

**LIFE CYCLE ASSESSMENT OF MARGARINE PRODUCTION FROM  
PALM OIL IN GHANA**

by

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I hereby declare that this submission is my own work towards the MSc. 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 acknowledgment has been made in the text.

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## ABSTRACT

100 % palm oil-based margarine has an outstanding demand by consumers as it is considered one of the spreads with beneficial nutritional value. Life cycle assessment (LCA) is an excellent tool of environmental management and it provides a widespread knowledge on the environmental burdens associated with a product or human activity. International Organisation for Standardisation (ISO) standards, ISO 14040-43, were followed in the execution of this work. Adequate data for inventory phase was obtained from different factories and farms. Through developed questionnaires submitted to the oil palm producer, TOPP (the largest supplier of crude palm oil to Unilever Ghana Limited) and Unilver Ghana Limited ( sole palm oil refiner and margarine producer in Ghana as of the time of data collection), and from Eco-invent database, inventory data was constantly sought for time duration of one year. Five phases of the 100 % palm oil-based margarine were studied namely oil palm production, palm oil production, palm oil refining and margarine production. LCA data associated with these phases were analysed by employing the GABI Software that was sponsored by the United Nations Environmental Program (UNEP) through the Life Cycle Initiative. The impact assessment method used in this study was the CML 2001 that was produced by Centre of Environmental Science of Leiden University. The analysis of these data by LCA has made it possible to quantify potential impact associated with 100 % palm oil-based margarine production. Seven impact categories were considered namely acidification potential, eutrophication potential, global warming potential, fresh water ecotoxicity potential, human toxicity potential, photochemical ozone creation potential and terrestrial ecotoxicity potential. Characterisation of the data revealed that the oil-refining phase posed the highest environmental burden. Since the product life cycle has a global coverage (e.g. resource extraction in diverse geographical regions), global data or normal

values were compared with data for this work. Normalising the characterised environmental interventions revealed that acidification potential, eutrophication potential, global warming potential and photochemical ozone creation potential need mitigation measures when compared to global emissions. Two mitigating measures were recommended: anaerobic reactor system to reduce high organic load in wastewater due to oil losses at the oil production, refining and margarine phases; gas scrubbing system inclusion to reduce the emissions of CO<sub>2</sub> and SO<sub>2</sub> gases at the steam boiler houses at the oil refining and oil production phases. Inclusion of these mitigating systems can lead to 19.1 % reduction of global normalised environmental impact.



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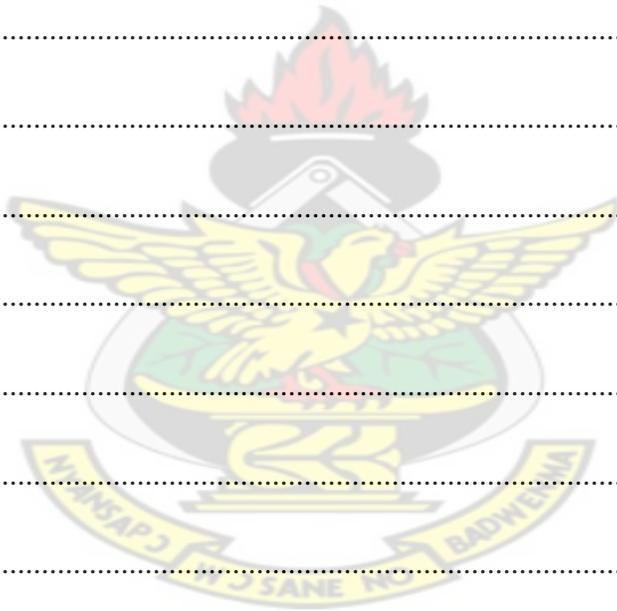
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## LIST OF ACRONYMS

AP – Acidification Potential	LCA – Life Cycle Assessment
BOPP – Benso Oil Palm Plantation Limited	LCC – Life Cycle Costing
BPO – Bleached Palm Oil	LCI – Life Cycle Inventory
CPKO – Crude Palm Kernel Oil	LCIA – Life Cycle Impact Assessment
CPO – Crude Palm Oil	NMVOC – Non Methane Volatile Organic Compound
DCB – 1,4 Dichlorobenzene	POCP – Photochemical Ozone Creation Potential
EFB – Empty Fruit Bunches	RBDPO – Refined Bleached Deodorised Palm Oil
EP – Eutrophication Potential	SETAC – Society of Environmental Toxicology and Chemistry
FAD – Fatty Acid Distillate	SPOLD – Society for the Promotion of Life Cycle Development
FAEP – Freshwater Aquatic Ecotoxicity Potential	TEP – Terrestrial Ecotoxicity Potential
FFA – Free Fatty Acid	TOPP – Twifo Oil Palm Plantation Limited
FFB – Fresh Fruit Bunches	UNEP – United Nations Environmental Program
GOPDC – Ghana Oil Palm Development Corporation	VOC – Volatile Organic Compound
GWP – Global Warming Potential	
HTP – Human Toxicity Potential	
ISO – International Organisation for Standardisation	

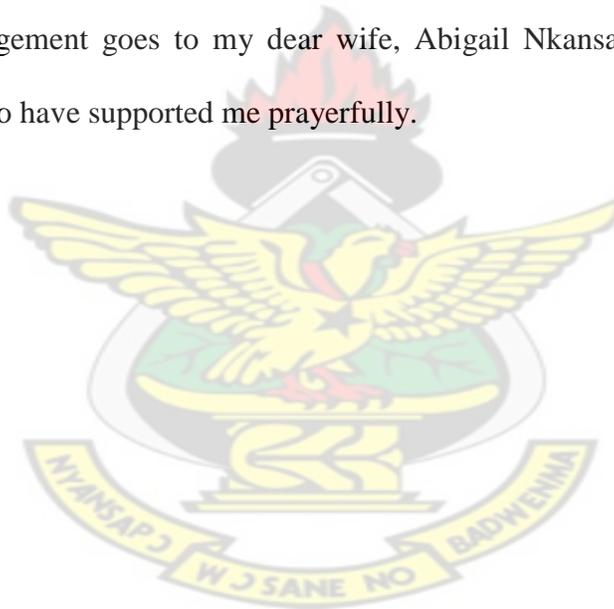
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## CHAPTER 1

### 1.0 INTRODUCTION

#### 1.1 Background and Justification

In January 2004, the President's Special Initiative (PSI) on oil palm plantation and exports was declared, which is expected to yield about \$90 million in export revenue within the short term. 100,000 hectares of oil palm is expected to produce 300,000 tonnes of palm oil a year at an export price of about \$300,000 / tonne in first phase of the initiative. 6,700 hectares of land had been cultivated leading to the employment of more than 27,000 farmers (Business in Africa, 2005).

In order to perpetuate the benefits of the 100 % palm oil-based margarine, manufacturers and consumers in Ghana and abroad need be aware or informed of the environmental performance of this product. Unfortunately, no work has been done on this type spread. The only data at the disposal of manufacturers and consumers of palm oil-based margarine are those of mixed oil-based margarine that has different environmental performance from that of 100 % palm oil-based margarine.

Green *et al* reported of the comparative impact assessment of six types of oils (palm, coconut, rapeseed, soybeans, sunflower and olive) at the cultivation stage and the amount of energy consumed to blend these different oils for margarine. It was evident that palm oil contributed about 40% of the impact posed by sunflower. However, this percentage does not exhaustively educate the manufactures of 100% palm oil-based margarine in Ghana since the process conditions of producing mixed oil-based margarine is different from that of 100% palm oil-based margarine (Green *et al*, 2006).

Hu *et al* has undertaken an LCA and economic analysis of butter versus margarine from a mixture of canola, palm, sunflower, rapeseed, olive, corn and soybean oils. The work only considered global warming potential without looking at other impact categories. Moreover, they did not point out the percentage environmental allocation to palm oil. Hydrogenation of canola oil that contributes the greatest environmental burden makes LCA of mixed oil-based margarine different from LCA of 100 % palm oil-based margarine (without hydrogenation). Thus, it does not fully inform the producers and consumers the actual environmental pressure exerted by 100% palm oil-based margarine (Hu *et al*, 2007).

Jefferies *et al* embarked on a pilot project to assess water impact on margarine produced from a mixture of palm oil, sunflower oil, rapeseed oil and maize oil using water footprint. Their work did not consider environmental impact contributed by energy, raw materials (such as polypropylene tub and lid, corrugated board, low density polyethylene film, etc.), and chemicals employed in all the processes. It means the results do not give a complete impact produced by the margarine. Moreover, it did not point out the percentage impact contributed by palm oil alone (Jefferies *et al*, 2009).

Schmidt has reported comparative life cycle assessment of rapeseed oil and palm oil. It became evident that palm oil was more environmentally friendly than rapeseed. In spite of this lower environmental friendliness of palm oil, it does not give enough information about 100 % palm oil-based margarine production since the work covered up to the oil production or extraction stage (Schmidt, 2010).

Nilsson *et al* reported of comparative LCA of mixed oil-based margarine and butter consumed in UK, Germany and France. Consequently, mixed oil-based margarine was more environmentally friendly than butter when considering global warming potential, eutrophication potential and acidification potential, but less environmentally friendly than

butter with respect to photochemical ozone creation potential due to high level of hexane employed in oil extraction (2010). This also did not point out the amount of environmental burden contributed by palm oil alone.

In terms of environmental product declaration and eco-labeling one cannot use environmental indicators of mixed oil-based margarine as a substitute for that of 100 % palm oil-based margarine. In this work, production of 100 % palm oil-based margarine in Ghana is subjected to life cycle assessment.

## 1.2 Research Aims and Objectives

The following outline the objectives of this work:

- To study the environmental impact of 100 % palm oil-based margarine production in Ghana.
- To develop an inventory of raw material resource consumption and environmental releases associated with the entire life cycle of margarine in Ghana.
- To recommend improvement measures to address any hot spot.

## 1.3 Limitations

There are besetting limitations associated with this work.

- Capital goods such as machines and equipment are not considered since these will clumsily broaden the system boundary of margarine production. This means that the result of this work does not give the total or complete environmental burden by 100 percent palm oil-based margarine in Ghana.
- Distribution and use phases are not considered for lack of data. It means that the results of this work do not give the gross environmental burden posed by margarine production from palm oil.

- There is a problem of representativeness of data associated this work. This means some pieces of data are not of local origin (Ghana). Coals, bleaching earth, citric acid, etc. are some of the data not from Ghana.
- Data on oil palm cultivation was taken from TOPP though BOPP and GOPDC transported CPO to Unilever Ghana Ltd. It means that contributions by BOPP and GOPDC were not considered because TOPP was the major CPO supplier to Unilever Ghana Ltd.
- Transport FFB to palm oil mill at TOPP was not considered because these FFBs were transported by out-growers from myriad of farms at different locations.
- Though Unilever Ghana Ltd. had three CPO suppliers (BOPP, TOPP and GOPDC), TOPP transportation data was used in the analysis as it supplied approximately 70 % of total CPO treated at Unilever Ghana Ltd.
- Life cycle of road construction and truck used for transporting CPO was not included.

#### **1.4 Approach**

This project was done by selecting major palm oil-producing companies in Ghana for raw material data collection. These companies are Unilever Tema Factory at the palm oil refining and margarine processing level, and Twifo Oil Palm Plantation (TOPP) at the oil palm cultivation and palm oil extraction level. Data on emissions from electricity production, water production and fuel (heavy oil and diesel fuel) production was obtained from the ecoinvent database. GABI Software was employed in the analysis of data from Unilever Ghana Limited and TOPP.

## CHAPTER 2

### 2.0 OVERVIEW OF LIFE CYCLE

#### 2.1 Definition of LCA

The first international accord 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, raw materials and wastes released into 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).

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”.

Both definitions are rather similar, since they stress the need to take into account the analysis the entire product chain and the potential consequences on the environment, based on the compilation of mass and energy balance of the product system.

## 2.2 Historical Development of LCA

The genesis of LCA can be traced to the energy crises of the late 1960s and early 1970s, which coerced industries into looking for energy efficient solutions for their products. The energy crisis of the early 1970s and the publication of the Limit to Growth had major influence on general environmental awareness. One of the results was a detailed system for analysing the energy required to manufacture individual products. LCA was developed parallel to the detailed system for analysing energy required to manufacture individual products. LCA extended the analysis to include not only the depletion of energy resource but also other activity such as raw material usage, and to include the impact of emission and waste generation (UNEP, 1996).

Interest in LCA has increased since the 1980s, and there have been two major changes: first, methods have been developed to quantify product impact on different categories of environmental problems (such as global warming; resource depletion); secondly, LCA studies have started to become more widely available for public use (UNEP, 1996).

A confusing situation arose towards the end of 1980s when environmental reports on similar products often contained conflicting results because they were based on different methods, data and terminology. It soon became clear that there was a need for standardisation in environmental reporting. This resulted in several environmental workshops, on several projects on LCA methodology, and the first international formulation of Code of Practice for LCA. The latter took place under the umbrella of SETAC, which has become the main forum for discussion on LCA (UNEP, 1996).

Today, knowledge of how to carry out an LCA is improving rapidly. The value of the technique is being increasingly recognized and is now being used for strategic decision and for designing environmental policies. United Nations Environment Program (UNEP) is

promoting the implementation of LCA through its Cleaner Production Programme. A number of firms have jointly set up the Society for the Promotion of Life Cycle Development (SPOLD). Today the rules governing LCA have been replaced with an international set of standards developed by the International Organization for Standardization (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 tailor any individual project to the desired application and result. There was a joint initiative launched by the UNEP and SETAC in 2002, called the Life-Cycle Initiative. The main aim of Life Cycle Initiative is to facilitate access to inventory data and to provide impact assessment procedures that are adapted to needs of the practitioner. The idea is to facilitate a global application of the tool, both in rich and poor countries, and in big companies.

### **2.3 LCA methodology**

ISO has established a uniform framework, uniform methods and procedures, and uniform terminology. The most important consequence of adhering to ISO standards is the need for careful documentation of goal and interpretative, educational, or communicational purposes. Secondly, one might need to include a peer reviewer by an independent expert as described in ISO 14040.

It is completely up to the LCA practitioner to conform to these standards or to deviate deliberately. Of course, if the practitioner deviates, he may not claim that his LCA is conformable to international standards, and it will be more difficult to convince others of the reliability of the results.

There are four ISO standards specifically designed for LCA application:

- Goal and Scope: ISO 14040 (1997);
- Life cycle inventory analysis : ISO 14041(1998);
- Life cycle impact assessment: ISO 14042(2000)
- Life cycle interpretation: ISO 14043(2000).

Figure 2.1 shows the phases of LCA according to ISO (1997) and typical phases in life cycle impact assessment (LCIA).

### 2.3.1 Goal and Scope

The goal points out the reason to perform the study and the intended use of the results. The scope clearly states the basic parameters of LCA such as functional unit, system boundaries, allocation rules, data quality and simplifications.

According to ISO 14040: 1997, the functional unit is defined as the quantified performance of a product system for use as a reference unit in LCA study. The ISO 14041: 1998 standard accomplished the definition by indicating that one of the primary purposes of the functional unit is to provide a reference to which the input and output data can be normalised in mathematical sense. For example, the functional unit for this project is chosen to be 1kg of margarine.

Since the study of LCA is so complex, system boundary is defined to render the study more manageable or reduce the system boundary to a smaller size. For example to transport crude palm oil to Unilever Ghana Ltd, a truck is needed. However, a truck is also a product with a life cycle. To produce a truck, steel is needed. To produce steel, coal is needed. To produce coal trucks are needed etc. It is clear that input and output of margarine cannot be trace. In

this work oil palm production, palm oil production, palm oil transportation (excluding LCA of truck), palm oil refining and margarine production.

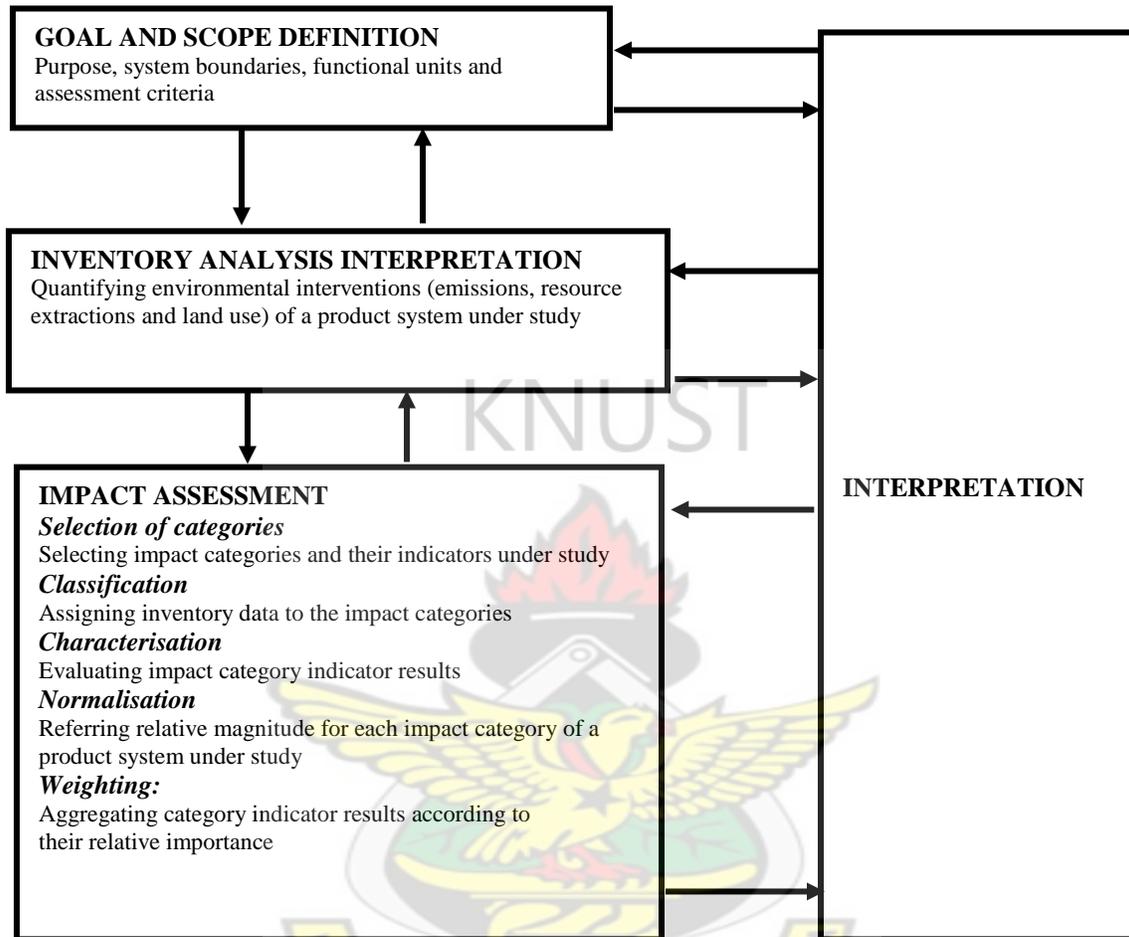


Figure 2.1 Phases of LCA according to ISO (1997) and typical phases in life cycle impact assessment.

This is done after the process flow chart has been developed and data collection has begun.

Three basic boundaries were considered: 1. boundary between system and the environment-extractions and all emissions into the environment, 2. boundary between system under study and other related systems, and allocations of various effects where necessary, 3. boundary between relevant and irrelevant processes.

Allocation problem arise when there are co-products coming from the same unit operation or product system. Allocation deals with the attribution of the environmental load by the

product of the system under study. This allocation is done based on mass, energy content and the economic value of a product.

### **2.3.2 Life cycle inventory analysis**

This is the aspect of LCA that deals with data collection on input (energy resource and raw material) and output (products and emissions) of product system. There are two main types of data in this stage of LCA: foreground and background data.

Foreground data refers to very specific data needed to model the product system- a typical data that describes a particular product system and particular specialized system. The foreground data such as amount of water used, RBDPO required per kilogram of margarine, etc. are collected from plant operators.

Background data is one for generic material, energy, transport and waste management system. Background data is obtained from databases and literature (ETH-ESU 96, BUWAL 250, ecoinvent database) (PRé Consultants, 2007)

### **2.3.3 Life cycle impact assessment**

By ISO 14042 definition, life cycle impact assessment is the phase in the LCA aimed at understanding and evaluating the magnitude and significance of the potential impacts of a product system. This means the inventory analysis is related to environmental problems or grouping the output into impact categories. These categories are abiotic depletion potential; energy depletion potential; global warming potential; acidification potential; photochemical oxidation formation; human toxicity potential; ecotoxicity aquatic; ecotoxicity terrestrial; eutrophication potential; ozone depletion potential. The impact assessment methods are grouped into obligatory elements (classification and characterisation) and optional elements (normalisation, ranking, grouping and weighting). The optional elements are used to simplify

interpretation of the LCA result. This means that according to ISO, every LCA must at least include classification and characterisation. If such procedures are not applied, one may refer to the study as a life cycle inventory.

There are different methods of impact assessment in LCA. The choice of the method depends on the goal of study. The following are the some of the environmental impact methods:

- CML 92 (this does not include noise, land use, and fine particle matter)
- Eco-indicator 95 (does not include land use, noise and fossil fuel depletion)
- Eco-indicator 99 (does not include noise)
- ESP 2000 (includes all the categories )
- Critical surface-time 95 (CST 95)
- CML(Center of Environmental Science of Leiden University) 2001 etc.

### **2.3.3.1 Classification and characterization**

The inventory result of an LCA usually contains hundreds of different emissions and natural resources extraction (e.g. coal, crude oil etc.). Once the relevant impact categories are determined, the life cycle inventory result must be assigned to impact categories (classification). For example, CO<sub>2</sub>, CH<sub>4</sub> and NO<sub>x</sub> are assigned to global warming; SO<sub>2</sub>, NH<sub>4</sub><sup>+</sup> and NO<sub>x</sub> are assigned to acidification. It is possible to assign emissions to more than one impact category at the same time; for example, NO<sub>x</sub> may be assigned to both global warming and acidification; resource extraction falls under resource depletion impact category. This is illustrated in figure 2.2.

Once the impact categories are defined and the life cycle inventory results are assigned to these impact categories, it is necessary to define characterisation or equivalent factors. These factors should reflect the relative contribution of life cycle inventory result to the impact

category indicator result. For example  $\text{SO}_2$  and  $\text{NO}_x$  have equivalent factors of 0.81 and 0.53 respectively. To characterise these emissions, the masses of the emissions are multiplied by their respective equivalent factors. Since both  $\text{SO}_2$  and  $\text{NO}_x$  contribute to acidification the total acidification potential equal to the sum of the characterised values.

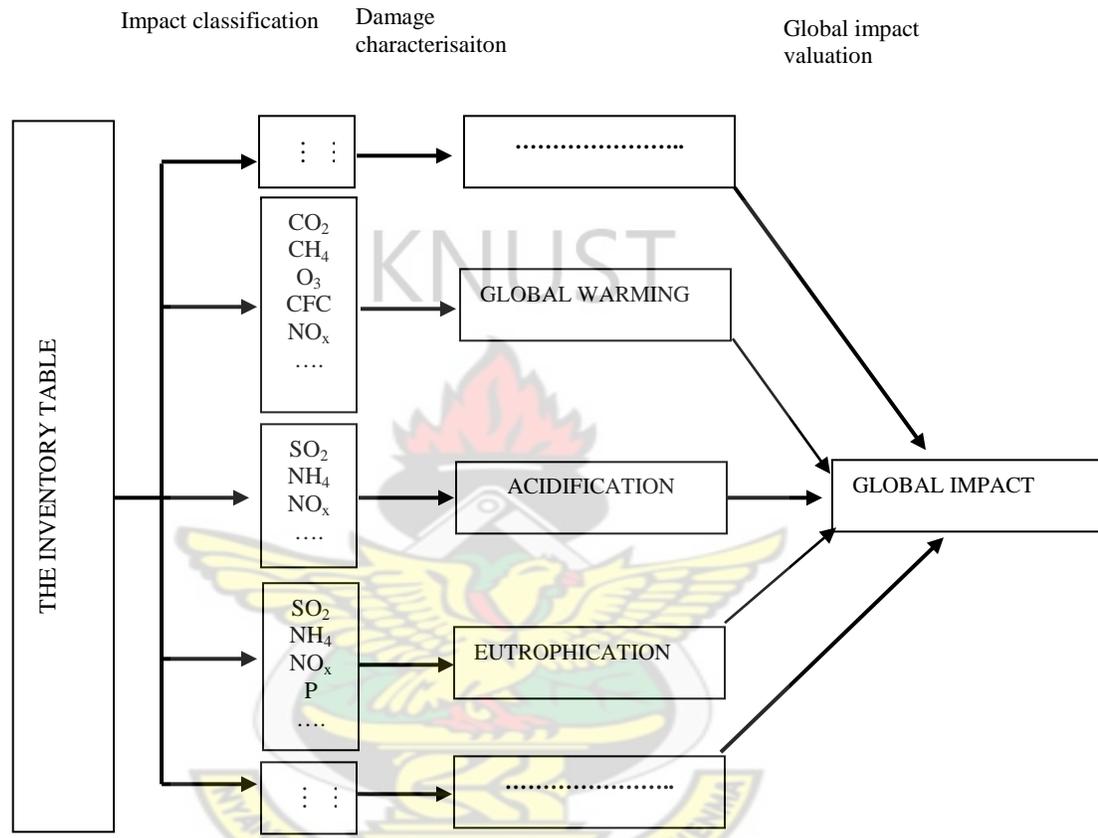


Figure 2.2 General Overview of the structure of impact assessment method (UNEP, 1996).

### 2.3.3.2 Normalisation (optional)

Normalisation is done by dividing the impact category results of a product system by the corresponding impact category indicator of a reference system (for example, activities in a given area over a certain time). Normalisation shows how much the impact category contributes to the overall environmental problem. This is done by dividing the impact category indicators by 'normal' value. Since life cycle of margarine has a global coverage

(e.g. resource extraction in diverse geographical regions), global data or normal values were compared with data for this work. This serves two purposes:

- impact category that can contribute only small amount compared to other impact categories can be left out of consideration to reduce the number of issues that need to be evaluated, and
- The normalised results show the order of magnitude of the environmental problem generated by the product life cycle, compared to the total environmental loads globally (Pre' Consultants, 2007).

### **2.3.3.3 Weighting (optional)**

This is an optional part of the life cycle impact assessment (LCIA). It includes the determination of impact category weights and the aggregation of different environmental impact categories in order to compress multi-dimensional information into a single value score. Weighting steps are based on value-choice and are not scientifically based. Different individuals, organizations and societies may have different preferences; therefore it is possible that different parties will reach different weighting results based on the same indicator results or normalized indicator results (ISO 14044, 2006).

In view of this fact, weighting will not be applied and reported in this work.

### **2.3.4 Interpretation of results**

Interpretation of result is done as follows: identifying major and minor contributors to LCIA results; explaining uncertainties; meeting the goal set; validating the solution if necessary by way of additional data collection, sensitivity analysis (analysis to determine the sensitivity of the outcome of a calculation to small changes in the assumptions or to variations in the range within which assumptions are assumed to be valid) and gravity analysis; and improving upon

the process that is done by looking at the areas of the process or products that pose the greatest environmental impact.

## **2.4 Application of LCA**

According to ISO 14040, the application of an LCA can assist in identifying opportunities to improve the environmental aspects of products at various points in their life cycle, making decision in industry, governmental or non-governmental organisations (e.g. strategic planning, priority setting, product or process design or re-design), and selecting the relevant indicators of environmental performance including measurement techniques, marketing (e.g. an environmental claim, ecolabelling scheme or environmental product declaration).

## **2.5 Disadvantages of LCA**

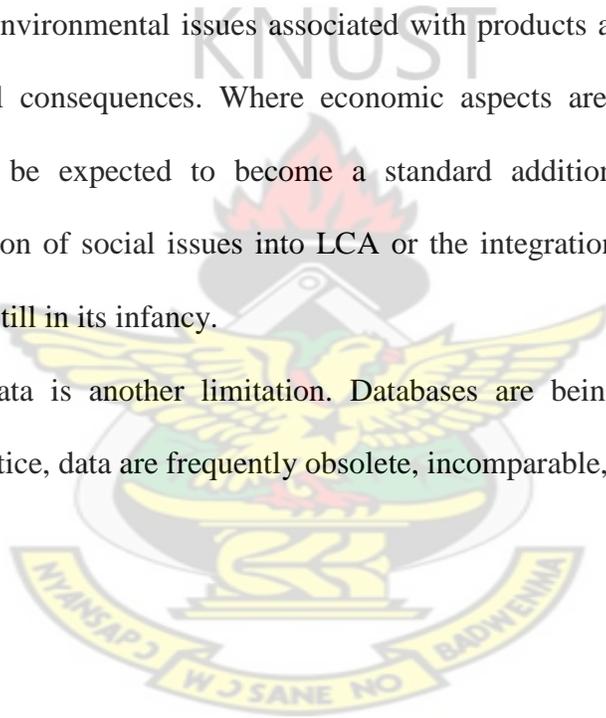
1. LCA addresses potential rather than actual impacts. This is because in LCA, impacts are not specified in space and time. The ISO 14042 standard, which deals with LCIA, specially cautions that LCA does not predict actual impacts or assess safety, risks and exceeded thresholds. The actual environmental 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. In this work, the actual environmental interventions such as CO<sub>2</sub> and SO<sub>2</sub> that cause global warming and acidification respectively are addressed locally by suggesting mitigation measures through LCA.

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, in both 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. 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.



## CHAPTER 3

### 3.0 OVERVIEW OF PALM OIL

#### 3.1 The oil palm

Elaeis guineensis that is commonly known as the oil palm is the most important species in the genus *Elaeis* that belongs to the family *Palmae*. The second specie is Elaeis oleifera (H.B.K) Cortes, which is found in South and Central America, is known as the American oil palm. Although significantly lower in oil-to-bunch content than its African counterpart (Elaeis guineensis), Elaeis oleifera has a higher level of unsaturated fatty acids and has been used for production of interspecific hybrids with Elaeis guineensis (Teoh, 2002).

The oil palm is an erect monoecious plant that produces separate male and female inflorescences. Oil palm is cross-pollinated and the key pollinating agent is the weevil, Elaeidobius kamerunicus Faust. In the past, oil palm was thought to be wind pollinated and owing to the low level of natural pollination, assisted pollination is a standard management practice in plantations. However, this practice was discontinued following the discovery that oil palm was insect pollinated and the introduction of Elaeis kamerunicus from the Cameroon (Teoh, 2002).

Harvesting commences about 24 to 30 months after planting and each palm can produce between 8 to 15 fresh fruit bunches (FFB) per year weighing about 15 to 25 kg each, depending on the planting material and age of the palm. Each FFB contains about 1000 to 1300 fruitlets; each fruitlet consists of a fibrous mesocarp layer and, the endocarp (shell) which contains the kernel. Present day planting materials are capable of producing 39 tonnes of FFB per ha, and 8.6 tonnes of palm oil. Actual yields from good commercial plantings are about 30 tonnes FFB per ha with 5.0 to 6.0 tonnes oil (Henson, 1990).

Cultivars or races of Elaeis guineensis can be differentiated by their fruit pigmentation and characteristics; the most common cultivars being the Dura, Tenera and Pisifera which are classified according to endocarp or shell thickness and mesocarp content. Dura palms have 2-8mm thick endocarp and medium mesocarp content (35%-55% of fruit weight), the tenera race has 0.5-3mm thick endocarp and high mesocarp content of 60%-95% and the pisifera palms have no endocarp and about 95% mesocarp (Teoh, 2002).

Traditionally, breeding of oil palm has focused on yield improvement, in terms of FFB and oil content, slow height increment, oil quality and disease tolerance. Currently, the industry has placed emphasis on the production of the following types of planting materials to meet industrial and market needs:

- Development of dwarf palms (PS1 type) – to reduce the palm height and significantly extend the economic cropping cycle.
- Breeding for high unsaturated oil (High iodine value) (PS2 type) – to produce materials with higher proportions of unsaturated fatty acids by crosses with high iodine value. An example is to cross Nigerian duras and *E. guineensis* with *E. oleifera* hybrids.
- Breeding for high lauric oil (PS3 type) – using high yielding Nigerian dura palms with high kernel contents
- Breeding for high carotenoid content (PS4 type) – using selected Nigerian duras and pisiferas as well as hybridisation with *E. oleifera*.

As current DxP planting materials derived from seeds have a high level of variation, several companies undertook research on production of clonal palms in the 1980s. This research was based on the premise that yields can be increased by about 30% with clones derived from elite palms in a DxP population. However, commercial production of clones was hampered

by the discovery of abnormal flowering behaviour, and the research effort was diverted to overcoming the occurrence of abnormalities in palm clones (Teoh, 2002).

### 3.2 Chemical composition of palm oil

The main components of palm oil are triglycerides. The minor components include mono- and diglycerides, free fatty acids, phosphatides, sterols, fat-soluble vitamins, tocopherols, pigments, waxes, and fatty alcohols. The free fatty acid content of crude oil varies widely based on the source of production. Phosphatides, sterols, fat-soluble vitamins, tocopherols, pigments, waxes, and fatty alcohols amount to 2% of crude palm oil. Table 3.1 shows the percentage fatty acid compositions.

Table 3.1 Fatty Acid Compositions (%weight) of Palm Oil

Type of fatty acid	palm oil	Palm olein	Palm stearine
C12:0 Lauric	0.2	0.2	0.3
C14:0 Myrstic	1.1	1.0	1.3
C16:0 Palmitic	44.0	39.8	55.0
C18:0 Stearic	4.5	4.4	5.1
C18:1 Oleic	39.2	42.5	29.5
C18:2 Linoleic	10.1	11.2	7.4
Others	0.8	0.9	0.7
Iodine Value	53.3	58.4	35.5

Source: Salmiah, 2000

### 3.2.1 The Major Component – Triglycerides

A triglyceride consists of three fatty acids attached to one glycerol molecule. When all three fatty acids are identical, it is referred to as a simple triglyceride. The more common forms, however, are the “mixed” triglycerides in which two or three kinds of fatty acids are present in the molecule. Fig.3.1 shows the molecular structures of simple triglyceride and mixed triglyceride.



Figure 3. 1 Molecular structures of simple triglyceride and mixed triglyceride

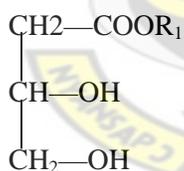
The fatty acids in a triglyceride define the properties and characteristics of the molecule. Triglycerides predominantly comprise fatty acids present in the form of esters of glycerol. 100 grams of palm oil yields approximately 95 grams of fatty acids. Both the physical and chemical characteristics of palm oil are influenced greatly by the kinds and proportions of the component fatty acids and the way these are positioned on the glycerol molecule. The predominant fatty acids are saturated and unsaturated carbon chains with an even number of carbon atoms and a single carboxyl group as illustrated in the general structural formula for a saturated fatty acid given as  $\text{CH}_3\text{-(CH}_2\text{)}_x\text{—COOH}$ . Saturated carbon chain is  $\text{CH}_3\text{-(CH}_2\text{)}_x$ , and the carboxyl group is  $\text{COOH}$ . (Strayer et al., 2006)

Saturated fatty acids are those with single carbon-to-carbon bonds; they are least chemically reactive. Stearic, myristic and palmitic acids are examples of saturated fatty acids in palm oil. Fatty acids containing one or more carbon-to-carbon double bonds are termed unsaturated (mono-unsaturated or poly-unsaturated respectively). Because of the presence of double

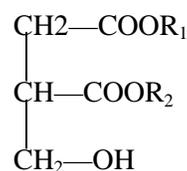
bonds, unsaturated fatty acids are more reactive chemically than saturated fatty acids. This reactivity increases as the number of double bonds increases. Linoleic and oleic fatty acids are examples of poly-unsaturated and mono-unsaturated fatty acids respectively.

### 3.2.2 The Minor Components

**a. Mono- and Di-glycerides.** Mono- and diglycerides are mono- and di-esters of fatty acids and glycerol. They are used frequently in foods as emulsifiers. They are prepared commercially by the reaction of glycerol and triglycerides or by the esterification of glycerol and fatty acids. Mono- and di-glycerides are formed in the intestinal tract of mammals because of the normal digestion of triglycerides. They occur naturally in minor amounts in palm oil. Mono- and di-glycerides account for about 3% to 6% by weight of the glycerides in the oil. Good oils having lower amount of mono and diglycerides is said to be of great importance in the fractionation process because they act as emulsifying agents inhibiting crystal formation and making filtration difficult. Fig.3.2 shows molecular structures of mono- and di-glyceride.



Monoglyceride



Diglyceride

Figure 3.2 Molecular structures of mono- and di-glyceride

**b. Free Fatty Acids.** As the name suggests, free fatty acids are the unattached fatty acids present in palm oil. Some unrefined palm oils may contain as much as 5%wt free fatty acids. The levels of free fatty acids are reduced in the refining process. Fully refined palm oil usually has a free fatty acid content of less than 0.1%. In the presence of heat and water, triglycerides hydrolyse to form free fatty acids (FFA) thus yielding mono- and di-glycerides

and FFA which is of crucial importance to refiners. The amount FFA is reduced in the process of refining. Figure 3.3 shows hydrolysis of palm oil.

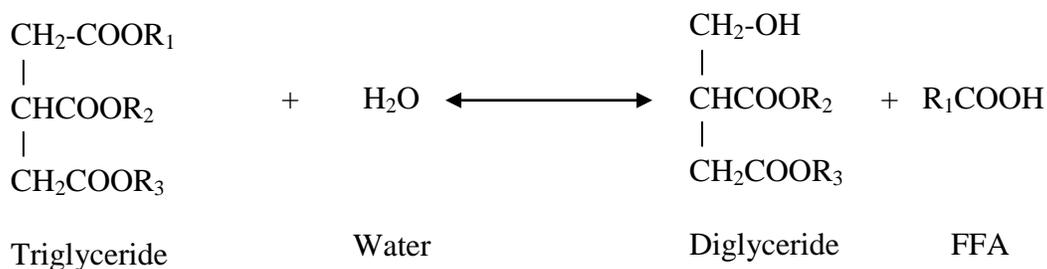


Figure 3.3 Hydrolysis of palm oil

**c. Phosphatides** also known as phospholipids, consist of an alcohol (usually glycerol) combined with fatty acids, and a phosphate ester. The majority of the phosphatides are removed from oil during refining. Phosphatides are an important source of natural emulsifiers marketed as lecithin. Phosphatide ranges  $0.075 \pm 0.05\%$  wt in palm oil (Strayer et al., 2006). Lecithins and cephalins are the two types of phosphatide. They are excellent emulsifying agents. In mayonnaise, the phosphoglycerides of the egg yolk keep the oil emulsified in the vinegar (Fessenden, 1990).

**d. Sterols** are found in palm oil. Cholesterol is the primary animal fat sterol and is found in palm oils in only trace amounts. The range of occurrence is  $2250 \pm 250$  ppm in palm oil.

**e. Tocopherols and Tocotrienols** are important minor constituents of palm oil. They serve as antioxidants to retard rancidity, and as sources of the essential nutrient vitamin E. The common types of tocopherols and tocotrienols are alpha ( $\alpha$ ), beta ( $\beta$ ), gamma ( $\gamma$ ), and delta ( $\delta$ ). They vary in antioxidation and vitamin E activity. Among tocopherols,  $\alpha$ -tocopherol has the highest vitamin E activity and the lowest antioxidant activity; however,  $\delta$ -tocopherol has the highest antioxidant activity. Tocopherols, which occur naturally in most palm oil, are partially removed during processing. Tocopherols and Tocotrienols in palm oil have values of  $240 \pm 60$  ppm and  $560 \pm 140$  ppm respectively. (Strayer et al., 2006)

**f. Pigments** consist mainly of carotenes such as lycopene and xanthophylls such as lutein. Carotenoids are yellow to deep red colour materials that occur naturally in fats and oils. Carotenoids give red palm oil a deep reddish colour, as compared to the straw-yellow colour of refined, bleached, and deodorized palm olein (RBDPO). Palm oil contains the highest concentration of carotene. Carotenoids are the main dietary source of pro-vitamin A in humans. Crude palm oil has the highest content of natural carotenes, ranging from 600 to 1000ppm, as well as, very high levels of vitamin E (500-800ppm) Conventional refining processes that produce RBDPO remove practically all of the natural carotenoids, but retain a substantial amount of vitamin E (Choo, 1996).

$\alpha$ -carotenoid (37%) and  $\beta$ -carotenoid (47%) constitute about 84% of the carotenoid content in red palm oil with another dozen or so making up the remaining 16% (Fife, 2007)

**g. Fatty Alcohols.** Long chain alcohols are of little importance in most edible fats. A small amount esterified with fatty acids is present in waxes found in some vegetable oils. Larger quantities are found in some marine oils.

### 3.2.3 Factors Affecting Physical Characteristics of Palm Oil

The physical characteristics of a fat or oil are dependent upon the degree of unsaturation, the length of the carbon chains, the isomeric forms of the fatty acids, molecular configuration, and processing variables. The degree of unsaturation determines the melting point of palm oil. The greater the unsaturation of palm oil, the lower melting point, and vice versa. Stearine (saturated) in palm oil has higher melting point than olein (unsaturated). Most of the palm oil that solidifies easily at room temperature contains more stearine than olein (Strayer et al., 2006).

The degree of unsaturation of a fat, i.e., the number of double bonds present, normally is expressed in terms of the iodine value (IV) of the fat. IV is the number of grams of iodine, which reacts with the double bonds in 100 grams of palm oil, and is calculated from the fatty acid composition. 'Iodine Value' (IV) and can be determined by adding iodine to the oil. The amount of iodine in grams absorbed per 100 ml of oil is then the IV. Generally, the higher IV of palm oil, the lower the temperature at which it solidifies.

As palm oil cools, wax crystals form, and the oil goes cloudy. Cloud point determines the crystallizing property of palm oil. A sample of oil is cooled under defined conditions and its turbidity is observed. The temperature, at which a cloud of oil crystals first appears, is known as the cloud point. The low- temperature behavior of palm oil products is very important for their usage, as it affects their ability to be pumped, transported and filtered. The melting properties of triglycerides are related to those of their fatty acids. As the chain length of a saturated fatty acid increases, the melting point also increases (Waynick, 2005).

The melting points of unsaturated fatty acids are profoundly affected by the position and conformation of double bonds. For example, the mono-unsaturated fatty acid oleic acid and its geometric isomer, elaidic acid, have different melting points. Oleic acid is liquid at temperatures considerably below room temperature, whereas elaidic acid is solid even at temperatures above room temperature. Isomeric fatty acids in many vegetable shortenings and margarines contribute substantially to the semi-solid form of these products

A mixture of several triglycerides has a lower melting point than would be predicted for the mixture based on the melting points of the individual components and will have a broader melting range than any of its components will have. For example, in cocoa butter, palmitic (P), stearic (S), and oleic (O) acids are combined in two predominant triglyceride forms (POS and SOS), giving cocoa butter its sharp melting point just slightly below body temperature.

This melting pattern partially accounts for the pleasant eating quality of chocolate. Mono-glycerides and di-glycerides have higher melting points than triglycerides with a similar fatty acid composition (Strayer et al., 2006).

### 3.2.4 Production and processing of palm oil

#### a. Crude Palm Oil

The oil palm produces two types of oils, palm oil from the fibrous mesocarp and lauric oil from the palm kernel. In the conventional milling process, the fresh fruit bunches (FFB) are sterilised and stripped of the fruitlets, which are then digested and pressed to extract the crude palm oil (CPO). The nuts are separated from fibre in the press cake and cracked to obtain palm kernels, which are crushed in another plant to obtain crude palm kernel oil (CPKO) and a by-product( palm kernel cake), which is used as an animal feed. Figure 3.4 describes the production of palm oil from the fresh fruit bunches.

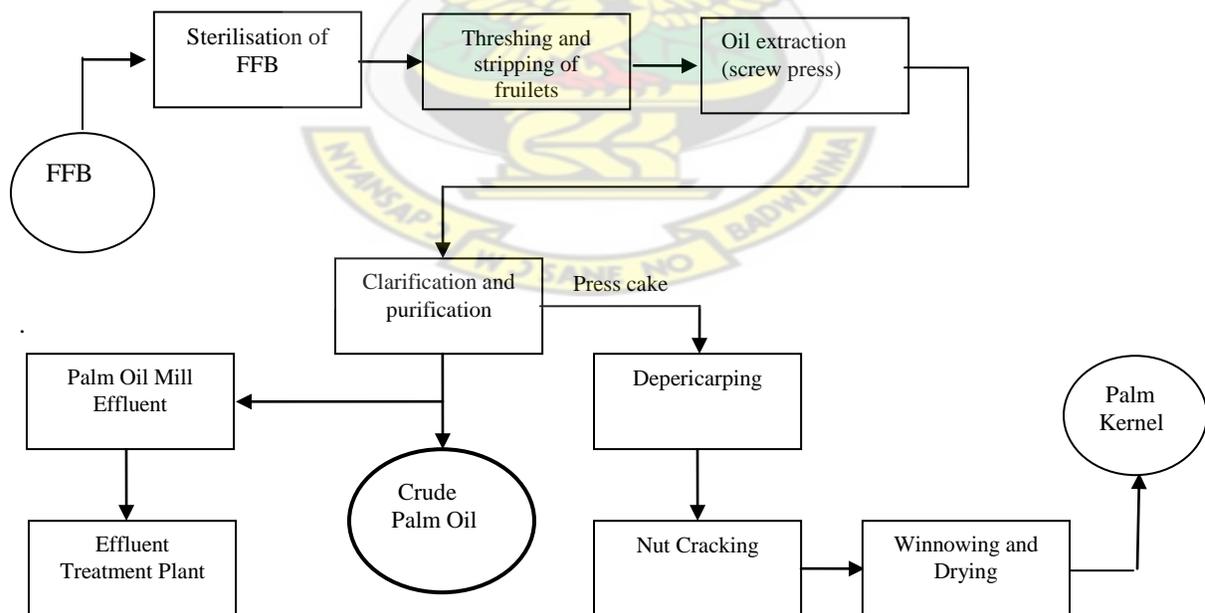


Fig.3.4 Production of Crude Palm Oil

Source: Teoh (2002)

## **b. Degumming**

The purpose of degumming is to produce commercial lecithin (contains phosphatides), to prevent crude oil from settling during storage or transport, to prevent acidulation of gums, to refine the oil physically and to reduce neutralisation losses.

There are two main types of gums: hydratable phosphatides (easy to remove from oil) and non-hydratable phosphatides (NHP) (hard to remove from oil). Some non-hydratables are removed with hydratables during water degumming while some non-hydratables require the use of acid to convert to hydratable for complete removal from oil. Degumming is accomplished by using acid or water (Longan,2002)..

In water degumming the crude palm oil is heated to 60°C or 70°C. Water is added to the oil and stirred for effective mixing. The oil-water mixture is stirred for 30minutes to allow the phosphatides to be hydrated. The hydrated gums are separate with the aid of a centrifuge. The degummed oil is subjected to vacuum drying. The gum is dried for edible lecithin or recombined in meal. After the water degumming, the phosphorus content in the oil ranges from 50ppm to 200ppm; percentage aluminium in the dried gums ranges from 65% to 70%, and the moisture content in the dried oil is less than 0.1% (Longan,2002).

In the acid degumming process, the crude palm oil is heated to 60°C or 70°C. Acid (normally dilute phosphoric acid) is added to the heated oil and stirred for 30minutes in order to hydrate the gums. The gums are separated by means of a centrifuge. The degummed oil is dried while the gums are recombined in meal. After acid degumming, the phosphorous content in the dried oil ranges from 20ppm to 50ppm, percentage aluminium in the dried gums ranges from 65% to 75%, and the moisture content in the dried oil can be less than 0.1% (Longan,2002).

A relatively new process in the United States is enzymatic degumming. An enzyme, phospholipase, converts phospholipids, present in crude oil, into lysophospholipids that can

be removed by centrifugation. Crude palm oil, pre-treated with a combination of sodium hydroxide (NaOH) and citric acid ( $C_6H_8O_7$ ), is mixed with water and enzymes (phospholipase) by a high shear mixer, creating a very stable emulsion. The emulsion allows the enzyme to react with the phospholipids, transforming them into water-soluble lysophospholipids. This emulsion is broken by centrifugation, separating the gums and phospholipids from the oil. This process generates a better oil yield than traditional degumming/refining (Strayer et al., 2006).

### **c. Chemical Refining/Neutralisation**

The process of refining (sometimes referred to as “alkali refining”) generally is performed on palm oils to reduce the free fatty acid (FFA) content and to remove other impurities such as phosphatides, proteinaceous, and mucilaginous substances. By far the most important and widespread method of refining is the treatment of the fat or oil with an alkali solution. This results in a large reduction of free fatty acids through their conversion into high specific gravity soaps. Most phosphatides and mucilaginous substances are soluble in the oil only in an anhydrous form; they are readily separated upon hydration with the caustic or other refining solution. Palm oil that has low phosphatide content may be physically refined (i.e., steam stripped) to remove free fatty acids. After alkali refining, the oil is water-washed to remove residual soap (Strayer et al., 2006).

### **d. Bleaching**

The term “bleaching” refers to the process of removing colour-producing substances and thereby further purifying the palm oil. Normally, bleaching is accomplished after the oil has been refined. The usual method of bleaching is by adsorption of the colour-producing substances on an adsorbent material. Acid-activated bleaching earth or clay, sometimes called bentonite ( $Al_2O_3 \cdot 4SiO_2 \cdot H_2O$ ) which contains trace elements like Na, Ti, Mg, Fe, Ca,

Zn and H, is the adsorbent material that has been used most extensively. This substance consists primarily of hydrated aluminum silicate. Other common clay materials are illite  $((K,H)Al_2(Si,Al)_4O_{10}(OH)_2 \cdot xH_2O)$  and montmorillonite  $((Na,Ca)(Al,Mg)_6(Si_4O_{10})_3(OH)_6 \cdot nH_2O)$ . Anhydrous silica gel and activated carbon also are used as bleaching adsorbents to a limited extent (Strayer et al., 2006).

#### **e. Deodorising**

This is a stripping process, which is accomplished after refining and bleaching. The deodorisation of palm oils is simply a removal of the relatively volatile components from the oil using steam. This is feasible because of the great differences in volatility between the substances (FFA>tocopherols>sterols) that give flavours, colours and odours to palm oil and the triglycerides. Table 3.2 shows the volatile components and their relative volatilities. Deodorisation is a vacuum (3-4mbar Pressure) steam distillation process (at approximately 260°C) for the purpose of removing trace constituents that give rise to undesirable flavours, colours and odours in palm oil. Deodorisation is carried out under vacuum to facilitate the removal of the volatile substances, to avoid undue hydrolysis of the palm oil and to make the most efficient use of the steam. Steam and nitrogen are the common stripping agents employed in deodorisation of oils. Steam is preferred to nitrogen because nitrogen is non-condensable; it requires more powerful vacuum system than steam; it is heavier than steam; it does not give high profits (De Greyt, 2004).

Deodorisation does not have any significant effect on the fatty acid composition of most palm oil. Depending upon the degree of unsaturation of the oil being deodorised, small amounts of trans fatty acids may be formed. Sufficient tocopherols remain in the finished oils after deodorisation to provide stability (Wim, 2004).

Table 3.2 Properties of volatile components in palm oil at 260°C.

Component	Molecular weight	Relative volatility
Free Fatty acid	280	2.50
Squelene	411	5.00
Tocopherol	415	1.00
Sterol	410	0.60
Sterol ester	675	0.04

Source: De Greyt, 2004

#### **f. Fractionation**

Fractionation is the removal of solids by controlled crystallisation and separation techniques involving the use of solvents or dry processing. Dry fractionation encompasses both winterisation and pressing techniques and is the most widely practiced form of fractionation. It relies upon the differences in melting points to separate the oil fractions. This is accomplished by heating the palm oil to temperature of about 60°C to destroy all potential crystals that would hinder appropriate crystallisation. The oil is cooled to a temperature of 18°C at which stearine portion of the palm crystallises waiting to be separated from the olein with a press filter (Dijkstra, 1998).

Winterisation is a process whereby material is crystallised and removed from the oil by filtration to avoid clouding of the liquid fraction at cooler temperatures. Pressing is a fractionation process used to separate liquid oil (palm olein) from solid (palm stearine). This process presses the liquid oil from the solid fraction by hydraulic pressure or vacuum filtration. This process is used commercially to produce hard butters and specialty fats from oils such as palm and palm kernel. In dry fractionation, feedstock can be crude, semi-refined

or fully refined palm oil. It is suitable for both single and double fractionation; cost of operation is low compared to solvent fractionation (Dijkstra, 1998).

In Solvent fractionation, the starting material is dissolved in a solvent like acetone ( $C_3H_6O$ ) or hexane ( $C_6H_{14}$ ) and then the solution is cooled so that triglycerides with the highest melting point start to crystallise. Crystals formed are separated by filtration and the fractions are recovered by solvent evaporation. Because the liquid present in the filter cake is a diluted olein solution, even a wet cake contains little olein so that the solvent fractionation process is quite “selective”. Besides, washing the filter cake with additional solvent can reduce its olein content even further. Another advantage of the solvent fractionation process over the dry fractionation process, which operates from the melt, is the high degree of crystallisation attainable: a high IV olein can be produced by solvent fractionation in a single operation, but it requires a multi-step operation in the dry fractionation process (Dijkstra, 1998).

On the other hand, the investment in a solvent fractionation plant is high. It has to handle large volumes of diluted solutions and has to be explosion proof. Operating costs are also high because cooling to low temperatures and solvent evaporation are energy intensive. Accordingly, solvent fractionation is in practice and it is only used for high benefit products such as cocoa butter equivalents (Dijkstra, 1998).

### **3.2.5 Chemical Reactions of Palm Oil**

#### **a. Hydrolysis**

Like other esters, glycerides can be hydrolyzed readily. Partial hydrolysis of triglycerides yields monoglycerides, diglycerides and free fatty acids. When hydrolysis is carried to completion with water in the presence of an acid catalyst, the mono-, di-, and tri-glycerides hydrolyze to glycerol and free fatty acids, which increases the rancidity of palm oil.

With aqueous sodium hydroxide (NaOH), glycerol and the sodium salts (soaps) are obtained.

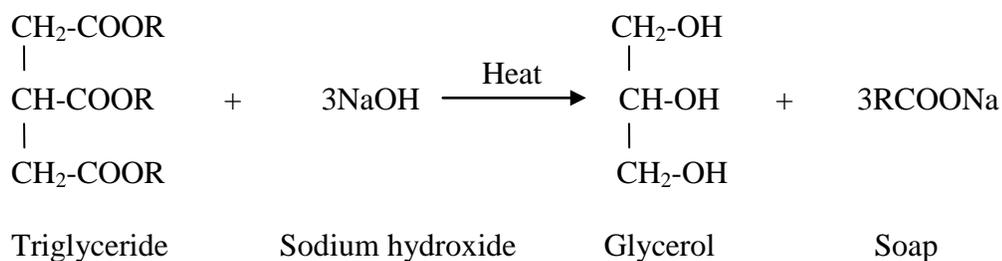


Fig.3.5 General chemical reaction for alkali hydrolysis of oil

Fig.3.5 shows the general saponification reaction. Soap is therefore a sodium or potassium salt of a long fatty acid. Sodium gives hard soaps while potassium gives soft soaps. The amount of NaOH or KOH required is determined mainly by the saponification value. Saponification value is expressed in the milligrams of potassium hydroxide or sodium hydroxide required to saponify 1g of fat under the conditions specified. It is a measure of the average molecular weight (or chain length) of all the fatty acids present. As most of the mass of an oil or triester is in the 3 fatty acids, it allows for comparison of the average fatty acid chain length.

Handmade soap makers who aim for bar soap use NaOH saponification values, which are derived from the saponification value calculated by laboratories (KOH saponification value). To convert NaOH values to KOH, multiply by the ratio of the atomic weights of Potassium and Sodium, or about 140%. The calculated saponification value is not applicable to oils containing high amounts of unsaponifiable material, free fatty acids (>0.1%), or mono- and di-acylglycerols (>0.1%).

In the digestive tracts of humans and animals and in bacteria, fats are hydrolyzed by enzymes (lipases). Lipolytic enzymes are present in palm oil. Any residues of these lipolytic enzymes

present in crude palm oil are deactivated by the elevated temperatures normally used in oil processing (Bodner and Pardue, 1995).

## **b. Oxidation**

**i. Autoxidation.** Of particular interest in the food industry, autoxidation is the oxidation process induced by air at room temperature. Ordinarily, this is a slow process, which occurs only to a limited degree. In autoxidation, oxygen reacts with unsaturated fatty acids. Initially, peroxides (ROOR) are formed which may break down into secondary oxidation products (hydrocarbons, ketones, aldehydes, and smaller amounts of epoxides and alcohols). Metals, such as copper or iron, present at low levels in palm oils can also promote autoxidation. Fats and oils are normally treated with chelating agents such as citric acid to complex these trace metals (thus deactivating their pro-oxidant effect). The result of the autoxidation of palm oils is the development of objectionable flavours and odours characteristic of the condition known as “oxidative rancidity”. Some oils resist this change to a remarkable extent while others are more susceptible depending on the degree of unsaturation, the presence of antioxidants, etc. The presence of light, for example, increases the rate of oxidation. It is common practice in the industry to protect palm oils from oxidation to preserve their acceptable flavour and to maximize shelf life. When rancidity has progressed significantly, it becomes readily apparent from the flavour and odour of the oil. Expert tasters are able to detect the development of rancidity in its early stages. The peroxide value determination, if used judiciously, is oftentimes helpful in measuring the degree to which oxidative rancidity in the fat has progressed. It has been found that oxidatively abused oil can complicate nutritional and biochemical studies because they can affect food consumption under ad libitum feeding conditions and reduce the vitamin content of the food. Excessive oxidation of palm oil can engender diets unpalatable (Strayer et al., 2006).

**ii. Oxidation at Higher Temperatures** is normally predominant in automobile engines where biodiesel is used. High temperature oxidation is pronounced in cooking and frying pans. At sufficiently high temperatures, the methylene-interrupted polyunsaturated olefin structure will begin to isomerise to the more stable conjugated structure. Once this isomerisation has begun, a conjugated diene group from one fatty acid chain can react with a single olefin group from another fatty acid chain to form a cyclohexene ring. This reaction between a conjugated di-olefin and a mono-olefin group is called the Diels Alder reaction, and it becomes important at temperatures of 250-300°C or more. The products formed are called dimers.

Thermal polymerization can also form trimers, but there is disagreement as to how they form. One study concluded that trimers are formed by reaction of an isolated double bond in a dimer side chain with a conjugated diene from another fatty oil or ester molecule (a Diels Alder reaction as shown in fig.3.6).

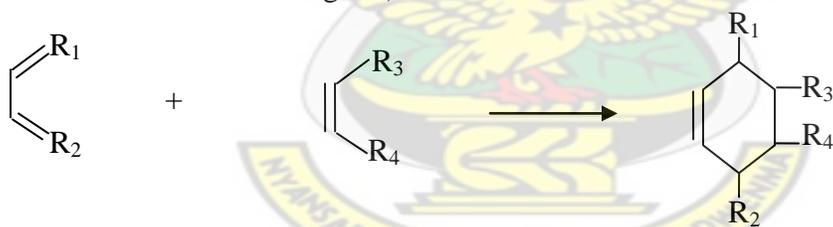


Fig.3.6 Diels Alder Reaction

This reaction is common in cooking oils. Dimethylsilicone (Si (CH<sub>3</sub>)<sub>2</sub>O) is usually added to institutional frying oils to reduce oxidation tendency and foaming at elevated temperatures. Frequently, partial hydrogenation is employed in the processing of liquid oil to increase the stability and functionality of the oil. In addition, oxidative stability has been increased in many of the oils developed through biotechnological engineering, a technique that effects a change in the fatty acid composition of oil. The stability of oil may be predicted to some degree by determining the oxidative stability index (Waynick, 2005).

### **c. Polymerisation**

All commonly used oils and particularly those high in polyunsaturated fatty acids tend to form larger molecules (known broadly as polymers) when heated at a high temperature and a long time. Under normal processing and cooking conditions, polymers are formed in insignificant quantities. Although the polymerisation process is not completely understood, it is believed that polymers in palm oils arise by formation of either carbon-to-carbon bonds or oxygen bridges between molecules. When an appreciable amount of polymer is present, there is a marked increase in viscosity (Strayer et al., 2006).

### **3.2.6 Some uses of palm oil**

#### **A. Food**

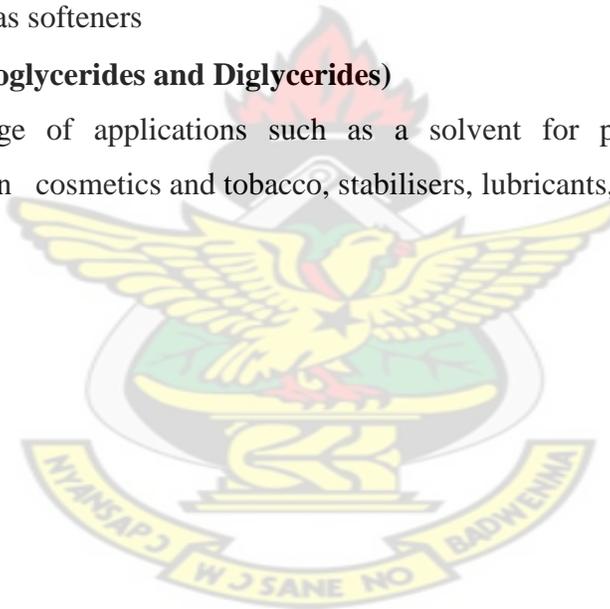
Palm oil has found many applications in the food industry. It is used to produce shortenings, margarines, cooking oils, ice cream, crackers, biscuits, non-diary creamer, etc.

#### **B. Oleochemicals**

Oleochemicals are produced by the hydrolysis or alcoholysis of oils and fats. The basic oleochemicals are fatty acids, esters, alcohols, nitrogen compounds and glycerol; their major applications are summarised below (Salmiah, 2000).

- **Fatty acids**
  - Medium chain triglycerides for use in the flavour and fragrance industries
  - Processing aids for rubber products, for softening and plasticising effect
  - Production of candles
  - Manufacture of cosmetic products from myristic, palmitic and stearic acids
  - Production of soaps via a neutralisation process
  - Production of non-metallic or non-sodium soaps

- **Fatty esters**
  - Production of pure soap – better quality than soaps from fatty acids
  - $\alpha$ -sulphonated methyl esters as active ingredients for washing and cleaning products (anionic surfactants)
  - Palm-based methyl esters as a substitute for diesel fuel for vehicles and engines
- **Fatty alcohols**
  - Fatty alcohol sulphates (anionic surfactants)
  - Fatty alcohol ethoxylates (nonionic surfactants)
  - Fatty alcohol ether sulphates (anionic surfactants)
- **Fatty nitrogen compounds**
  - Imidazolines with good surface active properties (for rust prevention)
  - Esterquats as softeners
- **Glycerol (Monoglycerides and Diglycerides)**
  - Wide range of applications such as a solvent for pharmaceutical products, humectants in cosmetics and tobacco, stabilisers, lubricants, antifreeze, etc



## CHAPTER 4

### 4.0 LCA OF MARGARINE IN GHANA

#### 4.1 METHODOLOGY

This project was undertaken in accordance with the ISO standards, that is, the ISO 14040 series as discussed in the literature in section 2.3 of this thesis. In this chapter the goal and scope are defined; the system boundary of margarine is assigned; functional unit of the product is selected; data collection method is discussed; allocation of environmental burdens are discussed; process flow sheet and information on input and output of materials and energy are also explained; and finally the results are analysed.

##### 4.1.1 GOAL AND SCOPE

###### 4.1.1.1 Goal of study

The aim of this study was to identify and quantify the potential environmental impacts associated with the life cycle of 100 % palm oil-based margarine, focusing attention on the palm oil supply chain. The availability of LCA data and results will help the major producers of palm oil in Ghana viz Twifo Oil Palm Plantation, Benso Oil Palm Plantation (BOPP), Ghana Oil Palm Development Corporation (GOPDC), Juabeng Oil Mills, and oil refiner and margarine producer (Unilever Tema Factory), Government of Ghana and consumers of the product. It will also improve on the competitiveness through ecolabeling of locally produced palm oil products on the increasingly environmentally sensitive global market. It will also offer opportunities to the aforementioned companies to improve on the environmental aspects of refined bleached deodorised palm oil and margarine at various points in their life cycle.

#### 4.1.1.2 Scope of study

Because of the enormity of the LCA of margarine from palm oil, a system boundary was assigned to the process to have easy assessment. The system boundary included oil palm cultivation, palm oil production, palm oil refinery, palm oil transportation and margarine production. Consumption and disposal phases were not considered because of time and data availability. The specified system boundary is illustrated in figure 4.1. Machinery and equipment employed in the manufacture of margarine were excluded from the study.

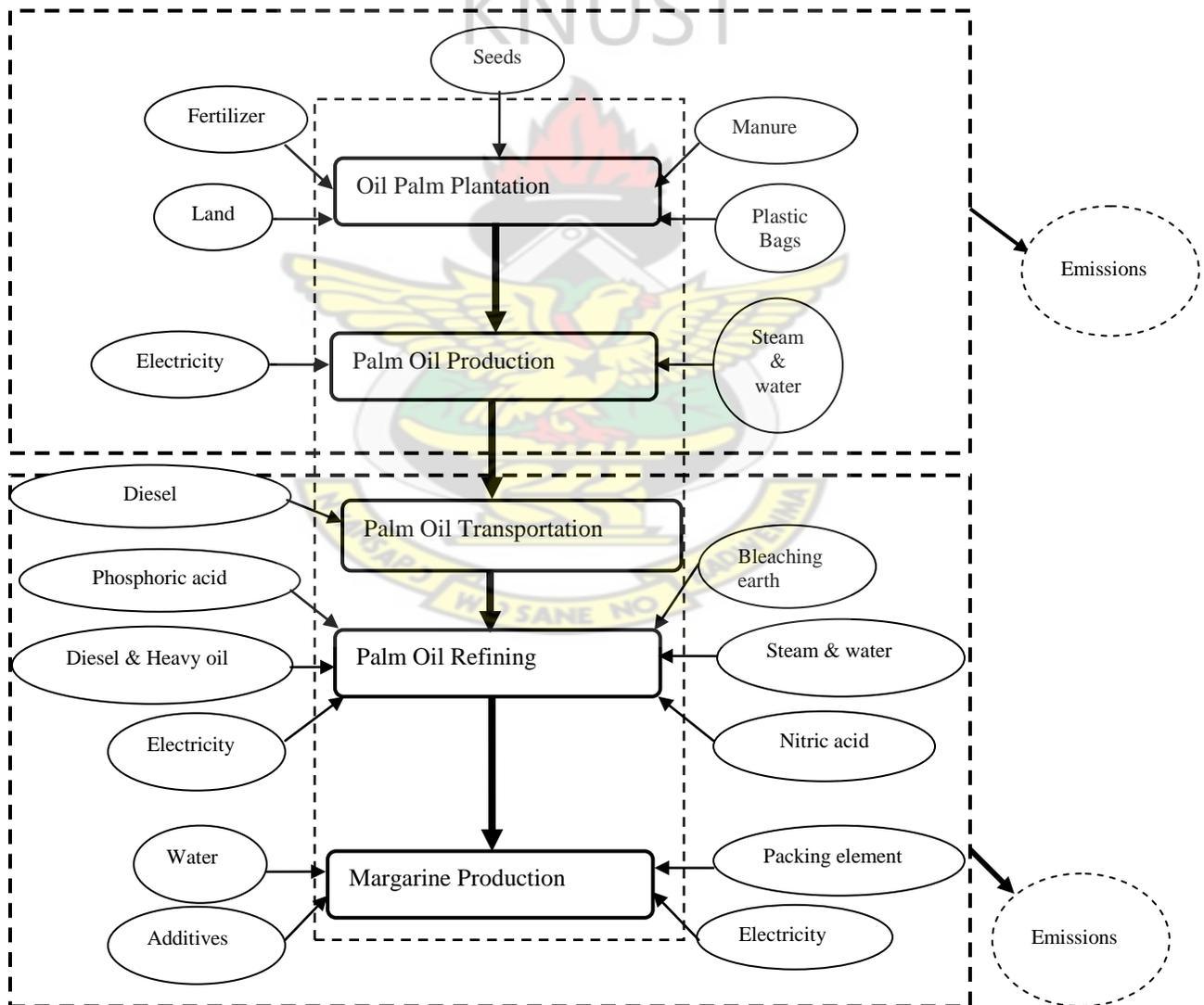


Figure 4.1 Schematic flow chart of the life cycle of margarine from palm oil in Ghana.(Author of this work)

Examples of which are pumps, boilers, deodorizers, heat exchangers, vacuum driers, cooling towers, etc. Exclusion of these capital goods is necessary because each of these equipment is a product with a life cycle, and this book cannot contain the analyses of these equipment. Moreover, the aim of this work is to analyse the major processes associated with margarine production in Ghana. For most LCAs the exclusion of capital goods can give satisfactory results, although this may result in missing 30 % of the environmental impacts (Pre Consultants, 2007).

#### **4.1.1.3. Functional Unit**

The functional unit chosen in this study was 1kg of margarine because most of the process parameters (amount of steam, electric energy, etc.) are measured per kilogram of margarine, and about 70 % of the products (margarine) was packaged net mass of 1 kg polypropylene tub. Thus choosing 1 kg as the functional unit facilitates the calculation of inputs and outputs. This means that all material inputs and outputs, and energy consumption were calculated based on the production of 1 kg of margarine.

#### **4.1.1.4 Data quality assurance and collection**

In order to achieve high data quality in this work, there was the need to establish good contact with the data providers. The level of knowledge of these data providers was assessed to know the kind of data that could be extracted, and to know the exact quarters where data could be acquired. Terminologies used at the industry were well understood. Openness was maintained as to why the data was needed, what would be done with it and how it would be presented. Emission data from the industries were made confidential by averaging them in order to conceal certain technical or commercial secrets.

Foreground data were obtained by questionnaire preparation (see Appendix D). Prior to this, generic information like annual reports of individual companies' brochures were obtained and read. This helped to know how these companies were organised. Input and output from a specific production line were obtained, and allocations of these impacts to the product in question were made. Allocation issues were explained to the data providers, and they were asked to calculate allocations when the allocation key was confidential. Clarity and straightforwardness were maintained to prevent error and to ease interpretation since filling in questionnaires was tedious. Interactive and friendly atmosphere was exercised throughout data collection; this made data providers provide data willingly.

Data on oil palm cultivation and palm oil production were collected from TOPP. Refinery data obtained from the Unilever Ghana, Tema factory. Data on transportation (distance traveled, type of fuel used, and weight of truck) was taken from truck drivers who transport palm oil to Tema for refining. Data were taken every month for a year to check for consistency and changes in production. Data on water, palm kernel shell and palm fibre obtained at TOPP's boiler house were verified by mass and energy balance calculations.

There were some uncertainties associated with the calculated values when compared to empirical values: amount of steam was 13.6% of 4000 kg/hr; palm shell and palm fiber 84.6 % of 700 kg/hr. The following calculations illustrate some checks made on data collection at the boiler house. These calculations are based on these assumptions: (i) steady state operation; (ii) pumps and turbine operations are reversible (isentropic), (iii) change in potential and kinetic energies are neglected; (iv) boiler, pumps and turbine operate at adiabatic condition.

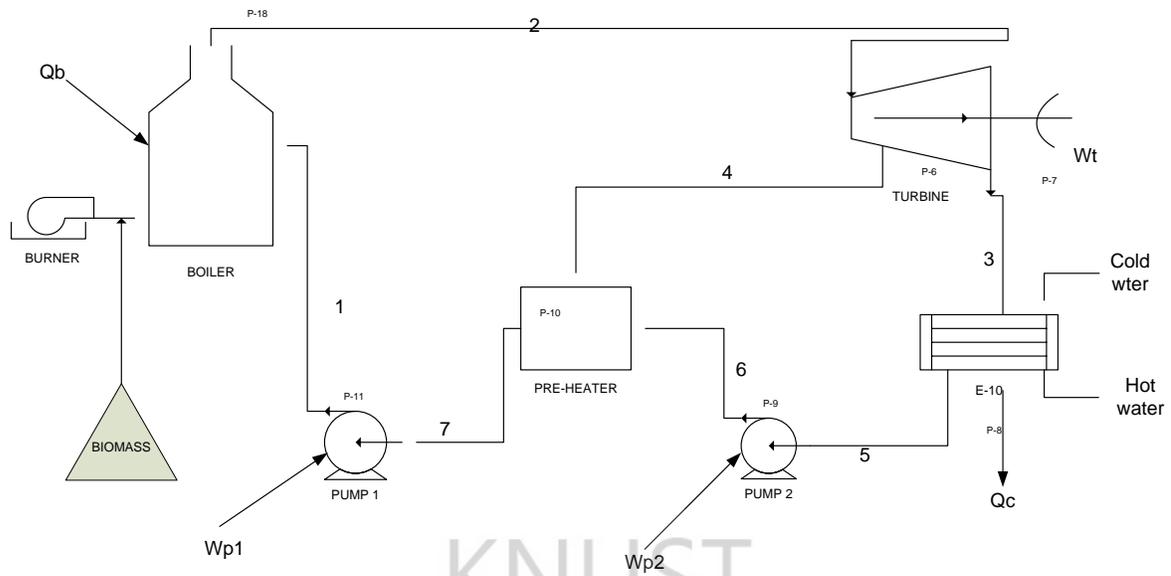


Figure 4.2 Power generation from biomass through steam (from TOPP).

Table 4.1 steam data the on the boiler house

state	P (kPa)	T (°C)	S (kJ/kg-K)		H (kJ/kg)		Quality, X
1	1000	125.0	$s_1$		$h_1$		
2	1000	260.0	6.9680		2965.2		
3	10	45.8	$s^L = 0.6493$	$s_3 = s_2$	$h^L = 191.832$	$h_3 = ?$	$x_2 = ?$
			$s^V = 8.1511$		$h^V = 2584.7$		
4	250	127.4	$s^L = 1.6071$	$s_4 = s_2$	$h^L = 535.343$	$h_4 = ?$	$x_4 = ?$
			$s^V = 7.052$		$h^V = 2716.4$		
5	10	45.8			$h_5 = 191.832$		
6	250				$h_6 = ?$		
7	250	125.0	$s_7 = s_1$		$h_7 = 524.9$		

### Parameters

Boiler Pressure = 1000 kPa; boiler efficiency = 78 %; steam Temp = 250 °C;

Turbine efficiency = 75 %; Turbine output = 500kw;

net heating value of biomass (palm kernel shell + fiber) = 18.24 MJ/kg;

efficiency for pump1 and motor,  $\varepsilon_{p1} = 75 \%$ , &  $\varepsilon_{m1} = 80 \%$  respectively;

efficiency for pump2 and motor,  $\varepsilon_{p2} = 75 \%$  &  $\varepsilon_{m2} = 80 \%$  respectively;

feed water temperature = 125 °C.

Table 4.1 gives the steam data from steam table at each in fig. 4.2.

The amount of steam and fuel (biomass) used are calculated by mass and energy balances.

The steam flowrate ( $m$ ) from the boiler is calculated by taking energy and mass balance around the turbine.

$$\text{Turbine output, } w_t = (mh_2 - m_4h_4 - m_3h_3) \times \varepsilon_t \dots\dots\dots \text{TB1}$$

$$m = m_4 + m_3 \dots\dots\dots \text{TB2}$$

$m_4$  can be obtained from mass and energy balance feed water tank:

$$m_4h_4 + m_6h_6 = m_7h_7 \dots\dots\dots \text{PH1}$$

$$m_4 + m_6 = m_7 = m \dots\dots\dots \text{PH2}$$

Solving TB2, PH1, and PH2 to eliminate  $m_6$ :

$$\frac{m_4}{m} = \frac{h_7 - h_6}{h_4 - h_6} \dots\dots\dots \text{TC1}$$

All enthalpies in TB1 and TC1 can be calculated as follows.

Consider state 3:  $h_3 = (1-x)h^L + xh^V$

$$x \text{ can be from } s_3 = s_2 = (1-x)s^L + xs^V \Rightarrow x = \frac{s_3 - s^L}{s^V - s^L} = \frac{6.968 - 0.6493}{8.1511 - 0.6493} = 0.842$$

$$\Rightarrow h_3 = (1-0.842) \times 191.832 + 0.842 \times 2584.8 = 2206.71 \text{ kJ/kg.}$$

Consider state 4:  $h_4 = (1-x)h^L + xh^V$

$$\text{But } x = \frac{s_3 - s^L}{s^V - s^L} = \frac{6.968 - 1.6071}{7.052 - 1.6071} = 0.985$$

$$\Rightarrow h_4 = (1-0.985) \times 535.343 + 0.985 \times 2716.4 = 2682.52 \text{ kJ/kg.}$$

Consider pump 2, i.e. states 5 and 6:

$$wp_2 = h_6 - h_5 = v_5(p_6 - p_5) \Rightarrow h_6 = h_5 + v_5(p_6 - p_5),$$

where  $v_3$  is the specific volume ( $0.00101 \text{ m}^3/\text{kg}$ ).

$$\Rightarrow h_6 = 0.00101(250 - 10) + 191.832 = 192.1 \text{ kJ/kg}$$

From equation TC1,  $\frac{m_4}{m} = \frac{524.9 - 191.1}{2682.52 - 191.1} = 0.1339 \Rightarrow m_4 = 0.134m$

$$\Rightarrow \text{from TB2 } m_3 = 0.866m$$

From equation TB1, the steam flowrate can be calculated as:

$$500 = 0.75(2965.2m - (0.134m \times 2682.2) - (0.866m \times 2206.71))$$

$$\Rightarrow m = 0.959 \text{ kg/s} = 3454.4 \text{ kg/hr}$$

To evaluate the amount of heat  $Q_b$  from the fuel,  $h_1$  is required.

From pump 1  $wp_1 = v_7(P_1 - P_7) = h_1 - h_7$

$$\Rightarrow h_1 = v_7(P_1 - P_7) + h_7 = 0.001049(1000 - 250) + 524.9 = 525.67 \text{ kJ/kg}$$

Energy balance around the boiler:  $Q_b = h_2 - h_1 = (2965.2 - 525.67) = 2439.53 \text{ kJ/kg}$ .

$$\Rightarrow Q_b = 3453.2 \text{ kg/hr} \times 2439.53 \text{ kJ/kg} = 8424184.99 \text{ kJ/hr}$$

The mass of biomass needed to provide this heat =  $\frac{8424184.99 \times 10^3 \text{ J/hr}}{0.78 \times 18.24 \times 10^6 \text{ J/kg}} = 592.1 \text{ kg/hr}$

In order to verify that the power generated is sufficient of run the pumps and that no external power is used, the following calculations are performed:

Consider pump 1:

Reversible work,  $wp_1 = v_7(p_1 - p_7)$ , where  $v_7$  ( $0.001049 \text{ m}^3/\text{kg}$ ) is the specific volume;

$$\Rightarrow wp_1 = 0.001049(1000 - 250) = 0.7867 \text{ kJ/kg} = 786.7 \text{ J/kg}$$

$$= 786.7 \text{ J/kg} \times 0.959 \text{ kg/s} = 754.49 \text{ W}$$

$$\Rightarrow \text{irreversible work} = \frac{\text{reversible work, } wp_1}{\epsilon_{m1} \epsilon_{p1}} = \frac{754.49 \text{ W}}{0.75 \times 0.8} = 1.26 \text{ kW}$$

Consider pump 2:  $wp_2 = v_5(p_6 - p_5) = 0.00101(250-10) \text{ kJ/kg} = 242.4 \text{ J/kg}$   
 $= 242.4 \text{ J/kg} \times 0.959 \text{ kg/s} = 232.46 \text{ W}$

Irreversible work =  $\frac{\text{reversible work}, wp_2}{\varepsilon_{m2} \varepsilon_{p2}} = \frac{232.46 \text{ W}}{0.75 \times 0.8} = 387.44 \text{ W} = 0.39 \text{ kW}$

It becomes clear that the total power (1.65 kW) the two pumps consume is infinitesimal as compared to turbine output of 500 kW.

#### 4.1.1.4.1 GABI Software

This software comes with the ecoinvent database. The ecoinvent database covers a broad range of data available as unit operations and and systems. Plastic, paper and board, basic chemicals, detergents, wastetreatment, metals, construction materials, woods, transports, energy supply, agriculture and emissions associated with unit operations.

The software contains lots of impact assessment methods such as Ecological Scarcity, Eco-indicator-99, Impact 2002+, Environmental Product Declaration (EPD), CML 2001, etc.

Besides, the software has characterisation or equivalent factors for all the environmental interventions. These factors are indices of the magnitude of environmental impact of the associated substance or compound. Moreover, the software has normal or reference values for individual impact categories such as global warming. These reference values are used for normalisation of impact categories. The only normal values present are that of the Netherlands, West Europe and that of the world.

Input from all processes are fed into the software. For example, emissions ( $\text{CH}_4$  and  $\text{CO}_2$ ) from the anaerobic decomposition discussed in this work are not quantified manually. The software gives the amount of  $\text{CH}_4$  and  $\text{CO}_2$  produced when the amount of manure is fed into the software. Furthermore, the amount of emissions due to transportation is not given by truck drivers. Given the gross weight of the truck, the total distance travelled and the type of

fuel used, the software provides all the environmental interventions associated with transportation. Basically, the software is able to provide emissions associated with processes.

#### **4.1.1.5. Allocation**

LCA of margarine from palm oil is associated with co-products (FAD, CPO, RBDPO, CPKO, palm kernel, palm kernel shell, palm fibre and palm kernel meal) with different functions. For example, palm kernel is used for crude palm oil. This crude palm oil use part of steam produced at the boiler house. It means that environmental burden posed by steam production will be shared among these by-products and the major product margarine. This is called allocation. Allocation of environmental burdens to the main and the by-products of the process was done by mass and economic values of these products.

At the palm oil production stage, allocation of environmental burden was done based on economic value of co-products: 80% and 10% were assigned to both CPO and CPKO respectively, while palm kernel meal, empty fresh bunches, palm kernel shell and palm fibre were assigned 2.5% each.

Based on mass, 95% was assigned to RBDPO while 5% was assigned to FAD at oil refining stage. Allocation was done based on mass because the amount of FAD was only 5 % the amount of RBDPO produced.

#### **4.1.1.6 Detailed description of LCA of margarine in Ghana**

##### **4.1.1.6.1 Oil Palm Plantation at TOPP**

At TOPP, oil palm is cultivated by seed. These seeds are nursed in polyethylene bags for about 9 months after which they are transplanted. The nursery is done in a soil that provides good drainage, pH range of 4-7 and tolerates periodic flooding or a high water table. The optimal temperatures are between 27°C and 33°C with 5 to 7 hours of direct sunlight per day is beneficial. The breeds of oil palm used at TOPP are very resistant to the prevailing palm diseases (fusariosis and coelaenomenodera (leaf miner)) and it implies that pest control is not a problem. Palm oil sludge from milling plants is used as organic manure. The optimal plant density is 58 trees per 4048.6 m<sup>2</sup> with triangular patterns about 9.15 m apart. The palm fruit bunches is harvested using chisels or hooked knives attached to long poles. The farm is visited every 10 to 15 days as bunches ripen throughout the year. The fresh fruit bunches are then transported by means of tractors to the milling plant that is about 3 km from the farms.

##### **4.1.1.6.2 Palm Oil Production at TOPP**

The fresh fruit bunches are transported to the oil mills as soon as possible to prevent the soaring of free fatty acid in the palm oil. Bruise or abrasions on FFB are reduced as much as possible by careful handling. The higher the bruise on the palm bunches, the higher the free fatty acid and the higher the cost of subsequent refining processes.

The first stage in the palm oil production is the steam sterilization where lipase enzymes are deactivated and microorganisms that produce free fatty acid are killed. The sterilised bunches are then sent to the stripping unit where the palm fruits are removed from the palm

bunches with the fresh empty bunches sent to plantation as mulching materials. The fruits are sent to a vessel for digestion. In this unit, the mesocarp is separated from the endocarp.

The digested palm is then sent for pressing where the oil is extracted from the macerated fruit by means of hydraulic press. The crude oil is then diluted with hot water and sent for screening while the endocarp containing the kernel is sent to palm kernel treatment plant. The fiber is used to fire boilers to produce steam and electricity.

The diluted oil is sent to settling tanks where the oil is separated from the sludge. The sludge is sent to a pond where anaerobic decomposition takes place to form organic manure for palm plantation. The crude oil is then purified and vacuum dried to reduce moisture content. The oil is sent to Unilever Ghana for refining.

#### **4.1.1.6.3 Palm oil refining at Unilever Ghana Ltd.**

Palm oil refining at Unilever Ghana undergoes the following processes.

(i) Chemical refining, (ii) Physical refining, (ii) Fractionation.

##### **(i) Chemical refining**

Crude palm oil (CPO) from BOPP, TOPP and sometimes from GOPDC is stored in two storage tankers each of capacity 300 tonnes. The tanks contain steam coils to heat the oil from 34°C to 41°C for effective pumping. The CPO is pumped into two bleaching vessels, each of capacity 15 tonnes, at the rate of 500 kg/min through a heat recovery system (plate heat exchanger) to increase the temperature to 60°C. The temperature of the CPO is further raised to 95°C by means of the steam coils in the bleaching vessels. This is the desired temperature for the reaction between the CPO and phosphoric acid. The CPO in the bleaching vessels is dosed with phosphoric acid at the rate of 0.36 kg/ton oil. The oil is stirred with overhead gear driven stirrer for 15 minutes to effect precipitation of gums.

Degumming is done to preclude the formation of scales in the subsequent processes (filtration, heat exchanging, etc.). Bleaching earth is added to the oil at the rate of 5 kg/ton oil for bleaching to begin. The bleaching process is carried out under vacuum of 600 mbars. Bleaching removes pigment, trace metals (copper and iron) and oxidation products from the CPO to improve the initial taste, final flavour and oxidative stability of product. The oil is bleached for 30 minutes at a temperature of 95°C. The bleached palm oil (BPO) is filtered through plate filters to remove the spent earth, which finally contains about 19.8% BPO, and is discharged into the environment (direct burden). Further filtration of the oil is done to remove earth fines through GAFF filters. The oil is sent to a holding tank maintaining the temperature between 75-95°C for physical refinery.

#### **(ii) Physical refining**

The purpose of physical refining is to make the oil suitable for human consumption by removing substances, which give it undesirable acidity, odour, colour and taste. The odorous and flavouring matter which are mainly aldehydes, ketones, alcohols and hydrocarbons, are removed at the same time as the free fatty acids (3% to 5% in the BPO). Being far more volatile than the oil, they are distilled by stripping at high temperatures with sparge steam under vacuum. This process is called deodorising (odour and taste removal) stage.

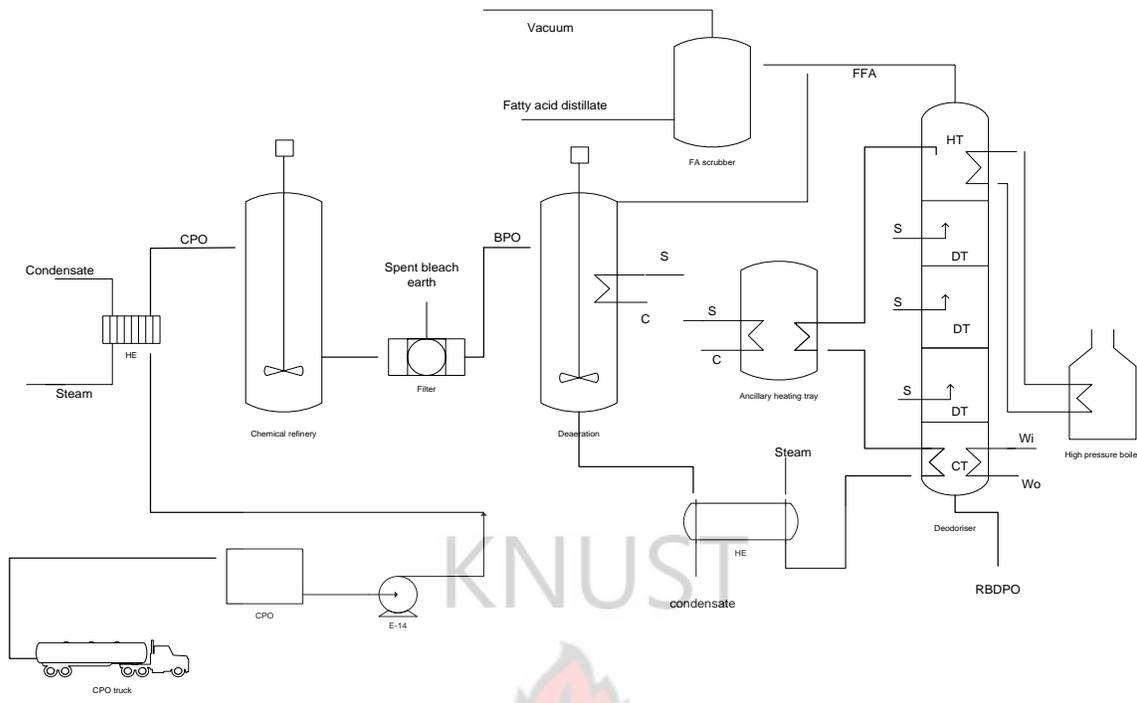
In physical refinery, the following processes occur concurrently: deaeration of oil (oxidation prevention), Heating (heat recovery and final heating), deodorising (deacidification, steam stripping, low pressure (vacuum), and condensation of volatiles), and cooling (heat recovery and final cooling).

At Unilever (Gh), the BPO from heat recovery unit enters the pre-stripping stage (deaerator) under vacuum. The oil is heated from 85-110°C for 73.5 minutes before leaving the

deaerator at the rate of 5 t/h. The oil enters the bottom of a deodorising column (distillation column with five trays at operating pressure range of 4-8 mbars) and exchanges heat with the bottom product. The bottom product loses heat to the oil coming from the deaerator to raise its temperature to 150°C. The heated oil then enters an auxiliary tray and it is further heated to 250°C before it enters the top of the deodoriser. Fig.4.3 shows the physical refining.

At the topmost column of the distillation column (heating tray), the oil is heated to 265°C by high-pressure heating coils. The steam in this coil flows at the rate of 550 kg/h and at the pressure of 50 bars. The heated oil goes through the next three trays for actual deodorising where sparged steam (80 kg/h at 0.5 bars) is introduced into these trays, and has direct contact with the oil. Citric acid also flows at 2.4 l/h into the column to remove fat at the walls of the column and to chelate trace metals in the oil.

At the bottom of the column is the cooling tray where the bottom product is cooled to 125°C with cooling water before leaving the column. The bottom product (refined bleached deodorised palm oil (RBDPO)) contains 0.1% of fatty acid. The residence time for the oil in this column is 3.5 hours. The free fatty acid in the palm oil is removed from the top of the column and condensed in a vacuum system. The vacuum unit consists of fatty acid scrubber, which helps cool the acid to 50°C. The acid is sent for soap making. Part of the RBDPO is sent to margarine blending tank and the rest is sent for fractionation where the oil is separated into stearine (high melting point) and olein (low melting point). Part of this stearine produced is added to the stored part of the RBDPO for margarine production.



S=steam, C= condensate, HT= heating tray, DT= deodorizing tray, CT = cooling tray  
 DE= deaerator, FAS= fatty acid scrubber, Wi = cooling water in, Wo = cooling water out

Fig.4.3 Flowsheet for physical refinery of bleached palm oil (Unilever Ghana Ltd).

**(iii) Fractionation of RBDPO**

In fractionation, the RBDPO is separated into two fractions. The triglyceride part of the oil with high melting point is crystallised out as stearine while the other part with lower melting point is filtered out as olein. Before fractionation, the RBDPO must pass the quality specification, colour <2.6R and FFA < 0.1%. The RBDPO is heated up to about 70°C by hot water in four crystallisers each of volume 20 m<sup>3</sup>. This heating is done to homogenise the oil and therefore destroy any potential crystal in the oil. After heating, the oil is cooled to 18°C by chilled water from a refrigerator system. This is accompanied by continuous stirring by overhead-gear driven stirrer moving at 11rpm. Full crystallisation is achieved in 14 hours and this is performed in batches. After 14 hours, a filter press separates the stearine and the olein. Part of the stearine is blended with part of the RBDPO (15% and

85% respectively) for margarine production while the olein is sent for cooking oil processing.

#### **4.1.1.6.4 Margarine production at Unilever Ghana Ltd.**

There are two types of margarine produced at Unilever (Gh) namely Holsum margarine and BBM bread fat margarine. To produce the margarine, the aqueous phase (milk, salt and water) and the oil phase (olein, stearine and lecithin) are prepared separately. The aqueous phase is heated to a temperature of 50°C while the oil phase is heated to 70°C. The aqueous phase is mixed with the oil phase in an emulsion mix tank where other additives (citric acid, potassium sorbate and beta carotene) are added. The emulsion in the emulsion mix tank is circulated through plate heat exchanger until pasteurization carried out at a temperature of 80°C. The emulsion is pumped into a margarine feed tank. The margarine in the margarine feed tank is circulated through a refrigeration system where the margarine is chilled to a temperature range of 2-3°C. The margarine is then packaged into bag-in-box, tubs and sachets.

#### **4.1.2 Life Cycle Inventory Analysis**

This section deals with the collection of data on the selected stages in the life cycle of margarine production. According to Hogaas and Ohlsson (1998), two methods can be used to carry out the LCI: the simplified method or the detailed method. The simplified method considers all the unit operations in each stage (palm cultivation, palm oil production, etc.) as a black box, quantifying the flows corresponding to the inputs and outputs of the systems. On the other hand, the detailed method allows to specify emissions, energy and water consumption for the different unit operations (for example pasteurisation unit, sterilization system, pumps, etc.), which requires a great effort because it is necessary to obtain input

and output for every unit operation. If there is not enough data from all the equipment and auxiliary devices, significant mistakes can be made. In this way, the philosophy of the simplified method has been followed in this study.

The simplified one was employed at the palm oil production, oil refining and margarine production stages. The reason is that there are many unit operations at these stages. Hence, each stage was taken as a blackbox in order to facilitate data acquisition from factory operators. For example, an operator at the oil refining section could not give the amount of steam used by the deodorizer alone because the operator recorded only the total amount of steam used at the refining section. The operator did not record the amount of steam that entered the individual unit operations. Moreover, most of these unit operations did not have flow metres. The only means to get steam flowrate to these unit operations is by tedious mass and energy balances. Hence, to reduce the task of obtaining data at these three stages was to lump them into blackboxes.

#### **4.1.2.1 Inventory on oil palm cultivation**

Data on palm cultivation was taken from TOPP. Data were calculated based on 1kg of margarine produced. Table C-1 in the appendix D gives the input and output of the farms. The impact of these inputs is discussed at the section 6.2.

#### **4.1.2.2 Inventory on Palm oil production**

Data was collected based on the average annual production of crude palm oil from TOPP and based on the functional unit (1kg of margarine). Palm fibre obtained from palm fruits is used to fire a boiler to generate both steam and electricity.

Water used at the palm oil production plant is tap water, which gives rise to the chlorine, chloride ions and aluminium hydroxide. Table C-2 in appendix C shows the inventory of palm oil production. The impact of these inputs is discussed at the section 6.2.

#### **4.1.2.3 Inventory data of palm oil transportation**

About three-quarters of palm oil used at Unilever (Gh) is transported from TOPP and BOPP which are 234 km from Tema. The rest is taken from GOPDC, which is 150 km to Tema. Unilever treats 200 tonnes of palm oil per day, implying that 73000 tonnes of palm oil is transported by 24-27 tonne trucks per year. The fuel used by the trucks is diesel and this data was obtained from the drivers of these trucks. Emissions from transportation of crude palm oil were obtained from the ecoinvent database. To do this, the GABI Software only requires the type of fuel used, the gross weight of the truck and the total distance traveled by the truck. Table C-3 in the appendix C represents the inventory data of palm oil transportation. The impact of these inputs is discussed at the section 6.2.

#### **4.1.2.4 Inventory data of palm oil refining**

There are three sub-sections at the refining section: chemical refining, physical refining and fractionation. Electrical energy used at these sections was for pumping and stirring. There were meters to give the amount of energy used for each section.

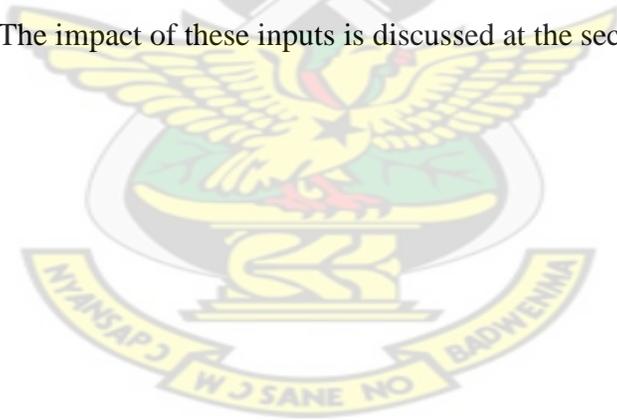
On the water consumption, the company took these three (3) sections as a black box and gave the total water consumption. Steam from boiler house was used at the chemical and physical sections while cold water at about 15°C (from a refrigerator) was used at the fractionation section. Energy used at the refining section is 531.5 kW. Steam employed at these sections was provided by boilers, which were fired by diesel oil, residual fuel oil

purchased directly from Tema Oil Refinery. Table C-4 shows the inventory data on the palm oil refining. The impact of these inputs is discussed at the section 6.2.

#### **4.1.2.5 Inventory data of margarine production**

The margarine section consists of production and packaging of margarine. Electrical energy consumption was due to the daily operation of a compressor; pumping of oil, hot water and margarine; and motors used to operate the stirrers. The ammonia compressor took 25% (74.25kJ/kg margarine) of energy consumed at the margarine section while 75% (222.75kJ/kg margarine) was for the rest of the operations including packaging equipment.

Raw materials, paper box polypropylene tubs, beta-carotene, citric acid, lecithin, etc., were assigned as input to the margarine production. Emissions from these materials were taken from ecoinvent database. Table C-5 in appendix C provides the inventory data of the margarine section. The impact of these inputs is discussed at the section 6.2.



## CHAPTER 5

### 5.0 LIFE CYCLE IMPACT ASSESSMENT (LCIA)

There are many impact assessment methods as state earlier, but the CML 2001 impact assessment method was chosen for this work because it contains all the impact categories.

There are seven impact categories under this method viz acidification (kg SO<sub>2</sub>-equivalent/kg emission), global warming (kg CO<sub>2</sub>-equivalent/kg emission), eutrophication(kg PO<sub>4</sub>-equivalent/kg emission), human toxicity (kg DCB-equivalent/kg emission), freshwater aquatic ecotoxicity (kg DCB-equivalent/kg emission), terrestrial ecotoxicity (kg DCB-equivalent/kg emission), and photochemical ozone creation potential (kg C<sub>2</sub>H<sub>4</sub>-equivalent/kg emission). Two elements are considered: obligatory elements (classification and characterisation) and optional element (normalisation).

#### 5.1 Characterisation

In the classification and characterization stages, emissions and resources coming from the inventory are sorted into different groups or impact categories according to their potential effect on the environment. Global warming potential (GWP), acidification potential (AP), eutrophication potential (EP), photochemical oxidation potential (POCP), human toxicity potential (HTP), freshwater aquatic ecotoxicity potential (FAEP) and terrestrial ecotoxicity potential (TEP) were the impact categories selected. The characterization was done using the Gabi Software. The results of the characterization are presented in table 5.1. It could be seen that the palm oil refining stage dominated the contributions to the impact categories, in that there are many unit operations and raw materials used as compared to the rest of the LCA stages.

**Table 5.1 Characterised stage based on 1kg of margarine**

Impact category	AP		EP		FAEP		GW		HTP		POCP		TEP	
	Kg SO <sub>2</sub>	%Total	KgPO <sub>4</sub> <sup>-3</sup>	%Total	Kg DCB	%Total	KgCO <sub>2</sub>	%Total	KgDCB	%Total	KgC <sub>2</sub> H <sub>6</sub>	%Total	KgDCB	%Total
Oil Palm Cultivation	1.57E-03	<b>10.4</b>	2.01E-04	<b>25.2</b>	0.0	<b>0.0</b>	4.22E-02	<b>43.8</b>	3.79E-04	<b>1.7</b>	3.84E-05	<b>10.5</b>	0.0	<b>0.0</b>
Palm oil produccion	3.80E-03	<b>25.2</b>	0.0	<b>0.0</b>	0.0	<b>0.0</b>	5.40E-03	<b>5.6</b>	0.0	<b>0.0</b>	6.21E-05	<b>17.1</b>	0.0	<b>0.0</b>
Palm oil transportation	1.38E-04	<b>0.9</b>	2.29E-05	<b>2.9</b>	1.75E-05	<b>23.9</b>	1.42E-02	<b>14.7</b>	2.36E-04	<b>1.0</b>	2.67E-05	<b>7.3</b>	5.69E-07	<b>3.4</b>
Palm oil refining	9.12E-03	<b>60.7</b>	5.33E-04	<b>66.9</b>	4.75E-05	<b>64.9</b>	4.07E-03	<b>4.3</b>	2.11E-02	<b>93.9</b>	1.59E-04	<b>43.7</b>	1.49E-05	<b>91.2</b>
Margarine production	4.27E-04	<b>2.8</b>	3.99E-05	<b>5.0</b>	8.19E-06	<b>11.2</b>	3.05E-02	<b>31.6</b>	7.49E-04	<b>3.4</b>	7.76E-05	<b>21.4</b>	8.69E-07	<b>5.4</b>
<b>Total impact score</b>	<b>1.51E-02</b>	<b>100</b>	<b>7.97E-04</b>	<b>100</b>	<b>7.32E-05</b>	<b>100</b>	<b>9.64E-02</b>	<b>100</b>	<b>2.25E-02</b>	<b>100</b>	<b>3.64E-04</b>	<b>100</b>	<b>1.63E-05</b>	<b>100</b>

Source: GABI Software

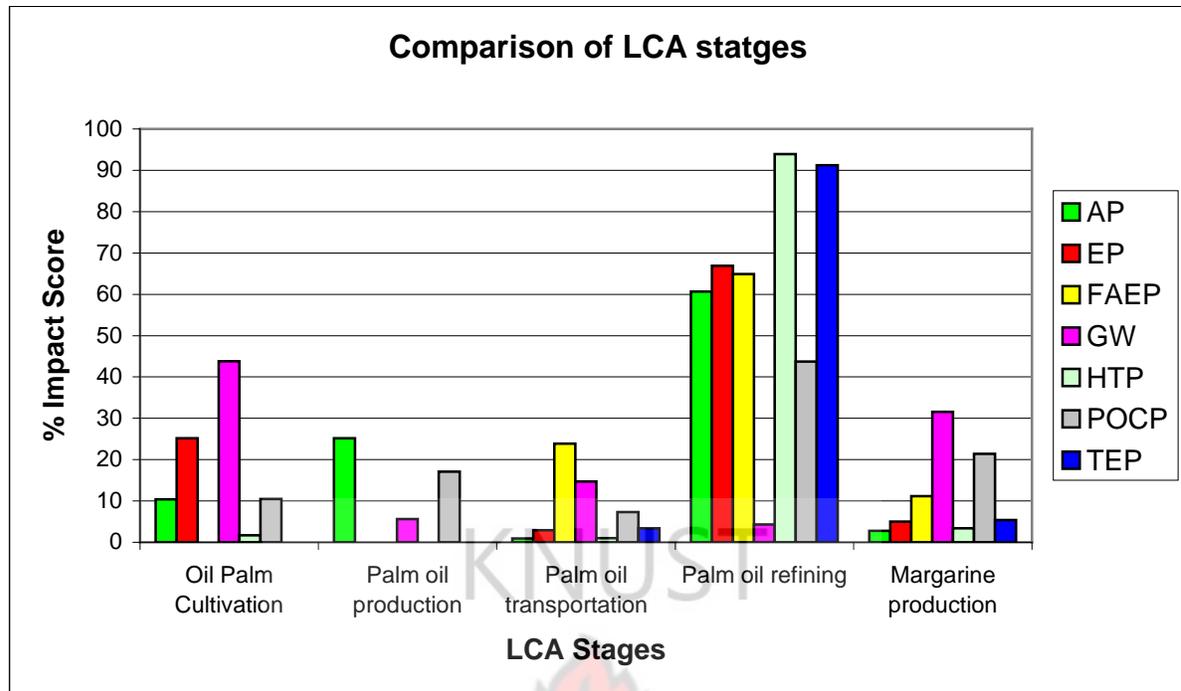


Figure 5.1 Comparison of LCA stages' contribution to the environmental burden

## 5.2 Normalisation

In order to make substantial improvements in the environmental performance of margarine production in Ghana, it is necessary to address the activities of major contributions to environmental impact. The normalisation phase allows the comparison all environmental impacts using the same scale (Figures 5.2 and 5.3). Moreover, after normalisation, all the impact categories obtain the same unit that makes it easier to compare. The study was compared to what pertains in the world as the reference scale. Global normal values were used as reference because LCA of margarine has a global coverage since raw materials (e.g. citric acid, polypropylene, diesel, residual fuel oil, phosphoric acid etc.) are extracted from diverse geographical regions.

Normalisation is done by dividing the total impact scores by the global annual score. This was done by the GABI Software. It could be done manually if the normalisation scores were known.

Table 5.2 shows the normalisation figures, the total impact scores and the normalised data.

Upon normalization AP, EP GWP and POCP proved to be exerting much pressure on the environment with FAEP, HTP and TEP exerting lower environmental pressure.

Table 5.2 Impact score, normalisation figure and normalisation results

Impact category	AP	EP	FAEP	GWP	HTP	POCP	TEP
Impact scores	1.51E-02	7.97E-04	7.32E-05	9.62E-02	2.25E-02	3.64E-04	1.63E-05
Normalisation Figures	299.4E+09	129.1E+09	203.1E+09	445.1E+11	497.7E+11	454.9E+08	267.9E+09
Normalised scores	5.040E-14	6.17E-15	3.60E-16	2.16E-15	4.52E-16	8.00E-15	6.08E-17

Source: GABI Software

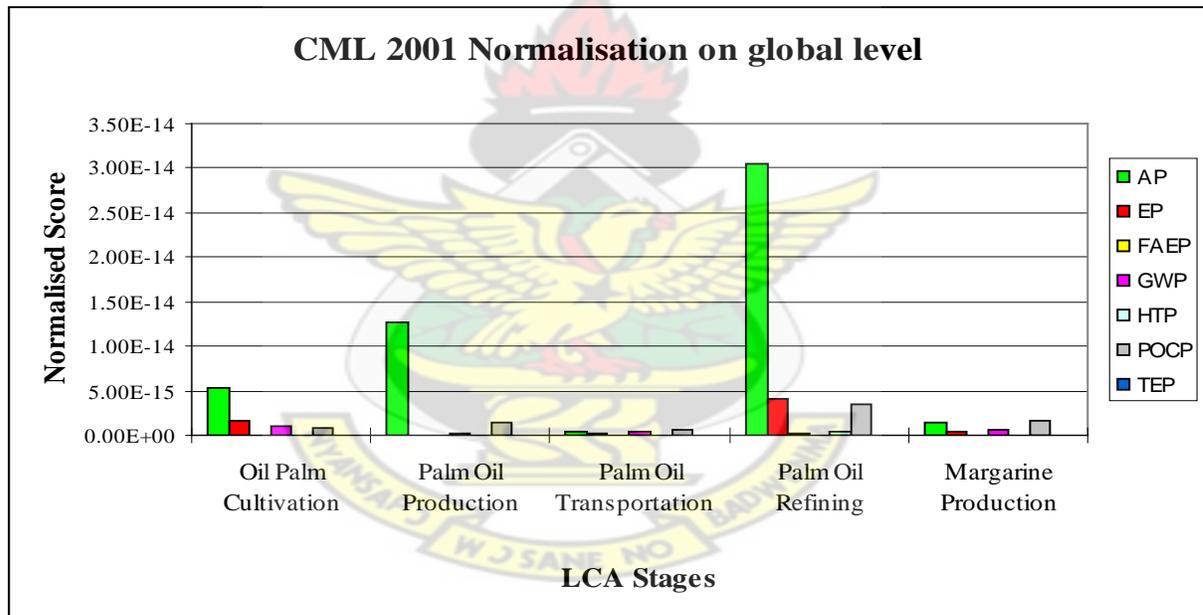


Figure 5.2 Significance of LCA stages on normalisation

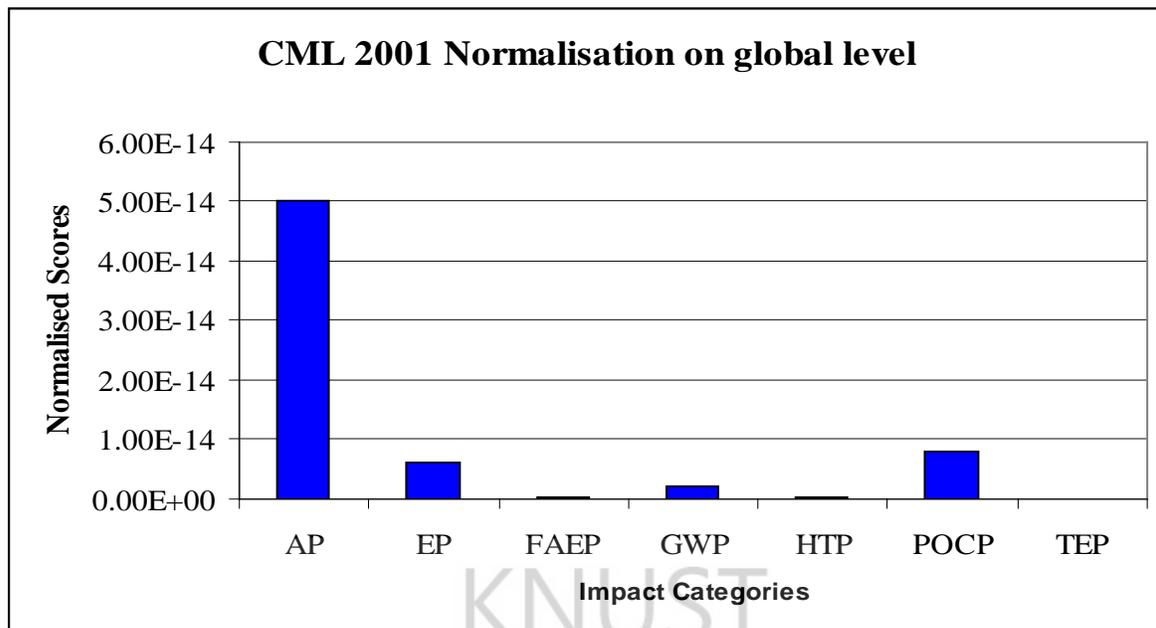


Figure 5.3 Significance of impact categories on normalisation.



## CHAPTER 6

### 6.0 IMPROVEMENT ACTIONS AND DISCUSSIONS

#### 6.1 IMPROVEMENT ACTIONS

The LCA process does not remove the environmental burdens imposed by emissions from industrial processes. However, it gives an indication of where the problems are for the needed remedial actions to be taken.

This LCA of 100 % palm oil-based margarine in Ghana has revealed that oil palm cultivation, palm oil production and palm oil refining stages pose the biggest environmental problem due to emissions from steam boilers using heavy oil, diesel oil and biomass (kernel shell and palm fiber) at the refining and palm oil production sections; manure from decomposition of palm oil mill effluent and empty fruit bunches on farms; wastewater effluents pregnant with phosphates and nitrate ions and high organic load due to palm oil losses. Emissions from the boilers contribute significantly to acidification potential (AP), photochemical oxidants creation potential (POCP), global warming potential (GWP) while wastewater give rise to eutrophication potential (EP). The emissions are SO<sub>2</sub>, CO<sub>2</sub>, NO<sub>2</sub> and other trace nitrogen and sulphur compounds. Because of these emissions two mitigating actions were recommended and if executed practically, the environmental burden would be reduced moderately. These actions are the inclusion of gas scrubbing system and a simple anaerobic reactor leading biogas utilisation.

All the actions proposed are independent and can therefore be executed simultaneously. In terms of relative impact reduction, the consideration of the two actions implies a total decrease of about 19.1%, which is the accumulated reduction of the two individual actions. Table 6.1 shows how the impact categories would be affected if these actions were executed.

Table 6.1 Normalisation data and evaluation of improvement actions

Impact category	AP	EP	FAEP	GWP	HTP	POCP	TEP	Impact reduction
	(x10 <sup>-14</sup> )	(x10 <sup>-15</sup> )	(x10 <sup>-16</sup> )	(x10 <sup>-15</sup> )	(x10 <sup>-16</sup> )	(x10 <sup>-15</sup> )	(x10 <sup>-17</sup> )	(%)
Without action	5.04	6.17	3.60	2.16	4.52	8.00	6.08	0.0
Action 1	4.97	6.17	3.60	1.99	3.31	3.53	6.08	9.6
Action 2	4.97	3.09	1.99	1.99	2.50	3.53	6.08	9.5
Action 1+2	0.07	3.08	1.61	0.17	2.02	4.47	6.08	19.1

Reduction: AP = 1.4%, EP = 50%, AEP = 45%, GW= 7.9.5%, POCP= 56%, HTP = 44.6%, TEP = 0.00%  
 Source: GABI Software

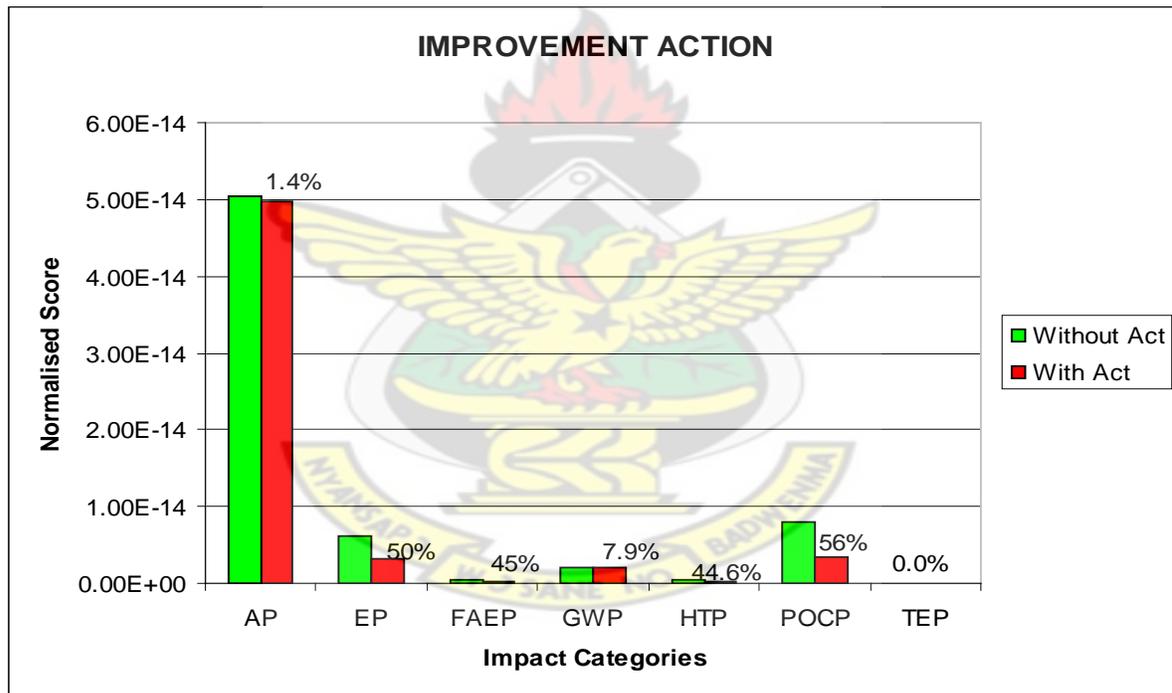


Figure 6.1 Results for improvement actions.

### 6.1.1 Gas scrubbing system

This is designed to absorb  $\text{SO}_2$  by limestone slurry while  $\text{CO}_2$  is absorbed by monoethanolamide solution,  $(\text{HO}(\text{CH}_2)_2\text{NH}_2)$ . In this gas scrubbing system, the limestone slurry (10% solids) is used to absorb the  $\text{SO}_2$  to produce  $\text{CaSO}_3$ . The latter is almost entirely oxidized to  $\text{CaSO}_4$ , partly by the excess oxygen in the flue gas in the scrubber, and partly by sparged air in an effluent hold tank for 10 minutes. The slurry is recirculated from the holding tank. A side stream is taken to a thickener to remove the solids ( $\text{CaSO}_4$ ). The solids can be sold for the manufacture of cement. The overflow from the thickener is sent back to the hold tank.

The effluent gas from the limestone-wet scrubber is then sent to the monoethanolamine scrubber to absorb  $\text{CO}_2$ . After the absorption of  $\text{CO}_2$ , the absorbent, monoethanolamine (15.3wt %), is sent to a stripping unit to strip the  $\text{CO}_2$  into container which can be used as fire extinguisher and can be used in the beverage industries. Sample calculation is as shown in appendix A. The input for this gas scrubbing system is shown in Table C-6. Transportation of limestone is not considered because it is not known where it will be transported from.

### 6.1.2 Anaerobic reactor

This second action helps to reduce high organic load due to palm oil losses, lather from soap used for washing floors, and morsels or pieces of food from pantry finds its way to wastewater(see Table A-1) produced at the margarine and the palm oil refining sections. The wastewater is filtered to reduce the suspended particles. The suspended particles are then sent to a decomposing unit where organic fertiliser is produced. The filtered wastewater that contains oil and fat is sent to a flotation unit to air float the fat and oil with floating agent, cationic hydroxy ethyl cellulose (20mg/l). The floated grease and scum, which can affect the bacteria action in the anaerobic reactor is sent to the decomposing unit. The wastewater is then

sent to equalisation unit where water is air stirred to keep the microbe aerobic to prevent unnecessary odour generation. The pH is maintained between 6.8 and 7.2 by addition of 40wt% of sodium hydroxide (NaOH) in this equalisation tank. The equalised water is then sent to the anaerobic reactor for microbial activity. The hydraulic retention time in the anaerobic reactor is 18 hours, which leads to reduction of COD content by 95% theoretically. Table C-7 in appendix C shows the inventory for the anaerobic reactor system.

## 6.2 DISCUSSION

Characterisation results (fig. 5.1) show that the environmental impact of 100 % palm oil-based margarine is due to the raw ingredient. This is in consonance with the report by Shonfield and Dumelin who present evidence to suggest that the environmental impacts of oil-based products are associated with the raw ingredients. This is due to the application of fertilizers (organic and inorganic) at the farming stage; more mechanical and chemical operations at the oil extraction and oil refining than those at the margarine section.

Palm oil refining posed the greatest environmental impact viz HTP, TEP, EP, FAEP, AP, POCP and GWP (the least contributor). Oil refining contributes to 94 % to human toxicity potential that is due to toxic substances: heavy metals (cadmium, lead, mercury etc.), nitrous oxides (NO<sub>x</sub>), sulphur dioxide (SO<sub>2</sub>), volatile organic compounds (VOC), chlorinated organic compounds, persistent organic pollutants (POP) and particulate matter (PM<sub>10</sub>). These are due to bleaching earth, residual fuel oil, diesel used at this section. 91.2% of TEP was caused by palm oil refining due to the release of toxic heavy metals. These are due to the emissions from the remote manufacture of phosphoric acid, citric acid, bleaching earth and nitric acid employed at this section. About 67% of the eutrophication potential aggregate was caused by palm oil refining because of emission of phosphate, nitrate ions and palm oil losses into wastewater. 65% to fresh water ecotoxicity potential due to the use of phosphoric acid, citric

acid, bleaching earth and nitric acid that released organic (e.g. polychlorinated dibenzo-p-dioxin), inorganic (barium, boron, cyanide, etc.) and heavy metals (e.g. arsenic, cadmium, chromium, copper, etc.) into freshwater (see table 5.1, fig.5.1 and table C-4).

Palm oil refining contributes 61% acidification potential due to the large amounts of heavy oil and diesel oil used to fire the boilers, which produced NO<sub>x</sub>, SO<sub>2</sub>, and CO<sub>2</sub> gases. Other distant emissions with lower concentrations compared to those released at the boiler houses were hydrogen chloride (HCl), nitric acid (HNO<sub>3</sub>), hydrogen fluoride (HF), hydrogen sulfide (H<sub>2</sub>S) and ammonia (NH<sub>3</sub>). 44% (POCP) in this study was caused by palm oil refining due to the use of diesel, residual fuel oil and nitric acid at refining section. These materials release of NO<sub>x</sub> and hydrocarbons (benzene, ethyl benzene, etc.) that could react in the presence of UV-light from the sun to produce ozone in the troposphere (see table 5.1, fig.5.1 and table C-4).

High global warming potential (43.8 %), acidification potential (10.4 %), eutrophication potential (25.2%), photochemical ozone creation potential (10.5 %) and human toxicity potential (1.4 %) at the oil palm cultivation section are due to emission of CH<sub>4</sub> from the decomposition of palm oil mill effluent and empty fruit bunches used as manure at the farming sections; application of inorganic fertilizer, and the use of low density polyethylene films at the early stages of the farming section (see table 5.1, fig.5.1 and table C-1).

Acidification potential (25.2 %), global warming potential (5.6 %) and photochemical ozone creation potential (17.1 %) at the palm oil extraction are due to water and biomass (kernel shell and palm fibre) to fire boilers cogeneration (see table 5.1, table C-2 and fig.5.1).

All impact categories (AP-0.9%, EP-2.9%, FAEP-23.9%, GWP-14.7%, HTP-1.0%, POCP-7.3% and TEP-3.4%) at the transportation stage are due to the emission from the manufacturing and burning of diesel during used by trucks for transporting crude palm oil from TOPP to Unilever Ghana Ltd (see table 5.1, table C-3, and fig. 5.1).

All impact categories including high GWP (31.6 %) at the margarine production are as results of employment of polypropylene tub and lid, corrugated board, low-density polyethylene film, electrical energy, etc. These inputs are not of local origin (see table 5.1, fig.5.1 and table C-).

After normalization (fig. 5.2), it became clear that acidification potential, eutrophication potential and global warming potential stood out among the other impact categories at the oil palm cultivation, palm oil production and palm oil refining with acidification potential being the highest impact category. This is in sympathy with the work by Katrina *et al* who report global warming potential, acidification potential and eutrophication potential are pronounced. Acidification potential is the greatest impact category after normalization. This is in line with the report by Green *et al* who compared palm oil to other oils (sunflower, rapeseed, soybean, coconut and palm kernel). Acidification potential is very pronounced when compared to global normal value (fig. 5.3) implies that the rate at which acid related compounds are released is higher than the rate at which greenhouse gases, for example, are released when compared to global emission. Hence, there is the need for mitigating actions on acidification potential, eutrophication potential, global warming potential, and photochemical ozone creation potential.

Two improvement actions recommended would have effect on all the impact categories except TEP if implemented. TEP would not be affected because none of the recommended options would reduce heavy metals that lead to TEP. Moreover, TEP is caused by remote emissions from raw materials used at the refining section. There would be reductions of 56 % POCP, 46 % HTP, 7.9 % GWP, 45 % FAEP, 50 % EP and 1.4 % AP (fig. 6.1 and table 6.1). One would sneer at the total reduction of AP (1.4 %). Percentages could be deceptive sometimes. This is rationalised by the following deduction: for 1 kg of margarine produced, AP of 0.00151 kg SO<sub>2</sub>-eq.; for 1 year, 131 400 000 kg margarine is produced leading to AP of 1 984 140 kg

SO<sub>2</sub>-eq.; but 61 % of this (1 984 140) is contributed by oil refining that gives AP of 1 210 325.4 kg SO<sub>2</sub>-eq; 15 % of 1 210 325.4 is contributed by SO<sub>2</sub>; 90 % of this SO<sub>2</sub> gas is captured by the gas scrubbing system which results in 131 161.6 kg SO<sub>2</sub> gas. This means approximately 136 tonnes/year of SO<sub>2</sub> gas is captured in the form of Calcium sulphate (290 tonnes/year salt for cement production or land filling), which is no mean value.

If these mitigating actions were considered the total normalized impact categories would reduce by 19.1 %.

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## CHAPTER 7

### 7.0 CONCLUSIONS AND RECOMENDATION

#### 7.1 Conclusion

In this work, a simplified LCA methodology has been applied to analyse the production of 100 % palm oil-based margarine by selecting different companies of which cultivate oil palm and produce palm oil, refines palm oil and produce 100 % palm oil-based margarine. Different sub-systems were identified and thoroughly studied: oil palm cultivation, palm oil production, palm oil transportation, and palm oil refining and margarine production. Inventory of raw materials associated with this product has been obtained and analysed. Unfortunately data for the inventory was not exhaustive because distribution and use phases were not considered for lack of data.

Palm oil refining, margarine production, transportation and palm oil cultivation have been identified as the crucial elements that pose considerable environmental threats due to the combustion of residual fuel oil water boilers; combustion of diesel in transporting trucks from TOPP to Unilever Ghana Ltd; application of organic and inorganic fertilisers; palm oil loss to wastewater effluents; employment of raw materials abroad.

It has been realised in this work that global warming, acidification and human toxicity potentials were pronounced. When compared to global emissions (normalisation), acidification potential proved to be very pronounced while eutrophication and photochemical ozone creation potential proved to be less pronounced, and human toxicity potential, aquatic ecotoxicity, global warming and terrestrial ecotoxicity proved to be insignificant.

Recommendation of different improvement actions could lead to 19.1 % reduction in the total emissions on the global level.

The results of this 100 % palm oil-based margarine give more reliable information on environmental performance to 100 % palm oil-based margarine manufactures than the results of mixed oil-based margarine do.

## **7.2 Recommendations**

In the course of this study, it was revealed that almost all the palm oil producing companies are able to generate their own electricity to run their unit operations and even supply part of the energy to neighbouring townships. It would therefore be recommended that at least every district in Ghana having a large palm plantation may embark upon cogeneration. This will supplement the energy produced in Ghana .

It is recommended that future study on margarine production should include product distribution and use stages. These last two stages would complement the information on environmental performance of palm oil when included in future study.

It is recommended that gas-scrubbing system be installed at the boiler house at both the palm oil extraction and refinery stages to reduce emission of acidic gases such as SO<sub>2</sub>, CO<sub>2</sub>, NO<sub>2</sub>, etc. For utilisation of biogas, anaerobic reactor system may be included at the oil extration and refining stages.

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## APPENDIX

### APPENDIX A-1

#### CALCULATION ON GAS SCRUBBER

##### 1. SO<sub>2</sub> REMOVAL

Flue gas is cooled from 260°C to 60°C near the adiabatic saturation temperature in the scrubber.

Initial enthalpy of the gas = 537.098 kJ/kg

Final enthalpy of the gas = 333.375 kJ/kg

Mass flowrate of gas = 160.69 kg/min

Amount of heat to be removed from the gas = 203.723 kJ/kg

$$\text{Amount of water required } 25^{\circ}\text{C to cool the gas, } m = \frac{Q}{C_{pw}\Delta T} = \frac{203.723 \times 10^3 \text{ J}}{4200 \text{ J/kg}^{\circ}\text{C} \times (60 - 25)^{\circ}\text{C}} = 1.386 \text{ kg/kg gas}$$

Mass flowrate of water = 1.386 x 160.69 kg/min = 222.72 kg/min.

##### Humidity of the gas after passing through scrubber

$$mC_{Pg}(\Delta T)_{gas} = m_w C_{Pw}(\Delta T)_{water} + L_v m_w$$

where  $m_g$  and  $m_w$  = mass of gas and water respectively

$$L_v = \text{enthalpy of vapourisation of water at } 25^{\circ}\text{C} = 2442.3 \text{ kJ/kg}$$

$$(\Delta T)_{gas} = \text{temperature change of gas} = 200^{\circ}\text{C}$$

$$(\Delta T)_{water} = \text{temperature change of water} = 35^{\circ}\text{C}$$

$$C_{Pw} = \text{specific heat capacity of water at } 25^{\circ}\text{C} = 4180 \text{ J/kg }^{\circ}\text{C}$$

$$C_{Pg} = \text{specific heat capacity of gas} = 1035.6 \text{ J/kg }^{\circ}\text{C}$$

$$\Rightarrow \frac{m_w}{m_g} = \frac{C_{Pg}(\Delta T)_{gas}}{C_{Pw}(\Delta T)_{water} + L_v} = \frac{1035.6 \text{ J/kg }^{\circ}\text{C} \times 200^{\circ}\text{C}}{4180 \text{ J/kg }^{\circ}\text{C} \times 35^{\circ}\text{C} + 2442.3 \times 10^3 \text{ J/kg}} = 0.08 \frac{\text{kg water}}{\text{kg gas}}$$

## APPENDIX A-2

It means 1 kg of gas contains 0.08 kg of water (8% of water goes to the effluent gas).

### Limestone slurry

Mass flowrate of water into the oxidation tank =  $222.7 - 222.7 \times 0.08 = 204.88 \text{ kg/min}$ .

$$\begin{aligned} \text{Mass of limestone added to the water to create 10\% solids: } 10\% &= \frac{m_{\text{Limestone}}}{m_{\text{Limestone}} + m_w} \\ &= \frac{m_{\text{Limestone}}}{m_{\text{Limestone}} + 222.7} \end{aligned}$$

$$\Rightarrow m_{\text{Limestone}} = \frac{0.1}{0.9} \times 222.7 \text{ kg/min} = 24.74 \text{ kg/min} = 412.3 \text{ g/s (1\% CaCO}_3\text{)}.$$

Mass flowrate of slurry into the scrubber =  $222.7 + 24.7 = 247.44 \text{ kg/min}$

$$\begin{aligned} \text{Volumetric flowrate of slurry into the scrubber} &= \frac{\text{mass of slurry flowrate}}{\text{density of slurry}} = \frac{247.44 \text{ kg/min}}{1053 \text{ kg/m}^3} \\ &= 0.235 \text{ m}^3/\text{min} \end{aligned}$$

### Possible reactions in the scrubber



Molar flowrate of  $\text{SO}_2$  in flue gas =  $0.02 \text{ mol/s}$

Amount of  $\text{SO}_2$  to be removed =  $0.018 \text{ mol/s}$  (90% reduction)

Mass of  $\text{CaCO}_3$  required =  $0.018 \text{ mol} \times 100 \text{ g/mol} = 1.80 \text{ g/s}$

But mass  $\text{CaCO}_3$  in the slurry is 1% of  $412.33 \text{ g/s} = 4.12 \text{ g/s}$

It means 46% of the  $\text{CaCO}_3$  is converted to  $\text{CaSO}_3$  in the scrubber in one pass through the scrubber.

### APPENDIX A-3

Amount of  $\text{CaSO}_3$  produced in the scrubber =  $1.8/100 \times 120 = 2.16 \text{ g/s}$

#### Dimensions of scrubber

Velocity of flue gas is chosen to be 2.4m/s.

Volumetric flowrate of flue gas,  $Q = \frac{\text{mass flowrate}}{\text{density of gas}} = \frac{160.69\text{kg/min}}{0.6637\text{kg/m}^3} = 4.035 \text{ m}^3/\text{s}$ .

Cross-sectional area of scrubber,  $A = \frac{4.035\text{m}^3 / \text{s}}{2.4\text{m/s}} = 1.65\text{m}^2$

Diameter of scrubber =  $\sqrt{\frac{4A}{\pi}} = \sqrt{\frac{4 \times 1.65\text{m}^2}{\pi}} = 1.45\text{m}$ .

Residence time of flue gas in the scrubber = 4 seconds

Height of scrubber = gas velocity x residence time = 2.4 m/s x 4s = 9.6m

#### Oxidation hold tank

Reaction in the oxidation:  $\text{CaSO}_3 + \frac{1}{2}\text{O}_2 \rightarrow \text{CaSO}_4$

Assuming 60% of  $\text{CaSO}_3$  (i.e. 1.296g) comes into the oxidation tank.

Amount of oxygen needed for oxidation =  $\frac{1.296\text{g}}{120} \times 8 = 0.0864 \text{ g/s}$

But 100g of air contains 23g of oxygen. Therefore 0.0864g of oxygen requires 0.376 g/s of air.

Practically, twice this amount of sparged air is used i.e. 0.752 g/s = 2.707 kg/h.

The residence time of slurry in the oxidation tank is 10 minutes.

The minimum volume of the tank = 10 min x 0.235m<sup>3</sup>/min = 2.35m<sup>3</sup>.

## APPENDIX A-4

### Thickener

The average particle size of the limestone is 80% to 90% of particles passing 200mesh (133.3  $\mu$ m).

Feed Pulp = 10% solids; underflow pulp = 35% solids.

Average particle settling rate extrapolated from Tyler's screen mesh chart,

$$R = 1.389 \times 10^{-5} \text{ m/s.}$$

Mass flowrate of limestone,  $Q = 0.412 \text{ kg/s.}$

The area of the thickener,  $A = \frac{Q(F-D)}{R\rho}$  .....B 4.1

where

$$F = \text{feed liquid to solid ratio} = 90\% = 0.90$$

$$D = \text{underflow liquid to solid ratio} = 65\% = 0.65.$$

$$\rho = \text{density of water at } 30^\circ\text{C} = 996 \text{ kg/m}^3$$

$$\Rightarrow A = \frac{0.412\text{kg/s}(0.90 - 0.65)}{996.0\text{kg/m}^3 \times 1.389 \times 10^{-5} \text{ m/s}} = 7.4\text{m}^2$$

$$\text{Diameter of thickener} = 3.1\text{m}$$

### 2. CO<sub>2</sub> REMOVAL

Flue gas content from limestone scrubber: CO<sub>2</sub> = 1542.6 kg/h (148 000ppm)

$$\text{SO}_2 = 0.588 \text{ kg/h (56.6ppm)}$$

$$\text{H}_2\text{O} = 1068 \text{ kg/h (103 000ppm)}$$

Gas flowrate = 10396.2 kg/h = 2.89 kg/s

Absorbent: monoethanolamine, HO(CH<sub>2</sub>)<sub>2</sub>NH<sub>2</sub> (15.3wt% at 25°C).

## APPENDIX A-5

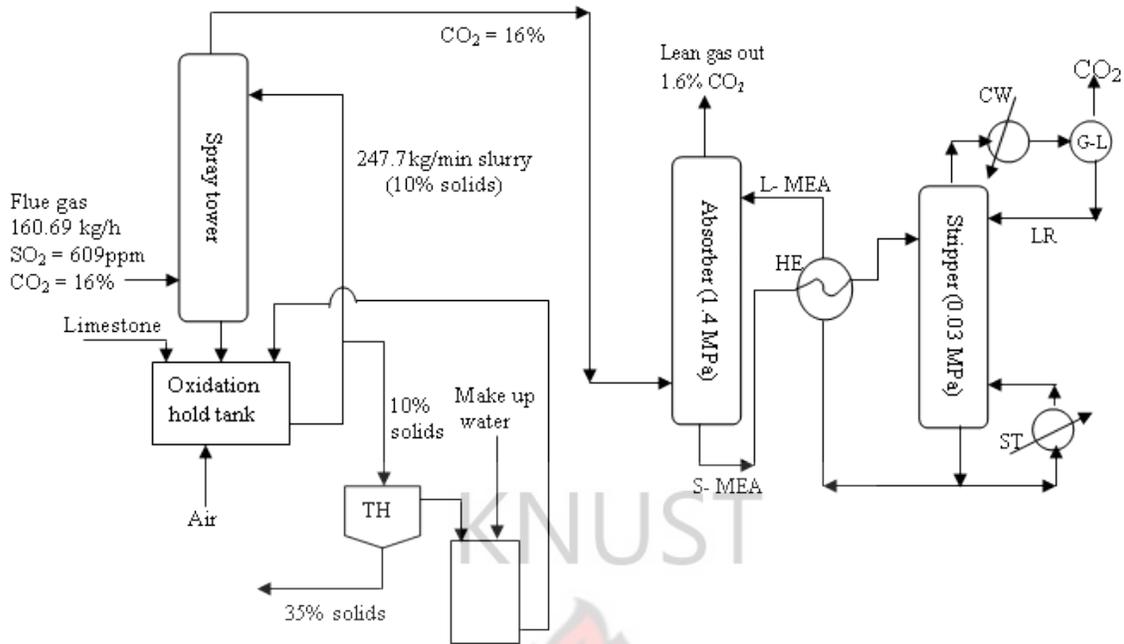


Figure A-1. Scrubbing system.

### Material balance on the transfer of CO<sub>2</sub> for small section dh of the scrubber

$$\left( \begin{array}{c} \text{Moles of CO}_2 \\ \text{transferred} \\ \text{from the gas} \end{array} \right) = \left( \begin{array}{c} \text{Moles of CO}_2 \\ \text{transferred} \\ \text{to the liquid} \end{array} \right) = \left( \begin{array}{c} \text{Mass transferred} \\ \text{per unit volume} \end{array} \right) (d \text{ volume}) \dots \dots \dots \text{B 5.1}$$

$$- G dY_{\text{CO}_2} = L dX_{\text{CO}_2} = K_a P (y_{\text{CO}_2} - y_{\text{CO}_2}^*) Adh \dots \dots \dots \text{B 5.2}$$

where

G = gas flowrate (mol/s)

L = liquid flowrate (mol/s)

Y<sub>CO<sub>2</sub></sub> = gas content of transferred CO<sub>2</sub> (mol/mol of non-transferred component)

X<sub>CO<sub>2</sub></sub> = liquid content of transferred CO<sub>2</sub>

## APPENDIX A-6

Adh = product of the column cross-sectional area and incremental height = column volume corresponding to dh

Ka = product of mass transferred coefficient and interfacial area for mass transfer (m<sup>2</sup>/m<sup>3</sup>)

P = pressure of the column = 200Psi = 13.6 atmospheres = 1.37 MPa

Integrating equation B 5.2:

$$\text{Liquid to gas ratio in the scrubber, } \frac{L}{G} = \frac{y_{\text{co}_2 \text{ bottom}} - y_{\text{co}_2 \text{ top}}}{x_{\text{co}_2 \text{ bottom}} - x_{\text{co}_2 \text{ top}}} \dots\dots\dots \text{B 5.3}$$

Assume the outlet liquid concentration to have  $y_{\text{co}_2}^* = 0.8 y_{\text{co}_2 \text{ bottom}}$

Using the strength and temperature, the vapour pressure of CO<sub>2</sub> over the absorbent is obtained from Kohl and Riesenfeld work which gives a plot  $p_{\text{co}_2} = Py_{\text{co}_2}^*$  as a function of moles CO<sub>2</sub> per mole absorbent. From the plot, the vapour pressure of CO<sub>2</sub>,

$$p_{\text{co}_2} = Py_{\text{co}_2}^* = (0.0028\text{Psi}) \exp(20.5x_{\text{co}_2}) \quad (\text{Kudson, 1971}).$$

$$\Rightarrow x_{\text{co}_2} = \frac{\ln(Py_{\text{co}_2}^*/0.0028\text{Psi})}{20.5} \dots\dots\dots \text{B 6.1}$$

$$\text{But } y_{\text{co}_2}^* = 0.8 y_{\text{co}_2 \text{ bottom}} = 0.8 \times 0.148 = 0.1184$$

$$\Rightarrow x_{\text{co}_2 \text{ bottom}} = \frac{\ln(200\text{Psi} \times 0.1184/0.0028\text{Psi})}{20.5} = 0.441$$

If it is required that the top of the column to have  $y_{\text{co}_2}^* = 0.8 y_{\text{co}_2 \text{ top}} = 0.8 \times 500 \times 10^{-6} = 4 \times 10^{-4}$

$$\Rightarrow x_{\text{co}_2 \text{ top}} = \frac{\ln(200\text{Psi} \times 4 \times 10^{-4}/0.0028\text{Psi})}{20.5} = 0.164$$

But the CO<sub>2</sub> is to be reduced by 90% (i.e. from 148000ppm to 500ppm).

$$\Rightarrow \frac{L}{G} = \frac{148000\text{ppm} - 500\text{ppm}}{0.441 - 0.164} = 0.532$$

## APPENDIX A-7

### ORGANIC WASTE REDUCTION

Table A-1 Composition of wastewater at 28.3°C

Parameters	Concentration (mg/L)
Total fatty materials	193.0
Cl <sup>-</sup>	12.0
PO <sub>4</sub> <sup>-3</sup>	20.0
SO <sub>4</sub> <sup>-2</sup>	431.0
Total suspended solids	253.0
COD	1466.0
BOD	978.0
bCOD*	1173

**bCOD = biodrgradable chemical oxygen demand**

**Source: Unilever (Gh)**

#### 1. Physicochemical treatment

Total wastewater flowrate from refining and margarine sections = 1.465 m<sup>3</sup>/h

Amount of required to float the fat depends on the amount of fat in the wastewater. The air to solid ratio is 0.01-0.05 l/g

1.465m<sup>3</sup> of waste water contains 1465 x 193 = 282745g of fat.

But 1.0g of solid = 0.05 litres

## APPENDIX B-2

282745g of fat =  $0.05 \times 282745 = 14137.25$  litres =  $14.137\text{m}^3$  of air.

Mass of air required =  $0.1079 \text{ kg/m}^3 \times 14.137\text{m}^3 = 1.53 \text{ kg/h}$ .

### Flotation tank

The relation between the volume ( $V_c$ ) of the flotation cell and volume ( $V_w$ ) of wastewater is

given by  $k = \frac{V_w}{V_c}$  ( $0.65 \leq k \leq 0.75$ )

But  $V_w = 1.465 \text{ m}^3/\text{h} = 4.07 \times 10^{-4} \text{ m}^3/\text{s}$

$$\Rightarrow V_c = \frac{4.07 \times 10^{-4} \text{ m}^3/\text{s}}{0.75} = 5.43 \times 10^{-4} \text{ m}^3$$

Assume that the residence time in the flotation chamber is 8 minutes (540 seconds)

The minimum volume of the flotation chamber =  $5.43 \times 10^{-4} \times 540 = 0.26\text{m}^3$ .

### Equalisation tank

The hydraulic retention time in the anaerobic reactor is 18 hours. This means the waste is held in the equalisation tank 18 hours.

The minimum volume of equalisation tank =  $1.465 \text{ m}^3/\text{h} \times 18\text{h} = 36.65\text{m}^3$

The PH of wastewater within this tank is maintained from 6.8 to 7.2

### Addition of caustic to the equalisation tank

At initial PH = 6.2,  $[H^+] = 10^{-6.2} = 6.31 \times 10^{-7} \text{ mol/dm}^3$ .

But one mole of acid ( $H^+$ ) requires 1mole of base ( $OH^-$ ).

$\Rightarrow [OH^-] = 6.31 \times 10^{-7} \text{ mol/dm}^3$  (needed to create PH = 7).

At PH = 7.2, POH = 6.8.

$\Rightarrow [OH^-] = 10^{-6.8} = 1.58 \times 10^{-7} \text{ mol/dm}^3$  present in excess.

### APPENDIX B-3

$$\Rightarrow \text{Total } [\text{OH}^-] = (6.31 \times 10^{-7} + 1.58 \times 10^{-7}) = 7.89 \times 10^{-7} \text{ mol/dm}^3$$

$\Rightarrow$  But 1 mole of NaOH gives 1 mole of OH<sup>-</sup>

$$\Rightarrow [\text{NaOH}] = 7.89 \times 10^{-7} \text{ mol/dm}^3 = 7.89 \times 10^{-4} \text{ mol/m}^3$$

$$\Rightarrow [\text{NaOH}] = 0.0289 \text{ mol} / 36.63 \text{ m}^3 \text{ wastewater.}$$

If 40wt% NaOH is prepared it would contain 10 mol/1000cm<sup>3</sup>.

But 0.0289 moles of 40wt% NaOH is needed to create PH = 7.2.

$$\text{Volume of 40wt\% NaOH needed} = \frac{0.0289 \text{ mol}}{10 \text{ mol}} \times 1000 \text{ cm}^3 = 2.89 \text{ cm}^3$$

This means 2.89 cm<sup>3</sup> of the caustic solution is added to the equalisation tank every 18 hours in order to provide PH = 7.2.

#### Anaerobic reactor

Coefficient at 35°C: Y = 0.04 gvss/gCOD

The COD is converted to methane gas. Steady- state mass balance anaerobic reactor gives:

$$\left( \begin{array}{c} \text{Influent} \\ \text{COD} \end{array} \right) = \left( \begin{array}{c} \text{Effluent} \\ \text{COD} \end{array} \right) + \left( \begin{array}{c} \text{Influent COD converted} \\ \text{to cell tissue} \end{array} \right) + \left( \begin{array}{c} \text{Influent COD} \\ \text{converted to CH}_4 \end{array} \right)$$

$$\text{COD}_{\text{in}} = \text{COD}_{\text{eff}} + \text{COD}_{\text{cvv}} + \text{COD}_{\text{CH}_4}$$

$$\text{COD}_{\text{in}} = Q S_o = 35.16 \text{ m}^3/\text{d} \times 1173 \text{ g/m}^3 = 41242.68 \text{ g/day} = 41.2 \text{ kg/day}$$

Assume that 95% of COD<sub>in</sub> is degraded

$$\text{COD}_{\text{eff}} = (1 - 0.95) \times 41.2 \text{ kg/day} = 2.02 \text{ kg/day}$$

$$\text{COD}_{\text{cvv}} = (1.42 \text{ gCOD/gvss})(0.04 \text{ gvss/gCOD})(0.95)41.2 \text{ kg/day} = 2.22 \text{ kg/day}$$

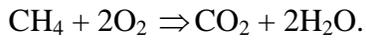
$$\text{COD}_{\text{CH}_4} = \text{COD}_{\text{in}} - \text{COD}_{\text{eff}} - \text{COD}_{\text{cvv}}$$

$$= 41.2 - 2.22 - 2.06 = 36.92 \text{ kg/day}$$

$$\text{Volume occupied by 1 mole of CH}_4 \text{ at } 35^\circ\text{C, } V_{\text{CH}_4} = \frac{nRT}{P}$$

$$= \frac{1 \text{ mole} \times 8.314 \text{ Pa m}^3/\text{mole K} \times (273 + 35)\text{K}}{101.3 \times 10^3 \text{ Pa}} = 0.0252 \text{ m}^3/\text{mole}$$

COD of methane is the amount of oxygen needed to oxidise methane to  $\text{CO}_2$  and  $\text{H}_2\text{O}$ , that is



From the oxidation of  $\text{CH}_4$ , the COD per mole  $\text{CH}_4 = 2 \times 32 \text{ g O}_2/\text{mole} = 0.064 \text{ kg COD/mole}$

The  $\text{CH}_4$  equivalent of COD converted under anaerobic conditions is

$$= 0.0252 \text{ m}^3/\text{mole} \times 0.064 \text{ kg COD/mole} = 1.613 \times 10^{-3} \text{ m}^3 \text{CH}_4/\text{kg COD}$$

Volume methane produced =  $1.613 \times 10^{-3} \text{ m}^3 \text{CH}_4/\text{kg COD} \times 36.92 \text{ kg/day}$

$$= 0.0595 \text{ m}^3 = 59.6 \text{ Litres/day} = 2.48 \text{ L/hr}$$

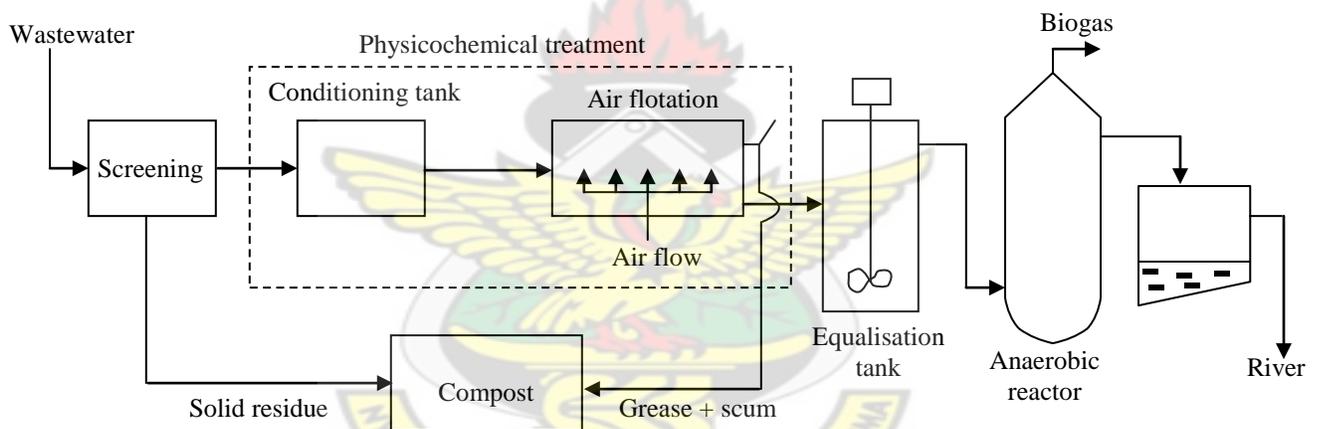


Figure B-3 Reduction of organic load in wastewater

## APPENDIX C

### DETAILED PRESENTATION OF INVENTORY TABLES.

**Table C-1. Oil Palm Production inventory (quantity in kg/ kg margarine)**

<u>INPUT</u>	
<b>Raw materials</b>	
Palm seeds	1.4720E-03
Manure	5.000E-2
Fertiliser	8.84E-01
LDPE film	9.050E-2
Water	2.7E-01
<b>Product</b>	
Fresh Palm fruit bunches	35.1E-01
<u>OUTPUT</u>	
<b>Emissions To Air</b>	
Ammonia	4.8900E-04
Carbon dioxide	4.2150E-03
Carbon monoxide	6.4000E-05
Hydrogen sulphide	2.6400E-04
Nitrogen oxides	2.2650E-04
Nitrous oxide (laughing gas)	1.4050E-04
Methane	1.59E-03

Source: Input from TOPP, output from ecoinvent database

**Table C-2. Palm Oil Production inventory (quantity in kg/ kg margarine)**

<u>INPUT</u>	
Water (ground water)	8.7909E-01
Water (lake water)	3.8015E-01
Water (river water)	1.1167E+00
Palm fruits	5.2626E+00
Empty fresh bunch	1.7540E+00
Palm Fibre	1.1562E+00
Palm Kernel	9.9620E-01
Palm oil	1.0525E+00
<u>OUTPUT</u>	
<b>EMISSIONS TO AIR</b>	
<i>Carbon dioxide</i>	5.4000E-03
<i>Carbon monoxide</i>	2.3000E-03
Nitrous oxide (laughing gas)	7.8000E-03
<i>Dust (combustion)</i>	1.1620E-01
<b>EMISSIONS TO FRESH WATER</b>	
Aluminum	2.7155E-06
Chloride	1.0609E-05
Chlorine (dissolved)	2.1050E-07

Source: Input from TOPP, output from ecoinvent database

**Table C-3 Inventory for Palm Oil Transportation (quantity in kg/ kg margarine)**

<b><u>INPUTS</u></b>	
Distance traveled by truck (km) <sup>a</sup>	234.0
Weight of truck (tonnes) <sup>b</sup>	28.0
<b><u>OUTPUT</u></b>	
Crude oil (resource)	4.5971E-03
Hard coal (resource)	2.3397E-07
Lignite (resource)	1.3282E-05
Natural gas (resource)	2.0891E-04
Uranium (resource)	2.1204E-09
Bentonite	3.3711E-05
Inert rock	7.5657E-04
Iron ore	2.1268E-07
Limestone (calcium carbonate)	1.8796E-06
<b>Heavy metals to air</b>	
Antimony	6.9126E-14
Arsenic	3.1408E-12
Cadmium	4.6607E-12
Chromium (unspecified)	1.8011E-11
Cobalt	3.6387E-13
Copper	2.2299E-12
Iron	4.2091E-10
Lanthanides	6.7006E-14
Lead	2.6166E-11
Manganese	4.6310E-12
Mercury	6.9847E-12
Molybdenum	2.8541E-13
Nickel	9.5802E-12
Selenium	7.1204E-12
Thallium	3.5199E-14
Tin	1.7176E-13
Titanium	1.2337E-11
Vanadium	6.7345E-13
Zinc	3.9775E-11
<b>Inorganic emissions to air</b>	
Ammonia	6.1535E-10
Barium	8.1171E-12
Beryllium	4.9618E-14
Boron compounds (unspecified)	7.9771E-10
Carbon dioxide	1.4786E-02
Carbon monoxide	4.1835E-05
Fluorides	4.1654E-11
Hydrogen chloride	1.2091E-08
Hydrogen cyanide (prussic acid)	1.6964E-15
Hydrogen fluoride	3.2536E-09

Source: Ecoinvent database.  
a, b- units are not in kg as stated.

**Table C-3 (continued)- Inventory for Palm Oil Transportation(quantity in kg/ kg margarine)****OUTPUT**

Hydrogen sulphide	6.7260E-11
Nitrogen oxides	1.7453E-04
Nitrous oxide (laughing gas)	6.6667E-09
Scandium	4.6650E-14
Strontium	6.7006E-13
Sulphur dioxide	1.5193E-05
Sulphuric acid	9.0755E-14
Group NMVOC to air	5.4499E-05
Benzo{a}pyrene	3.8346E-11
Polycyclic aromatic hydrocarbons (PAH)	8.7914E-12
Benzene	2.7752E-09
Formaldehyde (methanal)	1.8244E-12
NMVOC (unspecified)	5.4496E-05
Methane	1.8133E-05
Dust (unspecified)	9.3392E-06
Adsorbable organic halogen compounds (AOX)	5.4665E-11
Biological oxygen demand (BOD)	9.3130E-09
Chemical oxygen demand (COD)	5.4368E-08
Total organic bounded carbon	2.7290E-06
Arsenic	1.4712E-11
Cadmium	1.3541E-10
Chromium (unspecified)	9.0373E-10
Copper	4.5208E-10
Heavy metals to water (unspecified)	9.0797E-10
Iron	4.7116E-08
Lead	2.4733E-11
Mercury	1.9338E-12
Nickel	9.0585E-10
Zinc	5.5640E-11
Acid (calculated as H+)	3.3884E-14
Ammonium / ammonia	8.1395E-08
Chloride	2.8748E-04
Cyanide	1.2723E-15
Fluoride	4.6523E-09
Neutral salts	4.0606E-08
Nitrate	2.7765E-09
Phosphate	1.0810E-09
Sodium	1.8626E-04
Sulphate	4.0606E-07
Halogenated organic emissions to fresh water	2.1204E-15
Polychlorinated dibenzo-p-dioxins (2,3,7,8 - TCDD)	2.1204E-15
Hydrocarbons to fresh water	4.5100E-07
Hydrocarbons (unspecified)	4.0585E-07
Methanol	2.1137E-11
Phenol (hydroxy benzene)	4.5123E-08
Other emissions to fresh water	1.7956E-02
Waste water	1.7956E-02

Source: Ecoinvent database

**Table C-4 Inventory for palm oil refining(quantity in kg/ kg margarine)**

**INPUT**

**Raw Materials**

Electricity (kwh)	6.38E-02
Residual fuel oil	1.31026E-03
Bleaching earth	5.26E-03
Diesel	1.149E-02
Nitric acid	3.75E-05
Phosphoric acid	6.32E-04
Water	7.85E-01
Palm oil	1.0525E+00

**Products**

Fatty acids (by-product)	5.2626E-02
Stearine plus Olein	9.9957E-01

**OUTPUT**

**EMISSIONS TO AIR**

**Heavy metals to air**

Antimony	1.5638E-13
Arsenic	7.1054E-12
Cadmium	1.0544E-11
Chromium (unspecified)	4.0746E-11
Cobalt	8.2318E-13
Copper	5.0446E-12
Iron	9.5222E-10
Lanthanides	1.5159E-13
Lead	5.9196E-11
Manganese	1.0477E-11
Mercury	1.5802E-11
Molybdenum	6.4569E-13
Nickel	2.1673E-11
Selenium	1.6109E-11

**Inorganic emissions to air**

Ammonia	9.6818E-08
Barium	1.8363E-11
Beryllium	1.1225E-13
Boron compounds (unspecified)	1.8047E-09
Carbon dioxide	3.2802E-03
Carbon monoxide	2.2326E-06
Fluorides	9.4234E-11
Hydrogen chloride	2.7353E-08
Hydrogen cyanide (prussic acid)	3.8377E-15
Hydrogen fluoride	7.3606E-09
Hydrogen sulphide	1.5216E-10
Nitrogen dioxide	4.0700E-03
Nitrogen oxides	2.5051E-05
Nitrous oxide (laughing gas)	3.5165E-07
Scandium	1.0554E-13

Source: Input from Unilever Gh. Ltd., output from ecoinvent database

**Table C-4 (Continued)-Inventory for palm oil refining (quantity in kg/ kg margarine)****OUTPUT**

Strontium	1.5159E-12
Sulphur dioxide	2.5800E-04
Sulphuric acid	2.0531E-13
<b>Organic emissions to air</b>	
Group NMVOC to air	8.7181E-05
<i>Benzo{a}pyrene</i>	8.6750E-11
<i>Polycyclic aromatic hydrocarbons (PAH)</i>	1.9889E-11
Alkane (unspecified)	1.4808E-12
Alkene (unspecified)	8.1412E-14
Aromatic hydrocarbons (unspecified)	2.2212E-14
Benzene	2.0093E-07
Butane	1.9465E-06
Butene	4.8579E-08
Ethane	4.8579E-07
Ethene (ethylene)	9.7159E-08
Ethyl benzene	4.8579E-08
Formaldehyde (methanal)	4.1274E-12
Heptane (isomers)	4.8579E-07
Hexane (isomers)	9.7159E-07
Pentane (n-pentane)	2.4323E-06
Propane	1.9465E-06
Propene (propylene)	9.7159E-08
Toluene (methyl benzene)	2.9181E-07
Xylene (dimethyl benzene)	1.9465E-07
Methane	4.0045E-05
<b>Particles to air</b>	
Dust (> PM10)	3.3034E-07
Dust (unspecified)	2.4168E-07
<b>Emissions To Fresh Water</b>	
Analytical measures to fresh water	
Adsorbable organic halogen compounds (AOX)	3.9504E-10
Biological oxygen demand (BOD)	8.2044E-08
Chemical oxygen demand (COD)	4.6473E-07
Total dissolved organic bounded carbon	5.9300E-10
Total organic bounded carbon	6.4141E-06
<b>Heavy metals to fresh water</b>	
Arsenic	2.3732E-10
Cadmium	5.1037E-10
Chromium (unspecified)	2.0445E-09
Chromium +VI	4.5899E-09
Copper	1.2268E-09
Iron	1.1594E-07
Lead	6.5220E-09
Manganese	3.7188E-09
Mercury	6.2444E-12
Molybdenum	1.8695E-10
Nickel	2.3187E-09

Source: Input from Unilever Gh. Ltd., output from Ecoinvent database

**Table C-4 (Continued)-Inventory for palm oil refining (quantity in kg/ kg margarine)****OUTPUT**

Selenium	2.8042E-10
Silver	9.3473E-10
Strontium	1.4272E-08
Vanadium	6.1310E-10
Zinc	3.6437E-09
<b>Inorganic emissions to fresh water</b>	
Acid (calculated as H <sup>+</sup> )	7.6655E-14
Aluminum	1.5820E-09
Ammonium / ammonia	2.4177E-07
Barium	1.8695E-09
Boron	7.4712E-09
Calcium	9.3473E-07
Chloride	6.5185E-04
Chlorine (dissolved)	5.0174E-11
Cyanide	3.2364E-09
Fluoride	9.7875E-07
Magnesium	4.6569E-07
Neutral salts	9.1864E-08
Nitrate	1.5973E-07
Nitrogen	4.9104E-09
Nitrogen organic bounded	3.6518E-07
Phosphate	2.4455E-09
Phosphorus	7.2366E-09
Potassium	1.8695E-07
Sodium	4.2806E-04
Sulphate	4.3437E-06
Sulphide	1.8695E-09
<b>Organic emissions to fresh water</b>	
Halogenated organic emissions to fresh water	
Polychlorinated dibenzo-p-dioxins (2,3,7,8 - TCDD)	4.7971E-15
<b>Hydrocarbons to fresh water</b>	
Aromatic hydrocarbons (unspecified)	1.3435E-08
Benzene	3.8528E-10
Ethyl benzene	4.0539E-12
Hydrocarbons (unspecified)	9.2570E-07
Methanol	4.7817E-11
Phenol (hydroxy benzene)	1.0835E-07
Polycyclic aromatic hydrocarbons (PAH, unspec.)	2.7137E-10
Toluene (methyl benzene)	1.8695E-08
Xylene (isomers; dimethyl benzene)	1.8695E-09
<b>Other emissions to fresh water</b>	
Waste water	4.0622E-02
Particles to fresh water	1.8695E-07
Solids (suspended)	1.8695E-07

Source: Input from Unilever Gh. Ltd., Output from ecoinvent database

**Table C-5 Inventory for margarine production (quantity in kg/ kg margarine)**

<b><u>INPUT</u></b>	
<b>Raw Materials</b>	
Beta carotene	9.5000E-05
Citric acid	1.4000E-03
Dimodan	1.2150E-02
Lecithin	7.0700E-03
Milk powder	2.2500E-02
paper box (packaging)	2.0000E-02
Potassium sorbate	1.0000E-03
Stearine plus Olein	9.9957E-01
Polypropylene	2.22E-02
LDPE film	6.0E-03
Electricity (kJ) <sup>c</sup>	297.0
<b>Product</b>	
Packaged margarine	1.00E+00
<b><u>OUTPUT</u></b>	
<b>Inorganic emissions to air</b>	
Carbon dioxide	3.0563E-02
Carbon monoxide	2.2005E-05
Hydrogen chloride	1.7115E-06
Hydrogen fluoride	1.2225E-07
Nitrogen oxides	2.9340E-04
Nitrous oxide (laughing gas)	8.2141E-09
Sulphur dioxide	2.2005E-04
Group NMVOC to air	2.4450E-08
VOC	5.1345E-04
Dust (unspecified)	7.3350E-05
Metals (unspecified)	1.2225E-07
<b>Emissions To Fresh Water</b>	
Analytical measures to fresh water	
Biological oxygen demand (BOD)	4.8900E-06
Chemical oxygen demand (COD)	3.6675E-05
Solids (dissolved)	7.3350E-06
Total dissolved organic bounded carbon	4.8900E-07
<b>Inorganic emissions to fresh water</b>	
Acid (calculated as H <sup>+</sup> )	1.4670E-06
Aluminum	1.9608E-06
Ammonium / ammonia	1.2225E-07
Chloride	1.0839E-05
Chlorine (dissolved)	1.5200E-07
Nitrate	1.2225E-07
Nitrogen	2.4450E-07
Phosphate	1.2225E-07
<b>Organic emissions to fresh water</b>	
Hydrocarbons to fresh water	7.3350E-06

Source: Input from Unilever Gh. Ltd., Output from ecoinvent database

c = all quantities are in kg except this quantity.

**INVENTORY TABLE FOR IMPROVEMENT ACTIONS**  
**Table C-6 Inventory data of Gas Scrubber (quantity in kg/ kg margarine)**

---

**INPUT**

**Raw materials**

1. Limestone	4.12E-1
2. Water	79.11E-1
3. Monoethanolamide	5.32E-1
4. Air	27.07E-1

**Products**

1. Gypsum	5.263E-02
2. Liquefied CO <sub>2</sub>	3.930E-1

**OUTPUT**

**Emissions to air**

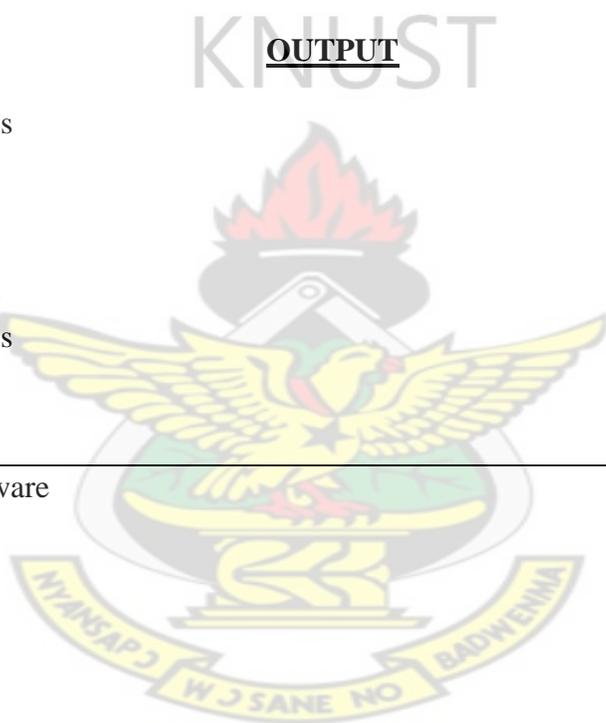
1. Heavy metals	1.10E-09
2. Inorganic	7.24E-03
3. Organic	1.36E-05
4. Particles	4.72E-06

**Emissions to water**

1. Heavy metals	1.57E-07
2. Inorganic	1.09E-04
3. Organic	1.27E-06
4. Others	6.06E-03

---

Source: GABI Software



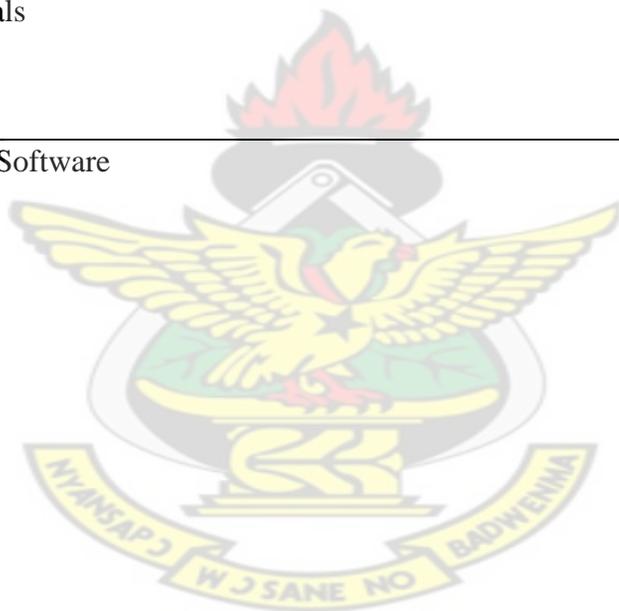
**Table C-7 Inventory data of anaerobic reactor (quantity in kg/ kg margarine)**

---

<b><u>INPUT</u></b>	
<b>Raw materials</b>	
1. Waste organic water	4.15E-01
2. Sodium Hydroxide	1.16E-03
3. Air	4.25E-04
<b>Product</b>	
1. Biogas	4.27E-04
2. Compost	2.53E-02
<b><u>OUTPUT</u></b>	
<b>Emissions to air</b>	
1. Heavy metals	2.45E-09
2. Inorganic	9.11E-05
3. Organic	2.40E-05
4. Particles	6.52E-09
<b>Emissions to water</b>	
1. Heavy metals	2.44E-06
2. Inorganic	5.51E-05
3. Organic	1.34E-07
4. Others	8.23E-04

---

Source: GABI Software



## APPENDIX D

Table D 1. QUESTIONNAIRE FOR OIL PALM CULTIVATION

Please mark them clearly if you have data in other units different from the ones proposed below. For allocation of water over other purposes (heating, drinking, nursery, etc.) you can use a percentage.			Why we want to this? Water is one of the materials needed in the nursery. With the allocation columns we want to further precisely allocate of water inputs to the nursery.				Data source for total		
							Direct data (derived from administration system)	Indirect data ( Based on some sort of calculation)	Estimated data
Total	Total used per month	Unit	Alt. Unit	Used for farming	Used for heating	Others			
Water		kg		%	%	%	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Inorganic fertiliser		kg		%	%	%	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
manure		kg		%	%	%	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Pesticide		kg		%	%	%	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Fresh fruit bunches		kg/hector		%	%	%	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Land		hector		%	%	%	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

Table D 2. QUESTIONNAIRE FOR PALM OIL PRODUCTION

Please mark them clearly if you have data in other units different from the ones proposed below. For allocation of water over other purposes (oil extraction, others.) you can use a percentage.			Why we want to this? Water is one of the materials needed in the oil extraction. With the allocation columns we want to further precisely allocate of water inputs to the oil extraction.				Data source for total		
							Direct data (derived from administration system)	Indirect data ( Based on some sort of calculation)	Estimated data
Total	Total used per month	Unit	Alt. Unit	Used for oil extraction	Used for other use	Others			
Water		kg		%	%	%	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Fresh fruit bunches		kg		%	%	%	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Empty fruit bunches		kg		%	%	%	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Palm kernel		kg		%	%	%	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Crude palm oil		kg		%	%	%	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Palm kernel shell		kg		%	%	%	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Electricity		kwh		%	%	%	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Crude palm kernel oil		kg		%	%	%	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
CO <sub>2</sub>		%		%	%	%	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
SO <sub>2</sub>		%		%	%	%	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
NO <sub>2</sub>		%		%	%	%	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
CO		%		%	%	%	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
O <sub>2</sub>		%		%	%	%	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Air flow rate		Kg/kg fuel		%	%	%	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

Table D 3. QUESTIONNAIRE FOR CRUDE PALM OIL TRANSPORTATION

Please mark them clearly if you have data in other units different from the ones proposed below.		Why we want to this? Since Unilver Ghana Lt. obtains crude palm oil from different factories, we need to know exactly where each consignment is coming from		Data source for total		
				Direct data (derived from administration system)	Indirect data ( Based on some sort of calculation)	Estimated data
Total	Total transported per month	Unit	Alternative Unit			
Crude Palm oil		kg		<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Gross weight of truck		kg		<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Total distance travelled		km		<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Kind of fuel use		kg		<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

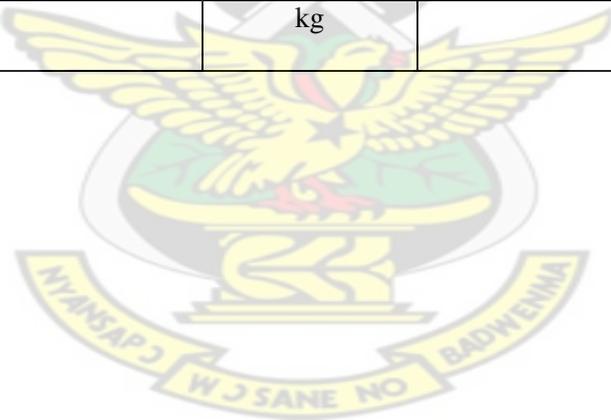


Table E 4. QUESTIONNAIRES FOR PALM OIL REFINING

Please mark them clearly if you have data in other units different from the ones proposed below. For allocation of water over other purposes (oil refining, soap making, others.) you can use a percentage.			Why we want to this? Water is one of the materials needed in the oil refining. With the allocation columns we want to further precisely allocate of water inputs to the oil refining.				Data source for total		
							Direct data (derived from administration system)	Indirect data ( Based on some sort of calculation)	Estimated data
Total	Total used per month	Unit	Alt. Unit	Used for oil refining	Used for soap making	Others			
Water		kg		%	%	%	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Phosphoric acid		kg		%	%	%	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Bleaching earth		kg		%	%	%	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Citric acid		kg		%	%	%	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Electricity		kwh		%	%	%	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Crude palm oil		kg		%	%	%	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Nitric acid		kg		%	%	%	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Fuel		kg		%	%	%	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
RBDPO		kg		%	%	%	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
SO <sub>2</sub>		%		%	%	%	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
NO <sub>2</sub>		%		%	%	%	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
CO		%		%	%	%	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
O <sub>2</sub>		%		%	%	%	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
CO <sub>2</sub>		kg		%	%	%	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Air flow rate		Kg/kg fuel		%	%	%	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

Table D 5. QUESTIONNAIRES FOR PALM OIL MARGARINE

Please mark them clearly if you have data in other units different from the ones proposed below. For allocation of water over other purposes (heating, etc.) you can use a percentage.			Why we want to this? Water is one of the materials needed in the margarine. With the allocation columns we want to further precisely allocate of water inputs to the margarine.				Data source for total		
							Direct data (derived from administration system)	Indirect data ( Based on some sort of calculation)	Estimated data
Total	Total used per month	Unit	Alt. Unit	Used for farming	Used for heating	Others			
Water		kg		%	%	%	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
RBDPO		kg		%	%	%	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Margarine		kg		%	%	%	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Milk powder		kg		%	%	%	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
LDPE		kg		%	%	%	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Polypropylene film		kg		%	%	%	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Corrugated cardboard		kg		%	%	%	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Salt		kg		%	%	%	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Electricity		kwh		%	%	%	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

## GLOSSARY

### **Abiotic depletion**

The use of resources faster than they are created. This lowers global supplies and may lead to scarcity.

### **Acidification**

Environmental problem produced by pollution. Acidification is defined as the amount of SO<sub>2</sub> (in kg) that would cause the same acidification as 1 kg of the substance emitted.

### **Allocation rule**

The basis on which an allocation is made, such as mass, commercial value and energy content.

### **Allocation**

Steps in LCA that determine how environmental intervention of a multiple process will be distributed over the various process functions.

### **Antioxidant**

A substance that slows down or interferes with the reaction of a fat or oil with oxygen. The addition of antioxidants to fats or foods retards rancidity and increases stability and shelf life.

### **Aquatic ecotoxicity**

Environmental problem caused by pollution. Aquatic ecotoxicity is defined as the volume of water (in m<sup>3</sup>) which would be polluted to a critical level by 1 kg of the substance concerned.

### **Bleaching**

Removal of colour and oxidizing bodies, residual gums, soap and trace metals by mixing oil with special adsorbents (silica and/or bleaching earth). The adsorbents containing the above mentioned impurities are then removed by filtration.

### **Characterisation**

Step in impact assessment in which the environmental intervention or stressors of a product system are aggregated into a limited number of environmental problems.

## **Chemical refining**

Refining based on neutralising, bleaching and deodorizing, where the bulk of the fatty acids are removed after being saponified by caustic in the neutralising step. Note that water degumming (before neutralizing) is required for lecithin production.

## **Classification**

Step of impact assessment in which the environmental interventions or stressors of a product system are quantitatively regrouped according to a number of environmental problems.

## **Collection of data**

Part of inventory analysis: finding out the economic and environmental numbers per individual process. The use of a proper questionnaire is recommended.

## **Degumming**

Generic expression for removal of phosphatides and other mucilaginous matter from the oil.

## **Deodorising**

Removal of fatty acids, odour, flavor and destabilizing impurities, as well as some colour bodies by subjecting the oil to high vacuum and temperature, augmented by direct steam agitation, under conditions so that the impurities are vaporized and removed while the oil remains liquid.

## **Ecolabelling**

Official award granted to a number of product alternatives in a product group conforming to the environmental criteria as set for that group, usually based on an LCA.

## **Emission**

Discharge of entities (such as chemicals, heat, noise and radiation) to the environment from the system under study.

### **Energy depletion**

A form of abiotic depletion, in which energy supplies are used up faster than they are created, thus reducing global supplies.

### **Equivalent factor**

Factor used in characterisation which expresses the contribution of a single stressor to specific environmental problem as a ratio to the contribution a standard stressor (for example, global warming potential of methane as a ratio to that of CO<sub>2</sub>).

### **Eutrophication potential**

Environmental caused by pollution. Eutrophication potential is defined as the amount of PO<sub>4</sub><sup>-3</sup> (in kg) that would cause nitrification equivalent to 1 kg of the substance emitted.

### **Fatty acid**

The fundamental unit within a triglyceride fat molecule composed of a chain of carbon and hydrogen atoms ending with a reactive group consisting of carbon, hydrogen, and oxygen.

### **Fire point**

The temperature, at which an oil sample, when heated under prescribed conditions, will ignite for a period of at least five seconds (spontaneous combustion).

### **Flash point**

The temperature, at which an oil sample, when heated under prescribed conditions, will flash when a flame is passed over the surface of the oil.

### **Flash point**

The temperature, at which an oil sample, when heated under prescribed conditions, will flash when a flame is passed over the surface of the oil but not maintain ignition.

### **Free fatty acid**

A fatty acid that is split from a triglyceride typically by hydrolysis. Fatty acids are impurities in refined oil that are removed in the neutralising and deodorising process.

### **Functional unit**

Specification of unit size of a product or system on the basis of which subsequent environmental scores are calculated.

### **Global warming**

Environmental problem caused by pollution. Global warming is defined as the amount of CO<sub>2</sub> (in kg) that would cause global warming equivalent to 1 kg of the substance emitted. It is mostly caused by the emission of CO<sub>2</sub>, as a result of the burning of fuels, and by emission of CH<sub>4</sub>.

### **Human toxicity**

This is defined as the human weight that would be exposed to the toxicologically acceptable limit by 1kg of the substance concerned.

### **Impact assessment**

Element of an LCA in which the contribution made by the environmental interventions to environmental problems is determined through model-based calculations, using equivalent factors.

### **Inventory analysis**

Element of an LCA in which an objective analysis is made of environmental interventions associated with a process or function.

### **Iodine value**

An expression of the degree of unsaturation of a fat. It is determined by measuring the amount of iodine which reacts with a natural or processed fat under prescribed conditions.

## **Normalisation**

Sub-step in characterisation in which the quantified contributions to impact categories are related to the total magnitude of these impacts as created in a year by all activities in the world (or possibly by those in a smaller area). The resulting figures are called the normalised effect scores.

## **Peer review**

Independent and external review of an LCA to establish the validity and reliability of the results and to enhance the quality and credibility of the LCA.

## **Peroxide**

The intermediate compounds formed during the oxidation of oil which may react further to form the compounds that cause rancidity.

## **Phosphatide**

The chemical combination of an alcohol (typically glycerol) with phosphoric acid and a nitrogen compound; synonymous with phospholipids, commonly referred to as gums.

## **Photochemical oxidant formation**

This is defined as the amount of ethylene (in kg) that would cause oxidant formation equivalent to that caused by 1 kg of the substance emitted.

## **Sensitivity analysis**

Analysis to determine the sensitivity of the outcome of a calculation to small changes in the assumptions or variations in the range within which the assumptions are assumed to be valid.

This changes the process data.

## **Smoke point**

The temperature, at which an oil sample, when heated under prescribed conditions, will form a thin continuous stream of smoke.

**System boundaries**

Part of the inventory analysis: the definition of borders between one system another.

**Terrestrial ecotoxicity**

This is the weight of soil (in kg) that would be polluted to a critical level by the emission of 1 kg of the substance concerned.

**Triglyceride**

The ester resulting from the chemical combination of glycerol and two fatty acids.

