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Environmental Footprints of Cocoa, Cocoa Products and Chocolate in Germany

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Content

1 Background and Objective

1.1 Background

In recent years, cocoa and chocolate have been used as prominent examples to raise public awareness of the environmental impact of food, using indicators such as carbon, water and land footprints.

In the literature, results for environmental footprints of cocoa and cocoa products vary widely, which limits their use in environmental assessments of food products, including life cycle assessments, or as a purchase recommendation. For example, the values for the carbon footprint of milk chocolate range from 3.6 kg CO_2 eq./kg foodstuff [Büsser & Jungbluth 2009] to 17.6 kg CO_2 eq./kg foodstuff [Colomb et al. 2014].

This is because analyses are often based on partly inconsistent assessment approaches, varying system boundaries, or different methodological approaches. Examples of different environmental footprints in the literature can be found in the Annex (Chapter 9).

1.2 Objective

The aim of this study is to present the most relevant environmental footprints for cocoa and cocoa products, such as chocolate, that are consumed in Germany, based on consistent and up-to-date assessment methods.

In addition to the carbon footprint, which is important from a climate protection perspective, other environmental impact categories, such as the water, land and phosphate footprints will be considered. Water, land, and phosphate are finite resources, largely used for food production, and subject to major conflicts. We therefore strongly support the inclusion of these impact categories in the environmental assessment of food.

The water and land footprints will take into account not only the amount of resources used, but also the severity of their environmental impact based scarcity (water) or the degree of 'naturalness' (land).

In order for the results to be used consistently for all cocoa products, the following products will be considered: cocoa beans, cocoa mass, cocoa butter, and cocoa powder as well as various chocolates. We will distinguish between milk, dark and white chocolate, as their cocoa content and other components vary considerably.

2 Methodology

This section defines the products and the processing steps (Chapter 2.1; Figure 1), presents the methods used to calculate the individual footprints (Chapter 2.2.2), and describes the system boundaries (Chapter 2.3).

2.1 Definitions of Cocoa and Cocoa Products

Cocoa pod:	The fruit of the cocoa tree (*Theobroma cacao*) has a husk that contains the raw cocoa beans surrounded by pulp.
Cocoa beans, raw:	The unprocessed seeds, which are taken from the cocoa pod, are referred to as “cocoa beans, raw".
Cocoa beans:	In this publication, “cocoa beans” refer to the beans after the first processing steps. These include: fermentation, drying, roasting, winnowing, cracking, refining and alkalisation. Cocoa beans broken into cocoa nibs are increasingly offered for direct consumption.
Cocoa mass:	Cocoa mass is produced from cocoa beans by grinding the beans under gentle heating.
Cocoa powder, highly defatted:	“Cocoa powder, highly defatted" is cocoa powder with a fat content < 10 %. It is produced from the press cake after pressing the cocoa mass and separating the cocoa butter.
Cocoa powder, slightly defatted:	“Cocoa powder, slightly defatted" is cocoa powder with a fat content > 10 %. It is produced from the press cake after pressing the cocoa mass and separating the cocoa butter.
Cocoa butter:	Cocoa butter is the fat that is extracted from the cocoa mass through pressing.
Milk chocolate:	Milk chocolate is a processed cocoa product. The dry matter content of cocoa must be at least 25 %. The dry matter content of milk must be above 14 % [KakaoV 2003].
Dark chocolate:	Similar to milk chocolate, dark chocolate is a processed cocoa product. To meet the criteria for chocolate, dry matter content of cocoa must be at least 35 %, of which at least 18 % is cocoa butter [KakaoV 2003]. Depending on the cocoa or sugar content, there are alternative terms, e.g., dark chocolate, fine dark chocolate, fine dark chocolate, bitter chocolate.
White chocolate:	White chocolate is a product made from cocoa butter, milk or milk products, and sugars, and must contain at least 20 % cocoa butter and 14 % milk solids [KakaoV 2003].

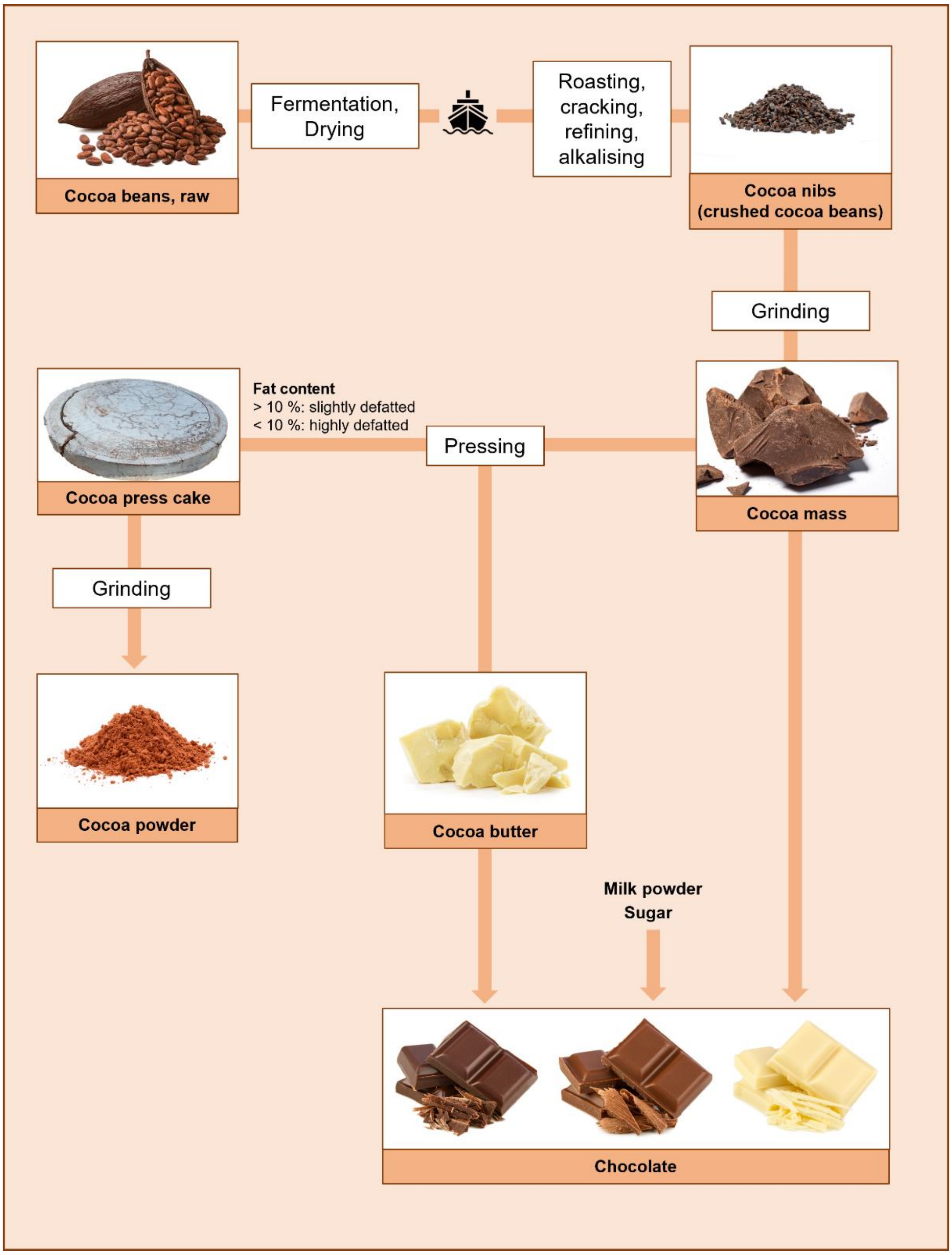


Figure 1: Steps in cocoa processing.

2.2 Products and Environmental Footprints considered

2.2.1 Products

To ensure that the results can be used consistently across the entire range of cocoa products, the following products are considered: cocoa beans, cocoa mass, cocoa butter and cocoa powder (highly defatted) as well as chocolates. We distinguish between milk, dark and white chocolate, as their cocoa content and chocolate components vary considerably. The products considered are both trade and consumer products in the value chain of cocoa and chocolate.

2.2.2 Environmental Footprints

The methods used to calculate the individual footprints are described below.

Carbon footprint:

- The carbon footprint was calculated according to ISO 14046 [ISO 2018]. It includes all greenhouse gas emissions (including carbon dioxide CO_2, methane CH_4, nitrous oxide N_2O) converted to CO_2 equivalents based on [IPCC 2021].
- The greenhouse gas emissions associated with land use and land use change were taken into account using the attributional land use/land use change (aLULUC) approach [Fehrenbach et al. 2020].

Water footprint:

- As clean (drinking) water is a scarce resource in some regions of the world and agriculture is a major water user worldwide, the water footprint plays an important role in the environmental assessment of food. In the form of "virtual" water, (imported) products come with a water footprint, which is influenced by agricultural production, processing and water availability in the source region.
- The calculation of the water footprint is based on the Available WAter REmaining (AWARE) method [Boulay et al. 2018] and - in addition to the amount of water required for production - takes into account the water availability in a country in relation to the global average. The methodology was extended to include irrigation technology and water desalination (combined AWARE, irrigation technology efficiency and desalination factor, ifeu-internal data). The water footprint is given in m^3 water equivalents.

Land footprint:

- As agricultural land is increasingly used for non-food purposes, there is increasing competition for land between the cultivation of food and feed crops, crops for material use or fuel production, and nature conservation areas (Food, Feed, Fibre, Fuel, Flower debate).
- The calculation is based on the actual area required for cultivation and the '*naturalness*' of the land. Therefore, the agricultural area used to produce a crop is converted into the equivalent of one year of fully sealed area based on the hemeroby concept. This is done by assessing the distance of the production area to near-natural areas ("distance to nature") [Fehrenbach et al. 2019]. The resulting unit is square metre years of natural area occupation ($m^2 \cdot yr$ DNP/kg) (also called *Distance-to-Nature-Potential*, DNP).

Phosphate footprint:

- Due to the finite nature of phosphate rock deposits, the amount of phosphate consumed by a product has to be considered. This is particularly relevant for the use of phosphate fertilisers in food production.
- The amount of phosphate per kg of product is given in g phosphate rock equivalents. For details, see Reinhardt et al [2019].

2.3 System Boundaries of the Products

The system boundaries are set as follows:

Cocoa beans:

- Cultivation of cocoa beans, including first processing steps, such as fermentation and drying, in the country of origin.
- Average German import mix of cocoa beans.
- Shipping from the countries of origin to Germany.
- Further processing, such as roasting and cracking, in Germany.

Cocoa mass:

- See cocoa beans.
- Grinding of cocoa beans in Germany, including logistics for transport to processing within Germany.

Cocoa butter:

- See cocoa mass, including pressing of cocoa mass.

Cocoa powder:

- See cocoa mass, including pressing of cocoa mass and grinding of press cake.

Beet sugar:

- Cultivation and processing up to the point of delivery to the chocolate factory. Production in Germany.

Milk powder:

- Dairy cow production and related emissions (such as feed provision, emissions from enteric fermentation and manure), consideration of parent and grandparent animals, milk production incl. deductions for co-products such as meat utilisation and farm manure. Processing of the milk into milk powder until delivery to the chocolate factory. Entire production chain in Germany.

Chocolates:

- From cocoa cultivation to the supermarket checkout in Germany.
- Including packaging and recycling.
- "Typical" chocolate recipes with average beet sugar and milk powder. Cocoa ingredients as described above.
- Complete production in Germany (i.e., imported chocolates or partially imported chocolate ingredients other than cocoa ingredients are not part of this study).

Reference unit was 1 kg of the respective product .

3 Environmental Footprint of Cocoa Beans

The cocoa tree (*Theobroma cacao*) is cultivated in many tropical countries. After harvesting, separating the cocoa beans from the cocoa pod (Figure 2), fermentation, and drying in the respective cultivating countries, the beans are exported.

The origin of the cocoa beans imported to Germany is of particular importance, because some components of environmental footprints, such as climate gas emissions from land use and land use change and water scarcity as part of the water footprint, are based on the weighted import shares. So are the transport distances for shipping the cocoa beans to Germany.

Therefore, we differentiate between "imports of cocoa beans" (3.1), "cocoa cultivation" (3.2), "processing and logistics" (3.3) in the following Chapters. Chapter 3.4 presents the results of the environmental footprints for cocoa beans.

Figure 2: Cocoa pods.

3.1 Imports of Cocoa Beans

To calculate environmental footprints of cocoa and chocolate products typical for Germany, the import shares of individual production countries are a key factor. Since the yields of the cocoa tree vary strongly by production country, the average yield must be weighted according to import shares to Germany and the respective country yields. Other parameters are also determined by import shares, such as shipping distance to Germany, the factors of attributional land use and land use change (aLULUC), as well as irrigation data and country-specific water availability values (AWARE factors).

The main cocoa-producing countries exporting to Germany are Côte d'Ivoire, Nigeria and Ghana [Destatis 2021](Table 1). In total, these three countries account for 72 % of direct imports of cocoa beans to Germany. In addition, cocoa beans are imported from these countries via Belgium and the Netherlands. If the import shares of these two countries are similar to those in Germany, roughly 90 % of the cocoa beans come from the three main supplier countries.

In terms of import volumes to Germany, cocoa cultivation in Ecuador (4 %) and Cameroon (3 %) is minor, which is why including these countries in the assessment does not result in major changes. The same applies to the other countries with low import shares. The countries exporting cocoa beans to Germany are representative for the European market [European Parliament et al. 2010; EuroStat 2017].

Therefore, for analyses where the origin of cocoa plays a role, we relate the import shares from the three main supplier countries to the total imports.

Table 1: Top 10 supplier countries of cocoa beans to Germany based on the 5-year average import volumes for the years 2016-2020 [Destatis 2021].

	Country	Share of import volume to Germany
1	Côte d'Ivoire	47 %
2	Nigeria	15 %
3	Ghana	9 %
4	Belgium	9 %
5	Netherlands	8 %
6	Ecuador	4 %
7	Cameroon	3 %
8	Peru	2 %
9	Dominican Republic	1 %
10	Guinea	1 %

3.2 Cocoa Cultivation

The following processes and parameters are used to assess the environmental impact of cocoa farming**:**

- Yields
- Land use and land use change
- Setting up the plantations (seedlings, field work)
- Operating the plantations (fertilisers, pesticides, field work)

3.2.1 Yields and Land Use

Yields play a key role in calculating the environmental footprints, as greenhouse gas emissions from land use and land use change and the water footprint are directly related to yields and therefore land occupation.

The total area under cocoa cultivation worldwide in 2019 was 12.2 million hectares. The average yield per hectare was 457.4 kg/ha. A total of 5,596,397 t of cocoa beans were produced worldwide in 2019 [FAOStat 2021](Table 2).

The main cocoa producing countries are in Africa. The country with the largest global cocoa production is Côte d'Ivoire in West Africa, which produced 39% of the global harvest in 2019. About 90 % of the cocoa beans imported to Germany come from Côte d'Ivoire, Nigeria and Ghana (see Chapter 3.1).

Table 2: Production volume from the top 10 cocoa producing countries, 2019 [FAOStat 2021].

	Country	Production quantity in t
1	Côte d'Ivoire	2,180,000
2	Ghana	811,700
3	Indonesia	783,978
4	Nigeria	350,146
5	Ecuador	283,680
6	Cambodia	280,000
7	Brazil	259,425
8	Peru	135,928
9	Dominican Republic	88,961
10	Colombia	85,139
	TOP 10	**5,258,957**

The mean yield is 444 kg/ha, calculated on the basis of the 5-year average yield of the three main supplier countries (Table 3) weighted according to import shares. It should be noted that the values vary substantially between countries and between years. For this reason, we use a rounded value of 450 kg/ha for annual yield in this study.

Table 3: Share of the main exporting countries of cocoa bean imports to Germany [Destatis 2021] with 5-year average yields in the respective country [FAOStat 2021].

	Share of import volume to Germany	5-year average values of yields in kg/ha [2015-2019]
Côte d'Ivoire	47 %	483.7
Nigeria	15 %	272.0
Ghana	9 %	525.3

A correction factor was applied to this value: In cocoa producing countries such as Brazil, Trinidad and Ecuador, cocoa is produced at large industrial scale under shade nets with relatively high yields per hectare. In Germany's main supplier countries Côte d'Ivoire, Nigeria and Ghana (Chapter 3.1), however, cocoa is produced by smallholders on farms of 2-5 ha with annual yields between 200 and 1,000 kg/ha [OroVerde 2021]. Here, shade trees, which grow in mixed cropping systems with cocoa trees, provide the necessary shade (Figure 3). As the above yield refers to the mixed crops, it is necessary to derive a net yield factor in order to allocate the environmental impacts associated with land use (such as the associated greenhouse gas emissions) to the cocoa trees and the other crops of the intercropping system. For this purpose, we estimate that about 75% of the land is occupied by cocoa trees. The remaining 25 % of the land is used to grow bananas and shade trees, among other things, which are used for firewood, construction timber or fruits. This results in an annual net yield of 600 kg/ha, which is used as the basis for the area-related environmental impacts from land use and land use changes as well as for the land footprint.

For land use and land use changes, we apply the method according to aLULUC [Fehrenbach et al. 2020] using the yield of 600 kg per hectare of cocoa beans as described above.

Figure 3: Cocoa cultivation under shade trees.

3.2.2 Fertiliser Use

To determine fertiliser use, two aspects are important: First, the allocation of fertiliser to the individual co-products of the cocoa pod and second, the fertiliser regime.

Co-products: The pods are usually opened directly at the collection point and the raw cocoa beans are taken out and immediately processed to prevent the seeds from germinating. The remaining pod husks are used as fertiliser, animal feed or fuel and the cocoa pulp is used to make jelly or is fermented into alcohol or vinegar. Since cocoa beans are the main product of cocoa cultivation, fertiliser credits for the use of co-products should be applied.

The fertiliser requirement can be derived from the nutrient content of the product. Different data on the nutrient content of the cocoa pod (raw cocoa beans with cocoa pulp and husk, see definition in Chapter 2.1) can be found (Table 4). According to [Rehm & Espig 1996], the nutrient content of cocoa beans amounts to 20 kg N, 4 kg P, and 10 kg K (for 1,000 kg dry beans).

As the fertiliser requirement for cocoa is comparatively low, we estimate the fertiliser applications conservatively. This applies to all following individual steps.

Fertiliser regime: here we assume sustainable fertilisation, i.e., based on nutrient content. Therefore, in a first step, we conservatively set the nutrient content for the cocoa pod (see Table 4 "this study"). To account for the use of the husks and pulp (as fertiliser, animal feed or bioenergy), we reduce the fertiliser requirement by half the difference to the values for cocoa beans according to [Rehm & Espig 1996].

Table 4: Main nutrient values (N, P, K) (in kg) removed with the harvested cocoa pods (including raw cocoa beans). The values refer to the amount of pods needed to obtain 1,000 kg of dry cocoa beans.

Country	N	P	K	Source
Côte d'Ivoire	35.3	4.8	50.5	Hartemink [2005]
Nigeria (1)	38.3	5.7	76.9	Hartemink [2005]
Nigeria (2)	39.8	6.3	85.6	Hartemink [2005]
Ghana	30-40	5.7-7.0	58-71	van Vliet & Giller [2017]
Various countries, worldwide	35	6	60	van Vliet & Giller [2017]
This study	**35**	**6**	**60**	

In addition to the nutrient removed at harvest, two other aspects must be considered when using the approach of a sustainable fertiliser regime: natural deposition, especially of nitrogen compounds, and losses (through erosion or leaching). For deposition, we set 7.5 kg N/(ha·yr) (where 75 % of this amount corresponds to the yield of 450 kg of cocoa beans) based on the value range of 5 - 12 kg N/(ha·yr) published by [van Vliet & Giller 2017]. There is no relevant deposition for P and K. For the losses, we use the approach suggested by [Müller-Lindenlauf et al. 2014]

This results in the following values, converted to typically used fertiliser data, per 1,000 kg of dry cocoa beans: 20.59 kg N, 12.08 kg P_2O_5 and 51.49 kg K_2O. For subsequent analyses we round these values (Table 5).

Table 5: Fertiliser requirement in [kg] for the production of 1,000 kg of dry cocoa beans.

Fertiliser	N	P_2O_5	K_2O
Quantity in kg	21	12	51

3.2.3 Other inputs

Planting and maintaining the cocoa trees as well as harvesting are mainly done manually in the production countries. The use of machinery is limited and does not have a significant impact on the results. Similarly, the provision of seedlings is negligible. For these processes, average data from IFEU 2022 are used [ifeu 2022].

According to Asogwa & Dongo [2009], the following amounts of active substance are applied per area: fungicides: 2.3-3.8 kg/ha and herbicides: 0.5-3.9 kg/ha. Afrane & Ntiamoah [2011] report the following data: fungicides: 1,997.7 t for 632,000 t of cocoa production in Ghana in 2009, which corresponds to 1.9 kg fungicide/ha for a yield of 0.6 t/ha, and insecticides: 2,300 l, also for 632,000 t of cocoa production in Ghana in 2009/10. Assuming that there is an error here in converting units by a factor of 1,000, this amounts to 2.2 l/ha (for a yield of 0.6 t/ha).

On this basis, we assume 5 kg of active substance for pesticide use per 450 kg cocoa beans (6.7 kg for 600 kg cocoa beans), which is negligible with regard to the footprints investigated.

3.3 Processing and Logistics

After harvesting, the raw cocoa beans (Figure 4) are separated from the cocoa pod and fermented and dried in the respective growing countries.

The cocoa beans are transported by ship. The transport distance corresponds to trade routes from ports in the production countries to Germany and weighted by the respective import share. The weighted transport distance amounts to a rounded 6,600 km.

Figure 4: Cocoa beans.

Afterwards, the cocoa beans are undergoing a multi-stage processing and refining process: roasting, crushing, refining (pressure reactor) and alkalising to remove acids and other undesirable flavour components. This creates the typical cocoa aroma.

For the individual processing steps, data were taken from the IFEU database [ifeu 2022].

3.4 Results for Cocoa Beans

Table 6 shows the four environmental footprints of cocoa beans and Table 7 illustrates the carbon footprint according to life cycle stage.

Table 6: Environmental footprints of cocoa beans.

	Carbon footprint [kg CO_2 eq./kg]	Phosphate footprint [g P eq./kg]	Water footprint* [m^3 H_2O eq./kg]	Land footprint** [$m^2 \cdot yr$ DNP/kg]
Cocoa beans	4.2	48	100.	2.1

*Water footprint based on AWARE (Chapter 2.2.2).

**Land footprint as Distance-to-Nature-Potential (Chapter 2.2.2).

Table 7: Carbon footprint of cocoa beans by life cycle stage.

[kg CO_2 eq./kg]	Agriculture	Land use	Long-distance transport	Processing	Total
Cocoa beans	0.7	2.8	0.2	0.5	4.2

Agricultural production and in particular land use determine the carbon footprint of cocoa beans (Figure 5). These two life cycle stages are strongly influenced by the low yield of 450 kg per hectare of total agricultural area. With regard to land use, the country-specific aLULUC factors also play an important role. Transport and processing account for only a small share of the carbon footprint.

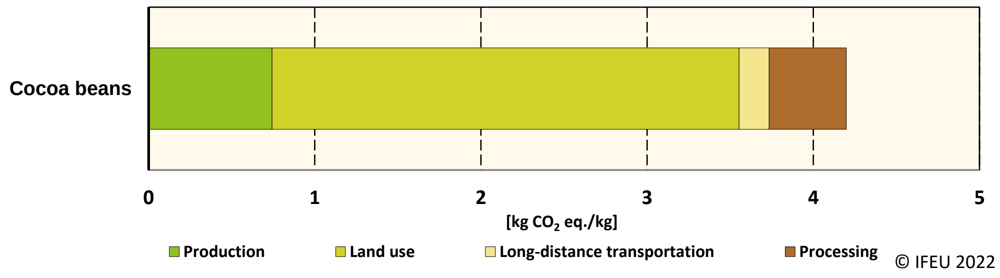


Figure 5: Carbon footprint of cocoa beans.

Note on the calculation: In addition to the methods described in the previous chapters, the calculation of the land footprint is based on the specific hemeroby class of the crop, which informs the *Distance-to-Nature-Potential* (Chapter 2.2.2). In line with other perennial tropical fruit trees, such as oil palm, coconut, rubber and mango, we have set the hemeroby value for cocoa to IV. This already takes into account shade trees (for the use of timber, firewood, food) (Chapter 3.2).

4 Environmental Footprints of Cocoa Butter and Cocoa Powder

To calculate the environmental footprints of cocoa butter and cocoa powder, the burden of the environmental footprints of cocoa beans has to be divided between the two products. According to the LCA standard ISO 14040/43, crediting methods (system expansion) are preferred over other methods such as allocation. However, we do not consider crediting methods to be appropriate in this case, as in our view there are no meaningful and realistic (market-driven) alternatives for either product. Therefore, in this study, we use allocation to divide the environmental burden between the two co-products.

We consider economic allocation the most appropriate method, and will additionally calculate allocation according to mass.

4.1 Derivation of Allocation Factors

As explained above, dividing the environmental footprints of cocoa beans between the two products is done using economic allocation. In addition, we provide values according to mass-based allocation.

4.1.1 Cocoa Butter and Cocoa Powder: Economic Allocation

For economic allocation, world market prices have proven to be a good indicator for products that are traded on the world market, as external distortions are reduced. Since both products under consideration are traded on the world market, the world market prices are used to derive the allocation factor.

Prices of cocoa products have been subject to strong fluctuations in recent years. Prices for cocoa butter rose sharply in 2012-2014, while cocoa powder prices fell. Since then, prices of cocoa butter have stabilised at a relatively high level. The cocoa powder price remains at a low level. Overall, the prices are associated with high uncertainties in the markets, which can be explained by the increasing virus infestation by *Cacao swollen shoot virus* (CSSV) in the cocoa producing countries. For the relationship between the price of cocoa butter and the price of cocoa powder, it is therefore necessary to consider a longer time series. For the prices of cocoa butter and cocoa powder we have therefore used the last 8 years as a basis for calculating the economic allocation factor (Figure 6).

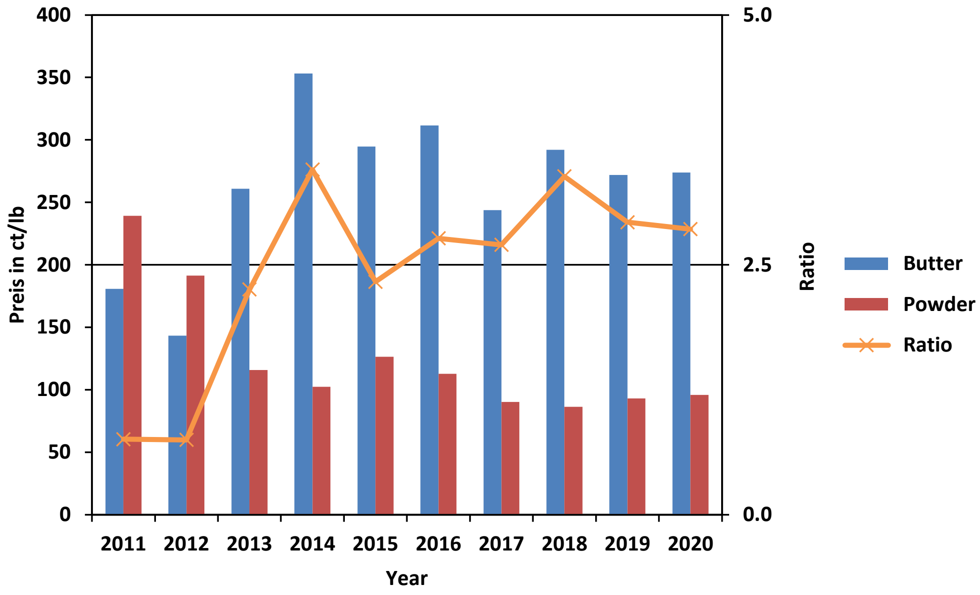


Figure 6: Prices of cocoa butter and cocoa powder and their ratio (butter/powder) over the last 10 years [Meyers 2021].

Here we consider the period from 2013 onwards, during which the world market prices for cocoa butter and cocoa powder have remained at roughly similar levels. The annual average value [2013-2020] of the cocoa butter/cocoa powder price ratio corresponds to 2.83. In order to account for the volatility of world market prices and to avoid pseudoprecision, we use a factor of 2.5.

Therefore, the allocation is calculated using the ratio 1: 2.5 (cocoa powder : cocoa butter).

The economic allocation is associated with limitations, as the world market price of cocoa is subject to various weaknesses. The following three examples show the limitations associated with the world market price [Deutsche Gesellschaft für Internationale Zusammenarbeit; Südwind e.V.; Germany / Federal Ministry for Economic Cooperation and Development et al. 2018]:

- The world market price is largely independent of actual supply/demand but influenced by a few individual companies.
- Speculation of cocoa beans and cocoa co-products on the world market
- Informal trade of cocoa beans and cocoa co-products bypassing the world market (e.g., smuggling)

However, in this study, we have chosen the economic allocation based on world market prices, as we believe that this is the best way to allocate the environmental burden of cocoa production to the co-products of the cocoa bean.

4.1.2 Cocoa Butter and Cocoa Powder: Allocation based on Mass

The cocoa butter content of cocoa beans varies widely, as data from different sources show (Table 8, Figure 7).

Table 8: Cocoa butter content of cocoa beans and related literature source.

Cocoa butter content of cocoa beans	Source
50-58 %	Naik & Kumar [2014]
47-56 %	Kamphuis [2017]
54 %	Bundesverband der Deutschen Süßwarenindustrie e.V. [2020]
45-55 %	Chclt.net [2013]

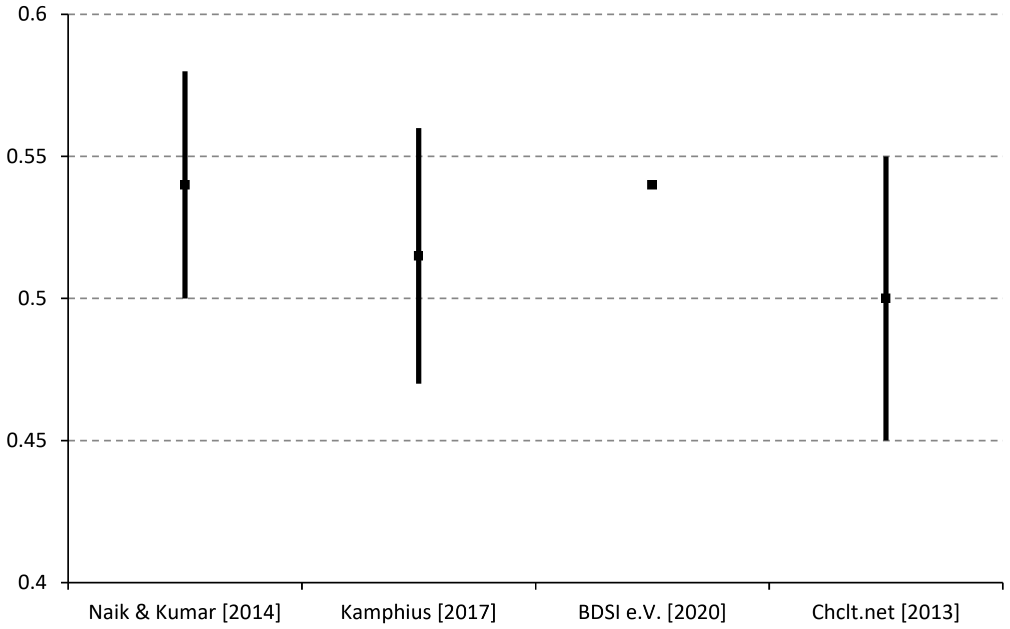


Figure 7: Mass fractions of cocoa butter in cocoa beans (data from literature).

These data indicate that the cocoa butter content of cocoa beans is just over 50 %. However, it is not clear whether the values refer to the total cocoa butter fat content of the cocoa beans or to the product obtained after the cocoa butter has been pressed out of the cocoa mass. The difference is that some of the cocoa butter fat remains in the powder, even in the case of highly defatted cocoa powder. To account for these uncertainties, we use a 50 : 50 ratio of cocoa butter to cocoa powder.

4.2 Results for Cocoa Butter and Cocoa Powder

In this chapter, we first present the environmental footprints of cocoa butter and cocoa powder according to economic allocation, the central result for these two products. Second, we compare these results with those derived from mass-based allocation.

4.2.1 Results for Cocoa Butter and Cocoa Powder

The environmental footprints of cocoa butter and cocoa powder by economic allocation are derived from the environmental footprints of cocoa mass, the mass fractions of cocoa butter and cocoa powder (Chapter 4.1.2), and the economic allocation factor (Chapter 4.1.1). The results are shown in Table 9 and in Figure 8 to Figure 11. The values are expressed per kg of traded product.

Table 9: Environmental footprints for cocoa mass, cocoa butter, and cocoa powder.

	Carbon foot-print [kg CO_2 eq./kg]	Phosphate footprint [g P eq./kg]	Water footprint* [m^3 H_2O eq./kg]	Land footprint** [$m^2 \cdot$ yr DNP/kg]
Cocoa mass	4.3	48	100	2.1
Cocoa butter	6.4	69	143	3.0
Cocoa powder	2.4	28	57	1.2

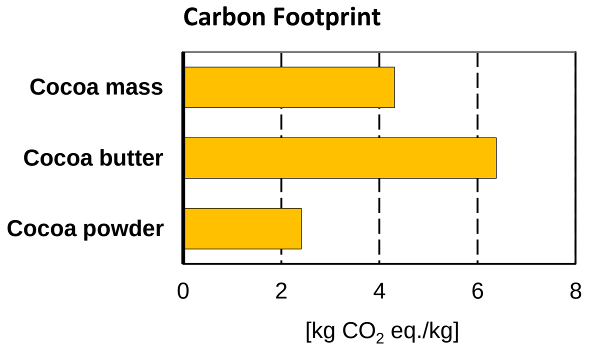


Figure 8: Carbon footprint of cocoa products.

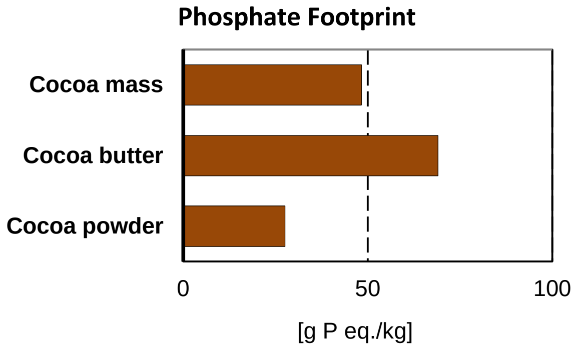


Figure 9: Phosphate footprint of cocoa products.

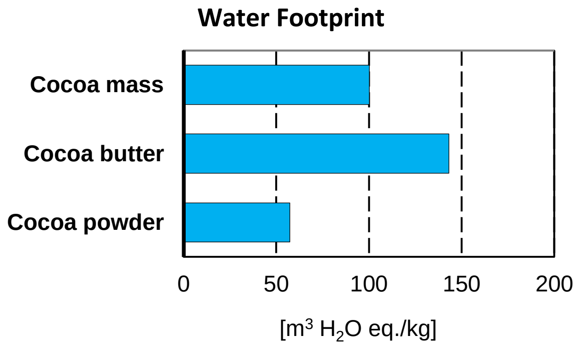


Figure 10: Water footprint* of cocoa products.

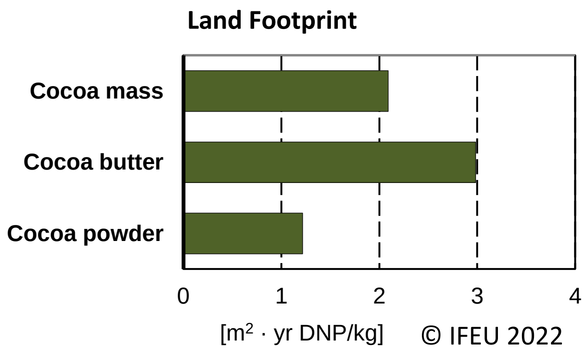


Figure 11: Land footprint** of cocoa products.

*Water footprint based on AWARE (Chapter 2.2.2).

**Land footprint as Distance-to-Nature-Potential (Chapter 2.2.2).

4.2.2 Excursus: Comparison of Different Allocation Methods

Table 10 shows the environmental footprints of cocoa butter and cocoa powder after mass-based allocation. Due to the assumed 50 : 50 mass ratio for cocoa butter and cocoa powder, the environmental footprint per kg of food is the same as for cocoa mass.

Table 10: Environmental footprints of cocoa mass, cocoa butter, and cocoa powder by mass-based allocation.

	Carbon footprint [kg CO_2 eq./kg]	Phosphate footprint [g P eq./kg]	Water footprint* [m^3 H_2O eq./kg]	Land footprint** [$m^2 \cdot yr$ DNP/kg]
Cocoa mass, cocoa butter & cocoa powder	4.3	48	100	2.1

*Water footprint based on AWARE (Chapter 2.2.2).

**Land footprint as Distance-to-Nature-Potential (Chapter 2.2.2).

Compared to the economic allocation the mass-based allocation underestimates the environmental burden of cocoa butter and overestimates the environmental burden of cocoa powder.

In the case of cocoa, the economic allocation based on world market prices accounts for the economic valuation of the product and is therefore considered more meaningful than the mass-based allocation. In particular, the consideration of long time periods is important here.

5 Environmental Footprints of Chocolates

5.1 Processing Cocoa Beans into Chocolate

After harvesting the cocoa pods, the raw cocoa beans are separated from the husk. The typical cocoa flavour is obtained through fermentation and roasting. The cocoa beans are crushed and refined in pressure reactors and then alkalised to remove acids and other unwanted flavours.

The cocoa beans are then ground under gentle heat to produce cocoa mass, which is used in many cocoa products (chocolate, beverage powder, glazes) - depending on the degree of grinding. In a next step, the cocoa mass is then pressed to extract the cocoa butter and to produce a press cake. Depending on the pressure, different amounts of cocoa butter are pressed out of the cocoa mass, which means that the residual fat content of the cocoa powder produced from the cocoa press cake can vary. After pressing, the press cake is ground and, depending on the pressure, further processed or distributed as slightly or highly defatted cocoa powder [CATALYSE Institute 2021].

Finally, chocolate is made by conching a mixture of cocoa products, sugar, and other ingredients such as milk powder. The process removes moisture from the mass by evaporation resulting in a smoothly melting, fine creamy structure. The chocolate is then packaged, stored, distributed, and sold in stores.

The environmental footprints of the individual cocoa components are listed in the preceding chapters. Environmental footprints of sugar and milk powder are presented in Chapter 5.2. For the final steps of processing, packaging and logistics, we use typical data including recycling/disposal of packaging (based on typical German conditions) [ifeu 2022]. A more detailed analysis of these processes has not been carried out, as their contribution to the overall result is small.

5.2 Chocolate Composition

To calculate the environmental footprints of chocolate, we identified the main ingredients and their respective proportions in the basic chocolate recipes for each of the three types of chocolate considered.

The ingredients listed in Table 11 were chosen to represent a range of chocolates [Chocolate recipes 2021]. In individual cases, the values in other recipes may vary by 10-20 % from the values given here.

In addition to cocoa, sugar and milk powder are the main ingredients needed to make chocolate. The environmental footprints of beet sugar and milk powder are shown in Table 12 and refer to production in Germany (Chapter 2.3, Table 12). The most common side ingredients, in particular emulsifiers such as lecithin and flavourings such as vanilla flavouring, were not included in the recipes due to their low content.

Table 11: Typical composition of milk chocolate, dark chocolate, and white chocolate including the proportions of their main ingredients.

Milk chocolate		Dark chocolate		White chocolate	
Sugar	45 %	Sugar	45 %	Sugar	45 %
Cocoa butter	20 %	Cocoa mass	45 %	Cocoa butter	30 %
Milk powder	20 %	Cocoa butter	10 %	Milk powder	25 %
Cocoa mass	15 %				

Milk chocolate consists mainly of sugar, cocoa butter, (whole) milk powder and cocoa mass. Other ingredients may include vanilla (extracts), hazelnut preparations and emulsifiers.

Unlike milk chocolate, **dark chocolate** rarely contains milk powder. Compared to milk chocolate, dark chocolate has a significantly higher cocoa mass content and a lower cocoa butter content.

In addition to sugar, **white chocolate** contains cocoa butter and various types of milk powder. Other optional ingredients are clarified butter, vanilla (flavour) and emulsifiers.

Figure 12: Dark chocolate, milk chocolate and white chocolate.

Table 12: Environmental footprints of beet sugar and milk powder [ifeu 2022].

	Carbon footprint [kg CO_2 eq./kg]	Phosphate footprint [g P eq./kg]	Water footprint* [m^3 H_2O eq./kg]	Land footprint** [$m^2 \cdot$ yr DNP/kg]
Beet sugar	0.7	24	0.4	0.5
Milk powder	9.5	113	11.0	2.7

*Water footprint based on AWARE (Chapter 2.2.2).

**Land footprint as Distance-to-Nature-Potential (Chapter 2.2.2).

5.3 Results for Chocolates

Figure 13 to Figure 16 the environmental footprints of the three types of chocolate considered (milk chocolate, dark chocolate, and white chocolate). The footprint is broken down according to the main ingredients: Cocoa, milk, and sugar. The "Other" category includes all other processes: the production of the chocolates (mixing, heating, conching), packaging and logistics to the store.

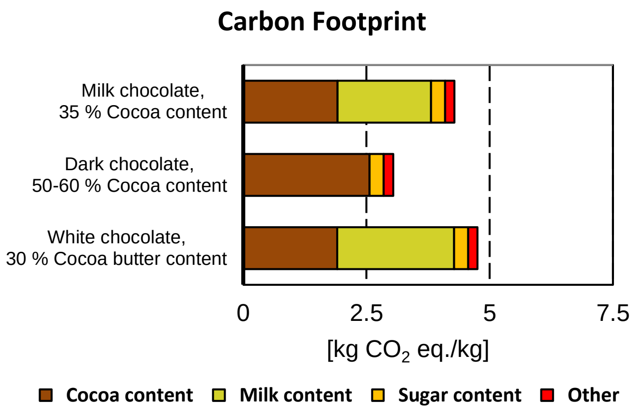


Figure 13: Carbon footprint of chocolates.

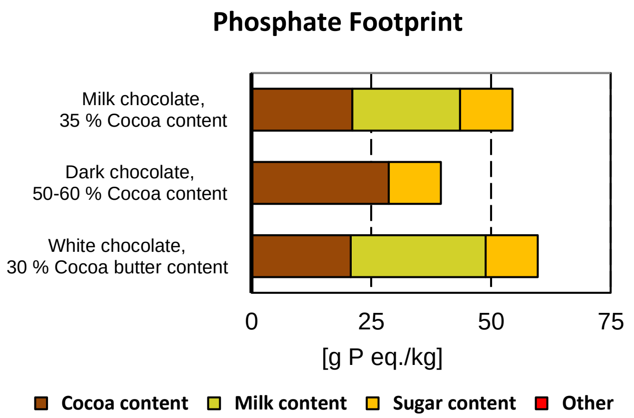


Figure 14: Phosphate footprint of chocolates.

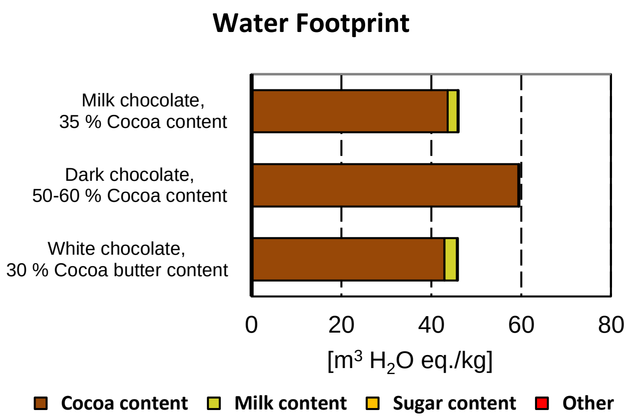


Figure 15: Water footprint* of chocolates.

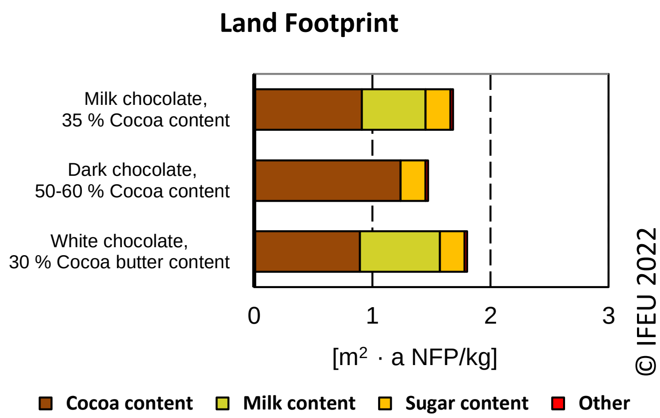


Figure 16: Land footprint** of chocolates.

*Water footprint based on AWARE (Chapter 2.2.2).

**Land footprint as Distance-to-Nature-Potential (Chapter 2.2.2).

Dark chocolate performs best in terms of carbon footprint and phosphate footprint compared to milk chocolate and white chocolate. These two environmental footprints show higher values for white chocolate compared to milk chocolate and dark chocolate. For the water footprint, milk chocolate performs best compared to the other chocolates, followed by white chocolate (Table 13).

Table 13: Environmental footprints of chocolates.

	Carbon footprint [kg CO_2 eq./kg]	Phosphate footprint [g P eq./kg]	Water footprint* [m^3 H_2O eq./kg]	Land footprint** [$m^2 \cdot yr$ DNP/kg]
Milk chocolate	4.3	54	46	1.7
Dark chocolate	3.0	40	60	1.5
White chocolate	4.8	60	46	1.8

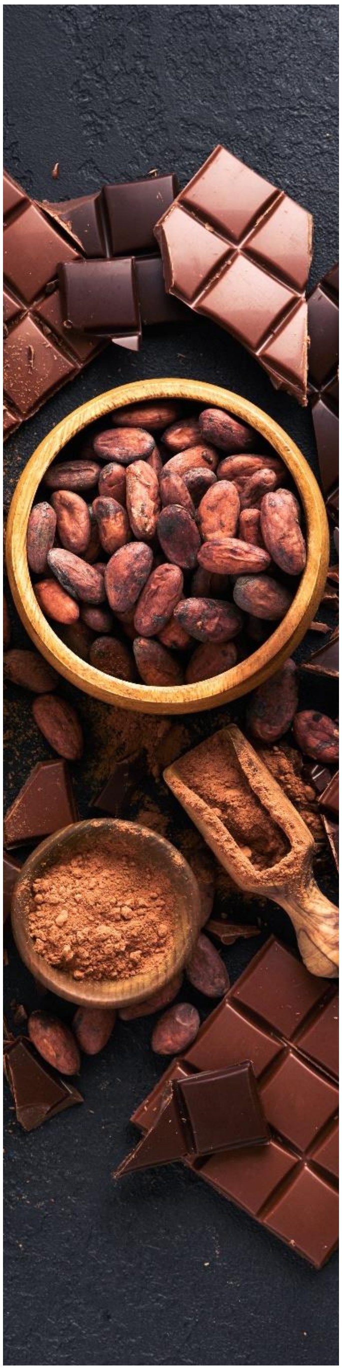
*Water footprint based on AWARE (Chapter 2.2.2).

**Land footprint as Distance-to-Nature-Potential (Chapter 2.2.2).

There are only small differences in the footprints of the different chocolates. This can be explained by the fact that milk powder has a land footprint that comes close to that of cocoa mass. With regard to the water footprint, milk powder has a significantly lower footprint than cocoa mass. This is not compensated by the slightly higher cocoa butter content.

Overall, it should be emphasised that the environmental burden from chocolates is not directly related to the share of cocoa components, as milk powder contributes substantially to the environmental footprints. Cocoa components only dominate in the case of the water footprint.

6 Transferability of the Results



The aim of this publication was to derive environmental footprints for typical cocoa and chocolate products.

The results of this study refer to products consumed in Germany in 2022, including Germany's supplier countries as countries of production, which may limit the applicability of the results.

For specific products and recipes, footprints may differ significantly from those shown here. In addition to the recipes, the **yield** parameter and the consideration of **land use change** (for the carbon footprint) have a significant impact on the results. Other important factors are the **allocation and weighting factors** used (e.g., AWARE) and the net yield factor, which relates the yield to 75% of the cultivated area, taking into account the predominant mixed cropping system in the production countries.

Appropriate adjustments to the conditions and parameters underlying the assessment methods proposed here will allow transferability to other cocoa and chocolate products, including:

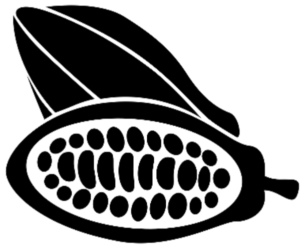
- Other recipes (e.g. drinking chocolate, sugar-reduced chocolate, nut chocolate),
- Other production locations (such as Belgian chocolate, Swiss chocolate) or
- Other production conditions (e.g., refinement in the country of production, organic chocolate)

The values shown here can be used, for example, to show the environmental impact of luxury food production and to illustrate trade-off effects when considering multiple environmental impact categories. One question might be whether the water footprint is more important than the carbon footprint.

In addition, the study can stimulate discussion on the methodology used and advance methodological development in the field of life cycle assessment (e.g., calculation of emissions from land use and land use change).

The results can also be used to guide consumption decisions, although personal preferences may be more important here.

7 Summary and Outlook



This study presents environmental footprints for cocoa, cocoa ingredients, and different chocolates based on:

- current methods for calculating the environmental footprints considered.
- typical conditions in Germany (for imported goods: according to import shares; for other products, especially chocolate: production in Germany).

The results therefore represent the current state of the art and can be used to answer questions or make comparisons under these boundary conditions. In addition, they include environmental footprints such as water and land footprint, which are not or only partially included in many other literature sources, or are based on outdated assessment methods. By considering four environmental footprints that are particularly important in the food transition, the results can be compared with those of other luxury foods.

Other environmental impacts often considered in life cycle assessments, such as acidification, ozone depletion or eutrophication, can be calculated using the system boundaries and procedures documented here.

Overall, the production of cocoa and cocoa products such as chocolate is associated with high local and global environmental impacts. Future improvements can be made by increasing yields and sourcing from countries with lower impacts. In particular, the clearing of tropical rainforest - even in the case of smallholder cultivation - leads to a considerable loss of biodiversity and the emission of climate gases. Social and economic factors associated with cocoa farming were explicitly not part of this study, although they influence the environmental footprints of cocoa beans through land tenure, investment incentives, and supply chains.

Conclusion:

The different environmental footprints derived in this study provide an overview of the different environmental impacts of cocoa and chocolate products and can thus contribute to an increased awareness of the environmental impact of food consumption. The main objective of this publication was to draw attention to other environmental impact categories in the food production and processing sector, in addition to the carbon footprint.

From the consumer's point of view, the results show that the overall differences between the chocolate varieties are small and that consumers can therefore eat the chocolate they like. The focus should be on organic and fair-trade products that have biodiversity and social benefits. Eventually, reducing consumption and substituting with other products is also a way to optimise one’s personal environmental footprint.

8 Abbreviations

aLULUC	Attributive land use/land use change
AWARE	Available WAter REmaining
CH_4	Methane, nitrous oxide
CO_2	Carbon dioxide
CSSV	Cacao swollen shoot virus
dLUC	Direct land use change
DNP	Distance-to-Nature-Potential
eq.	Equivalent
g	Gram
H_2O	Water
ha	Hectare
K_2O	Potassium oxide
kg	Kilogram
m	Metre
N	Nitrogen
N_{22}	Nitrous oxide
P	Phosphate
P_2O_5	Phosphorus pentoxide
t	tonne
yr	Year

9 Annex

Other studies on environmental footprints of cocoa and cocoa products show very different results (Figure 17 - Figure 20). Direct comparison with other studies is limited because in some cases different calculation methods, system boundaries and units have been used. The figures are therefore only indicative.

The results of this study are partly within the range of previous publications on the carbon footprint of chocolate [Büsser & Jungbluth 2009; Konstantas et al. 2018]. However, the effect cannot be attributed to similar accounting methods, but is partly due to two opposing effects in our assessment. The inclusion of mixed cropping systems in the assessment reduces "our" carbon footprint, while the inclusion of aLULUC leads to a significant increase. Neither of these aspects were considered in the publications mentioned.

The much higher carbon footprints in other studies [Colomb et al. 2014; Draeger de Teran & Suckow 2021] are presumably due to a different calculation of land use change (dLUC vs. aLULUC) and different system boundaries (see Chapter 2.2.2). The extent to which the energy mix and transport distances used vary cannot be assessed here. However, the contribution of these processes to the results is negligible.

For the water and land footprint, differences with previously published results can be explained by different methodological approaches. For example, the assessment of the use of limited water resources is a major difference (e.g., AWARE vs. Blue Water).

The phosphate footprint was not considered in the other studies and is a unique feature of this study.

These examples show that the methodology and definition of system boundaries for assessing the environmental impacts of food production are not standardised and can have a substantial effect on the results.

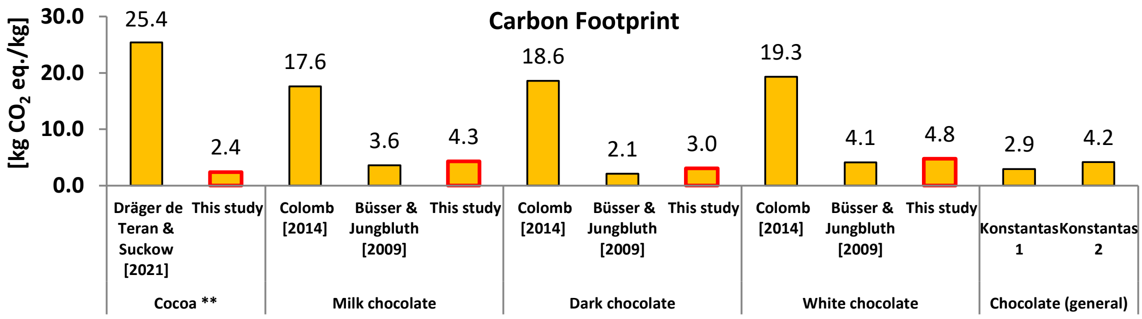


Figure 17: Carbon footprint of cocoa and chocolate products from literature compared to values from this study.

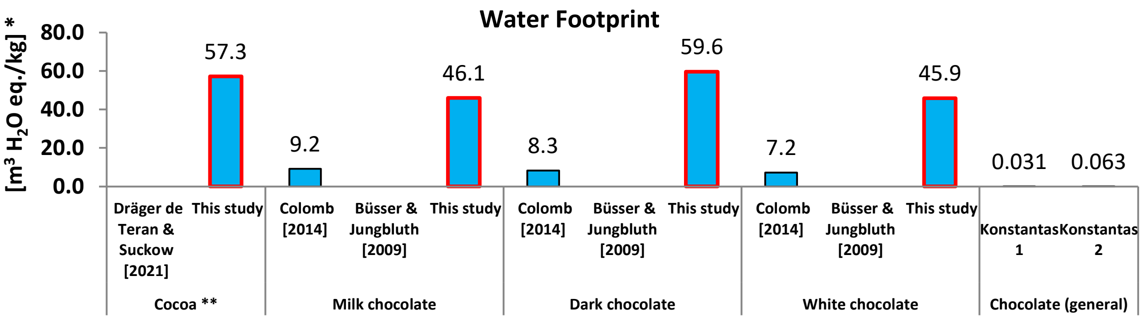


Figure 18: Water footprint of cocoa and chocolate products from literature compared to values from this study.

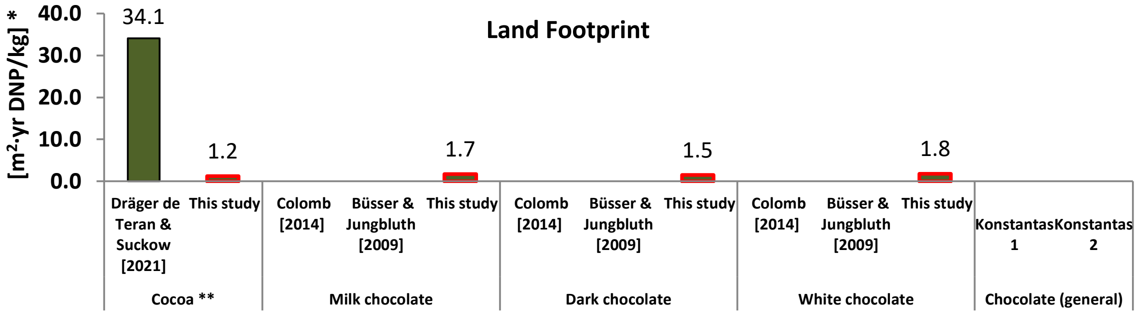


Figure 19: Land footprint of cocoa and chocolate products from literature compared to values from this study.

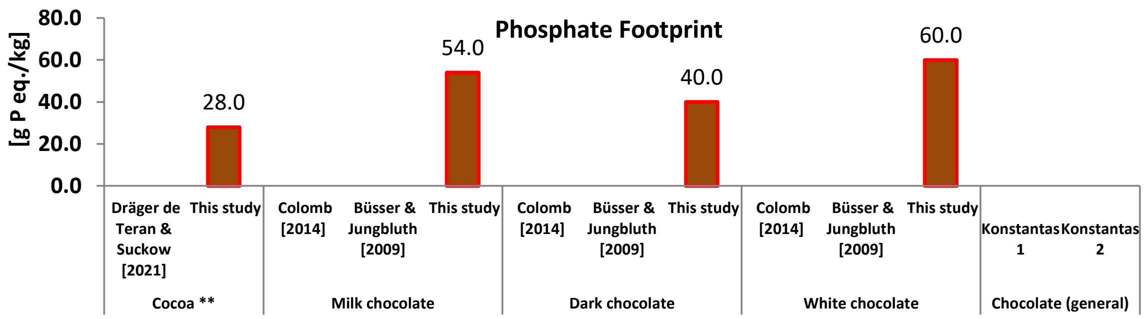


Figure 20: Phosphate footprint of cocoa and chocolate products from literature compared to values from this study.

* for details, see Chapter 2.2.2

** "Cocoa" is understood here as cocoa powder, strongly defatted - the term is taken from [Draeger de Teran & Suckow 2021].

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