertainty.

Uncertainty due to customer operations and disposal of banana boxes are high due to the lack of complete information and the high impact of both areas. The uncertainty in emissions from end of life is inherently uncertain due to the forward looking nature of the process, however the issue is important for CBI due to the predominance of cardboard in the packaging. The large variation between emissions due to different disposal scenarios of cardboard creates high uncertainty regarding the disposal of the banana box.

The uncertainty surrounding customer operations is high due to the large impact of the retail store on the carbon footprint and the lack of representative data for many customers. Data has been collected for only one store in the United States, and extending the results from this store to all retail outlets in North America and Europe creates a high level of uncertainty.

This analysis suggests three possible areas for CBI to explore to reduce uncertainty. First, gathering data on specific chemical usage at a representative sample of farms. Second, collaborating with customers to improve estimates of emissions from retail outlets and the final disposal of packaging materials. Third, explore increasing the granularity of the functional unit to reduce uncertainty related to shipping distances across Europe and North America.

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Appendix A: Summary of Emissions Factors

The tables below provide a summary of all emissions factors used in the LCA model of this project. All emissions factors used in this project were calculated without infrastructure included, but the values with infrastructure are included for reference. Each table represents emissions factors related to one type of emissions: electricity, other energy, transportation, packaging materials & processes, and chemicals.

Electricity

Process	Without Infrastructure (kg CO_2e/kwh)	With Infrastructure (kg CO_2e/kwh)
Electricity, medium voltage, at grid/Belgium	0.333	0.339
Electricity, medium voltage, at grid/Costa Rica	0.080	0.087
Electricity, medium voltage, at grid/Germany	0.650	0.656
Electricity, medium voltage, at grid/Great Britain	0.596	0.603
Electricity, medium voltage, at grid/Greece	0.995	1.002
Electricity, medium voltage, at grid/Guatemala	0.384	0.394
Electricity, medium voltage, at grid/Honduras	0.560	0.576
Electricity, medium voltage, at grid/Italy	0.572	0.582
Electricity, medium voltage, at grid/Netherlands	0.675	0.682
Electricity, medium voltage, at grid/Panama	0.347	0.359
Electricity, medium voltage, at grid/Poland	1.117	1.120
Electricity, medium voltage, at grid/Portugal	0.602	0.613
Electricity, medium voltage, at grid/Sweden	0.086	0.091
Electricity, medium voltage, at grid/USA	0.762	0.770
Electricity, medium voltage, production, at grid/European Average	0.497	0.503

Table 66: Emissions Factors from Electricity

Other Energy

Process	Without Infrastructure (kg CO_2e/MJ)	With Infrastructure (kg CO_2e/MJ)
Heat, natural gas, at boiler atm. low-NOx condensing non-modulating <100kW/Europe	0.074	0.075
Diesel, burned in building machine/Global	0.085	0.091
Diesel, burned in diesel-electric generating set/Global	0.085	0.087
Heat, light fuel oil, at boiler 100kW condensing, non-modulating/Switzerland	0.087	0.089

Table 67: Emissions Factors for Other Energy Production

Transportation

Process	Without Infrastructure (kg CO2e)	With Infrastructure (kg CO2e)	Unit of Output
Operation, lorry 16-32t, EURO3/Europe	0.789	0.804	km
Operation, lorry >32t, EURO3/Europe	1.079	1.100	km
Transport, lorry 16-32t, EURO3/Europe	0.137	0.168	tonne-km
Transport, Chiquita freight ship/Ocean	0.046	0.048	tonne-km
Transport, transoceanic freight ship/Ocean	0.009	0.011	tonne-km
Transport, helicopter/Global	94.274	96.922	hr
Operation, passenger car, petrol, EURO3/Switzerland	0.233	0.238	km
Operation, passenger car, natural gas/Switzerland	0.209	0.211	km

Table 68: Emissions Factors for Transportation

Packaging, Materials, and Processes

Process	Without Infrastructure (kg CO_2e/kg)	With Infrastructure (kg CO_2e/kg)
Polyethylene, HDPE, granulate, at plant/Europe	1.930	1.931
Corrugated board, recycling fibre, double wall, at plant/Europe	0.719	0.777
Packaging, corrugated board, mixed fibre, single wall, at plant/Europe	0.746	0.826
Ethanol from ethylene, at plant/Europe	1.2	1.26
Injection moulding/Europe	1.242	1.277
Packaging film, LDPE, at plant/Europe	2.582	2.603
Packaging film, HDPE, at plant/Europe	2.406	2.428
Refrigerant R134a, at plant/Europe	103	103
Refrigerant Leakage, 1 kg HFC-134a to Air	1430	1430
Refrigerant Leakage, 1 kg R12 to Air	10900	10900

Table 69: Emissions Factors for Packaging, Materials, and Processes

Chemicals

Process	Without Infrastructure (kg CO_2e/kg)	With Infrastructure (kg CO_2e/kg)
Ammonium nitrate, as N, at regional storehouse/Europe	8.157	8.686
Ammonium nitrate phosphate, as P2O5, at regional storehouse/Europe	1.052	1.274
Potassium chloride, as K2O, at regional storehouse/Europe	0.363	0.533
Magnesium oxide, at plant/Europe	1.048	1.051
Secondary sulphur, at refinery/Europe	0.307	0.314
Quicklime, milled, packed, at plant/Switzerland	0.983	0.988
Borax, anhydrous, powder, at plant/Europe	1.598	1.653
Zinc monosulphate, ZnSO4.H2O, at plant/Europe	1.680	1.850
Iron sulphate, at plant/Europe	0.116	0.189
Copper oxide, at plant/Europe	1.748	2.063
Manganese, at regional storage/Europe	2.476	2.598
Pesticide unspecified, at regional storehouse/Europe	7.336	7.734
Refrigerant R134a, at plant/Europe	102.847	103.417

Table 70: Emissions Factors for Chemicals

Appendix B: Notes on External Review

The following changes have been made to this report to reflect comments from the external review.

Methodology and Goal/Scope Comments

Functional Unit and Allocation Procedures

The functional unit has been clarified to be a box of bananas delivered to the customer. Further, one kg of bananas sold has been identified as a secondary functional unit. Allocation procedures have been described as such throughout the report.

Data Quality Requirements

A section assessing the data quality for source, time period, and representativeness has been added.

Study Assumptions and Conclusion Comments

Assumptions

Packaging

The description of the transportation and end of life for packaging material has been clarified. Further, the primary packaging materials have been identified and reported separately from other materials used in the supply chain. Packaging disposal scenarios have been clarified and additional sensitivity analysis added to consider the impact of different scenarios.

Refrigerant Modeling

More description has been added to clarify the modeling of refrigerant emissions. A comparison of emissions from production of four types of refrigerants was added to assess a worst case scenario.

Ocean Transport

The description of the ocean transport has been changed to clearly identify the use of primary data.

Aerial Spraying

The description of the procedure used to estimate aerial spraying by the farm operations team has been clarified.

Sources of Data

Data Representativeness

A discussion of representativeness has been added to the data quality section. Additional sensitivity analysis around the electricity emissions intensity in the tropics has been added to address the use of a single growing region.

Completeness, Consistency, and Transparency

The format of the report has been updated to include data and methods together. Additional data has been added to each section to provide a clearer depiction of what data was used and how. The Ecoinvent abbreviations have been removed and replaced with the actual country

Conclusions
A conclusions section has been added to the report that discusses the results and sensitivity analysis in the context of the three goals identified for this study.

Other Issues
Significant digits have been reduced to reflect the uncertainty of the results. Additional sensitivity analyses regarding consumer transportation, ground transportation efficiency, and the electricity production mixes in the tropics have been added.