

Carbon footprint along the Ecuadorian banana supply chain: Methodological improvements and calculation tool

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ABSTRACT

Bananas are among the most important food and agricultural commodities worldwide, being Ecuador its main exporter as it represents over a third of the global banana exportation. A detailed carbon footprint assessment of the complete Ecuadorian banana value chain has been carried out. Special attention was paid to the adaptation of the emission factors to the local conditions, especially in those activities that were expected to contribute most to the whole footprint. The carbon footprint of Ecuadorian bananas from cradle-to-grave was 1.25 ton CO₂e per ton of banana at the consumption point in Spain. Farm stage was identified as the main contributor (22.1 %) and significant differences were found between the environmental performance of conventional and organic farms, mainly due to the use of synthetic fertilizers in the former and the related N₂O emissions. An Excel calculation tool was developed, to allow Ecuadorian stakeholders to evaluate different operating conditions.

Keywords: fruit, food, cradle-to-grave, value chain

1. Introduction

Food production and consumption has been proven as an important contributor to environmental degradation, being responsible from 20 to 30% of the impacts of private consumption (Tukker et al. 2006).

In developed countries, consumers start demanding food produced with minimal environmental losses (de Boer 2003) and increasingly base their purchase decisions on environmental indicators shown in food packaging. Within these indicators, the carbon footprint (CF) of a certain product, defined as the total greenhouse gas (GHG) emissions over its whole life cycle, expressed as CO₂ equivalents (Carbon Trust 2012), has achieved widespread development over the past decades, because of being very intuitive and easily understandable for non-expert users, which facilitates the diffusion of the results (Weidema et al. 2008).

Provided that agriculture accounts for about 14% of global GHG emissions (IPCC 2007), due to the recent technological developments that farms have experienced, vegetal food production has become an important contributor to climate change. Thus, a substantial number of carbon footprint assessments of plant-based products have been published recently (Espinoza-Orias et al. 2011; Gan et al. 2012; Rööös et al. 2010). Within these studies of plant products, the CF assessment of tropical fruits consumed in Europe is of great interest, since the emissions related to transoceanic transportation from production countries to consumption sites must be added to those associated with the farming stage (Brito de Figueirêdo et al. 2013; Ingwersen 2012; Sim et al. 2007).

This study analyzes the carbon footprint of the whole value chain of bananas grown in Ecuador, the world's largest exporter (A.E.B.E. 2011), and consumed in Spain. To the best of our knowledge there are five studies that have already evaluated the carbon footprint of banana production (Eitner et al. 2012; Iriarte et al. 2014; Lescot 2012; Luske 2010; Svanes and Aronsson 2013). All these papers place their final destinations in northern Europe, and only one includes consumption stage (Svanes and Aronsson 2013). In particular, Ecuadorian plantations were studied by Eitner et al. (2012) and Iriarte et al. (2014). In the first one, CF calculations were conducted using the Footprint Expert Tool¹, in which the assessment of farm emissions is based on average European data and process calculation is not as transparent as desirable as emission factors are not published, while the second one only considers data collected in a single farm in El Oro region.

This study starts from the identification of the main contributions reported and the weaknesses found in existing literature, to perform a more adapted assessment to the actual conditions considered here. Firstly, data from farming stage have been collected from a set of plantations located in the three provinces with higher banana yields (Guayas, Los Ríos and El Oro (A.E.B.E. 2011)); secondly, the assessment of nitrous oxide (N₂O) emis-

¹ <http://www.carbontrust.com/software#footprintexpert>

sions from fertilized soils has been adapted to tropical climate, while all the available studies on banana production used default values for temperate climate; and finally, a detailed revision of the emission factor for overseas transport has been carried out in order to better represent the real transportation mode of the Ecuadorian bananas.

2. Methods

To determine the carbon footprint of the whole value chain of Ecuadorian bananas, the methodologies defined by ISO 14067 (ISO 2013) and PAS 2050:2011 (BSI 2011b) have been followed.

2.1. Functional unit and system boundaries

A cradle-to-grave assessment has been performed, including all the stages shown in Figure 1, from banana farming in Ecuador to consumption phase in Spain, which complements the available studies with final destinations in countries of northern Europe, such as Germany or Norway.

A ton of banana arriving to the consumption stage (S8) has been chosen as the functional unit (FU). One ton of banana is the FU normally selected by other authors but not always located at the end of the value chain, i.e. at the consumers' hands, so results are not directly comparable due to food losses along each of the chain stages.

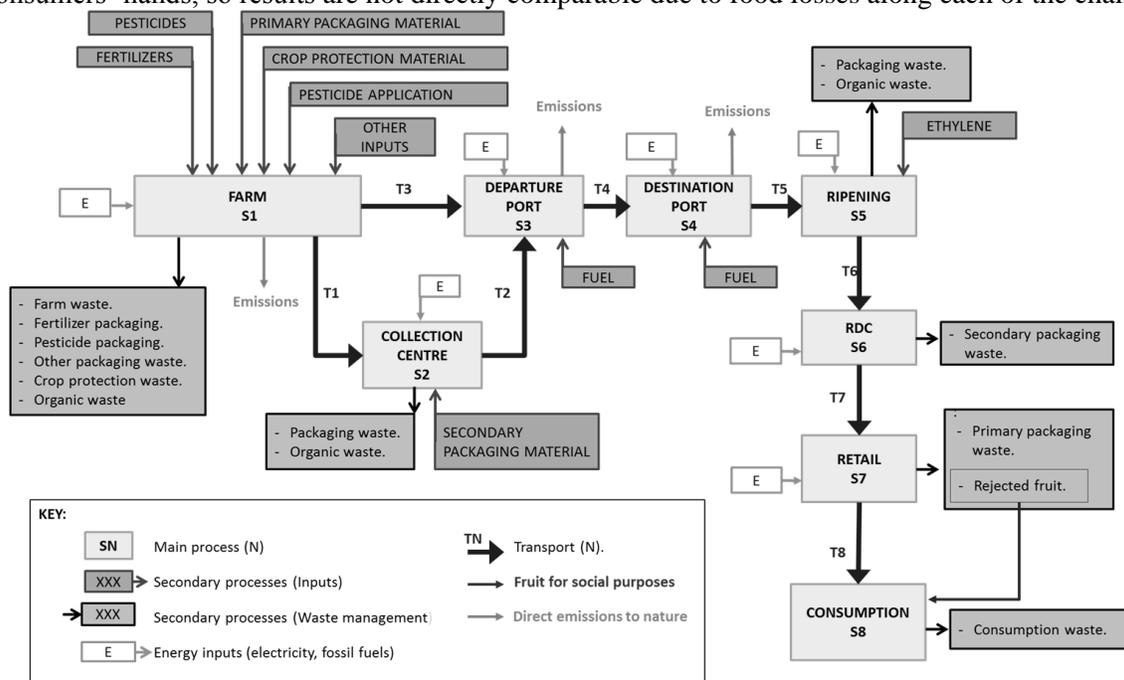


Figure 1. The banana supply chain under assessment.

An exhaustive data collection process has been carried out for obtaining inventories of inputs and outputs of each of the stages under study. The transport associated to the provision of secondary processes (inputs/outputs) has been excluded, with the exceptions of those transports that were expected to have a meaningful contribution to the whole carbon footprint: the provision of fertilizers and pesticides in S1, as the great majority come from Europe, and the waste transport of municipal solid waste generated in S8, due to their relatively high weight.

The GHG emissions arising from the production of capital goods have been included in the assessment when available, i.e. the manufacture of the vehicles used in transportation systems. The emissions related to the production of those capital goods having a very long lifetime (i.e. buildings, cableway, irrigation system...) have not been considered, provided that the corresponding share of those emissions to the functional unit is negligible.

As recommended in the aforementioned guidelines (BSI 2011a), neither biogenic carbon, and the delayed emissions associated to its storage in food products, nor emissions from land use change have been taken into account, as no change in the land use of the plantations has took place in the last 20 years.

For the determination of nitrous oxide emissions from fertilized soils, the IPCC guidelines (IPCC 2006) were used, having been adapted to the characteristics of the Ecuadorian region, as shown later in this document.

In order to keep uniformity and to make the results comparable, the Ecoinvent database (Frischknecht et al. 2007) has been used in the majority of the cases for the provision of the background emissions factors, being modified when necessary to adapt them to the Ecuadorian conditions, and complemented if required with some other sources as detailed in the next section.

2.2. Data sources

To characterize the farm system (S1), primary data was obtained from seventeen Ecuadorian plantations, of which nine were organic farms and the remaining eight, conventional farms. This classification was meant to allow establishing differences in the carbon footprint among both farm production systems provided that, for many foods, the environmental impacts of organic agriculture are lower than for the equivalent conventionally-grown food (Foster et al. 2006).

A questionnaire has been prepared and interviews with those responsible for the plantations have been performed. The data collected were, among others: general data of their planting site (coordinates, area, annual yield), use of crop protecting materials (type and amount of each item), use of fertilizers and pesticides (type and amount of each product), electricity and fuel consumption (pumps, irrigation systems, aerial and terrestrial spraying of pesticides), use of packaging materials (cardboard boxes and plastic bags for banana packing) and waste generation (amount and destination of the residues).

Given the impossibility of summarizing the vast amount of data collected by means of these questionnaires, Table 1 shows, as an example, the main inputs of the S1 system for some similarly sized farms.

Table 1. Summary of the main inventory data gathered for S1, for medium-sized farms.

Inputs	Organic				Conventional		
Crop protection material							
Cover (u)	49.62	60.05	39.06	55.60	42.63	70.10	49.10
Bow tie (u)	-	-	-	-	85.26	140.20	98.20
Banana hand cover (u)	-	-	-	-	-	-	39.28
Tape (u)	-	60.05	39.06	55.60	42.63	70.10	-
Nun's neck (u)	99.23	102.94	55.80	148.27	170.53	198.62	-
Packaging material							
Cardboard box (u)	55.13	55.13	55.13	55.13	55.13	55.13	55.13
Plastic bag (u)	55.13	55.13	55.13	55.13	55.13	55.13	55.13
Rubber (u)	55.13	55.13	55.13	55.13	55.13	55.13	55.13
Label (u)	1985	1874	1874	1985	1874	1874	1323
Glue (kg)	0.36	0.22	0.22	0.28	0.22	0.28	0.24
Pesticides							
Fungicide (l)	0.98	0.36	0.21	0.47	0.01	0.08	0.13
Herbicide (l)	-	-	-	-	-	-	0.09
Growth regulator (l)	0.28	0.24	0.01	0.10	-	-	-
Insecticide (l)	-	-	-	0.10	-	-	-
Unspecified pesticide (l)	0.07	0.04	0.21	0.28	-	-	-
Other compounds (kg)	-	-	-	-	0.19	0.35	0.33
Fertilizers							
Average fertilizer from algae (kg)	-	-	-	0.18	-	-	0.10
Lime (from carbonation) (kg)	23.85	11.93	-	-	3.85	1.52	-
Potassium chloride (kg)	-	-	-	-	11.54	17.32	2.51
Compost (kg)	67.27	35.78	17.55	-	-	-	-
Ammonium nitrate (kg)	-	-	-	-	3.85	4.23	10.02
Diammonium phosphate (kg)	-	-	-	-	-	3.23	2.51
Ammonium sulfate (kg)	-	-	-	-	3.85	14.04	2.51
Calcium sulfate (kg)	-	-	-	-	3.85	-	-
Potassium sulfate (mineral) (kg)	50.09	19.22	23.40	65.74	-	2.92	-
Poultry manure (kg)	-	-	-	59.16	-	-	-
Magnesium sulfate (kg)	-	-	-	-	-	0.45	-
Zinc sulfate (kg)	-	-	-	-	-	3.38	-
Urea (kg)	-	-	-	-	7.69	15.43	4.38
Other fertilizers (kg)	-	-	-	-	-	1.69	11.90
Energy							
Electricity (kWh)	-	7.61	-	1.80	1.16	11.81	7.68
Diesel (l)	21.19	19.38	46.68	12.76	25.53	30.52	3.48
Petrol (l)	3.82	1.93	4.02	1.99	1.73	1.73	10.95

A brief questionnaire has also been defined for cardboard boxes and plastic protection elements manufacturers, as those products are produced within the country, and information from two companies has been gathered in order to adapt the Ecoinvent datasets to the Ecuadorian productive systems.

Depending on their farm of origin, banana boxes can be shipped directly to the expenditure port (T3) or through a collection center (T1+T2). Data regarding T1, T2 and T3 transports, such as the type, size and load percentage of the trucks that transport bananas from the farm to the departure port in Ecuador, have also been gathered from farmers. When fruit was sent directly from the farms to the port (T3), refrigerated container trucks were used, which were loaded at the farms and kept closed until their arrival to Europe, while when fruit was sent to a collection center before its transport to the departure port, conventional trucks of different sizes were used in T1, and the type of truck (conventional or refrigerated) depended on the transport distance in T2.

To establish the energy requirements at the collection center (S2), an average facility has been considered (Martínez 2011), and a 0.20% of losses at this stage has been assumed.

There are two main harbors in Ecuador from which bananas are sent overseas: Puerto Bolivar and Guayaquil harbors (S3). Rotterdam (The Netherlands) has been selected as destination port (S4), as it is the main European destination of the shipping companies interviewed. Energy-related GHG emissions from ports have been determined based on data of a Chilean Port (Terminal de Puerto Arica 2011) for S3, and of several European ports (GreenCranes 2013) for S4.

Regarding overseas transport (T4), a weighted average has been calculated to establish the distance to be covered by the fruit (Searates 2013), based on the percentage of the total export of banana represented by each of the two Ecuadorian ports (A.E.B.E. 2011). The characteristics of the vessels used (type, size, load percentage in both trips (outbound and return) were provided by two shipping companies (Maersk Line and Sea Trade) responsible for the transoceanic transportation of this fruit.

The stages of ripening, distribution center, retail and consumption have been assumed to take place in Spain. Thus, once the fruit has arrived to Rotterdam, it is transported by refrigerated trucks (T5) to a ripening facility in Madrid (S5). Distances covered by all terrestrial transports were determined using Google Maps (2013).

At S5, fruit is ripened by controlled temperature and the addition of ethylene. Several bibliographic sources were used to determine electricity use (Eitner et al. 2012; Luske 2010; Svanes and Aronsson 2013), ethylene consumption (Svanes and Aronsson 2013), and the amount of fruit rejected at quality control (Luske 2010).

After ripening, cold chain ends and fruit is transported to Regional Distribution Centers (RDCs) by non-refrigerated trucks (T6). At RDCs (S6), secondary packaging is removed, and bananas are stored at room temperature until they are sent to retailers (T7). To model T6 and T7 transports, some of the more important RDCs for food products in Spain, and the main cities located in their areas of influence, were selected in order to guarantee the coverage of the whole country.

At retail stores (S7), primary packaging materials are removed (i.e. plastic bag and cardboard box) and fruits are sold at room temperature. Inventory data of the retail system was determined based on the distribution of fruit sales in Spain into different store categories (ICE 2011), and the energy requirements of each of them (Tassou et al. 2010). Regarding fruit waste at this stage, it has been estimated that only 2.24% of the bananas that reach this stage are sent to waste management, based on Spanish statistics (MAGRAMA 2012).

Once the fruit leaves the store, it is transported to households (T8) either on foot (90%) or by car (10%). The ending stage of the value chain is fruit consumption (S8). In Europe, bananas are stored at room temperature and eaten raw, being the main residue here the banana peel (40% of the total weight). Besides, the input and output flows associated to the ingestion and posterior excreta of the fruit have also been included (Muñoz et al. 2008). It has been assumed that all bananas reaching this stage are consumed.

It should be noted that, for all waste generated in the systems located in Spain (S5, S6, S7, S8), it has been assumed that waste management follows the current distribution in the country for each type of residue, based on Spanish statistics (INE 2011).

2.3. Adjustment of emission factors

To perform the carbon footprint assessment of the banana value chain, some methodological adjustments have been made to adapt the emission factors to the actual conditions of the study, which are described below.

2.3.1. N₂O emissions from managed soils

According to the IPCC guidelines (IPCC 2006), direct and indirect N₂O emissions arising from N fertilized soils can be determined from the amount of anthropogenic N inputs (i.e. synthetic or organic fertilizers, manure application, agricultural waste) through the use of emission factors.

On the one hand, to determine the N₂O direct emissions, a default value of 0.01 for EF1 is suggested, meaning that 1% of the applied nitrogen is emitted to the atmosphere as N₂O-N. Nevertheless, this factor is adapted to temperate countries, and independent of soil texture. In this study, specific emission factors for tropical climates have been used (Table 2), adapted to the three main types of existing soils in the area (MAGAP 2002).

Table 2. Emission factors for tropical countries used in determining N₂O direct emissions.

Soil texture	EF1 (%)	Source
Loamy (medium)	2.91%	(Veldkamp and Keller 1997)
Clayey (fine)	1.26%	(Veldkamp and Keller 1997)
Sandy (coarse)	0.78%	(Marquina et al. 2013)

On the other hand, for the estimation of the N₂O indirect emissions two flows were considered: NH₃ volatilization and NO₃ leaching. For the former, IPCC proposes Frac_{GASF} (Fraction of synthetic fertilizer N that volatilizes as NH₃ and NO_x) and Frac_{GASM} (Fraction of applied organic N fertilizer that volatilizes as NH₃ and NO_x) values of 0.1 and 0.2, respectively, but higher figures (0.15 and 0.30), extracted from Bouwman et al. (2001) for Central America and upland crops, were used here instead. For the latter, the Frac_{LEACH} (Fraction of all N added to/mineralized in managed soils that is lost through leaching and runoff) default value of 0.3 (for irrigated crops) was used, since all studied plantations have irrigation systems.

2.3.2. Adjustment of emission factors for transports

Some modifications have been made in Ecoinvent emission factors to adapt transport emissions to the real conditions of the study. These affect mainly the load factor or each vehicle and the use of refrigeration systems, both for terrestrial and sea transport.

Ecoinvent operation emission factors for road transport consider full outbound and empty return journeys (Spielmann et al. 2007). For different situations, a correction was made based on Swiss emission factors that report full truck emission factors (outbound journey) and empty truck emission factors (return leg) separately. Thus, when load factors for outbound and return trips were different than 100 and 0%, respectively, Equation 1 was used to model each of the trips.

$$EF = E \cdot (0.002 \cdot X + 0.4) \quad \text{Eq. 1}$$

Being EF the new emission factor, E the Ecoinvent emission factor for the operation of the type of truck considered and X the load capacity percentage (0-100).

Ecoinvent database does not include refrigerated transport, so adjustments were required in order to include the inputs and outputs associated to the cooling system. Two types of refrigerated trucks were considered: refrigerated container trucks (T2 and T3) and refrigerated conventional trucks (T5).

In container trucks, goods are cooled by a diesel generator set, and therefore the vehicle fuel consumption increases. Based on the specifications provided by a manufacturer (GTL Reefer 2013), this increase was estimated in 5.15 liters of diesel per hour. Taking into account the maximum speed for heavy vehicles allowed on Ecuadorian highways (Ecuador-vial 2013), an average speed of 60 km/h was considered and therefore the increase in diesel consumption to be added at the Ecoinvent process was 0.086 l/km, together with the associated combustion emissions. The new emission factors obtained are shown in Table 3. Note that refrigerant losses were not included here due to the lack of information.

Transport from the destination port to the ripening center (T5) is done by refrigerated trucks, but not container trucks, so adjustments are also required here. Values for the increase of fuel consumption due to cooling of between 2 and 4 l/h were obtained from literature (Tassou et al. 2009; Ziegler et al. 2013) depending on the truck load and cooling temperature (-20°C to 0°C). Temperature required by bananas is higher (14°C), so the lowest

value of the available ones was used: 2 l/h. An average speed of 80 km/h was used for heavy vehicles on French and Spanish highways, and therefore an increase in fuel consumption of 0.025 l/km was obtained.

Refrigerant leakage, considering both its direct emission to the environment and the emissions associated to its replacement, was included here: a trailer requires an average amount of 6.5 kg of refrigerant (Ziegler et al. 2013) and 8% losses were considered every year. R134a was selected as it is one of the most used refrigerants for these vehicles. Assuming that a truck travels 100,000 km/year, a leakage of 0.0052 g R134a/km was obtained. The new emission factors for this type of truck are shown in Table 3.

Table 3. Modification of the emission factors (EF) for road transport in refrigerated trucks.

Ecoinvent process	Ecoinvent original EF	Recalculated EF (Refrigerated container trucks)	Recalculated EF (Refrigerated trucks)
Operation, lorry >32 T, EURO 3	1.15 kg CO ₂ e/km	1.64 kg CO ₂ e/km	1.23 kg CO ₂ e/km
Transport, lorry >32 T, EURO 3	0.121 kg CO ₂ e/tkm	0.163 kg CO ₂ e/tkm	0.128 kg CO ₂ e/tkm

Regarding sea transport, Ecoinvent provides an emission factor for vessel operation which is not consistent with the actual conditions of the ships used in banana maritime transport (Table 4).

Ecoinvent dataset considers an empty return of the ships to their origin, but according to data provided by the shipping companies, 20% of their capacity is used in the return trip, which is uncooled, and therefore only 80% of that journey has to be allocated to the banana value chain. Applying the equation obtained for road transport, the resulting factor would be 95.2% of the original emission factor.

Concerning the additional fuel consumption for refrigeration, a TEU container has an electric power of about 4.1 kW (4 reefer 2013), which combined with the ship's maximum speed (14 knots) results in 0.158 kWh/km/TEU. Considering 160 g fuel/kWh (Ziegler et al. 2013), an additional consumption of 25,32 g fuel/km/TEU or 2,91 g fuel/tkm (1 TEU = 8,71 ton banana) is obtained. Regarding refrigerant leakage, 0.88 gCO₂e/tkm was used (Luske 2010).

Table 4. Modification of the emission factors (EF) for sea transport in refrigerated container ships.

Ecoinvent process	Ecoinvent original EF	Recalculated EF
Operation, transoceanic freight ship	0.009 kg CO ₂ e/tkm	0.0199 kg CO ₂ e/tkm
Transport, transoceanic freight ship	0.011 kg CO ₂ e/tkm	0.0216 kg CO ₂ e/tkm

2.3.3. Adjustment of emission factors for electricity

Ecoinvent database provides emission factors for individual sources, such as coal or hydropower, as well as the mix for several countries but not Ecuador. Therefore, the national electricity production profile for 2010 was defined (IEA 2010) and the corresponding emission factors were calculated. Moreover, the Spanish electricity mix already included in Ecoinvent was updated by adapting it to the current distribution of sources (REE 2012).

3. Results

3.1. Carbon footprint of the Ecuadorian banana supply chain

According to the results obtained (Table 6), the carbon footprint of Ecuadorian banana consumed in Spain is 1.25 ton CO₂e/ton banana or 0.84 ton CO₂e/ton banana if consumption is excluded and therefore the system ends up at the RDC. The stages that contribute most are: Plantation (S1: 22.1% on average), Consumption (S8: 19.2% on average) and Maritime Transport (T4: 18.7%). Differences are located on the stages placed in Ecuador (S1-S2 and T1-T2-T3) as once the fruit is shipped the downstream processes are exactly the same to all.

Table 6. Carbon footprint results of the average banana value chain, for each plantation type.

Plantation type	Total	S1 ^a	S2 ^a	S3 ^a	S4 ^a	S5 ^a	S6 ^a	S7 ^a	S8 ^a	T1 ^a	T2 ^a	T3 ^a	T4 ^a	T5 ^a	T6 ^a	T7 ^a	T8 ^a
Organic average	1.23	0.26	0.01	0.00	0.00	0.03	0.00	0.06	0.24	0.00	0.01	0.00	0.23	0.23	0.04	0.12	0.00
Conventional average	1.29	0.32	0.01	0.00	0.00	0.03	0.00	0.06	0.24	0.00	0.01	0.01	0.23	0.23	0.04	0.12	0.00
Global average	1.25	0.28	0.01	0.00	0.00	0.03	0.00	0.06	0.24	0.00	0.01	0.01	0.23	0.23	0.04	0.12	0.00

^aS1: Farm; S2: Collection center; S3: Departure port; S4: Destination port; S5: Ripening; S6: Regional Distribution Center (RDC); S7: Retail store; S8: Households; T1: Transport from farm to collection center; T2: From collection center to departure port; T3: From farm to departure port; T4: Overseas transport; T5: Destination port to ripening; T6: Ripening to RDC; T7: RDC to retail store; T8: Retail store to households.

As explained earlier, farms inventoried in this study were classified according to their production system (organic and conventional). A significant difference was found between the average organic (0.25 ton CO₂e/ton banana at the farm gate) and conventional plantation (0.31 ton CO₂e/ton banana at the farm gate).

3.2. Excel CF calculation tool

An Excel tool for the automatic calculation of the carbon footprint was developed in order to allow future users to obtain an independent estimation of the CF value, from a set of input data (Hospido 2014). This tool allows the user to change a significant number of input parameters related to the plantation stage (S1) and the Ecuadorian transport stages (T1, T2 and T3), analogous to those requested in the questionnaires sent to farmers.

In addition, the spreadsheet includes default values for the rest of the systems, which can be modified in case of having better quantifications or different destinations.

Once all data is introduced, the tool displays a report that summarizes the main results of the calculation, which can be exported as a pdf file. These CF results are divided into subsystems, and major contributions to the total footprint are identified for the most relevant ones. In addition, a comparison is shown among the CF of the actual banana value chain, the average value obtained in this study for Ecuadorian plantations, and the values obtained by other authors for the carbon footprint of bananas and other fruits.

4. Discussion

Figure 2 presents the comparative results of this study with those reported by other authors (Eitner et al. 2012; Iriarte et al. 2014; Lescot 2012; Luske 2010; Svanes and Aronsson 2013).

Luske (2010) carried out a cradle-to-gate analysis of Costa Rican bananas to be consumed in Germany (the chain ends at the retailer). Svanes and Aronsson (2013) is based on the previous study, but consumption is now placed in Norway and results are reported both for cradle-to-gate (up to the retailer, Svanes I column in Figure 2) and cradle-to-grave (i.e. including banana consumption, Svanes II column). Eitner et al. (2012) evaluated five banana plantations in three different Latin American countries, in a study that goes till the RDC assessing different locations in Europe. Lescot (2012) compiles four case studies from three different farms: Plantation A corresponds to Luske (2010), while results included in Figure 2 start from farms B and C, ending up either at the RDC (Lescot BI) or at the European harbor (Lescot BII and C). Finally, Iriarte et al. (2014) presents two results, both ending at the European port, which differ only in the overseas transport stage: a best-case-scenario (Iriarte I) that considers overseas transport in container vessels, and a worst-case-scenario (Iriarte II) in which small reefer ships are assumed.

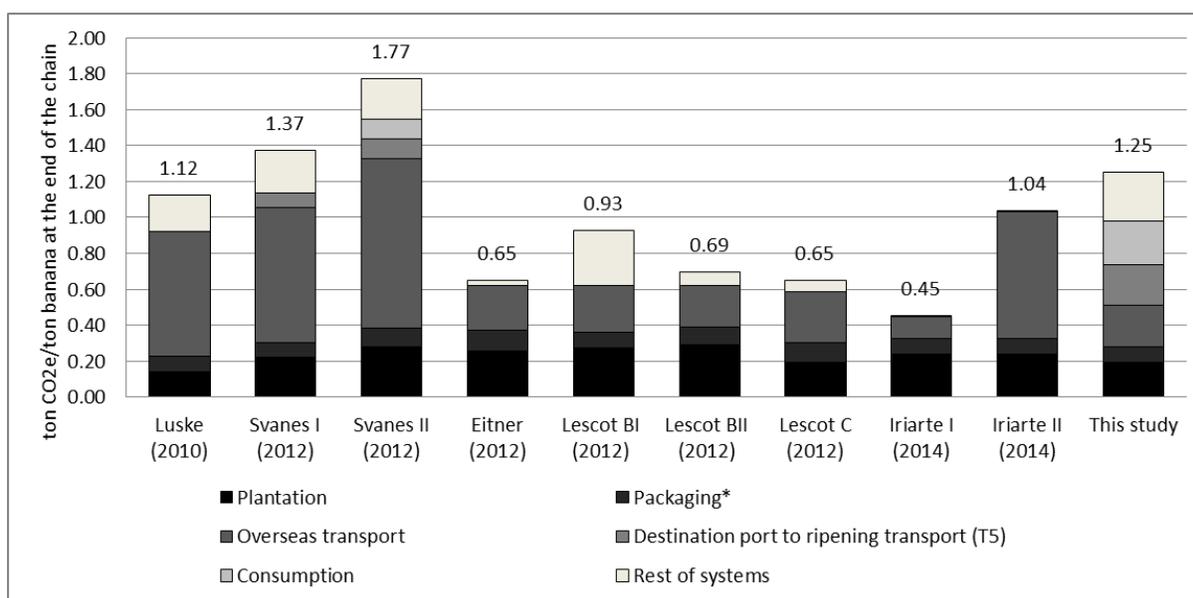


Figure 2. Comparison of the results obtained in this study with those reported by several authors.

* Packaging at plantations is separately reported here in line with the other studies on banana value chain.

The results obtained in this study are lower than those reported by Svanes and Aronsson (2013) for the whole value chain: 1.25 versus 1.77 ton CO₂e/ton banana; and also lower than the figures reported by Luske (2010) and Svanes and Aronsson (2013) until the retailer: 1.01 versus 1.12 and 1.37, respectively, ton CO₂e/ton banana. The main reason behind this difference is the smaller contribution of shipping reported here, due to i) the bigger size of the vessels considered (deadweight tonnage : 40,000 versus 15,000 tons) so the fuel usage per unit of banana transported is lower, ii) the fact that return trip is partially used (20%) for transporting other goods as reported by the shipping companies (while the other studies assumed an empty return) and iii) the assumption of efficient use of the vessel capacity (100% according also to the information provided by the shipping companies), different to the 65% reported by Luske (2010).

Our results are also lower than the ones reported by Lescot (2012) for the chain up to the RDC: 0.84 (this study) versus 0.93 ton CO₂e/ton banana, but higher than those reported by Eitner et al. (2012): 0.65 ton CO₂e/ton banana at the RDC. In both cases the reasons behind the differences are hidden behind the lack of information provided due to confidentiality issues by the former and due to the use of black-box software by the latter.

Results obtained in this study up to the destination port, 0.54 ton CO₂e/ton banana, are lower than the ones reported by Lescot (2012), 0.65 and 0.69 ton CO₂e/ton banana at the European port, and between both values provided by Iriarte et al. (2014) for the best and worst scenarios: 0.45 and 1.04, respectively. Lescot (2012) does not reveal the characteristics of any of the stages included in his assessment, while Iriarte et al. (2014) consider a best-case scenario, in which a non-refrigerated Ecoinvent process is directly used to model overseas transport, and a worst-case-scenario in which emissions from sea transport are based on data from Luske (2010).

5. Conclusion

This study has calculated the carbon footprint associated to banana produced in Ecuador and consumed in Spain (Europe). The whole value chain has been covered, with special emphasis on the activities that take place in the banana plantations: fruit cultivation and packaging. To do so, two groups of farms were assessed based on their production system and significant differences were found between the organic (0.25 ton CO₂e/ton banana) and the conventional plantations (0.31 ton CO₂e/ton banana).

Looking at the whole value chain, the carbon footprint of Ecuadorian banana consumed in Spain is 1.25 ton CO₂e/ton banana or 0.84 ton CO₂e/ton banana leaving the RDC. The stages that contribute most are: Plantation (22.1%), Consumption (19.2%) and Maritime Transport (18.7%).

Taking into account the previous studies on banana carbon footprint and the uncertainties and weakness there identified, special effort has been made here in refining the calculation of N₂O direct emissions at plantation and maritime transport. The values reported in this study are lower or in line with those available in the literature but this calculation is considered more adapted to the characteristics of the actual case study: the Ecuadorian banana.

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This paper is from:

Proceedings of the 9th International Conference on Life Cycle Assessment in the Agri-Food Sector



8-10 October 2014 - San Francisco

Rita Schenck and Douglas Huizenga, Editors
American Center for Life Cycle Assessment

The full proceedings document can be found here:
http://lcacenter.org/lcafood2014/proceedings/LCA_Food_2014_Proceedings.pdf

It should be cited as:

Schenck, R., Huizenga, D. (Eds.), 2014. Proceedings of the 9th International Conference on Life Cycle Assessment in the Agri-Food Sector (LCA Food 2014), 8-10 October 2014, San Francisco, USA. ACLCA, Vashon, WA, USA.

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ISBN: 978-0-9882145-7-6