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MASTER OF SCIENCE DEGREE IN

FOOD AND BEVERAGE INNOVATION AND MANAGEMENT

A LIFE CYCLE ASSESSMENT OF CHOCOLATE PRODUCED IN GHANA

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ABSTRACT

The threat of climate change and the need to ensure environmental sustainability in the agri-food sector have become a global agenda. The cocoa is an important cash crop to Ghana and its products mainly chocolate is of high economic demand. However, there are limited studies conducted to measure the potential environmental impacts associated with the different phases of production and processing of cocoa in Ghana. This study therefore sought to evaluate the life cycle environmental impacts associated with chocolate production in a Ghanaian medium sized company using the Life Cycle Assessment (LCA), using the CML 2001 Baseline impact assessment method. The results obtained revealed that global warming potential (GWP), acidification potential (AP), eutrophication potential (EP) and abiotic depletion potential (ADP) were 2.51E+00 kg CO_2 eq., 1.56E-02 kg SO_2 eq., 7.29E-03 kg PO_4^{3-} eq. and 1.14E-02 kg Sb eq. respectively. The chocolate manufacturing and packaging were identified as the major hotspots. The most impacting materials included aluminium for packaging, milk powder and sugar for chocolate manufacturing and pesticides and fertiliser for cocoa cultivation. The improvement opportunities targeting the key contributing stages could significantly help reduce impacts from those phases. A scenario involving the transport of workers by buses was also considered due to the high amount of diesel used. Significantly high scores of 2.53E+01 kg CO_2 eq., 1.52E-01 kg SO_2 eq., 3.96E-02 kg PO_4^{3-} eq. and 1.73E-01 kg Sb eq. were obtained for GWP, AP, EP and ADP respectively. The quantification of the environmental impacts of chocolate through LCA, the identification of the main hotspots along the supply chain in this study could effectively support chocolate companies, cocoa farmers, policy makers, chocolate producers and consumers in their pathway towards environmentally sustainable production and consumption of chocolate products.

Keywords: Chocolate, Cocoa, Emissions, Environmental impacts, Life cycle assessment, Sustainability.

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1. INTRODUCTION AND OBJECTIVE

Background

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 (Franzen and Borgerhoff, 2007). Over the past 50 years, world supply and demand for cocoa has been increasing fairly at an annual growth rate of 2.5% (International Cocoa Organization, 2015). 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 (International Cocoa Organization, 2015). According to FAOSTAT (2017), world production of cocoa beans stood at 5.2 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, producing 900,000 Mt of dried cocoa beans in 2017/2018. The crop is a major contributor to Government revenue, generating about $2 billion in foreign exchange annually while contributing about 3.9% to Gross Domestic Product (GDP) (COCOBOD, 2017). Cocoa is mainly cultivated for its beans which is processed into products such as cocoa liquor, butter and powder serving 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, thus it is sold at a premium price (Kolavalli and Vigneri, 2011). 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%) (COCOBOD, 2017). The Ghanaian cocoa industry is estimated to employ about 60% of the nation's agricultural labour force (Ntiamoah and Afrane, 2008). Cocoa is produced by over 800,000 households mainly small holders spread over six of the ten regions in Ghana (COCOBOD, 2017).

In recent times, the threat of climate change and the need to ensure environmental sustainability have become a global agenda. This has led to the proposal of useful and adoptable mitigating strategies in all sectors including agriculture, energy supply and industry by companies, governments and international bodies (Sala *et al*., 2017). Climate change is a major contributory factor to food price crisis, and its negative impact on agriculture and food security in developing countries are expected to increase (Ericksen, 2008). Agriculture is highly vulnerable to climate change, as farming activities directly depend on climatic conditions especially in developing countries. The Agri-food industry contributes about 24% of the total greenhouse gas (GHG) emissions resulting from all anthropogenic emissions (IPCC, 2007). Food systems are heavily prioritised on the 2030 Agenda for Sustainable Development (UN, 2015), a global commitment to eradicate poverty and hunger while ensuring reduction of environmental and socio-economic concerns. Thus, several sustainable development goals such as zero hunger, climate action, responsible consumption and production and life on land must be achieved.

Food and energy supply chains are associated with complex and intertwined environmental and socio-economic impacts (Ericksen, 2008). Therefore, in order to advocate for sustainable measures, it is important to accurately assess the impacts of various activities and processes on the environment. This has led to the development of tools and methodologies for assessing these impacts along various supply chains. The Life Cycle Assessment (LCA) is a decision-making tool which gives a comprehensive approach for evaluating the environmental impacts of a product. LCA quantifies the environmental impacts (emissions) being contributed by each component (inputs) of the product (output) on the environment from raw material extraction to its end of life. It details the specific impacts and their effect on both mid-point categories including global warming, eutrophication, acidification and end-point categories which include damages on human health, ecosystem quality and non-renewable natural resources. LCA is an internationally recognised standardised methodology based on the ISO 14040/14044 series guidelines.

In Ghana, the cocoa value chain is 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. The Government of Ghana in its quest to increase output from the cocoa sector has implemented several initiatives, such as subsidy of fertilizer for farmers and Cocoa Disease and Pest Control Project (CODAPEC), to facilitate the increase in cocoa production (Ntiamoah and Afrane, 2008; Daily Graphic, 2017). The COCOBOD has also received a $600 million syndicated loan from the African Development Bank, and Credit Suisse Group Ag to increase productivity along the cocoa supply chain (CNBCAfrica, 2019).

Problem Statement

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. However, there are very limited studies conducted to measure the potential environmental impacts associated with the production and processing of cocoa in Ghana.

Justification

This study would provide the much-needed information geared towards sustaining the environment; particularly on the environmental impacts associated with the local cultivation and processing of cocoa into chocolate in Ghana. This would help in the identification of environmental hotspots along the cocoa value chain. In addition, relevant stakeholders could adopt feasible strategies to improve efficiency and to mitigate potential negative environmental impacts. The information obtained from this study would also help chocolate manufacturers improve their carbon footprint while enhancing their competitive urge in both the local and international markets. Furthermore, governing bodies could also develop guidelines and policies to ensure a more environmentally sustainable cocoa value chain. Thus, there is the urgent need to update and provide new insights on scientific basis for improvement analysis towards the sustainability of the production chain.

Objective

The tentative goal of this LCA is to assess the environmental impacts of the production and consumption of chocolate produced in Ghana adopting a cradle-to-gate approach. The system boundary will include: Production of raw materials, Transport, Processing of cocoa beans in chocolate, Packaging, and Distribution. Consumption and waste management are not taken into account.

Expected Outcomes

- A complete life cycle assessment of the Ghanaian cocoa industry.
- Suggestions on ways of mitigating for all relevant stakeholders.
- Increase awareness on energy and environmental sustainability in the Agrifood industry.

2. LITERATURE REVIEW

The Concept of Sustainable Development and Environmental Initiatives

Sustainable development is defined as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs." Globally, sustainable development has become increasingly imperative influencing principal policy goals of organizations and institutions coupled with the increase in academic interest since its inception by the United Nations (UN) in 1972. Furthermore, it has become a fundamental objective of the UN as well as the EU so as to achieve a sustainable low-carbon and low-input economy, increase resource efficiency, decrease energy consumption, reverse the loss of biodiversity and natural resources, and to limit climate change (Shah, 2008).

Several sustainable development and environmental agenda and initiatives have been developed and continue to be updated since the 20th century. The UN in the 1972 conference in Stockholm highlighted the concerns for preserving and enhancing the environment and its biodiversity to ensure human rights to a healthy and productive world. The 1982 Nairobi Summit further called upon national governments to intensify efforts to protect the environment and stressed the need for international cooperation. In 1983 the United Nations Commission on Environment and Development was created and in 1987, the Commission issued the Brundtland Report. This report indicated that equity, growth, and environmental maintenance are simultaneously possible and that individual nations can achieve their full economic potential while at the same time enhancing their resource base. It emphasized three fundamental components to sustainable development: environmental protection, economic growth, and social equity (UN, 1972; UN, 1982; UN, 1987).

In 1992 during the Earth Summit, world's governments established the Agenda 21, a comprehensive blueprint of actions toward sustainable development, including detailed work plans, goals, responsibilities, and estimates for funding. In 2012, The UN Conference on Sustainable Development (Rio Declaration on Environment and Development) in Rio de Janeiro, Brazil, led to the development of a set of Sustainable Development Goals (SDGs), built upon the Millennium Development Goals (MDGs). The MDGs expired in 2015 and were implemented over 15 years. The United Nations General Assembly formally adopted in September 2015 the 2030 Agenda for Sustainable Development and the set of 17 SDGs with 169 associated targets (UN,1992; UN, 2002; UN, 2018).

Numerous concepts and tools have been developed to help in the assessment and understanding of sustainable development. These concepts are usually ideas on how to achieve sustainability and are often developed in different disciplines for specific purposes. Some of the concepts include:

Life Cycle Thinking, Design for the Environment, Industrial Ecology, Dematerialization and Eco-Efficiency. The tools are developed based on the concepts to provide a systematic and standardized means of assessing or measuring environmental issues for evaluation of progress towards sustainability. Life Cycle Assessment, Environmental Impact Assessment, Strategic Environmental Assessment, Risk Assessment and Cost-Benefit Analysis are some of the comprehensive tools that are currently in use (OECD, 1995). However, some of these tools are still being improved to have more consistent and standardized methodologies which can be universally accepted.

Environmental Life Cycle Assessment

The contribution of environmental impacts arising from products and services has become critical in many decision-making processes at every level: political, economic, industrial, and individual. This stems from the continuous increase in environmental problems which has the potential to limit development of society due to environment's limited capacity to absorb the effects of human activities. This limit has already been reached in many regions of the planet (UNEP, 2012). The environmental impacts associated with a product or service need to be considered at each stage of the product's life cycle. Thus, 'Life Cycle Approach' has become fundamental in environmental policies and sustainable business decision-making. Life Cycle Assessment is a tool to review the environmental impact of products throughout their entire life cycle (from cradle to grave); from raw material extraction through transport, manufacturing and use all the way to their end of life.

The Life Cycle Assessment Tool

Life Cycle Assessment (LCA) is an important environmental management tool which is widely used to support environmental decision-making across several fields including agriculture. LCA has become increasingly accepted as a standardized method that enables the quantification of environmental interventions and evaluation of the improvement options throughout the life cycle of a process, product or activity from 'cradle to grave'. LCA serves as the tool by which companies and organizations can improve their environmental performance as they move from narrow system definitions and concepts to broader and complex ones (Azapagic, 1999).

LCA continues to receive methodological development since the 1990s when its relevance as an environmental management tool became evident. This led to a paradigm shift in how environmental challenges were addressed, resulting in the integration of life cycle thinking into environmental management. It emphasized that sustainable solutions to environmental problems must be sought more on a global level. The concept of LCA was first developed and published as Net Energy Analysis study in the 1970s, where only material quantification and energy consumption over a product or process was considered. Later, some studies went ahead to include waste and emissions (Hannon, 1972; Sundstrom, 1973; Ayres, 1978).

In 1990, the Society for Environmental Toxicology and Chemistry (SETAC) made the initiative to define LCA and develop a standardized methodology for conducting LCA studies. The International Organisation for Standardisation (ISO), also started developing principles and guidelines for the LCA methodology independently of SETAC. Currently, both bodies have reached a consensus on the methodological framework, with a few differences with respect to details only. The methodology developed by SETAC remained widely accepted among LCA practitioners until the ISO methodology was finalized (ISO, 1997; Azapagic, 1999).

Several advancements have been made in improving the use of an LCA to assess the environmental impacts associated with processes and systems. Inconsistency in methodological choices (e.g. of functional units and system boundaries) makes comparisons across studies difficult. As such, efforts are being made to harmonize the methodologies. Recently, a joint initiative dubbed 'Life-Cycle Initiative' has been launched with the aim of easing access to inventory data and providing flexible impact assessment procedures for practitioners by the United Nations Environmental Program (UNEP) and SETAC (Sonnemann and Valdivia, 2007). The LCA basically evaluates the associated environmental impacts of a product or service, which is based on a specific function while considering all life cycle stages (Jolliet *et al.*, 2016).

Framework for ISO Life Cycle Assessment Methodology

According to definitions by the ISO 14040 framework and by the Society of Environmental Toxicology and Chemistry (SETAC), an LCA should have four distinct methodological phases. The ISO has four main components for LCA study, which are: ISO 14040: Principles and Framework; ISO 14041: Goal and Scope Definition and Inventory Analysis; ISO 14042: Life Cycle Impact Assessment and ISO 14043: Life Cycle Interpretation. These four phases should be completed in the following order: goal and scope definition, life cycle inventory analysis (LCI), life cycle impact assessment (LCIA) and interpretation of the results (Jolliet *et al.*, 2016). These methodologies help quantify the use of environmental energy and material flows that are either directly or indirectly associated with the production processes of a product. These four main phases are represented in Figure 2.1.

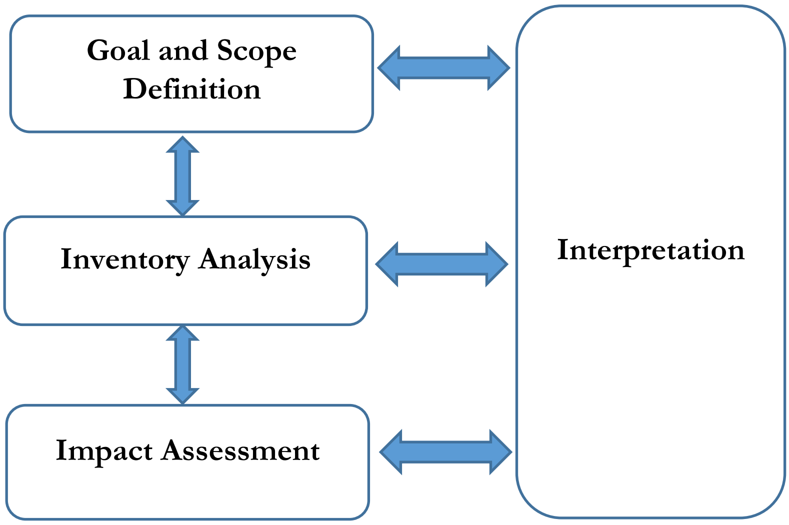

Figure 2.1: Components of a Life Cycle Assessment (ISO 14040)

The goal and scope defines the following: the function of the system, the functional unit on which the emissions and extractions will be based, the unit system boundaries, the environmental impact categories of interest, and the required level of detail (limitations of the study) (ISOb, 2006; Jolliet *et al.*, 2016).

The life cycle inventory (LCI) process involves the quantitative description of flows of matter, energy, and pollutants that are related to the chocolate manufacturing processes in the system under study (Jolliet *et al.*, 2016). These inputs and outputs directly relate to the defined functional unit and any requirements related to the goal and scope of the research (Baumann & Tillman, 2004). The system inputs for this research contain the associated energy and raw materials that are used in the production of the chocolate. The outputs are documented as all the semi-finished products, emissions and waste that result from the use of the energy and material resources required to produce the functional unit.

Life Cycle Impact Assessment (LCIA) evaluates the environmental impacts associated with the emissions from the listed inventory. It involves the selection of the impact categories, classification of the emissions that affect each selected impact category, characterization, normalization and weighting (Joliet *et al.*, 2016).

Interpretation of results and improvement of assessment basically involves interpretation of the results obtained and evaluation of uncertainties. The key parameters and improvement options can be identified through sensitivity analysis, allocations and uncertainty propagation. In addition, critical analysis is done to evaluate the influence of the chosen system boundaries and hypotheses. It must also be noted that the phases are simply followed in a single sequence due to the flexibility of the methodology in allowing for considerable feedback between the phases, making it an iterative process as shown in Figure 2.1. Lastly, comparison of the environmental impacts with economic or social impacts can also be performed (Joliet *et al.*, 2016).

Application of Life Cycle Assessment

LCA has proven to be very useful in many applications. The main objective of LCA is to provide information on the interaction between an activity or process and the environment as a system analysis tool. LCA helps decision makers to quantify and evaluate the environmental performance of a process or product especially when comparing among alternatives. In addition, LCA plays a key role in strategic planning or environmental strategy development by both public and corporate decision makers. It can also be used in the optimisation, design and innovation of products and processes as well as help in the identification of environmental hotspots and improvement opportunities. LCA can assist in selection of relevant performance indicators of environmental performance including measurement techniques. Furthermore, it can be used in environmental reporting and marketing and in the creation of a framework for environmental audits (Azapagic, 1999). Moreover, LCA can guide in the development of policies to mitigate challenges related to environmental sustainability. It can also help in the identification of new research and project ideas for environmental sustainability improvement options along the supply chain. LCA has been applied in many different sectors and industries including; agriculture, transport, energy, chemical, nuclear, mining, petroleum, water, electronic, metal, textile and leather (Franke *et al.*, 1995; Audus, 1996; Eriksson *et al.*, 1996; Griffen, 1997; Dones and Frischknecht, 1998; Dennison *et al.*, 1998; Solberg-Johansen, 1998).

Limitations of LCA

LCA has several limitations that sometimes lead to skepticism and mistrust about results and conclusions. This is because many assumptions and scenarios are made by the researcher in order to provide a simplified model of the more complex reality. Studies often differ in terms of choice of functional unit, scope, allocation methods and impacts, which may lead to misinterpretations of results especially by non-experts. These decisions are often based on the discretion of the researcher and may lead to some form of bias. Furthermore, LCA studies are resource consuming due to the large amount of data needed. Poor data collection or insufficiency in data availability may lead to weak conclusions (Finnveden, 2000).

An LCA may only give an indication of the environmental impact associated with the average or industry standard production of a product without necessarily indicating the best case scenario of a particular food product (i.e. novel production systems with the potential to drastically reduce environmental impacts may exist for a particular product, but this may or may not be considered in any given LCA study). In addition, it is quite difficult to communicate the results of an LCA study especially with regards to the different environmental impacts that can be assessed during the study. Thus, during comparison, a product may only perform better than another product only with respect to certain impacts requiring further analysis to explain the differences and highlight the benefits and drawbacks of both products. This can make decision making difficult when considering which impacts should be traded off. LCA is a useful but incomplete tool for measuring sustainability since it does not consider social impacts coupled with its inability to provide sustainability thresholds or acceptable limitations for the entire society (Curan, 2014).

History of Commercial Cocoa Cultivation in Ghana

Cocoa production in Ghana has suffered its fair share of instability, undergoing several expansions and contractions since the 19th century. Several distinct phases have been identified with regard to the trend in Ghanaian cocoa production; introduction and exponential growth (1879–1937); stagnation followed by a brief but rapid growth following the country's independence (1938–1964); near collapse (1965–1982); and recovery and expansion, starting with the introduction of the Economic Recovery Program (1983 to present) (Kolavalli and Vigneri, 2003). Several factors including availability of forest lands, ecological factors such as deforestation and outbreak of diseases, geographical shifts in production and economic and social factors such as migration have been identified as having directly influenced the level of Ghana's cocoa production (Ruf and Siswoputranto, 1995).

Introduction and exponential growth (1879–1937): Cocoa is believed to have been first introduced to the Gold Coast, as Ghana was previous known then, in 1879 from Fernando Po, an island off the coast of Cameroon, by Tetteh Quarshie. The crop then spread across the southern and middle belt of Ghana from the Eastern region of Ghana following the purchase of unoccupied forest lands by commercial farmers from local chiefs for cocoa cultivation. After 1885, the fall in prices of other export crops such as palm fruit coupled with the establishment of European produce buying companies on the coast of West Africa that were ready to trade in cocoa, compelled farmers to invest in cocoa due to its promising potential (Hill 1963; Gunnarsson, 1978; Amanor, 2010). In 1891, twelve years after its arrival, the exportation of cocoa as a cash crop began and within 20 years Ghana was the world's largest producer, exporting nearly 40,000 tons. Facilitated by the rapid expansion of the road and rail network which began in 1920 and the organization of cocoa marketing by Ghanaian middlemen, cocoa earnings accounted for 84% of the country's total exports by 1927. By the mid-1930s, production reached 300,000 tons; a record that was unbroken until after independence in 1957 (Acquaah, 1999; Adjinah and Opoku, 2010).

Stagnation and Growth Post-independence (1938-1964): The two world wars that occurred during this period resulted in a decline in demand for cocoa. In addition, poor infrastructure such as bad roads, outbreak of pests and diseases (capsid pest and swollen shoot virus disease) also contributed to the reduction in cocoa production in Ghana (Gunnarsson, 1978; Amanor, 2010). Production began rising again during the second half of the 1940s and in 1947 the Cocoa Marketing Board (CMB) was established by the colonial government, giving it the monopoly as the sole purchaser of beans. In 1961 a cooperative society also gained the monopoly right to purchase cocoa replacing the network of private agents, brokers, traders, and middlemen who until then had controlled internal marketing. From 1957 to 1964 exports grew steadily, and production reached an unprecedented level of 430,000 tons despite the significant decline in world prices between 1960 and 1962 (Kolavalli and Vigneri, 2003).

Near Collapse (1965-1982): During this period the cocoa sector was plagued with major external and internal challenges such as a drop in the world cocoa prices and bad monetary expansion policy which led to the devaluation of the Cedi, the local currency (Stryker, 1990; Amanor, 2005). Farmers refused to maintain their farms, harvesting from the aging crops which later became infested with the cocoa pod disease. Thus, cocoa farming became a bad investment for local farmers, so they switched to food production. These events led to the lowest drop of cocoa production in Ghana's history of 159,000 tons in 1982 (Kolavalli and Vigneri, 2003).

Recovery Expansion (1983-Date): The improvement in cocoa production began with the implementation of the ERP in 1983, which included a special program to revive the sector (the Cocoa Rehabilitation Project). Changes in policy resulted in an increase in the farm gate prices paid to Ghanaian farmers in comparison to what was being paid in bordering countries, thus it minimized the smuggling of cocoa beans and increased farmer revenues. As part of the Cocoa Rehabilitation Project, farmers were also compensated for removing trees infected with swollen shoot virus and planting new ones. This effort led to significant rehabilitation, with many farms planting higher-yielding cocoa tree varieties developed by the Cocoa Research Institute of Ghana, CRIG. Production rebounded to 400,000 tons by 1995/96 and productivity increased from 210 to 404 kilograms per hectare. Another important reform took place in 1992, when COCOBOD (as CMB was renamed in 1984) shifted responsibility for domestic cocoa procurement to six privately licensed companies (commonly known as licensed buying companies or LBCs) and reduced its staff by 90% between 1992 and 1995 (Kolavalli and Vigneri, 2003).

Since the early 2000s till date, Ghana's cocoa production has witnessed major expansions and stability. Between 2011 to 2018, the average annual production of cocoa in Ghana was about 854,000 tonnes, accounting for about 20% of world production as shown in Figure 2.2.

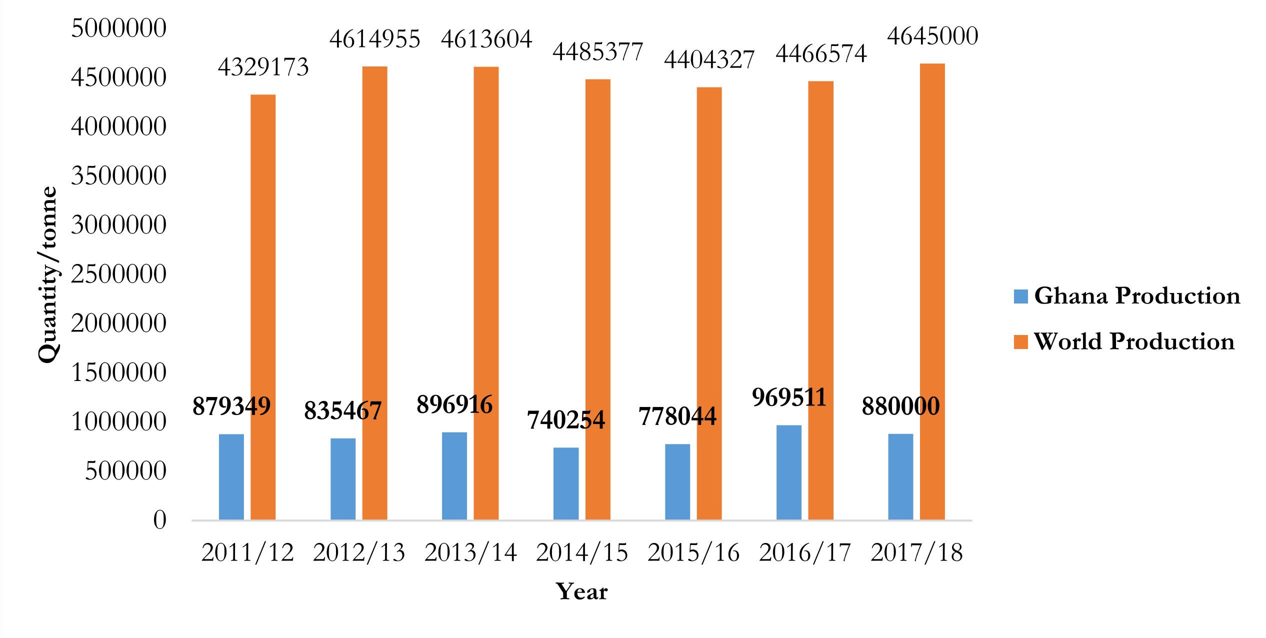

Figure 2.2: Ghana cocoa production vs. global production (ICCO, 2018).

This has been mainly driven by the increase in world prices of cocoa, increased share being passed on to farmers, adoption of improved varieties through the Cocoa Rehabilitation Program, and a series of interventions still being carried out by the COCOBOD to improve farming practices such as mass spraying programs and high-tech subsidy packages to promote the adoption of higher and more frequent applications of fertilizer (Vigneri and Santos 2008). Overall, these improved practices have resulted in an increase in productivity, with a strong correlation between production and area harvested.

Cocoa's contribution to Ghana's Economy

Cocoa has and continuous to play an essential role in the development and stability of Ghana's economy for over a century. Cocoa became widely accepted as a profitable cash crop mainly due to the lower cost involved in cultivation, in comparison with other known crops such as oil palm coupled with natural forest conditions in the forest belts that favoured its growth and survival. In addition, the cocoa could be cultivated together with other crops in a mixed cropping system which was practiced by most indigenous farmers (Acquaah, 1999).

Agriculture contributes about 35% of Ghana's GDP, out of which cocoa alone significantly contributes 16.5%. Approximately 65% of the country's agricultural workforce is employed directly or indirectly within the cocoa sector. In the Southern forest zones of Ashanti, Western, Eastern, Central and Volta regions of Ghana, cocoa is mainly produced by small holder farmers and their families. Aggregate figures suggest that through the 1990s, cocoa-farming households experienced improvements in their living conditions compared with food crop farmers (McKay and Coulombe 2003). Cocoa farming has also contributed significantly to the alleviation of poverty in many households. Surveys conducted indicate that poverty reduced from 60.1% to 23.9% among cocoa-producing households at the beginning of the 1990s (World Bank, 2007). Furthermore, increased access to education, health services, and land ownership, has facilitated the increase in growth rate of the economy leading to a drastic reduction in the national poverty rate from 51.7% in 1991/92 to 28.5% in 2005/06 (Breisinger *et al.*, 2008). Despite the increase in cocoa production and revenues from bean exportation, the huge potential that exists in the addition of value to cocoa before export remains unharnessed.

The global cocoa and chocolate market size was valued at US$ 44.35 billion in 2019 and is projected to reach US$ 61.34 billion by 2027, with an estimated cumulative average growth rate (CAGR) of 4.4% during the forecast period (ReportLinker, 2020). Unfortunately, due to technological challenges many African countries have been unable to take advantage of this lucrative sector. Among the world leading producers and exporters of cocoa, Ivory Coast processes between 24% and 35% of its cocoa exports, Ghana 6% and 15%, Indonesia 23% and 34%, Nigeria 6% and 14%, and Cameroon 10% and 27% (Boansi, 2013). However, almost all minor exporters of cocoa like Thailand, India, Brazil, Mexico and Guatemala (the last two being North American countries) export mainly processed products, including Costa Rica which adds value to approximately 90% of its cocoa products before export.

Ghana exports mainly raw cocoa beans, about 90%, while a small percentage of semi-processed products like cocoa liquor, cake, butter or powder are exported to developed countries where the cocoa is then processed into final products such as chocolate, confectionaries and cosmetics as shown in Figure 2.3. Thus, the need to add value to cocoa before export necessitated setting up several cocoa processing companies in Ghana. With one of the major national goals being exporting at least 50% of cocoa as processed, currently about eleven large cocoa processing companies are operating in Ghana of which four (4) are global or multinationals such as Barry Callebaut, Archer Daniels Midland (ADM), Touton, and Cargill. The others include; the Cocoa Processing Company (CPC), Afro tropics and Niche Cocoa Company which are mainly local entrepreneurs in joint ventures with global partners. Unfortunately, the presence of multinationals underscores the intense competition for Ghana's cocoa beans globally.

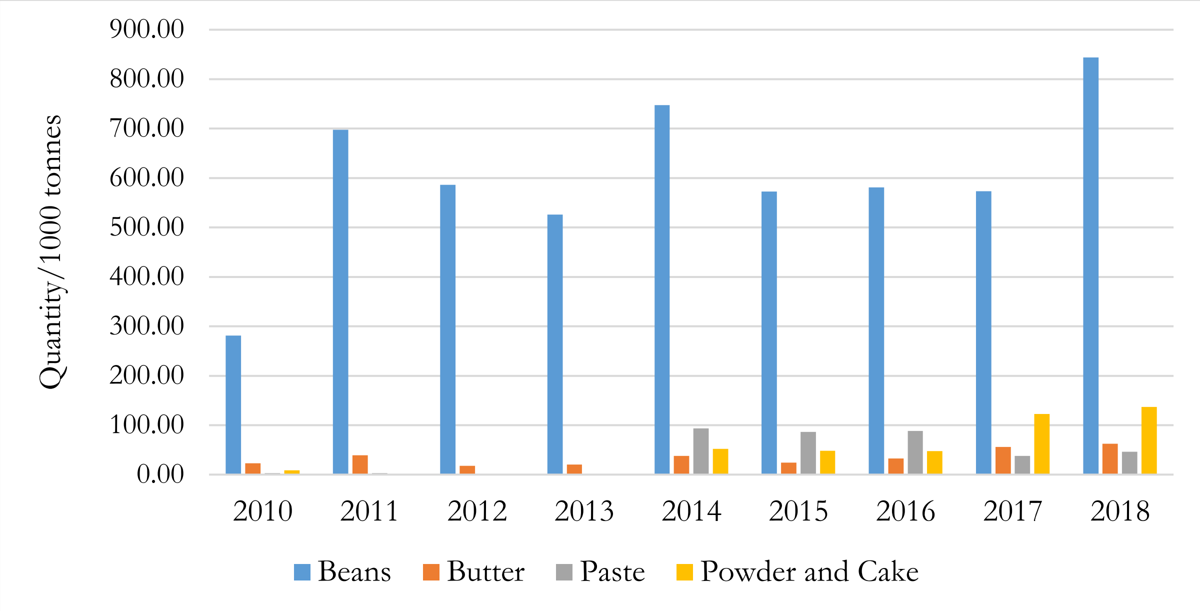

Figure 2.3: Value addition in Ghana's cocoa export products (FAOSTAT, 2018)

Most of the cocoa products are exported mainly to Europe and North America where they are used in the production of confectionery products like chocolate, cocoa beverages, cocoa powder and other chocolate candies, ice cream, and chocolate drinks. The top importers of Ghana's premium cocoa include Holland, Malaysia, USA and UK as found in Figure 2.4. The finished products are re-imported, where they flood the Ghanaian market. Due to the relatively less expensive price these imported products are sold at, locally manufactured products are unable to compete. Lack of government support for local manufactures coupled with the weak link between cocoa processing companies and scientific institutions have been identified as some of the factors impeding cocoa value addition (Essigbey and Ofori-Gyamfi, 2012).

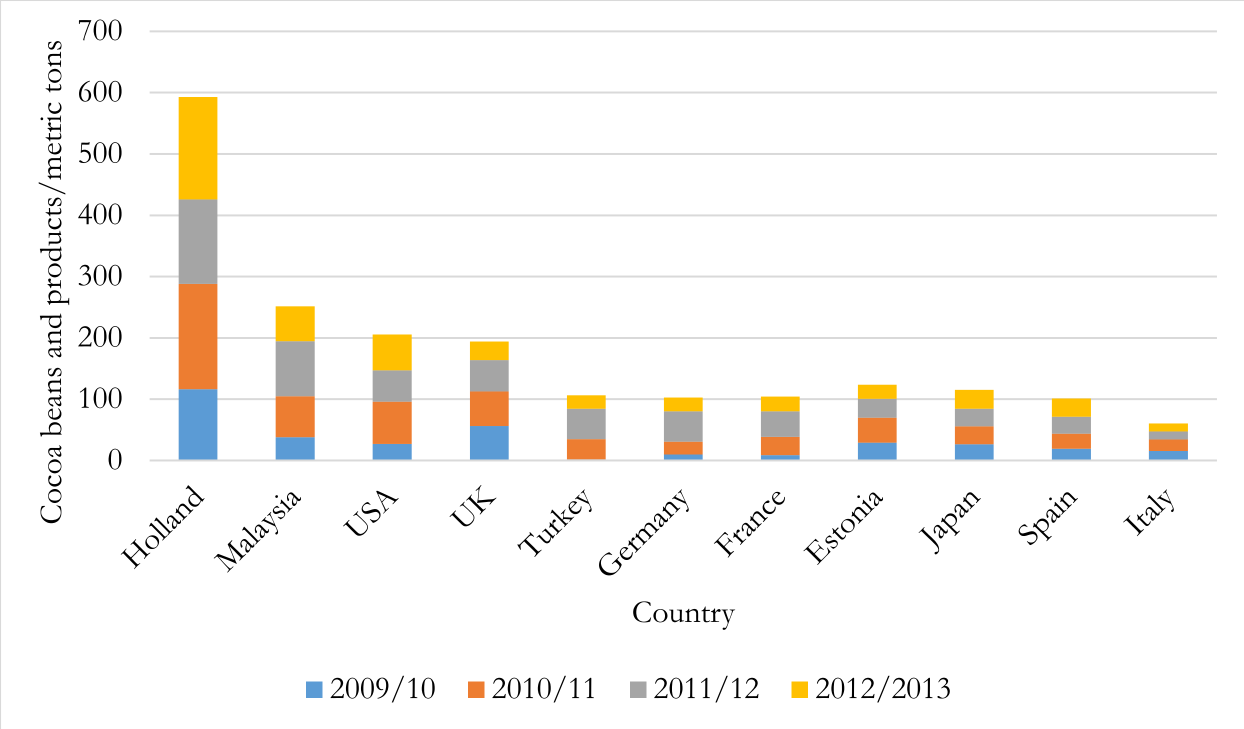

Fig 2.4 Quantity and export destination of Ghanaian cocoa beans and its products

Sustainability of the cocoa/chocolate industry

Food supply chains have become complex which involves the use of resource-intensive operations that encompasses human, financial and natural resources, with its associated social, economic and environmental implications. The need to reduce related negative impacts drives key stakeholders including companies, public authorities, international bodies and other stakeholders of the agro-food sector to develop innovative solutions and mitigating strategies for the improvement of working conditions, efficient use of resources to derive maximum economic benefit with minimum environmental impacts (García-herrero *et al.*, 2019). This quest for sustainability hinges on integrating and creating a balance between economic, social and environmental parameters along the whole supply chain, which is further reiterated by the United Nations' 17 Sustainable Development Goals (SDGs) (Pope *et al.*, 2004; UN, 2015). SDG 12 specifically targets the responsible consumption and production of products at all stages of the food supply chain with emphasis on semi-processed and processed products all geared towards promoting the optimization of resource and energy leading to more sustainable production along the life cycle. Chocolate is a highly processed food product characterised by a complex value chain and interconnected series of operations from cultivation, to post-harvest, transport, processing and packaging. Thus, the cocoa/chocolate value chain has varying impacts on the different sustainability dimensions.

Actors in the Chocolate Supply Chain

Many different actors are involved either directly or indirectly in the chocolate supply chain. The chain begins with the input industry (seedlings, hybrids, fertilisers, insecticides, technology), before reaching the farmers. The farmers after cultivation and harvesting sell to local buyers. Part of the cocoa beans is exported raw, while other parts are sold to processing companies and chocolate manufacturers. Consumers buy the final chocolate product and after consumption part of the packaging material is recycled and partly disposed of in landfills or in incineration plants. In addition, there are other stakeholders of the supply chain that add value to the process. Private sector members include, the companies involved in storage, packaging, transport, retail, and recycling facilities. The sugar and dairy industries are also key players as noted; they provide ingredients necessary for making chocolate as shown in Figure 2.5.

Several indirect actors include NGOs, media, researchers, investors, governments and industry associations and foundations. NGOs work with companies to support farmers to improve production systems and with national governments to develop socio-economic and environmental initiatives. The media disseminates information related to chocolate sustainability to the public and researchers contribute to generating knowledge concerning strategies for increasing sustainability of all phases of the supply chain. Industry associations and foundations collaborate to promote synergies between its members to ensure an organized and harmonized supply chain.

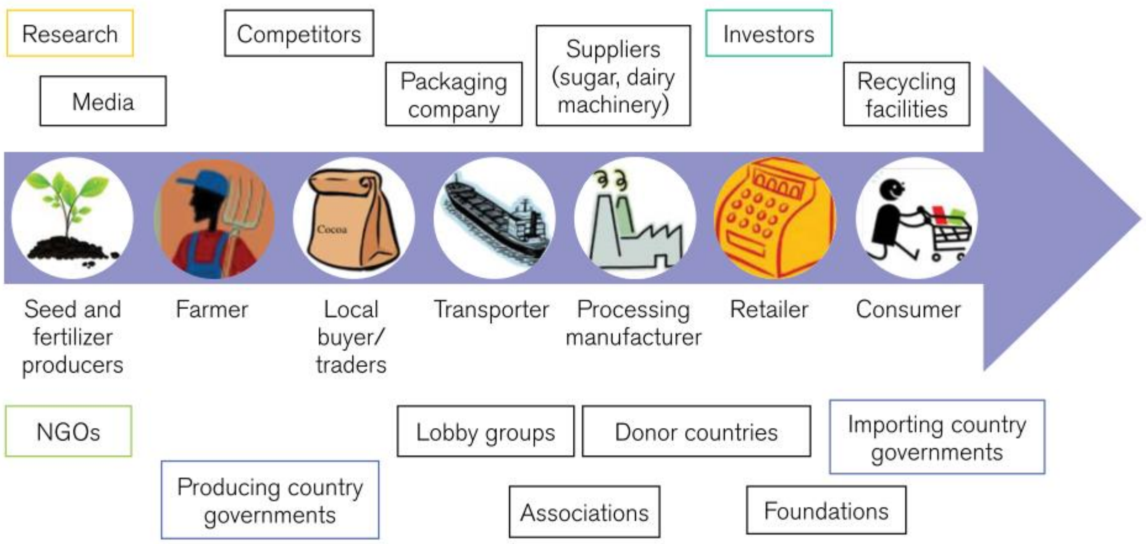

Figure 2.5. Actors in the chocolate value chain (Nhantumbo and Camargo, 2016)

All these numerous actors contribute to the survival and continuity of the chocolate supply chain. However, they are also responsible for generating negative impacts. Hence, they have a role to play in ensuring a more sustainable supply chain.

The Cocoa Supply Chain in Ghana

The Ghanaian cocoa sector is partially liberalised. However, COCOBOD, which is managed by the state, has a monopoly on cocoa marketing and export through its subsidiary, the Cocoa Marketing Company (CMC). Although, the upstream collection of cocoa (from farmers to COCOBOD warehouses) has been privatised, COCOBOD still coordinates and manages all processes and activities in the supply chain. The cocoa industry has three segments: production, processing and marketing. Production and processing cover activities such as drying, collection and bagging, quality control, haulage and warehousing (Nhantumbo and Camargo, 2016).

The cocoa supply chain mainly involves the farmers, local buyers and COCOBOD as illustrated in Figure 2.6. The cocoa farmers are responsible for the growth and maintenance, harvest, extraction, fermentation, drying, and bagging of the cocoa beans. Licensed buying companies (LBCs) accounting for 98% of bean purchases, under the supervision of the COCOBOD, buy the cocoa beans from the farmers and transport them to warehouses, where they are either exported or sold to local cocoa processing and chocolate manufacturing plants (de Brito *et al.*, 2001).

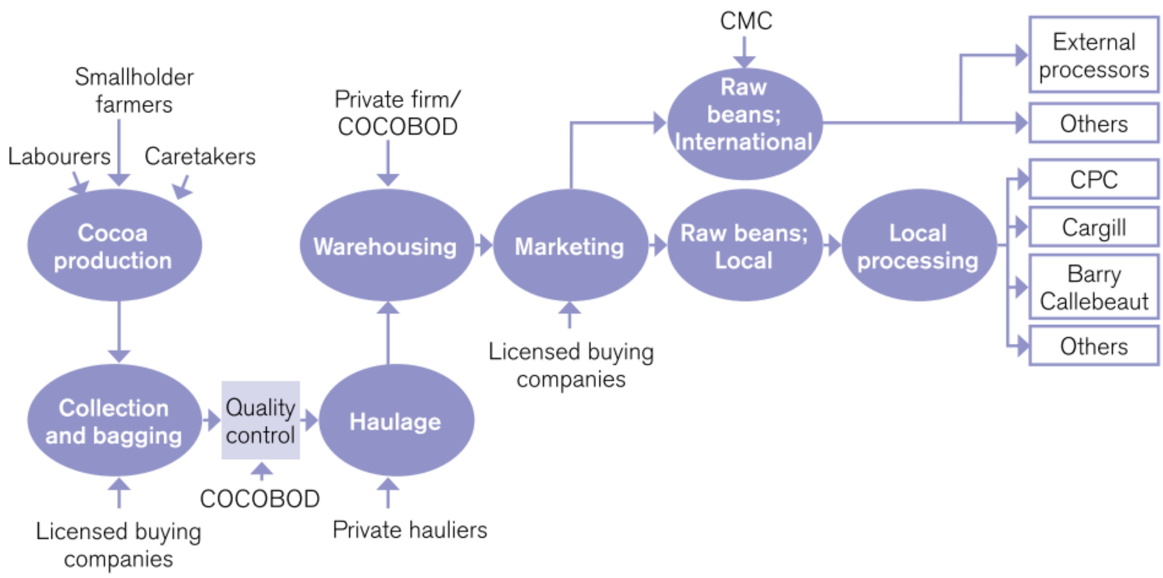

Figure 2.6. The cocoa supply chain in Ghana (Sutton and Kpentey, 2012).

Cultivation of cocoa beans in Ghana

Cocoa cultivation is predominantly undertaken by small-holder farmers with average farm sizes of about 4.0 ha and average production yields of 246.4 kg/ha (Afoakwa, 2010; Knudsen and Fold, 2011). The three main cultivars of cocoa that are commonly cultivated globally are: Forastero, Criollo and Trinitario. However, the major cultivar grown by Ghanaian farmers is the Forastero variety with estimated proportions of grown cultivars being Amazonica (34.4%), the Amelonado (13.3%) and the hybrid developed by CRIG (52.3%) (Afoakwa, 2010).

Farmers usually clear the undergrowth of the forest floor, followed by the elimination of certain tree species that are harmful to cocoa. The cut materials are burnt to clear the land for planting. Cocoa is then planted under the shade of the remaining trees together with other crops such as plantain, banana, yam and other fruit crops. Most cocoa is raised from seeds, which is easier, cheaper and faster than vegetative propagation. During the unproductive years after planting, it is necessary to create good preconditions for the development of the young cocoa plants through adequate shade, careful weeding and pruning, soil cultivation and plant nutrition. Other activities such fertilization, weeding and pruning, pest and disease management and shade management are also periodically carried out on the farm before harvest.

Fertilization

Fertilizers increase cocoa yield significantly. Mineral fertilizers which consist of N, P, K, Ca and Mg are often used. Fertilizers applied could be either granular or liquid. The common fertilizers used in cocoa production in Ghana are the mixed and compound fertilizers, locally known as "Asaase wura" with the composition N: P: K (0: 22: 18) + 9CaO + 7S + $6MgO_{(s)}$ and YaraLiva Nitrabor (15.4% N + 25.9% CaO + 0.3% B), which is sometimes used to complement Asaase wura.

Pruning and Weeding

Pruning is carried out to increase pod size, ease harvest and maintenance, and to aid in the control of pests and diseases. The cutlass is the main tool used in pruning and it is also used for manual weeding by slashing the weeds. The cut materials are left along the rows as mulch. Herbicides are often not used for controlling weed; however, glyphosate can be used (Konlan *et al.*, 2019). Shading by mature cocoa trees also reduces weed growth.

Pest and Diseases Management

Pest and disease management is critical in cocoa cultivation. Due to the warm and humid climatic conditions, many pests and diseases can thrive well and cause severe damage to cocoa trees resulting in considerable loss of up to 45% of potential production. The most significant insect pest that infests cocoa trees in Ghana is the mirid or capsid ("akate"). The major diseases that infect cocoa trees are caused by fungi*; Phytophthora spp*., responsible for the black pod disease. Other pod diseases are caused by *P. palmivora* and *P. megakarya* that can cause between 5-19% and 60-100% losses (Darkwa, 1987). Other pests of the cocoa tree include parasitic plants such as mistletoe (*Tapinanthus bangewensis*) and epiphytes such as *Bulbophyllum sp.* (Wilson, 1999; Dormon *et al.*, 2004).

The Cocoa Research Institute of Ghana (CRIG) are responsible for recommending pesticides to farmers as well as doses to apply and times of application for successful pest and disease control. The main pesticides and fungicides used in Ghana are listed in Table 2.1.

Table 2.1 Insecticides and fungicides approved by Ghana COCOBOD for use by cocoa farmers in Ghana

Trade Name	**Active Ingredient**	**Main use**	**Chemical hazardous class (WHO)**
Cocostar	Bifenthrin +Pirimiphos-methyl	Insecticide	II
Carbamult	Promecarb	Insecticide	
Akatemaster	Bifenthrin	Insecticide	II
Confidor	Imidacloprid	Insecticide	II
Fungikill	Cuprous hydroxide + Metalaxyl	Fungicide	III
Metalaxyl-M	Cuprous oxide + Metalaxyl	Fungicide	III
Champion	Cuprous hydroxide	Fungicide	
Kocide	Cuprous hydroxide	Fungicide	III
Nordox	Cuprous oxide	Fungicide	

Source: Extracted from Denkyirah *et al.* (2016).

Harvesting

Cocoa pods are harvested when fully matured which can be seen from the orange to yellowish colour of the shell. The pods are cut from the tree using a cutlass or sickle. The harvested pods are carried to a central point, where they are spilt open to remove the beans for fermentation and the husks are discarded as waste.

Fermentation

Bean fermentation begins right after removal from pods. After harvesting and storing, the cocoa beans are extracted from the pods and prepared for fermentation. Different methods namely; platforms, heaps, baskets and boxes can be used for fermenting cocoa beans depending on farmer and areas. However, in Ghana the heap method is mainly used where the beans are heaped on and covered with banana leaves to allow proper liquid drainage and good air circulation. Fermentation occurs between 6-8 days. Fermentation reduces the moisture content in the cocoa beans, removes mucilage around the beans, kills the embryo to prevent germination and ensures that biochemical reactions that affect the sensorial properties of chocolate are developed (Afoakwa *et al.*, 2013; Saltini *et al.,* 2013).

Drying

Drying of cocoa beans on raised mats using the natural sun drying method is carried out after fermentation to reduces the moisture content of the beans to less than 7.5% (W/W) in order to prevent deterioration. Drying takes about a week, during which the beans are periodically stirred to ensure uniform drying and covered overnight and in rain. Removal of defected beans, germinated beans and foreign materials is also done during drying (Lainé, 2001).

Storage

Dried cocoa beans are weighed and bagged in clean jute bags and sold to licensed local buying companies who transport and store them at warehouses. The warehouses are periodically fumigated to prevent insect infestation.

Transportation

Haulage is mainly by road (90-95%) and by rail (5-10%) by volume. Heavy trucks are used to transport the cocoa from the warehouses to the cocoa processing and chocolate manufacturing plants or to the harbour for export.

Cocoa Bean Processing

Cocoa processing encompasses the conversion of cocoa beans into semi-finished products like butter, liquor, cake and cocoa powder which are used as ingredients in finished products such as chocolate, confectionaries, pharmaceutical and cosmetic products. The main processes involved in cocoa processing in Ghana are described by Awua (2002) as follows;

Bean cleaning

Dried cocoa beans received at the processing plant undergo several quality checks and are thoroughly cleaned of all extraneous matter including stones, twigs, metal fragments, dust, wood or jute. The cleaning process consists of several operations which involves the use of varying screens, brushes, strong flow of air, magnetic separators and vibratory sieves.

Roasting

The clean beans are roasted introducing humidity to control removal of volatile substances. It is a high temperature process, usually conducted at temperatures between 120 and 140 °C, which is important for the occurrence of Maillard reactions. Roasting reduces contents of undesirable components, produces chocolate-specific aroma and flavour, and aid in the microbiological quality of the product.

De-shelling and Winnowing

The roasted beans are de-shelled to separate the cocoa shell, which is of less value, from the cocoa nibs, the valuable part. Roasting makes the shell loose and easy to crush which ensures that the nibs remain intact preventing the creation of smaller particles and dust. The shells are the separated from the nibs by winnowing under high pneumatic suction or pressure due to the light weight of the shells. The nibs are further conveyed to the millers for grinding.

Grinding and Pressing

After the cocoa beans are roasted to the desired flavour profile, the nibs are then ground into cocoa liquor by a variety of types and combinations of grinding equipment. These include shear mills, ball mills and stone mills. Equipment chosen is dependent on its ability to achieve appropriate particle size reduction, fat release, flow rate capacity, energy consumption, design and cost. The cocoa liquor is pressed to obtain the butter and cake. The cake can be further ground into the cocoa powder.

Chocolate Manufacturing

Chocolate manufacturing covers the blending of cocoa liquor, butter and other ingredients such as milk, sugar and flavour to produce chocolate.

Blending and mixing

Cocoa liquor is mixed with other ingredients including milk, sugar, butter and emulsifier except for the vanillin and lecithin.

Conching and Refining

Conching is a mixing and heating treatment that is conducted to produce liquid chocolate (all solid particles are coated with fat), evaporate volatile acids, achieve a proper viscosity, remove excess moisture, and develop a desirable colour. The initial powdery fine masse is gradually converted to a viscous liquid by the application of heat as well as continuous stirring. It is also carried out to achieve rheology optimization done through the addition of butter and lecithin. The darker the chocolate the longer the conching time. Typically, the mass is fed to roller refiners where the particle size is reduced to the required fineness. A refiner is a series of rolls which reduce particle size of the incoming ingredients using differential roll speed causing sheer. Pre-refiners are often used to condition the mass prior to the five roll refiners. The mass is introduced to the lower roller and moves up the rolls increasing the surface area and causing a dry paste or flake to come off the refiner.

Tempering

Tempering is a process used to obtain a stable product. Tempering is conducted thermally and results in stable and consistently sized crystals of cocoa butter which then affect growth of a stable crystalline network during cooling to avoid blooming.

Moulding and Cooling

The tempered chocolate is then dispensed into moulds to produce the desired shapes. The chocolate is then cooled under low temperatures. Afterwards, the cooled chocolate is removed from the moulds and arranged into trays ready for wrapping.

Wrapping and Packaging

Each chocolate bar is weighed and wrapped with aluminium foil and a paper wrapper. The wrapped bars are packaged into display boxes and then into cartons.

Environmental Impacts Associated with cocoa value chain

The surge in public awareness of environmental issues has compelled many industries and businesses to develop more ecological products and to inform stakeholders on how their activities produce emissions and consume natural resources. This has consequently led to a surge in life cycle assessment studies being carried out around the world. Most of these studies are being carried out in developed countries particularly in Europe, North America, parts of Asia and Australia. Unfortunately, very few LCA studies have been conducted in Africa, particularly in the agri-food sector. According to Maepa *et al.* (2017), only 31 LCA and environmental studies had been conducted and published in West Africa, specifically Nigeria, Ghana and Ivory Coast between 2000 and 2016. All the studies which were conducted after 2008 belong to the following industries; energy sector, waste management, real estate, food sector and others such as timber and gold. A total of 10 LCA research publications including master theses were found to have been conducted in Ghana, out of which only two were carried out in the agriculture or food sector, which both focused on the cocoa industry. Numerous reasons which could account for the low patronage of such important studies may include the failure of companies to encourage quantitative environmental studies, or that these studies are carried out for internal use. Other reasons could include the lack of policies and legislature that compel companies to take up more active role in environmental issues as well as lack of funding and modern research resources for academic research institutions to carry out LCA, environmental impacts, carbon and water footprint studies.

Several studies have been carried out to assess the environmental impacts associated with the cocoa/chocolate industry in different parts of the world. The goals and scope differed for most of the studies: with some having a cradle-to-grave system boundary (Büsser and Jungbluth, 2009; Konstantas *et al.*, 2018; Recanati, *et al.,* 2018) whiles others had a cradle-to-gate approach (Ntiamoah and Afrane, 2008; Ntiamoah and Afrane, 2009; Orlando Ortiz-R, *et al.*, 2014; Budi *et al.*, 2015). None of the studies conducted pre-date 2008, which correlates with the recent interest in environmental sustainability globally. Most of the studies were carried out in Europe in countries such as Italy and UK where chocolate products and other cocoa confectionaries are highly consumed (Büsser and Jungbluth, 2009; Konstantas *et al.*, 2018; Recanati, *et al.,* 2018), a few studies were carried out in South America and Asia, where cocoa cultivation is gaining popularity (Orlando Ortiz-R, *et al.*, 2014; Budi *et al.*, 2015) and two studies were conducted in Ghana, West Africa (Ntiamoah and Afrane, 2008; Ntiamoah and Afrane, 2009). No LCA studies have been conducted in the cocoa/chocolate industry in Ivory Coast even though they are the leading producer and exporter of cocoa and semi-processed cocoa. The reviewed publications of LCA studies conducted in the cocoa/chocolate industry are summarised in the tables below.

Table 2.2: From beans to bar: A life cycle assessment towards sustainable chocolate supply chain (Recanati, *et al.,* 2018).

Goal	To assess the environmental impacts of an Italian dark chocolate adopting a cradle-to-grave approach.
Scope	• System boundary: Cradle-to-grave (complete LCA) • Cocoa liquor, butter and powder from Peruvian cocoa beans. • Aluminium foil (primary package) and cardboard (secondary package) • Geographical location: South America (Peru) to Europe (Northern Italy) • Time boundary: 2014 to 2015 • Technology: Best technologies available
Functional Unit	1 kg of dark chocolate (10 bars of 100g) and the relative packaging
Data Source and Quality	• Primary: Chocolate producer (mainly cultivation, transportation to manufacturing, chocolate industry) • Secondary: Ecoinvent 3.3 (mainly raw material production, downstream phase)
Allocations	• Cocoa shells though 13 -15 % of the cocoa bean weight is neglected due to its negligible economic value. • The disaggregation of heat, cooling energy, water, auxiliary materials, wastewater and industrial waste among the unit processes in the manufacturing plant, be- cause only aggregated data for the whole production are available
Impact Assessment	CML-IA 2001 assessment method • baseline for eutrophication, ozone layer depletion, photochemical oxidation, global warming and abiotic depletion categories • non-baseline for acidification category Cumulative Energy Demand (CED, version 1.09)- direct and indirect energy uses due to the chocolate under study
Sensitivity Analysis	• methodological assumption concerning the allocation of impacts to the cocoa shells • alternative scenarios of the life cycle phase emerged as environmental hotspots from the LCIA
Findings	• The relevant contributions of upstream phase (63% for the ODP, 92% for EU and 99% for the AD) and core processes (39% for the GW and 49% for the CED) on the overall impacts. • Major hotspots identified were cocoa provision (cultivation and transport) and energy supply for the processing phase. • Environmental benefits guaranteed by an efficient trigeneration system implemented in the manufacturing plant.
Study Limitations	Downstream processes could also have included data on distribution and retail and waste management and perhaps export of chocolate products. Scenario where semi-finished cocoa raw materials were imported and further processed into chocolate could have also been considered. Cocoa pod husks were not taken into consideration even though based on mass allocation it can significantly alter results (however its economic value may be negligible).

Table 2.3: Environmental impacts of chocolate production and consumption in the UK (Konstantas *et al.*, 2018).

Goal	To assess the environmental impacts of production and consumption of chocolate products {chocolate coated wafers (chocolate countlines), milk chocolate (moulded chocolate) and malty chocolates (chocolates in bag)} in the UK.
Scope	System boundary: Cradle-to-grave
Functional unit	None was specifically mentioned
Data Source and Quality	Foreground: publicly available information provided by manufacturers and from the literature Background: Ecoinvent V2.2 (Ecoinvent, 2010). Any data gaps were filled using Ecoinvent V3.3 (Ecoinvent, 2016) and the GaBi database
Allocations	Basis of mass allocation and economic value allocation
Impact assessment	ReCiPe impact assessment method • Primary energy demand (PED) • Global warming potential (GWP) • Fossil fuel depletion (FFD) • Ozone depletion (OD) • Freshwater eutrophication (FE) • Marine eutrophication (ME) • Human toxicity (HT) • Terrestrial ecotoxicity (TET) • Freshwater ecotoxicity (FET) • Marine ecotoxicity (MET) • Terrestrial acidification (TA) • Land use and transformation • Photochemical oxidant formation (POF) • Mineral depletion (MD) • Water consumption • Water footprint
Sensitivity Analysis	land-use change (LUC) associated with cocoa production Basis of mass allocation and economic value allocation
Findings	• The raw materials are the major hotspot across all impact categories for all three product types, followed by the chocolate production process and packaging. • The improvement opportunities targeting the key contributing stages suggest that GWP of chocolates could be reduced by 14%-19%
Study Limitation	• No direct primary data was used for any of the phases

Table 2.4: Applying life cycle management of Colombian cocoa production (Orlando Ortiz-R, *et al.*, 2014).

Goal	To evaluate the use of LCM in the agricultural sector focusing on the environmental and socio-economic aspects of decision making in the Colombian cocoa production
Scope	The system boundary comprises the cocoa production (cradle-to-gate) • nursery sowing • site preparation • planting • fertilizer application • phytosanitary management (insecticides, herbicides and fungicides) • energy consumption (fuel and transport) Time boundary: 2012
System boundary	1 ha of land planted with cocoa with a projected 25-year life span.
Data Source and Quality	Primary data: Use of questionnaire for inputs and outputs Sample size: 30 farms Secondary data: Ecoinvent
Allocation	None
Impact Assessment	The CML 2 baseline 2000 method (Centre for Environmental Studies, 2001) Global Warming Potential calculated over the next 100 years
Sensitivity Analysis	None
Findings	• The highest environmental impact resulted from the use of fertilizers (about 90-96% of the total life cycle's emissions) • The highest emission percentage among the studied farms corresponds to a 250 kg·ha–1 dose of a 15-15-15 fertilizer, which exceeded records of the other farms employing synthetic fertilizers.
Study Limitations	• No clear goal was stated for the LCA • Only impact assessed was GWP, other mid-point impact categories could have been included such as acidification and eutrophication. • Inputs such as water, planting materials and land use could have been considered. • External databases could have been used as secondary data • Waste management was also not considered

Table 2.5: Environmental performance of cocoa production from monoculture and agroforestry systems in Indonesia (Budi *et al.*, 2015).

Goal	To evaluate environmental performance of cocoa production from cocoa monoculture and cocoa-agroforestry systems in order to promote sustainable agri- cultural practices in cocoa cultivation.
Scope	• System boundary: Cradle-to-gate (complete LCA) ➢ Nursery stage ➢ Unproductive stage (immature phase and any decline in production at the end of life) ➢ Productive stage (farm maintenance, crop protection, harvesting and packing) • Geographical location: Indonesia • Time boundary: 2014
Functional Unit	1 metric tonne of cocoa pods
Data Source and Quality	• Foreground: literature review, purposive cocoa plantation survey, consultation with field advisor, cocoa expert from the Indonesia Coffee and Cocoa Research Institute (ICCRI). • Background: Ecoinvent 3.3 (production of fertilizer and pesticides)
Allocations	• Based on co-product economic values.
Impact Assessment	ReCiPe2008 • global warming • acidifying • eutrophication • land use by measuring soil organic matter, organic content and soil microbes • Land productivity by Land Equity Ratio (LER) indices.
Sensitivity Analysis	None
Findings	• Cocoa-coconut agroforestry had the least impact of the three identified global impact categories of global warming, acidification and eutrophication accounting for 3.67E+01 kgCO2-eq, 4.31E-02 kg SO2-eq, and 2.25E-05 kgPO4-eq respectively per metric tonne of cocoa pod.
Study Limitations	• Goal of LCA was not clearly stated. • Other mid-point categories such as water consumption and human toxicity could have been included. • No sensitivity analysis was also conducted.

Table 2.6: LCA of chocolate packed in aluminium foil based packaging (Büsser and Jungbluth, 2009).

Goal	To investigate the environmental performance of chocolate packed in aluminium foil and wrapped with paper with respect to its function within the life cycle of chocolate as well as the environmental relevance of stages and interdependencies within the life cycle of chocolate including consumption patterns.
Scope	• System boundary: Cradle-to-grave (complete LCA) • Aluminium foil (primary package) and paper (secondary package) • Geographical location: Tropical regions to Europe • Technology: Best technologies available
Functional Unit	1 kg chocolate, packed in 100 g chocolate bars to be consumed in the household.
Data Source and Quality	Not stated
Allocations	• Cocoa shells though 13 -15 % of the cocoa bean weight is neglected due to its negligible economic value. • The disaggregation of heat, cooling energy, water, auxiliary materials, wastewater and industrial waste among the unit processes in the manufacturing plant, be- cause only aggregated data for the whole production are available
Impact Assessment	Mid-point categories assessed • Cumulative Energy Demand (CED) non-renewable [MJ-eq.] • Global Warming [kg CO2 eq.] • Ozone Layer Depletion Potential (ODP) [kg CFC-11 eq.] • Acidification [kg SO2 eq.] • Eutrophication [kg PO43- eq.]
Sensitivity Analysis	Consumer choices (chocolate type) and consumption patterns are investigated. Different shopping scenarios and refrigeration at home were assumed
Findings	• Between 77 -97 % of the non-renewable energy consumption is produced in the phase of raw material production and chocolate manufacture. • The share of retail packaging is between 1% (eutrophication) and 9% (CED non-renewable). • One kg milk chocolate corresponds to the emission of about 3.6 kg CO2-eq in a range between 2.1 kg CO2eq (dark) and 4.1 kg CO2-eq (white).
Study Limitations	Information on the data source and quality, inventory list and allocations were also considered.

Table 2.7: Life cycle assessment of chocolate produced in Ghana (Ntiamoah and Afrane, 2009).

Goal	To identify and quantify the potential environmental impacts associated with chocolate production, focusing attention on the cocoa supply chain. To assess the relative contribution of each stage of production to the identified environmental impact categories and suggest improvement options.
Scope	System boundary: Cradle-to-gate • Cocoa production on the farms • Transportation of cocoa beans to processing factories • Industrial processing of cocoa beans into butter and liquor • Mixing of cocoa liquor, butter and other ingredients to produce chocolate Geographical location: Ghana, West Africa
Functional Unit	1 kg of chocolate
Data Source and Quality	Primary data and secondary data (production of fertilizers and pesticides, transportation and electricity generation) obtained from eco-invent and GaBi 4 LCA database
Allocations	None
Impact Assessment	Mid-point categories assessed • Abiotic Depletion Potential (ADP) • Global Warming Potential (GWP) • Ozone Layer Depletion Potential (ODP) • Acidification Potential (AP) • Eutrophication Potential (EP) • Human Toxicity Potential (HTP) • Photochemical Ozone Creation Potential (POCP) • Terrestric Eco-Toxicity Potential (TETP) • Freshwater Aquatic Eco-Toxicity Potential (FAETP)
Sensitivity Analysis	None
Findings	The most significant impacts (mainly from cocoa production) associated with the chocolate production chain in Ghana are FAETP, HT and GWP. Industrial processing of cocoa beans made the largest contribution to GWP (63.70%). Transportation stage had the least impact on the environmental.
Study Limitations	Only the environmental impacts resulting from the acquisition of cocoa butter and cocoa liquor was included in this work. No table was provided for the inventory list making it difficult to know the inputs, outputs and emissions considered. Allocations based on economic value and sensitivity analysis comparing dark and milk chocolate could have been conducted. Time boundary for data collection was also not included.

Table 2.8: Environmental impacts of cocoa production and processing in Ghana: life cycle assessment approach (Ntiamoah and Afrane, 2008).

Goal	To identify and quantify the potential environmental impacts associated with cocoa production and processing in Ghana, to identify the activities that are not performing sustainably and then to suggest improvement options or impact reduction strategies towards the sustainability of the system studied.
Scope	System boundary: Cradle-to-gate (complete LCA) • Cocoa cultivation • Transport to processing factory • Processing to semi-finished cocoa products Geographical location: Ghana, West Africa
Functional Unit	1 kg of cocoa beans processed
Data Source and Quality	Primary data for cultivation and processing phases supplemented with secondary data from Swiss eco-invent and GaBi 4 LCA.
Allocations	None
Impact Assessment	Mid-point categories assessed • Abiotic Depletion Potential (ADP) • Global Warming Potential (GWP) • Ozone Layer Depletion Potential (ODP) • Acidification Potential (AP) • Eutrophication Potential (EP) • Human Toxicity Potential (HTP) • Photochemical Ozone Creation Potential (POCP) • Terrestric Eco-Toxicity Potential (TETP) • Freshwater Aquatic Eco-Toxicity Potential (FAETP)
Sensitivity Analysis	Comparison of; different fuel sources (natural gas vs diesel in cocoa processing); inorganic fertilizer vs compost; and 100% pesticide use vs 50% reduction were investigated.
Findings	Cocoa production makes the largest contribution to the environmental impacts of EP, ODP, freshwater aquatic eco-toxicity, HTP, and TETP, with average contributions greater than 96%. Processing phase mainly contributed to POCP (95.84%), GWP (80.89%), AP (96.47%) and ADP (76.35%).
Study Limitations	Allocations based on mass and economic value of semi-finished products could have been done. Time boundary for data collection was also not included.

3. METHODOLOGY

This section addresses the standardized procedure of performing a research-based life cycle assessment and how to apply a life-cycle perspective on a complex food value chain.

ISO 14040 Standardized Framework to Perform an LCA

This study was conducted in accordance with the ISO procedural framework for performing LCA detailed in the ISO 14040. Data storage and analysis were performed using the SimaPro 9 LCA analysis software. The method used for the impact assessment is the CML 2001 method, developed by the Centre for Environmental Science, University of Leiden, Sweden. According to the ISO standards, LCA study has four main phases; the goal and scope definition, the life cycle inventory analysis, the impact assessment and interpretation of results. Activities carried out in these phases pertaining to this study are described in detail.

Goal and Scope Definition

Goal

The LCA study of a packaged chocolate bar was undertaken to assess the environmental impacts of the production and consumption of chocolate produced in Ghana to help improve the environmental aspects of the product. The LCA data will be used 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, retailers and consumers.

The specific objectives of this study are to:

- conduct a complete life cycle assessment of chocolate produced in Ghana.
- compare the environmental burdens associated with each major stage of the chocolate production chain.
- suggest mitigation strategies to improve the environmental performance of chocolate production based on the findings.

The target group for this study includes all stakeholders within the Ghanaian cocoa industry, namely: COCOBOD, cocoa farmers, cocoa processors, environmental authorities and policy makers, the companies involved in storage, packaging, transport, retail, and recycling facilities, researchers, NGOs and LCA practitioners who may also find the results and methodology of this study useful.

Scope

Product: Ghanaian manufactured chocolate bar

Product system: The Ghanaian manufactured chocolate bar plus its upstream and downstream processes consist of a product system. This includes cocoa cultivation, cocoa processing and chocolate manufacturing, packaging, distribution and use. In addition, all transportation and energy used, not only for the product but also for all elements in the product system, is included in the product system.

Function: Food

Functional Unit: The defined functional unit of this study is 1kg of 100g packaged chocolate bar (10 x 100g packaged bars) made entirely from Ghanaian cultivated cocoa and consumed by a local resident.

System boundary: The system boundary encompasses the essential energy and material inputs/outputs that are related to the processes of producing chocolate. This include; production of raw materials, cocoa cultivation, transport, processing of cocoa beans in chocolate, packaging, distribution as shown in the Figure 3.1.

Other phases including consumption and waste management as shown in the Figure 3.1 were not included in the system boundary due to limited available data and their little relevance on the overall impact assessment. A more elaborate version of the system boundary is in Appendix A.

The Life Cycle Inventory Analysis

The system inputs for this research contain data collected on the associated energy and raw materials that are used in the production of the chocolate. The outputs are documented as all the semi-finished products, emissions and waste that result from the use of the energy and material resources required to produce the functional unit. After the input and output data were collected and tabulated (Appendix B), it was incorporated into the SimaPro 9 LCA software for analysis. Detailed documentation of this entire process is required (ISO, 2006).

Cocoa Cultivation Phase

The cocoa production phase 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. Secondary data on these processes were obtained from academic peer reviewed publications and other forms of literature (Ntiamoah, 2009). Additionally, information related to cocoa beans cultivation which included: land use and land preparation activities, fuel inputs, crop yield per hectare, economic lifetime of the cocoa plant, waste generated and background data on production of inputs such as fertilizer, pesticides, sugar, milk and flavour were also obtained from academic peer reviewed publications, and LCA databases such as Eco-Invent database.

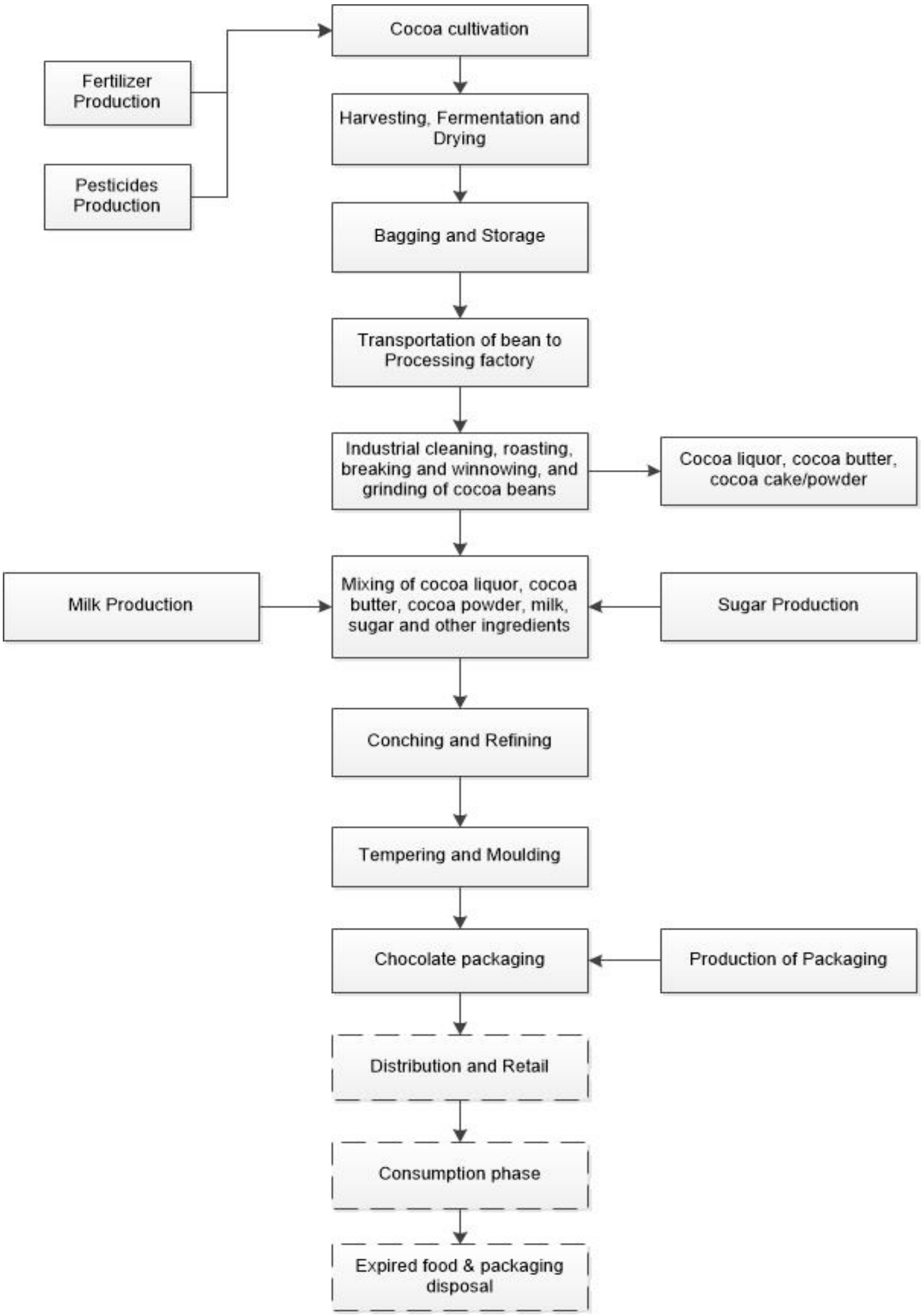

Figure 3.1. The LCA system boundary (sub-stages) and process flow for chocolate produced in Ghana.

Transportation of beans to Processing Factories

Dried and bagged cocoa beans are transported by trucks from the farming communities to the warehouses of CMC 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 Acra. The truck chosen was a 38-tonne total capacity (and 26 tonne payload) long distance truck-trailer (which is the average truck capacity of most cocoa haulage trucks in Ghana) (Ntiamoah, 2009). Data on fuel consumption and emissions for the transportation were obtained from the database. Thus, the assumption being the truck used in Ghana are in similar conditions to those used in Europe.

Processing of cocoa beans into chocolate

Primary data were collected using detailed questionnaires that were completed by Niche Cocoa Processing Company, located in Tema, Ghana, which is involved in the processing of Ghanaian cocoa beans into semi-finished products like liquor, butter and powder and finished products such as chocolate. This questionnaire for the processing of cocoa beans into chocolate life cycle inventory data is attached as Appendix B. This questionnaire collected information 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.

Additional secondary data inputs for processes for which primary data could not be obtained directly for this step were obtained from academic peer reviewed publications, and LCA databases such as Eco-Invent. This background data included production of energy (electricity from hydropower and diesel) consumed by the plant, manufacture of key ingredients such as sugar, milk and flavour.

Transport, Packaging and Retail Phases

The associated input and emission data for the chocolate production was highly dependent upon the data that was available from the questionnaires. Any insufficient production data, energy sources and transportation data, was supplemented with background process data in the LCA databases to address these gaps. Round trip transportation distances were established and modelled for the transportation of cocoa beans from farming communities to warehouse, transportation of the beans to the manufacturing facility and further distribution of chocolate product to retail shops.

Three different types of packaging were considered; primary package which included two different typologies; aluminium foil and aluminium foil combined with paper, paper as the secondary package and cardboard as the tertiary package. In addition, locations for the manufacturing of the packaging materials were considered and the average distance determined.

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.

Use and Waste Management

Finally, to quantify the associated material and energy emissions for the packages of the end-of-life of a 100g Ghanaian chocolate bar, the LCA model considered all the activities and processes related to the Metropolitan solid waste and collection of the discarded packages to waste management facilities. Thus, assumptions were made regarding the mode of waste disposal which included; incineration, recycling and landfilling.

Life Cycle Impact Assessment

The collected and aggregated data were input in the SimaPro 9 software to perform an LCIA assessment. The data were then exploited to construct all the significant process flows (inputs and outputs for each life cycle stage) and generate the product systems (the process flows connected to the activity as a whole unit). The SimaPro 9 software provides numerous scientific models in the form of methods, which sort through the inventory data and identify the types of environmental impacts caused due to the chocolate manufacturing. After identification, the software shows an impact assessment which highlights the effects of the resources and emissions generated during the chocolate making process. An LCIA method is understood as a set of LCIA impact categories that is selected based on the purpose of the study. In this study two LCIA methods; CML 2 Baseline 2000 and Eco-Indicator 1999 were used.

The CML (Centre of Environmental Science of Leiden University) 2 Baseline 2000 Version 2.05 method, which elaborates the problem-oriented (midpoint) approach was used to generate the LCIA results based on both characterisation and normalization. Direct emissions to air (CO_2, CH_4 and N_2O), water (Phosphorus compounds) and land (Phosphorus compounds) were calculated based on inputs. Eco-indicator 99 is also an impact assessment method in LCA used for endpoint impact evaluation. It calculates impacts scores on characterisation as well as allows the expression of the environmental impact in one single score as damage assessment. The method analyses the impact of damage on human health, ecosystem quality and resources by aggregating similar impacts from the characterisation step. Relevant information about Eco-indicator 99 is that the standard unit given in all the categories is point (Pt) or millipoint (mPt). The Eco-indicator was used to calculate the impact scores for characterisation and damage assessment for 1 kg of packaged chocolate in this study.

Allocation in LCA study refers partitioning the input and/or output flows of a process to the product system under study. It could be based on physical properties of the outputs or economic value. Economic allocation is recommended as baseline method for most LCA studies although the economic value of the product is not conservative. In this study, the allocation of environmental impacts associated with the co-products from cocoa processing was based on the economic value of the cocoa products as shown in Tables 1 and 2.

Table 3.1: Economic value of cocoa products.

Product	**Ton**	**Amount (Ghc)**	**Ton/Ghc**
cocoa liquor	106,920	1383179187	12936.58
Butter	38539	747604928.7	19398.66
Cake	10020	26386813.03	2633.414
Powder	31889	246413949.6	7727.24

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

Table 3.2: Allocation based on economic value.

Product	**Kg**	**Economic value (Ghc)**	**Allocation (%)**
cocoa liquor	17239840.00	32510871.42	49.2%
Butter	10306000.00	29143233.55	44.1%
Cake	54010.00	60837.93307	0.1%
Powder	11423000.00	4385057.367	6.6%

These results were expressed as the percentage contribution each process activity makes in each of the identified impact categories (Baumann and Tillman, 2004). The data were then normalized in order to interpret the results (ISO, 2006). In this study the impact categories examined for CML 2 baseline method include; Abiotic depletion, Acidification, Eutrophication, Global Warming Potential (GWP 100yr), Ozone layer depletion (ODP), Human Toxicity, Fresh water aquatic ecotoxicity, Marine aquatic ecotoxicity, Terrestrial ecotoxicity and Photochemical Oxidation. The midpoint and endpoint impact categories examined by the Eco-indicator 99 method were also depletion of abiotic resources, human toxicity and ecotoxicity.

Interpreting Results and Improvement Assessments

The results obtained through the calculation of the emissions from the product systems were interpreted and improvement assessments were conducted. The results identify and highlight the significant areas where reduction of the impact of the product and/or service on the environment can be evaluated and re-examined such that it becomes useful within the context of the original goal and scope of the study (ISO, 2006). The objective of this study was then evaluated and several additional improvement scenarios as well. Scenario modelling allows for testing these two alternative scenarios to assess the potential impact of these alternations within the chocolate productions life cycle. These improvement scenarios were selected based on other life cycle assessment case studies indicating where they were identified as the areas with the highest levels of environmental impacts. Therefore, these proposed alternatives sought to see if altering these parameters improves or exacerbates the products life cycle environmental impacts. A sensitivity analysis was also incorporated to determine which results of the study were influenced by any uncertainties, if these improvement options will reduce the system's environmental impacts, if the variations in the methods used influenced the results, if decisions made by the researcher affected the results, and/or if the data employed during the thesis research affected the results (Guinee *et al.*, 2001; ISO 2006). This analysis allows justification measures to be made during the analysis and rationalizes the suggested recommendations and conclusions at the end of the study.

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. This makes the scenarios different from forecasts. Effective scenarios are distinct, logical and they are different enough from each other so that they are able to describe the central changing factors of the future and place questions on existing assumptions (Vartia, 1994). 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 x 100g) 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 the worst-case 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 ton was selected and the estimated distances were also obtained using Google maps as shown in Appendix C. 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 3.2 below.

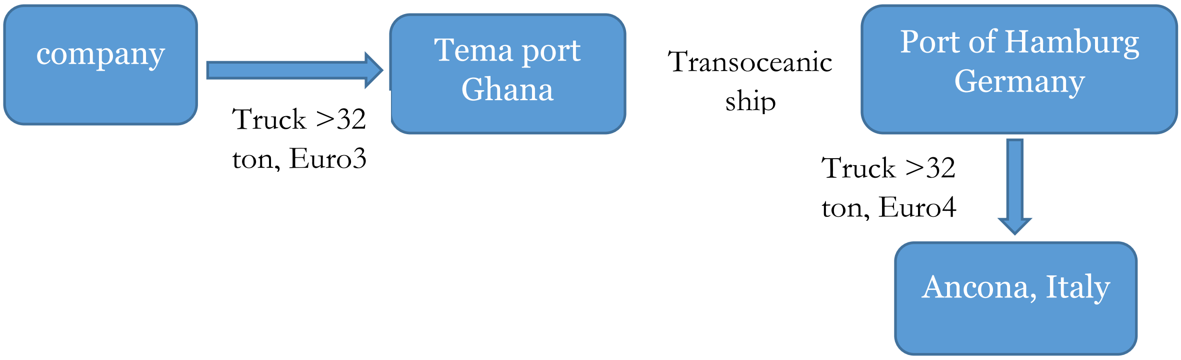

Figure 3.2. A scenario for 1 kg packaged chocolate bar produced in Ghana and transported to Ancona, Italy.

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 availability of primary data on diesel used for transport it was examined. The company has seven regular buses with the capacity of 15 persons per bus and runs a double shift system. Thus, the average distances were calculated, and the impact associated with the transportation of workers were examined using the CML 2 baseline method.

Sensitivity Analysis

Incorporating a sensitivity analysis within an LCA helps in the evaluation of the effect of changes in some parameters within the datasets can affect the modelled results for the system under study. While every attempt has been made to secure accurate datasets and generate appropriate process systems to model the Ghanaian chocolate life cycle processes, any simplifications, assumptions, or lack of pertinent datasets, do not and cannot possibly reflect all facets of the system under study. A sensitivity analysis helps address these degrees of uncertainty in assumptions and parameter values and indicates to what extent the results are influenced by these uncertainties. However, no sensitivity analysis was conducted within the cocoa processing and chocolate manufacturing phase of the LCA to determine the significance of key parameters and materials on the overall impacts.

4. RESULTS AND DISCUSSION

Impacts associated with 1 kg packaged chocolate based on Characterisation using CML 2001 baseline method

The characterisation results (overall impact scores) for 1 kg packaged chocolate produced in Ghana based on CML 2001 (Baseline) method are represented in Table 4.1. Using the Problem-Oriented Approach, the impact scores for 10 different midpoint impact categories were calculated in relation to their respective reference units. From the results obtained, the impact scores ranged between 7.36E-07 to 1.01E+03 with the least being Ozone layer depletion (ODP) and the highest Marine aquatic ecotoxicity. Due to the differences in characterisation factors and reference units, the scores for impact categories are mutually exclusive and therefore cannot be compared with each other even though they are generated from the same processes.

Table 4.1: The overall environmental impact score for 1 kg packaged chocolate produced in Ghana, in absolute values, based on the CML 2 baseline 2000 method.

Environmental Impact Category	Overall Impact Score	Unit
Abiotic depletion	1.14E-02	kg Sb eq
Acidification	1.56E-02	kg SO_2 eq
Eutrophication	7.29E-03	kg PO_4^{3-}eq
Global warming (GWP100)	2.51E+00	kg CO_2 eq
Ozone layer depletion (ODP)	7.36E-07	kg CFC-11 eq
Human toxicity	3.14E+00	kg 1,4-DB eq
Fresh water aquatic ecotoxicity	6.14E-01	kg 1,4-DB eq
Marine aquatic ecotoxicity	1.01E+03	kg 1,4-DB eq
Terrestrial ecotoxicity	3.97E-03	kg 1,4-DB eq
Photochemical oxidation	5.75E-04	kg C_2H_4 eq

To obtain a clearer overview and understanding of which phases (sub-system) contributed the most to the environmental impacts category, a contribution analysis was performed. The results are presented in Table 4.2 below. From the results obtained, chocolate manufacturing was the most impacting phase for all the impact categories except for Ozone layer depletion while transport of cocoa beans from the farm gate to the processing plant was the least contributing phase.

Table 4.2: Characterisation results for sub-stages (phases) contribution obtained by using the CML 2 (baseline) 2000 method.

Impact category	Unit	Packaging	Chocolate man.	Cocoa processing	Transport	Cocoa cultivation
Abiotic depletion	kg Sb eq	28.78%	27.75%	15.10%	2.07%	26.31%
Acidification	kg SO_2 eq	23.27%	56.06%	5.69%	1.01%	13.98%
Eutrophication	kg PO_4^{3-}eq	14.77%	44.01%	0.04%	0.52%	40.66%
GWP100	kg CO_2 eq	20.38%	52.60%	12.55%	1.26%	13.21%
Ozone layer dep.	kg CFC-11 eq	3.24%	36.69%	2.31%	0.30%	57.45%
Human toxicity	kg 1,4-DB eq	33.36%	42.82%	9.05%	0.36%	14.41%
FWAE	kg 1,4-DB eq	49.99%	24.85%	14.56%	0.62%	9.98%
MAE	kg 1,4-DB eq	52.95%	5.84%	28.52%	0.80%	11.89%
TE	kg 1,4-DB eq	46.04%	22.92%	6.72%	1.16%	23.17%
Photochemical ox.	kg C_2H_4 eq	34.94%	29.07%	11.89%	0.92%	23.18%

Abiotic depletion

Abiotic depletion is generally related to the consumption of non-biological resources such as fossil fuels, minerals, metals and water. 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. Abiotic depletion can lead to damage to natural resources and possible ecosystem collapse (Acero *et al.*, 2016). From this study, the abiotic depletion potential was estimated to be 1.14E-02 kg Sb eq. (antimony equivalents). However, Ntiamoah and Afrane (2008) and Recanati *et al.* (2018) reported significantly lower values of 1.62E-03 kg Sb eq. and 1.11E-05 kg Sb eq. for 1 kg unpackaged and packaged chocolate respectively as shown in Figure 4.1. The most impacting phase from Table 4.2 was packaging (28.78%), due to emissions associated with packaging materials used particularly aluminium foil. Konstantas *et al.* (2018) and Recanati *et al.* (2018) reported that 15g and 18g of aluminium foil was used as primary package respectively for 1 kg of chocolate. However, a comparatively lower amount of 9.2g of aluminium foil was used as a primary package for 1 kg of chocolate in this study. This was followed by the chocolate manufacturing phase (27.75%) due to emissions associated with the production and use of sugar (16%) and milk (12.9%). Cocoa cultivation also contributed 26.31% with the most impacting materials being pesticide (11%) and fertiliser (6.82%). Cocoa processing contributed the least (15.10%) to the total impacts with liquified petroleum gas (LPG) accounting for 11.8%. Abiotic depletion is a function of all non-renewable resources directly or indirectly related to the input materials in the inventory table. Other factors such as geographical location, type and age of technology being used could also influence the overall impact score.

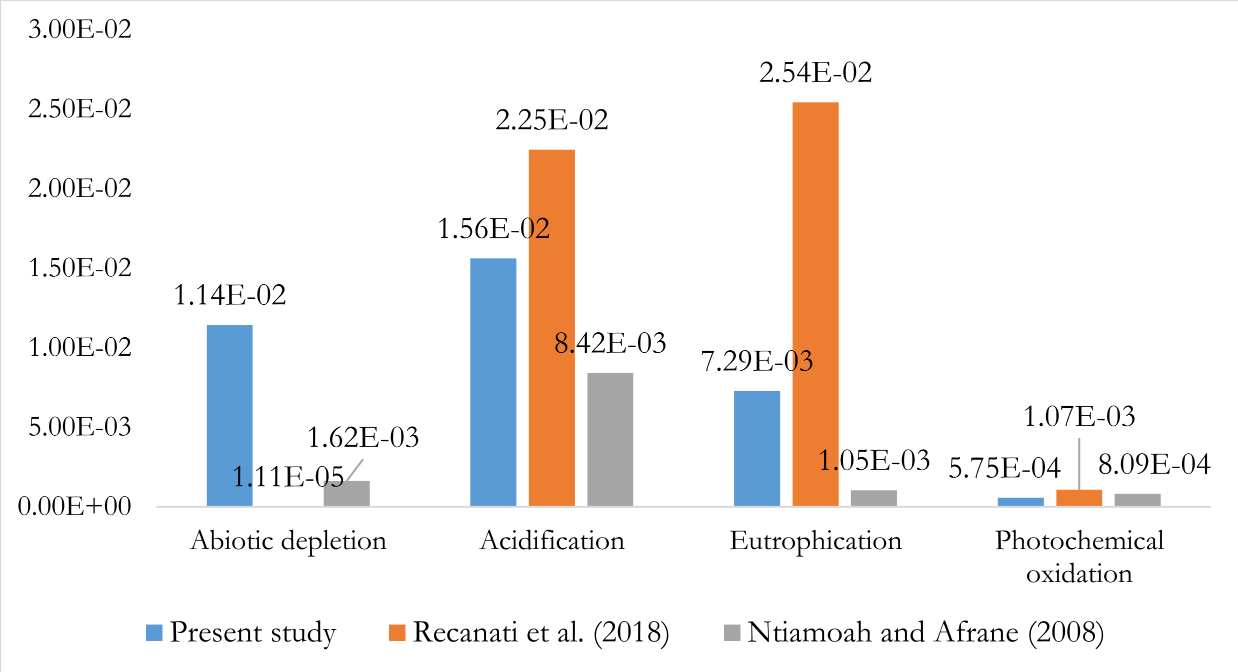

Figure 4.1: Comparison of the different impact assessment of similar chocolate LCA studies.

Acidification

Some anthropogenic activities that release emissions have the potential to reduce pH due to the acidifying effects. These emissions which are acidic gases such as sulphur and nitrogen compounds, when released interact with atmospheric water to form acid rain or deposition. This negatively impacts ecosystems by increasing acidity in water and soil systems, consequently decreasing biodiversity. Acid rain or deposition usually occur at a considerable distance from the original source of the gas. Gases that cause acid deposition include ammonia (NH_3), nitrogen oxides (NOx) and sulphur oxides (SOx) (Acero *et al.*, 2016). From this study, the acidification potential was estimated to be 1.56E-02 kg SO_2 eq. which was comparable to 2.25E-02 kg SO_2 eq. obtained by Recanati *et al.* (2018) for 1 kg processed chocolate. However, Ntiamoah and Afrane (2008) reported a significantly lower value of 8.42E-03 kg SO_2 eq. as shown in Figure 4.1. The CML 2 baseline 2000method only accounts for acidification caused by SO_2 and NOx when generating the impact score and it does not consider regional differences in terms of susceptible to acidification. The most impacting phases were chocolate manufacturing (56.06%) and packaging (23.27%) as shown in Table 4.2. The major materials that contributed to the acidification potential due to the emission of acidic gases associated with their production and use from this study were aluminium (17%) milk (46%) and sugar (10%) in the chocolate manufacturing phase, pesticides (9.54%) used in cocoa cultivation and LPG (3.51%) used for cocoa processing.

Eutrophication

Eutrophication refers to the accumulation of a concentration of chemical nutrients within an ecosystem that may result in abnormal productivity. This often leads to excessive plant growth biomass formation (algae) in rivers that can significantly lower water quality and shrink animal populations, potentially reducing the ecosystem quality. Eutrophication values are often influenced by the estimated amounts of ammonia, nitrates, nitrogen oxides and phosphorous emitted to both air and water (Acero *et al.*, 2016). The overall characterisation impact score from this study was 7.29E-03 kg PO_4^{3-} eq., which was comparable to 1.05E-03 kg PO_4^{3-} eq. reported by Ntiamoah and Afrane (2008), but significantly lower than 2.54E-02 kg PO_4^{3-} eq. discovered by Recanati *et al.* (2018) as shown in Figure 4.1. The low eutrophication potential impact score reported in this study was mainly due to the net positive credit from sugar production. A negative impact score of -4.47E-04 kg PO_4^{3-} eq. was obtained for sugar in the chocolate manufacturing phase 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. Therefore, the EP of molasses is significantly lower than that of spring barley and the difference accounts for the net positive impact on the environment. Furthermore, the study of Recanati *et al.*, (2018) was conducted on dark chocolate, which uses little amount of sugar in the manufacturing phase. The most impacting phase in this study was chocolate manufacturing, which contributed 44.01% out of which emissions associated with the production and use of milk powder accounted for 52.4%. Cocoa cultivation also contributed 40.66% to the overall impact score as presented in Table 4.2, mainly due to direct and indirect emissions associated with fertiliser production and use. Other relevant materials that significantly influenced the EP in this study were packaging materials which accounted for 14.77% of the total impact.

Global Warming

Global warming refers to the change in global temperature due to human activities that leads to the emissions of heat-trapping greenhouse gas in the Earth's atmosphere which is having noticeable effect on climate. Greenhouse gas absorbs and emits radiation within the thermal infrared range. Global warming could potentially lead to climatic disturbance, desertification, food insecurity, rising sea levels and spread of disease. Climate change is one of the major environmental effects of economic activity, thus it is widely investigated (Acero *et al.*, 2016).

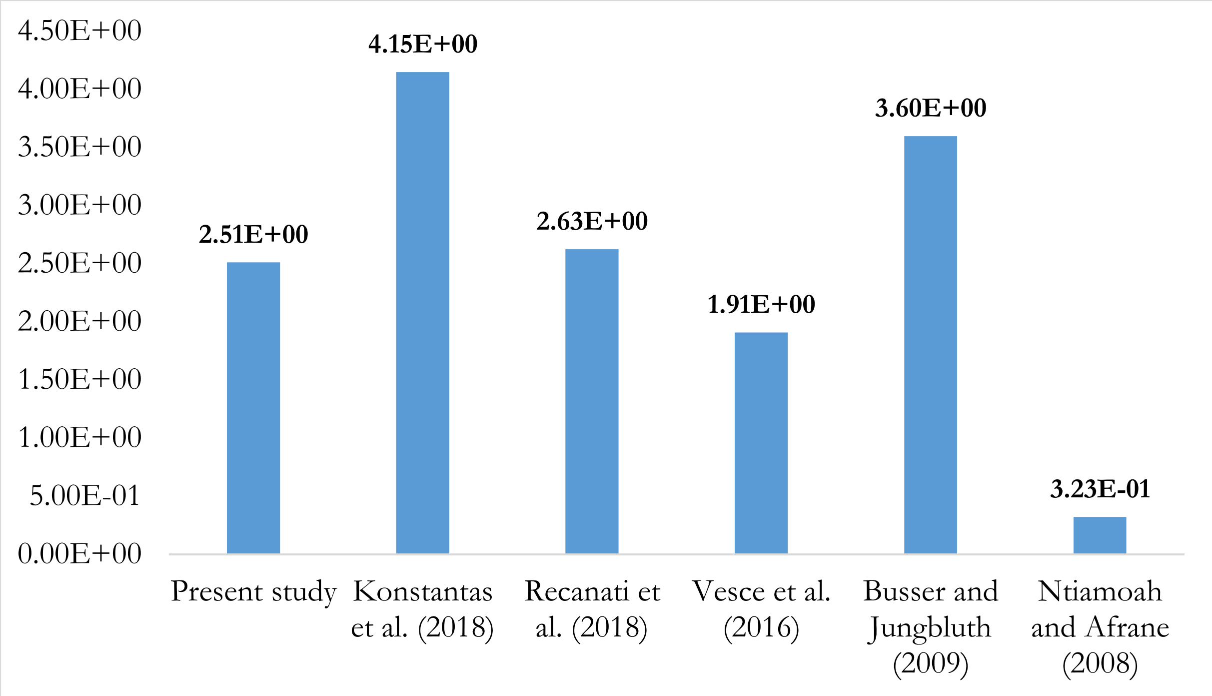

Figure 4.2: Comparison of impact scores of GWP (100yr) for similar 1 kg chocolate products.

From this study the Global Warming Potential estimated over a time horizon of 100 years (GWP 100yr) was 2.51E+00 kg CO_2 (carbon (IV) oxide) eq. which is comparable with other similar works as shown in Figure 4.2. However, Ntiamoah and Afrane (2008) and Vesce *et al.* (2016) did not include impacts associated with packaging. The most impacting phases were chocolate manufacturing (52.60%), packaging (20.38%) and cocoa cultivation (13.21%) as shown in Table 4.2. Emissions associated with milk powder and sugar production and use were the highest, accounting for 35.5% and 11.1% of the chocolate manufacturing phase. This is mainly due to the heat energy required in both processes and the methane gas emission associated with cattle farming. Production and use of packaging materials also contributed 20.38% to the GWP. Electricity from hydro-energy and LPG also contributed 7.64% and 8.6% respectively. Alkalization of cocoa beans contributed an impact of 2.66% to cocoa processing due to emissions associated with extraction and use of potassium bicarbonates. Pesticides and fertilizer contributed 5.77% and 2.46% to the overall GWP score for chocolate production in this study. Other factors such as geographical location, type and age of technology being used could also account for the differences in results.

Ozone layer depletion (Stratospheric Ozone depletion)

Ozone layer depletion refers to the shrinking of the stratospheric ozone layer due to anthropogenic emissions of ozone depleting substances (gases). However, the synergistic effect of different gases in the stratosphere remain uncertain, although chlorinated and brominated compounds that are stable enough to reach the stratosphere can have an effect. CFCs, halons and HCFCs are the major compounds responsible for ozone depletion. The ozone layer protects the earth's surface from ultraviolet (UV), thus reducing the amount of carcinogenic UV-B light reaching the earth's surface consequently improving human health and ecosystem quality. (Acero *et al.*, 2016). The overall impact score based on characterisation obtained for this study was 7.36E-07 kg CFC-11 eq. (chlorofluorocarbon-11). Recanati *et al.* (2018) and Vesce *et al.*, (2016), found similar scores of 5.67E-07 kg CFC-11 eq. and 2.34E-07 kg CFC-11 eq. respectively. However, Ntiamoah and Afrane (2008) found a score of 5.73E-09 kg R11(trichlorofluoromethane) equivalent. The lower score reported by the latter could be due to selection of a different classification and characterization set or method. The most impacting phases were cocoa cultivation (57.45%) and chocolate manufacturing (37%) as shown in Table 4.2. The score for this study was mainly influenced by the type and amount of pesticides used in the cocoa cultivation (39.5%). Sugar and milk contributed 28.5% and 16.7% respectively to the chocolate manufacturing phase.

Human toxicity

The Human Toxicity Potential indicates the potential amount of a chemical which 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 often released during electricity production from fossil sources (Konstansas *et al.*, 2018). These chemicals can potentially damage human health through inhalation, ingestion, and even contact and may also lead to cancer formation. The overall impact Human Toxicity Potential value obtained for this study was 3.14E+00 kg 1,4-DB (dichlorobenzene) equivalents. Ntiamoah and Afrane (2008) reported a similar value of 5.11E +00 kg 1,4-DB while Konstansas *et al.* (2018), reported 1.66 kg 1,4 DB eq. and 2.03 kg 1,4 DB eq. for chocolate countlines and chocolates in bag respectively. Chocolate manufacturing was the most impacting phase (42.82%), out of which emissions associated with the production and use of hydro-electric power accounted for 40.4%. Emissions associated with the amount and type of packaging material used also contributed 33.36% with Aluminium extraction and processing accounting for 29.82%. The cocoa processing and cocoa cultivation phases also contributed 9.05% and 14.41% to the overall impact as shown in Table 4.2, which was mainly due to emissions from LPG (5.6%) and pesticides (8.42%) respectively. However, in the study conducted by Konstansas *et al.* (2018), majority of the human toxicity potential was related to milk powder, sugar and flour.

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. Assessment of toxicity has been based on maximum tolerable concentrations in water for ecosystems. From this study the overall impact scores for Freshwater aquatic ecotoxicity (FWAE), Marine aquatic ecotoxicity (MAE) and Terrestrial ecotoxicity (TE were 6.14E-01 kg (1,4 -DB), 1.01E+03 kg (1,4 -DB) and 3.97E-03 kg (1,4 -DB) equivalents respectively. Ntiamoah and Afrane (2008), reported higher values of 5.85E+00 kg (1,4 -DB) eq. and 7.12E-03 kg (1,4 -DB) eq. for Fresh water aquatic ecotoxicity and Terrestrial ecotoxicity respectively. Vesce *et al.* (2016), reported 2.96E+02 kg TEG (Triethylene Glycol) and 4.72E+01 kg TEG equivalents for Aquatic ecotoxicity and Terrestrial ecotoxicity respectively. Konstansas *et al.*, (2018) also reported for 1 kg of moulded milk chocolate; 1.33E-01 kg 1,4– DB, 1.21E-01 kg 1,4– DB and 3.1E-02 kg 1,4– DB eq. for freshwater aquatic, marine aquatic and terrestrial ecotoxicity respectively. The scores for all three impacts categories were mostly influenced by emissions associated with the packaging materials as shown in Table 4.2. In relation to FWAE, electricity from hydro-source contributed 20.3% to the manufacturing phase and LPG contributed 10.3% to the processing phase while pesticide emissions also contributed 6.97% to the cocoa cultivation phase. For MAE, LPG contributed 22.8% to the cocoa processing phase while pesticide emissions contributed 8.89%. However for Terrestrial ecotoxicity, the most impacting materials were sugar (11%), milk (11%) and pesticides (8.89%).

Photochemical oxidation

Photochemical oxidation also known as ground level ozone is the type of smog created from the effect of sunlight, heat and volatile non-methane volatile organic compounds (NMVOC) and NOx. Although ozone is protective in the stratosphere, it can be toxic to humans in high concentrations on the ground-level. Photochemical ozone creation potential primarily depends on the concentration of carbon monoxide (CO), sulphur dioxide (SO_2), nitrogen oxide (NO), ammonium and NMVOC emitted into the air. Photochemical oxidation has the potential to cause damage to human health and ecosystem quality (Acero *et al.*, 2016). From Table 4.1, the impact score for photochemical oxidation was estimated to be 5.75E-04 kg C_2H_4 eq. (ethylene). Recanati *et al.* (2018), reported a higher value of 1.07E-03 kg C_2H_4 eq. while Ntiamoah and Afrane (2008) discovered a similar value of 8.09E-04 kg C_2H_4 eq. as shown in Figure 4.1. The most impacting phases were packaging (34.94%), chocolate manufacturing (29.07%) and cocoa cultivation (23.18%) as shown in Table 4.2. The Photochemical oxidation potential score obtained in this study was largely influenced by the direct and indirect emissions related to packaging materials (34.94%), sugar and milk (29%), LPG (7.89%) and fertilizers (15%).

Impact assessment based on characterisation for different packaged chocolate products

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 for marketing (Anukiruthika, 2020). In view of that, a comparison of the different impact categories associated with the different final packaged chocolate products was carried out using the CML 2001 (baseline) method in this study.

Table 4.3: Impact Assessment of the different chocolate product types.

Impact category	Unit	packaged chocolate strip (12.5g)	packaged chocolate bite pouches (12.5g)	packaged chocolate bar (100g)
Abiotic depletion	kg Sb eq	9.16E-03	9.42E-03	1.14E-02
Acidification	kg SO_2 eq	1.29E-02	1.32E-02	1.56E-02
Eutrophication	kg PO_4^{3-} eq	6.55E-03	6.63E-03	7.29E-03
GWP100	kg CO_2 eq	2.15E+00	2.19E+00	2.51E+00
Ozone layer dep.	kg CFC-11 eq	7.21E-07	7.22E-07	7.36E-07
Human toxicity	kg 1,4-DB eq	2.32E+00	2.41E+00	3.14E+00
FWAE	kg 1,4-DB eq	3.79E-01	4.05E-01	6.14E-01
MAE	kg 1,4-DB eq	6.05E+02	6.50E+02	1.01E+03
TE	kg 1,4-DB eq	2.70E-03	2.84E-03	3.97E-03
Photochem. Ox.	kg C_2H_4 eq	4.26E-04	4.43E-04	5.75E-04

From the results obtained; there were little differences in the impact scores for all the impact categories as shown in Table 4.3. The impact scores for 100g packaged chocolate bar were relatively the highest, followed by 12.5g packaged chocolate bite pouches and 12.5g packaged chocolate strips recording the least. The differences are mainly due to the amount of packaging materials used and the different primary package typologies. Chocolate bar is first wrapped around aluminium foil primary package, followed by paper as a secondary package. However, both chocolate strips and chocolate pouches are wrapped around a multi-layer primary package composed of aluminium and paper. Thus, based on the results from this study the multi-layer packaging was more environmentally sustainable as compared to the conventional packaging material. Chocolate is a typical confectionary product with a longer shelf-life, thus exposure to air and light can result in loss of taste and flavour and loss of surface gloss. To prevent these undesirable sensory attributes, aluminium foil (primary package) is mostly used as a barrier against light, moisture and other gases. Additionally, the mechanical properties of aluminium foil allow a re-wrapping of opened packages supporting the prevention of spoilage. Paper is used as a secondary package to augment the mechanical resistance and provide options for printing in chocolate packaging (Konstansas *et al.*, 2018). Carton boxes are used as tertiary packaging for distant transportation of chocolate.

Impact assessment based on characterisation for different transport destinations

Another scenario which was considered in this study was different transport destinations for 100g packaged chocolate product from the manufacturing plant. The total impact scores for the four destination points out of which three were local (Takoradi, Kumasi and Koforidua) and the other being international (Germany to Italy) were analysed using the CML 2001 (baseline) method. From the results obtained, there were no significant differences identified in the impact scores for all the impact categories for the local destinations as shown in Table 4.4. The same transportation mean, truck >32 metric ton, EURO3, was considered for the local destinations, with a loading capacity of 100%. Although, there were differences in the estimated distances for the local distributions; Takoradi (251 km), Kumasi (273 km) and Koforidua (100 km), the impacts scores showed little differences. This implies that the mid-point impact categories for local distribution in Ghana are more likely to be influenced by the transport mean and its characteristics than the estimated distances.

Table 4.4: Environmental impacts associated with the transportation of packaged 100g of chocolate bar to different destinations.

Impact category	Unit	Takoradi	Kumasi	Koforidua	Germany (Hamburg to Ancona)
Abiotic depletion	kg Sb eq	1.17E-02	1.17E-02	1.15E-02	1.35E-02
Acidification	kg SO2 eq	1.58E-02	1.58E-02	1.57E-02	1.85E-02
Eutrophication	kg PO4- eq	7.33E-03	7.33E-03	7.31E-03	7.67E-03
GWP100	kg CO2 eq	2.54E+00	2.55E+00	2.52E+00	2.79E+00
Ozone layer dep.	kg CFC-11 eq	7.38E-07	7.38E-07	7.37E-07	7.55E-07
Human toxicity	kg 1,4-DB eq	3.15E+00	3.15E+00	3.15E+00	3.28E+00
FWAE	kg 1,4-DB eq	6.17E-01	6.18E-01	6.15E-01	6.46E-01
MAE	kg 1,4-DB eq	1.02E+03	1.02E+03	1.02E+03	1.09E+03
Terrestrial ecotox.	kg 1,4-DB eq	4.02E-03	4.02E-03	3.99E-03	4.44E-03
Photochem. Ox.	kg C2H4 eq	5.80E-04	5.81E-04	5.77E-04	6.69E-04

The impact scores for the international destination were higher than those recorded for the local destinations as shown in Table 4.4 for all the impact categories assessed. This is because the hypothetical situation considered involved different transport means consisting of trucks and ships. A truck >32 metric ton, EURO3, was considered for the transportation of 1 kg of packaged 100g chocolate bars from the manufacturing plant to the Tema port and the distance was estimated to be 14 km. A transoceanic ship was then used to transport the product from Tema port in Ghana to Hamburg port in Germany over an estimated 4,811 nautical miles distance while finally a truck >32 metric ton, EURO4, was considered for the transportation of the product from Hamburg to Ancona (Italy) with the distance estimated to be 1,577 km. Transoceanic ships are generally considered to be highly efficient transport means though it was estimated to be responsible for about 2.1% of global greenhouse gas (GHG) emissions annually (Third IMO GHG study, 2014). Therefore, this accounts for the relative low impact scores associated with this transport scenario. In addition, the truck means, EURO4, used is more efficient with less emission as compared to other EURO 1-3.

Normalization results obtained by using the CML 2 Baseline 2000 method

According to ISO 14044 (ISO 2006), normalisation is an optional step of Life Cycle Impact Assessment (LCIA) that can be performed in an LCA. The normalisation factors represent the total impact of a reference region for a certain impact category (e.g. climate change, eutrophication, etc.) in a reference year. The factors are obtained by multiplying the characterisation factors by their respective emissions. The sum of these products in every impact category gives the normalization factor (Sala *et al.*, 2017). The normalisation factors were selected from World 1995 as specific data for Africa is currently unavailable. The estimated normalised impact scores are shown in Table 4.5. From the results obtained, Marine aquatic ecotoxicity recorded the highest impact score whiles Ozone layer depletion recorded the least. Normalisation has a relevant role to play in the Environmental Footprint to support the identification of the most relevant impact categories, life cycle stages, process and resource consumptions or emissions to ensure that the focus is put on those aspects that matter the most and for communication purposes.

Table 4.5: Normalized results based on CML 2 Baseline 2001 world normalization values.

Impact Category	Impact Score	Normalized Impact Scores
Abiotic depletion	1.14E-02	6.70E-12
Acidification	1.56E-02	2.33E-11
Eutrophication	7.29E-03	1.45E-11
Global warming (GWP100)	2.51E+00	9.95E-12
Ozone layer depletion (ODP)	7.36E-07	7.51E-13
Human toxicity	3.14E+00	1.67E-11
Fresh water aquatic ecotox.	6.14E-01	8.16E-11
Marine aquatic ecotoxicity	1.01E+03	3.18E-10
Terrestrial ecotoxicity	3.97E-03	4.33E-12
Photochemical oxidation	5.75E-04	3.16E-12

Impact Assessment results obtained by using the Eco-Indicator 1999 Method

Damage to human health is expressed in Disability Adjusted Life Years (DALY) which is based on weighing different disabilities caused by diseases. Damage to ecosystem quality quantifies the percentage of species that have disappeared in a certain area due to environmental load and is expressed as Potentially Disappeared Fraction of plant species (PDF) multiplied by the area size and the estimated time interval for the damage to occur. Damage to resources is expressed as the surplus energy requirement to compensate lower future ore grade (Goedkoop and Spriensma, 2001). The damage categories (and not the impact categories) are normalized on a European level of damage caused by 1 European per year. The hierarchist perspective was also chosen since it calculates impacts on long-term. The damage assessment results and impact categories scores for characterisation using the Eco-Indicator 99 method are presented in Table 4.6 and 4.7.

Table 4.6: Impact Scores for Damage Assessment using Eco-indicator 99 (Hierarchy Approach).

Damage category	Unit	Total
Resources	MJ surplus	2.34E+00
Ecosystem Quality	PDF*m2yr	8.02E-01
Human Health	DALY	2.58E-06

From the results obtained, the most impacting damage category was resources, which was mainly influenced by the impact score for fossil fuel and minerals as shown in Table 4.6. Diesel is a fossil fuel and therefore due to the high amount of diesel used, a high amount of emissions is also released due to its extraction, processing and use. Ecosystem quality is influenced by land use, ecotoxicity and acidification and eutrophication as shown in Table 4.7. Human health recorded the least impact score since the midpoint impact scores associated with climate change, carcinogens, ozone layer, radiation, resp. organics and inorganics were also low. This Eco-Indicator 99 method is the comparison of products or components, the value itself is not most relevant but rather a comparison of values. The midpoint categories scores using the Eco-Indicator 99 method are comparable to the total impact score for characterisation using the CML 2001 baseline method.

Table 4.7: The overall environmental impact score for 1 kg packaged chocolate produced in Ghana based on Characterisation using the Eco-Indicator 99 method.

Impact category	Unit	Total
Fossil fuels	MJ surplus	2.26E+00
Land use	PDF*m2yr	8.46E-02
Ecotoxicity	PAF*m2yr	6.74E-01
Acidification/ Eutrophication	PDF*m2yr	9.51E-02
Minerals	MJ surplus	3.30E-01
Resp. inorganics	DALY	7.77E-10
Climate change	DALY	2.30E-09
Carcinogens	DALY	5.28E-07
Resp. organics	DALY	1.69E-06
Radiation	DALY	2.16E-09
Ozone layer	DALY	3.58E-07

Scenario: Impact of workers transportation on chocolate production.

A high amount of diesel was consumed in the year (570,680 litres) by the cocoa processing company, mainly for the transportation of workers by company buses. A transport mean, which was a regular bus fuelled by diesel that carries an average of 15 people in line with the real-life scenario was considered. The number of persons by kilometre covered by bus (personkm) was calculated based on the total distances covered by the seven buses in Appendix C. Each bus covers the same distance 8 times in a day due to the double shift system run by the company. The total impacts associated with the transportation of workers per 1 kg of packaged chocolate produced in Ghana was assessed using the CML 2 baseline 2000 method and the results are shown in Table 4.8.

Table 4.8: Impact of workers transportation on the overall environmental impact scores for 1 kg packaged chocolate produced with in Ghana based on the CML 2 baseline 2000 method.

Impact category	Unit	Chocolate with diesel	Chocolate without diesel	Impacts for only diesel
Abiotic depletion	kg Sb eq	1.73E-01	1.14E-02	1.62E-01
Acidification	kg SO_2 eq	1.52E-01	1.56E-02	1.36E-01
Eutrophication	kg PO_4^{3-} eq	3.96E-02	7.29E-03	3.23E-02
GWP100	kg CO_2 eq	2.53E+01	2.51E+00	2.28E+01
Ozone layer dep.	kg CFC-11 eq	2.57E-06	7.36E-07	1.84E-06
Human toxicity	kg 1,4-DB eq	8.58E+00	3.14E+00	5.44E+00
FWAE	kg 1,4-DB eq	2.09E+00	6.14E-01	1.48E+00
MAE	kg 1,4-DB eq	5.24E+03	1.01E+03	4.23E+03
TE	kg 1,4-DB eq	2.88E-02	3.97E-03	2.49E-02
Photochem. Ox.	kg C_2H_4 eq	5.46E-03	5.75E-04	4.89E-03

From the results obtained, there was a very high increase in all impact categories after the transportation of workers was taken into consideration. Most LCA studies often do not take some important but indirect impacts such as transportation of workers into consideration during LCA studies. However, due to the very high environmental impacts associated with daily transportation of workers, it would be prudent for LCA studies to seriously consider it and suggest appropriate mitigation strategies to reduce associated impacts. Therefore, to reduce impacts associated with the transportation of workers, the company 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 must 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. A better work management could also be suggested to improve worker efficiency.

Improvement Options for Sustainability

Several hotspots for different impact categories were identified after analysis. Therefore, to improve the environmental performance of packaged chocolate produced in Ghana, mitigation strategies can be applied to reduce emissions associated with this food system. From the results, the most important impact categories that need to be addressed are marine aquatic ecotoxicity, human toxicity, freshwater aquatic ecotoxicity and global warming. Chocolate manufacturing and cocoa cultivation were identified as the most impacting phases. Therefore, the implementation of improvement options to reduce the impacts associated with these phases will result in a more environmentally sustainable chocolate product.

Improvement Options for Cocoa Cultivation Phase

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 its related impacts. Another option that could be considered is inter-cropping cocoa trees with other agroforestry crops like coconut. According to Utomo *et al.* (2016), cocoa-coconut agroforestry recorded 3.67E-01 kg CO_2-eq and 4.31E-02 kg SO_2-eq for global warming and acidification, while cocoa monoculture recorded significantly higher values of 7.06E+01 kg CO_2-eq and 8.11E-02 kg SO_2-eq respectively. The use of low input systems which rely on integrated pest management, that involves the use of biological agents for pest and diseases control, adequate soil fertility management, including high yielding and more resilient cocoa varieties developed by the CRIG are recommended to enhance the environmental performance of cocoa cultivation in Ghana. Finally, the use of more advanced farming systems could be employed to increase cocoa yield which may consequently improve its sustainability. Production of dried cocoa using a technified management system yielded 1,400 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_2-eq. (Perez Neira, 2016).

Improvement Options for Cocoa Processing and Chocolate Manufacturing Phase

According to the results, the production of milk powder, sugar and cocoa semi-processed products in the cocoa processing and chocolate manufacturing phases are the main contributors to the impacts and should therefore be targeted for improvements. Since most of the milk powder impacts are associated with the raw milk production at farms, possible improvement options related to the raw milk production that can be considered include manure composting to yield a positive effect on the environment and the modification of the diet of cattle to reduce methane emissions from enteric fermentation. Roibas *et al. (*2016) considered the effect on the emissions of the addition of linseeds to the feed and found that the GWP of milk was reduced by 10%.

Increasing the efficiency of energy use in the sugar production, milk powder production, cocoa processing and manufacturing process through implementation of integrated energy management systems or more advanced and innovative production technologies could significantly reduce emissions from LPG, hydro-electricity and other fuels (Konstantas *et al.*, 2018). The main by-product of cocoa processing, which is the cocoa shell, is also used as a supplementary energy source to heat the boiler and is not considered as a solid waste in this system.

Improvement Options for Packaging Phase

Packaging was 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. 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 addition, processes associated with the extraction and manufacturing of aluminium foil should also be more efficient to reduce aluminium ingot supply as well as electricity and heat consumption.

5. CONCLUSION

The tentative goal of this LCA study was to assess the environmental impacts of the production and distribution of chocolate produced in Ghana, in order to suggest mitigation strategies to improve the environmental performance. The most relevant impact categories identified for 1 kg packaged chocolate produced in Ghana were global warming, human toxicity, acidification, abiotic depletion and eutrophication with impact scores of 2.51E+00 kg CO_2 eq., 3.14E+00 kg 1,4-DB eq., 1.56E-02 kg SO_2 eq., 1.14E-02 kg Sb eq. and 7.29E-03 kg PO_4^{3-} eq. respectively. Impacts associated with three chocolate types revealed that, the impact scores for 100g packaged chocolate bar were relatively the highest, followed by 12.5g packaged chocolate bite pouches and 12.5g packaged chocolate strips being the least. A scenario comparing different destination points for the manufactured chocolate All the impact scores for the international destination were higher than those recorded for the local destinations. A scenario involving the transport of workers by buses was also considered due to the high amount of diesel used. Significantly high scores of 2.53E+01 kg CO_2 eq., 1.52E-01 kg SO_2 eq., 3.96E-02 kg PO_4^{3-} eq. and 1.73E-01 kg Sb eq. were obtained for GWP, AP, EP and ADP respectively. The most impacting phases along the chocolate supplied chain identified in this study were cocoa cultivation, mainly due to the emissions associated with the production and use of fertilisers and pesticides, chocolate manufacturing which was largely influenced by emissions associated with the production and use of milk powder and sugar, and packaging mainly due to aluminium. Therefore, practicing integrated farming to increase yield and reduce impacts associated with cocoa cultivation targeting the production of these raw materials such as milk powder and sugar through composting the dairy manure, using alternative feed sources and more efficient heating systems would significantly improve the environmental performance of chocolate. The use of recycled aluminium and a general reduction in the weight of the packaging materials are also highly recommended. This would be considered as 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. The quantification of the environmental impacts of chocolate through LCA and the identification of the main hotspots along the supply chain in this study could effectively support chocolate companies, cocoa farmers, policy makers, chocolate producers and consumers in their pathway towards environmentally sustainable production and consumption of chocolate products.

Limitations and Recommendations from the study

LCA studies are more robust if primary data is used as compared to secondary data. Unfortunately, due to the COVID-19 situation, primary data for the cultivation phase could not be obtained from the farmers and other relevant organizations like CRIG. As a result, secondary data from academic peer reviewed publications and other forms of literature was used in this study. Therefore, there is the need to obtain foreground data to yield more accurate and reliable results for a better environmental assessment of cocoa cultivation in Ghana.

In developing countries, baseline data describing many background systems are unavailable due to limited studies conducted. Therefore, the unavailable data is supplemented with data provided by commercial LCA software, which could reduce the confidence level of the LCA results. Due to lack of specific regional data pertaining to electricity generation, fuels and agrochemicals production, milk powder and sugar data were taken from European databases for this study. A significant number of impact categories were also covered. However, due to unavailability of data pertaining to some materials such as active ingredients in pesticides and insecticides (metalaxyl, Imidacloprid and Bifenthrin), a more accurate impact assessment could not be obtained. LCA is an important tool that has the potential to drive sustainable development in Africa especially in agriculture, thus there is the need to further develop the tool and promote its application.

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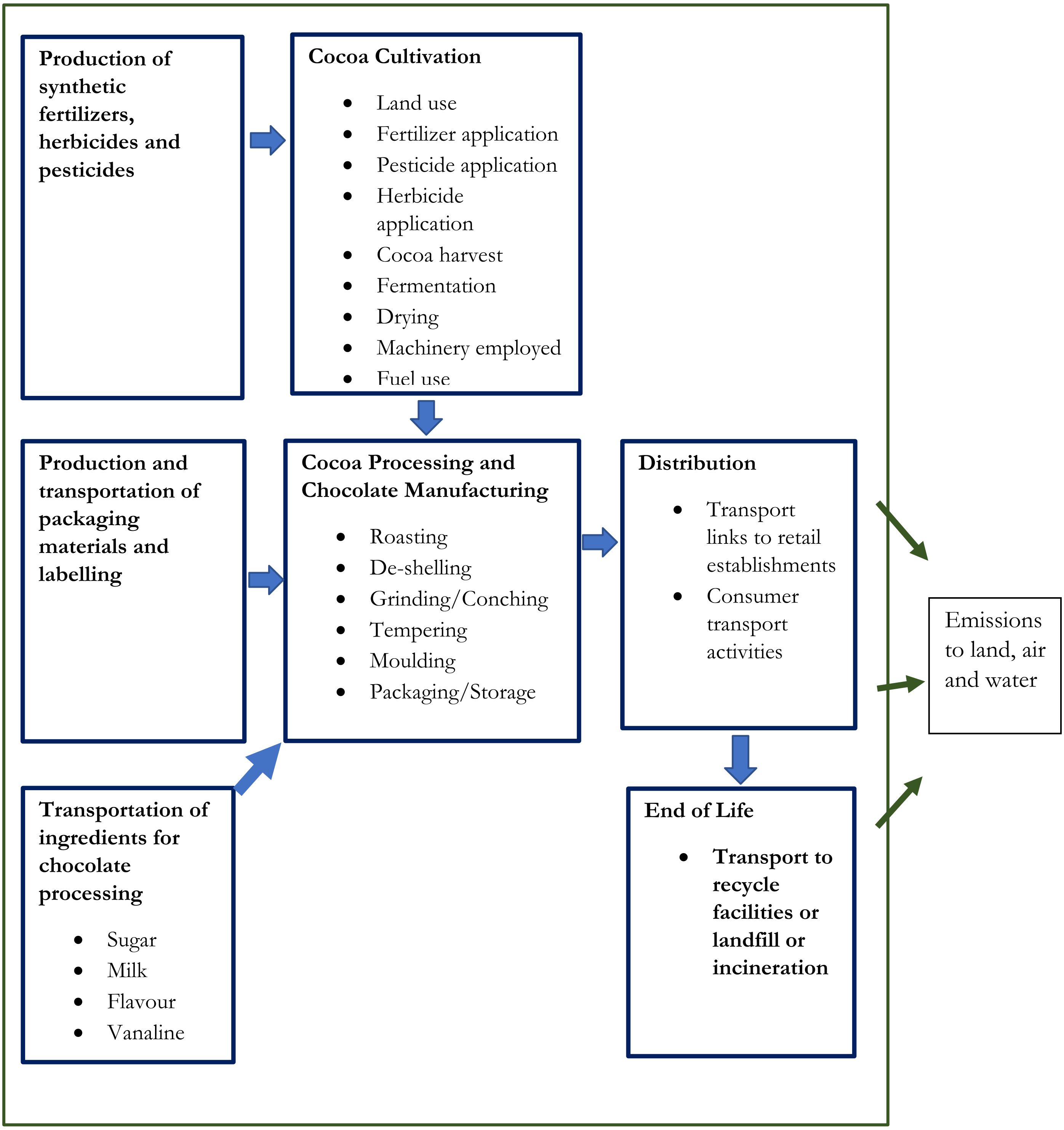
APPENDIX

Appendix A: The LCA stages of Ghanaian produced chocolate. This system flow diagram includes all the major life cycle phases and sub-system phases associated with the cocoa/chocolate industry.



Appendix B: Life Cycle Inventory Table for 1 Kg packaged chocolate produced in Ghana.

Phase/Element	Unit	Quantity
1. Cocoa cultivation		
Inputs		
Average cocoa age	yr	30
Land use	ha	
Planting seeds	kg/ha/yr	1.5
Water	L/ha/yr	4000
Petrol (for spraying)	kg/ha/yr	8.112915851
Fertilizers		
Major Nutrients		
N		
P	kg/ha/yr	44.00195695
K	kg/ha/yr	35.98825832
Minor Nutrients		
S	kg/ha/yr	14.00195695
MgO	kg/ha/yr	11.99608611
CaO	kg/ha/yr	17.99412916
Insecticides		
Confidor 200SL (Imidacloprid)	kg/ha/yr	0.599119374
Akate Master (Bifenthrin)	kg/ha/yr	0.599119374
Carbamult (Promecarb)	kg/ha/yr	5.6
Pesticides		
Champion (77% Cuprous hydroxide)	kg/ha/yr	1.8
Ridomil 72 (12% metalaxyl. 60% Cu2O)	kg/ha/yr	0.9
Kocide 101 (Cuprous hydroxide)	kg/ha/yr	1.8
Nordox 75 (86% Cu2O, 14% inert)	kg/ha/yr	1.8
Output		
Dry cocoa beans	kg/ha/yr	850
Cocoa pulp (beans sweating)	kg/ha/yr	276.4187867
Cocoa pod husk	kg/ha/yr	6742.172211
2. Transportation to cocoa beans to factory		
Transport mean	type	35 ton truck
Fuel consumption	type	Diesel
Average distance	km	250.00
Loading factor	%	85.00
Return journey		Empty
Fuel consumption	L	61.72
Cocoa beans transported	kg/yr	46757710.00
3. **Cocoa bean processing**		
Inputs		
Cocoa beans	kg/yr	46757710.00
Electricity	kWh	7882353
Shell used to fuel boiler	kg/yr	6570000.00
LPG	kg/yr	3020874.00
Machinery	Age	(70%, 25% and 5% purchased in 2011, 2012 and 2017 resp.)

Building (Land Use)	Acres	6.42
Dutching-Alkaline	L/kg/yr	1335934.57
Chemicals (cleaning agents)	L/yr	3179.74
Oil and grease	kg/year	350.00
Water	kg (1000kg=1M3)	22844000.00
Output		
Cocoa shell (used as an input for boiler)	kg	4675771.00
Cocoa liquor	kg	17239840.00
Cocoa butter	kg	10306000.00
Cocoa powder	kg	54010.00
Cocoa cake	kg	11423000.00
4. Chocolate Manufacturing		
Cocoa liquor	kg/yr	34357.20
Cocoa butter	kg/yr	25640.40
Cocoa powder	kg/yr	8184.00
Vanillin	kg/yr	50.40
Sugar	kg/yr	39285.60
Milk Powder	kg/yr	12000.00
Flavour	kg/yr	86.40
Electricity	kWh	3284271
Diesel for transport of workers	L/yr	570680
Output		
Chocolate	kg/yr	118200.00
5. Packaging		
Inputs		
Aluminium foil (Primary)	kg/yr	834.82
Paper wrapper (Secondary)	kg/yr	2758.80
Carton box (Tertiary)	kg/yr	3015.12
Aluminium + Paper sealed (Primary)	kg/yr	1063.46
100g chocolate bars (43% of chocolate produced)		
Primary package (aluminium foil)	kg/yr	834.82
Secondary package (paper wrapper)	kg/yr	2758.80
Tertiary Package (Carton box)	kg/yr	3015.12
12.5g chocolate bite strips (23% of chocolate produced)		
Primary/Secondary package (aluminium foil and paper wrapper sealed as one)	kg/yr	323.46
Tertiary Package (Carton box)	kg/yr	1603.91
12.5g chocolate bite pouches (34% of chocolate produced)		
Primary/Secondary package (aluminium foil and paper wrapper sealed as one)	kg/yr	740.00
Tertiary Package (Carton box)	kg/yr	2372.13
6. Transportation to supermarkets		

Transport mean	type	35 ton truck
Fuel consumption	type	Diesel
Loading factor	%	100.00
Return journey		Empty
Estimated distances of major towns		
Tema to Accra	km	28
Tema to Kumasi	km	273
Tema to Koforidua	km	100
Tema to Takoradi	km	251
7. **Waste Management**		
Aluminium foil (Primary)	kg/yr	834.82
Paper wrapper (Secondary)	kg/yr	2758.80
Carton box (Tertiary)	kg/yr	3015.12
Aluminium + Paper sealed (Primary)	kg/yr	1063.46

Appendix C: Data estimations for transportation of workers

Destination	**km**	**Number of buses**
Prampram	21	1
Kpone	9.9	1
Tema	7.7	1
Adjei Kojo	9.4	1
sAshaiman	18.6	2
Afienya	16	1
total	**82.6**	**7**
km covered/ day	660.8	
Number of persons	105	
Number of working days	360	
personkm	**24978240**	