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Environmental impacts of cocoa production and processing in Ghana: life cycle assessment approach

Augustine Ntiamoah [a], George Afrane [b,*]

[a] Chemical Engineering Department, Kwame Nkrumah University of Science & Technology, Kumasi, Ghana
[b] Koforidua Polytechnic, Koforidua, Ghana

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Abstract

Ghana is the world's second largest producer of cocoa beans. In addition to exporting raw cocoa beans, the country also processes some of its beans into finished and semi-finished cocoa products for both the local and international markets. This paper is aimed at providing a comprehensive picture of the environmental impacts associated with cocoa production and processing in Ghana by applying the life cycle assessment (LCA) methodology. The analysis considered the entire system required to produce and process 1 kg of cocoa bean. It included the extraction of raw materials (e.g. fossil fuels, minerals), the production of farming inputs (e.g. fertilizers and pesticides) and all agricultural operations in the field (e.g. tillage, fertilizer and pesticides application, harvest, etc.). Transportation of beans to processing factory and industrial processing of the beans into cocoa butter, liquor, cake and powder were also included. The study was conducted in accordance with the international ISO procedural framework for performing LCA in the ISO 14040–14043 series.

The overall environmental impacts resulting from cocoa production and processing activities and improvement options towards the sustainability of the system studied are presented and discussed.

Keywords: Ghanaian cocoa industry; Environmental impacts; Life cycle assessment; Sustainability

1. Introduction

Cocoa, which is used mainly in the production of chocolate, is an important agricultural export commodity. Currently Ghana, producing about 700,000 tons of cocoa beans annually, is ranked second in the world, after her western neighbour Côte d'Ivoire. In terms of quality however, Ghana is recognized as the world leader in premium quality cocoa beans production. Cocoa serves as the major source of revenue for the provision of socio-economic infrastructure in the country. In terms of employment, the industry employs about 60% of the national agricultural labour force in the country [1]. For these farmers, cocoa contributes about 70–100% of their annual household incomes [2].

Improving the livelihood of farmers is a crucial aspect of government's plans for reducing poverty in Ghana. It has therefore been the intention of government, which is committed to reaping the maximum benefit from the cocoa sector, to ensure that the country increases its cocoa production and also processes more of the beans into downstream products for both the local and export markets [3]. In pursuance of this goal, the government in year 2001 initiated a nationwide Cocoa Disease and Pest Control Project (CODAPEC), to help address the two major causes of decline in cocoa production: pests and diseases. Under this programme, cocoa farms across the country were sprayed with insecticides and fungicides at no cost to the farmers. This exercise has resulted in tremendous increases in cocoa production from 340,562 metric tons in the 2001/02 season to 496,846 metric tons in 2002/03 and 736,000 metric tons in the 2003/04 seasons, respectively [1,4].

The percentage of locally processed beans has also jumped from 20% to 35% with further re-capitalization and expansion

* Corresponding author.
E-mail addresses: ntigh@yahoo.com (A. Ntiamoah), gafrane@yahoo.com (G. Afrane).

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programs underway to reach a target of 50% in the near future. The beans are normally processed into four semi-finished products, namely, cocoa liquor, cocoa butter, cocoa powder and cake; and a finished product, chocolate.

However, along with the positive effects of the CODAPEC programme, some negative impacts on the environment have also been caused. For instance the use of pesticides on the farms can lead to the destruction of part of the soil flora and fauna through both physical and chemical deterioration [5].

This study was aimed at providing a comprehensive picture of the environmental impacts associated with the current cocoa production and processing techniques in Ghana, using the life cycle assessment (LCA) tool. LCA determines the potential environmental impacts, throughout a product's life cycle, from raw material acquisition through production, use, end-of-life treatment, recycling and to final disposal (i.e. cradle-to-grave) [6].

2. Method

The study was conducted in accordance with the ISO procedural framework for performing LCAs in the ISO 14040–14043 series [6–9]. According to the ISO standards, LCA study has four main phases, namely, goal and scope definition, life cycle inventory analysis, life cycle impact assessment, and interpretation of results.

2.1. Goal and scope of the study

The goal and scope definition phase states why an LCA is being conducted and describes the system to be studied. The objectives of this particular study were 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 (i.e. those with the largest environmental impacts) and then to suggest a number of improvement options or impact reduction strategies towards the sustainability of the system studied. The results of the study could be used by the Ghana Cocoa Board (COCOBOD) – the main government agency in charge of the cocoa industry – and other stakeholders like cocoa scientists, farmers and processors, in decision-making to improve the environmental performance of the industry.

The system studied was sub-divided into three main stages as follows: cocoa production (comprising pesticides and fertilizer production, cocoa cultivation, on-farm processing and temporary storage of cocoa beans); transportation (involving transport of beans to processing factory); and industrial processing of cocoa beans (comprising beans-cleaning, roasting, breaking and winnowing, and grinding into cocoa liquor, cocoa butter, cake and cocoa powder). Life cycle tracing of all packaging materials was excluded from the study due to lack of relevant data.

2.1.1. Functional unit

LCA is a relative approach which is structured around a functional unit. This functional unit defines what is being studied [6]. For this study, the functional unit chosen was 1 kg of cocoa beans processed. All the inputs and outputs in the life cycle inventory (LCI) and impact scores produced in the life cycle impact assessment (LCIA) phase of this LCA study were expressed with reference to this functional unit.

2.2. Life cycle inventory (LCI) analysis

The life cycle inventory (LCI) analysis segment is the second phase of LCA. It is an inventory of input/output data with regard to the system being studied. The inventory analysis consists of two major steps: data collection and data analysis.

2.2.1. Data collection

Data for cocoa production were collected from government records on cocoa production in Ghana, and also by paying site visits to farms and institutions and interviewing cocoa farmers and researchers at the Cocoa Research Institute of Ghana (CRIG). Background data on production of fertilizers and pesticides, transportation and electricity generation were included using the Swiss eco-invent database and the GaBi 4 LCA database. Emissions due to fertilizer and pesticide usage were quantified using estimation methods [10,11]. Inventory data for transportation was calculated based on average distance of 250 km traveled by diesel engine trucks in Ghana. The truck used for the analysis was assumed to be 22 tons total capacity/14.5 tons payload/long distance truck. A state-owned cocoa processing company, considered state of the art, was selected for detailed study and data gathering on cocoa processing. A summary of the inventory data collected is presented in Table 1.

2.2.2. Data analysis

The data collected were converted to values that relate to the functional unit. The adjusted data were entered into the GaBi 4 LCA software and modeled into environmental inputs and outputs and then aggregated to result in an inventory table.

2.3. Life cycle impact assessment

This step calculates the likely human and ecological effects of material consumption and environmental releases identified during the inventory analysis. Classification and characterization following the ISO 14042 [8] guidelines were applied to the inventory data in order to assess their potential impacts on the environment. According to these guidelines, four optional elements, namely, normalization, valuation, grouping and data quality analysis may be included in the impact assessment. However, in this study the mandatory elements (classification and characterization) were believed to be sufficient to achieve the stated goals of the study and therefore only these were considered. In the classification step, the inventory data were grouped into the environmental impacts of global warming, atmospheric acidification, eutrophication, photochemical ozone creation, freshwater aquatic eco-toxicity, terrestrial eco-toxicity, human toxicity, and ozone layer depletion potentials and depletion of abiotic resources. In the characterization step the inventory data that have been classified under each environmental

Table 1
Summary of inputs and outputs data for the production and processing of 1 kg cocoa bean in Ghana, for the reference year 2004/2005

Inputs/outputs	Amount	Unit
Energy inputs		
Electricity (from national grid)	3.1716E−01	MJ
Diesel	5.3142E−02	kg
Petrol	8.9967E−03	kg
Materials inputs		
Water	5.1274E+00	kg
Fertilizer (N:P:K 0:22:18 + 9CaO + 7S + 6MgO)	1.4590E−01	kg
Pesticides		
-Fungicides	7.4200E−03	kg
-Insecticides	8.0000E−04	kg
Land use	3.9218E−05	ha
Products/by-products		
Cocoa liquor	3.1948E−01	kg
Cocoa butter	2.3125E−01	kg
Cocoa cake	2.6875E−01	kg
Cocoa powder	7.5000E−02	kg
Cocoa shells	9.8000E−02	kg
Air emissions		
Dust (PM2,5 − PM10) [particles to air]	2.5000E−03	kg
Sulphur dioxide [inorganic emissions to air]	8.0000E−03	kg
Heavy metals to air	3.5745E−05	kg
Carbon dioxide [inorganic emissions to air]	2.3790E−01	kg
Carbon monoxide [inorganic emissions to air]	8.4100E−03	kg
Pesticides to air	8.1308E−04	kg
Water emissions		
Biological oxygen demand (BOD)	5.0437E−12	kg
Chemical oxygen demand (COD)	9.8212E−12	kg
Nitrates	3.7500E−15	kg
Oil and grease	1.0000E−14	kg
Phosphates	4.4204E−14	kg
Total dissolved solids	5.1525E−12	kg
Total suspended solids	4.1287E−12	kg
Heavy metals to freshwater	7.4761E−04	kg
Pesticides to freshwater	3.6880E−03	kg
Soil emissions		
Pesticides to soil	9.4477E−04	kg
Heavy metals to agricultural soil	4.1870E−05	kg

impact category were quantified in terms of a common unit for that category. This was done by multiplying the mass value of the relevant emission by its corresponding characterization (or equivalency) factor (provided with the GaBi 4 LCA software) to give an indicator result for that inventory item. All indicator results under each impact category were summed to result in an overall impact score (or characterization results) for the impact category. The impact assessment was done by using the CML 2001 method developed by the Centre for Environmental Science, University of Leiden.

3. Results and discussion

The characterization results for the production and processing of 1 kg cocoa in Ghana, based on the CML 2001 method, is presented in Table 2 and illustrated graphically in Fig. 1. As shown in Fig. 1, freshwater aquatic eco-toxicity, human toxicity and global warming potentials are the most significant environmental impacts associated with the system studied. Fig. 2 illustrates the relative contributions of each life cycle stage studied to the overall environmental impacts.

Table 2
Characterization results in absolute values for the production and processing of 1 kg cocoa in Ghana, based on the CML 2001 method

Environmental impact category	Total impact score	Unit
Abiotic Depletion Potential (ADP)	1.6184E−03	kg Sb-equiv.
Acidification Potential (AP)	8.4237E−03	kg SO_2-equiv.
Eutrophication Potential (EP)	1.0476E−03	kg PO_4^{3-}-equiv.
Freshwater Aquatic Eco-toxicity Potential (FAETP)	5.8496E+00	kg DCB-equiv.
Global Warming Potential (GWP 100 years)	3.2286E−01	kg CO_2-equiv.
Human Toxicity Potential (HTP)	5.1144E+00	kg DCB-equiv.
Ozone Layer Depletion Potential (ODP)	5.7284E−09	kg R11-equiv.
Photochemical Ozone Creation Potential (POCP)	8.0877E−04	kg C_2H_4-equiv.
Terrestric Eco-toxicity Potential (TETP)	7.1222E−03	kg DCB-equiv.

DCB: 1,4-dichlorobenzene, R11: trichlorofluoromethane.

3.1. Cocoa production stage

Fig. 2 shows that, cocoa production makes the largest contribution to the environmental impacts of eutrophication, ozone layer depletion, freshwater aquatic eco-toxicity, human toxicity, and terrestrial eco-toxicity, with average contributions greater than 96%. The analysis revealed that production and use of fertilizers and pesticides were a major cause of the environmental burdens in the cocoa production stage. Ozone layer depletion is caused by the emission of halogens and CFCs during the production of pesticides. Eutrophication is mainly caused by leakage of nutrients during cultivation and emission of phosphates from the production of phosphorus fertilizers. For all the three toxicity categories the main contributors are heavy metals content in phosphorus fertilizers and leakage of pesticides. Agricultural machinery and implements are not used in cocoa production in Ghana because of the small farm holdings, and production largely depends on rainfall. Drying of the beans is by ‘‘sun drying’’. Therefore improvement measures should focus on reducing fertilizers and pesticides usage.

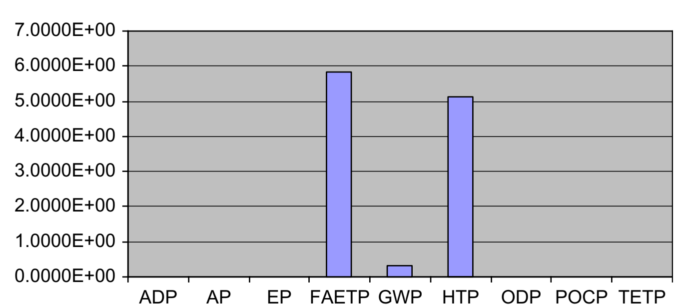

Fig. 1. Characterized results for the production and processing of 1 kg cocoa in Ghana.

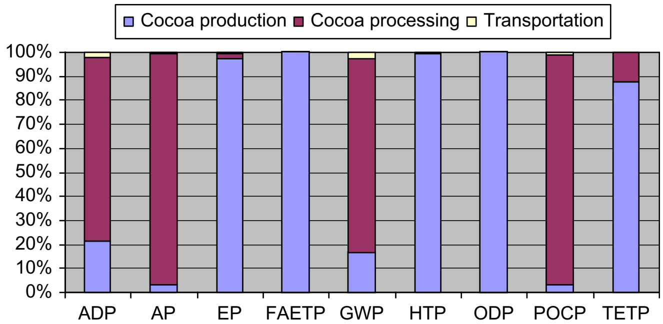

Fig. 2. Contributions by different stages of production to overall impact scores.

In addition to these impacts derived quantitatively by the LCA tool, there are other known important impacts that result from cocoa production. The cocoa production stage generates a large amount of solid waste in the form of pod husks. The pod husk constitutes about 67% of the fresh pod weight [12]. At present, pod husks are largely a waste product of the Ghanaian cocoa industry, and present a serious disposal problem. The direct impacts of these could not be assessed by the LCA tool. However, according to Figueira et al. [13] they became a significant source of disease when used as mulch inside the plantation. Cocoa seeds are surrounded by an aromatic pulp which arises from the seed teguments (technically an aril). During on-farm processing of cocoa beans, the pulp is removed by fermentation and is hydrolyzed by microorganisms. Hydrolyzed pulp is known in the industry as "sweatings." Approximately 40 l of pulp can be obtained from 800 kg of wet beans [13]. The sweatings are also allowed to drain off as liquid waste in the farms. The sweatings and wastes from cocoa pod husks have already found uses and studies are being undertaken in Ghana to determine their viability as commercial products [12]. The commercialization of these new products could be an important economic incentive to cocoa production in the country.

Another important environmental issue of concern is loss of biodiversity. Large quantities of healthy and genetically diverse native flora and fauna are an indication of a balanced ecosystem [14]. The biodiversity loss of clearing original vegetation such as forest and the loss through the use of pesticides must be estimated. This indicator is now under development for the LCA methodology [15].

3.2. Cocoa processing stage

Industrial processing of cocoa beans was found to be the most predominant stage in the environmental impacts of photochemical ozone creation potential (95.84%), global warming potential (80.89%), atmospheric acidification potential (96.47%) and abiotic depletion potential (76.35%). The production and consumption of fossil fuels in boilers and roasters were identified as the main cause of environmental impacts in the cocoa processing stage. Therefore efforts must be focused on improving the efficiency of energy use in these energy-intensive equipments. It also proposed to substitute the use of diesel with natural gas since it is known to be relatively more environmentally friendly. The main by-product from the processing industry, cocoa shell, is no longer considered a solid waste, as it is being processed and packed for sale as animal feed by the Cocoa Processing Company.

Table 3
Proposed improvement options

Life cycle stage	Base case	Improvement option suggested
Cocoa production	Mineral fertilizer	Organic fertilizer
Cocoa production	Mineral fertilizer	50% Reduction
Cocoa production	Pesticides	50% Reduction
Cocoa processing	Diesel oil	Natural gas

3.3. Transportation stage

The transportation stage is relatively the most environmentally friendly of the sub-systems studied, since its contributions to the impact categories considered were not very significant.

4. Improvement analysis

Proposed improvement options were modeled and their results compared with the baseline case to find out whether these modifications will reduce the environmental impact potentials. The baseline data depends on the present techniques and practices of cocoa production and processing in Ghana. The proposed improvement options tested are summarized in Table 3. Each improvement option was tested independently of all others so that the extent of its effects on the reference case could be assessed alone. Figs. 3–6 compare the environmental scores of these modifications with the baseline.

From Fig. 3, it is evident that the exclusive use of natural gas instead of diesel in the cocoa processing factory shows many reductions in environmental impact potentials. The reductions are acidification potential (38%), global warming potential (47%), photochemical ozone creation potential (21%) and terrestrial eco-toxicity potential (10%). However, natural gas consumption contributes to energy use and depletion of abiotic resources. This comes from the relatively higher amount of gas required to produce the same amount of energy compared to diesel. Figs. 4 and 5 show that reduction in fertilizer and pesticide use reduces their toxicity impacts significantly. Exclusive

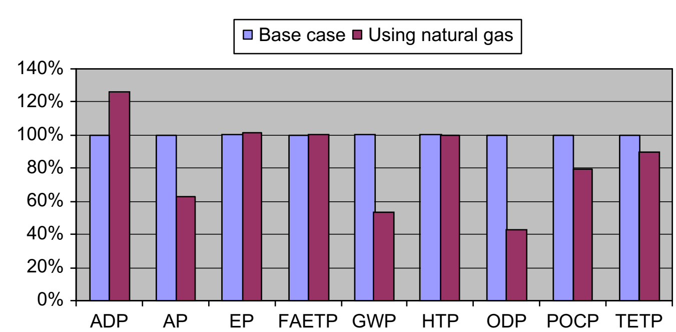

Fig. 3. Comparison of environmental impact potentials between the base case using diesel and an assumed case using natural gas for cocoa processing.

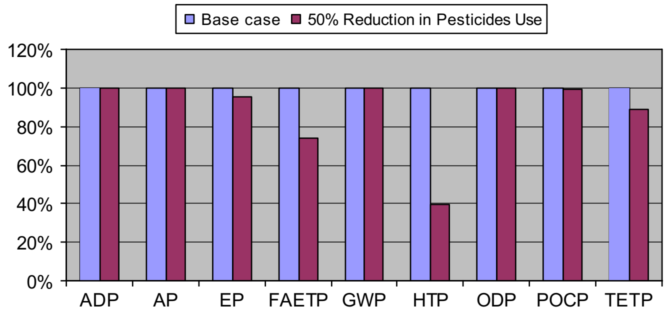

Fig. 4. Comparison of environmental impact potentials using pesticides: 100% (base case) versus 50% reduction.

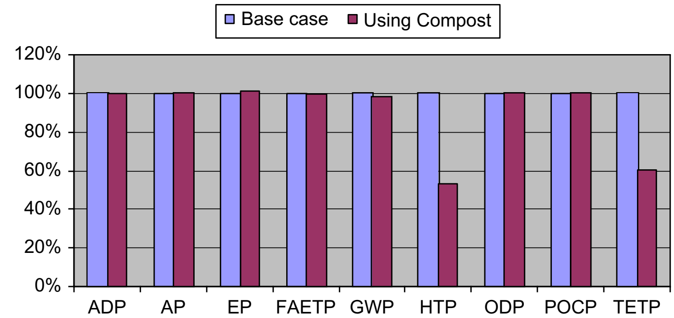

Fig. 6. Comparison of environmental impact potentials using fertilizers (base case) versus using compost.

use of compost instead of inorganic fertilizers was also tested and the results are shown in Fig. 6. Using compost ensures significant reductions in the environmental impacts of human toxicity and terrestrial eco-toxicity potentials.

5. Conclusions and recommendations

The overall aim of conducting this LCA was to measure the potential environmental impacts associated with the production and processing of cocoa in Ghana. This was done in order to establish a scientific basis for improvement analysis towards the sustainability of the production chain. A significant number of impact categories were covered. However, some relevant environmental impacts resulting from cocoa production such as loss of biodiversity and disposal impacts of pod husks have not been assessed and included in the impact assessment, since their methodology is not included in the impact assessment method adopted.

High quality and representative data are critical for reliable LCA results [16]. In this study, data pertaining to electricity generation, fuels and agrochemicals production and transportation were taken from European databases, since specific local or regional databases are lacking. Mungkung et al. [17] have also observed that in developing countries, baseline data, especially describing background systems, are not always available and thus LCA practitioners have to supplement the missing data by using the databases provided in commercial LCA softwares. This sometimes adds to the low confidence level of LCA results. Lack of awareness of the LCA approach in the country was also seen as a barrier. A lot of

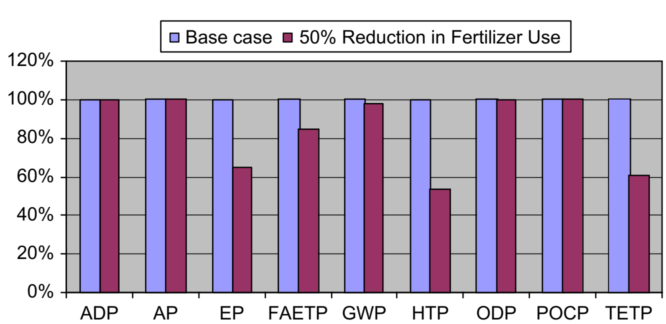

Fig. 5. Comparison of environmental impact potentials using fertilizer: 100% (base case) versus 50% reduction.

educational effort had to be made to introduce and explain the concept of life cycle assessment to the people contacted during data collection.

Considering the potential of the method for sustainable development, there is the need to further develop and promote its application in the country's development priority areas. This will require a substantial effort to develop a simplified language that communicates the concepts, tools and benefits of LCA to policy and decision-makers and the development of database relevant to domestic conditions [18]. Current LCA methodologies address only environmental aspects and impacts, therefore recommendations based on LCA's fail to address possible trade-offs between environmental protection and both social and economic concerns in the product life cycle [19,20]. This raises questions about LCA's ability to support actual decision-making in companies, which aim for sustainability, and it creates an incentive for developing LCA methodology to include these other dimensions of sustainability [20].

Despite these general limitations regarding the application of the LCA tool in developing countries like Ghana, one cannot underestimate the environmental perspective offered by a method which makes it possible to identify key environmental issues in support of sustainability measures. For this case study, the LCA tool proved to be successful in identifying and quantifying a number of significant impacts associated with cocoa production and processing in Ghana.

This study is believed to be one of the first LCA studies, and certainly the first in the cocoa industry, in Ghana. The cocoa industry was chosen due to its significant position in the Ghanaian economy. Though the use of the pesticides and fertilizer are assumed to be within acceptable limits [21], this study has revealed that they are a major contributor to the impacts in the cocoa production stage. This means that the government's current Cocoa Disease and Pest Control (CODAPEC) programme must be reviewed, from the environmental point of view. The use of low input systems which rely on integrated pest management involving a high degree of biological control of the major pests and diseases, adequate soil fertility management, as well as high yielding and pests resistant cocoa varieties developed by the CRIG, are recommended to further enhance the environmental friendliness of cocoa production in Ghana [22]. At the industrial processing stage, the use of natural gas instead of diesel oil for roasters and boilers is recommended due to its relatively low emissions. Future study could use other tools to assess land use impacts such loss of biodiversity and soil fertility, etc., to complement the findings made in this LCA study.

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