

## Article

# Environmental Performance of Chocolate Produced in Ghana Using Life Cycle Assessment

Kofi Armah Boakye-Yiadom , Daniele Duca \* , Ester Foppa Pedretti and Alessio Ilari 

Department of Agricultural, Food and Environmental Sciences, Università Politecnica delle Marche, 60131 Ancona, Italy; kofiboakyeiyadom2@gmail.com (K.A.B.-Y.); e.foppa@univpm.it (E.F.P.); a.ilari@univpm.it (A.I.)

\* Correspondence: d.duca@univpm.it; Tel.: +39-0712204631

**Abstract:** Ghana is an important cocoa producer and exporter and this production is of high economic importance. Increasing interest in the sustainable productions of cocoa/chocolate necessitated the need to assess the environmental impacts associated with the production of different chocolate variants (extra dark (EDC), dark (DC), milk (MC) and flavoured milk (FMC) in Ghana, including the identification of environmental hotspots for improvement. The life cycle assessment tool was used following the CML\_IA and CED impact assessment methods. EDC had the lowest scores for most of the impact categories while FMC was most impactful. For Global Warming Potential (GWP), EDC and FMC were estimated to be 1.61 kg CO<sub>2</sub> eq. and 4.21 kg CO<sub>2</sub> eq., respectively. CED ranged from  $1.44 \times 10^2$  to  $1.50 \times 10^2$  MJ-eq. Chocolate manufacturing phase was generally more impactful than cocoa cultivation due to high emissions from milk and sugar production. The impact scores for 100 g packaged chocolate bar were the lowest in comparison to 300 g chocolate pouches and 12.5 g packaged chocolate strips. GWP for 100 g and 12.5 g were 0.20 kg CO<sub>2</sub> eq. and 0.39 kg CO<sub>2</sub> eq., respectively. Comparing different destination points for the manufactured chocolate, impact scores for the international destination were similar to those recorded for local destinations. Improvement options are suggested for all phases to ensure more sustainable chocolate production and distribution.

**Keywords:** sustainability; cocoa; environmental impacts; emissions; processing; packaging



**Citation:** Boakye-Yiadom, K.A.; Duca, D.; Foppa Pedretti, E.; Ilari, A. Environmental Performance of Chocolate Produced in Ghana Using Life Cycle Assessment. *Sustainability* **2021**, *13*, 6155. <https://doi.org/10.3390/su13116155>

Academic Editors: Eugenio Cavallo, Niccolò Pampuro and Marcella Biddoccu

Received: 29 April 2021  
Accepted: 25 May 2021  
Published: 30 May 2021

**Publisher's Note:** MDPI stays neutral with regard to jurisdictional claims in published maps and institutional affiliations.



**Copyright:** © 2021 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

## 1. Introduction

Environmental sustainability has been emerging as a pivotal issue in the agri-food sector as it directly impacts food and agriculture. Agriculture is highly vulnerable to climate change, as farming activities directly depend on climatic conditions, especially in developing countries. Climate change is a major contributing factor to the food price crisis, and its negative impacts on agriculture and food security in developing countries are expected to increase. The food sector is estimated to contribute about 25–30% of the total greenhouse gas (GHG) emissions due to anthropogenic emissions from agriculture and land use, storage, transport, processing, packaging, retail, and consumption [1]. Thus, food systems are heavily prioritised on the 2030 Agenda for Sustainable Development [2], a global commitment to eradicate poverty and hunger while ensuring reduction of environmental and socioeconomic concerns. Therefore, in order to advocate for sustainable measures, it is important to accurately assess the impacts of various activities and processes on the environment. Food and energy supply chains are associated with complex and intertwined environmental and socioeconomic impacts [3]. This has led to the use of tools and methodologies for assessing these impacts along various supply chains, including the Life Cycle Assessment (LCA).

Cocoa (*Theobroma cacao*) is an international cash crop that is mainly cultivated by smallholder farmers in lowland tropics, including parts of West Africa, Latin America, and Asia [4]. Over the past 50 years, world supply and demand for cocoa has been increasing at an annual growth rate of 2.5% [5]. Africa remains by far the most dominant cocoa

producing region, contributing over 76% of world cocoa output, with the shares of the Americas and Asia and Oceania accounting for 16% and 8%, respectively [5]. According to FAOSTAT [6], world production of cocoa beans stood at 5.5 million tonnes, with Ivory Coast and Ghana alone contributing 55%. Cocoa is the chief agricultural export of Ghana and the main cash crop of the country. Ghana is the second largest producer and exporter of cocoa worldwide, and produced an estimated 900,000 metric tonnes of dried cocoa beans in the 2017/2018 crop year. The crop is a major contributor to Government revenue, generating about \$2 billion in foreign exchange annually while contributing about 7% to Gross Domestic Product (GDP) and about one quarter of the country's export earnings [7]. Cocoa is mainly cultivated for its beans which are processed into products such as cocoa liquor, butter, and powder, which serve as ingredients for other food products such as chocolate, medicinal products, and cosmetic products. Ghana cocoa is considered premium due to its unique flavour, slightly higher-than-average fat content; low levels of debris and bean defects, and thus it is sold at a premium price [8]. The European Union (EU) continues to be the largest importer of Ghanaian cocoa beans, accounting for 53.27%, followed by Asia (26.58%), North America (10.96%), South America (8.59%), and Africa (0.60%) [7].

In Ghana, the cocoa value chain is tightly regulated by the Ghana Cocoa Board (COCOBOD). The value chain consists of several phases which include production of seedlings, cultivation, harvesting, transportation, processing, and export. COCOBOD in its quest to increase output from the cocoa sector has implemented several initiatives, such as subsidy of fertilizer for farmers, mass pruning exercises, irrigation schemes, and mass spraying through the Cocoa Disease and Pest Control Project (CODAPEP), to facilitate the increase in cocoa production [9,10]. Currently, almost 80% of cocoa produced annually is exported in raw form. The government announced its intention to implement policies that will ensure that at least 50% of Ghana's cocoa beans are processed locally and consumed [11]. Consequently, COCOBOD secured a \$600 million syndicated loan to increase productivity along the cocoa supply chain while the government announced its decision to no longer export cocoa beans to Switzerland, one of its biggest trading partners [12,13].

Although it is important to increase the production and processing of cocoa, it is also paramount that negative impacts associated with these activities on the environment need to be assessed, an aspect considered increasingly important by many importing countries and consumers. Due to the interest in this topic several studies have been carried out to assess the environmental impacts associated with the cocoa and chocolate/confectionery industry in different parts of the world. Research in this area has gradually evolved from impact assessment of single chocolate products [9,14–16], to comparison of different chocolate variants and other chocolate product derivatives [17,18]. Additionally, different cultivation systems for cocoa cultivation such as traditional management systems and more innovative organic, cocoa-agroforestry, and technical systems have also been analysed [9,16,19–21]. Evaluation of the environmental burden of different packaging systems for chocolate products have also gained a lot of interest [14–18,22,23]. Different impact assessment methods, in some cases combinations of these methods, are now being used to provide a more robust assessment of the environmental performance of cocoa/chocolate products. However, not much emphasis has been placed on product distribution. The goals and scopes differed for most of the studies, with some having a 'cradle-to-grave' approach [15–18,22,24], others a 'cradle-to-gate' approach [9,19,20], and others a 'gate-to-gate' approach [14]. Most of the studies were carried out in European countries such as Italy and the UK where chocolate products and other cocoa confectionaries are highly consumed [15,17,22,25], a few studies were carried out in South America and Asia, where cocoa cultivation is gaining popularity [19,20]. However, there have been very limited studies conducted to measure the potential environmental impacts associated with the production and processing of cocoa and chocolate in West Africa even though the region produces more than half of the global cocoa beans and other cocoa product derivatives. While no LCA studies have been published in the Ivory Coast, only one study was conducted in Ghana over a decade ago by Ntiamoah and Afrane [9], necessitating the need

to conduct further studies to update existing literature as Ghana is fast becoming a major chocolate producing country.

Presently, consumers are more interested in knowing product impacts before making purchasing choices. Thus, key stakeholders, especially manufacturers, within the food sector, need to develop innovative strategies for the improvement of working conditions and efficient use of resources to derive maximum economic benefit with minimum environmental impacts [25]. Manufacturers generally seek to either reduce the pollution caused by their products or highlight their environmental advantages. Governments also need reliable information to refine environmental policies or to devise incentives to promote environmental behaviours [26]. Therefore, the tentative goal of this study was to assess the environmental impacts of the production and distribution of chocolate produced in Ghana. Furthermore, this study sought to provide information geared towards sustaining the environment, particularly on the environmental impacts associated with the local cultivation and processing of cocoa into chocolate in Ghana, and subsequently help in the identification of environmental hotspots along the Ghanaian cocoa value chain.

## 2. Materials and Methods

Life cycle assessment (LCA) was used to estimate the impacts of 1 kg of packaged chocolate bar, following the ISO 14040 and 14044 standards. The standard LCA has four distinct methodological phases and are completed in the following order: goal and scope definition, life cycle inventory analysis (LCI), life cycle impact assessment (LCIA), and interpretation of results. LCA is an iterative process, where the different phases can be repeated until the final objective is met [27,28]. LCA is a method that can relate multiple environmental impacts to the function of a product or service. LCA is a decision-making tool which gives a comprehensive approach for evaluating the environmental impacts of a product during the entire production system [27,29]. It is often used to identify the hotspots and the mitigation options of environmental loads associated with a production. LCA is widely accepted and used in the evaluation of activities and processes of the agri-food sector, including agricultural activities, transportation, processing, packaging, storage, and distribution. LCA has numerous applications—it can be used industrially for a variety of purposes, including support of a corporate strategy, research and development, and the design of products or processes. LCA is also used in education as well as for labels and product descriptions [30]. The importance of LCA studies is increasing as companies increasingly apply them to their own products and require LCA data from their suppliers.

The methodology, data, and the assumptions considered in this study are further detailed in the following sections.

### 2.1. Goal and Scope Definition

The goal of the study was to assess the environmental impacts associated with the production of a packaged chocolate produced in Ghana. The study sought to identify environmentally weak points along the cocoa value chain where improvement can be made by farmers, chocolate manufacturers, transporters of cocoa beans and chocolate products to help improve the environmental aspects of the product. The target group for this study includes all stakeholders within the Ghanaian cocoa/chocolate industry, namely: COCOBOD, cocoa farmers, cocoa processors, chocolate manufacturers, environmental authorities and policy makers, the companies involved in storage, packaging, transport, retail, and recycling facilities, researchers, and NGOs.

The system boundary encompasses the essential energy and material inputs/outputs that are related to the processes of producing chocolate. The defined functional unit, based on which the inventory data was normalized for assessing the impacts in this study, was 1 kg chocolate made from cocoa cultivated in Ghana and other ingredients. As shown in Figure 1, the system boundary covers both upstream and downstream processes including the following phases:

Cocoa cultivation: materials included were pesticide, insecticide, fertilizer, diesel.

Cocoa processing and chocolate manufacturing: raw materials included were cocoa beans, sugar, milk, flavour, and alkaline (Dutching). Electricity, steam, and water consumption in the manufacturing processes, including cleaning activities.

Packaging: Aluminium foil (primary), paper wrapper, and carton boxes.

Transport and Distribution: Transport of raw materials as well as packaging materials to the production facility. Distribution of the packaged product from the production facility to major retail centres was also considered in this study.

Other phases including consumption and waste management were excluded from the system boundary as done in other similar studies due to the many different scenarios that needed to be considered, making it difficult for standardization and comparison.

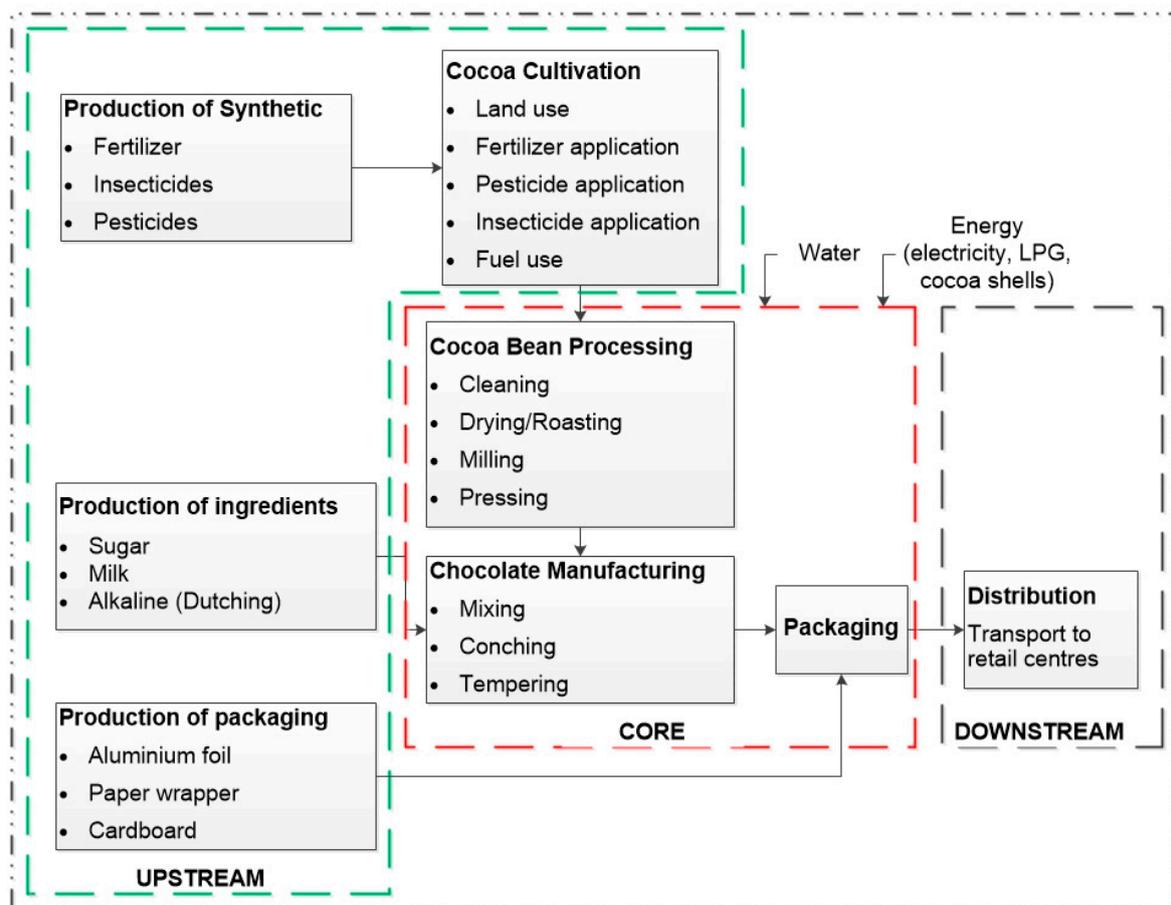


Figure 1. The system boundaries of the LCA of 1 kg of chocolate bar considered in this study.

### System Description and Data Quality

Data was obtained from different sources to complete the inventory table as shown in Table 1. The foreground data were obtained from a local Ghanaian chocolate manufacturer using a specific questionnaire for the cocoa bean processing, chocolate manufacturing, and packaging phases. The company was established in 2011 on a 158-ha plot of land at the Free zones enclave Tema, and has the capacity to process 60,000 metric tons of cocoa beans per year, making it the largest fully integrated cocoa processor in Ghana. It is involved in the processing of Ghanaian cocoa beans into semi-finished products and confectionery for supply to the worldwide chocolate, ice cream, and bakery industries. Semi-finished products include natural and deodorised cocoa butter, specialised cocoa liquor, and natural and alkalised cocoa powder. In confectioneries, the manufacturer is a bean-to-bar producer of refined chocolate, chocolate drinks, and spreads. The background life cycle inventory (LCI) data and data to fill in gaps were obtained from academic peer reviewed publications and Ecoinvent v.3.01 [31], as detailed further below.

**Table 1.** Summary of the Inventory data types and sources used in this study.

| Life Cycle Phase         | Technological Flow   | Source               | Data Type                     |
|--------------------------|----------------------|----------------------|-------------------------------|
| Raw materials production | Cultivation          | [9] *                | Secondary                     |
|                          | Ghanaian cocoa beans | Ecoinvent v.3.01     | Secondary                     |
|                          | Sugar                | Ecoinvent v.3.01     | Secondary                     |
|                          | Milk powder          | Ecoinvent v.3.01     | Secondary                     |
|                          | Packaging            | Ecoinvent v.3.01     | Secondary                     |
| Transportation to plant  | Auxiliary materials  | Ecoinvent v.3.01     | Secondary                     |
|                          | Cocoa beans          | Chocolate producer   | Primary                       |
|                          | Sugar from Brazil    | Chocolate producer   | Primary                       |
|                          | Milk powder          | Chocolate producer   | Primary                       |
|                          | Packaging from China | Chocolate producer   | Primary                       |
| Chocolate Manufacturing  | Chocolate production | Chocolate producer   | Primary                       |
|                          | Energy               | Chocolate producer   | Primary                       |
|                          | Transportation       | Product distribution | Based on real market scenario |
|                          | Transport of workers | Chocolate producer   | Primary                       |

\* The standard agricultural guidelines and activities for cocoa cultivation did not change significantly over the past decade, as the considerations made in the study especially with regards to fertilizers and chemicals are still approved by the COCOBOD. Attempts were however made to obtain primary data from the farmers and other stakeholders, but due to the COVID-19 situation no positive response was received.

### Cocoa Cultivation

The production of dried cocoa beans encompasses the production of farm inputs and farm activities carried out during cocoa cultivation such as fertilizer application, pest and disease management, harvesting and breaking of pods, fermentation, drying, and temporary storage of dried beans. The average economic lifespan of cocoa trees was also estimated to be thirty years. Secondary data on the cultivation phase was obtained from [9]. Additionally, background data on production of inputs such as fertilizer, insecticide, fuel were also obtained from Ecoinvent v.3.01 [31].

### Transportation of Cocoa Beans to Processing Factories

Dried and bagged cocoa beans are transported by trucks from the farming communities to the warehouses of Cocoa Marketing Company located in Tema, Takoradi, and Kumasi. Afterwards, they are further transported to the processing factories. Inventory data for transportation was calculated based on the average distance of 250 km travelled by engine trucks in Ghana from Kumasi to Accra. The truck chosen was a >32 metric ton based on the average 38-tonne total capacity (and 26 tonne payload) long distance truck-trailer of most cocoa haulage trucks in Ghana as was indicated by the local manufacturer. Data on fuel consumption and emissions for the transportation were obtained from the database based on the selected Euro-3 truck typology as shown in Table 2.

**Table 2.** Summary of the transportation means and estimated distances considered in the study.

| Life Cycle Stage | Transport Step | Country of Origin | Transportation Means             | Distance (km) |
|------------------|----------------|-------------------|----------------------------------|---------------|
| Raw materials    | Cocoa beans    | Ghana             |                                  |               |
|                  | • by road      |                   | Lorry > 32 metric ton,<br>Euro 3 | 250           |
|                  | Sugar          | Brazil            |                                  |               |
|                  | • by sea       |                   | Transoceanic ship                | 6043.1        |
|                  | Milk powder    | Belgium           |                                  |               |
| • by sea         |                |                   | Transoceanic ship                | 8226.6        |

Table 2. Cont.

| Life Cycle Stage | Transport Step                  | Country of Origin | Transportation Means                      | Distance (km) |
|------------------|---------------------------------|-------------------|---|---------------|
| Manufacturing    | Workers                         |                   |   |               |
|                  | • by road                       | Ghana             | Regular bus                               | 660.8 *       |
|                  | • by road                       | Europe            | Passenger car, small size, diesel, EURO 5 | 660.8         |
| Packaging        | Product to distribution centres |                   |   |               |
|                  | • by road                       | Ghana             | Lorry >32 metric ton, Euro 3              | 208 **        |
|                  | • by sea                        | China             | Freight ship                              | 19,036.7      |

\* Total distance covered by seven company buses on a working day. \*\* Average distance for three distribution centres: Kumasi (273 km), Takoradi (251 km) and Koforidua (100 km).

### Processing of Cocoa Beans into Chocolate

Cocoa beans are first processed into semi-finished products: cocoa liquor, butter, and powder. These serve as ingredients in the chocolate manufacturing process. Primary data on the sources of the cocoa beans (round trip distance from the cocoa bean warehouse to the manufacturing plant), the type, source, and the transportation links associated with obtaining the other ingredients such as sugar, flavour, and milk, use of electricity to run machines, water use, packaging materials, and the total output of chocolate produced in 2019 were obtained from the manufacturer. An average technology was considered for the processing and manufacturing of chocolate based on information provided by the manufacturer. Machines and equipment were purchased between 2011 and 2017 (70% purchased in 2011, 25% purchased in 2012, and 5% purchased in 2017). Additional background data included production of energy (electricity from hydropower and Liquefied Petroleum Gas (LPG)) consumed by the plant's manufacture of key ingredients such as sugar, milk, and flavour.

The manufacturer produces twelve different chocolate variants for the market, namely: extra dark chocolate (EDC) (72% cocoa solids), dark chocolate (DC) (56% cocoa solids), milk chocolate (MC) (38% cocoa solids), and flavoured milk chocolate (FMC) derivatives (38% cocoa solids) including; strawberry, lime, coconut, ginger, honey, mango, coffee, orange, and banana. Further details are provided in Table 3.

Table 3. Percentage share of major ingredients in chocolate product variants.

| Ingredients  | EDC (%) | DC (%) | MC (%) | FMC (%) |
|--------------|---------|--------|--------|---------|
| Cocoa liquor | 40.5    | 47.5   | 18     | 18      |
| Cocoa butter | 14.5    | 8.5    | 20     | 20      |
| Cocoa powder | 17      | -      | -      | -       |
| Milk powder  | -       | -      | 30     | 30      |
| Sugar        | 27.5    | 43.5   | 30     | 30      |
| Flavour      | -       | -      | -      | 0.1     |

### Packaging

Packaging is key in the food supply chain as it performs many functions including the protection of food products, containment, easy handling, safe transport, extension of shelf life, and marketing [32]. The chocolate products are packaged after production to ensure maintenance of quality, ease of handling and labelling, and protection of the product. Three levels of packaging were considered in this study: aluminium foil (primary packaging) for protection against air and light, printed paper wrapper (secondary packaging) for labelling, and cardboard (tertiary package) for protection and ease of handling during transport. The manufacturer produces three different chocolate product typologies for

the local market. Details on the different products and their respective packaging are presented in Table 4. Primary data on the amount of packaging used was obtained from the manufacturer. In addition, the transportation of the packaging materials from China, where they are manufactured, was also taken in consideration.

**Table 4.** Description of the different chocolate products and their corresponding packaging.

| Product Type          | Dimension                 | Packaging Materials                             | Weight/Product (g) |
|-----------------------|---------------------------|---|--------------------|
| 100 g chocolate bar   | L75 mm × W158 mm × H10 mm | Aluminium foil                                  | 1.37               |
|                       |                           | Paper wrapper                                   | 4.29               |
| 65 g chocolate strip  | L170 mm × W35 mm × H13 mm | Paper covered aluminium foil with paper sticker | 2.25               |
|                       |                           | Paper box                                       | 7.14               |
| 300 g chocolate pouch | L92 mm × W50 mm × H192 mm | Paper covered aluminium foil with paper sticker | 10.78              |
|                       |                           | Paper box                                       | 23.37              |

#### Distribution Assumption

Due to the impracticalities related to determining a consumer's intent to specifically leave their house to only purchase a bar of chocolate, assumptions had to be made for the distance consumers would travel to purchase the product. The average transportation distance was calculated from the travel distance to a store within heavily populated areas where the chocolate is mainly sold. The major towns selected were Kumasi, Takoradi, and Koforidua.

#### Allocation

Allocation procedures are applied in two phases. The first one regards cocoa shells, which constitutes one of the outflows of cocoa bean processing. Shell mass accounts for about 10% of cocoa beans and are used to fuel boilers in the processing plant as it is more economical—thus, no environmental impacts are associated with it. In this study, 100% of the impacts from cocoa bean processing were allocated to the co-products from cocoa processing (liquor, butter, cake, and powder) adopting an economic value allocation criterion as shown in Table 5.

**Table 5.** Economic value of cocoa product derivatives.

| Product      | Ton     | Amount (Ghc)  | Ton/Ghc   |
|--------------|---------|---------------|-----------|
| cocoa liquor | 106,920 | 1,383,179,187 | 12,936.58 |
| Butter       | 38,539  | 747,604,928.7 | 19,398.66 |
| Cake         | 10,020  | 26,386,813.03 | 2633.414  |
| Powder       | 31,889  | 246,413,949.6 | 7727.24   |

Source: Extracted from Ghana COCOBOD 48th Annual Report and Financial Statement (2017).

#### 2.2. Life Cycle Inventory Table and Scenarios

Based on the assumptions reported in the previous section, the inventory table has been reported separating cocoa bean processing and chocolate manufacturing of four different products to improve transparency. Table 6 reports values referred to the sum of all chocolate products (1 kg of each chocolate product—four kg in total).

**Table 6.** LCI Table for the production of 1 kg of different chocolate for the reference year 2019.

| Phase                                       | Unit | Value                 |                       |                       |                       |
|---|------|-----------------------|-----------------------|-----------------------|-----------------------|
| <b>Cocoa cultivation</b>                    |      |                       |                       |                       |                       |
| Land use                                    | ha   | $2.88 \times 10^{-6}$ |                       |                       |                       |
| Planting seeds                              | kg   | $4.31 \times 10^{-3}$ |                       |                       |                       |
| Water                                       | L    | $1.15 \times 10^1$    |                       |                       |                       |
| Petrol (for spraying)                       | kg   | $2.33 \times 10^{-2}$ |                       |                       |                       |
| Fertilizer (N:P:K 0:22:18 + 9CaO + 7S+6MgO) | kg   | $3.57 \times 10^{-1}$ |                       |                       |                       |
| Insecticide                                 | kg   | $1.95 \times 10^{-2}$ |                       |                       |                       |
| Fungicide                                   | kg   | $1.81 \times 10^{-2}$ |                       |                       |                       |
| Cocoa pulp (beans sweating)                 | kg   | $7.95 \times 10^{-1}$ |                       |                       |                       |
| Cocoa pod husk                              | kg   | $1.94 \times 10^1$    |                       |                       |                       |
| <b>Transportation of cocoa beans</b>        |      |                       |                       |                       |                       |
| Fuel consumption                            | L    | $3.23 \times 10^{-6}$ |                       |                       |                       |
| <b>Cocoa bean processing</b>                |      |                       |                       |                       |                       |
| Cocoa beans                                 | kg   | 2.44                  |                       |                       |                       |
| Electricity                                 | kWh  | $4.12 \times 10^{-1}$ |                       |                       |                       |
| LPG   | kg   | $2.92 \times 10^{-1}$ |                       |                       |                       |
| Dutching-Alkaline                           | L    | $6.98 \times 10^{-2}$ |                       |                       |                       |
| Chemicals (cleaning agents)                 | L    | $1.66 \times 10^{-4}$ |                       |                       |                       |
| Oil and grease                              | kg   | $1.83 \times 10^{-5}$ |                       |                       |                       |
| Water                                       | kg   | 1.19                  |                       |                       |                       |
| <b>Output</b>                               |      |                       |                       |                       |                       |
| Cocoa liquor                                | kg   | 1.24                  |                       |                       |                       |
| Cocoa butter                                | kg   | 0.63                  |                       |                       |                       |
| Cocoa powder                                | kg   | 0.17                  |                       |                       |                       |
| Cocoa cake                                  | kg   | 0.84                  |                       |                       |                       |
| <b>Chocolate Manufacturing</b>              |      |                       |                       |                       |                       |
|   |      | <b>EDC</b>            | <b>DC</b>             | <b>MC</b>             | <b>FMC</b>            |
| Cocoa liquor                                | kg   | $4.05 \times 10^{-1}$ | $4.75 \times 10^{-1}$ | $1.80 \times 10^{-1}$ | $1.80 \times 10^{-1}$ |
| Cocoa butter                                | kg   | $1.45 \times 10^{-1}$ | $8.50 \times 10^{-1}$ | $2.00 \times 10^{-1}$ | $2.00 \times 10^{-1}$ |
| Cocoa powder                                | kg   | $1.70 \times 10^{-1}$ | -                     | -                     | -                     |
| Vanillin                                    | kg   | $4.26 \times 10^{-4}$ | $4.26 \times 10^{-4}$ | $4.26 \times 10^{-4}$ | $4.26 \times 10^{-4}$ |
| Sugar                                       | kg   | $2.75 \times 10^{-1}$ | $4.35 \times 10^{-1}$ | $3.00 \times 10^{-1}$ | $3.00 \times 10^{-1}$ |
| Milk Powder                                 | kg   | -                     | -                     | $3.00 \times 10^{-1}$ | $3.00 \times 10^{-1}$ |
| Flavour                                     | kg   | -                     | -                     | -                     | $1.00 \times 10^{-3}$ |
| Electricity                                 | kWh  | $2.77 \times 10^1$    | $2.77 \times 10^1$    | $2.77 \times 10^1$    | $2.77 \times 10^1$    |
| Chocolate                                   | kg   | 1.00                  | 1.00                  | 1.00                  | 1.00                  |

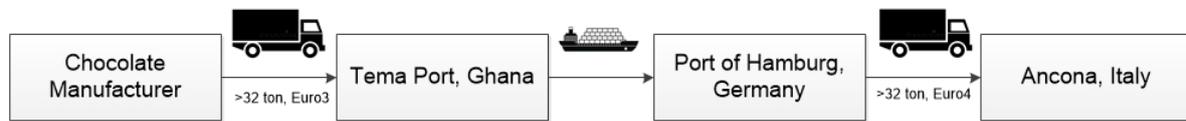
NB: EDC = Extra dark chocolate, DC = Dark chocolate, MC = Milk chocolate, FMC = Flavoured milk chocolate.

### Scenarios

In LCA studies, a scenario describes a possible future situation relevant for specific LCA applications based on specific assumptions about the future, and may also include the presentation of the development from present to future. Scenarios provides possibilities to prepare for alternative and uncertain future options without knowing anything about the probability of the possible outcomes [33]. In this study, the impacts associated with several scenarios were considered and examined, to help in the suggestion of useful and relevant mitigation strategies.

The first scenario examined was the impacts associated with different destination for 1 kg (10 × 100 g) packaged chocolate bars to different destinations. The major cities in Ghana such as Kumasi, Koforidua, and Takoradi were considered as the baseline destinations while Ancona, Italy was considered as a scenario for the export of the product. In the scenario for local destination, a transport-mean which was a truck with a load capacity >32 metric ton was selected, and the distances were estimated using Google maps. In the scenario for international destination, the distance from the company to Ghana port, and

from there to the port to Hamburg and by road to Ancona in Italy is illustrated in Figure 2 below. The sea distances were also obtained from an online world seaports catalogue, marine, and port info website (<http://ports.com/> (accessed on 18 February 2021)).



**Figure 2.** A scenario for 1 kg packaged chocolate bar produced in Ghana and transported to Ancona, Italy.

Another scenario considered was the transportation of workers by company buses to the factory. This scenario is not directly linked to the process flow for chocolate production, however due to the possible importance of transportation of workers in Ghana it was considered. The company has seven regular buses with a capacity of 15 persons per bus for 105 estimated workers and runs a double shift system. Thus, the average distances were calculated, and the impact associated with the transportation of workers were determined as shown in Table 7. This was compared to transportation of workers by private cars in Europe covering the same distance as shown in Table 2.

**Table 7.** Estimated distances for the transportation of workers to manufacturing plant.

| Destination | Distance (km) | Number of Buses |
|-------------|---------------|-----------------|
| Prampram    | 21.0          | 1               |
| Kpone       | 9.9           | 1               |
| Tema        | 7.7           | 1               |
| Adjei Kojo  | 9.4           | 1               |
| Ashaiman    | 18.6          | 2               |
| Afiencya    | 16.0          | 1               |

### 2.3. Life Cycle Impact Assessment

The collected and aggregated data were input in the PRéConsultants SimaPro 8.2.3 software to construct all the significant process flows (inputs and outputs for each life cycle phase) to model the product systems. The CML\_IA baseline V3.01 method was applied to estimate the environmental impacts based on the problem-oriented (midpoint) approach for 1 kg chocolate. In this study, the impact categories examined for CML\_IA included: Abiotic Depletion Potential (ADP), Abiotic Depletion Potential (fossil fuels) (ADP), Acidification Potential (AP), Eutrophication Potential (EP), Global Warming Potential (GWP 100yr), Ozone layer depletion (ODP), Human Toxicity Potential (HTP), Fresh Water Aquatic Ecotoxicity Potential (FAETP), Marine Aquatic Ecotoxicity Potential (MAETP), Terrestrial Ecotoxicity Potential (TETP), and Photochemical Oxidation Potential (POCP) [34]. Additionally, the Cumulative Energy Demand (CED V1.08) single issue was used. The calculation of CED included: non-renewable (from fossil and nuclear) and renewable (wind, solar, geothermal, and water) energy sources [35].

## 3. Results and Discussion

### 3.1. Impacts Associated with 1 kg Chocolate Using CML\_IA Baseline Method

The characterisation results (overall impact scores) for different impact categories for 1 kg chocolate produced in Ghana are shown in Figure 3a–k. From the results obtained, extra dark chocolate (EDC) predominantly recorded the least scores for most impact categories while milk chocolate (MC) had the highest scores for most impact categories. Impact scores for EDC and dark chocolate (DC) were not significantly different while MC and flavoured milk chocolate (FMC) also showed little differences. Significant differences were however observed between EDC and DC and FMC and MC for several impact categories including GWP, EP, POCP, and AP. The differences were mainly due to the type and amount of different ingredients used for the different chocolate product types. Results showed

different relative contribution for the two phases considered: CCP (cocoa cultivation and processing) and CM (chocolate manufacturing) for different impact categories. ADP, HTP, TETP, and FAETP were largely influenced by the CCP phase while GWP, ODP, EP, and AP were significantly influenced by the CM phase.

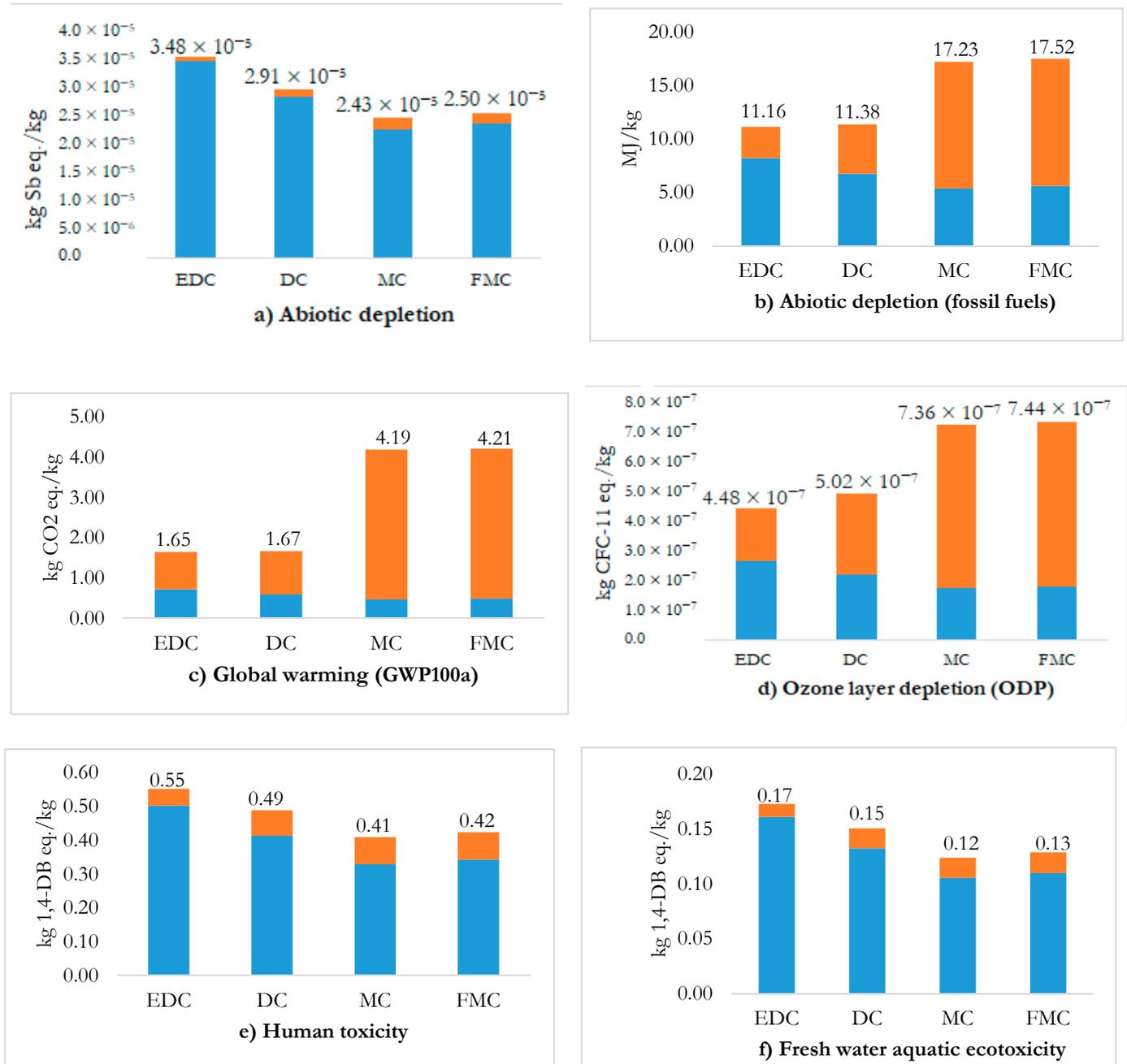
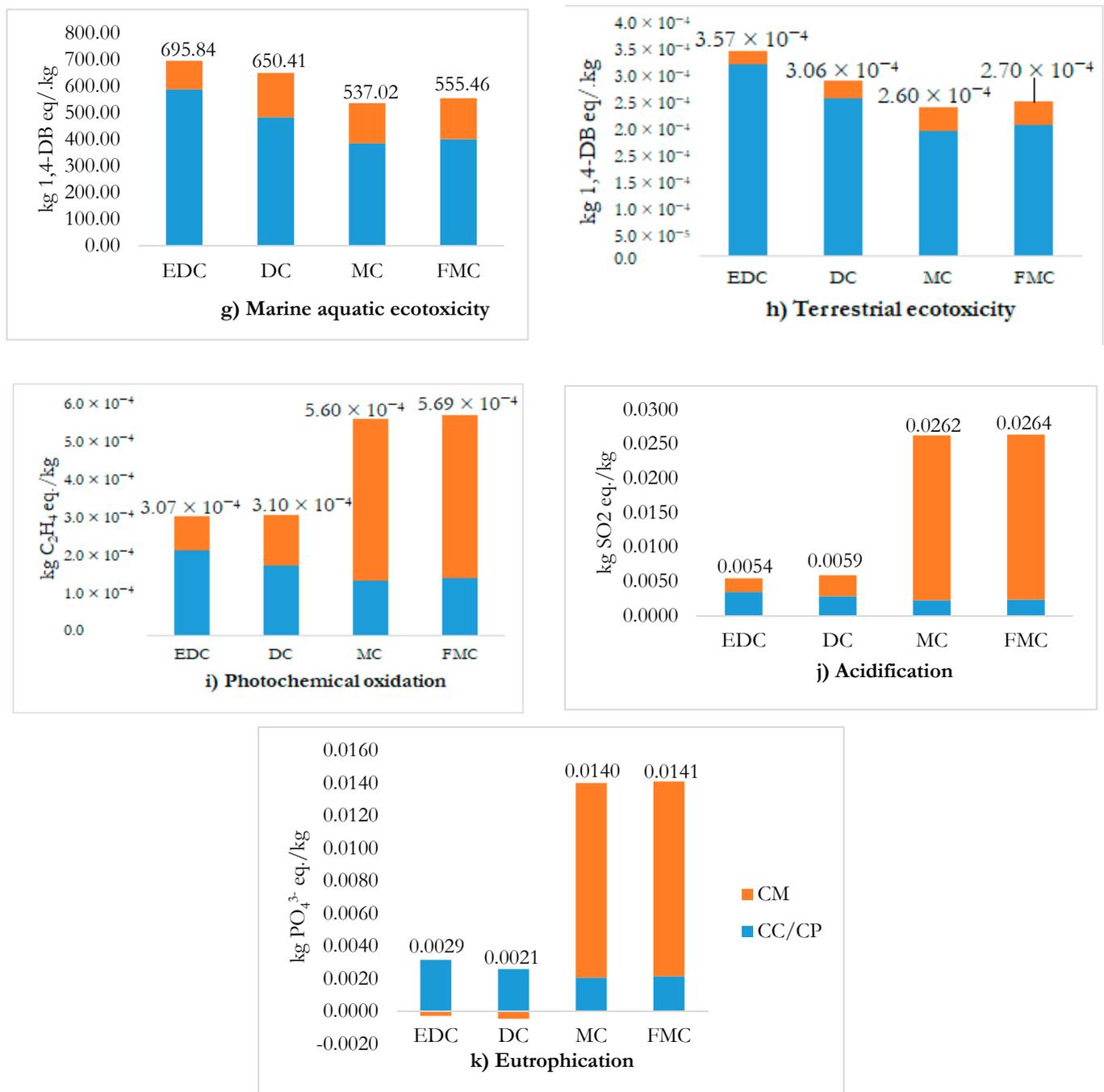


Figure 3. Cont.



**Figure 3.** (a–k) Characterisation results (overall impact scores) for different impact categories for 1 kg chocolate produced in Ghana with contribution of cocoa cultivation and processing (in blue) and chocolate manufacturing (orange).

### 3.1.1. Abiotic Depletion (ADP)

Abiotic depletion is generally related to the consumption of non-biological resources and its value is a measure of the scarcity of a substance which is affected by the quantity available in nature and its rate of extraction [36]. From this study, ADP ranged from  $3.48 \times 10^{-5}$  kg Sb eq. (EDC) to  $2.43 \times 10^{-5}$  kg Sb eq. (MC) per kg chocolate as shown in Figure 3a. ADP was mainly influenced by emissions from the cocoa bean cultivation phase (89.7–95.6%) due to pesticide (67.5–72%), fertilizer (11.4%) and insecticide (10.7–12.2%) production and use for MC and EDC, respectively. The differences were because of the amount of cocoa liquor, butter, and powder used. Recanati et al. [15] reported a slightly lower value of  $1.11 \times 10^{-5}$  kg Sb eq. for 1 kg dark chocolate while Ntiamoah and Afrane [9]

and Mial et al. [18] obtained comparatively estimated higher values of  $1.62 \times 10^{-3}$  kg Sb eq. for cocoa production and processing and  $7.00 \times 10^{-3}$  kg Sb eq. per unit for both milk and dark chocolate confectionary, respectively.

### 3.1.2. Abiotic Depletion (ADP) Fossil Fuels

As shown in Figure 3b, EDC recorded the least score of 11.20 MJ while FMC recorded the highest score of 1.75 MJ for ADP fossil fuels. The CM phase was more impacting with emissions resulting from mainly milk powder (50%) and sugar (18%) while the CCP phase was influenced by LPG (12.5%) and pesticide (10%) for FMC and MC. For EDC, impacts were mainly associated with the production and use of LPG (30%), pesticide (24%), and transported sugar (26%).

### 3.1.3. Global Warming

Global warming is one of the major environmental effects of economic activity, and thus it is widely investigated [36]. From this study the Global Warming Potential estimated over a time horizon of 100 years (GWP 100yr) ranged from 1.65 kg CO<sub>2</sub> eq. (EDC) to 4.21 kg CO<sub>2</sub> eq. (FMC), as shown in Figure 3c. Chocolate manufacturing was the most impacting phase due to emissions from transported milk powder, N<sub>2</sub>O and CH<sub>4</sub>, gas emissions from cattle rearing [37], and electricity generation from hydroelectric powerplant. Several studies have been conducted to estimate the GWP for dark chocolate. Büsser and Jungbluth [22], Vesce et al. [14], Perez Niera [16], Recanati et al. [15] and Miah et al. [18] reported 2.1 kg CO<sub>2</sub> eq., 1.91 kg CO<sub>2</sub> eq. (only manufacturing phase considered), 2.57 kg CO<sub>2</sub> eq. (estimated from 100% Ecuadorian cocoa), 2.53 kg CO<sub>2</sub> eq. and 5.80 kg CO<sub>2</sub> eq. (dark chocolate confectionary), respectively. For milk chocolate, Büsser and Jungbluth [22], Konstantas et al. [17], and Miah et al. [18] reported 3.6 kg CO<sub>2</sub> eq., 3.05 kg CO<sub>2</sub> eq., and 4.60 kg CO<sub>2</sub> eq. (milk chocolate confectionary), respectively. Konstantas et al. [17] considered 24.5% milk constituents while Miah et al. [18] considered 45–50% milk constituents per chocolate.

### 3.1.4. Ozone Layer Depletion (Stratospheric Ozone Depletion)

The ozone layer protects the earth's surface from ultraviolet (UV), thus reducing the amount of carcinogenic UV light reaching the earth's surface, consequently improving human health and ecosystem quality [36]. EDC recorded the least while FMC recorded the highest— $4.48 \times 10^{-7}$  kg CFC-11 eq. and  $7.44 \times 10^{-7}$  kg CFC-11 eq., respectively, as shown in Figure 3d. Recanati et al. [15] and Vesce et al. [14] found comparative scores of  $5.67 \times 10^{-7}$  kg CFC-11 eq. and  $2.34 \times 10^{-7}$  kg CFC-11 eq., respectively. CM was the most impacting phase due to emissions from transported milk powder (49%) and transported sugar (26%).

### 3.1.5. Human Toxicity

HTP indicates the potential amount of a chemical that can cause harm when released into the environment. It is calculated based on both the inherent toxicity of a compound and its potential dose. These chemicals are usually by-products, and include arsenic, sodium dichromate, hydrogen fluoride, phosphorus, manganese, zinc, and chlorine and are often released during electricity production from fossil sources [17]. From this study, HTP ranged from 0.55 kg 1,4-DB eq. (EDC) to 0.41 kg 1,4-DB eq. (MC) as shown in Figure 3e. HTP was mainly influenced by emissions from the CCP phase (80–91%) due to pesticide (about 42–47%) and LPG (33–38%) production and use for MC and EDC, respectively. Ntiamoah and Afrane [9] reported a similar value of 5.11 kg 1,4-DB while Konstantas et al. [17], reported 1.66 kg 1,4 DB eq. and 2.03 kg 1,4 DB eq. for chocolate countlines and chocolates in bag, respectively.

### 3.1.6. Ecotoxicity

Environmental toxicity encompasses the toxic effects of chemicals on an ecosystem and is measured as three separate impact categories which examine freshwater, marine,

and land. The emission of some substances, such as heavy metals, can have impacts on the ecosystem. From this study, a general trend was observed for FAETP, MAETP, and TETP. EDC comparatively had the highest values while MC recorded the least as shown in Figure 3f–h. Most of the impacts were associated with emissions from the CCP phase, contributing over 70% for all impact categories. Most impacting materials for FAETP and MAETP included pesticides, LPG (34–43%), (22–27%), and alkaline for Dutching (12–14%) for MC and EDC, respectively. Sugar also contributed 20% to the CM phase for MC and FMC. TETP was mainly influenced by emissions from pesticides (34–38%), Dutching (20–22%), and cleaning soap (18–20%). Ntiamoah and Afrane [9] reported higher values of 5.85 kg (1,4-DB) eq. and  $7.12 \times 10^{-3}$  kg (1,4-DB) eq. for FAETP and TETP, respectively. Konstansas et al. [17], also reported for 1 kg of moulded milk chocolate;  $1.33 \times 10^{-1}$  kg 1,4-DB,  $1.21 \times 10^{-1}$  kg 1,4-DB, and  $3.1 \times 10^{-2}$  kg 1,4-DB eq. for FAETP, MAETP, and TETP, respectively.

### 3.1.7. Photochemical Oxidation

Photochemical oxidation is the type of smog created from the effect of sunlight, heat, and volatile non-methane volatile organic compounds (NMVOC) and NO<sub>x</sub>. POCP primarily depends on the concentration of CO, SO<sub>2</sub>, NO, NH<sub>4</sub>, and NMVOC emitted into the air [36]. EDC recorded the least while FMC recorded the highest of  $3.07 \times 10^{-4}$  kg C<sub>2</sub>H<sub>4</sub> eq. and  $5.69 \times 10^{-4}$  kg C<sub>2</sub>H<sub>4</sub> eq., respectively, as shown in Figure 3i. CM was more impacting than CCP due to emissions from transported milk powder (57%) and transported sugar (14%) for FMC and MC. Emissions from CCP resulted from pesticide production and use. Recanati et al. [15], reported a higher value of  $1.07 \times 10^{-3}$  kg C<sub>2</sub>H<sub>4</sub> eq. for dark chocolate while Ntiamoah and Afrane [9] discovered a similar value of  $8.09 \times 10^{-4}$  kg C<sub>2</sub>H<sub>4</sub> eq. for processed cocoa.

### 3.1.8. Acidification

Some anthropogenic activities that release emissions have the potential to reduce pH due to the acidifying effects. These emissions which are gases such as ammonia (NH<sub>3</sub>), nitrogen oxides (NO<sub>x</sub>) and sulphur oxides (SO<sub>x</sub>) can cause acid deposition [36]. From this study, AP estimated was least for EDC ( $5.44 \times 10^{-3}$  kg SO<sub>2</sub> eq.) and highest for FMC ( $2.64 \times 10^{-2}$  kg SO<sub>2</sub> eq.) as shown in Figure 3j. CM was the most impacting phase with transported milk powder accounting for 80–83%. Konstansas et al. [17] also reported  $6.50 \times 10^{-2}$  kg SO<sub>2</sub> eq. for moulded chocolate with milk powder contributing 90%.

### 3.1.9. Eutrophication

Eutrophication values are often influenced by the estimated amounts of ammonia, nitrates, nitrogen oxides and phosphorous emitted to both air and water [36]. From this study, EP estimated was least for DC ( $2.13 \times 10^{-3}$  PO<sub>4</sub><sup>3-</sup> eq.) and highest for FMC ( $1.41 \times 10^{-2}$  PO<sub>4</sub><sup>3-</sup> eq.) as shown in Figure 3k. CM was the most impacting phase with transported milk powder accounting for 87% for FMC and MC. Sugar had a net positive credit of −2% to −24% (FMC and DC, respectively), mainly due to the difference between impacts of the co-product (molasses) and the final sugar product. Molasses is considered to be an alternative to spring barley (global product) used as animal feed through system expansion with a comparatively lower impact which accounts for the net positive impact on the environment. CM was mainly influenced by direct and indirect emissions associated with fertiliser production and use. Ntiamoah and Afrane [9] and Recanati et al. [15] reported comparable scores of  $1.05 \times 10^{-3}$  kg PO<sub>4</sub><sup>3-</sup> eq. and  $2.54 \times 10^{-2}$  kg PO<sub>4</sub><sup>3-</sup> eq. for processed cocoa and dark chocolate, respectively.

### 3.1.10. Impact Assessment for Different Packaged Chocolate Products

From the results obtained, the impact scores for 65 g packaged chocolate strips were highest across all impact categories while 100 g packaged chocolate bar and 300 g packaged chocolate pouch were relatively identical as shown in Table 8. The differences are

mainly due to the amount of packaging materials used and the different primary package typologies; 65 g packaging recorded the highest scores due to the comparatively higher amount of paper used for secondary packaging. Chocolate is a typical confectionary product with a longer shelf-life, and thus exposure to air and light can result in loss of taste and flavour and loss of surface gloss [17,22]. Carton boxes are used as tertiary packaging for distant transportation of chocolate. The GWP results obtained in this study which range between 0.20 kgCO<sub>2</sub> eq. and 0.39 kgCO<sub>2</sub> eq. are comparable to values of 0.20 kg CO<sub>2</sub> eq., 0.34 kg CO<sub>2</sub> eq., 0.81 kg CO<sub>2</sub> eq., and 1.91 kgCO<sub>2</sub> eq. per kg chocolate bar (FU) reported by Konstantas et al. [17], Recanati et al. [15], Allione et al. [23], and Perez Neira [16], respectively.

**Table 8.** The environmental impact scores for the different packaging typologies per FU based on the CML\_IA baseline method.

| Impact Category    | Unit                                 | 65 g Packaging        | 100 g Packaging       | 300 g Packaging       |
|--------------------|--------------------------------------|-----------------------|-----------------------|-----------------------|
| ADP                | kg Sb eq.                            | $6.88 \times 10^{-7}$ | $4.46 \times 10^{-7}$ | $4.73 \times 10^{-7}$ |
| ADP (fossil fuels) | MJ                                   | 3.85                  | 2.18                  | 2.74                  |
| GWP (100yr)        | kg CO <sub>2</sub> eq.               | 0.39                  | 0.20                  | 0.23                  |
| ODP                | kg CFC-11 eq.                        | $2.94 \times 10^{-8}$ | $1.45 \times 10^{-8}$ | $1.44 \times 10^{-8}$ |
| HTP                | kg 1,4-DB eq.                        | $1.41 \times 10^{-1}$ | $7.70 \times 10^{-2}$ | $6.95 \times 10^{-2}$ |
| FAETP              | kg 1,4-DB eq.                        | $6.29 \times 10^{-2}$ | $4.11 \times 10^{-2}$ | $4.22 \times 10^{-2}$ |
| MAETP              | kg 1,4-DB eq.                        | $4.94 \times 10^2$    | $2.94 \times 10^2$    | $2.44 \times 10^2$    |
| TETP               | kg 1,4-DB eq.                        | $2.56 \times 10^{-4}$ | $1.83 \times 10^{-4}$ | $1.64 \times 10^{-4}$ |
| POCP               | kg C <sub>2</sub> H <sub>4</sub> eq. | $1.35 \times 10^{-4}$ | $6.59 \times 10^{-5}$ | $8.53 \times 10^{-5}$ |
| AP                 | kg SO <sub>2</sub> eq.               | $2.62 \times 10^{-3}$ | $1.43 \times 10^{-3}$ | $1.60 \times 10^{-3}$ |
| EP                 | kg PO <sub>4</sub> <sup>3-</sup> eq. | $6.27 \times 10^{-4}$ | $3.26 \times 10^{-4}$ | $4.54 \times 10^{-4}$ |

### 3.2. Impacts Associated with 1 kg Chocolate Based on CED Method

The characterisation results (overall impact scores) for different impact categories for the different chocolate types and packages are shown in Table 9. From the results obtained, there was little difference between the chocolate types with the most impacting energy source being renewable (water) with a score of  $1.29 \times 10^2$  MJ eq. (86–90%) for the generation of hydroelectricity. A substantially lower value of 33.75 MJ/FU was reported by Recanati et al. [15] for dark chocolate produced in Italy. This was primarily due to the use of a highly efficient trigeneration system for electricity, heating, and cooling. Over 70 MJ/kg chocolate was also estimated for milk chocolate produced in Ecuador and Indonesia by Bianchi et al. [24].

**Table 9.** Impact scores for different products per FU based on the CED method.

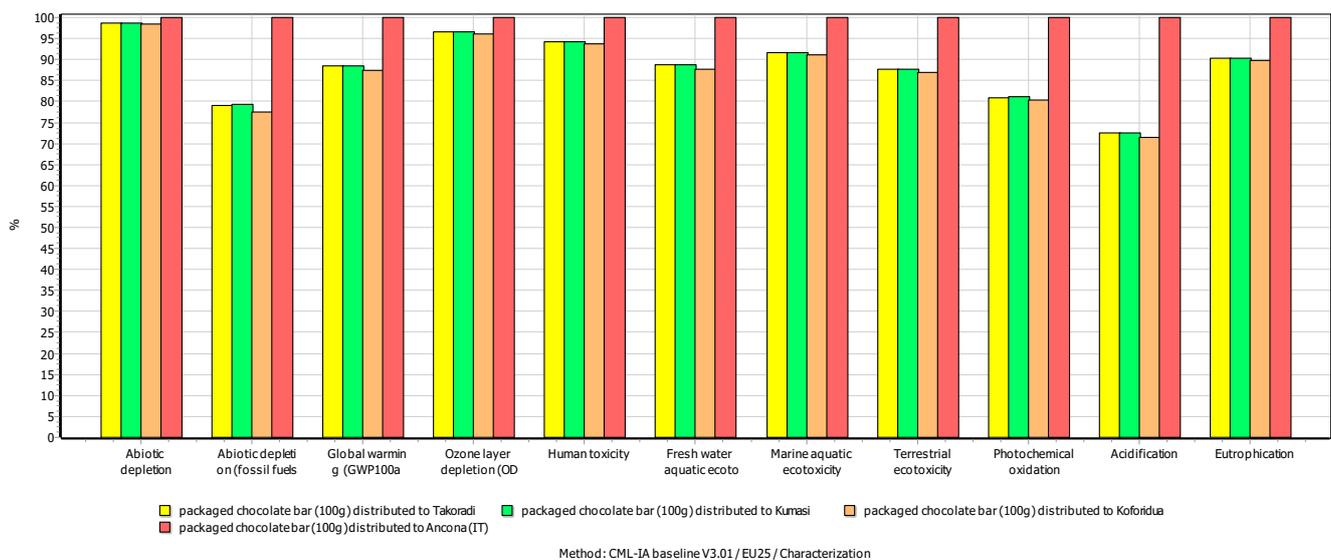
| Chocolate Type           | Unit   | Total CED          |
|--------------------------|--------|--------------------|
| Extra dark chocolate     | MJ-eq. | $1.44 \times 10^2$ |
| Dark chocolate           | MJ-eq. | $1.44 \times 10^2$ |
| Milk chocolate           | MJ-eq. | $1.49 \times 10^2$ |
| Flavoured milk chocolate | MJ-eq. | $1.50 \times 10^2$ |
| Packaging                |        |                    |
| 65 g packaging           | MJ-eq. | 4.93               |
| 100 g packaging          | MJ-eq. | 3.08               |
| 300 g packaging          | MJ-eq. | 4.16               |

The impact score trend for the different packaging types based on the CED method was similar to that observed using the CML\_IA method. The 65 g packaged chocolate strips recorded the highest score, followed by the 300 g packaging with the 100 g packaged chocolate bar recording the least as shown in Table 9. For all the packaging typologies, non-renewable (fossil) contributed the most (83–88%) mainly due to the energy for the

production of paper and cardboard; 65 g packaging recorded the highest scores due to the comparatively higher amount of paper used for secondary packaging, with relative contribution of paper (70%) and cardboard (22%). For 300 g packaging, paper contributed 62.7%, cardboard 25%, and aluminium foil 12.3%; 100 g packaging was least impacting with paper contributing 38%, cardboard 35%, and aluminium foil 27%.

### 3.3. Impact Assessment Based on Characterization for Different Transport Destinations

The relative contribution of impacts associated with the distribution scenarios for 1 kg packaged EDC considered in this study are shown in Figure 4. The total impact scores for the three destination points (Takoradi, Kumasi, and Koforidua) did not show many differences in impact scores across all categories. This could imply that the midpoint impact categories for local distribution in Ghana are more likely to be influenced by the transport mean and its characteristics than the estimated distances. The impact scores for the international destination (Ancona, Italy) were slightly higher than those recorded for the local destinations for most of the impact categories assessed. For GWP, Koforidua had the least impact score of 1.86 kg CO<sub>2</sub> eq. while Ancona recorded 2.13 kg CO<sub>2</sub> eq., while for AP Koforidua and Ancona had scores of  $6.93 \times 10^{-3}$  kg SO<sub>2</sub> eq. and  $9.71 \times 10^{-3}$  kg SO<sub>2</sub> eq., respectively. This could be attributed to the general high efficiency of transoceanic ships, though it was estimated to be responsible for about 2.1% of global greenhouse gas (GHG) emissions annually [38]. Therefore, this accounts for the relative low impact scores associated with this transport scenario. In addition, the truck means selected, EURO 4, is more efficient with less emission as compared to EURO 1–3.



**Figure 4.** Relative comparative environmental impacts associated with the transportation of 1 kg packaged EDC (100 g) to different destinations.

### 3.4. Impacts Associated with Transportation of Workers

The total impacts associated with the transportation of workers for this scenario using the CML\_IA baseline method is shown in Figure 5.

From the results obtained, there were no significant differences for the impact categories, with transportation by regular buses being slightly more impacting. The relative differences ranged between (0–10%) with ADP fossil fuels and TETP recording the most differences. The differences were due to the transport means since the same distance and number of workers were considered. LCA studies often do not take some important but indirect impacts such as transportation of workers into consideration. However, due to the high environmental impacts associated with daily transportation of workers, who are essential for the production of the chocolate, it was prudent to compare the different

transport scenarios and suggest appropriate mitigation strategies. According to the emission inventory analysis, road transportation including private cars, trucks, and buses is the main contributor to local air pollution [39]. The activities of the transport industry release several million tons of gases each year into the atmosphere which contribute to global warming and stratospheric ozone layer depletion. These include lead (Pb), carbon monoxide (CO), carbon dioxide (CO<sub>2</sub>; not a pollutant), methane (CH<sub>4</sub>), nitrogen oxides (NO<sub>x</sub>), nitrous oxide (N<sub>2</sub>O), chlorofluorocarbons (CFCs), perfluorocarbons (PFCs), silicon tetrafluoride (SF<sub>6</sub>), benzene and volatile components (BTX), heavy metals (zinc, chrome, copper and cadmium), and particulate matters (ash, dust) [40].

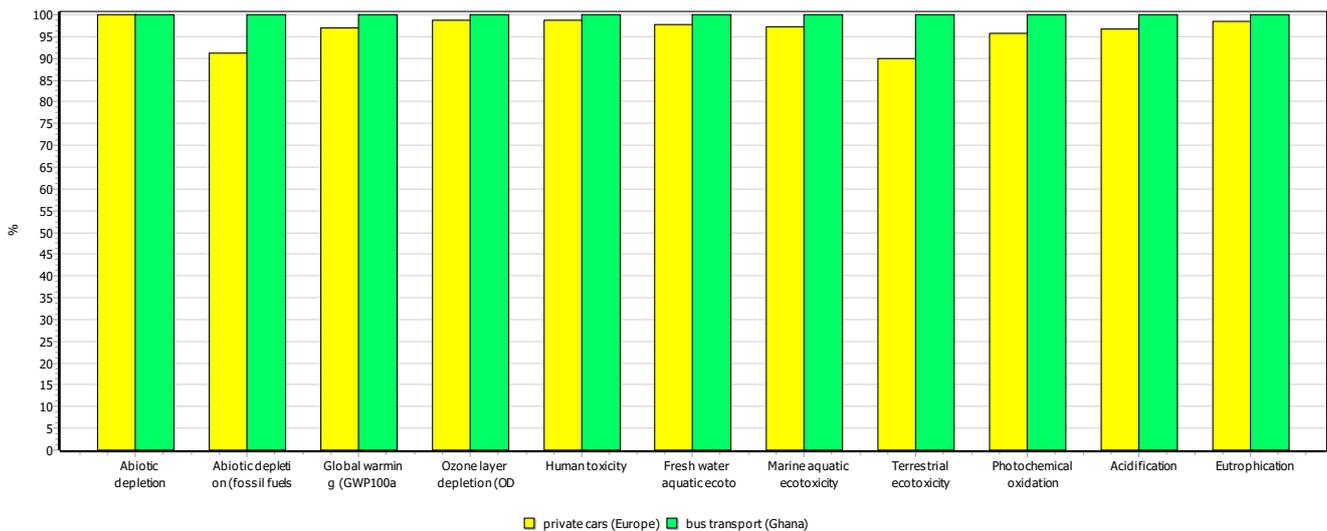


Figure 5. Relative comparison of environmental impacts for transportation of workers using different transport means.

### 3.5. Improvement Options for Sustainability

Several improvement options along the cocoa/chocolate supply chain can be suggested to improve the environmental performance of chocolate as all the phases were equally impacting for different impact categories. Most cocoa farmers in Ghana use traditional farming methods for the cultivation of cocoa. This method involves relying on the rainfall for irrigation, less use of agricultural machinery and sun drying of harvested cocoa beans. Emissions associated with energy use and water that could potentially impact global warming, acidification, and abiotic depletion are reduced. As shown in this study, most of the environmental impacts associated with cocoa cultivation are related to the amount and type of inorganic fertilisers, pesticides, and insecticides used. Therefore, substituting the use of inorganic fertiliser with organic fertiliser would decrease the emissions and their related impacts. Cocoa pod husk, which is generally considered as waste product after pod splitting, can also be used as organic fertiliser during cultivation [41]. Another option that could be considered is inter-cropping cocoa trees with other agroforestry crops like coconut. According to Utomo et al. [19], cocoa-coconut agroforestry recorded  $3.67 \times 10^{-1}$  kg CO<sub>2</sub>-eq. and  $4.31 \times 10^{-2}$  kg SO<sub>2</sub>-eq. for GWP and AP, while cocoa monoculture recorded substantially higher values of  $7.06 \times 10^1$  kg CO<sub>2</sub>-eq and  $8.11 \times 10^{-2}$  kg SO<sub>2</sub>-eq, respectively. The use of low input systems which rely on integrated pest management, that involve the use of biological agents for pest and diseases control, adequate soil fertility management, including the cultivation of high yielding and more disease and pest resilient cocoa varieties developed by the CRIG and other research bodies could also enhance the environmental performance of cocoa cultivation in Ghana. Also, advanced farming systems could be employed to increase cocoa yield. Production of dried cocoa using a technical management system yielded 1400 kg/year as compared to a traditional farming method of 300 kg/year with comparable GHG emissions of 2.49 and 2.82 kg CO<sub>2</sub>-eq. [16].

The production and transport of milk powder and sugar were the main impacting materials for the chocolate manufacturing phase. Substitution of milk powder and sugar with other less impacting ingredients able to perform similar functions could be useful. Milk powder impacts are mainly associated with cattle rearing, thus possible improvement options could include the modification of the diet of cattle to reduce methane emissions from enteric fermentation [42]. Roibas et al. [43] considered the effect of modified cow diet through the inclusion of high-quality forages (linseeds) on the emission of GHGs and found that the GWP of milk was reduced by 10%. Increasing the efficiency of energy use in ingredients production and chocolate manufacturing through implementation of integrated energy management systems or more advanced and innovative technologies such as trigeneration systems could potentially reduce emissions from LPG and hydro-electricity [17].

Packaging was also identified as a major contributor to several of the impact categories and should also be subject to improvements. Most of the impacts in this phase were associated with the extraction, manufacturing, and use of aluminium foil and paper. Data for alternative packaging that could be substituted with aluminium foil while preserving functionality is currently unavailable. Therefore, the use of recycled aluminium and a general reduction in the weight of the packaging materials used are recommended.

In relation to impacts associated with the transportation of workers, the manufacturer could consider using more efficient transport means to reduce fuel consumption and emissions. Also, the company could consider changing the transport means to larger buses to reduce the number of buses for one destination. A more efficient bus schedule could also be developed to reduce the number of times the buses travel the same distance in relation to the shift system. Furthermore, the company may consider hiring workers who stay close by or perhaps a future consideration to provide accommodation for workers closer the company to reduce the distance. Better work management could also be suggested to improve worker efficiency.

Stakeholders could adopt these feasible strategies to improve efficiency and to mitigate potential negative environmental impacts. Local chocolate manufacturers can improve their carbon footprint while enhancing their competitive urge on both the local and international markets. This would be considered a shared value by consumers as environmental protection awareness increases and could be beneficial for the marketing of chocolate produced in Ghana for higher profit gains. Furthermore, governing bodies could also develop guidelines and policies to ensure a more environmentally sustainable cocoa value chain.

### *3.6. Some Limitations of the LCA*

The Life Cycle Assessment methodology, although very useful, is also characterized by some limitations. Although the ISO standard gives a consensus definition for LCA and provides a general framework for conducting an assessment, it leaves much to interpretation by the person conducting the assessment, which may lead to high variation among results for even the same product. Other limitations include time and resource constraints in gathering inventory data, missing impact data and models for LCIA, challenges with data uncertainty, allocation of environmental burden across co-products, and assigning credit for avoided burden. The standard LCA methodology can also be regarded as an incomplete tool for measuring sustainability since it does not take social welfare into consideration and is unable to provide sustainability thresholds or acceptable limitations for the entire society [44]. Today, there is a burgeoning interest in updating and standardizing social and economic life cycle assessment for universal application. Despite these limitations, LCA can be improved through research, inherent in the methodology and alternate modelling choices. LCA offers a strong environmental tool in the movement toward sustainability.

## **4. Conclusions**

The tentative goal of this LCA study was to assess the environmental impacts of the production and distribution of chocolate produced in Ghana. Generally, the environmental

impact scores obtained were consistent with other similar studies conducted, particularly in Europe. Along the cocoa/chocolate supply chain, the manufacturing phase was found to be most impacting with milk and sugar accounting for most of the environmental burden. Consequently, darker chocolates were found to be more environmentally sustainable than milk chocolate derivatives. Although the 300 g packaged chocolate was expected to have the least environmental impact due to its larger size, the 100 g chocolate was rather found to have the least environmental burden, while the smaller 65 g chocolate was most impacting. With regards to transportation, impacts associated with the export of chocolate to Europe was not substantially different from distribution within Ghana. Furthermore, the comparison of impacts for the transportation of workers by buses in Ghana to passenger cars in Europe did not show any significant differences for the same distance. Therefore, the location of the processing and manufacturing plant in either Ghana or Europe does not confer any additional advantage from the environmental point of view. Plant siting in Ghana may be favoured due to availability of cocoa while Europe may be favoured by proximity to milk, sugar, and more efficient energy systems. Mitigation strategies should therefore be more focused on the cultivation phase, especially on the use of fertilizers and pesticides, and the manufacturing phase, particularly milk and sugar production. The quantification of the environmental impacts associated with chocolate could effectively support cocoa farmers, chocolate manufacturers, policy makers, and consumers in their pathway towards sustainable production, distribution, and consumption of chocolate products.

**Author Contributions:** Conceptualization, K.A.B.-Y. and D.D.; methodology, D.D., A.I. and E.F.P.; software, A.I. and K.A.B.-Y.; validation, D.D. and K.A.B.-Y.; formal analysis, A.I. and K.A.B.-Y.; investigation, A.I. and K.A.B.-Y.; resources, D.D. and E.F.P.; data curation, K.A.B.-Y., A.I. and D.D.; writing—original draft preparation, A.I., D.D. and K.A.B.-Y.; writing—review and editing, A.I., D.D., K.A.B.-Y. and E.F.P.; supervision, D.D.; project administration, D.D. and E.F.P.; funding acquisition, D.D. All authors have read and agreed to the published version of the manuscript.

**Funding:** This research received no external funding.

**Institutional Review Board Statement:** Not applicable.

**Informed Consent Statement:** Not applicable.

**Data Availability Statement:** Data available on request due to restrictions eg privacy or ethical.

**Acknowledgments:** The authors would like to thank Niche Cocoa Industry Limited, Ghana. We gratefully acknowledge Edmund Poku (the Managing Director) and especially John Attu, Esther Asante and Ebenezer Terkper-Mensah for the constant support and willingness to help conduct this research, through data collection and provision of other relevant information regarding cocoa processing and chocolate manufacturing.

**Conflicts of Interest:** The authors declare no conflict of interest.

## References

1. Shukla, P.R.; Skea, J.; Buendia, E.C.; Masson-Delmotte, V.; Pörtner, H.-O.; Roberts, D.C.; Zhai, P.; Slade, R.; Connors, S.; van Diemen, R.; et al. *IPCC, 2019: Climate Change and Land: An IPCC Special Report on Climate Change, Desertification, Land Degradation, Sustainable Land Management, Food Security, and Greenhouse Gas Fluxes in Terrestrial Ecosystems*; In Press; 2019; pp. 1–864.
2. Johnston, R. Arsenic and the 2030 Agenda for Sustainable Development. In *Arsenic in the Environment—Proceedings*; CRC Press: Boca Raton, FL, USA, 2016; Volume 2016, pp. 12–14.
3. Ericksen, P.J. What Is the Vulnerability of a Food System to Global Environmental Change? *Ecol. Soc.* **2008**, *13*. [[CrossRef](#)]
4. Franzen, M.; Mulder, M.B. Ecological, Economic and social perspectives on cocoa production worldwide. *Biodivers. Conserv.* **2007**, *16*, 3835–3849. [[CrossRef](#)]
5. International Cocoa Organization. *Annual Report International Cocoa Organization (ICCO) 2014/2015*; International Cocoa Organization: London, UK, 2015; p. 76.
6. FAOSTAT. Cocoa Beans Production Quantity. Food Agric Organ United Nations, Corp Stat Database. 2019. Available online: <http://www.fao.org/faostat/en/> (accessed on 29 March 2021).
7. Ghana Cocoa Board (COCOBOD). *47th Annual Report & Financial Statement*; Ghana Cocoa Board (COCOBOD): Accra, Ghana, 2017.
8. Chuhan-Pole, P.; Angwafo, M. (Eds.) *Yes, Africa Can*; The World Bank: Washington, DC, USA, 2011; pp. 201–218. [[CrossRef](#)]

9. Ntiamoah, A.; Afrane, G. Environmental impacts of cocoa production and processing in Ghana: Life cycle assessment approach. *J. Clean. Prod.* **2008**, *16*, 1735–1740. [[CrossRef](#)]
10. Daily Graphic. *Cocoa Farmers to Benefit from Subsidies*; Daily Graphic: Accra, Ghana, 2017.
11. Ghana Cocoa Board (COCOBOD). *The National Cocoa Consumption Campaign: All Hands on Deck*; Ghana Cocoa Board (COCOBOD): Accra, Ghana, 2018.
12. CNBCAfrica. Africa Investment Forum: Ghana's COCOBOD Signs Historic \$600 Million Cocoa Deal 2019. Available online: <https://www.cnbcfricia.com/news/west-africa/2019/11/12/africanvestmentforum-ghanas-cocobod-signs-historic-600-million-cocoa-deal/> (accessed on 12 November 2019).
13. Displore. Ghana's President Nana Akufo-Addo Says Ghana Will No Longer Export Cocoa to Switzerland. 9 May 2021. Available online: <https://www.youtube.com/watch?v=DbvocKxDtSc> (accessed on 2 April 2021).
14. Vesce, E.; Olivieri, G.; Pairotti, M.B.; Romani, A.; Beltramo, R. Life cycle assessment as a tool to integrate environmental indicators in food products: A chocolate LCA case study. *Int. J. Environ. Health* **2016**, *8*, 21. [[CrossRef](#)]
15. Recanati, F.; Marveggio, D.; Dotelli, G. From beans to bar: A life cycle assessment towards sustainable chocolate supply chain. *Sci. Total Environ.* **2018**, *613–614*, 1013–1023. [[CrossRef](#)] [[PubMed](#)]
16. Neira, D.P. Energy sustainability of Ecuadorian cacao export and its contribution to climate change. A case study through product life cycle assessment. *J. Clean. Prod.* **2016**, *112*, 2560–2568. [[CrossRef](#)]
17. Konstantas, A.; Jeswani, H.K.; Stamford, L.; Azapagic, A. Environmental impacts of chocolate production and consumption in the UK. *Food Res. Int.* **2018**, *106*, 1012–1025. [[CrossRef](#)] [[PubMed](#)]
18. Miah, J.; Griffiths, A.; McNeill, R.; Halvorson, S.; Schenker, U.; Espinoza-Orias, N.; Morse, S.; Yang, A.; Sathukhan, J. Environmental management of confectionery products: Life cycle impacts and improvement strategies. *J. Clean. Prod.* **2018**, *177*, 732–751. [[CrossRef](#)]
19. Utomo, B.; Prawoto, A.A.; Bonnet, S.; Bangviwat, A.; Gheewala, S.H. Environmental performance of cocoa production from monoculture and agroforestry systems in Indonesia. *J. Clean. Prod.* **2016**, *134*, 583–591. [[CrossRef](#)]
20. Ortizr, O.O.; Amanda, R.; Gallardo, V.; Rangel, J.M. Applying life cycle management of colombian cocoa production. *Food Sci. Technol.* **2014**, *34*, 62–68. [[CrossRef](#)]
21. Kamp, A.; Østergård, H. Environmental sustainability assessment of fruit cultivation and processing using fruit and cocoa residues for bioenergy and compost. Case study from Ghana. *J. Clean. Prod.* **2016**, *129*, 329–340. [[CrossRef](#)]
22. Büsser, S.; Jungbluth, N. LCA of Chocolate Packed in Aluminium Foil Based Packaging. In *Executive Summary*; ESU-services Ltd. Uster: Düsseldorf, Germany, 2009.
23. Petruccelli, L.; Allione, C.; De Giorgi, C.; Lerma, B. A Multicriteria System Useful for Evaluating the Eco-performances of Food Packaging Connected to the Functional, Communicative and Design Criteria. In Proceedings of the 2nd World Sustainability Forum, 2012. Available online: <https://sciforum.net/event/wsf2> (accessed on 16 April 2021). [[CrossRef](#)]
24. Bianchi, F.R.; Moreschi, L.; Gallo, M.; Vesce, E.; Del Borghi, A. Environmental analysis along the supply chain of dark, milk and white chocolate: A life cycle comparison. *Int. J. Life Cycle Assess.* **2021**, *26*, 807–821. [[CrossRef](#)]
25. García-Herrero, L.; De Menna, F.; Vittuari, M. Sustainability concerns and practices in the chocolate life cycle: Integrating consumers' perceptions and experts' knowledge. *Sustain. Prod. Consum.* **2019**, *20*, 117–127. [[CrossRef](#)]
26. Jolliet, O.; Saade-Sbeih, M.; Shaked, S.; Jolliet, A.; Crettaz, P. *Environmental Life Cycle Assessment*; CRC Press: Boca Raton, FL, USA, 2015.
27. ISO (International Organization for Standardization). *Environmental Management—Life Cycle Assessment—Principles and Framework (ISO 14040:2006)*; ISO (International Organization for Standardization): Geneva, Switzerland, 2006.
28. ISO (International Organization for Standardization). *Environmental Management—Life Cycle Assessment—Requirements and Guidelines (ISO 14044:2006)*; ISO (International Organization for Standardization): Geneva, Switzerland, 2006.
29. Chiamonti, D.; Recchia, L. Is life cycle assessment (LCA) a suitable method for quantitative CO<sub>2</sub> saving estimations? The impact of field input on the LCA results for a pure vegetable oil chain. *Biomass Bioenergy* **2010**, *34*, 787–797. [[CrossRef](#)]
30. Cooper, J.S.; Fava, J.A. Life-Cycle Assessment Practitioner Survey: Summary of Results. *J. Ind. Ecol.* **2008**, *10*, 12–14. [[CrossRef](#)]
31. Weidema, B.P.; Bauer, C.; Hischier, R.; Mutel, C.; Nemecek, T.; Reinhard, J.; Vadenbo, C.O.; Wernet, G. Data quality guideline for the ecoinvent database version 3. Ecoinvent Report 1 (v3). *Swiss Cent Life Cycle Invent.* **2013**, *3*. Available online: [https://www.ecoinvent.org/files/dataqualityguideline\\_ecoinvent\\_3\\_20130506.pdf](https://www.ecoinvent.org/files/dataqualityguideline_ecoinvent_3_20130506.pdf) (accessed on 16 April 2021).
32. Anukiruthika, T.; Sethupathy, P.; Wilson, A.; Kashampur, K.; Moses, J.A.; Anandharamakrishnan, C. Multilayer packaging: Advances in preparation techniques and emerging food applications. *Compr. Rev. Food Sci. Food Saf.* **2020**, *19*, 1156–1186. [[CrossRef](#)] [[PubMed](#)]
33. Pesonen, H.-L.; Ekvall, T.; Fleischer, G.; Huppes, G.; Jahn, C.; Klos, Z.S.; Rebitzer, G.; Sonnemann, G.W.; Tintinelli, A.; Weidema, B.P.; et al. Framework for scenario development in LCA. *Int. J. Life Cycle Assess.* **2000**, *5*, 21–30. [[CrossRef](#)]
34. Guinée, J.B.; Gorrée, M.; Heijungs, R.; Huppes, G.; Kleijn, R.; de Koning, A.; Oers, L.V.; Wegener, S.A.; Suh, S.; Udo de Haes, H.A.; et al. *Handbook on Life Cycle Assessment. Operational Guide to the ISO Standards. I: LCA in Perspective. Ila: Guide. Iib: Operational Annex. III: Scientific Background*; Springer: Dordrecht, The Netherlands, 2002.
35. Frischknecht, R.; Jungbluth, N.; Althaus, H.-J.; Doka, G.; Dones, R.; Hischier, R.; Hellweg, S.; Humbert, S.; Margni, M.; Nemecek, T.; et al. Implementation of Life Cycle Impact Assessment Methods. Ecoinvent Report 3. *Swiss Cent Life Cycle Invent.* **2004**. Available online: <https://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.195.358&rep=rep1&type=pdf> (accessed on 13 April 2021).

36. Acero, A.P.; Rodriguez, C.; Ciroth, A. LCIA Methods: Impact Assessment Methods in Life Cycle Assessment and Their Impact Categories. 2017. Available online: <https://www.openlca.org/wp-content/uploads/2015/11/LCIA-METHODS-v.1.5.4.pdf> (accessed on 16 April 2021).
37. Garnett, T. Livestock-related greenhouse gas emissions: Impacts and options for policy makers. *Environ. Sci. Policy* **2009**, *12*, 491–503. [[CrossRef](#)]
38. Johansson, L.; Jalkanen, J.-P.; Kukkonen, J. Global assessment of shipping emissions in 2015 on a high spatial and temporal resolution. *Atmos. Environ.* **2017**, *167*, 403–415. [[CrossRef](#)]
39. Demirel, H.; Sertel, E.; Kaya, Ş.; Seker, D.Z. Exploring impacts of road transportation on environment: A spatial approach. *Desalination* **2008**, *226*, 279–288. [[CrossRef](#)]
40. Rodrigue, J.P. *The Geography of Transport System*, 5th ed.; Routledge, Taylor & Francis Group: London, UK, 2020; pp. 124–149. Available online: <https://doi.org/10.4324/9780429346323> (accessed on 18 March 2021).
41. Takyi, S.A.; Amponsah, O.; Inkoom, D.K.B.; Azunre, G.A. Sustaining Ghana’s cocoa sector through environmentally smart agricultural practices: An assessment of the environmental impacts of cocoa production in Ghana. *Afr. Rev.* **2019**, *11*, 172–189. [[CrossRef](#)]
42. Moss, A.R.; Jouany, J.-P.; Newbold, J. Methane production by ruminants: Its contribution to global warming. *Anim. Res.* **2000**, *49*, 231–253. [[CrossRef](#)]
43. Roibás, L.; Martínez, I.; Goris, A.; Barreiro, R.; Hospido, A. An analysis on how switching to a more balanced and naturally improved milk would affect consumer health and the environment. *Sci. Total Environ.* **2016**, *566–567*, 685–697. [[CrossRef](#)] [[PubMed](#)]
44. Curran, M.A. Strengths and Limitations of Life Cycle Assessment. 2014. Available online: <https://doi.org/10.1007/978-94-017-8697-3> (accessed on 25 May 2021).