LIFE CYCLE ASSESSMENT APPLIED TO CHOCOLATE PRODUCTION IN GHANA

by

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A thesis submitted to the Department of Chemical Engineering,

Kwame Nkrumah University of Science and Technology

in partial fulfilment of the requirements for the degree of

MASTER OF SCIENCE

Faculty of Chemical and Materials Engineering,

College of Engineering

November 2009

DECLARATION

I hereby declare that this submission is my own work towards the MSc. degree and that, to the best of my knowledge, it contains no material previously published by another person nor material which has been accepted for the award of any other degree of the university, except where due acknowledgement has been made in the text.

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ABSTRACT

The Life Cycle Assessment (LCA) tool has received increasing attention for its role in environmental decision making processes, where it supports the process of identifying where there is the need for environmental improvements along a product's life cycle. The International Organisation for Standardisation (ISO) has developed a guideline for conducting LCA in the 14040 – 14043 series. The LCA method involves collecting data on raw materials used, energy consumption and wastes to air, water and land. Data is collected for every stage of the life cycle of a product, from mining or cultivation of the raw materials through to processing, transport, consumption and disposal. Based on a relevant functional unit for the system under study, this data is then aggregated and modelled into a life cycle inventory, which in turn is classified and characterized to determine the environmental impacts of the system. The method is also called cradle-to-grave environmental assessment.

This study aims to introduce the concept of LCA to the cocoa industry in Ghana and specifically perform an LCA on chocolate production including the stages of cocoa production, transportation of cocoa beans, industrial cocoa processing and chocolate manufacturing. The CML 2001 and Eco-indicator 1999 methods included in the LCA software GaBi have been used for the impact calculations. The functional unit, to which all masses and emissions in this assessment have been adjusted, is the production of 1 kg of chocolate in Ghana.

The impacts related to the cocoa production stage were found to be mainly caused by the production and use of fertilizers and pesticides. The impacts for the transportation stage

resulted from combustion of diesel and at the processing industry boilers and roasters were found to be the significant contributors to the environmental impacts. The results clearly showed that freshwater aquatic ecotoxicity, followed by energy resources consumption, human toxicity and global warming are the most significant environmental impacts associated with the chocolate production chain in Ghana. Fertilizers and pesticides as inputs to the cocoa production stage were the main cause of the freshwater aquatic ecotoxicity and human toxicity impacts, while diesel consumption at the cocoa processing stage contributed the most to global warming and resource energy consumption. It is also evident from the results that chocolate manufacturing and transportation are the most environmentally friendly stages of the life cycle stages studied.

The study recommends that improvement activities along the chocolate production chain should be focussed on fertilizers and pesticides at the cocoa production stage and consumption of diesel in boilers and roasters at the cocoa processing stage. The general limitations regarding the application of the LCA tool in developing countries like Ghana are also discussed.

ACKNOWLEDGEMENTS

I thank God for giving me the strength and good health to carry out this work.

The UNEP/SETAC Life Cycle Initiative is gratefully acknowledged for awarding the GaBi 4 LCA analysis software used for this study.

My special thanks go to my supervisors Dr George Afrane and Dr Lawrence Darkwah for good co-operation and efficient supervision of this thesis. A great deal of thanks is owed to the management of the Cocoa Processing Company (CPC) and Cocoa Research Institute of Ghana (CRIG) for giving me the opportunity to use their facilities for data collection. I am particularly grateful to Messrs Frank Asante, Manager, Research & Development Department, CPC; Kofi Acheampong, Agronomy Department, CRIG; and Gyimah Gyamfi, Cocoa Swollen Shoot Virus Disease Control Division, COCOBOD, Kumasi, for the technical assistance given me during data collection. I thank the families of Mr & Mrs Buabeng, Tafo, and Mr & Mrs Okyere, Accra for the invaluable social assistance they gave me during my travels for data collection.

I thank the staff of the chemical engineering department of KNUST, and all my course mates for their kindness, encouragement and the great friendship enjoyed with them. I also thank my friend Mr. Prince Charles Acquah, Geomatic Engineering Department, KNUST, for his assistance. Finally I thank my family for their prayers, support and encouragement. Special thanks to my wife, Theresa, for what her love and care has meant to me during this study period.

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LIST OF ABBREVIATIONS AND ACRONYMS

AC/EU	Acidification/Eutrophication
ADP	Abiotic Resources Depletion
AP	Acidification Potential
CCH	Climate Change
CE	Carcinogenic Effects
CML	Centre for Environmental Science, University of Leiden
COCOBOD	Ghana Cocoa Board
CODAPEC	Cocoa Disease and Pest Control Project
COPAL	Cocoa Producers Alliance
CRIG	Cocoa Research Institute of Ghana
DALY	Disability Adjusted Life Years
DCB	1,4-dichloro benzene
ECOT	Ecotoxicity
EP	Eutrophication Potential
EU	Energy use
FAETP	Freshwater Aquatic Ecotoxicity Potential
FUELS	Fossil fuels
GWP	Global Warming Potential
HTP	Human Toxicity Potential
ICCO	International Cocoa Organization
IIASA	International Institute of Applied Systems Analysis, Austria
IPCC	Intergovernmental Panel on Climate Change

ISO	International Organization for Standardization
LCA	Life Cycle Assessment
LCI	Life Cycle Inventory Analysis
LCIA	Life Cycle Impact Assessment
MIN	Minerals
NMVOC	Non-Methane Volatile Organic Compounds
ODP	Ozone Layer Depletion Potential
OECD	Organisation for Economic Co-operation and Development
PDF	Potentially Disappeared Fraction
POCP	Photochemical Ozone Creation Potential
POCP	Photochemical Ozone Creation Potential
R11	Trichlorofluoromethane, $CFCl_3$
RAD	Radiation
RAINS	Regional Acidification Information and Simulation
ResIN	Respiratory (inorganic)
ResOR	Respiratory (organic)
RIVM	National Institute for Public Health and the Environment, the Netherlands
RRP	Radioactive Radiation Potential
SETAC	Society for Environmental Toxicology and Chemistry
SPOLD	Society for the Promotion of Life-Cycle assessment Development
TETP	Terrestrial Ecotoxicity Potential
UNECE	United Nations Economic Commission for Europe
UNEP	United Nations Environment Program
USEPA	United States Environmental Protection Agency
USES 2.0	Uniform System for the Evaluation of Substances (Version 2.0)

VOC	Volatile Organic Compounds
WMO	World Meteorological Organization
YLD	Years Lived Disabled
YLL	Years of Life Lost

CHAPTER 1

INTRODUCTION

Cocoa was first imported into Ghana and planted in the year 1879. The country became the leading producer of cocoa in the world in the 1920/21 season and maintained that position till the 1977/78 season. Currently Ghana, producing over 700,000 tons of cocoa beans annually, is ranked second in the world, coming after her western neighbour Côte d'Ivoire, which produces more than twice as much as Ghana. In terms of quality however, Ghana is recognised as the world leader in premium quality cocoa beans production. In spite of all the significant gains made by other sectors of the Ghanaian economy in recent times, cocoa continues to occupy a key position in the country's economy as far as foreign exchange generation and domestic income sources are concerned. In 2004, 36.7% of Ghana's GDP and 60% of total employment were derived from agriculture. The Cocoa Industry is the single largest contributor to agricultural GDP (4.5%). The industry also employs about 60% of the national agricultural labour force (Appiah, 2004, Aryeetey and Kanbur 2005). For these farmers, cocoa contributes about 70-100% of their annual household incomes (COCOBOD, 1998). Improving the livelihood of farmers is a crucial aspect of the plan for reducing poverty in Ghana. It has therefore been the avowed aim of government, which is committed to reaping the maximum benefit from the cocoa sector, to ensure that the country increases its cocoa production. The government also plans to process more of the beans into downstream products for both the local and export markets, rather than exporting the raw beans (Awua, 2002).

In pursuance of this, the government in year 2001 initiated a national Cocoa Disease and Pest Control (CODAPEC) Project, commonly known as the Mass Spraying Program, to help address the two major causes of decline in cocoa production, namely pests and diseases. By this programme, cocoa farms across the country are sprayed with pesticides at no cost to the farmers. This exercise resulted in tremendous increases in cocoa production from 340,562 metric tonnes in 2001/02 to 496,846 metric tonnes in 2002/03 and 736,000 metric tonnes in the 2003/04 season. The percentage of locally processed beans has also jumped from 20% to about 35% with further re-capitalization and expansion programs underway to reach a target of 50% in the near future (Appiah, 2004 and ICCO, 2004).

With the growing awareness and concern about issues of natural resource depletion and environmental degradation, the impact of products and processes on the environment has become a key issue. The impacts of food production have attracted increasing interest because of the scale and relevance of food production. Not only the content and quality of foods are important to consumers these days, but also the environmental impacts of farming, processing and transporting to the market are also becoming important issues (Ellingsen and Aanondsen, 2006). With a nationwide use of agrochemicals (through the CODAPEC programme) at cocoa farms, transportation trucks emitting gaseous pollutants, and wastes and emissions from the processing factories, the cocoa industry has both environmental responsibilities to live up to and money to save by making the right technological investments and incorporating the right environmental management strategies along the production chain. To remain competitive in this emerging environmentally sensitive global market, it is essential to introspect, substantiate and defend the cocoa industry's position with a scientific scrutiny on the environmental performance of the production and supply chains. Life Cycle Assessment (LCA) is one of the most internationally accepted environmental management tools that can be used to generate the needed environmental information on the cocoa industry. LCA traces both direct and indirect impacts associated with a product throughout the entire life cycle from cradle to grave. This helps to get a holistic overview of the environmental burdens associated with a product or process. Many companies across the world have now turned to a life-cycle approach in an attempt to assess the full environmental impacts of their products (Ellingsen and Aanondsen, 2006).

When performing an LCA not only processes directly related to the products are assessed. Each input will have a prior history of environmental impacts, which must be included in the assessment. This makes LCAs very heavy in data and calls for a structured procedure. The International Organization for Standardization (ISO) has produced a guideline for conducting LCAs in the ISO 14040 – 14043 series. To deal with numerous data inputs and outputs from a product life cycle, all of which have their own life cycles that must be included in the assessment, existing databases must be taken to use. A number of LCA softwares including databases with life cycle inventories (LCIs) and impacts are available on the market.

This project aims to apply the LCA tool to the cocoa industry in Ghana and specifically performs LCA on chocolate. About 90% of the cocoa produced in the world is used in the manufacture of chocolate (ICCO, 2004), thus establishing the relevance of this project.

CHAPTER 2

LITERATURE REVIEW ON ENVIRONMENTAL LIFE CYCLE ASSESSMENT

2.1 The Concept of Sustainable Development and Environmental Initiatives

The principal components of sustainable development emerged at the United Nations Conference on the Human Environment, Stockholm, 1972. The themes of the conference were:

- interdependence of human beings and the natural environment;
- links between economic and social development and environmental protection;
- need for a global vision and common principles.

In developing these themes, the World Commission on Environment and Development (Brundtland Commission), 1987, defined sustainable development simply as: "development that meets the needs of the present generation without compromising the ability of future generations to meet their own needs". In more detail, sustainable development is a process of change in which the exploitation of resources, the direction of investments, the orientation of technological development, and institutional change are all in harmony and enhance both current and future potential to meet human needs and aspirations (WCED, 1987). Ways of fulfilling needs are considered sustainable when they comply with three basic requirements (Milá, 2003):

- technically feasible and economically viable
- socially acceptable, and
- environmentally friendly.

Several concepts and tools for achieving a more sustainable future have been developed. They are developed within separate disciplines and for somewhat different purposes. Concepts are usually ideas on how to reach sustainability. Design for the Environment, Industrial Ecology, Dematerialization, Life Cycle Thinking and Eco-Efficiency are examples of concepts. Tools, on the other hand, are often supporting a concept and presenting a more systematic way of measuring environmental burden, indicating progress towards sustainability. Examples of environmental assessment tools include Environmental Impact Assessment, Strategic Environmental Assessment, Life Cycle Assessment, Cost-Benefit Analysis, Risk Assessment, etc. (OECD, 1995). Many of these tools are still under development and therefore do not have standardized methodologies.

2.2 The Life Cycle Assessment Tool

Life Cycle Assessment (LCA) is one of a number of tools available to support environmental decision-making in industrial settings. LCA addresses the environmental aspects and potential environmental impacts (e.g. use of resources and the environmental consequences of releases) throughout a product's life cycle from raw material acquisition through production, use, end-of-life treatment, recycling and final disposal (i.e. cradle-to-grave) (ISO 14040, 1997). LCA has been recognized not only as an analytical environmental management tool, but also as a concept. This concept helps in understanding the overall environmental implications of the services required by society. Life Cycle Thinking reflects the acceptance that key societal factors cannot strictly limit their responsibilities to those phases of a life cycle in which they are directly involved. It expands the scope of their responsibility from the cradle to the grave of the product, process or activity (Muñoz, 2006). Fundamentally, LCA is a material and energy balance applied to the product's system, combined with an assessment of the environmental impacts related to the inputs and outputs to and from the product system. The main strength of LCA is its comprehensive character that helps to avoid problem shifting. Three common types of problem shifting can be identified (UNEP, 1996) as:

(i) shifting from one stage of the life cycle to the other, e.g. substituting a hazardous raw material by a less hazardous one, which may however produce more wastes during its production

(ii) shifting from one problem to another (such as replacing a gaseous emission problem by the introduction of gas scrubbers producing solid waste or liquid effluent) and

(iii) shifting from one location to another.

2.2.1 Definition of LCA

The first international consensus on the definition of LCA was reached at the beginning of the 1990s by the Society of Environmental Toxicology and Chemistry (SETAC), which considers LCA as

"an objective process to evaluate the environmental burdens associated with a product, process or activity by identifying and quantifying energy and materials used and wastes released to the environment; to assess the impact of those energy and material uses and releases to the environment; and to identify and evaluate opportunities to effect environmental improvements. The assessment includes the entire life cycle of a product, process or activity, encompassing extracting and processing raw materials; manufacturing, transportation and distribution; use, re-use, maintenance; recycling, and disposal" (Consoli *et al*, 1993).

The International Organization for Standardization (ISO) has also provided very relevant input to the process of defining LCA. According to ISO 14040 (1997), LCA is "a compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its life cycle. A product system is a collection of materially or energetically connected unit processes, which performs one or more defined functions".

As can be seen, both definitions are quite similar, highlighting the need of taking into account, in the analysis, the entire product chain and the potential consequences on the environment, based on the compilation of a mass and energy balance of the product system.

2.2.2 Historical Development of LCA

The origin of LCA has been traced to the energy crises of the late 1960s and early 1970s, which forced industries to look for energy efficient solutions for their products. Several authors consider the (unpublished) study carried out in 1969 by the Midwest Research Institute for the Coca-Cola Company to be the first LCA study. The aim of this project was to compare and determine which container had the lowest release to the environment and the lowest consumption of material resources (Weidema, 1997). Instead of the term LCA, this study and subsequent ones were called Resource and Environmental Profile Analysis (REPA). During this initial period, studies were simple and generally restricted to calculating energy requirements and solid waste. During the 1970s, extensive energy studies based on Life Cycle Inventories (LCI) were performed for a range of industrial systems. By the end of the 1980s, numerous studies using LCA had been performed, mainly by private companies in Sweden, Switzerland and the USA (Udo de Haes, 1993). However, these studies were performed using different methods and without a common theoretical framework. This resulted in the situation where different studies for the same product gave different and sometimes conflicting conclusions because of different methodological choices (Weidema, 1997). Many initiatives were taken to harmonize LCA methodology. These efforts resulted in methodological guidelines, most of which were valid for a specific geographical area, a particular category of products, or a particular application of LCA (Russell, Ekvall and Baumann, 2005). Some of these initiatives include: the Product Ecology Project in Sweden, which developed the Environmental Priority System (EPS) method, the United States Environmental Protection Agency (USEPA) life cycle design project, the Nordic Environmental Sound Product Development (NEP) project in Norway and Sweden, and the Environmental Design of Industrial Products (EDIP) project in Denmark (Weidema, 1997). The various guidelines include different and often conflicting recommendations. An effort to reach consensus on a broad, international level was initiated within the Society of Environmental Toxicology and Chemistry (SETAC) in 1990. In 1993, this organization published a "Code of Practice" which presented general principles and a framework for the conduct, review, presentation and use of LCA findings. (Russell, Ekvall and Baumann, 2005).

Today the "Code of Practice" has been replaced with an international set of standards developed by the ISO in the period 1997 to 2000 (ISO 14040-43). These standards provide an internationally agreed method of conducting LCA, but leave significant degrees of flexibility in methodology to customize any individual project to the desired application and outcomes.

More recently, a joint initiative by the United Nations Environment Program (UNEP) and SETAC has been launched, called Life-Cycle Initiative (UNEP/SETAC Life-Cycle Initiative 2002). Mainly, the Life Cycle Initiative is aimed at facilitating access to inventory data and providing impact assessment procedures that are adapted to practitioner's needs.

The idea is to facilitate a global application of the tool, both in rich and poor countries, and in big companies and Small and Medium Sized Enterprises (SMEs).

2.2.3 The ISO LCA Methodology

ISO has four main standards for LCA. These 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 standards are broken down into four main phases as presented in figure 2.1.

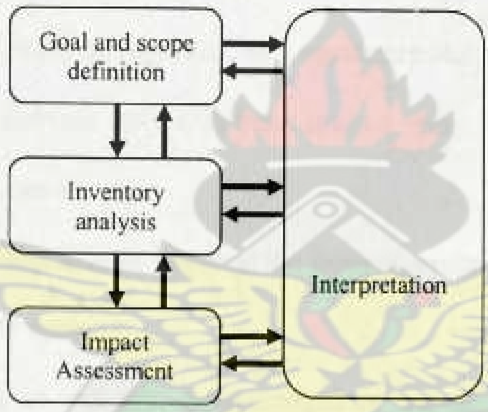

Figure 2.1 Components of a Life Cycle Assessment (ISO 14040)

Whereas ISO 14040 provides the general framework of LCA, ISO 14041 provides guidance for determining the goal and scope of an LCA study, and for conducting a life cycle inventory. ISO 14042 is about the life cycle impact assessment phase, and ISO 14043 provides guidance for the interpretation of results from an LCA study. In brief, the goal and scope definition states the intended objectives of the study, and define the system under study; its function, the system's boundaries, data requirements, etc. In the life cycle inventory (LCI) analysis, those substances crossing the system's boundaries that may be relevant from an environmental point of view are identified and quantified. It is the data collection phase of the LCA study. The environmental significance of the inventory data is assessed in the life cycle impact assessment (LCIA) phase. The interpretation is the final phase of the LCA, in which the results of LCI and LCIA are discussed in the light of the goals set in the beginning of the study. A more detailed description of each phase according to the ISO 14040- series is presented in Appendix A. It must be noted that the phases are not simply followed in a single sequence. The making of LCA is an iterative process, with considerable feedback between the phases, as illustrated in figure 2.1.

2.2.4 Applications of LCA

Typically, LCA is used to evaluate the environmental implications of materials and products, although services have also been studied using this tool. According to the ISO 14040 (1997), LCA can assist in:

- identifying opportunities to improve the environmental aspects of products at various points in their life cycle;
- decision making in industry, governmental or non-governmental organizations (e.g., strategic planning, priority setting, product or process design or redesign);
- selection of relevant indicators of environmental performance, including measurement techniques; and
- marketing (e.g., an environmental claim, eco-labelling scheme or environmental product declaration).

2.2.5 Limitations and Common Problems of LCA

Besides the unique advantages of LCA, there are shortcomings and limitations which have to be understood and considered when applying it. According to Guinée *et al* (2001), the core characteristic of LCA, its holistic nature, in addition of its main strength is also its main limitation, since the broad scope of analyzing the entire life cycle of products and processes can only be achieved at the expense of simplifying other aspects. Particular limitations of LCA can be summarized as follows:

1. LCA addresses potential rather than actual impacts. This is due to the fact that in LCA, impacts are not specified in space and time. The ISO 14042 standard, dealing with Life Cycle Impact Assessment, specially cautions that LCA does not predict actual impacts or assess safety, risks, or whether thresholds are exceeded. The actual environmental effects of emissions will depend on when, where and how they are released into the environment. Concerning spatial differentiation, it is possible to identify the regions where certain emissions take place, and take into account the different environmental sensitivities of these regions. However, LCA does not provide the framework for a complete risk assessment, in which the actual impacts associated with the operation of a facility in a specific place can be predicted. The same can be applied for the time aspect, since LCA is typically a steady- state, rather than a dynamic approach.
2. The LCA model focuses on physical characteristics of industrial activities and other economic processes. Market mechanisms or other secondary effects on technological development are not included.
3. LCA generally regards all processes as linear, both in the economy and the environment. Doubling the production of a material is assumed to have double impact, and the same applies for doubling the release of a pollutant to the environment. Although some progress is being made in reducing this limitation, LCA at its core is based on linear modeling
4. LCA focuses on environmental issues associated with products and processes, excluding economic and social consequences. Where economic aspects are concerned,

Life Cycle Costing (LCC) can be expected to become a standard addition to LCA applications. However, the inclusion of social issues into LCA or the integration of LCA with tools for social assessment is still in its infancy.

5. Finally, availability of data is another limitation. Databases are being developed in various countries, but in practice, data are frequently obsolete, incomparable, or of unknown quality.

Clearly no single tool can provide answers to all the questions posed by environmental issues. The limitations of LCA highlight the fact that in order to fill these gaps, other analytical tools must be added to given decision situations.

CHAPTER 3

COCOA PRODUCTION, COCOA PROCESSING AND CHOCOLATE MANUFACTURING IN GHANA.

3.1 Production of Cocoa Beans in Ghana

3.1.1 Cultivation

The cultivation of cocoa in Ghana is in the hands of a very large number of Ghanaian peasant farmers, each with an average farm holding of about three hectares. There are very few large-scale plantations (Pabi and Owusu, 1998). The farmers usually clear the undergrowth of the forest floor, followed by the elimination of certain species of trees that are harmful to cocoa. The cut materials are burnt to clear the land for planting. Cocoa is then planted and cultivated under the shade of the remaining trees in association with plantains, banana and other fruit trees. Most cocoa is raised from seed, which is easier and cheaper than vegetative propagation. During the unproductive years after planting, it is necessary to create excellent preconditions for the development of the young cocoa plants through adequate shade, careful weeding and pruning, soil cultivation as well as plant nutrition. Annually returning activities in mature plants include fertilization, pest and disease control, pruning, shade management and harvesting. Planting material is more varied. The national averages for the distribution of the four types of cocoa commercially grown in the country, according to a 1995 survey, are as follows: Amelonado, 42%; Amazon, 36%; hybrids developed by the Cocoa Research Institute of Ghana, Akokorabedi, 19%; and mixed cocoa, 3% (Takrama, 2005).

3.1.2 Fertilization

The overall goal of fertilizing is to increase the field's productivity. Mineral fertilizers are usually used. The most commonly used fertilizer in cocoa production currently in Ghana is the special, pre-mix fertilizer called "Asaase wura" with the composition N : P : K (0 : 22 : 18) + 9CaO + 7S + $6MgO_{(s)}$.

3.1.3 Pruning and Weeding

Pruning aims at getting the trees into such a shape as to maximize production, to ease harvesting and maintenance, and to achieve the best control of pests and diseases. This is normally done by using cutlass. Slashing with cutlass is the method of weeding in Ghanaian cocoa farms. The cut material is left to form mulch. Control of weeds by herbicides is not common. Shading by mature cocoa and shade trees reduces weed growth in established areas.

3.1.4 Pests and Diseases management

Pests and diseases constitute the most serious constraint for cocoa. These pests and diseases thrive in the warm, humid climate in which cocoa is grown (Inge de Groot, 2001). The important insect pest affecting cocoa trees in Ghana is the mirid or capsid ("akate").

There are two key cocoa diseases in Ghana that are caused by fungi, namely the black pod and the cocoa swollen shoot diseases. Successful pest and disease management relies on careful application of selective insecticides and fungicides that are recommended by the Cocoa Research Institute of Ghana (CRIG). The main pesticides and fungicides used are

Confidor 200SL (Imidacloprid), Akate master (Bifenthrin), Carbamult (Pirimicarb), Champion (77% Cupric hydroxide), Ridomil 72' (12% metalaxyl, 60% copper-1- oxide) and Nordox 75 (86% Cu_2O, 14% inert) (Ghana Cocoa Farmers Newspaper, 2006).

3.1.5 Harvesting

Cocoa pods are harvested when fully ripe, which is visible from the orange or yellow shell colour. The pods are cut off the tree with cutlasses without damaging the cushion, on which further fruits will form. Once harvested, baskets of cocoa are carried to a central point where the pods are opened with a blunt machete or wooden club to remove the beans for fermentation. The husk is a waste product.

3.1.6 Fermentation

The beans are fermented as soon as they are removed from the pod. The beans are usually heaped on to and covered by banana leaves to permit liquid to drain out and to let air circulate freely around the beans. Fermentation usually takes 6 to 8 days. Fermentation has four objectives:

- to remove the mucilage attached to the beans
- to kill the embryo so that the beans cannot germinate
- to encourage chemical changes within the bean which produce the substances responsible for the chocolate aroma, and
- to reduce the moisture content of the beans

3.1.7 Drying

Fermented beans are dried to prevent deterioration. This is mainly done by spreading them out in the sun on raised mats. The beans need to be covered overnight and in rain. Sun drying takes at least a week. Stirring of the beans is needed to ensure uniform drying. Defective and germinated beans and foreign matter are picked out from the beans during the drying period. The dried beans have a moisture content of 6 to 7%.

3.1.8 Storage

Dried cocoa beans are bagged in clean jute sacks. The local buying companies then purchase the cocoa and store them in warehouses. The stored cocoa is fumigated when found to be infested by insects.

3.1.9 Transportation

Haulage is by road or rail. The rail haulage is only 5-10% by volume. Heavy trucks are used to convey the 90-95% to the harbour for export or to the cocoa processing company (COPAL Report, 2004).

3.2 Industrial Processing of Cocoa in Ghana

Cocoa processing covers converting the beans into intermediate products namely; cocoa liquor, butter, cake and powder. The main processes involved in cocoa processing in Ghana are described by Awua (2002) as follows:

3.2.1 Bean Cleaning

After dried cocoa beans have been received at the processing plant, they are inspected and thoroughly cleaned of all extraneous matter, such as sticks, stones, metal fragments, dust, loose shells, small fragments and clumps of cocoa beans. The cleaning process consists of series of operations, which by means of screens of varying apertures, brushes, airlifts and magnetic separators remove the unwanted materials.

3.2.2 Roasting

The cocoa beans are roasted to develop the chocolate flavour. The energy is supplied by gas oil or electricity. During roasting, the beans loose moisture, the shell is loosened and the nib (cotyledon) becomes friable and generally darker in colour.

3.2.3 Breaking and Winnowing

The main objective of this process is to separate the nib, which is the valuable part, from the shell, which has a minimal value. The shells which have been loosened by roasting are lightly crushed with the aim of preserving large pieces of nib and avoiding the creation of smaller particles and dust. This process is referred to as breaking.

The mixture of broken shell pieces and nibs is then winnowed. Winnowing machines use a multi-layer sieve frame with meshes of different sizes, one above the other, with the largest mesh at the top and the smallest at the bottom. The shell pieces are removed by pneumatic suction at the overflow of each sieve, with remaining nib pieces being directed to chutes at the side of the machine.

3.2.4 Nib Grinding and Cocoa Butter Extraction

The roasted and crushed beans are ground into a paste known as cocoa liquor or cocoa masse. The grinding process is achieved in two or three stages, using a combination of mills. The cocoa liquor obtained is heat-treated in storage tanks at temperatures of about 90-100 °C for aging and microbial destruction. Part of the treated cocoa liquor is subjected to hydraulic pressing to extract cocoa butter.

3.2.5 Cake Grinding

The cocoa cake released after pressing is passed through kibbling machines, which break them into smaller pieces. These are then packed and sold as kibbled cake.

3.3 Chocolate Manufacturing in Ghana

Chocolate manufacturing covers the blending and refining of cocoa liquor, cocoa butter and other ingredients such as milk and sugar. The main processes involved in chocolate manufacturing are described by Awua (2002) as follows:

3.3.1 Kneading

Cocoa liquor is mixed with the other ingredients of chocolate, viz. butter, sugar, milk and emulsifiers. The ingredients are dispensed by automatic methods controlled by computers which deliver the exact quantities according to a given formula.

3.3.2 Conching and Refining

After mixing, the blend is put into large agitators called conches to stir with simultaneous heating to remove any residual moisture and to enhance its viscosity. The liquid chocolate obtained may be used by the confectionery, dairy and baking industry or converted into bars for retailing.

3.3.3 Tempering and Moulding

Tempering is the art of transforming liquid or semi-liquid chocolate into a solid. The chocolate is heated to a specific temperature until the cocoa butter crystals have melted completely. This is followed by cooling at a carefully selected temperature. It is then poured and moulded into different shapes, depending on the types of moulds used. It is finally wrapped, labelled, and packed into cartons ready for distribution.

CHAPTER 4

METHODOLOGY

This study was conducted in accordance with international ISO procedural framework for performing LCA in the ISO 14040-14043 series. Data storage and analysis were performed using the GaBi 4 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, namely, goal and scope definition, life cycle inventory analysis, life cycle impact assessment and interpretation of results. These phases are described in more detail in appendix A.

4.1 Goal and Scope of the Study

The goal of the study requires that the reasons for carrying out the study, its intended audience and intended applications are defined. The scope on the other hand describes the system being studied.

4.1.1. Defining the Goal of the Study

The goal of the study is to generate LCA type of environmental information on the production of chocolate in Ghana, to identify the improvement potentials for the production chain and to compare the environmental burden of the major stages of production. Thus this study aims to:

1. present stakeholders of Ghanaian cocoa industry with the life cycle environmental consequences of the industry's production processes, and

2. highlight areas for improvement of the environmental performance of selected activities.

The specific objectives of the study are:

1. to conduct life cycle assessment of chocolate, the main cocoa product.
2. to compare the environmental burdens associated with each major stage of chocolate's production chain, and
3. to make suggestions towards improvement of the environmental performance of chocolate production based on the results obtained.

The intended audience or the target group for this study is made up of all stakeholders of the Ghanaian cocoa industry, namely: COCOBOB, cocoa farmers, cocoa processors and cocoa researchers. Environmental authorities and environmental planners as well as LCA practitioners elsewhere may also find the results and methodology of the study useful.

4.1.2 Defining the Scope of the Study

According to (ISO 14040, 1997), the scope includes items such as the system boundary, the functional unit, allocation procedures, data quality requirements, etc.

4.1.2.1 The System Boundary

The system boundary specifies which of the life cycle stages and/or processes contributing towards a system will be included within an LCA study. Taking into consideration the interests of stakeholders, the systems studied was sub-divided into four life cycle stages (sub-systems) as follows:

1. Cocoa production stage (including pesticides and fertilizer production, cocoa cultivation, primary processing on the farm and temporary storage of beans),
2. Transportation stage (transport of beans to the processing factory),
3. Cocoa processing stage (including cleaning, roasting, breaking and winnowing, and grinding of cocoa beans at the factory), and
4. Chocolate manufacturing stage (including mixing of ingredients, conching and refining, tempering and moulding, and packaging).

The following aspects were excluded from the study due to lack of relevant data:

- Product distribution and consumption phases of the product's life cycle. Thus the study can be described as cradle-to-gate as it ends at the factory gate (Khan et al, 2004).
- Life cycle tracing of all packaging materials and additives that are used in chocolate manufacturing, including transportation of additives.
- Machinery and equipment used in the production and processing of cocoa are also excluded from the system.

A flowchart displaying the inputs to and outputs from the various life cycle stages within the life cycle of chocolate is presented in figure 4.1.

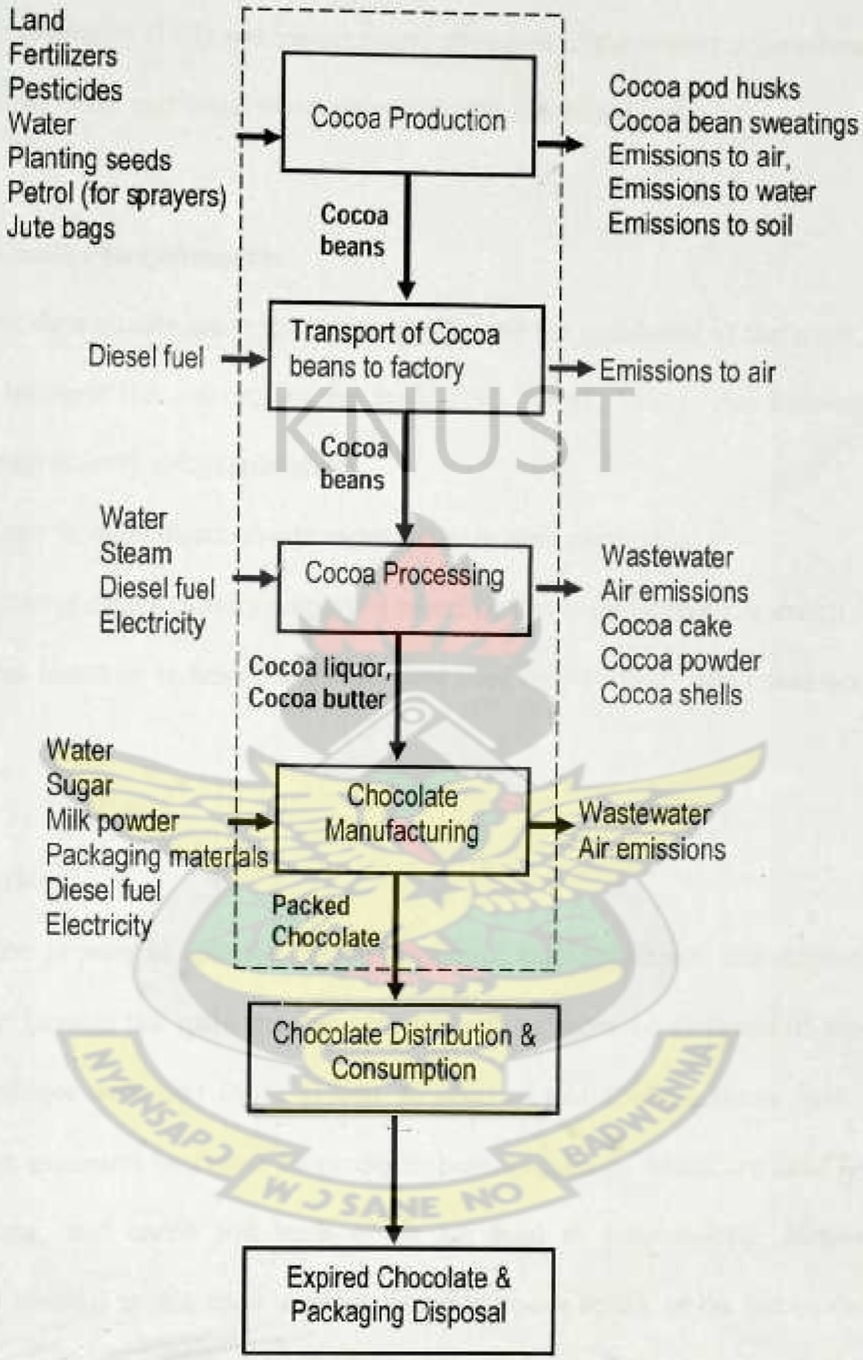

Figure 4.1: Flowchart for the life cycle of chocolate

4.1.2.2 The Functional Unit

For this study, the functional unit chosen is 1 kg of chocolate. All the inputs and outputs in the Life Cycle Inventory (LCI) and impact scores produced in the Impact Assessment phase of this LCA study were expressed with reference to the functional unit.

4.1.2.3 Data Quality Requirements

Descriptions of data quality are important to understand the reliability of the study results and properly interpret the outcome of the study (ISO 14041, 1998). The following data requirements and priority were established.

- Data obtained through direct on-site measurements were preferable.
- Mass and energy balances were employed where no direct measurements exist.
- Calculations based on technical literature were used only if direct data could not be obtained.

4.1.2.4 Allocation

Allocation is the process of splitting the environmental burdens (inputs and outputs) for a process, which besides the main product also has one or more co-products of economic value in accordance with ISO 14041 (1998). In addition to the cocoa beans itself, cocoa production also generates two more co-products: bean sweatings, which are used for wine and jam making, and cocoa pod husk which are used in soap-making. However all environmental burdens at this stage were attributed to cocoa beans, as the use of these co-products is not yet commercially viable. Thus the cocoa pod husk and bean sweatings were considered as waste. At the processing stage, 90% of the environmental burdens were attributed to cocoa liquor and cocoa butter and 10% to cocoa cake and shells which are now used to manufacture fertilizers. The allocation was based on the economic values of the products.

4.2 Life Cycle Inventory Analysis (LCI)

This is the second phase of the LCA methodology and it involves identifying and quantifying the inputs to and outputs from each process in the life cycle. The inventory analysis consists of two major steps namely, data collection and data processing.

4.2.1 Data Collection

Data on energy and raw materials consumed, emissions to air, water and soil, and solid waste produced were collected for each of the life cycle stages studied.

4.2.1.1 Collection of Data for Cocoa Production Stage of the Product's Life Cycle

The cocoa production stage of the life cycle covers the production of farm inputs and activities undertaken in mature cocoa farms such as fertilizer application, pests and diseases control, harvesting and splitting of pods, fermentation, drying and temporary storage of dried beans. Data on these processes were obtained through site visits to farms and interviews conducted with cocoa farmers and researchers at the Cocoa Research Institute of Ghana (CRIG). Background data on production of fertilizers and pesticides were included using the Swiss eco-invent database. Emissions due to fertilizer and pesticide usage were quantified using estimation methods (Hauschild, 2000 and Heathwaite, 2000).

Average cocoa yield per hectare varies in relation to the variety of crop and characteristics of the land on which it is planted, together with other ecological factors, as well as to the age of the cocoa plants. The approximate yield ranges from 350 to 3000 kg dry beans per hectare. In consultation with experts from COCOBOD, a yield of 850 kg/hectare/year was assumed for this study. Thirty (30) years was assumed as the economic lifetime of the cocoa plant for calculating the annual land occupation.

4.2.1.2 Collection of Data for Transportation of Beans to Processing Factory

Dried cocoa beans are transported by truck from the farming areas to the processing factory. Inventory data for transportation was calculated based on average distance of 250 km travelled by diesel engine trucks in Ghana. The truck chosen was 38 ton total capacity (and 26 ton payload) long distance truck-trailer. (This is the average truck capacity of some cocoa haulage trucks inspected). Data on fuel consumption and emissions for the transportation was taken from the GaBi 4 LCA database. Thus it was assumed that the trucks used in Ghana are similar in condition to those used in Europe.

4.2.1.3 Collection of Data for Cocoa Processing and Chocolate Manufacturing

The Cocoa Processing Company (CPC), Tema, owned by the COCOBOD, which is considered to be state of the art, was selected for a detailed study and data gathering on cocoa processing and chocolate manufacturing. Background data on the production of the energy (electricity from hydropower and diesel) consumed by the plant, were adapted from the eco-invent database and the GaBi 4 LCA database respectively.

4.2.2 Data Processing

In this step, the raw data collected were converted to values that relate to the functional unit (i.e. 1 kg of chocolate). This involved simple conversion calculations.

4.2.3 Sample calculation

The amount of fertilizer applied on a land = 200 kg/ha/yr. Also a hectare of land yields 850 kg of cocoa beans per year and 1 kg of chocolate requires 0.8687 kg cocoa beans.

The amount of fertilizer required for the production of 1kg chocolate

$$= \frac{0.8687 \text{ kg cocoa} \times 200 \text{ kg fertilizer}}{850 \text{ kg cocoa}} = 0.2044 \text{ kg fertilzer/functional unit}$$

The data per functional unit for each life cycle stage (as presented in Appendix B) were then entered into the GaBi 4 LCA tool as individual process data. The various processes were linked together in the GaBi object "plan" to form a flowchart. Mass was used as reference flow from one process to the other. The GaBi object "plan" is shown in figure 4.2. All the inputs and outputs data in the various unit processes were then aggregated to result in an inventory table, which is a list containing the quantities of pollutants released to the environment and the amount of energy and material resources consumed. The inventory table is presented in Appendix C. The sources of inputs and outputs data for the various unit processes identified in figure 4.2 are shown in table 4.1.

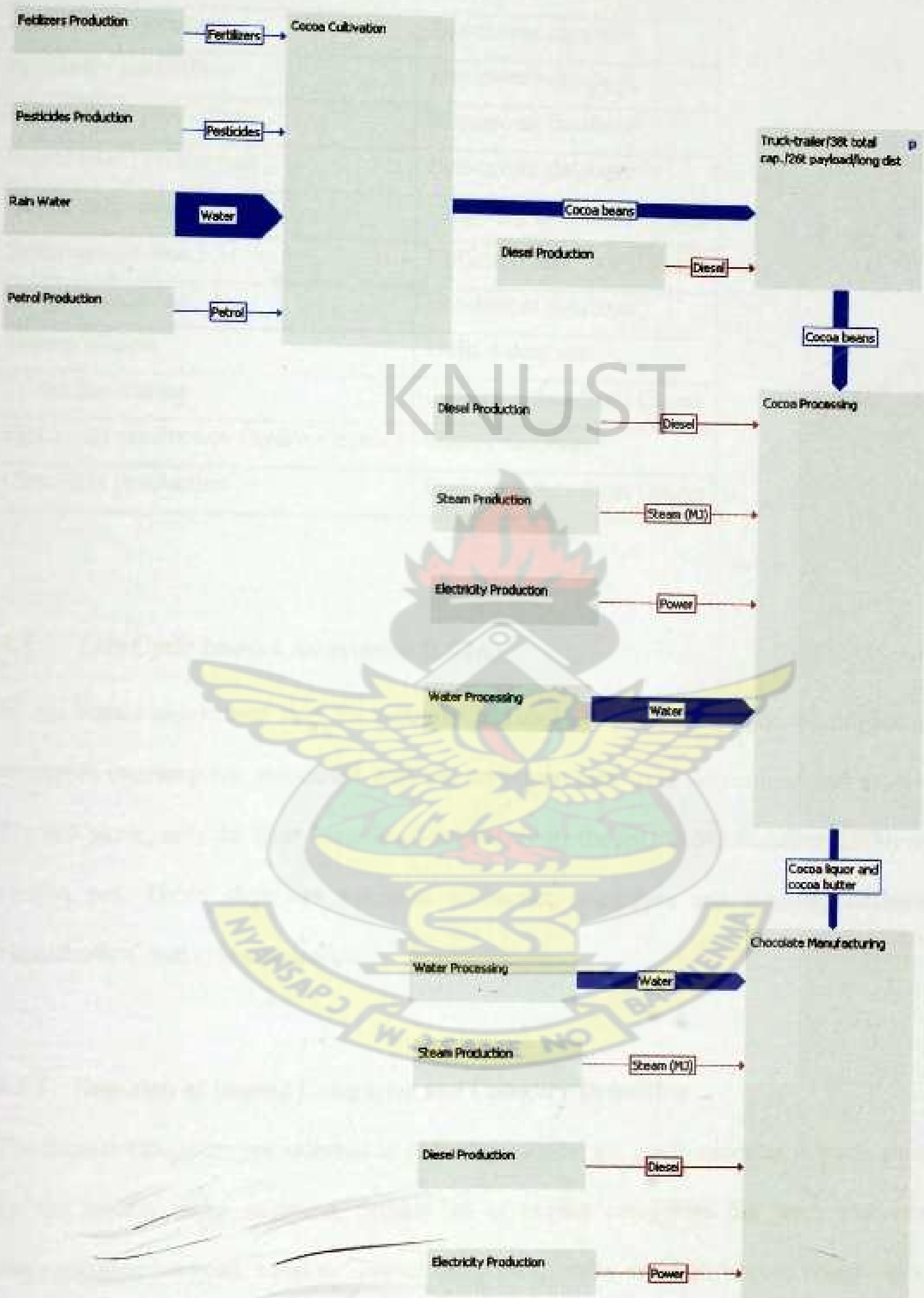

Figure 4.2 GaBi plan for processes studied

Table 4.1 Data Sources for Unit Processes

Data	Source
Fertilizer production	Eco-invent database
Pesticides production	Eco-invent database
Petrol (fuel) production	Eco-invent database
Diesel (fuel) production	Eco-invent database
Cocoa cultivation	Collected data from Ghana
Steam production	Collected data from Ghana
Water processing	Eco-invent database
Transportation	GaBi 4 database
Cocoa processing	Collected data from Ghana
Electricity production (hydro-electric)	GaBi 4 database
Chocolate production	Collected data from Ghana

4.3 Life Cycle Impact Assessment (LCIA)

In the impact assessment step, the potential human health and environmental impacts and resources consumption associated with the inventory data were determined and analysed. For this phase, only the steps considered mandatory by the ISO 14042 standard (2000) were carried out. These steps are selection of impact categories and category definition, classification, and characterization.

4.3.1 Selection of Impact Categories and Category Definition

The impact categories are selected in order to describe the environmental impacts caused by the system under study. A default list of impact categories has been elaborated, distinguishing between 'baseline' impact categories, 'study-specific' impact categories and 'other' impact categories (Guinée *et al,* 2001). In this study only baseline impact categories were selected, as their characterization models are well established and included in the software used. These impact categories are resource energy use, abiotic resources depletion, acidificationl, eutrophication, climate change, photo-oxidant ozone formation, ozone layer depletion, impacts of ionising radiations, human toxicity, freshwater aquatic ecotoxicity and terrestrial ecotoxicity potential. Study-specific impact categories (categories that may merit inclusion depending on the object being studied), such as loss of biodiversity resulting from the destruction or alteration of land, and land occupation in the sense of land being temporarily unavailable) were not included as their characterization models are not included in the software used. Description of the impact categories considered and their characterisation models are presented in Appendix D.

4.3.2 Classification

In the classification step the resources consumed and environmental emissions identified in the inventory table were grouped or classified into environmental impact categories or indicators selected above. For example CO_2 and CH_4 emissions were classified into the environmental impact category of global warming.

4.3.3 Characterization

In the characterization step, the environmental emissions within each impact category were expressed in terms of a reference unit. This was done by multiplying the amounts of the emissions by their concomitant characterization factors and aggregating the results of these multiplications for each impact category. The resulting figure for one particular impact category is referred to as a category indicator result, and the complete set of category indicator results is referred to as the environmental profile of the system studied. The equivalency factor for an emission is a value that expresses the extent to which a mass unit of the emission can contribute to the impact category compared with a mass unit of the reference substance. Sample classification and characterization calculation is shown in figure 4.3. These steps were carried out using the GaBi LCA software.

The characterization factors used by CML method of impact assessment for each environmental impact categories as used in this study are presented in Appendix E. The characterization results (the overall environmental impact profile) and their analyses are presented in chapter 5.

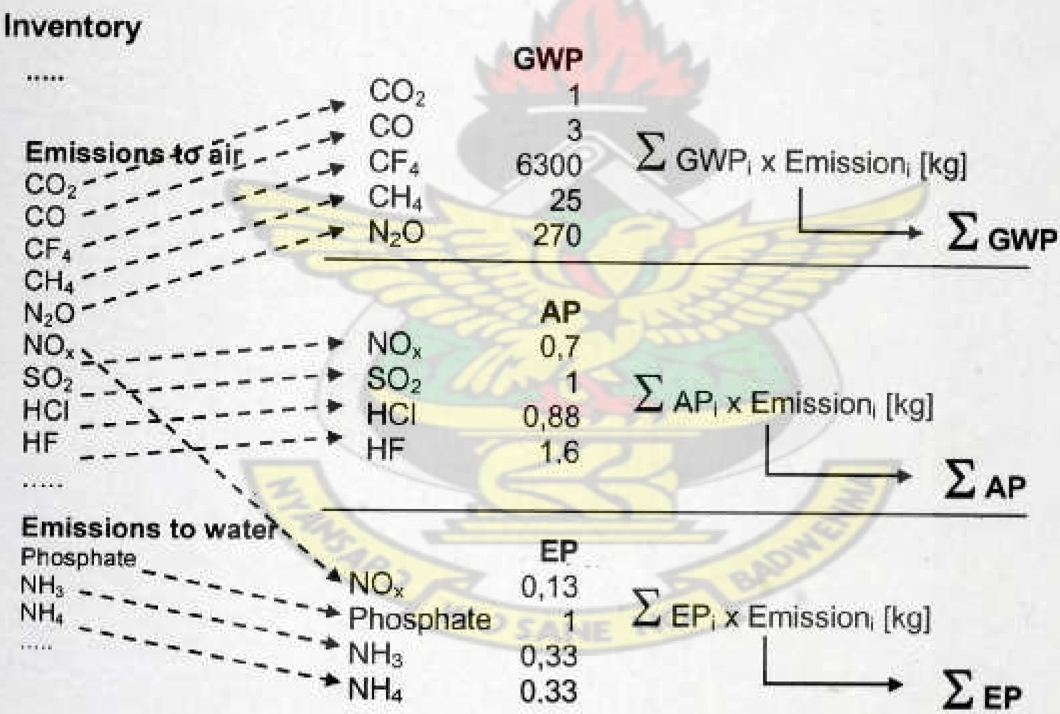

Figure 4.3 Sample Classification and Characterization calculation

4.4 Life Cycle Interpretation

The last stage in conducting an LCA according to ISO 14040 (1997) is the interpretation stage. The objectives of life cycle interpretation are to analyze results, reach conclusions, explain limitations and provide recommendations based on the findings of the preceding phases of the LCA or LCI study and to report the results of the life cycle interpretation in a transparent manner. For this thesis the interpretation stage is presented in chapters 5 and 6 as the results and discussion, and conclusion and recommendation respectively.

CHAPTER 5

RESULTS AND DISCUSSION OF RESULTS

Several life cycle impact assessment methods have been developed for use by LCA practitioners. The ISO 14042 standard describes procedures and not specific methodologies or models for the life-cycle impact assessment phase. Therefore, all the impact assessment methods and methodologies available in literature are acceptable as long as they meet the ISO procedural requirements (Friedrich, 2001). In this project, the CML 2001 method was chosen as the main impact assessment method. The results obtained by the CML impact method were however verified with another widely used impact assessment method, namely the eco-indicator 1999 method.

5.1 Impact Assessment Results Obtained by Using the CML 2001 Method

5.1.1 Characterization results obtained by using the CML 2001 method

The characterization results for the production of 1 kg chocolate in Ghana based on the CML 2001 method is presented in table 5.1 and illustrated graphically in figure 5.1.

As shown in figure 5.1, the most significant impacts associated with chocolate production are freshwater aquatic eco-toxicity potential (FAETP), human toxicity potential (HTP), resource energy use (EU) and global warming potential (GWP).

Table 5.1 Characterization results (overall impact scores) for the production of 1 kg chocolate in Ghana, obtained by using the CML 2001 method

Environmental Impact Category	Impact Score	Unit
Abiotic Resources Depletion (ADP)	1.7636E-03	kg Sb.
Acidification Potential (AP)	9.7351E-03	kg SO_2
Energy use (gross calorific value) (EU)	4.1090E+00	MJ
Eutrophication Potential (EP)	9.1568E-04	kg PO_4^{3-}
Freshwater Aquatic Ecotoxicity Potential (FAETP)	5.0797E+00	kg DCB
Global Warming Potential (GWP)	3.5602E-01	kg CO_2
Human Toxicity Potential (HTP)	4.4426E+00	kg DCB
Ozone Layer Depletion Potential (ODP)	4.9805E-09	kg R11
Photochemical Ozone Creation Potential (POCP)	9.3002E-04	kg Ethene
Radioactive Radiation Potential (RRP)	3.7042E-10	DALY
Terrestrial Ecotoxicity Potential (TETP)	6.3796E-03	kg DCB

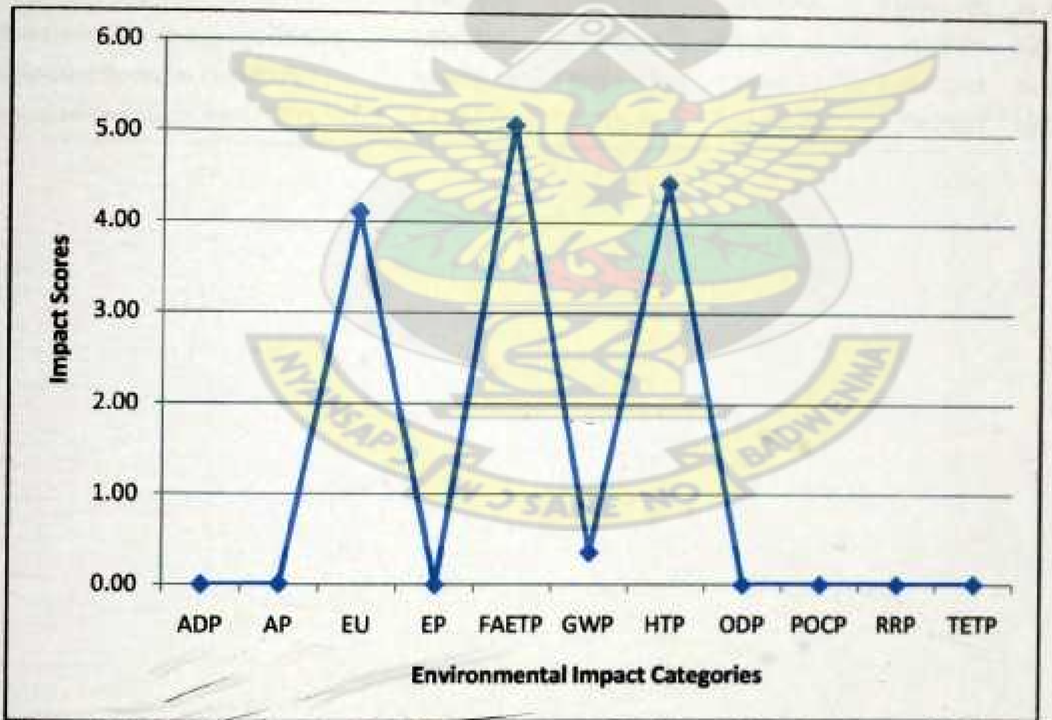

Figure 5.1 Graph of impact assessment scores for the entire system studied (production of 1 kg chocolate in Ghana), based on the CML 2001 method

In order to obtain a clear overview of which stage (sub-system) contributes the most to the environmental impacts, the results are presented per stage in table 5.2 and figure 5.2. From the figure 5.2, the cocoa production stage clearly stands out. The impacts from the cocoa production stage are mainly caused by the production and use of pesticides and fertilizer.

Table 5.2 Characterization results for sub-systems (life cycle stages), obtained by using the CML 2001 method

Environmental Impact Category	Cocoa production	Cocoa processing	Chocolate manufacturing	Transportation	Unit
Abiotic Resources Depletion (ADP)	3.0212E-04	1.0729E-03	3.5789E-04	3.0642E-05	kg Sb
Acidification Pot. (AP)	2.1791E-04	7.1066E-03	2.3698E-03	4.0700E-05	kg SO_2
Energy use (gross calorific value) (EU)	8.3559E-01	2.4031E+00	8.0160E-01	6.8631E-02	MJ
Eutrophication Pot. (EP)	8.8507E-04	1.7721E-05	5.9112E-06	6.9791E-06	kg PO_4^{3-}
Freshwater Aq. Ecotoxicity Pot. (FAETP)	5.0790E+00	6.3288E-04	6.4887E-05	5.2790E-06	kg DCB
Global Warming Pot. (GWP)	4.5918E-02	2.2677E-01	7.5624E-02	7.7089E-03	kg CO_2
Human Toxicity Pot. (HTP)	4.4269E+00	1.4606E-02	1.0405E-03	7.1547E-05	kg DCB
Ozone Layer Depletion Pot. (ODP)	4.9805E-09	0.0000E+00	0.0000E+00	0.0000E+00	kg R11
Photochem. Oz. Creation Pot. (POCP)	2.2292E-05	6.7553E-04	2.2528E-04	6.9224E-06	kg ethene
Radioactive Radiation Pot. (RRP)	3.6660E-10	2.8080E-12	9.3664E-13	8.0192E-14	DALY
Terrestrial Ecotoxicity Pot. (TETP)	5.4306E-03	7.5751E-04	1.9140E-04	1.5982E-07	kg DCB

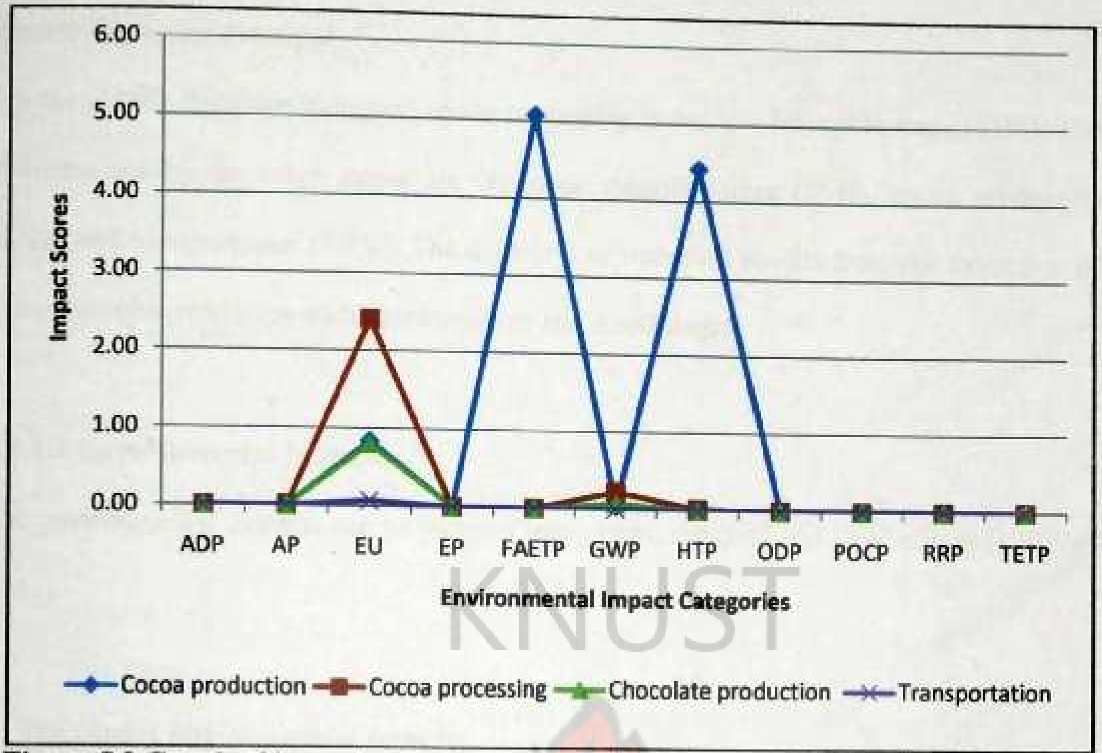

Figure 5.2 Graph of impact assessment scores for various sub-systems (life cycle stages) based on the CML 2001 method.

5.1.1.1 Resources Consumption

Impact categories that relate to resources consumption are energy use and abiotic depletion potential.

Energy use

From figure 5.2, the energy requirements of the cocoa processing subsystem is the highest (contributing about 58% to the total energy consumption), followed by chocolate manufacturing (20%) and cocoa production (18%). The energy consumption by the transportation sub-system is least as compared with the other sub-systems. The cocoa processing stage uses relatively higher amounts of diesel, electricity and liquefied natural gas.

Abiotic Depletion Potential

For the abiotic depletion category, cocoa processing is the key life cycle stage (61%). The contributions by the other stages are chocolate manufacturing (20%), cocoa production (17%) and transportation (1.7%). The depletion of materials results from the extraction of non-renewable resources such as mineral ore and fossil fuels.

5.1.1.2 Environmental Impacts

The environmental impacts can be grouped into global, regional and local effects (USEPA, 2001).

(a) Global Environmental Impacts

The main global impacts are global warming and ozone layer depletion potentials (USEPA, 2001). The cocoa processing stage of the product's life cycle makes the largest contribution to global warming (about 64%) because of its relatively high consumption of fossil fuels. The cocoa production stage contributes nearly 100% to ozone layer depletion potential. The impact was found to be caused by some emission of halons and CFCs during the production of pesticides.

(b) Regional Environmental Impacts

Acidification, eutrophication and photochemical ozone creation potentials are classified as regional environmental problems. Eutrophication is mainly caused by leakage of nutrients during fertilization and emission of phosphates and nitrates from the fertilizer production operations (USEPA, 2001). For eutrophication, the cocoa production stage is an obvious hot-spot (contribution of about 96%). Industrial processing of beans made the largest contribution to photochemical ozone creation potential (about 73%) and atmospheric acidification potential (about 73%). The impacts are mainly caused by emissions from energy supply and fuel combustion.

(c) Local Environmental Impacts

Local environmental impacts include all toxicity impacts and radioactive radiation effects (USEPA, 2001). The characterization results show that local toxicity impacts (human toxicity, freshwater aquatic eco-toxicity and terrestrial eco-toxicity) are relatively high. For these impacts, the cocoa production (farming) stage is a hot-pot. The main contributors are heavy metals content in phosphorus fertilizers and leakage of pesticides during spraying as well as emissions resulting from fertilizers and pesticides manufacturing operations. The cocoa production stage is also the sole contributor to radioactive radiation effects. The reason is the emission of radon caused by the extraction of coal used in the production of agrochemicals.

5.1.2 Normalization results obtained by using the CML 2001 method

Normalization, which is an optional step, was however performed on the impact scores (characterization results). Normalization allows for comparison of the impact scores to the total impact scores contributed in a specified area. The data should have been compared to a national or an Africa regional reference scale, but for lack of such data, the world was used as reference. The estimated annual contribution to each impact category (normalization values) and normalized impact scores are presented in table 5.5 and figure 5.5. The normalized scores were obtained by dividing the impact scores for each impact category by the normalization values.

Table 5.3 Normalization results based CML 2001 global normalization values

Environmental Impact Category	Impact Score	Normalization values	Normalized Impact Scores
Abiotic Resources Depletion (ADP)	1.7636E-03	1.5654E+11	1.1266E-14
Acidification Potential (AP)	9.7351E-03	2.9940E+11	3.2516E-14
Eutrophication Potential (EP)	9.1568E-04	1.2913E+11	7.0910E-15
Freshwater Aq. Ecot. Pot. (FAETP)	5.0797E+00	2.0305E+12	2.5017E-12
Global Warming Potential (GWP)	3.5602E-01	4.4509E+13	7.9989E-15
Human Toxicity Potential (HTP)	4.4426E+00	4.9772E+13	8.9259E-14
Ozone Layer Depletion Pot. (ODP)	4.9805E-09	5.1518E+08	9.6676E-18
Photochem. Oz. Creation Pot. (POCP)	9.3002E-04	4.5491E+10	2.0444E-14
Radioactive Radiation Potential (RRP)	3.7042E-10	1.3374E+05	2.7698E-15
Terrestrial Ecotoxicity Potential (TETP)	6.3796E-03	2.6787E+11	2.3816E-14

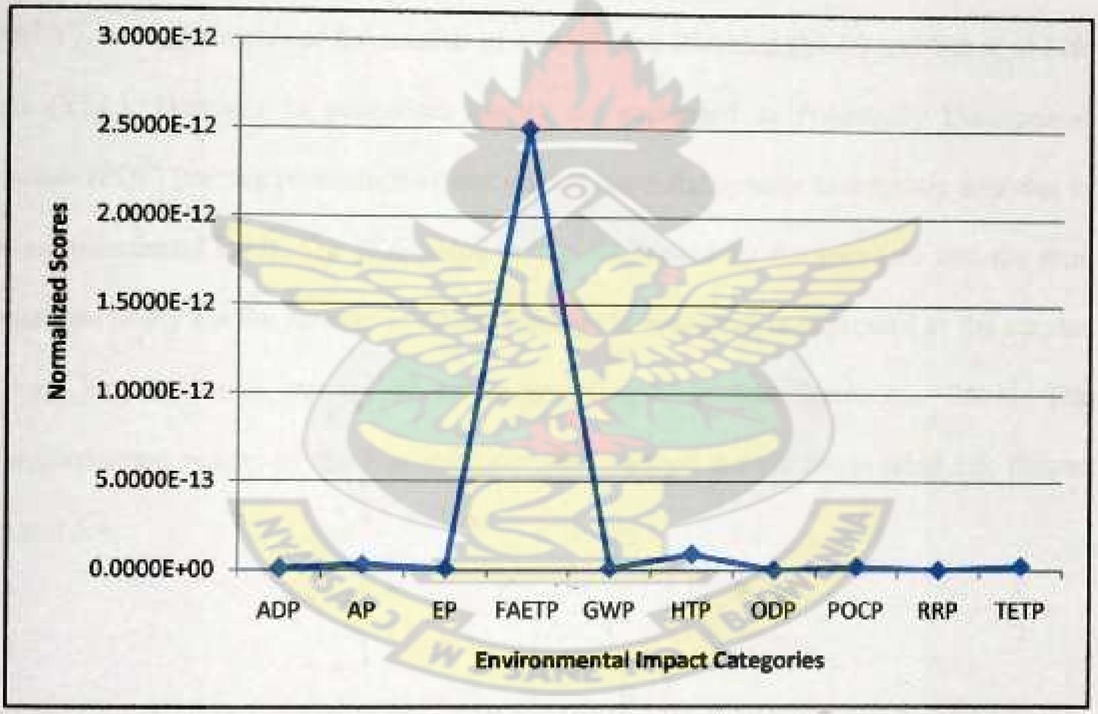

Figure 5.3 Graph of normalization results for production of 1 kg chocolate in Ghana based on the CML 2001 global normalization values

After normalization, freshwater aquatic ecotoxicity impact (FAETP) still stands out as the most significant impact associated with the systems studied. The contribution of the system studied to the other impacts are however seem not to be significant when compared with the contribution from all processes across the globe to impact categories.

5.2 Impact Assessment Results Obtained by Using the Eco-indicator 1999 Method

5.2.1 Characterization results obtained by using the Eco-indicator 1999 method

The Eco-indicator 1999 method assesses the impacts on human health, ecosystem quality and resources. Damages to human health are expressed in Disability Adjusted Life Years (DALY), using estimates of the number of Years Lived Disabled (YLD) and Years of Life Lost (YLL). Damages to ecosystem quality are expressed as Potentially Disappeared Fraction (PDF) (i.e. the percentage of species that have disappeared in a certain area due to the environmental load). The PDF value is then multiplied by the area size and the time period necessary for the damage to occur. Damage to resources is expressed as the surplus energy for the future mining of resources. (Goedkoop and Spriensma, 2001). The characterization results by the Eco-indicator 1999 method are shown in table 5.3, figures 5.3 and 5.4.

Table 5.4 Characterization Results (overall impact scores) for the Production of 1 kg chocolate in Ghana, obtained by using the Eco-indicator 1999 method (Hierarchical Approach).

Environmental Impact Category	Total Impact Score	Unit
Resources, Fossil fuels (FUELS)	3.9704E-01	MJ[surplus energy]
Resources, Minerals (MIN)	9.8741E-05	MJ [surplus energy]
Ecosystem quality, Acidification/Eutrophication (AC/EU)	1.1518E-02	PDF*m^2*a
Ecosystem quality, Ecotoxicity (ECOT)	1.5451E-01	PDF*m^2*a
Human health, Carcinogenic effects (CE)	7.0781E-08	DALY
Human health, Climate Change (CCH)	7.4619E-08	DALY
Human health, Ozone layer depletion (ODP)	5.2390E-12	DALY
Human health, Radiation (RAD)	3.7040E-10	DALY
Human health, Respiratory (inorganic) (ResIN)	1.3283E-06	DALY
Human health, Respiratory (organic) (ResOR)	5.0046E-10	DALY

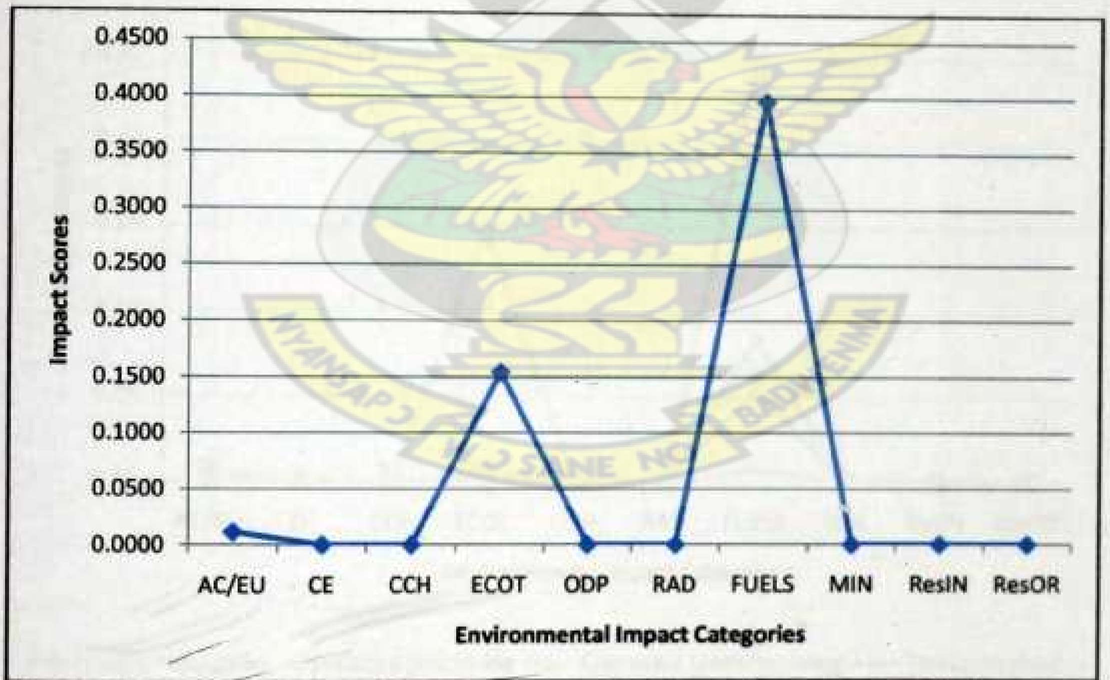

Figure 5.4 Graph of impact assessment scores for the entire system studied (production of 1 kg chocolate in Ghana), based on the Eco-Indicator 1999 method

Table 5.5 Characterization Results for sub-systems (life cycle stages), obtained by using the Eco-indicator 1999 method (Hierarchical Approach).

Environmental Impact Category	Cocoa production	Cocoa processing	Chocolate manufacturing	Transpor-tation	Unit
Acid./Eutroph. (AC/EU)	5.6253E-04	7.9854E-03	2.6629E-03	3.0732E-04	PDF*m^2*a
Carcinogenic Effects (CE)	6.8745E-08	1.5239E-09	5.0720E-10	4.8972E-12	DALY
Climate Change (CCH)	9.6065E-09	4.7540E-08	1.5854E-08	1.6166E-09	DALY
Ecotoxicity (ECOT)	1.4799E-01	6.4730E-03	4.3726E-05	2.2072E-07	PDF*m^2*a
Fossil Fuels (FUELS)	5.2822E-02	2.5271E-01	8.4294E-02	7.2170E-03	MJ
Minerals (MIN)	9.8649E-05	6.7112E-08	2.2386E-08	1.9166E-09	MJ
Ozone Layer Depl. (ODP)	5.2390E-12	0.0000E+00	0.0000E+00	0.0000E+00	DALY
Radiation (RAD)	3.6658E-10	2.8080E-12	9.3664E-13	8.0192E-14	DALY
Respiratory (inorganic) (ResIN)	7.7881E-08	1.1138E-06	1.3142E-07	5.2174E-09	DALY
Respiratory (organic) (ReSOR)	2.5820E-11	3.4633E-10	1.1552E-10	1.2792E-11	DALY

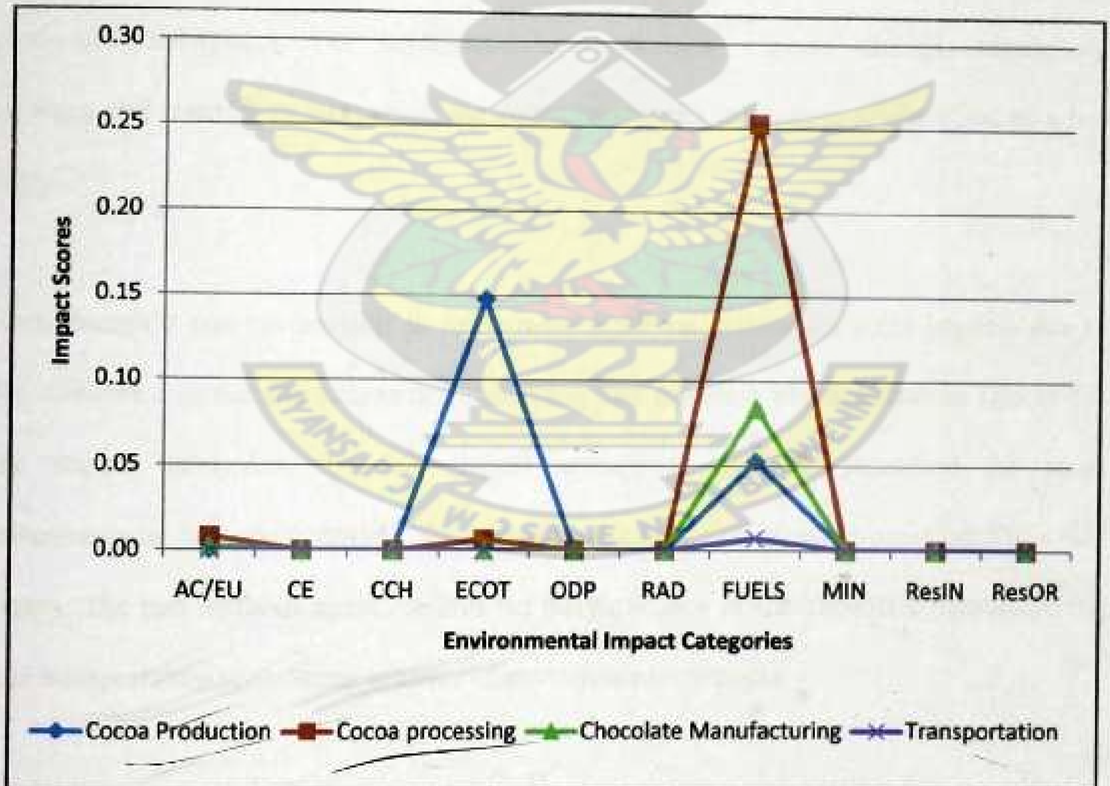

Figure 5.5 Graph of impact assessment scores for various sub-systems (life cycle stages) based on the Eco-Indicator 1999 method

As can be seen from figure 5.3, the "fossil fuels" impact category (i.e. the surplus energy required for the future extraction of fossil fuel) and ecotoxicity are the most significant environmental impacts. For radioactive radiation impacts, the Eco-Indicator 1999 method gave exactly the same characterization result as the CML 2001 method. For depletion of non-renewable resources, the Eco-Indicator 1999 method distinguishes between fossil fuels and minerals consumption whilst the CML 2001 method does not. Here, the cocoa production stage makes the highest contribution to minerals consumption whereas cocoa processing is the key stage in fossil fuels consumption. For ecotoxicity impacts, the CML 2001 method distinguishes between terrestrial and freshwater aquatic eco-toxicity, but the Eco-Indicator 1999 method combines the two. Acidification and eutrophication are treated as a single impact category by the Eco-Indicator 1999 method. Ecotoxicity, carcinogens, ozone depletion and radiation categories exhibited a very high contribution in the cocoa production subsystem. For acidification/eutrophication, climate change, respiratory organics and respiratory inorganics, the cocoa processing subsystem is identified as a hot spot.

Even though it was not possible to make meaningful validations for some impacts due to the difference in the characterisation modelling and available characterisation factors for the impact categories, the two impact assessment methods identified the same environmental hot spots namely the cocoa production and cocoa processing life cycle stages. The two methods again confirm the insignificance of the chocolate manufacturing and transportation subsystems in terms of environmental impacts.

5.2.2 Normalization Results Obtained by Using the Eco-indicator 1999 Method

The characterization results obtained using the Eco-indicator 1999 method were also normalized using world normalization values based on EI99, HA (Hierarchist approach).

Table 5.6 Normalization results based on EI99, HA (Hierarchist approach) world normalization values.

Environmental Impact Category	Impact Score	Normalization Values	Normalized Scores
Fossil fuels (FUELS)	3.9704E-01	8.2600E+03	4.8068E-05
Minerals (MIN)	9.8741E-05	1.4800E+02	6.6717E-07
Acidification/Eutroph.(AC/EU)	1.1518E-02	3.7500E+02	3.0715E-05
Ecotoxicity (ECOT)	1.5451E-01	8.1100E+02	1.9052E-04
Carcinogenic Effects (CE)	7.0781E-08	2.0000E-03	3.5391E-05
Climate Change (CCH)	7.4619E-08	2.3900E-03	3.1221E-05
Ozone Layer Depletion (ODP)	5.2390E-12	2.1900E-04	2.3922E-08
Radiation (RAD)	3.7040E-10	2.6800E-05	1.3821E-05
Respiratory (inorganic) (ResIN)	1.3283E-06	1.0700E-02	1.2414E-04
Respiratory (organic) (ResOR)	5.0046E-10	6.8400E-05	7.3167E-06

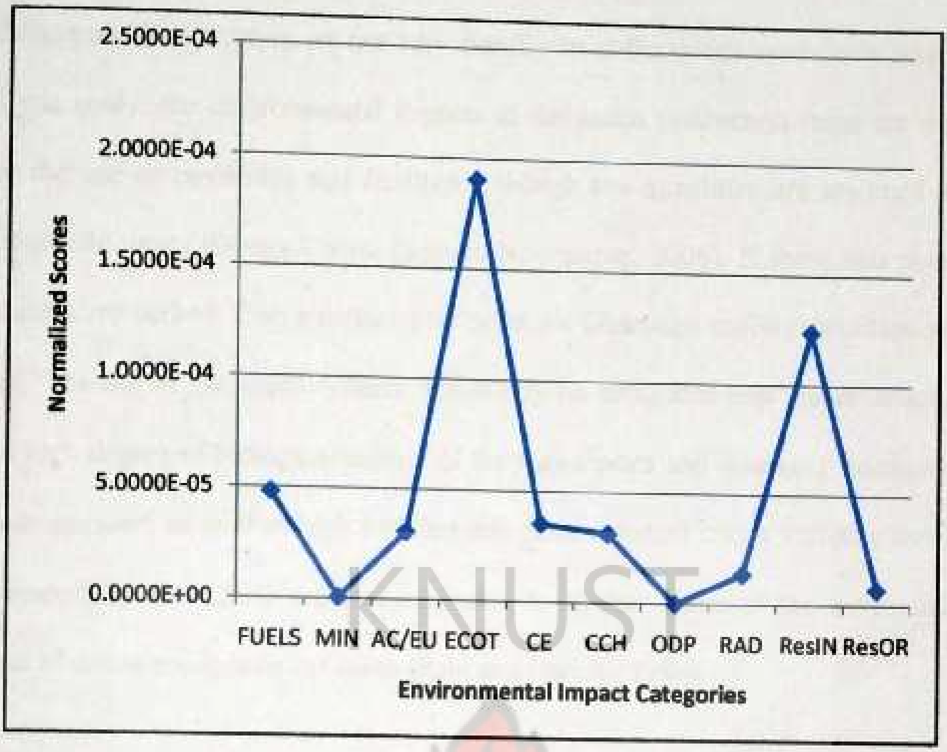

Figure 5.6 Graph of normalization results for production of 1 kg chocolate in Ghana based on the EI99, HA (Hierarchist Approach) world normalization values

5.3 Improvement Options for Sustainability

The analysis has revealed that the most important resources and environmental concerns that need to be addressed are freshwater aquatic eco-toxicity, human toxicity energy consumption and global warming. The cocoa production and cocoa processing stages are also identified as "hot spots" (i.e. the life cycle stages contributing the most to the environmental impacts) and therefore offer opportunities for environmental improvements.

5.3.1 Improvement Options for Cocoa Production Stage

Due to the practice of sun-drying of the cocoa beans, and non-usage of agricultural machinery in cocoa production in Ghana, energy use and its associated impacts such as climate change and acidification are not very significant at the cocoa production stage. As shown in this study, the environmental impacts at the cocoa production stage are mainly caused by the use of pesticides and fertilizers, though the quantities are assumed to be within acceptable limits (Ghana Cocoa Farmers Newspaper, 2006). If these two potential impact sources are curbed, then a further plus point for Ghanaian cocoa production would be attained. The use of low input systems which rely on integrated pest management (that involves 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 that have been developed by the CRIG are recommended to further enhance the environmental friendliness of cocoa production in Ghana (Pabi and Owusu, 1998).

In addition to the 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 (Adu-Amankwa and Twumasi, 2002 unpublished). 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*, 1993), they become 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 seed (the valuable product), the pulp is removed by fermentation and is hydrolyzed by micro-organisms. Hydrolyzed pulp is known in the industry as "sweatings." Approximately 40 litres of pulp can be obtained from 800 kg of wet seeds (Figueira *et al*, 1993). The sweatings are also allowed to drain off as liquid waste in the farms. Viable technologies have been developed for using cocoa pod husks to make soap and animal feed, and cocoa pulp for making wine (Adu-Amankwa and Twumasi, 2002 unpublished). The commercialization of these new products could be an important economic incentive to cocoa production in the country as well as help green the cocoa supply chain. 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 (Narayanaswamy *et al*, 2002). The biodiversity lost from an area where original vegetation has been cleared, for cocoa cultivation must be estimated. However, the application of LCA to Agriculture is recent, and therefore some of these impacts resulting from agricultural practices are still under development for the LCA methodology (Mattson *et al* 2000). Notwithstanding biodiversity loss due to cocoa production, increased cocoa production in Ghana must be commended for the sequestration of carbon dioxide by the cocoa trees.

5.3.2 Improvement Options for Cocoa Processing Stage

The production and consumption of fossil fuels in boilers and roasters were identified as the main cause of the environmental impacts in the cocoa processing stage. Therefore, efforts must be focused on improving the efficiency of energy use in these energy-intensive equipments.

The main by-product from the processing industry, namely, cocoa shell, is no longer considered a solid waste, as it is being processed and packed for sale as animal feed and cocoa fertilizer by the cocoa processing company.

CHAPTER 6

CONCLUSION AND RECOMMENDATIONS

The overall aim for conducting this LCA study was to identify and quantify the potential environmental impacts associated with the entire production chain of chocolate, so that improvement actions can be focussed on the most significant environmental impacts. The assessment has been carried out on four stages in the life cycle of chocolate, namely cocoa production, at which pesticides and fertilizer production are use are significant, transport, which deals with diesel consumption, and industrial processing of cocoa and chocolate manufacturing, where emissions from boilers from roasters must be taken seriously.

A significant number of impact categories were covered. However, some relevant environmental impacts resulting from cocoa production such as loss of biodiversity, disposal impacts of pod husks, etc, have not been assessed and included in the impact assessment since their methodology is not included in the impact assessment methods adopted.

High quality and representative data are critical for reliable LCA results (UNEP, 1996). In developing countries, it is often the case that 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, adding to the low confidence level of LCA results (Mungkung, Udo de Haes and Clift, 2006). 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. Considering the potential of the tool for sustainable development, there is the need to further develop the tool 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 and tools of LCA together with its benefits to policy and decision-makers (Ramjeawon *et al*, 2005) and the development of database relevant to domestic conditions. Current LCA methodologies address only environmental aspects and impacts, therefore recommendations based on LCAs fail to address possible trade-offs between environmental protection and both social and economic concerns in the product life cycle (Guinée *et al*, 2001 and Dreyer *et al*, 2006). 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 (Dreyer *et al*, 2006).

Despite these general limitations regarding the application of the LCA tool in developing countries like Ghana, and in finding ways towards sustainability, one cannot underestimate the environmental perspective offered by a tool, 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.

Future studies could expand the system boundary to include the product distribution and consumption phase of the life cycle and also cover other processes such as the production of packaging, sugar and other ingredients to chocolate omitted in the current study. Such a 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. The outcome of such a complete LCA could start the process of eco-labelling of the product, which will help meet the increasing demand of consumers for better information on the environmental impacts of the product.

Sensitivity and uncertainty analyses have not been carried out and therefore the specific result values of the study must be adapted with caution. However, the general conclusions of the assessment are not likely to be affected by the uncertainties.

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APPENDIX A

METHODOLOGICAL FRAMEWORK FOR LCA - A REVIEW OF THE ISO 14040-14043 STANDARDS

APPENDIX A1: GOAL AND SCOPE DEFINITION

A1.1 Defining the Goal of the Study

The ISO 14040 states that the goal of any LCA study shall unambiguously state the intended application, the reasons for carrying out the study and the intended audience, i.e. to whom the results of the study are intended to be communicated (ISO 14040, 1997).

A1.2 Defining the Scope of the Study

The scope of the study should be sufficiently well defined to ensure that the breadth, the depth and the detail of the study are compatible and sufficient to address the stated goal (ISO 14040, 1997). Furthermore, according to the same document, under the scope of the study the following list of items should be considered and clearly defined: the function of the product system, or, in the case of comparative studies, the systems, the functional unit, the product system to be studied, the product systems boundaries, allocation procedures, types of impact and methodology of impact assessment, and subsequent interpretation to be used, data requirements, assumptions, limitations, initial data quality requirements, type of critical review, if any, and type and format of the report required for the study.

A1.2.1 Functional Unit

Defining the functional unit is one of the most important steps in performing an LCA because the functional unit sets the scale for comparison of two or more products (systems) including improvement on one product (system). The functional unit is used to relate all data collected in the inventory phase to one or more functions of the system under consideration. It has particular importance in comparative LCA studies where products or systems fulfilling the same function are evaluated against each other. The ISO 14041 states: "The functional unit defines the quantification of the identified functions. The functional unit shall be consistent with the goal and scope of the study. One of the primary purposes of a functional unit is to provide a reference to which the input and output data are normalized (in a mathematical sense). Therefore the functional unit should be clearly defined and measurable. Having defined the functional unit, the amount of product which is necessary to fulfil the function shall be quantified. The result of this quantification is the reference flow. The reference flow is then used to calculate the inputs and outputs of the system. Comparisons between systems shall be made on the basis of the same function, quantified by the same functional unit in the form of their reference flow" (ISO 14041, 1998).

A1.2.2 System Boundaries

In a detailed LCA study all input flows should be traced back to the extraction from the environment for inputs and to the discharge into the environment for outputs. However, this approach could lead to endless regression since some inputs could be the result of several processes and the products and by-products of a system may be used as inputs for another series of processes. Therefore, it is important to define the boundaries of a system. The system boundaries specify which of the processes contributing towards a system will be included within an LCA study. According to ISO 14040 several factors determine the system boundaries including the intended application of the study, the assumptions made, cut-off criteria, data and cost constraints and the intended audience. Also the criteria used in establishing the system boundaries shall be identified and justified in the scope of the study (ISO 14040, 1997).

A1.2.3 Data Quality

The ISO 14040 (1997) states that data quality requirements should be defined to enable the goals and scope of the LCA study to be met. The data quality requirements should address: time-related coverage; geographical coverage; technology coverage; precision, completeness and representativeness of the data; consistency and reproducibility of the methods used throughout the LCA; sources of the data and their representativeness; and uncertainty of the information. ISO 14041 (1998) elaborates on each of the data quality requirements presented above and states that where a study is used to support a comparative assertion that is disclosed to the public, all data quality requirements described shall be included in the study.

A1.2.4 Critical Review

The aim of a critical review process is to ensure the quality of an LCA, facilitate understanding and enhance the credibility of LCA studies. ISO 14040 (1997) defines critical review as a technique to verify whether an LCA study has met the requirements of this International Standard for methodology, data and reporting. The review can be internal, external or it may involve interested parties and the ISO 14040 (1997) document gives more specifications for the types as well as for the whole review process.

APPENDIX A2: INVENTORY ANALYSIS

The inventory analysis is the second phase of an LCA study; this involves data collection and calculation procedures to quantify relevant inputs and outputs of the system studied. Usually the inventory produced in this phase is used as input for the next phase which is the life cycle impact assessment. There are some simplified LCA studies where an inventory analysis is enough to draw conclusions; however, this has to be specified in the goal and scope of the study.

The first procedure of the inventory analysis is to prepare for data collection. The ISO 14041 sets five steps for this procedure as follows:

- Drawing of specific process diagrams that outline all unit processes to be modelled, including inter-relationships,
- Description of each unit process in detail and listing of data categories associated with each unit process
- Development of a list that specifies the units of measurement
- Description of data collection techniques and calculation techniques for each data category, to assist personnel at the reporting locations to understand what information is needed for the LCA study and
- Provision of instructions to reporting locations to document clearly any special cases, irregularities or other items associated with the data provided (ISO 14041, 1998).

Data collection is the next step and this step requires good knowledge of each process included in the system since inputs and outputs for each process have to be collected. In most cases this step is the most work-intensive part of the entire LCA study. In accordance to the goal and scope of the study, different data from different sources should be collected. These data can be quantitative (preferably) and qualitative (when quantitative data are not available) and site specific or general. Site specific data, i.e. data from a specific company, area or country are needed for very detailed studies. More average or general data can be obtained from trade organizations, public surveys, manufacturers associations, etc.

The third step in inventory analysis is data validation and this may involve mass balances, energy balances and/or comparative analysis of emission factors. In case of anomalies alternative data values have to be collected in order to fulfil the data quality requirements established.

Two steps follow the validation of data: relating data to a unit process and relating data to the functional unit. Usually these steps involve simple mathematical calculations. Firstly, to relate data to a unit process, a reference flow is established for each unit process and the inputs and outputs for that particular process are calculated in relation to that reference flow. Usually mass or energy units are used, for example, input (and output) per kg (or ton) of material or input (and output) per MJ of energy. Relating data to the functional unit involves normalizing the flows of all unit processes in the system to the functional unit. For this step, the flow chart of the system is important since it shows how the different unit processes are interconnected. Finally, all the normalized values for inputs and outputs for all unit processes involved in the system are aggregated in an inventory table.

Refining the system boundaries is the last step in an inventory analysis and at this stage all the unit processes of the system are reviewed in light of the information collected. This refining process may entail exclusion of unit processes or material flows considered unimportant or inclusion of new unit processes which have become significant. These exclusion or inclusion processes are based on sensitivity analysis. The ISO 14041 makes the following statement with regard to this issue:

"Reflecting the iterative nature of LCA, decisions regarding the data to be included shall be based on a sensitivity analysis to determine their significance, thereby verifying the initial analysis. The initial product system boundaries shall be revised as appropriate in accordance with the cut-off criteria established in the scope definition. This sensitivity analysis may result in:

- exclusion of life cycle stages or unit processes when lack of significance can be shown by the sensitivity analysis;
- exclusion of inputs and outputs which lack significance to the results of the study;
- inclusion of new unit processes, inputs and outputs that are shown to be significant in the sensitivity analysis.

The results of this refining process and the sensitivity analysis shall be documented. This analysis serves to limit the subsequent data handling to those inputs and outputs data which are determined to be significant to the goal of the LCA study" (ISO 14041, 1998).

A2.1 Allocation

Allocation is the process of splitting the environmental burdens (inputs and outputs) for a process, which besides the main product also has one or more co-products of economical value. ISO 14041 states that most industrial processes yield more than one product and they recycle intermediate or discarded products as raw materials. Therefore, the material and energy flows as well as associated environmental releases shall be allocated to the different products according to clearly defined procedures (ISO 14041, 1998). This standard states three principles for allocation.

1. The study shall identify the process shared with other product systems and deal with them according to the procedures presented
2. The sum of the allocated inputs and outputs of a unit process shall equal the unallocated inputs and outputs of the unit process
3. Whenever several alternative allocation procedures seem applicable, a sensitivity analysis shall be conducted to illustrate the consequences of the departure from the selected approach.

For the actual allocation procedures, the ISO 14041 standard suggests the following stepwise succession:

1. Whenever possible allocation should be avoided by:
   - dividing the unit processes to be allocated into two or more sub-processes and collecting the input and output data related to these sub-processes
   - expanding the product system to include the additional functions related to co-products, taking into account the requirements of the functional unit of the system.
2. Where allocation cannot be avoided, the inputs and outputs of the system should be partitioned between its different products or functions in a way which reflects the underlying physical relationship between them; i.e. they shall reflect the way in which the inputs and the outputs are changed by quantitative changes in the products or functions delivered by the system. The resulting allocation will not necessarily be in proportion to any simple measurements, such as the mass or molar flow of co-products.
3. Where physical relationship alone cannot be established or used as the basis for allocation, the inputs should be allocated between the products and functions in a way which reflect other relationships between them. For example, input and output data

might be allocated between co-products in proportion to the economic value of the products.

APPENDIX A3: LIFE CYCLE IMPACT ASSESSMENT (LCIA)

The impact assessment is the third phase of an LCA study and it has been defined as the phase of the LCA aimed at evaluating the significance of potential environmental impacts using the results of the life cycle inventory analysis (ISO 14040, 1997). The life cycle impact assessment uses selected environmental issues (defined as impact categories) and indicators for each of these issues to model the data from the inventory. In general, this process involves associating inventory data with specific environmental impacts and attempting to understand those impacts (ISO 14040, 1997). In most of the published LCA studies, the impact assessment phase had four steps: category definition, classification, characterization and valuation (or weighting). (see Figure A3).

As seen in figure A3, the ISO 14042 document describes procedures and not specific methodologies or models for the life-cycle impact assessment phase. Therefore, all the impact assessment methods and methodologies available in literature are acceptable as long as they meet the ISO procedural requirements. The methodology developed by the Center for Environmental Science, Leiden University in The Netherlands (also known as the CML methodology) is one of the methodologies most used in Europe. This methodology is the one employed in this study.

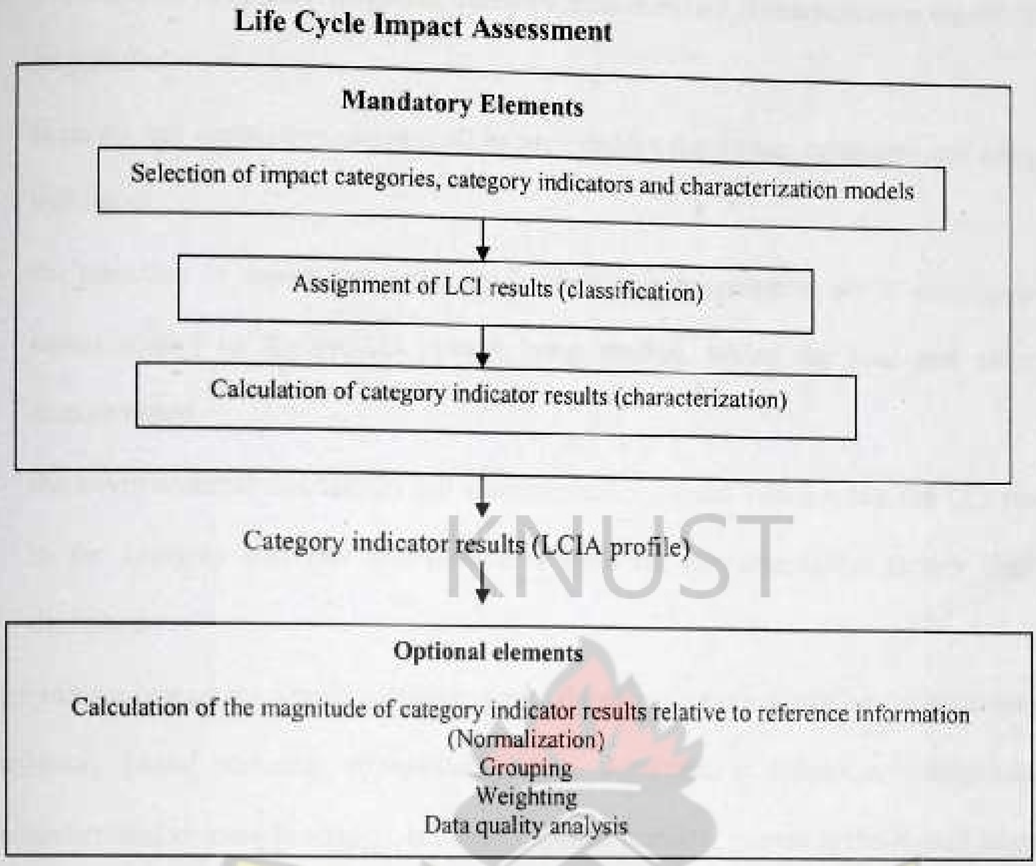

Figure A3: Elements of the Life Cycle Impact Assessment phase (Source: ISO 14042, 2002)

A3.1 Selection of impact categories, category indicators and classification models

Selection of impact categories, category indicators and classification models is the first mandatory step required. The impact categories are selected in order to describe the impacts caused by the inputs and outputs of the studied system, and this step should be a follow up of the decisions made in the goal and scope definition stage.

ISO 14042 (2000) sets the list of requirements for this step as:

- the selection of impact categories, category indicators and characterization models shall be consistent with the goal and the scope of the study
- the sources of impact categories, category indicators and characterisation models shall be referenced

- the selection of impact categories, category indicators and characterisation models shall be justified
- accurate and descriptive names shall be provided for the impact categories and category indicators.
- the selection of impact categories shall reflect a comprehensive set of environmental issues related to the product system being studied, taking the goal and scope in consideration.
- the environmental mechanism and characterization model which relate the LCI results to the category indicator and provide a basis for characterisation factors shall be described.

The impact categories mostly considered are: abiotic resources depletion, biotic resources depletion, global warming, stratospheric ozone depletion, acidification, eutrophication, photochemical oxidant formation, eco-toxicological impacts, human toxicological impacts, land use and work environment.

A3.2 Classification

Classification is the process by which inventory results are assigned to the impact categories chosen in the previous step. This is a qualitative step based on a scientific analysis of the relevant environmental processes. This scientific analysis makes up the characterisation model and determines the category indicator as in the ISO terminology. ISO 14042 states "assignment of LCI results to impact categories should consider the following, unless otherwise required by the goal and scope:

- assignment of LCI results which are exclusive to one impact category and

- identification of LCI results which relate to more than one impact category, including distinction between parallel mechanisms, e.g. SO_2 is allocated between the impact categories of human health and acidification, and allocation among serial mechanisms, e.g. NO_x may be assigned to both ground level ozone formation and acidification".

If LCI results are unavailable or of insufficient data quality for the LCIA to achieve the goal and scope of the study, either an iterative data collection or an adjustment of the goal and scope is required.

A3.3 Characterization

This is the third mandatory step according to the ISO procedures and it involves the conversion of LCI results to common units and the aggregation of the converted results within an impact category. The result is one score for each impact category taken into consideration a score which should reflect the loading for that particular category. In order to perform the conversion, characterisation (or equivalency) factors are used.

Calculation of indicator results involves two steps:

- selection and use of characterization factors to convert the assigned LCI results to common units and
- aggregation of the converted LCI results into the indicator result.

For some of the impact categories, there is consensus regarding the characterization factors or equivalency factors to be used. Such categories are global warming, acidification and ozone depletion. However, for other impact categories like human and ecological toxicity, biotic resources or land use, there is no consensus about characterization factors and different methods have been used.

As can be seen from Figure A3, characterization, classification and selection of impact categories (with indicators and models) are the three mandatory steps according to ISO 14042. In addition to these mandatory steps the ISO standards presents a series of optional steps, specifically normalization, grouping, weighting and data quality analysis (gravity analysis, uncertainty analysis and sensitivity analysis). The following paragraphs briefly introduce these optional elements.

A3.4 Normalization

The normalization step is the procedure by which the indicator (or score) for each impact category is compared in relation to baseline and/or reference information. ISO 14042 states that "This procedure transforms an indicator result by dividing it by a selected reference value. Some examples of reference values are:

- the total emissions or resource use for a given area, which may be global, regional, national or local,
- the total emissions or resource use for a given area on a per capita basis or similar measurements, and
- a baseline scenario, such as given alternative product systems" (ISO 14042, 2000).

The selection of the reference system should consider the consistency of the spatial and temporal scales of the enrichment mechanism and the reference value.

The normalization of the indicator results changes the outcome of the mandatory elements of the LCIA phase. It may be desirable to use several reference systems to show the consequences on the outcome of mandatory elements of the LCIA phase. A sensitivity analysis may provide additional information about the choice of reference. The collection of normalized indicator results represents a normalized LCIA profile.

A3.5 Grouping

Grouping is the process by which impact categories are assigned together in one set. According to ISO 14042 (2000) "Grouping is an optional element with two possible procedures:

- to sort the impact categories on a nominal basis, e.g. by characteristics such as global, regional or local impacts; and /or
- to rank the impact categories on an ordinal scale, e.g. in a given order or hierarchy, such as high, medium and low priority".

The application and use of grouping methods shall be consistent with the goal and scope of the LCA study and it shall be fully transparent. Different individuals, organizations and societies may have different preferences; therefore it is possible that different parties will reach different ranking results based on the same indicator results or normalized indicator results.

A3.6 Weighting

In order to deduce the relative importance of the indicator results or scores obtained for each of the impact categories, another optional element, the weighting or valuation step, is introduced. This step is seldomly based on natural science but on political or ethical values. ISO 14042 (2000) states the following regarding this step:

"Weighting is an optional element with two possible procedures:

- to assign (normalized) indicator results for each impact category with numerical factors (weighting factors) according to their relative importance. (This may be determined by a panel of experts or the public)
- to multiply the normalized results by these factors and possibly aggregate them.

All weighting methods and operations used shall be documented to provide transparency. Data and indicator results or normalized indicator results reached prior to weighting should be made available together with the weighting results. This ensures that:

- trade-off and other information remain available to decision-makers and to others, and
- users can appreciate the full extent and ramifications of the results".

A3.7 Data quality analysis

Additional techniques and information may be needed to better understand the significance, uncertainty and sensitivity of the LCIA results in order to

- help distinguish if significant differences are or are not present,
- remove negligible LCI results, or
- guide the iterative LCIA process.

The need for and choice of techniques depend upon the accuracy and detail needed to fulfil the goal and scope of the LCA study.

The specific techniques and their purposes are described below.

- Gravity analysis (e.g. Pareto analysis) is a statistical procedure which identifies those data having the greatest contribution to the indicator result. These items may then be investigated with increased priority to ensure that sound decisions are made.

- Uncertainty analysis describes the statistical variability in data sets in order to determine if indicator results from the same impact category are significantly different from each other.
- Sensitivity analysis measures the extent to which changes, e.g. in the LCI results, characterization models, etc., influence the indicator results. Likewise, the extent to which modifications in the calculation procedures influence the LCIA profile can be examined. Different "what if" scenarios are used in sensitivity analysis.

APPENDIX A4: INTERPRETATION

The interpretation is the fourth phase in life cycle assessment. The aim of this phase is to reduce the number of quantitative and qualitative data gathered during an LCA study to a number of key issues, which will be usable in a decision-making process. However, this reduction should give an acceptable coverage and representation of the previous phases in an LCA.

"The objectives of life cycle interpretation are to analyze results, reach conclusions, explain limitations and provide recommendations based on the findings of the preceding phases of the LCA or LCI study and to report the results of the life cycle interpretation in a transparent manner. Life cycle interpretation is also intended to provide a readily understandable, complete and consistent presentation of the results of an LCA or LCI study, in accordance with the goal and scope of the study" (ISO 14043, 2000).

According to ISO 14043 (2000), the life cycle interpretation phase comprises three elements, namely:

- Identification of the significant issues based on the results of the LCI and LCIA phases of LCA

- Evaluation which considers completeness, sensitivity and consistency checks;
- Conclusions, recommendations and reporting.

The significant issues can be: inventory data categories, such as energy, emissions, waste, etc.; impact categories, such as resource use, Global Warming Potential, etc.; and essential contributions from life cycle stages to LCI or LCIA results, such as individual unit processes or groups of processes like transportation and energy production.

The objectives of the evaluation element are to establish and enhance the confidence in and the reliability of the results of the LCA or the LCI study, including the significant issues identified in the first element of the interpretation. The objective of the completeness check is to ensure that all relevant information and data needed for the interpretation are available and complete. The objective of the sensitivity check is to assess the reliability of the final results and conclusions by determining whether they are affected by uncertainties in the data, allocation methods or calculation of category indicator results, etc. The consistency check is a qualitative procedure determining "whether the assumptions, methods and data are consistent with the goal and scope" (ISO 14043, 2000). Four main questions must be asked with regard to checking for consistency, and these are:

1. Are differences in data quality along a product system life cycle and between different product systems consistent with the goal and scope of the study?
2. Have the regional and/or temporal differences, if any, been consistently applied?
3. Have the allocation rules and the system boundaries been consistently applied to all product systems?
4. Have the elements of impact assessment been consistently applied? (ISO 14043, 2000).

APPENDIX B
RAW DATA COLLECTED

B1: DATA FOR COCOA PRODUCTION STAGE

Data for this stage were collected in Ghana through questionnaires, by paying site visits to farms and through interviews with cocoa farmers and scientists at the Cocoa Research Institute of Ghana (CRIG).

B1.1 INPUTS

Land use	0.000034053ha
Planting seeds	0.001533kg
Water	4.088L
Petrol (for sprayers)	0.01063L

Fertilizers

Major Nutrients	
N	-
P	0.04497kg
K	0.03678kg
Minor Nutrients	
S	0.01431kg
MgO	0.01226kg
CaO	0.01839kg

Pesticides

Insecticides	
Confidor 200SL (Imidacloprid)	0.0006123kg
Akate master (Bifenthrin)	0.0006123kg
Carbamult (Promecarb)	0.0057232kg
Fungicides	
Champion (77% cupric hydroxide)	0.0018396kg
Ridomil 72+ (12% metalaxyl, 60% Cu_2O)	0.0009198kg
Kocide101	0.0018396kg

Nordox 75 (86% Cu_2O, 14% inert)	0.0018396kg

B1.2 PRODUCTS/BY-PRODUCTS

Dry cocoa beans	0.8687kg
Cocoa pulp (bean sweating)	0.2825kg
Cocoa pod husk	6.8905kg

B1.3 ENVIRONMENTAL RELEASES

B1.3.1: Water Emissions

Bifenthrin (pesticides to freshwater)	1.28E-07kg
Copper (pesticides to freshwater)	6.49E-04kg
Promecarb (pesticides to freshwater)	1.18E-04kg
Phosphates (inorganic emission to freshwater)	2.13E-04kg

B1.3.2: Soil Emissions

Bifenthrin (pesticides to soil)	7.17E-09kg
Copper (pesticides to soil)	3.64E-05kg
Promecarb (pesticides to soil)	6.63E-06kg
Phosphates (inorganic emission to soil)	6.86E-04kg

B1.3.3: Air Emissions

Bifenthrin (pesticides to air)	6.0E-09kg
Copper (pesticides to air)	3.08E-05kg
Promecarb (pesticides to air)	5.62E-06kg

NB: All data are per 1kg chocolate.

B2: DATA FOR COCOA PROCESSING STAGE

Data for this stage were collected from Cocoa Processing Company (CPC), Tema, Ghana.

The data represents the company's production data for the year 2004/2005.

B2.1: INPUTS

Cocoa beans	0.8687kg
Electricity	0.076489kwh
Diesel	0.055287L
Water	0.902958L

B2.2: PRODUCTS/BY-PRODUCTS

Cocoa liquor	0.1827kg
Cocoa butter	0.2960kg
Cocoa cake	0.2335kg
Cocoa powder	0.0652kg
Cocoa shells	0.0851kg

B2.3: ENVIRONMENTAL RELEASES

B2.3.1: Water Emissions

Total Dissolved Solids	4.4760E-12kg
Total Suspended Solids	3.5866E-12kg
Chemical Oxygen Demand	8.5317E-12kg
Biological Oxygen Demand	4.3815E-12kg
Oil & Grease	1.2849E-14kg
Phosphates	3.8540E-14kg
Nitrates	3.2576E-15kg

B2.3.2 : Air Emissions

Carbon dioxide	0.20666kg
Carbon monoxide	0.0073063kg

Sulphur dioxide	0.007kg
Dust particles (PM2.5 – PM10)	0.00192kg
Cadmium (heavy metal to air)	1.0E-08kg
Chromium (heavy metal to air)	5.0E-08kg
Copper (heavy metal to air)	1.7E-06kg
Lead (heavy metal to air)	1.1E-07kg
Mercury (heavy metal to air)	2.0E-08kg
Nickel (heavy metal to air)	7.0E-08kg
Selenium (heavy metal to air)	1.0E-08kg
Zinc (heavy metal to air)	1.0E-06kg

B3: DATA FOR CHOCOLATE MANUFACTURING STAGE

Data for this stage were collected from Cocoa Processing Company (CPC), Tema, Ghana.

The data represents the company's production data for the year 2004/2005.

B3.1: INPUTS

Cocoa liquor	0.1827kg
Cocoa butter	0.2960kg
Sugar	0.3011kg
Milk powder	0.2200kg
Vanillin	0.000049kg
Lecithin	0.0042kg
Electricity	0.03187kwh
Diesel	0.018434L
Water	0.37623L

B3.2: PRODUCTS

Chocolate	1.00kg

B3.3: ENVIRONMENTAL RELEASE

B3.3.1: Water Emissions

Total Dissolved Solids	1.4920E-12kg
Total Suspended Solids	1.1955E-12kg
Chemical Oxygen Demand	2.8439E-12kg
Biological Oxygen Demand	1.4605E-12kg
Oil & Grease	1.2849E-14kg
Phosphates	1.0625E-15kg
Nitrates	1.0859E-15kg

B3.3.2 : Air Emissions

Carbon dioxide	0.06885kg
Carbon monoxide	0.0024353kg

Sulphur dioxide	0.002333kg
Cadmium (heavy metal to air)	3.33E-09kg
Chromium (heavy metal to air)	1.67E-10kg
Copper (heavy metal to air)	5.67E-11kg
Lead (heavy metal to air)	3.67E-10kg
Mercury (heavy metal to air)	6.67E-10kg
Nickel (heavy metal to air)	2.33E-10kg
Selenium (heavy metal to air)	3.33E-09kg
Zinc (heavy metal to air)	3.33E-11kg

B3.4: BASIS FOR CALCULATION OF BOILER EMISSIONS

Composition of Diesel, 1kg.

Main Elements

C	0.865kg
H	0.133kg
O	0.000kg
N	0.000kg
S	0.0035kg

Trace Elements

Cd	0.01mg
Cr	0.05mg
Cu	1.7mg
Hg	0.02mg
Ni	0.07mg
Pb	0.11mg
Se	0.01mg
Zn	1mg

Density of Diesel: 0.84 kg/L

Combustion efficiency assumed: 90%

(Source: Ecoinvent LCA Database)

B4: DATA FOR TRANSPORTATION STAGE

Data for this stage were adapted from the GaBi 4 software database. The data were obtained in Germany, based on a 38 ton total capacity/26 ton payload long distance truck-trailer.

Parameter	Value
Average utilisation ratio	85%
Distance (start - destination)	250 km
Tonnage (ton complete. load forward)	22.1
[kg] Diesel per kg cargo	0.0032293
[kg] Diesel total consumption	71.367
Emissions	**Amount**
Carbon dioxide [Inorganic emissions to air]	0.010184
Carbon monoxide [Inorganic emissions to air]	2.36E-05
Dust (unspecified) [Particles to air]	5.92E-06
Methane [Organic emissions to air (group VOC)]	1.03E-08
Nitrogen oxides [Inorganic emissions to air]	1.26E-04
NMVOC (unspecified) [Group NMVOC to air]	9.95E-06
Sulphur dioxide [Inorganic emissions to air]	9.69E-06

(Source: GaBi 4 professional database)

APPENDIX C: LIFE CYCLE INVENTORY RESULTS FOR THE PRODUCTION OF 1 KG CHOCOLATE IN GHANA

Appendix C presents an inventory of material and energy resources inputs; and products, by-products and emissions outputs resulting from the production of 1 kg chocolate in Ghana. The inventory data were obtained by performing life cycle inventory analysis on the inputs and outputs data in the various unit processes identified in figure 4.2, and aggregating the results. For example, if diesel is an input into a process, the resource consumption (crude oil, etc.) and emissions resulting from the production of diesel are added to the resource inputs and emissions output of the particular process. Hence diesel does not appear in the final inventory table. The inventory analysis was done with the help of the GaBi LCA software.

INPUTS-OUTPUTS	Unit	Total Inventory	Chocolate manufacturing	Cocoa processing	Cocoa production	Transpor-tation
RESOURCES						
Land use	kg	3.4053E-05	0.0000E+00	0.0000E+00	3.4053E-05	0.0000E+00
Energy resources						
Crude oil (resource)	kg	7.8752E-02	1.6686E-02	5.0022E-02	1.0616E-02	1.4286E-03
Hard coal (resource)	kg	4.8666E-03	8.4921E-07	2.5459E-06	4.8631E-03	7.2707E-08
Lignite (resource)	kg	4.2739E-03	4.8210E-05	1.4453E-04	4.0771E-03	4.1276E-06
Natural gas (resource)	kg	3.0963E-03	7.5824E-04	2.2731E-03	0.0000E+00	6.4918E-05
Uranium (resource)	kg	3.2593E-07	7.6963E-09	2.3073E-08	2.9450E-07	6.5893E-10
Renewable energy resources	kg	8.2468E-06	2.0180E-06	6.0497E-06	6.3431E-09	1.7277E-07
Wood	kg	6.3431E-09	0.0000E+00	0.0000E+00	6.3431E-09	0.0000E+00
Material resources						
Antimonite	kg	1.5348E-13	0.0000E+00	0.0000E+00	1.5348E-13	0.0000E+00
Barium sulphate	kg	5.7354E-05	0.0000E+00	0.0000E+00	5.7354E-05	0.0000E+00
Basalt	kg	1.1314E-05	0.0000E+00	0.0000E+00	1.1314E-05	0.0000E+00
Bentonite	kg	5.0664E-04	1.2236E-04	3.6681E-04	7.0001E-06	1.0476E-05

INPUTS-OUTPUTS	Unit	Total Inventory	Chocolate manufacturing	Cocoa processing	Cocoa production	Transpor-tation
Material resources inputs cont'd						
Borax	kg	1.7783E-09	0.0000E+00	0.0000E+00	1.7783E-09	0.0000E+00
Chrysotile	kg	5.9467E-09	0.0000E+00	0.0000E+00	5.9467E-09	0.0000E+00
Cinnabar	kg	5.5106E-10	0.0000E+00	0.0000E+00	5.5106E-10	0.0000E+00
Clay	kg	3.0907E-04	0.0000E+00	0.0000E+00	3.0907E-04	0.0000E+00
Colemanite ore	kg	5.0462E-08	0.0000E+00	0.0000E+00	5.0462E-08	0.0000E+00
Diatomite	kg	1.4782E-12	0.0000E+00	0.0000E+00	1.4782E-12	0.0000E+00
Dolomite	kg	5.1934E-07	0.0000E+00	0.0000E+00	5.1934E-07	0.0000E+00
Feldspar (aluminum silicates)	kg	3.6756E-13	0.0000E+00	0.0000E+00	3.6756E-13	0.0000E+00
Fluorspar (calcium fluoride; fluorite)	kg	1.6557E-06	0.0000E+00	0.0000E+00	1.6557E-06	0.0000E+00
Granite	kg	1.3989E-09	0.0000E+00	0.0000E+00	1.3989E-09	0.0000E+00
Gypsum (natural gypsum)	kg	1.9936E-08	0.0000E+00	0.0000E+00	1.9936E-08	0.0000E+00
Inert rock	kg	1.1214E-02	2.7460E-03	8.2324E-03	0.0000E+00	2.3511E-04
Iron ore	kg	3.1522E-06	7.7194E-07	2.3142E-06	0.0000E+00	6.6091E-08
Kaolinite (24% in ore as mined)	kg	7.5891E-08	0.0000E+00	0.0000E+00	7.5891E-08	0.0000E+00
Kieserite (25% in ore as mined)	kg	4.6384E-10	0.0000E+00	0.0000E+00	4.6384E-10	0.0000E+00
Limestone (calcium carbonate)	kg	4.7728E-04	6.8220E-06	2.0452E-05	4.4942E-04	5.8408E-07
Magnesit (Magnesium carbonate)	kg	2.7821E-02	0.0000E+00	0.0000E+00	2.7821E-02	0.0000E+00
Olivine	kg	6.3998E-11	0.0000E+00	0.0000E+00	6.3998E-11	0.0000E+00
Sylvite (25% in Sylvinite)	kg	6.9504E-02	0.0000E+00	0.0000E+00	6.9504E-02	0.0000E+00
Ulexite	kg	1.4612E-09	0.0000E+00	0.0000E+00	1.4612E-09	0.0000E+00
Vermiculite	kg	3.5001E-10	0.0000E+00	0.0000E+00	3.5001E-10	0.0000E+00
Renewable resources	kg	7.8764E+00	4.8276E-01	1.1930E+00	6.1957E+00	4.9763E-03
Water (ground water)	kg	1.3002E+00	1.5712E-01	3.7693E-01	7.6613E-01	0.0000E+00
Water (lake water)	kg	2.3131E-01	6.7944E-02	1.6300E-01	3.6607E-04	0.0000E+00
Water (river water)	kg	5.0231E+00	1.9958E-01	4.7879E-01	4.3448E+00	0.0000E+00
Water (sea water)	kg	2.3367E-02	0.0000E+00	0.0000E+00	2.3367E-02	0.0000E+00
Cocoa beans	kg	0.0000E+00	0.0000E+00	8.6834E-01	0.0000E+00	0.0000E+00
Cocoa Liquor plus Butter	kg	0.0000E+00	4.7850E-01	0.0000E+00	0.0000E+00	0.0000E+00
Cocoa seeds	kg	1.5324E-03	0.0000E+00	0.0000E+00	1.5324E-03	0.0000E+00
Lecithin	kg	4.2000E-03	4.2000E-03	0.0000E+00	0.0000E+00	0.0000E+00
Skimmed milk powder	kg	2.2000E-01	2.2000E-01	0.0000E+00	0.0000E+00	0.0000E+00
Sugar	kg	3.0110E-01	3.0110E-01	0.0000E+00	0.0000E+00	0.0000E+00
Vanillin	kg	4.9000E-05	4.9000E-05	0.0000E+00	0.0000E+00	0.0000E+00

INPUTS-OUTPUTS	Unit	Total Inventory	Chocolate manufacturing	Cocoa processing	Cocoa production	Transpor-tation
EMISSIONS TO AGRICULTURAL SOIL						
Heavy metals to agricultural soil						
Antimony	kg	5.4879E-15	0.0000E+00	0.0000E+00	5.4879E-15	0.0000E+00
Arsenic	kg	1.6594E-12	0.0000E+00	0.0000E+00	1.6594E-12	0.0000E+00
Cadmium	kg	8.2121E-12	0.0000E+00	0.0000E+00	8.2121E-12	0.0000E+00
Chromium (unspecified)	kg	3.9418E-10	0.0000E+00	0.0000E+00	3.9418E-10	0.0000E+00
Cobalt	kg	4.7574E-12	0.0000E+00	0.0000E+00	4.7574E-12	0.0000E+00
Copper	kg	3.6360E-05	0.0000E+00	0.0000E+00	3.6360E-05	0.0000E+00
Iron	kg	1.9992E-08	0.0000E+00	0.0000E+00	1.9992E-08	0.0000E+00
Lead	kg	1.1157E-10	0.0000E+00	0.0000E+00	1.1157E-10	0.0000E+00
Manganese	kg	4.3439E-09	0.0000E+00	0.0000E+00	4.3439E-09	0.0000E+00
Mercury	kg	1.9199E-13	0.0000E+00	0.0000E+00	1.9199E-13	0.0000E+00
Molybdenum	kg	1.3196E-12	0.0000E+00	0.0000E+00	1.3196E-12	0.0000E+00
Nickel	kg	2.4976E-10	0.0000E+00	0.0000E+00	2.4976E-10	0.0000E+00
Silver	kg	7.3626E-12	0.0000E+00	0.0000E+00	7.3626E-12	0.0000E+00
Strontium	kg	1.1723E-11	0.0000E+00	0.0000E+00	1.1723E-11	0.0000E+00
Tin	kg	2.1974E-12	0.0000E+00	0.0000E+00	2.1974E-12	0.0000E+00
Titanium	kg	2.9733E-10	0.0000E+00	0.0000E+00	2.9733E-10	0.0000E+00
Vanadium	kg	8.4953E-12	0.0000E+00	0.0000E+00	8.4953E-12	0.0000E+00
Zinc	kg	2.5769E-09	0.0000E+00	0.0000E+00	2.5769E-09	0.0000E+00
Inorganic emissions to agricultural soil						
Aluminum	kg	6.1732E-09	0.0000E+00	0.0000E+00	6.1732E-09	0.0000E+00
Barium	kg	3.2962E-12	0.0000E+00	0.0000E+00	3.2962E-12	0.0000E+00
Chlorine	kg	6.9095E-10	0.0000E+00	0.0000E+00	6.9095E-10	0.0000E+00
Phosphorus	kg	6.8522E-04	0.0000E+00	0.0000E+00	6.8522E-04	0.0000E+00
Sulphur	kg	1.4304E-03	0.0000E+00	0.0000E+00	1.4304E-03	0.0000E+00
Organic emissions to agricultural soil						
Carbon (unspecified)	kg	2.8148E-08	0.0000E+00	0.0000E+00	2.8148E-08	0.0000E+00
Metaldehyde	kg	7.0794E-14	0.0000E+00	0.0000E+00	7.0794E-14	0.0000E+00
Oil (unspecified)	kg	4.1428E-05	0.0000E+00	0.0000E+00	4.1428E-05	0.0000E+00
Other emissions to agricultural soil						
Pesticides to agricultural soil	kg	6.7000E-07	0.0000E+00	0.0000E+00	6.7000E-07	0.0000E+00
Bifenthrin	kg	7.1714E-09	0.0000E+00	0.0000E+00	7.1714E-09	0.0000E+00
Pirimicarb	kg	6.6263E-07	0.0000E+00	0.0000E+00	6.6263E-07	0.0000E+00

INPUTS-OUTPUTS	Unit	Total Inventory	Chocolate manufacturing	Cocoa processing	Cocoa production	Transportation
EMISSIONS TO AIR						
Heavy metals to air						
Antimony	kg	5.6568E-10	2.5090E-13	7.5218E-13	5.6465E-10	2.1481E-14
Arsenic	kg	6.7295E-09	1.1400E-11	3.4176E-11	6.6829E-09	9.7601E-13
Cadmium	kg	1.8926E-08	3.3502E-09	1.0047E-08	5.5276E-09	1.4483E-12
Chromium (unspecified)	kg	7.0178E-08	2.3204E-10	5.0175E-08	1.9766E-08	5.5970E-12
Chromium +VI	kg	4.6441E-10	0.0000E+00	0.0000E+00	4.6441E-10	0.0000E+00
Cobalt	kg	7.1414E-09	1.3207E-12	3.9593E-12	7.1360E-09	1.1307E-13
Copper	kg	3.2549E-05	6.4759E-11	1.6993E-06	3.0850E-05	6.9294E-13
Iron	kg	8.3262E-08	1.5277E-09	4.5800E-09	7.7024E-08	1.3080E-10
Lanthanides	kg	9.9313E-13	2.4320E-13	7.2910E-13	0.0000E+00	2.0822E-14
Lead	kg	1.4214E-07	4.6163E-10	1.1024E-07	3.1433E-08	8.1313E-12
Manganese	kg	2.7135E-09	1.6809E-11	5.0391E-11	2.6449E-09	1.4391E-12
Mercury	kg	2.7617E-08	6.6920E-09	2.0068E-08	8.5519E-10	2.1705E-12
Molybdenum	kg	2.6944E-09	1.0359E-12	3.1056E-12	2.6902E-09	8.8693E-14
Nickel	kg	1.9438E-07	2.6810E-10	7.0075E-08	1.2403E-07	2.9771E-12
Platinum	kg	1.3139E-15	0.0000E+00	0.0000E+00	1.3139E-15	0.0000E+00
Selenium	kg	1.6821E-08	3.3591E-09	1.0073E-08	3.3868E-09	2.2127E-12
Silver	kg	9.2882E-15	0.0000E+00	0.0000E+00	9.2882E-15	0.0000E+00
Thallium	kg	4.4409E-12	1.2776E-13	3.8301E-13	3.9192E-12	1.0938E-14
Tin	kg	6.4252E-10	6.2340E-13	1.8689E-12	6.3998E-10	5.3374E-14
Titanium	kg	5.4701E-10	4.4777E-11	1.3424E-10	3.6416E-10	3.8337E-12
Vanadium	kg	3.9023E-07	2.4443E-12	7.3279E-12	3.9022E-07	2.0928E-13
Zinc	kg	1.0284E-06	1.7770E-10	1.0000E-06	2.8148E-08	1.2360E-11
Inorganic emissions to air						
Ammonia	kg	6.0601E-07	2.2335E-09	6.6957E-09	5.9689E-07	1.9122E-10
Barium	kg	1.4796E-09	2.9461E-11	8.8323E-11	1.3592E-09	2.5224E-12
Beryllium	kg	4.8868E-12	1.8009E-13	5.3990E-13	4.1514E-12	1.5419E-14
Boron	kg	1.4555E-09	0.0000E+00	0.0000E+00	1.4555E-09	0.0000E+00
Boron compounds (unspecified)	kg	1.3755E-07	2.8953E-09	8.6800E-09	1.2573E-07	2.4789E-10
Bromine	kg	7.9289E-09	0.0000E+00	0.0000E+00	7.9289E-09	0.0000E+00
Carbon dioxide	kg	3.4727E-01	7.4148E-02	2.2235E-01	4.3183E-02	7.5834E-03
Carbon disulphide	kg	1.0761E-07	0.0000E+00	0.0000E+00	1.0761E-07	0.0000E+00
Carbon monoxide	kg	9.8367E-03	2.4389E-03	7.3140E-03	7.6991E-05	6.8817E-06

INPUTS-OUTPUTS	Unit	Total Inventory	Chocolate manufacturing	Cocoa processing	Cocoa production	Transpor-tation
Inorganic emissions to air cont'd						
Chlorine	kg	8.7784E-09	0.0000E+00	0.0000E+00	8.7784E-09	0.0000E+00
Cyanide (unspecified)	kg	7.9289E-09	0.0000E+00	0.0000E+00	7.9289E-09	0.0000E+00
Fluorides	kg	6.1737E-10	1.5119E-10	4.5324E-10	0.0000E+00	1.2944E-11
Fluorine	kg	5.9467E-10	0.0000E+00	0.0000E+00	5.9467E-10	0.0000E+00
Helium	kg	3.8059E-08	0.0000E+00	0.0000E+00	3.8059E-08	0.0000E+00
Hydrogen	kg	1.3026E-07	0.0000E+00	0.0000E+00	1.3026E-07	0.0000E+00
Hydrogen chloride	kg	1.4702E-06	4.3884E-08	1.3156E-07	1.2910E-06	3.7572E-09
Hydrogen cyanide (prussic acid)	kg	2.5142E-14	6.1570E-15	1.8458E-14	0.0000E+00	5.2715E-16
Hydrogen fluoride	kg	4.9397E-06	1.1809E-08	3.5403E-08	4.8915E-06	1.0111E-09
Hydrogen sulphide	kg	2.0488E-07	2.4413E-10	7.3187E-10	2.0389E-07	2.0901E-11
Iodine	kg	4.2760E-09	0.0000E+00	0.0000E+00	4.2760E-09	0.0000E+00
Nitrate	kg	3.5057E-11	0.0000E+00	0.0000E+00	3.5057E-11	0.0000E+00
Nitrogen oxides	kg	2.7800E-04	3.9313E-05	1.1786E-04	6.7674E-05	5.3158E-05
Nitrous oxide (laughing gas)	kg	9.4524E-07	2.6651E-08	7.8428E-08	8.3809E-07	2.0717E-09
Ozone	kg	1.5008E-07	0.0000E+00	0.0000E+00	1.5008E-07	0.0000E+00
Phosphorus	kg	2.3051E-09	0.0000E+00	0.0000E+00	2.3051E-09	0.0000E+00
Scandium	kg	1.8524E-12	1.6932E-13	5.0760E-13	1.1610E-12	1.4497E-14
Silicium tetrafluoride	kg	1.6141E-12	0.0000E+00	0.0000E+00	1.6141E-12	0.0000E+00
Steam	kg	1.1808E-06	0.0000E+00	0.0000E+00	1.1808E-06	0.0000E+00
Strontium	kg	1.3635E-09	2.4320E-12	7.2910E-12	1.3536E-09	2.0822E-13
Sulphur dioxide	kg	9.5298E-03	2.3423E-03	7.0240E-03	1.6005E-04	3.4844E-06
Sulphur hexafluoride	kg	2.3843E-09	0.0000E+00	0.0000E+00	2.3843E-09	0.0000E+00
Sulphuric acid	kg	1.3451E-12	3.2940E-13	9.8752E-13	0.0000E+00	2.8202E-14
Organic emissions to air (group VOC)						
Group NMVOC to air	kg	5.4275E-04	1.2504E-04	3.7487E-04	2.8960E-05	1.3869E-05
Methane	kg	3.4946E-04	6.3371E-05	1.8998E-04	9.0673E-05	5.4295E-06
Other emissions to air						
Particles to air						
Aluminum	kg	7.7716E-07	0.0000E+00	0.0000E+00	7.7716E-07	0.0000E+00
Dust (> PM10)	kg	1.0840E-04	0.0000E+00	0.0000E+00	1.0840E-04	0.0000E+00
Dust (PM2,5 - PM10)	kg	2.0110E-03	0.0000E+00	1.9192E-03	9.1805E-05	0.0000E+00
Dust (PM2.5)	kg	4.0945E-05	0.0000E+00	0.0000E+00	4.0945E-05	0.0000E+00
Dust (unspecified)	kg	4.0897E-06	3.8774E-07	1.1624E-06	0.0000E+00	2.5395E-06

INPUTS-OUTPUTS	Unit	Total Inventory	Chocolate manufacturing	Cocoa processing	Cocoa production	Transpor-tation
Pesticides to air	kg	8.1189E-04	0.0000E+00	0.0000E+00	8.1189E-04	0.0000E+00
Bifenthrin	kg	6.0804E-09	0.0000E+00	0.0000E+00	6.0804E-09	0.0000E+00
Pesticides, unspecified (pesticide)	kg	8.0626E-04	0.0000E+00	0.0000E+00	8.0626E-04	0.0000E+00
Pirimicarb	kg	5.6182E-06	0.0000E+00	0.0000E+00	5.6182E-06	0.0000E+00
Radioactive emissions to air	kg	4.7027E+03	5.4665E-11	1.6388E-10	4.7027E+03	4.6802E-12
EMISSIONS TO FRESHWATER						
Analytical measures to fresh water						
Adsorbable organic halogen compounds (AOX)	kg	1.4261E-09	1.9841E-10	5.9482E-10	6.1588E-10	1.6987E-11
Biological oxygen demand (BOD)	kg	1.0903E-04	3.3804E-08	1.0134E-07	1.0890E-04	2.8940E-09
Chemical oxygen demand (COD)	kg	4.5095E-04	1.9734E-07	5.9160E-07	4.5015E-04	1.6895E-08
Solids (dissolved)	kg	1.8498E-05	0.0000E+00	0.0000E+00	1.8498E-05	0.0000E+00
Total dissolved organic bounded carbon	kg	3.3172E-05	0.0000E+00	0.0000E+00	3.3172E-05	0.0000E+00
Total organic bounded carbon	kg	7.3827E-05	9.9051E-06	2.9695E-05	3.3379E-05	8.4805E-07
Heavy metals to fresh water						
Antimony	kg	3.0526E-09	0.0000E+00	0.0000E+00	3.0526E-09	0.0000E+00
Arsenic	kg	4.3887E-07	5.3397E-11	1.6008E-10	4.3865E-07	4.5717E-12
Cadmium	kg	4.3578E-07	4.9148E-10	1.4734E-09	4.3378E-07	4.2080E-11
Cesium	kg	4.4968E-10	0.0000E+00	0.0000E+00	4.4968E-10	0.0000E+00
Chromium (unspecified)	kg	1.3395E-08	3.2802E-09	9.8337E-09	0.0000E+00	2.8084E-10
Chromium +VI	kg	1.2444E-06	0.0000E+00	0.0000E+00	1.2444E-06	0.0000E+00
Cobalt	kg	8.3820E-08	0.0000E+00	0.0000E+00	8.3820E-08	0.0000E+00
Copper	kg	6.5135E-04	1.6408E-09	4.9191E-09	6.5134E-04	1.4048E-10
Heavy metals to water (unspecified)	kg	1.3458E-08	3.2956E-09	9.8798E-09	0.0000E+00	2.8216E-10
Iron	kg	1.5357E-05	1.7101E-07	5.1268E-07	1.4659E-05	1.4642E-08
Lead	kg	1.3710E-06	8.9769E-11	2.6912E-10	1.3707E-06	7.6858E-12
Manganese	kg	3.8176E-08	0.0000E+00	0.0000E+00	3.8176E-08	0.0000E+00
Mercury	kg	2.1182E-07	7.0190E-12	2.1042E-11	2.1179E-07	6.0095E-13
Molybdenum	kg	1.1203E-08	0.0000E+00	0.0000E+00	1.1203E-08	0.0000E+00
Nickel	kg	1.9498E-06	3.2879E-09	9.8567E-09	1.9364E-06	2.8150E-10
Selenium	kg	1.4727E-09	0.0000E+00	0.0000E+00	1.4727E-09	0.0000E+00
Silver	kg	6.6536E-10	0.0000E+00	0.0000E+00	6.6536E-10	0.0000E+00
Strontium	kg	2.7237E-06	0.0000E+00	0.0000E+00	2.7237E-06	0.0000E+00
Thallium	kg	5.4879E-11	0.0000E+00	0.0000E+00	5.4879E-11	0.0000E+00
Tin	kg	5.8334E-11	0.0000E+00	0.0000E+00	5.8334E-11	0.0000E+00

INPUTS-OUTPUTS	Unit	Total Inventory	Chocolate manufacturing	Cocoa processing	Cocoa production	Transportation
Heavy metals to fresh water cont'd						
Titanium	kg	2.4580E-09	0.0000E+00	0.0000E+00	2.4580E-09	0.0000E+00
Tungsten	kg	9.6280E-10	0.0000E+00	0.0000E+00	9.6280E-10	0.0000E+00
Vanadium	kg	3.6924E-09	0.0000E+00	0.0000E+00	3.6924E-09	0.0000E+00
Zinc	kg	5.8111E-06	2.0195E-10	6.0543E-10	5.8103E-06	1.7290E-11
Inorganic emissions to fresh water						
Acid (calculated as H+)	kg	1.0199E-09	1.2298E-13	3.6870E-13	1.0194E-09	1.0530E-14
Aluminum	kg	1.7762E-06	4.8534E-07	1.1643E-06	1.2652E-07	0.0000E+00
Ammonium / ammonia	kg	1.3176E-06	2.9543E-07	8.8567E-07	1.1123E-07	2.5294E-08
Barium	kg	3.9690E-07	0.0000E+00	0.0000E+00	3.9690E-07	0.0000E+00
Beryllium	kg	5.8901E-12	0.0000E+00	0.0000E+00	5.8901E-12	0.0000E+00
Boron	kg	1.4046E-08	0.0000E+00	0.0000E+00	1.4046E-08	0.0000E+00
Bromate	kg	3.1489E-08	0.0000E+00	0.0000E+00	3.1489E-08	0.0000E+00
Bromine	kg	3.2452E-07	0.0000E+00	0.0000E+00	3.2452E-07	0.0000E+00
Calcium	kg	9.3572E-05	0.0000E+00	0.0000E+00	9.3572E-05	0.0000E+00
Carbonate	kg	2.9337E-08	0.0000E+00	0.0000E+00	2.9337E-08	0.0000E+00
Chlorate	kg	2.4410E-07	0.0000E+00	0.0000E+00	2.4410E-07	0.0000E+00
Chloride	kg	9.3762E-03	1.0453E-03	3.1327E-03	5.1089E-03	8.9336E-05
Chlorine (dissolved)	kg	1.3025E-07	3.7623E-08	9.0258E-08	2.3730E-09	0.0000E+00
Cyanide	kg	2.2880E-06	4.6178E-15	1.3844E-14	2.2880E-06	3.9536E-16
Fluoride	kg	4.3189E-06	1.6886E-08	5.0622E-08	4.2500E-06	1.4457E-09
Hydrogen sulphide	kg	1.6254E-10	0.0000E+00	0.0000E+00	1.6254E-10	0.0000E+00
Hydroxide	kg	3.7549E-10	0.0000E+00	0.0000E+00	3.7549E-10	0.0000E+00
Hypochlorite	kg	5.1311E-09	0.0000E+00	0.0000E+00	5.1311E-09	0.0000E+00
Iodide	kg	4.5478E-08	0.0000E+00	0.0000E+00	4.5478E-08	0.0000E+00
Magnesium	kg	4.4763E-04	0.0000E+00	0.0000E+00	4.4763E-04	0.0000E+00
Metal ions (unspecific)	kg	5.7201E-10	0.0000E+00	0.0000E+00	5.7201E-10	0.0000E+00
Neutral salts	kg	6.0185E-07	1.4738E-07	4.4185E-07	0.0000E+00	1.2619E-08
Nitrate	kg	4.4319E-07	1.0078E-08	3.0212E-08	4.0204E-07	8.6281E-10
Nitrite	kg	1.4215E-09	0.0000E+00	0.0000E+00	1.4215E-09	0.0000E+00
Nitrogen	kg	1.5461E-07	0.0000E+00	0.0000E+00	1.5461E-07	0.0000E+00
Nitrogen organic bounded	kg	1.6958E-07	0.0000E+00	0.0000E+00	1.6958E-07	0.0000E+00
Phosphate	kg	1.9883E-04	3.9236E-09	1.1763E-08	1.9881E-04	3.3592E-10
Phosphorus	kg	2.1299E-04	0.0000E+00	0.0000E+00	2.1299E-04	0.0000E+00
Potassium	kg	6.2039E-05	0.0000E+00	0.0000E+00	6.2039E-05	0.0000E+00

INPUTS-OUTPUTS	Unit	Total Inventory	Chocolate manufacturing	Cocoa processing	Cocoa production	Transportation
Inorganic emissions to fresh water cont'd						
Rubidium	kg	6.5130E-09	0.0000E+00	0.0000E+00	6.5130E-09	0.0000E+00
Scandium	kg	4.4006E-10	0.0000E+00	0.0000E+00	4.4006E-10	0.0000E+00
Sodium	kg	5.6089E-03	6.7604E-04	2.0267E-03	2.8483E-03	5.7881E-05
Sulphate	kg	1.5399E-04	1.4738E-06	4.4185E-06	1.4797E-04	1.2619E-07
Sulphide	kg	1.6380E-09	0.0000E+00	0.0000E+00	1.6380E-09	0.0000E+00
Sulphite	kg	2.8148E-08	0.0000E+00	0.0000E+00	2.8148E-08	0.0000E+00
Sulphur	kg	4.5979E-04	0.0000E+00	0.0000E+00	4.5979E-04	0.0000E+00
Organic emissions to fresh water						
Halogenated organic emissions to fresh water	kg	8.6481E-09	7.6963E-15	2.3073E-14	8.6481E-09	6.5893E-16
Chlorous dissolvent	kg	4.7007E-10	0.0000E+00	0.0000E+00	4.7007E-10	0.0000E+00
Dichloroethane (ethylene dichloride)	kg	4.8876E-11	0.0000E+00	0.0000E+00	4.8876E-11	0.0000E+00
Dichloromethane (methylene chloride)	kg	8.0988E-09	0.0000E+00	0.0000E+00	8.0988E-09	0.0000E+00
Polychlorinated dibenzo-p-dioxins (2,3,7,8 - TCDD)	kg	3.1428E-14	7.6963E-15	2.3073E-14	0.0000E+00	6.5893E-16
Trichloromethane (chloroform)	kg	1.0647E-17	0.0000E+00	0.0000E+00	1.0647E-17	0.0000E+00
Vinyl chloride (VCM; chloroethene)	kg	3.0300E-11	0.0000E+00	0.0000E+00	3.0300E-11	0.0000E+00
Hydrocarbons to fresh water	kg	6.5060E-05	1.6369E-06	4.9074E-06	5.8376E-05	1.4015E-07
Acenaphthene	kg	2.7978E-12	0.0000E+00	0.0000E+00	2.7978E-12	0.0000E+00
Acenaphthylene	kg	1.7500E-13	0.0000E+00	0.0000E+00	1.7500E-13	0.0000E+00
Acetic acid	kg	6.0600E-10	0.0000E+00	0.0000E+00	6.0600E-10	0.0000E+00
Alkane (unspecified)	kg	5.8334E-08	0.0000E+00	0.0000E+00	5.8334E-08	0.0000E+00
Alkene (unspecified)	kg	5.3973E-09	0.0000E+00	0.0000E+00	5.3973E-09	0.0000E+00
Aromatic hydrocarbons (unspecified)	kg	2.4000E-07	0.0000E+00	0.0000E+00	2.4000E-07	0.0000E+00
Benzene	kg	3.1423E-08	0.0000E+00	0.0000E+00	3.1423E-08	0.0000E+00
Butene	kg	9.9678E-13	0.0000E+00	0.0000E+00	9.9678E-13	0.0000E+00
Ethene (ethylene)	kg	1.0364E-09	0.0000E+00	0.0000E+00	1.0364E-09	0.0000E+00
Ethyl benzene	kg	1.0818E-08	0.0000E+00	0.0000E+00	1.0818E-08	0.0000E+00
Ethylene oxide	kg	3.5227E-13	0.0000E+00	0.0000E+00	3.5227E-13	0.0000E+00
Fatty acids (calculated as total carbon)	kg	1.6548E-06	0.0000E+00	0.0000E+00	1.6548E-06	0.0000E+00
Formaldehyde (methanal)	kg	3.0583E-10	0.0000E+00	0.0000E+00	3.0583E-10	0.0000E+00
Hydrocarbons (unspecified)	kg	6.0248E-06	1.4731E-06	4.4161E-06	9.4826E-09	1.2612E-07
Methanol	kg	4.0333E-10	7.6717E-11	2.2999E-10	9.0050E-11	6.5683E-12
Methyl tert-butylether	kg	6.2178E-09	0.0000E+00	0.0000E+00	6.2178E-09	0.0000E+00
Oil (unspecified)	kg	5.6215E-05	0.0000E+00	0.0000E+00	5.6215E-05	0.0000E+00
Phenol (hydroxy benzene)	kg	7.0652E-07	1.6378E-07	4.9099E-07	3.7735E-08	1.4022E-08

INPUTS-OUTPUTS	Unit	Total Inventory	Chocolate manufacturing	Cocoa processing	Cocoa production	Transpor-tation
Organic emissions to fresh water cont'd						
Polycyclic aromatic hydrocarbons (unspec.)	kg	2.5992E-09	0.0000E+00	0.0000E+00	2.5992E-09	0.0000E+00
Propene	kg	2.2824E-09	0.0000E+00	0.0000E+00	2.2824E-09	0.0000E+00
Propylene oxide	kg	4.6554E-10	0.0000E+00	0.0000E+00	4.6554E-10	0.0000E+00
Sodium formate	kg	1.8406E-12	0.0000E+00	0.0000E+00	1.8406E-12	0.0000E+00
Toluene (methyl benzene)	kg	5.6251E-08	0.0000E+00	0.0000E+00	5.6251E-08	0.0000E+00
Xylene (isomers; dimethyl benzene)	kg	4.3044E-08	0.0000E+00	0.0000E+00	4.3044E-08	0.0000E+00
Cumene (isopropylbenzene)	kg	5.1708E-09	0.0000E+00	0.0000E+00	5.1708E-09	0.0000E+00
Ethylenediamine	kg	1.8860E-14	0.0000E+00	0.0000E+00	1.8860E-14	0.0000E+00
VOC	kg	1.6084E-07	0.0000E+00	0.0000E+00	1.6084E-07	0.0000E+00
Other emissions to fresh water						
Particles to fresh water	kg	1.8556E-06	0.0000E+00	0.0000E+00	1.8556E-06	0.0000E+00
Solids (suspended)	kg	1.8556E-06	0.0000E+00	0.0000E+00	1.8556E-06	0.0000E+00
Radioactive emissions to fresh water	kg	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
PRODUCT/BY-PRODUCTS						
Chocolate	kg	1.0000E+00	1.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Cocoa bean sweatings	kg	2.8238E-01	0.0000E+00	0.0000E+00	2.8238E-01	0.0000E+00
Cocoa beans	kg	0.0000E+00	0.0000E+00	0.0000E+00	8.6834E-01	0.0000E+00
Cocoa Cake	kg	2.3340E-01	0.0000E+00	2.3340E-01	0.0000E+00	0.0000E+00
Cocoa Liquor plus Butter	kg	0.0000E+00	0.0000E+00	4.7850E-01	0.0000E+00	0.0000E+00
Cocoa pod husk	kg	6.8876E+00	0.0000E+00	0.0000E+00	6.8876E+00	0.0000E+00
Cocoa Powder	kg	6.5173E-02	0.0000E+00	6.5173E-02	0.0000E+00	0.0000E+00
Cocoa Shells	kg	8.5064E-02	0.0000E+00	8.5064E-02	0.0000E+00	0.0000E+00

APPENDIX D

DESCRIPTION OF ENVIRONMENTAL IMPACT CATEGORIES USED IN THE STUDY

This appendix describes the impact categories considered in this study. A detailed discussion can be found in Heijungs *et al* (1992) and Guinee *et al* (2001).

D.1: ABIOTIC RESOURCES DEPLETION

Abiotic resources are natural resources such as iron ore, which are regarded as non-living. The debate on the characterization of depletion-related impact categories is not settled.

Impact category	Abiotic depletion
LCI results	Extraction of minerals and fossil fuels
Characterization model	Concentration-based reserves and rate of de-accumulation approach
Category indicator	Depletion of the ultimate reserve in relation to annual use
Characterization factor	Abiotic depletion potential (ADP) for each extraction of minerals and fossil fuels (in kg antimony equivalents/kg extraction
Unit of indicator result	Kg (Sb eq)

D.2: CLIMATE CHANGE

Climate change is defined here as the impact of human emissions on the radiative forcing (i.e. heat radiation absorption) of the atmosphere. This may in turn have adverse impacts on ecosystem health, human health and material welfare. Most of these emissions enhance radiative forcing, causing the temperature at the earth's surface to rise.

Impact category	Climate change
LCI results	Emissions of greenhouse gases to air
Characterization model	The model developed by the Intergovernmental Panel on Climate Change (IPCC) defining the global warming potential of different greenhouse gases
Category indicator	Infrared radiative forcing (W/m^2)
Characterization factor	Global warming potential for a 100 year time horizon (GWP100) for each greenhouse gas emission to the air (in kg carbon dioxide equivalent/kg emission)
Unit of indicator result	Kg (carbon dioxide eq)

D.3: STRATOSPHERIC OZONE DEPLETION

Stratospheric ozone depletion refers to the thinning of the stratosphereic ozone layer as a result of anthropogenic emissions. This causes a greater fraction of solar UV-B radiation to reach the earth's surface, with potentially harmful impacts on human and animal health, terrestrial and aquatic ecosystems, biochemical cycles and materials.

Impact category	Stratospheric ozone depletion
LCI results	Emissions of ozone-depletion gases to the air
Characterization model	The model developed by the World Meteorological Organization (WMO), defining the ozone depletion potential of different gases
Category indicator	Stratospheric ozone breakdown
Characterization factor	Ozone depletion potential in the steady state (ODP steady state) for each emission to the air (in kg CFC-11 equivalent/kg emission
Unit of indicator result	Kg (CFC-11 eq)

D.4: HUMAN TOXICITY

This impact category covers the impacts on human health of toxic substances present in the environment. The area of concern is human health.

Impact category	Human toxicity
LCI results	Emissions of toxic substances to air, water and soil
Characterization model	USES 2.0 model developed at RIVM, describing fate, exposure and effects of toxic substances, adapted to LCA
Category indicator	Acceptable daily intake/predicted daily intake
Characterization factor	Human-toxicity potential (HTP) for each emission of a toxic substance to air, water and/or soil (in kg 1,4-dichlorobenzene equivalent/kg emission)
Unit of indicator result	Kg (1,4-dichlorobenzene)

D.5: ECOTOXICITY

This impact category covers the impacts of toxic substances on aquatic and terrestrial ecosystems. The area of concern is the natural environment (and natural resources).

D.5.1: Freshwater aquatic ecotoxicity

Freshwater aquatic ecotoxicity refers to the impacts of toxic substances on freshwater aquatic ecosystems.

Impact category	Freshwater aquatic ecotoxicity
LCI results	Emissions of toxic substances to air, water and soil
Characterization model	USES 2.0 model developed at RIVM, describing fate, exposure and effects of toxic substances, adapted to LCA
Category indicator	Predicted environmental concentration/predicted no-effect concentration
Characterization factor	Freshwater aquatic ecotoxicity potential (FAETP) for each emission of a toxic substance to air, water and/or soil (in kg 1,4-dichlorobenzene equivalents/kg emission)
Unit of indicator result	Kg (1,4-dichlorobenzene eq)

D.5.2: Terrestrial ecotoxicity

Terrestrial ecotoxicity refers to impacts of toxic substances on terrestrial ecosystems.

Impact category	Terrestrial ecotoxicity
LCI results	Emissions of toxic substances to air, water and soil
Characterization model	USES 2.0 model developed at RIVM, describing fate, exposure and effects of toxic substances, adapted to LCA
Category indicator	Predicted environmental concentration/predicted no-effect concentration
Characterization factor	Terrestrial ecotoxicity potential (TETP) for each emission of a toxic substance to air, water and/or soil (in kg 1,4-dichlorobenzene equivalents/kg emission)
Unit of indicator result	Kg (1,4-dichlorobenzene eq)

D.6: PHOTO-OXIDANT FORMATION

Photo-oxidant formation is the formation of reactive chemical compounds such as ozone by the action of sunlight on certain primary air pollutants. These reactive compounds may be injurious to human health and ecosystems and may also damage crops. Photo-oxidant are formed in the troposphere under the influence of ultraviolet light, through photochemical oxidation of Volatile Organic Compounds and carbon monoxide (CO) in the presence of nitrogen oxides (NO_x). Ozone is considered the most important of these oxidizing compounds, along with peroxyacetylnitrate (PAN). Photo-oxidant formation is also known as summer smug, Los Angeles smog or secondary air pollution.

Impact category	Photo-oxidant formation
LCI results	Emissions of substances (VOC, CO) to air
Characterization model	UNECE Trajectory model
Category indicator	Tropospheric ozone formation
Characterization factor	Photochemical ozone creation potential (POCP) for each emission of VOC or CO to the air (in kg ethylene equivalents/kg emission)
Unit of indicator result	Kg (ethylene eq)

D.7: ACIDIFICATION

Acidification is the environmental impact caused by the build-up of protons in soils and lakes. Higher acidity in certain types of soils cause the mobilisation of different fixed ions, which are then absorbed by plants and damage them. Run-offs from acidic soils can harm aquatic ecosystems in the different lakes and rivers and in worst cases render them lifeless. Acidification can be caused directly by acids and indirectly by acidic anhydrides (sulphur dioxide and trioxide and oxides of nitrogen) and ammonia.

Impact category	Acidification
LCI results	Emissions of acidifying substances to the air
Characterization model	RAINS10 model, developed at IISA, describing the fate and deposition of acidifying substances, adapted to LCA
Category indicator	Deposition/acidification critical load
Characterization factor	Acidification potential (AP) for each acidifying emission to the air (in kg SO_2 equivalents/kg emission)
Unit of indicator result	Kg (SO_2 eq)

D.8: EUTROPHICATION

The cause of oxygen depletion found in the bottom layers of lakes and coastal waters is eutrophication. Eutrophication is defined here as an over enrichment of aquatic environments with macronutrients (the most important of which are nitrogen and phosphorous), leading to an increased production of plankton, algae and higher aquatic plants. The algae sink to the bottom and are broken down consuming oxygen in the bottom layer. If fresh oxygen-rich water from the surface does not reach the bottom layers, the oxygen concentration near the bottom will gradually be reduced until the bottom-dwelling organisms move away or die. In, addition, high nutrient concentration may render surface waters unacceptable as a source of drinking water.

Impact category	Eutrophication
LCI results	Emissions of nutrients to air, water and soil
Characterization model	The stoichiometric procedure, which identifies the equivalence between N and P for both terrestrial and aquatic systems
Category indicator	Deposition /N/P equivalents in biomass.
Characterization factor	Eutrophication potential (EP) for each eutrophying emission to air, water and soil (in kg PO4 equivalents/kg emission)
Unit of indicator result	Kg (PO_4 eq)

D.9: IMPACTS OF IONISING RADIATION

This impact covers the impacts arising from releases of radioactive substances as well as direct exposure to radiation. Exposure to ionizing radiation is harmful to both humans and animals.

Impact category	Impacts of ionising radiation
LCI results	Emissions of ionising radiation to air, water and soil
Characterization model	Fate and exposure models combined with epidemiological studies and the concept of disability-adjusted life years (DALY)
Category indicator	Disability-adjusted life years (DALY)
Characterization factor	Radioactive radiation potential (RRP)
Unit of indicator result	DALY

APPENDIX E

CHARACTERIZATION FACTORS USED IN THE IMPACT ASSESSMENT

Appendix E presents characterization factors based on the CML 2001 method, for emissions contributing to the various impact categories. The data were taken from the GaBi 4 LCA software.

APPENDIX E1: CML 2001, ACIDIFICATION POTENTIAL

Flow	Kg SO_2-Equiv.
Ammonia [Inorganic emissions to air]	1.8800E+00
Ammonium [Inorganic emissions to air]	3.7600E+00
Ammonium nitrate [Inorganic emissions to air]	8.4600E-01
Hydrogen chloride [Inorganic emissions to agricultural soil]	8.8000E-01
Hydrogen chloride [Inorganic emissions to sea water]	8.8000E-01
Hydrogen chloride [Inorganic emissions to fresh water]	8.8000E-01
Hydrogen chloride [Inorganic emissions to industrial soil]	8.8000E-01
Hydrogen chloride [Inorganic emissions to air]	8.8000E-01
Hydrogen fluoride [Inorganic emissions to air]	1.6000E+00
Hydrogen fluoride (hydrofluoric acid) [Inorganic emissions to sea water]	1.6000E+00
Hydrogen fluoride (hydrofluoric acid) [Inorganic emissions to industrial soil]	1.6000E+00
Hydrogen fluoride (hydrofluoric acid) [Inorganic emissions to fresh water]	1.6000E+00
Hydrogen fluoride (hydrofluoric acid) [Inorganic emissions to agricultural soil]	1.6000E+00
Hydrogen sulphide [Inorganic emissions to air]	1.8800E+00
Hydrogen sulphide [Fresh water]	1.8800E+00
Hydrogen sulphide [Inorganic emissions to industrial soil]	1.8800E+00
Hydrogen sulphide [Inorganic emissions to agricultural soil]	1.8800E+00
Hydrogen sulphide [Inorganic emissions to sea water]	1.8800E+00
Nitric acid [Inorganic emissions to sea water]	5.1000E-01
Nitric acid [Inorganic emissions to fresh water]	5.1000E-01
Nitric acid [Inorganic emissions to agricultural soil]	5.1000E-01
Nitric acid [Inorganic emissions to industrial soil]	5.1000E-01
Nitrogen dioxide [Inorganic emissions to air]	7.0000E-01
Nitrogen oxides [Inorganic emissions to air]	7.0000E-01
Phosphoric acid [Inorganic emissions to fresh water]	9.8000E-01
Phosphoric acid [Inorganic emissions to agricultural soil]	9.8000E-01
Phosphoric acid [Inorganic emissions to sea water]	9.8000E-01
Phosphoric acid [Inorganic emissions to air]	9.8000E-01
Phosphoric acid [Inorganic emissions to industrial soil]	9.8000E-01
Sulphur dioxide [Inorganic emissions to air]	1.0000E+00
Sulphur trioxid [Inorganic emissions to air]	8.0000E-01
Sulphuric acid [Inorganic emissions to sea water]	6.5000E-01
Sulphuric acid [Inorganic emissions to agricultural soil]	6.5000E-01
Sulphuric acid [Inorganic emissions to air]	6.5000E-01
Sulphuric acid [Inorganic emissions to fresh water]	6.5000E-01
Sulphuric acid [Inorganic emissions to industrial soil]	6.5000E-01

APPENDIX E2: CML 2001, EUTROPHICATION POTENTIAL

Flow	kg Phosphate-Equiv.
Acetic acid [Hydrocarbons to sea water]	2.3500E-02
Ammonia [Inorganic emissions to fresh water]	2.8800E-01
Ammonia [Inorganic emissions to sea water]	3.5000E-01
Ammonia [Inorganic emissions to air]	3.5000E-01
Ammonium [Inorganic emissions to air]	3.3000E-01
Ammonium / ammonia [Inorganic emissions to fresh water]	3.3000E-01
Ammonium / ammonia [Fresh water]	3.3000E-01
Ammonium / ammonia [Inorganic emissions to sea water]	3.3000E-01
Ammonium nitrate [Inorganic emissions to air]	1.5175E-01
Biological oxygen demand (BOD) [Analytical measures to sea water]	2.2000E-02
Biological oxygen demand (BOD) [Analytical measures to fresh water]	2.2000E-02
Calcium nitrate (Ca(NO3)2) [Inorganic emissions to fresh water]	7.5610E-02
Calcium nitrate (Ca(NO3)2) [Inorganic emissions to sea water]	7.5610E-02
Chemical oxygen demand (COD) [Analytical measures to fresh water]	2.2000E-02
Chemical oxygen demand (COD) [Analytical measures to sea water]	2.2000E-02
Ethanol [Hydrocarbons to sea water]	4.4040E-02
Heptane [Hydrocarbons to sea water]	7.7440E-02
Hexane (isomers) [Hydrocarbons to fresh water]	7.7767E-02
Hexane (isomers) [Hydrocarbons to sea water]	7.7767E-02
Hydrocarbons (unspecified) [Hydrocarbons to fresh water]	7.5430E-02
Methanol [Hydrocarbons to fresh water]	3.3000E-02
Methanol [Hydrocarbons to sea water]	3.3000E-02
Nitrate [Fresh water]	1.0000E-01
Nitrate [Inorganic emissions to air]	1.0000E-01
Nitrate [Inorganic emissions to fresh water]	1.0000E-01
Nitrate [Inorganic emissions to sea water]	1.0000E-01
Nitric acid [Inorganic emissions to sea water]	1.0000E-01
Nitric acid [Inorganic emissions to industrial soil]	1.0000E-01
Nitric acid [Inorganic emissions to fresh water]	1.0000E-01
Nitrite [Inorganic emissions to sea water]	1.0000E-01
Nitrite [Fresh water]	1.0000E-01
Nitrite [Inorganic emissions to fresh water]	1.0000E-01
Nitrogen [Inorganic emissions to sea water]	4.2000E-01
Nitrogen [Inorganic emissions to fresh water]	4.2000E-01
Nitrogen [Inorganic emissions to industrial soil]	3.5000E-01
Nitrogen [Inorganic emissions to air]	4.2000E-01
Nitrogen dioxide [Inorganic emissions to air]	2.3500E-02
Nitrogen organic bounded [Fresh water]	2.8800E-01
Nitrogen organic bounded [Inorganic emissions to fresh water]	3.5000E-01
Nitrogen organic bounded [Inorganic emissions to sea water]	3.5000E-01
Nitrogen oxides [Inorganic emissions to air]	3.3000E-01
Octane [Hydrocarbons to sea water]	3.3000E-01
Oil (unspecified) [Hydrocarbons to fresh water]	3.3000E-01
Oil (unspecified) [Hydrocarbons to sea water]	3.3000E-01
Organic compounds (dissolved) [Organic emissions to sea water]	1.5175E-01
Organic compounds (dissolved) [Organic emissions to fresh water]	2.2000E-02
Organic compounds (unspecified) [Organic emissions to fresh water]	2.2000E-02
Organic compounds (unspecified) [Organic emissions to sea water]	7.5610E-02

Phosphate [Inorganic emissions to air]	7.5610E-02
Phosphate [Inorganic emissions to sea water]	2.2000E-02
Phosphate [Fresh water]	2.2000E-02
Phosphate [Inorganic emissions to fresh water]	4.4040E-02
Phosphoric acid [Inorganic emissions to sea water]	7.7440E-02
Phosphoric acid [Inorganic emissions to fresh water]	7.7767E-02
Phosphoric acid [Inorganic emissions to air]	7.7767E-02
Phosphoric acid [Inorganic emissions to industrial soil]	7.5430E-02
Phosphoruos-pent-oxide [Inorganic emissions to sea water]	3.3000E-02
Phosphoruos-pent-oxide [Inorganic emissions to air]	3.3000E-02
Phosphoruos-pent-oxide [Inorganic emissions to fresh water]	1.0000E-01
Phosphorus [Inorganic emissions to industrial soil]	1.0000E-01
Phosphorus [Inorganic emissions to sea water]	1.0000E-01
Phosphorus [Inorganic emissions to fresh water]	1.0000E-01
Phosphorus [Inorganic emissions to air]	1.0000E-01
Sodium nitrate (NaNO3) [Inorganic emissions to fresh water]	1.0000E-01
Sodium nitrate (NaNO3) [Inorganic emissions to sea water]	1.0000E-01
Total dissolved organic bounded carbon [Analytical measures to fresh water]	1.0000E-01
Total dissolved organic bounded carbon [Analytical measures to sea water]	1.0000E-01
Total organic bounded carbon [Analytical measures to sea water]	1.0000E-01
Total organic bounded carbon [Analytical measures to fresh water]	4.2000E-01
Xylene (isomers; dimethyl benzene) [Hydrocarbons to fresh water]	4.2000E-01
Xylene (meta-Xylene; 1,3-Dimethylbenzene) [Hydrocarbons to fresh water]	3.5000E-01
Xylene (meta-Xylene; 1,3-Dimethylbenzene) [Hydrocarbons to sea water]	4.2000E-01
Xylene (ortho-Xylene; 1,2-Dimethylbenzene) [Hydrocarbons to fresh water]	2.3500E-02
Xylene (ortho-Xylene; 1,2-Dimethylbenzene) [Hydrocarbons to sea water]	2.8800E-01
Xylene (para-Xylene; 1,4-Dimethylbenzene) [Hydrocarbons to fresh water]	3.5000E-01
Xylene (para-Xylene; 1,4-Dimethylbenzene) [Hydrocarbons to sea water]	3.5000E-01

APPENDIX E3: CML 2001, GLOBAL WARMING POTENTIAL (GWP 100 YEARS)

Flow	kg CO_2-Equiv.
1,1,1-Trichloroethane [Halogenated organic emissions to air]	1.4000E+02
Carbon dioxide [Renewable resources]	1.0000E+00
Carbon dioxide [Inorganic emissions to air]	1.0000E+00
Carbon dioxide (biotic) [Air]	1.0000E+00
CFC 12 (dichlorodifluoromethane) [Halogenated organic emissions to sea water]	8.5000E+03
Chloromethane (methyl chloride) [Halogenated organic emissions to air]	1.6000E+01
Dichloromethane (methylene chloride) [Halogenated organic emissions to air]	1.0000E+01
Halon (1301) [Halogenated organic emissions to air]	6.9000E+03
Methane [Organic emissions to air (group VOC)]	2.3000E+01
Methane (biotic) [Air]	2.3000E+01
Nitrous oxide (laughing gas) [Inorganic emissions to air]	2.9600E+02
Perfluorobutane [Halogenated organic emissions to air]	8.6000E+03
Perfluorocyclobutane [Halogenated organic emissions to air]	1.0000E+04
Perfluorohexane [Halogenated organic emissions to air]	9.0000E+03
Perfluoropentane [Halogenated organic emissions to air]	8.9000E+03
Perfluoropropane [Halogenated organic emissions to air]	8.6000E+03
R 11 (trichlorofluoromethane) [Halogenated organic emissions to air]	4.6000E+03
R 114 (dichlorotetrafluoroethane) [Halogenated organic emissions to air]	9.8000E+03
R 116 (hexafluoroethane) [Halogenated organic emissions to air]	1.1900E+04
R 12 (dichlorodifluoromethane) [Halogenated organic emissions to air]	1.0600E+04
R 13 (chlorotrifluoromethane) [Halogenated organic emissions to air]	1.4000E+04
R 134 [Halogenated organic emissions to air]	1.1000E+03
R 22 (chlorodifluoromethane) [Halogenated organic emissions to air]	1.7000E+03
R 41 [Halogenated organic emissions to air]	9.7000E+01
Sulphur hexafluoride [Inorganic emissions to air]	2.2200E+04
Tetrafluoromethane [Halogenated organic emissions to air]	5.7000E+03
VOC [Organic emissions to fresh water]	1.6100E+01
VOC [Organic emissions to sea water]	1.4700E+01
VOC (unspecified) [Organic emissions to air (group VOC)]	1.6100E+01

APPENDIX E4: CML 2001, OZONE LAYER DEPLETION POTENTIAL

Flow	kg R11-Equiv.
1,1,1-Trichloroethane [Halogenated organic emissions to air]	1.1000E-01
CFC 12 (dichlorodifluoromethane) [Halogenated organic emissions to sea water]	8.2000E-01
Chloromethane (methyl chloride) [Halogenated organic emissions to air]	2.0000E-02
Halon (1301) [Halogenated organic emissions to air]	1.2000E+01
HBFC-1201 (Halon-1201) [Halogenated organic emissions to air]	1.4000E+00
HBFC-1202 (Halon-1202) [Halogenated organic emissions to air]	1.2500E+00
HBFC-2311 (Halon-2311) [Halogenated organic emissions to air]	1.4000E-01
HBFC-2401 (Halon-2401) [Halogenated organic emissions to air]	2.5000E-01
HBFC-2402 (Halon-2402) [Halogenated organic emissions to air]	7.0000E+00
R 11 (trichlorofluoromethane) [Halogenated organic emissions to air]	1.0000E+00
R 114 (dichlorotetrafluoroethane) [Halogenated organic emissions to air]	8.5000E-01
R 12 (dichlorodifluoromethane) [Halogenated organic emissions to air]	8.2000E-01
R 22 (chlorodifluoromethane) [Halogenated organic emissions to air]	3.4000E-02

APPENDIX E5: CML 2001, PHOTOCHEMICAL OZONE CREATION POTENTIAL

Flow	kg Ethene-Equiv.
1,1,1-Trichloroethane [Halogenated organic emissions to air]	9.0000E-03
1,2,3-Trimethylbenzene [Group NMVOC to air]	1.2670E+00
1,2,4-Trimethylbenzene [Group NMVOC to air]	1.2780E+00
1-Butoxypropanol [Group NMVOC to air]	4.6300E-01
1-Hexene [Group NMVOC to air]	8.7400E-01
1-Methoxy-2-propanol [Group NMVOC to air]	3.5500E-01
1-Pentene [Group NMVOC to air]	9.7700E-01
1-Propanol [Group NMVOC to air]	5.6100E-01
1-Propylbenzene [Group NMVOC to air]	6.3600E-01
1-Undecane [Group NMVOC to air]	3.8400E-01
2,2-Dimethylbutane [Group NMVOC to air]	2.4100E-01
2,3-Dimethylbutane [Group NMVOC to air]	5.4100E-01
2-Butoxy-ethanol [Group NMVOC to air]	4.8300E-01
2-Ethoxy-ethanol [Group NMVOC to air]	3.8600E-01
2-Methoxy-ethanol [Group NMVOC to air]	3.0700E-01
2-Methyl-1-butene [Group NMVOC to air]	7.7100E-01
2-Methyl-2-butene [Group NMVOC to air]	8.4200E-01
2-Methylbutan-1-ol [Group NMVOC to air]	4.8900E-01
2-Methylbutan-2-ol [Group NMVOC to air]	2.2800E-01
2-Methylhexane [Group NMVOC to air]	4.1100E-01
2-Methylpentane [Group NMVOC to air]	4.2000E-01
3,5-Diethyltoluene [Group NMVOC to air]	1.2950E+00
3,5-Dimethylethylbenzene [Group NMVOC to air]	1.3200E+00
3-Methyl-1-butene [Group NMVOC to air]	6.7100E-01
3-Methylbutan-1-ol [Group NMVOC to air]	4.3300E-01
3-Methylbutan-2-ol [Group NMVOC to air]	4.0600E-01
3-Methylhexane [Group NMVOC to air]	3.6400E-01
3-Methylpentane [Group NMVOC to air]	4.7900E-01
3-Pentanol [Group NMVOC to air]	5.9500E-01
Acetaldehyde (Ethanal) [Group NMVOC to air]	6.4100E-01
Acetic acid [Group NMVOC to air]	9.7000E-02
Acetone (dimethylcetone) [Group NMVOC to air]	9.4000E-02
Alkane (unspecified) [Group NMVOC to air]	4.0000E-01
Alkene (unspecified) [Group NMVOC to air]	1.0000E+00
Benzaldehyde [Group NMVOC to air]	-9.2000E-02
Benzene [Group NMVOC to air]	2.1800E-01
Butadiene [Group NMVOC to air]	8.5100E-01
Butane [Group NMVOC to air]	3.5200E-01
Butane (n-butane) [Group NMVOC to air]	3.5200E-01
Butanone (methyl ethyl ketone) [Group NMVOC to air]	3.7300E-01
Butyraldehyde [Group NMVOC to air]	7.9500E-01
Carbon monoxide [Inorganic emissions to air]	2.7000E-02
Carbon monoxide (biotic) [Air]	2.7000E-02
Chloromethane (methyl chloride) [Halogenated organic emissions to air]	5.0000E-03
cis-2-Butene [Group NMVOC to air]	1.1460E+00
cis-2-Hexene [Group NMVOC to air]	1.0690E+00
cis-2-Pentene [Group NMVOC to air]	1.1210E+00

cis-Dichloroethene [Halogenated organic emissions to air]	4.4700E-01
Cyclohexane (hexahydro benzene) [Organic intermediate products]	2.9000E-01
Decane [Group NMVOC to air]	3.8400E-01
Diacetone alcohol [Group NMVOC to air]	3.0700E-01
Dichloromethane (methylene chloride) [Halogenated organic emissions to air]	6.8000E-02
Diethyl ether [Group NMVOC to air]	4.4500E-01
Diethylketone [Group NMVOC to air]	4.1400E-01
Diisopropylether [Group NMVOC to air]	3.9800E-01
Dimethoxy methane [Group NMVOC to air]	1.6400E-01
Dimethyl carbonate [Group NMVOC to air]	2.5000E-02
Dimethyl ether [Group NMVOC to air]	1.8900E-01
Dodecane [Group NMVOC to air]	3.5700E-01
Ethane [Group NMVOC to air]	1.2300E-01
Ethanol [Group NMVOC to air]	3.9900E-01
Ethene (ethylene) [Group NMVOC to air]	1.0000E+00
Ethine (acetylene) [Organic intermediate products]	8.5000E-02
Ethyl benzene [Group NMVOC to air]	7.3000E-01
Ethylene glycol [Group NMVOC to air]	3.7300E-01
Ethyl-trans-butyl ether [Group NMVOC to air]	2.4400E-01
Formaldehyde (methanal) [Group NMVOC to air]	5.1900E-01
Hexan-2-one [Group NMVOC to air]	5.7200E-01
Hexan-3-one [Group NMVOC to air]	5.9900E-01
Hexane (isomers) [Group NMVOC to air]	4.8200E-01
iso-Butane [Group NMVOC to air]	3.0700E-01
iso-Butanol [Group NMVOC to air]	3.6000E-01
iso-Butene [Group NMVOC to air]	6.2700E-01
iso-Butyraldehyde [Group NMVOC to air]	5.1400E-01
iso-Pentane [Group NMVOC to air]	4.0500E-01
Isoprene [Group NMVOC to air]	1.0920E+00
iso-Propyl acetate [Group NMVOC to air]	2.1100E-01
meta-Ethyltoluene [Group NMVOC to air]	1.0190E+00
Methane [Organic emissions to air (group VOC)]	6.0000E-03
Methane (biotic) [Air]	6.0000E-03
Methanol [Group NMVOC to air]	1.4000E-01
Methyl formate [Group NMVOC to air]	2.7000E-02
Methyl isopropylketone [Group NMVOC to air]	3.6400E-01
Methyl propyl Ketone [Group NMVOC to air]	5.4800E-01
Methyl tert-butylether [Group NMVOC to air]	1.7500E-01
Methyl tert-butylketone [Group NMVOC to air]	3.2300E-01
Neopentane [Group NMVOC to air]	1.7300E-01
Nitrogen dioxide [Inorganic emissions to air]	2.8000E-02
Nitrogen oxides [Inorganic emissions to air]	2.8000E-02
NMVOC (unspecified) [Group NMVOC to air]	3.6401E-01
Nonane [Group NMVOC to air]	4.1400E-01
ortho-Ethyltoluene [Group NMVOC to air]	8.9800E-01
para-Ethyltoluene [Group NMVOC to air]	9.0600E-01
Pentanaldehyde [Group NMVOC to air]	7.6500E-01
Pentane (n-pentane) [Group NMVOC to air]	3.9500E-01
Propane [Group NMVOC to air]	1.7600E-01
Propene (propylene) [Group NMVOC to air]	1.1230E+00
Propionaldehyde [Group NMVOC to air]	7.9800E-01

Propionic acid (propane acid) [Group NMVOC to air]	1.5000E-01
Propylene glycol [Organic intermediate products]	4.5700E-01
sec-Butanol [Group NMVOC to air]	4.0000E-01
sec-Butyl acetate [Group NMVOC to air]	2.7500E-01
Styrene [Group NMVOC to air]	1.4200E-01
Sulphur dioxide [Inorganic emissions to air]	4.8000E-02
tertiary-Butanol [Group NMVOC to air]	1.0600E-01
tertiary-Butyl acetate [Group NMVOC to air]	5.3000E-02
Toluene (methyl benzene) [Group NMVOC to air]	6.3700E-01
trans-2-Butene [Group NMVOC to air]	1.1320E+00
trans-2-Hexene [Group NMVOC to air]	1.0730E+00
trans-2-Pentene [Group NMVOC to air]	1.1170E+00
trans-Dichloroethene [Halogenated organic emissions to air]	3.9200E-01
VOC [Organic emissions to fresh water]	1.1340E-01
VOC [Organic emissions to sea water]	1.1340E-01
VOC (unspecified) [Organic emissions to air (group VOC)]	1.1340E-01
Xylene (dimethyl benzene) [Group NMVOC to air]	1.0600E+00
Xylene (meta-Xylene; 1,3-Dimethylbenzene) [Group NMVOC to air]	1.1080E+00
Xylene (ortho-Xylene; 1,2-Dimethylbenzene) [Group NMVOC to air]	1.0530E+00
Xylene (para-Xylene; 1,4-Dimethylbenzene) [Group NMVOC to air]	1.0100E+00

APPENDIX E6: CML 2001, HUMAN TOXICITY POTENTIAL

Flow	kg DCB-Equiv.
Alkene (unspecified) [Group NMVOC to air]	6.3675E-01
Ammonia [Inorganic emissions to air]	1.0000E-01
Anthracene [Group PAH to air]	5.2042E-01
Anthracene [Organic emissions to agricultural soil]	5.1463E-01
Anthracene [Organic emissions to industrial soil]	1.9814E-02
Anthracene [Hydrocarbons to sea water]	1.5668E-01
Anthracene [Hydrocarbons to fresh water]	2.0571E+00
Antimony [Heavy metals to agricultural soil]	8.8862E+03
Antimony [Heavy metals to air]	6.7075E+03
Antimony [Fresh water]	5.1415E+03
Arsenic [Fresh water]	9.5062E+02
Arsenic [Heavy metals to fresh water]	9.5062E+02
Arsenic [Heavy metals to industrial soil]	1.0204E+03
Arsenic [Heavy metals to air]	3.4770E+05
Arsenic [Heavy metals to agricultural soil]	3.1813E+04
Arsenic trioxide [Heavy metals to air]	2.8657E+05
Barium [Inorganic emissions to fresh water]	6.3048E+02
Barium [Inorganic emissions to industrial soil]	3.1799E+02
Barium [Fresh water]	6.3048E+02
Barium [Inorganic emissions to agricultural soil]	3.6280E+02
Barium [Inorganic emissions to air]	7.5646E+02
Barium compounds (unspecified; rel. to Ba) [Inorganic emissions to air]	7.5646E+02
Benzene [Group NMVOC to air]	1.8999E+03
Benzene [Hydrocarbons to fresh water]	1.8309E+03
Benzene [Organic emissions to agricultural soil]	1.4806E+04
Beryllium [Inorganic emissions to industrial soil]	7.0495E+03
Beryllium [Fresh water]	1.3975E+04
Beryllium [Inorganic emissions to agricultural soil]	1.2760E+04
Beryllium [Inorganic emissions to air]	2.2663E+05
Beryllium [Inorganic emissions to fresh water]	1.3975E+04
Bifenthrin [Pesticides to fresh water]	9.8186E+01
Bifenthrin [Pesticides to industrial soil]	2.9711E-01
Bifenthrin [Pesticides to agricultural soil]	2.8595E+01
Bifenthrin [Pesticides to sea water]	7.4840E-01
Bifenthrin [Pesticides to air]	1.9421E+01
Butadiene [Group NMVOC to air]	2.2244E+03
Butadiene [Organic emissions to agricultural soil]	3.0688E+03
Butadiene [Hydrocarbons to fresh water]	6.9924E+03
Cadmium [Heavy metals to industrial soil]	6.6684E+01
Cadmium [Heavy metals to fresh water]	2.2891E+01
Cadmium [Heavy metals to air]	1.4504E+05
Cadmium [Fresh water]	2.2891E+01
Cadmium [Heavy metals to agricultural soil]	1.9635E+04
Carbon disulphide [Inorganic emissions to agricultural soil]	3.6095E+00
Carbon disulphide [Inorganic emissions to fresh water]	2.4304E+00
Carbon disulphide [Inorganic emissions to industrial soil]	2.2357E+00
Carbon tetrachloride (tetrachloromethane) [Organic emissions to industrial soil]	2.1858E+02
Carbon tetrachloride (tetrachloromethane) [Organic emissions to agric. soil]	2.2185E+02

Chlorobenzene [Organic emissions to agricultural soil]	7.0615E+00
Chlorobenzene [Halogenated organic emissions to sea water]	5.1645E+00
Chlorobenzene [Organic emissions to industrial soil]	6.8329E+00
Chlorotoluene (Benzylchloride) [Halogenated organic emissions to air]	3.5212E+03
Chlorotoluene (Benzylchloride) [Organic emissions to industrial soil]	4.8666E+02
Chlorotoluene (Benzylchloride) [Halogenated organic emissions to fresh water]	2.3808E+03
Chlorotoluene (Benzylchloride) [Organic emissions to agricultural soil]	5.5297E+03
Chromium (unspecified) [Heavy metals to industrial soil]	2.9984E+02
Chromium (unspecified) [Heavy metals to fresh water]	2.0523E+00
Chromium (unspecified) [Heavy metals to air]	6.4684E+02
Chromium (unspecified) [Heavy metals to agricultural soil]	5.1277E+03
Chromium +VI [Fresh water]	3.4204E+00
Chromium +VI [Heavy metals to agricultural soil]	8.5462E+03
Chromium +VI [Heavy metals to fresh water]	3.4253E+06
Chromium +VI [Heavy metals to sea water]	1.6733E+01
Cobalt [Heavy metals to air]	1.7470E+04
Cobalt [Heavy metals to fresh water]	9.6702E+01
Cobalt [Heavy metals to agricultural soil]	2.3854E+03
Cobalt [Fresh water]	9.6702E+01
Copper [Heavy metals to air]	4.2950E+03
Copper [Fresh water]	1.3393E+00
Copper [Heavy metals to agricultural soil]	9.3857E+01
Copper [Heavy metals to industrial soil]	1.2545E+00
Copper [Heavy metals to fresh water]	1.3393E+00
Cypermethrin [Pesticides to air]	1.6643E+02
Cypermethrin [Pesticides to industrial soil]	1.8461E+00
Cypermethrin [Pesticides to agricultural soil]	5.2032E+03
Cypermethrin [Pesticides to fresh water]	5.5488E+00
Dichloroethane (1,2-Dichloroethane) [Organic emissions to agricultural soil]	1.2897E+03
Dichloroethane (1,2-Dichloroethane) [Organic emissions to industrial soil]	5.6668E+00
Dichloroethane (ethylene dichloride) [Halogenated organic emissions to air]	6.8077E+00
Dichloromethane (methylene chloride) [Halogenated organic emissions to sea water]	2.9849E-01
Dichloromethane (methylene chloride) [Organic emissions to agricultural soil]	2.4473E+00
Dichloromethane (methylene chloride) [Organic emissions to industrial soil]	1.2981E+00
Dichloromethane (methylene chloride) [Halogenated organic emissions to air]	1.9751E+00
Dust (PM10) [Particles to air]	8.2000E-01
Dust (PM2,5 - PM10) [Particles to air]	8.2000E-01
Dust (PM2.5) [Particles to air]	8.2000E-01
Dust (unspecified) [Particles to air]	2.4600E-01
Ethene (ethylene) [Organic emissions to industrial soil]	6.1737E-01
Ethene (ethylene) [Hydrocarbons to sea water]	4.7072E-02
Ethene (ethylene) [Organic emissions to agricultural soil]	7.7956E-01
Ethene (ethylene) [Group NMVOC to air]	6.3675E-01
Ethene (ethylene) [Hydrocarbons to fresh water]	6.5405E-01
Ethyl benzene [Organic emissions to industrial soil]	5.0193E-01
Ethyl benzene [Organic emissions to agricultural soil]	7.5275E-01
Ethyl benzene [Hydrocarbons to fresh water]	8.2661E-01
Ethyl benzene [Group NMVOC to air]	9.7321E-01
Ethylene oxide [Hydrocarbons to fresh water]	1.1426E+04
Ethylene oxide [Organic emissions to industrial soil]	4.5773E+03

Ethylene oxide [Organic emissions to agricultural soil]	1.0727E+05
Ethylene oxide [Group NMVOC to air]	1.4075E+04
Formaldehyde (methanal) [Organic emissions to agricultural soil]	2.2660E+00
Formaldehyde (methanal) [Group NMVOC to air]	8.3067E-01
Formaldehyde (methanal) [Organic emissions to industrial soil]	1.9006E-02
Glyphosate [Pesticides to sea water]	1.5100E-05
Glyphosate [Pesticides to fresh water]	6.6238E-02
Glyphosate [Pesticides to industrial soil]	6.4887E-04
Glyphosate [Pesticides to agricultural soil]	1.4873E-02
Glyphosate [Pesticides to air]	3.0990E-03
Graphites [Particles to air]	8.2000E-01
Hydrogen chloride [Inorganic emissions to air]	5.0000E-01
Hydrogen fluoride [Inorganic emissions to air]	2.8506E+03
Hydrogen fluoride (hydrofluoric acid) [Inorganic emissions to agricultural soil]	1.8469E+03
Hydrogen fluoride (hydrofluoric acid) [Inorganic emissions to fresh water]	3.6397E+03
Hydrogen fluoride (hydrofluoric acid) [Inorganic emissions to industrial soil]	1.8199E+03
Hydrogen sulphide [Inorganic emissions to air]	2.2000E-01
Lead [Heavy metals to fresh water]	1.2260E+01
Lead [Heavy metals to agricultural soil]	3.2807E+03
Lead [Fresh water]	1.2260E+01
Lead [Heavy metals to air]	4.6652E+02
Lead [Heavy metals to industrial soil]	2.9331E+02
Mercury [Heavy metals to air]	6.0082E+03
Mercury [Heavy metals to agricultural soil]	5.9212E+03
Mercury [Fresh water]	1.4260E+03
Mercury [Heavy metals to fresh water]	1.4260E+03
Mercury [Heavy metals to industrial soil]	1.0805E+03
Metals (unspecified) [Particles to air]	8.2000E-01
Methyl bromide [Organic emissions to industrial soil]	2.6346E+02
Methyl bromide [Organic emissions to agricultural soil]	2.6218E+02
Metolachlor [Pesticides to agricultural soil]	1.1448E+01
Metolachlor [Pesticides to industrial soil]	1.0980E-01
Metolachlor [Pesticides to fresh water]	5.5436E-01
Metolachlor [Pesticides to air]	2.5771E+00
Molybdenum [Fresh water]	5.5137E+03
Molybdenum [Heavy metals to air]	5.4263E+03
Molybdenum [Heavy metals to fresh water]	5.5137E+03
Molybdenum [Heavy metals to agricultural soil]	6.1683E+03
Nickel [Heavy metals to air]	3.5633E+04
Nickel [Heavy metals to fresh water]	3.3108E+02
Nickel [Heavy metals to agricultural soil]	2.6788E+03
Nickel [Fresh water]	3.3108E+02
Nitrogen dioxide [Inorganic emissions to air]	1.2000E+00
Nitrogen oxides [Inorganic emissions to air]	1.2000E+00
NMVOC (unspecified) [Group NMVOC to air]	5.8486E-02
Phenol (hydroxy benzene) [Organic emissions to industrial soil]	6.0397E-03
Phenol (hydroxy benzene) [Organic emissions to agricultural soil]	1.8608E+00
Phenol (hydroxy benzene) [Hydrocarbons to fresh water]	4.9158E-02
Pirimicarb [Pesticides to industrial soil]	2.8870E-01
Pirimicarb [Pesticides to agricultural soil]	2.6083E+01
Pirimicarb [Pesticides to fresh water]	1.6588E+00

Pirimicarb [Pesticides to air]	3.4358E+00
Polychlorinated dibenzo-p-dioxins (2,3,7,8 - TCDD) [Halogenated organic emissions to air]	1.9340E+09
Polychlorinated dibenzo-p-dioxins (2,3,7,8 - TCDD) [Halogenated organic emissions to fresh water]	8.5827E+08
Polychlorinated dibenzo-p-dioxins (2,3,7,8 - TCDD) [Halogenated organic emissions to sea water]	4.2234E+08
Polychlorinated dibenzo-p-dioxins (2,3,7,8-TCDD) [Organic emissions to agricultural soil]	1.2992E+09
Polychlorinated dibenzo-p-dioxins (2,3,7,8-TCDD) [Organic emissions to industrial soil]	1.0124E+07
Polycyclic aromatic hydrocarbon (carcinogen) [Hydrocarbons to fresh water]	2.8047E+05
Polycyclic aromatic hydrocarbons (carcinogenic) [Organic emissions to industrial soil]	2.7349E+03
Polycyclic aromatic hydrocarbons (carcinogenic) [Group PAH to air]	5.7240E+05
Polycyclic aromatic hydrocarbons (carcinogenic) [Organic emissions to agricultural soil]	7.1015E+04
Propylene oxide [Hydrocarbons to fresh water]	2.6430E+03
Propylene oxide [Hydrocarbons to sea water]	1.5845E+01
Propylene oxide [Group NMVOC to air]	1.2624E+03
Propylene oxide [Organic emissions to industrial soil]	5.8743E+02
Propylene oxide [Organic emissions to agricultural soil]	2.1959E+05
Selenium [Heavy metals to air]	4.7687E+04
Selenium [Heavy metals to sea water]	6.2918E+04
Selenium [Heavy metals to agricultural soil]	2.8863E+04
Selenium [Heavy metals to fresh water]	5.6011E+04
Selenium [Fresh water]	5.6011E+04
Styrene [Hydrocarbons to sea water]	1.0187E-02
Styrene [Organic emissions to industrial soil]	1.7503E-02
Styrene [Group NMVOC to air]	4.7385E-02
Styrene [Organic emissions to agricultural soil]	4.7708E-01
Styrene [Hydrocarbons to fresh water]	8.5066E-02
Silicon dioxide (silica) [Particles to air]	8.2000E-01
Sulphur dioxide [Inorganic emissions to air]	9.6000E-02
Tetrachloroethene (perchloroethylene) [Organic emissions to industrial soil]	5.1591E+00
Tetrachloroethene (perchloroethylene) [Organic emissions to agricultural soil]	6.4237E+00
Thallium [Heavy metals to air]	4.3219E+05
Thallium [Heavy metals to fresh water]	2.2512E+05
Thallium [Heavy metals to agricultural soil]	2.0171E+06
Thallium [Heavy metals to industrial soil]	1.1779E+05
Thallium [Fresh water]	2.2512E+05
Tin [Heavy metals to industrial soil]	5.2473E-01
Tin [Heavy metals to air]	1.7341E+00
Tin [Fresh water]	1.7320E-02
Tin [Heavy metals to agricultural soil]	1.3139E+01
Tin [Heavy metals to fresh water]	1.7320E-02
Toluene (methyl benzene) [Organic emissions to agricultural soil]	3.4662E-01
Toluene (methyl benzene) [Hydrocarbons to fresh water]	3.0276E-01
Toluene (methyl benzene) [Organic emissions to industrial soil]	2.0805E-01
Toluene (methyl benzene) [Group NMVOC to air]	3.2692E-01
Trichloroethene (isomers) [Organic emissions to agricultural soil]	3.1646E+01
Trichloroethene (isomers) [Organic emissions to industrial soil]	3.1586E+01

Trichloromethane (chloroform) [Organic emissions to industrial soil]	1.0072E+01
Trichloromethane (chloroform) [Organic emissions to agricultural soil]	1.4139E+01
Vanadium [Heavy metals to air]	6.2403E+03
Vanadium [Heavy metals to agricultural soil]	1.8500E+04
Vanadium [Fresh water]	3.1630E+03
Vanadium [Heavy metals to fresh water]	3.1630E+03
Vinyl chloride (VCM; chloroethene) [Halogenated organic emissions to sea water]	4.2605E+01
Vinyl chloride (VCM; chloroethene) [Halogenated organic emissions to air]	8.4343E+01
Vinyl chloride (VCM; chloroethene) [Organic emissions to industrial soil]	8.2610E+01
Vinyl chloride (VCM; chloroethene) [Organic emissions to agricultural soil]	5.1651E+02
VOC [Organic emissions to fresh water]	1.7546E-02
VOC [Organic emissions to sea water]	1.7546E-02
VOC (unspecified) [Organic emissions to air (group VOC)]	1.7546E-02
Xylene (dimethyl benzene) [Group NMVOC to air]	6.5000E-02
Xylene (isomers; dimethyl benzene) [Hydrocarbons to fresh water]	3.7071E-01
Xylene (meta-Xylene; 1,3-Dimethylbenzene) [Group NMVOC to air]	2.7149E-02
Xylene (meta-Xylene; 1,3-Dimethylbenzene) [Organic emissions to agricultural soil]	3.8050E+00
Xylene (meta-Xylene; 1,3-Dimethylbenzene) [Hydrocarbons to sea water]	1.0335E-02
Xylene (meta-Xylene; 1,3-Dimethylbenzene) [Hydrocarbons to fresh water]	3.3678E-01
Xylene (meta-Xylene; 1,3-Dimethylbenzene) [Organic emissions to industrial soil]	1.8868E-02
Zinc [Heavy metals to sea water]	3.2000E+00
Zinc [Fresh water]	5.8395E-01
Zinc [Heavy metals to fresh water]	5.8395E-01
Zinc [Heavy metals to agricultural soil]	6.3745E+01
Zinc [Heavy metals to air]	1.0444E+02
Zinc [Heavy metals to industrial soil]	4.2213E-01

APPENDIX E7: CML 2001, FRESHWATER AQUATIC ECOTOXICITY POTENTIAL

Flow	kg DCB-Equiv.
Acrolein [Hydrocarbons to fresh water]	2.5147E+05
Acrolein [Organic emissions to industrial soil]	4.5449E+04
Acrolein [Organic emissions to agricultural soil]	4.5449E+04
Alkene (unspecified) [Group NMVOC to air]	1.4300E-11
Antimony [Heavy metals to air]	3.7238E+00
Antimony [Fresh water]	1.9747E+01
Antimony [Heavy metals to agricultural soil]	9.9806E+00
Arsenic [Heavy metals to industrial soil]	1.3441E+02
Arsenic [Heavy metals to agricultural soil]	1.3441E+02
Arsenic [Heavy metals to air]	4.9504E+01
Arsenic [Heavy metals to fresh water]	2.0675E+02
Arsenic [Fresh water]	2.0675E+02
Barium [Inorganic emissions to industrial soil]	1.1475E+02
Barium [Inorganic emissions to agricultural soil]	1.1475E+02
Barium [Inorganic emissions to fresh water]	2.2775E+02
Barium [Inorganic emissions to air]	4.2822E+01
Barium [Fresh water]	2.2775E+02
Barium compounds (unspecified; rel. to Ba) [Inorganic emissions to air]	4.2822E+01
Benzene [Hydrocarbons to fresh water]	9.1442E-02
Benzene [Group NMVOC to air]	8.3700E-05
Benzene [Organic emissions to agricultural soil]	7.1523E-04
Beryllium [Inorganic emissions to industrial soil]	4.5898E+04
Beryllium [Inorganic emissions to air]	1.7130E+04
Beryllium [Inorganic emissions to fresh water]	9.1349E+04
Beryllium [Inorganic emissions to agricultural soil]	4.5898E+04
Beryllium [Fresh water]	9.1349E+04
Bifenthrin [Pesticides to agricultural soil]	1.0319E+02
Bifenthrin [Pesticides to air]	8.2043E+02
Bifenthrin [Pesticides to industrial soil]	4.1195E+02
Bifenthrin [Pesticides to fresh water]	2.4398E+05
Butadiene [Group NMVOC to air]	3.2500E-07
Butadiene [Organic emissions to industrial soil]	5.6800E-05
Butadiene [Organic emissions to agricultural soil]	5.6800E-05
Butadiene [Hydrocarbons to fresh water]	2.9695E+00
Butadiene [Hydrocarbons to sea water]	5.6000E-08
Cadmium [Heavy metals to industrial soil]	7.7611E+02
Cadmium [Heavy metals to agricultural soil]	7.7611E+02
Cadmium [Heavy metals to air]	2.8943E+02
Cadmium [Heavy metals to fresh water]	1.5230E+03
Cadmium [Fresh water]	1.5230E+03
Carbon disulphide [Inorganic emissions to sea water]	6.5293E-03
Carbon disulphide [Inorganic emissions to fresh water]	1.0517E+02
Carbon disulphide [Inorganic emissions to agricultural soil]	3.4013E-01
Carbon disulphide [Inorganic emissions to industrial soil]	3.4013E-01
Carbon tetrachloride (tetrachloromethane) [Organic emissions to agricultural soil]	5.6447E-04
Carbon tetrachloride (tetrachloromethane) [Halogenated organic emissions to sea water]	1.9056E-04

Carbon tetrachloride (tetrachloromethane) [Organic emissions to industrial soil]	5.6447E-04
Chlorotoluene (Benzylchloride) [Halogenated organic emissions to fresh water]	1.9892E+02
Chlorotoluene (Benzylchloride) [Halogenated organic emissions to air]	7.5701E-01
Chlorotoluene (Benzylchloride) [Organic emissions to agricultural soil]	9.1737E-01
Chlorotoluene (Benzylchloride) [Organic emissions to industrial soil]	3.2348E+00
Chromium (unspecified) [Heavy metals to agricultural soil]	5.2547E+00
Chromium (unspecified) [Heavy metals to fresh water]	6.9139E+00
Chromium (unspecified) [Heavy metals to air]	1.9226E+00
Chromium (unspecified) [Heavy metals to industrial soil]	5.2547E+00
Chromium +VI [Heavy metals to fresh water]	7.6906E+00
Chromium +VI [Heavy metals to agricultural soil]	2.1019E+01
Chromium +VI [Fresh water]	2.7656E+01
Cobalt [Heavy metals to fresh water]	3.4078E+03
Cobalt [Fresh water]	3.4078E+03
Cobalt [Heavy metals to agricultural soil]	1.7126E+03
Cobalt [Heavy metals to air]	6.3919E+02
Copper [Heavy metals to fresh water]	1.1573E+03
Copper [Heavy metals to industrial soil]	5.9465E+02
Copper [Heavy metals to air]	2.2165E+02
Copper [Heavy metals to agricultural soil]	5.9465E+02
Copper [Fresh water]	1.1573E+03
Ethene (ethylene) [Organic emissions to agricultural soil]	1.1300E-09
Ethene (ethylene) [Group NMVOC to air]	1.4300E-11
Ethene (ethylene) [Organic emissions to industrial soil]	1.1300E-09
Ethene (ethylene) [Hydrocarbons to fresh water]	2.2491E-02
Ethyl benzene [Group NMVOC to air]	1.3123E-04
Ethyl benzene [Hydrocarbons to fresh water]	5.4552E-01
Ethyl benzene [Organic emissions to agricultural soil]	1.7536E-03
Ethyl benzene [Organic emissions to industrial soil]	1.7766E-03
Formaldehyde (methanal) [Organic emissions to agricultural soil]	1.4679E+01
Formaldehyde (methanal) [Organic emissions to industrial soil]	4.4198E+01
Formaldehyde (methanal) [Group NMVOC to air]	8.2559E+00
Glyphosate [Pesticides to air]	2.1933E+01
Glyphosate [Pesticides to industrial soil]	3.6719E+00
Glyphosate [Pesticides to agricultural soil]	9.2165E-01
Glyphosate [Pesticides to fresh water]	1.3682E+03
Hydrogen fluoride [Inorganic emissions to air]	4.6385E+00
Hydrogen fluoride (hydrofluoric acid) [Inorganic emissions to industrial soil]	9.3855E+00
Hydrogen fluoride (hydrofluoric acid) [Inorganic emissions to fresh water]	1.8771E+01
Hydrogen fluoride (hydrofluoric acid) [Inorganic emissions to agricultural soil]	9.3855E+00
Lead [Heavy metals to industrial soil]	6.5278E+00
Lead [Heavy metals to air]	2.3996E+00
Lead [Heavy metals to agricultural soil]	6.5278E+00
Lead [Fresh water]	9.6157E+00
Lead [Heavy metals to fresh water]	9.6157E+00
Mercury [Heavy metals to air]	3.1679E+02
Mercury [Heavy metals to fresh water]	1.7171E+03
Mercury [Heavy metals to agricultural soil]	8.4813E+02
Mercury [Fresh water]	1.7171E+03
Mercury [Heavy metals to industrial soil]	8.4813E+02
Metolachlor [Pesticides to air]	1.4666E+03

Metolachlor [Pesticides to fresh water]	3.8379E+04
Metolachlor [Pesticides to industrial soil]	5.8094E+03
Metolachlor [Pesticides to agricultural soil]	1.8937E+03
Molybdenum [Fresh water]	4.7619E+02
Molybdenum [Heavy metals to fresh water]	4.7619E+02
Molybdenum [Heavy metals to air]	9.7319E+01
Molybdenum [Heavy metals to agricultural soil]	2.6207E+02
Naphthalene [Organic emissions to industrial soil]	1.2493E+01
Nickel [Heavy metals to air]	6.2947E+02
Nickel [Fresh water]	3.2376E+03
Nickel [Heavy metals to agricultural soil]	1.6903E+03
Nickel [Heavy metals to fresh water]	3.2376E+03
NMVOC (unspecified) [Group NMVOC to air]	4.9538E-02
Phenol (hydroxy benzene) [Organic emissions to agricultural soil]	3.4684E+00
Phenol (hydroxy benzene) [Hydrocarbons to fresh water]	2.3701E+02
Phenol (hydroxy benzene) [Organic emissions to industrial soil]	1.2702E+01
Pirimicarb [Pesticides to industrial soil]	5.2206E+03
Pirimicarb [Pesticides to air]	2.3995E+03
Pirimicarb [Pesticides to agricultural soil]	1.6702E+03
Pirimicarb [Pesticides to fresh water]	3.5841E+04
Polychlorinated dibenzo-p-dioxins (2,3,7,8 - TCDD) [Halogenated organic emissions to air]	2.1268E+06
Polychlorinated dibenzo-p-dioxins (2,3,7,8 - TCDD) [Halogenated organic emissions to fresh water]	1.7276E+08
Polychlorinated dibenzo-p-dioxins (2,3,7,8-TCDD) [Organic emissions to agricultural soil]	1.2311E+05
Polychlorinated dibenzo-p-dioxins (2,3,7,8-TCDD) [Organic emissions to industrial soil]	4.9121E+05
Polycyclic aromatic hydrocarbon (carcinogen) [Hydrocarbons to fresh water]	2.7544E+04
Polycyclic aromatic hydrocarbons (carcinogenic) [Organic emissions to agricultural soil]	5.8491E+01
Polycyclic aromatic hydrocarbons (carcinogenic) [Group PAH to air]	1.7183E+02
Polycyclic aromatic hydrocarbons (carcinogenic) [Organic emissions to industrial soil]	2.3146E+02
Selenium [Heavy metals to fresh water]	2.9192E+03
Selenium [Heavy metals to agricultural soil]	1.4634E+03
Selenium [Heavy metals to air]	5.4624E+02
Selenium [Fresh water]	2.9192E+03
Styrene [Group NMVOC to air]	5.0900E-05
Styrene [Organic emissions to agricultural soil]	1.5362E-03
Styrene [Hydrocarbons to fresh water]	4.3967E-01
Styrene [Organic emissions to industrial soil]	2.6454E-03
Tetrachloroethene (perchloroethylene) [Halogenated organic emissions to sea water]	2.0211E-04
Tetrachloroethene (perchloroethylene) [Organic emissions to agricultural soil]	2.2301E-03
Tetrachloroethene (perchloroethylene) [Organic emissions to industrial soil]	2.2301E-03
Thallium [Fresh water]	8.0107E+03
Thallium [Heavy metals to agricultural soil]	4.1704E+03
Thallium [Heavy metals to industrial soil]	4.1704E+03
Thallium [Heavy metals to fresh water]	8.0107E+03
Thallium [Heavy metals to air]	1.5533E+03
Tin [Heavy metals to air]	2.5370E+00

Tin [Heavy metals to fresh water]	1.0166E+01
Tin [Heavy metals to industrial soil]	6.9015E+00
Tin [Fresh water]	1.0166E+01
Tin [Heavy metals to agricultural soil]	6.9015E+00
Toluene (methyl benzene) [Group NMVOC to air]	7.0400E-05
Toluene (methyl benzene) [Organic emissions to industrial soil]	1.0535E-03
Toluene (methyl benzene) [Organic emissions to agricultural soil]	1.0535E-03
Toluene (methyl benzene) [Hydrocarbons to fresh water]	2.9451E-01
Trichloroethane (Isomers) [Halogenated organic emissions to sea water]	7.1000E-05
Trichloroethene (isomers) [Organic emissions to agricultural soil]	4.6226E-04
Trichloroethene (isomers) [Organic emissions to industrial soil]	4.6226E-04
Trichloromethane (chloroform) [Organic emissions to industrial soil]	4.7395E-04
Trichloromethane (chloroform) [Organic emissions to agricultural soil]	4.7395E-04
Vanadium [Heavy metals to fresh water]	8.9657E+03
Vanadium [Fresh water]	8.9657E+03
Vanadium [Heavy metals to air]	1.7338E+03
Vanadium [Heavy metals to agricultural soil]	4.6542E+03
VOC [Organic emissions to fresh water]	1.4861E-02
VOC (unspecified) [Organic emissions to air (group VOC)]	1.4861E-02
Zinc [Heavy metals to fresh water]	9.1712E+01
Zinc [Fresh water]	9.1712E+01
Zinc [Heavy metals to agricultural soil]	4.7745E+01
Zinc [Heavy metals to industrial soil]	4.7745E+01
Zinc [Heavy metals to air]	1.7784E+01

APPENDIX E8: CML 2001, TERRESTRIAL ECOTOXICITY POTENTIAL

Flow	kg DCB-Equiv.
Acrolein [Hydrocarbons to fresh water]	5.8377E+00
Acrolein [Organic emissions to industrial soil]	6.9831E+03
Acrolein [Organic emissions to agricultural soil]	6.9831E+03
Alkene (unspecified) [Group NMVOC to air]	1.3500E-12
Anilazine [Pesticides to sea water]	7.0000E-10
Anilazine [Pesticides to air]	9.1524E-02
Antimony [Heavy metals to air]	6.1071E-01
Antimony [Fresh water]	1.6600E-20
Antimony [Heavy metals to agricultural soil]	1.2532E+00
Antimony [Heavy metals to sea water]	2.9600E-20
Arsenic [Heavy metals to industrial soil]	3.3357E+03
Arsenic [Heavy metals to agricultural soil]	3.3357E+03
Arsenic [Heavy metals to air]	1.6091E+03
Arsenic [Heavy metals to fresh water]	1.0400E-17
Arsenic [Fresh water]	1.0400E-17
Arsenic trioxide [Heavy metals to air]	1.3259E+03
Barium [Inorganic emissions to industrial soil]	9.9709E+00
Barium [Inorganic emissions to agricultural soil]	9.9709E+00
Barium [Inorganic emissions to fresh water]	5.0800E-19
Barium [Inorganic emissions to air]	4.8598E+00
Barium [Fresh water]	5.0800E-19
Barium compounds (unspecified; rel. to Ba) [Inorganic emissions to air]	4.8598E+00
Benzene [Hydrocarbons to fresh water]	1.3700E-05
Benzene [Group NMVOC to air]	1.5600E-05
Benzene [Organic emissions to agricultural soil]	3.4367E-03
Benzo{a}pyrene [Group PAH to air]	2.4115E-01
Benzo{a}pyrene [Organic emissions to agricultural soil]	2.2933E+01
Beryllium [Inorganic emissions to industrial soil]	3.6247E+03
Beryllium [Inorganic emissions to air]	1.7670E+03
Beryllium [Inorganic emissions to fresh water]	3.3000E-16
Beryllium [Inorganic emissions to agricultural soil]	3.6247E+03
Beryllium [Fresh water]	3.3000E-16
Bifenthrin [Pesticides to sea water]	5.9355E-04
Bifenthrin [Pesticides to agricultural soil]	8.3310E+01
Bifenthrin [Pesticides to air]	8.7815E+00
Bifenthrin [Pesticides to industrial soil]	8.3150E+01
Bifenthrin [Pesticides to fresh water]	2.1023E-02
Cadmium [Heavy metals to industrial soil]	1.6681E+02
Cadmium [Heavy metals to agricultural soil]	1.6681E+02
Cadmium [Heavy metals to air]	8.1249E+01
Cadmium [Heavy metals to fresh water]	1.4200E-20
Cadmium [Fresh water]	1.4200E-20
Carbon disulphide [Inorganic emissions to fresh water]	4.8058E-03
Carbon disulphide [Inorganic emissions to agricultural soil]	1.6388E+00
Carbon disulphide [Inorganic emissions to industrial soil]	1.6388E+00
Carbon tetrachloride (tetrachloromethane) [Organic emissions to agricultural soil]	2.0686E-03
Carbon tetrachloride (tetrachloromethane) [Organic emissions to industrial soil]	2.0686E-03
Chlorobenzene [Organic emissions to industrial soil]	1.1747E-01

Chlorobenzene [Organic emissions to agricultural soil]	1.1747E-01
Chlorotoluene (Benzylchloride) [Halogenated organic emissions to fresh water]	8.2661E-04
Chlorotoluene (Benzylchloride) [Halogenated organic emissions to air]	1.6618E-03
Chlorotoluene (Benzylchloride) [Organic emissions to agricultural soil]	8.0219E-01
Chlorotoluene (Benzylchloride) [Organic emissions to industrial soil]	7.0733E-01
Chromium (unspecified) [Heavy metals to agricultural soil]	6.3029E+03
Chromium (unspecified) [Heavy metals to fresh water]	2.2700E-19
Chromium (unspecified) [Heavy metals to sea water]	2.0500E-18
Chromium (unspecified) [Heavy metals to air]	3.0311E+03
Chromium (unspecified) [Heavy metals to industrial soil]	6.3029E+03
Chromium +VI [Heavy metals to fresh water]	3.0311E+03
Chromium +VI [Heavy metals to agricultural soil]	6.3029E+03
Chromium +VI [Fresh water]	2.2700E-19
Chromium +VI [Heavy metals to sea water]	2.0500E-18
Cobalt [Heavy metals to fresh water]	2.6900E-18
Cobalt [Fresh water]	2.6900E-18
Cobalt [Heavy metals to agricultural soil]	2.2301E+02
Cobalt [Heavy metals to air]	1.0871E+02
Copper [Heavy metals to fresh water]	4.0600E-21
Copper [Heavy metals to industrial soil]	1.4360E+01
Copper [Heavy metals to air]	6.9913E+00
Copper [Heavy metals to agricultural soil]	1.4360E+01
Copper [Fresh water]	4.0600E-21
Ethene (ethylene) [Organic emissions to agricultural soil]	2.2600E-09
Ethene (ethylene) [Group NMVOC to air]	1.3500E-12
Ethene (ethylene) [Organic emissions to industrial soil]	2.2600E-09
Ethene (ethylene) [Hydrocarbons to fresh water]	1.1200E-12
Ethoprophos [Pesticides to fresh water]	2.3536E-01
Ethyl benzene [Group NMVOC to air]	1.4300E-06
Ethyl benzene [Hydrocarbons to fresh water]	1.1900E-06
Ethyl benzene [Organic emissions to agricultural soil]	1.9476E-03
Ethyl benzene [Organic emissions to industrial soil]	1.9207E-03
Ethylene oxide [Hydrocarbons to sea water]	9.6900E-05
Ethylene oxide [Organic emissions to industrial soil]	1.8956E-01
Ethylene oxide [Organic emissions to agricultural soil]	2.1839E-01
Ethylene oxide [Group NMVOC to air]	2.5237E-03
Ethylene oxide [Hydrocarbons to fresh water]	1.7572E-03
Formaldehyde (methanal) [Organic emissions to agricultural soil]	5.7921E+00
Formaldehyde (methanal) [Organic emissions to industrial soil]	4.3713E+00
Formaldehyde (methanal) [Group NMVOC to air]	9.3975E-01
Glyphosate [Pesticides to air]	4.6591E-02
Glyphosate [Pesticides to industrial soil]	9.5958E-02
Glyphosate [Pesticides to agricultural soil]	9.6342E-02
Glyphosate [Pesticides to fresh water]	2.2500E-11
Hydrogen fluoride [Inorganic emissions to air]	2.9499E-03
Hydrogen fluoride (hydrofluoric acid) [Inorganic emissions to industrial soil]	6.0263E-03
Hydrogen fluoride (hydrofluoric acid) [Inorganic emissions to fresh water]	4.5500E-05
Hydrogen fluoride (hydrofluoric acid) [Inorganic emissions to agricultural soil]	6.0263E-03
Lead [Heavy metals to industrial soil]	3.2518E+01
Lead [Heavy metals to air]	1.5670E+01
Lead [Heavy metals to agricultural soil]	3.2518E+01

Lead [Fresh water]	4.7700E-22
Lead [Heavy metals to fresh water]	4.7700E-22
Mercury [Heavy metals to air]	2.8313E+04
Mercury [Heavy metals to fresh water]	9.3033E+02
Mercury [Heavy metals to agricultural soil]	5.5994E+04
Mercury [Fresh water]	9.3033E+02
Mercury [Heavy metals to industrial soil]	5.5994E+04
Metolachlor [Pesticides to air]	1.1257E-01
Metolachlor [Pesticides to fresh water]	2.1311E-04
Metolachlor [Pesticides to industrial soil]	4.1316E-01
Metolachlor [Pesticides to agricultural soil]	5.3770E-01
Molybdenum [Fresh water]	2.3100E-18
Molybdenum [Heavy metals to fresh water]	2.3100E-18
Molybdenum [Heavy metals to air]	1.7538E+01
Molybdenum [Heavy metals to agricultural soil]	3.6145E+01
Nickel [Heavy metals to air]	1.1604E+02
Nickel [Fresh water]	1.0300E-18
Nickel [Heavy metals to agricultural soil]	2.3855E+02
Nickel [Heavy metals to fresh water]	1.0300E-18
Phenol (hydroxy benzene) [Organic emissions to agricultural soil]	4.5277E-02
Phenol (hydroxy benzene) [Hydrocarbons to fresh water]	2.4900E-06
Phenol (hydroxy benzene) [Organic emissions to industrial soil]	4.1467E-02
Pirimicarb [Pesticides to industrial soil]	9.4119E+01
Pirimicarb [Pesticides to air]	4.5611E+01
Pirimicarb [Pesticides to agricultural soil]	1.2042E+02
Pirimicarb [Pesticides to fresh water]	9.3437E-04
Polychlorinated dibenzo-p-dioxins (2,3,7,8 - TCDD) [Halogenated organic emissions to air]	1.1992E+04
Polychlorinated dibenzo-p-dioxins (2,3,7,8 - TCDD) [Halogenated organic emissions to fresh water]	5.8734E+02
Polychlorinated dibenzo-p-dioxins (2,3,7,8-TCDD) [Organic emissions to agricultural soil]	2.6973E+04
Polychlorinated dibenzo-p-dioxins (2,3,7,8-TCDD) [Organic emissions to industrial soil]	2.6909E+04
Polycyclic aromatic hydrocarbon (carcinogen) [Hydrocarbons to fresh water]	2.1171E-03
Polycyclic aromatic hydrocarbons (carcinogenic) [Organic emissions to agricultural soil]	6.3453E+00
Polycyclic aromatic hydrocarbons (carcinogenic) [Group PAH to air]	1.0192E+00
Polycyclic aromatic hydrocarbons (carcinogenic) [Organic emissions to industrial soil]	6.2779E+00
Polycyclic aromatic hydrocarbons (PAH, unspec.) [Hydrocarbons to sea water]	8.1422E-04
Propylene oxide [Organic emissions to agricultural soil]	1.4488E-01
Propylene oxide [Hydrocarbons to fresh water]	6.4747E-04
Propylene oxide [Organic emissions to industrial soil]	1.2288E-01
Propylene oxide [Group NMVOC to air]	1.5090E-03
Selenium [Heavy metals to sea water]	1.7600E-17
Selenium [Heavy metals to fresh water]	1.5500E-17
Selenium [Heavy metals to agricultural soil]	1.0968E+02
Selenium [Heavy metals to air]	5.3473E+01
Selenium [Fresh water]	1.5500E-17
Styrene [Group NMVOC to air]	1.3600E-07
Styrene [Organic emissions to agricultural soil]	1.4130E-03

Styrene [Hydrocarbons to fresh water]	1.2700E-07
Styrene [Organic emissions to industrial soil]	1.1542E-03
Tetrachloroethene (perchloroethylene) [Halogenated organic emissions to sea water]	4.0093E-03
Tetrachloroethene (perchloroethylene) [Organic emissions to agricultural soil]	3.0223E-01
Tetrachloroethene (perchloroethylene) [Organic emissions to industrial soil]	3.0223E-01
Thallium [Fresh water]	3.1300E-17
Thallium [Heavy metals to agricultural soil]	6.9849E+02
Thallium [Heavy metals to industrial soil]	6.9849E+02
Thallium [Heavy metals to fresh water]	3.1300E-17
Thallium [Heavy metals to air]	3.3983E+02
Tin [Heavy metals to air]	1.4364E+01
Tin [Heavy metals to fresh water]	7.8600E-22
Tin [Heavy metals to industrial soil]	2.9808E+01
Tin [Fresh water]	7.8600E-22
Tin [Heavy metals to agricultural soil]	2.9808E+01
Tin oxide [Inorganic emissions to air]	1.2658E+01
Toluene (methyl benzene) [Group NMVOC to air]	1.5900E-05
Toluene (methyl benzene) [Organic emissions to industrial soil]	1.8634E-02
Toluene (methyl benzene) [Organic emissions to agricultural soil]	1.8634E-02
Toluene (methyl benzene) [Hydrocarbons to fresh water]	1.4200E-05
Trichloroethene (isomers) [Organic emissions to agricultural soil]	2.1437E-03
Trichloroethene (isomers) [Organic emissions to industrial soil]	2.1437E-03
Trichloromethane (chloroform) [Organic emissions to industrial soil]	1.5638E-03
Trichloromethane (chloroform) [Halogenated organic emissions to sea water]	1.9100E-05
Trichloromethane (chloroform) [Organic emissions to agricultural soil]	1.5638E-03
Vanadium [Heavy metals to fresh water]	1.0200E-17
Vanadium [Fresh water]	1.0200E-17
Vanadium [Heavy metals to air]	6.6523E+02
Vanadium [Heavy metals to agricultural soil]	1.3671E+03
Vanadium [Heavy metals to sea water]	2.1600E-17
VOC [Organic emissions to fresh water]	1.6917E-03
VOC [Organic emissions to sea water]	1.6917E-03
VOC (unspecified) [Organic emissions to air (group VOC)]	1.6917E-03
Zinc [Heavy metals to fresh water]	2.5300E-21
Zinc [Fresh water]	2.5300E-21
Zinc [Heavy metals to agricultural soil]	2.4589E+01
Zinc [Heavy metals to industrial soil]	2.4589E+01
Zinc [Heavy metals to air]	1.1963E+01