LCA database for Chocolate Production Worldwide

Methodological note

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Introduction:

Definition of a supply chain:

Agroindustrial production systems analysis requires the concept of **supply chain**. From a **cradle-to-gate approach**, supply chains are considered as a sequence of processes from the initial primary production to its end use. Each sequence is then analyzed from the three main dimensions of sustainability: economy, environment and social balance [1]. In scientific impact studies, **potential indicators** are measured on a defined **functional unit** of end product for each subprocess then aggregated to provide a global view of the product's impact along the supply chain. This method called **Life Cycle Analysis (LCA)** is the most common tool for impact assessment and can be declined to both environmental and social assessment.

Life Cycle Analysis

Life Cycle Analysis is originaly designed for environmental sustainability evaluation of a value chain. Over the last few decades the method has been normalized (ISO 14040 and ISO 14044) and allows to identify both the use/destruction of resources and the emission of substances that can create pollution at different stage of the value chain [2]. The choice of the indicators is to the discretion of the scientists and is generally made with regards to what is at stake in the agroindustrial process.
In order to carry out a quantifiable analysis of the impacts resulting from the production and distribution of highly manufactured products, such as cocoa or chocolate, LCA hence seams to be a very performant tool.

Relevance of environmental LCA of cococa and chocolate production value chain:

Cocoa production value chain is the backbone of many countries' economy, encompassing a wide varieties of actors across the world [3]. This supply chain has been known for showing social discrepancies among actors and environmental issues [4].According to the FAO, conventional cocoa cultivation can have significant environmental impacts. Some of these impacts include deforestation, soil erosion and a loss of biodiversity, occurring due to the excessive use of pesticides and fertilizers and the effects of monoculture agriculture [5]. While consumers are increasingly interested in the sustainability of its end product - chocolate - and LCA studies accumulate on the topic [6], there is no broad spectrum meta-analysis gathering this data to improve its accessibility.
This project consists in creating a database to gather scientific data from LCA studies that focus on cocoa and chocolate production worldwide. This tool would allow for comparing supply chains across countries, products and practices by simple requests and several univariate statistic functions. We therefore chose to differentiate cocoa and chocolate production on two levels: (i) that of the global supply chain and (ii) that of the agriculture type. This forces us to combine many environmental assessment studies and build a comprehensive overview of chocolate value chains worldwide.

Description of the database:

The database has been build up on Excel. Table 1 shows a description of the different columns and their description.

Table 1: Overview of the database structure.
(NB: Columns are here displayed as rows for formatting purposes.)

Reference	Title	title of the article / scientific reference used
	Author(s)	Main autor(s) of the study
	Journal	Journal where the study was published
	Year	Year of publication
	DOI	Digital Object Identifier with hyperlink towards the online version
Supply Chain Characteristics	Supply Chain Type	Conventional, Quality, Organic, Fair trade, etc.
	Agriculture Type	Conventional, Organic, Agroforestry, etc.
	Boundaries	Cradle-to-gate, Cradle-to-retailer, cradle-to-grave, etc.
	Functional unit	Unit of product used for the study
	FU type	Raw material for Cocoa or End product for any chocolate of confectionnery type
	% Cocoa	Percentage of cocoa in the final product
	Cocoa mass	Cocoa mass in the final product
	Country	Country where the SC last sub-process within the boundaries of the study was conducted (eg. country of retail when using a cradle-to-retailer approach)
Environmental Assesment	AD (kg Sb eq.)	Abiotic Depletion potential
	GW (kg CO2 eq.)	Global Warming potential
	ODP (kg CFC-11 eq.)	Ozone Depletion potential
	AC (kg SO2 eq.)	Acidification potential
	EU (kg PO4 eq.)	Eutrophication potential
	CED (MJ)	Cumulative Energy Demand
	TE (kg 1,4-DB eq.)	Terrestrial Ecotoxicity
Environmental Assesment *per kg ofcocoa*	Idem	In each LCA study, impact potential indicators are calculated for the functional unit. Values of these columns are defined as: $\frac{EA}{kgCocoa} = \frac{EA}{FU} \times \frac{MassCocoa}{FU}$. This allows for a comparison across studies that don't have the same functional unit.

Supply chain characteristics

Supply chain type

Conventional = This is the default supply chain type. The primary objective of SCM is to fulfill customer demands through the most efficient use of resources, including distribution capacity, inventory, and labor [7]. A supply chain seeks to match demand with supply and do so with minimal inventory which is usually done through economies of scale on volumes. It is structured around collection centers of collectors/brokers supplied by conventioanl producers [8]. Since farm types vary from one country to another, we chose not to focus on farm characteristics but to consider «conventional» farms as representative entities of the producing country.

Semi-processed = This sub-chain is structured around a small group of primary, industrial processors, which use cocoa blends to produce semi-processed products (i.e. liquor, butter, powder) mainly for the international market.[8]

Quality = This type of supply chain is structured around private or corporate collection centres. It focuses on moderate volumes of quality cocoa to be exported as beans by national agro-exporters. Produces smaller quantities of semi-processed products.[8]

Premium = It is structured around producers who produce very high-quality cocoa, in very small volumes, traded (after careful post-harvesting) at very high prices on the international market.[8] Producers usualy work with artisan chocolate makers who select their beans carefully for a high quality end product.

Fair trade = Fairtrade (FT) certification tries to ensure global social welfare and address the environmental responsibilities of consumers. For now, the products most involved with FT are coffee, cocoa, bananas and cane sugar. In 2021, 10% of the world's cocoa was FT[4], showing the erection of an alternative sub-chain that is nothing but marginal on the international market.

Organic = This sub-chain can be identified through the involvement of a handful of associative collection centres or with cooperative statutes working with organic certified producers only. This sub-chain represents a very low weight in terms of volume and value, not due to a lack of demand, but to supply capacity (as the organic price differential does not compensate for the certification costs). It is linked in many cases to Fairtrade certification.[8]

Agriculture type

Conventional = This is the default agriculture type. Farms are considered conventional when they match the most common agricultural practices for cocoa production in the country.
Table 2 shows the diversity of «conventional» farming across the world's cocoa producing countries.

Organic = Organic farming consists of a system of agricultural practices based on standards through which it is possible to ensure food production without using certain chemical products that are environmentaly harmful and can cause damage to farmers' health while promoting a reduced use of resources. Inputs are regulated by the corresponding regional organic certification laws, which have previously analysed the noxious impacts of such additives and their organic origin. [4] However, regulations can change from one country to the other.

Technified = This type of agriculture is characterized by the use of technology to build up highly performant agricultural processes (technified irrigation, high fertilization doses, mechanisation,etc.) [9] resulting in very high production yields. This model can only be applied in oversized farms with high economic input and therefore often found within higly integrated supply chains (ie. upstream, core and downstream phases are managed by a single decisionary actor). This cannot be found in every country.

Agroforestry = Agroforestry is defined as a dynamic, ecologically based, natural resource management system that integrates trees in farmland for increased social, economic and environmental benefits [11]. However, the integration of trees in agricultural system can look different depending on the biome and the land characteristics (cf.Table 3 shows the diversity of agroforestry practices across cocoa producing countries.

Table 2: Average farm characteristics in several cocoa producing countries, defining «conventional» agriculture type. *(source: [10])*

Country	**Farm size**	**Density**	**Inorganic fertilisat°**	**Yield** (FAO)	**Labour**
Ivory Coast	2.9 ha	975 trees/ha	10% farms	500-600 kg/ha	73 day/ha total from household (94% farms) and seasonal workers (hired)
Ghana	2.1 ha	1245 trees/ha	80% farms	400- 500 kg/ha	120 day/ha total from houshold and farming communities (hired & communal)
Indonesia	0.8 ha	890 trees/ha	80% farms	700-800 kg/ha	—
Ecuador	3.7 ha	625 trees/ha	33% farms	800-900 kg/ha	39 day/ha from household (100%) and daily contractors
Brazil	5.5 ha	980 trees/ha	30% farms	500-600 kg/ha	household and seasonal hired labour depanding on farm size
Nicaragua	0.9 ha	650 trees/ha	33% farms	500-600 kg/ha	91 day/ha from household (80% farms) and hired labour
Costa Rica	7.4 ha	450 trees/ha	400-500 kg/ha	—	

Table 3: Common agroforestry practices in several cocoa producing countries. *(source: [10])*

Country	**Agroforestry practices**
Ivory Coast	- In the first 2-3 years of establishment, cocoa trees may be intercropped with food crops (maize, plantain, cassava and vegetables). Poultry and livestock can also be breeded on farm. - Cocoa is generaly cultivted under the shade of a selectively thinned forest.
Ghana	- Cocoa trees are planted in association with other crops (banana, plantain, cassava, etc.) and sometimes with livestock. It concerns 53.9% of cocoa farmers. - Cocoa trees often constitutes the canopy as 66% of cocoa plantations have little or no shade.
Indonesia	Coconut, banana, durian, rambutan, avocado, robusta coffee, spice, ginger and other fruit crops are commonly grown on cocoa farms and sometimes associated with livestock (eg.tree prunings and pod husk may be used to feed goats)
Ecuador	- Around 57% of cocoa farms are shaded with timber, fruit and shade trees. - Smaller cocoa farms often have a larger area devoted to subsistence crops (cassava, rice, sweet potato, beans, tomatoes, bananas) corn, passion fruit.
Brazil	- In the Atlantic forest region of Southern Bahia, cocoa trees are planted under the canopy of the cabrucas. - Intercropping with rubber is sometimes encountered and provides shading to the cocoa trees. Otherwise, food crops and liveestock remain exceptional in cocoa farms.
Costa Rica	Much of the cocoa is produced in smallholder farms with diverse integrated agroforestry and high levels of shade.

Scope & boundaries

LCA methodology uses a cradle-to-approach that requires well defined boundaries between each step of the overall production process. Cocoa supply chain flowchart is shown on Figure 1. Boundaries considered in our methodology are defined as indicated by the dotted lines on the graph.

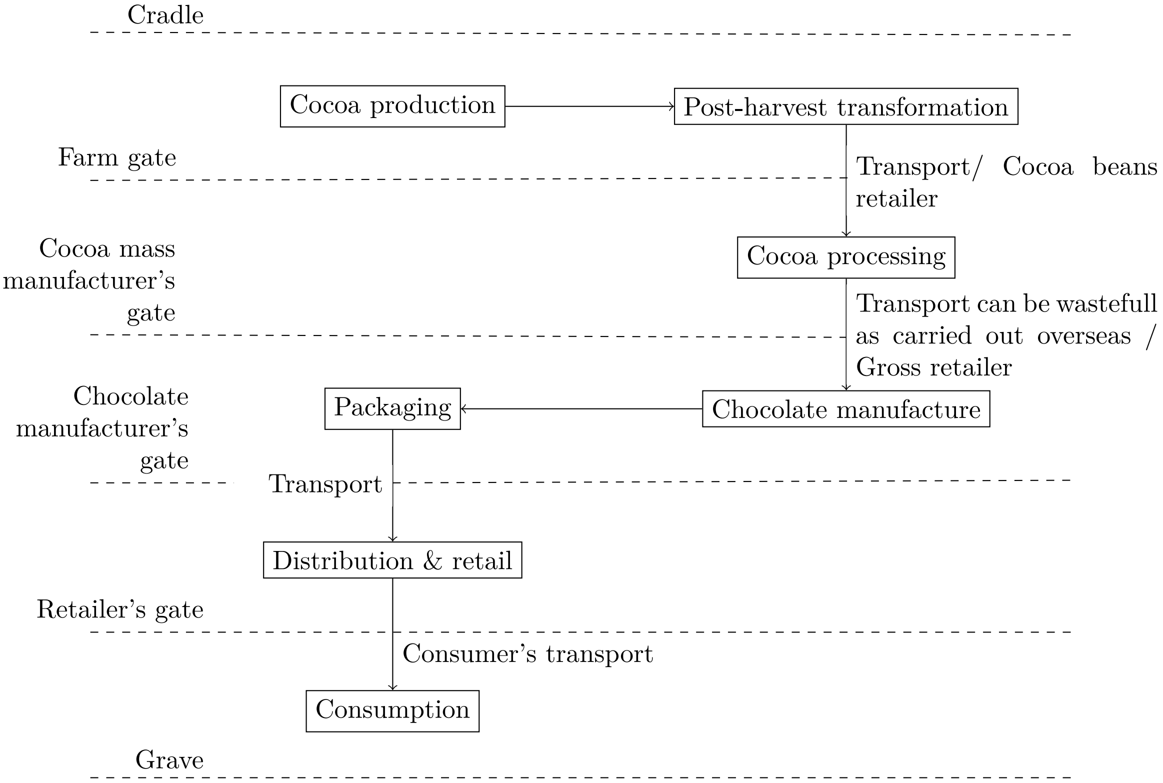

Figure 1: Chocolate supply chain with boundaries as defined in LCA studies and considered in this meta analysis.

Cradle-to-farm gate = As post-harveting processes are usually carried out on farm, we chose to consider the upstream phase overall in this scope.

Cradle-to-cocoa mass manufacturer's gate = This scope is defined as the last sub-process of the cocoa processing phase but the first step of the core phase. It usually takes place in the cocoa producing country.

Cradle-to-chocolate manufacturer's gate = This scope is defined as the second step of the core phase. It can take place in a completely different country than that of where the raw material is produced. Transport is therefore taken into account within this boundary. Packaging is also included when considered in the study.

Cradle-to-retailer = This scope is defined as the fist sub-process of the downstream phase. Distribution can take place in many different countries.

Cradle-to-grave = This scope is rarely used as end-of-life processing are hard to assess. It is however the most holistic approach of LCA studies.

% Cocoa and Cocoa mass

In order to compare studies that do not have the same functional unit and provide a comparison depending on product type based on studies that do not necessarily have the same scope, environmental indicators are divided by the total cocoa mass in the final product. Therefor, studies tat focus only on cocoa production can be treated as studies that focus on chocolate or other cocoa end-products. Cocoa percentage is defined as the percentage of cococa solids (cocoa powder + cocoa mass) in the final product [12]. Cocoa mass is then calculated as $FU_{endproduct} \times \%Cocoa$.

Environmental assessment

In product base LCA studies, the environmental impact of the product is assessed through **impact potential indicators**. These indicators measure the potential impact of the process on the environment using inference data.

Abiotic Depletion potential (AD) = This indicator represent the depletion of non-renewable resources(abiotic, non-living (fossil fuels, metals, minerals)). It is based on concentration reserves and the rate of de-accumulation and is expressed in kg antimony equivalents.

Global warming potential (GW) = This represents the potential change in climate attributable to increased concentrations of CO2, CH4, and other GHG emissions that trap heat. It leads to increased droughts, floods, losses of polar ice caps, sea-level rising, soil moisture losses, forest losses, changes in wind and ocean patterns, and changes in agricultural production. It is expressed in CO2 equivalents usually for time horizon 100 y.

Ozone depletion potential (ODP) = This is the potential for the reduction in the protective stratospheric ozone layer. The ozone-depleting substances are freons, chlorofluorocarbons, carbon tetrachloride, and methyl chloroform.

Acidification potential (AC) = This indicator is based on the potential of acidifying pollutants (SO2,NOx, HCl, NH3, HF) to form H1 ions. It leads to damage to plants, animals, and structures.

Eutrophication potential (EU) = Eutrophication leads to an increase in aquatic plant growth attributable of nutrients left by over-fertilization of water and soil, such as nitrogen and phosphorus. EP measures nutrient enrichment that may cause fish death, declining water quality, decreased biodiversity, and foul odors and tastes.

Terrestrial Ecotoxicity (TE) = This potential focuses on the emissions of toxic substances into the air, water, and soil. It includes the fates, exposures, and effects of toxic substances.

(source: [13])

Database access:

The database can be found on the following github link:
`https://github.com/lisaparuit/LCA-for-cocoa-and-chocolate-production-database/blob/main/Chocolate%20LCA.xlsx`

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