USE OF MONTE CARLO ANALYSIS IN LIFE CYCLE ASSESSMENT:

CASE STUDY – FRUITS PROCESSING PLANT IN GHANA

BY

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DEDICATION

THIS WORK IS DEDICATED TO MY GRANDMOTHER, PROPHETESS MARY ADWOA POKUAAH AND MY MOTHER, MADAM ELIZABETH AMPONSAH. THE WORK IS ALSO DEDICATED TO MY WIFE, MARGARET AND MY CHILDREN: EBENEZER, SYLVIA, CORNELIA AND PAUL AS WELL AS MY NEPHEW, JOSEPH.

DECLARATION

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

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ABSTRACT

i. Introduction

Life-cycle studies range from highly detailed and quantitative assessments that characterize, and sometimes assess the environmental impacts of energy use, raw material use, wastes and emissions over all life stages, to assessments that qualitatively identify and prioritize the types of impacts that might occur over a life cycle.

ii. Objectives

The study is to improve the understanding of the environmental impact of fruit processing in a global context and to suggest improvements at the most important environmental hotspots. It is also to effectively reflect the environmental burdens arising from fruit processing industries, and to make precise alternatives often encountered in environmental decisions

iii. Methodology

The methodology is proposed to systematically analyze the uncertainties involved in the entire procedure of Life Cycle Assessment (LCA) for pineapple fruit processing at the fruit processing plant. The methodology also explores the degree of uncertainty of various impact categories. The Monte Carlo simulation is used to analyze the uncertainties associated with Life Cycle Inventory (LCI), Life Cycle Impact Assessment (LCIA), and the normalization and weighting processes. The uncertainty of the environmental performance for individual impact categories is also calculated and compared.

iv. Results and Discussion

The study investigated the impact of access to electricity from 100% diesel-electric generating set, 100% national grid, and hybrid (94% of national grid electricity and 6% of diesel-electric generating set) on the environment by fruit processing plant. Their respective impacts were compared using Monte Carlo simulations.

The impact on the environment in the use of only electricity from the national grid source or from diesel-electric generating set as well as a combination (hybrid) of the two, to establish optimum model that would minimize environmental burden were also investigated. The use of Poly-Ethylene Terephthalate (PET) containers in packing different weights of sliced pineapple and then packaging (different quantities of PET containers with sliced pineapple) in cardboard packaging boxes as part of the processes at the fruit processing plant and its consequential impact on the environment is also examined to ascertain environmental load of these processes.

Outcome of the Monte Carlo simulation runs in systematic comparison of the different models of electricity sources suggests that the use of 100% of diesel-electric generating set to provide electricity in production of sliced pineapple at the fruit processing plant has highest impact on human health and ecosystem quality damage categories. There is a significant difference in impact on human health by the use of diesel-electric generating set. Sourcing of electricity solely from the national grid has the highest impact on resources in the damage category. The use of electricity from hybrid source generates the least total environmental load.

v. Conclusion

The processing plant must source 85.6% of its electricity from national grid and, sliced pineapple must be packed at 300 g net weight in PET containers and then 5 of that packaged in a cardboard packaging box as the optimized conditions to minimize climate change at 1.08537E-07 DALY.

It would achieve minimum ozone layer impact value of 8.78226E-11 DALY at the optimized conditions of 295 g net weight of sliced pineapple in PET containers and then, 5 of that packaged in a cardboard packaging box. The electricity from the national grid source should be 87.3%. The minimum impact on ecotoxicity under optimal conditions was determined as 0.097831954 PDF*m2yr. The minimum ecotoxicity could be achieved under the optimal conditions of packaging sliced pineapple in 203 g net weight units and then pack 8 of such PET containers in a cardboard box, and 85.2% electricity is sourced from national gird.

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BUWAL	-	Bundesamt für Umwelt, Wald und Landschaft
CCD	-	Central Composite Design
CML	-	Centre of Environmental Science, University of Leiden, the Netherlands
DALY	-	Disability Adjusted Life Years
DQI	-	Data Quality Indicator
ELMIS	-	Environmental Life Cycle Information System
EPS	-	Environmental Priority Strategy (impact assessment method)
ERP	-	Enterprise Resource Planning System
GAP	-	Good Agricultural Practices
GRI	-	Global Reporting Initiative
IPCC	-	Intergovernmental Panel on Climate Change
IPP	-	Integrated Product Policy
ISO	-	International Organization for Standardizations
LCA	-	Life Cycle Assessment
LCI	-	Life Cycle Inventory
LCIA	-	Life Cycle Impact Assessment
MDO	-	Multi-disciplinary design optimization
NMVOC	-	Non-methane volatile organic compounds
PAF	-	Potentially Affected Fraction
PCA	-	Principal Component Analysis
PDF	-	Potentially Disappeared Fraction
PET	-	Poly-Ethylene Terephthalate

RSM - Response Surface Methodology

SQL - Structured Query Language (computer language for accessing and manipulating databases)

WHO - World Health Organization

CHAPTER 1

1.0. INTRODUCTION

This research work seeks to investigate and develop an approach to support the potential environmental decision making in the fruit processing industry. The overall aim of this thesis is to improve the understanding of the environmental impact of fruit processing in a global context and to suggest improvements at the most important environmental hotspots. The main objectives of the approach are that it should be able to effectively reflect the environmental burdens arising from fruit processing industries, and to make precise alternatives often encountered in environmental decisions. In addition, it needs to be able to structure large, contrasting data sets of varying quality and completeness into useful information able to provide the environmental objective in a decision-making process.

1.1 Background of the Study

Primary industries involved in vast consumption of resources, generally have a large spatial footprint, and generate significant volumes of solid waste and liquid effluent. According to Notten (2001), a comprehensive management strategy is essential to minimize the impacts of these industries on the environment. In particular, a consistent framework for technology selection is necessary, recognizing that the context in which the assessment takes place has important consequences on data availability and quality, and consequently the certainty with which technological systems can be evaluated

Industrial ecology is a new concept emerging in the evolution of environmental management paradigms (Ehrenfeld 1995), and springs from interests in integrating notions of sustainability into environmental and economic systems (Allenby, 1992; Jelinski et al., 1992; Allen and Behmanish, 1994; Ehrenfeld, 1995). Environmental thinking has recently focused on a consciousness of the intimate and critical relationships between human actions and the natural world, and reflects limits in the current reliance on command-and-control regulation in much of the industrialized world.

According to Ehrenfeld and Gertler (1997), the critical problem is that, for the most part, the economy operates as an open system, drawing raw materials from the environment and returning vast amounts of unused by-products in the form of pollution and waste. The accumulation of persistent toxic materials will not be addressed if attention is focused on products that companies are interested to sell whilst the processes are viewed in isolation. This could lead to larger systemic challenge to the environment.

The concept of conducting a detailed examination of the life cycle of a product or a process is a relatively recent one, which emerged in response to increased environmental awareness on the part of the general public, industry and governments. The immediate precursors of Life Cycle Analysis and Assessment (LCAs) were the global modeling studies and energy audits of the 1960s and early 1970s. These attempted to assess the resource cost and environmental implications of different patterns of human behaviour.

Life Cycle Assessment (LCA) has received increasing attention for its role in environmental decision-making processes, where it supports the process of defining the contribution of human activities to (at least the environmental dimension of) sustainable development (Notten, 2001; Cowell, 2001). LCA has been found to be very helpful tool to define eco-design measures for products (Muñoz *et.al.*, 2009). LCAs attempt to approximate comprehensive treatment of the environmental, health and resource burdens associated with product systems. In theory, this comprehensiveness entails inclusion of "all significant" burdens (e.g., pollution releases, resource consumption flows, or other impacts) of "all" causally-connected processes. Thus, the system boundary for a life cycle inventory model requires a series of choices along two dimensions: environment and supply chain.

According to a survey of organizations actively involved in life-cycle studies, the most important goal of life-cycle studies is to minimize the magnitude of pollution (Ryding, 1994). Other goals include conserving non-renewable resources, including energy; ensuring that every effort is being made to conserve ecological systems, especially in areas subject to a critical balance of supplies; developing alternatives to maximize the recycling and reuse of materials and waste; and applying the most appropriate pollution prevention or abatement techniques (Rooselot and Allen, 2001). Lifecycle studies have been applied in many ways in both the public and private sectors for uses such as developing, improving, and comparing products.

Moreover, Baumann and Tillman (2004) identified three (3) roles of LCA as decision-making, communication and learning, indicated in Table 1.1.

Table 1.1: Roles and applications of LCA in industry

Role of LCA	Application of LCA
Decision-making, communication, and learning	• Product development • Choices and optimization of production processes • Business policy formulation • Supply-chain management • Purchasing • Market communication • Environmental Product Declarations

Increased economic output will cause increased environmental harm in such a frame of analysis. Strong links between environment and development emerged from the global consensus following the 1992 Rio Earth Summit. For example, the recent report of the President's Council for Sustainable Development (PCSD) in the United States of America concludes, "In the end, we found agreement around the idea that to achieve our vision of sustainability some things must grow jobs, productivity, wages, profits, capital and savings, information, knowledge, education and others - pollution, waste, poverty, energy and material use per unit of output - must not" (PCSD, 1996).

Accomplishing economic growth and environmental protection simultaneously requires fundamentally new ways of examining and designing socioeconomic systems. One way to get beyond the analytic limits of standard economic theory is to draw on an ecological metaphor as

a means to better understand energy and material flows and as a guide to the design of industrial structures and public policies (Daly, 1991).

Robert Ayres (1989) called system-wide material flows the industrial metabolism of an economy (Ayres 1989; Ayres and Simonis, 1994). Emerging models for operationalizing industrial ecology suggest simple principles for design, for example, closing material loops, avoidance of upsets to the metabolism of the natural system (toxics elimination and pollution prevention), dematerialization, and thermodynamically efficient energy utilization (Ehrenfeld 1995; Lowe 1994; Tibbs 1992). These principles have the potential of moving society away from unsustainable development patterns by greatly reducing the flows of energy and materials into and out of an economy.

Moving from linear throughput to closed-loop material and energy use are key themes in industrial ecology**.** Industrial activity based on such an ecological conception can greatly reduce harmful impacts associated with pollution and waste disposal, while easing the drain on finite strategic resources. Familiar practices such as reuse, remanufacture, and recycling represent a move in this direction. Industrial symbiosis is closely related and involves the creation of linkages between firms to raise the efficiency, measured at the scale of the system as a whole, of material and energy flows through the entire cluster of processes. Some of the firms, viewed independently, may appear to be inefficient compared to conventional measures of environmental performance. Yet environmental performance can be superior in the overall group of firms because of the linkages. The cascading use of energy and the use of industrial by-products as feedstocks for processes other than the ones that created them are fundamental

to this approach. In such cases, byproducts can replace virgin materials as feedstocks. Energy cascading involves the use of the residual energy in liquids or steam emanating from one process to provide heating, cooling, or pressure for another process. The evolution of a set of interrelated symbiotic links among groups of firms in an area gives rise to a complex that we (and others) call an industrial ecosystem.

The use of LCA to support decision-making in fruit processing industries is investigated in this thesis. It is necessary to distinguish between life cycle thinking (as a concept), and LCA as a decision-making process or analytical tool (Notten 2001, Baumann and Tillman, 2004). Life cycle thinking proves the philosophical basis to the decision-making process in that it supports the process of defining the contribution of human activities to the environmental aspects of sustainable development (Cowell, 2001). This it does by identifying and assessing the environmental impacts associated with services delivered to societies, regardless of their geographical and temporal location (where identifying the relative magnitude of these impacts is a first step towards minimizing them). It is thus able to incorporate the issues of intra-generational equity (impacts occurring on different geographical scales) and inter-generational equity (impacts occurring on different time scales), integral to defining the contribution of human activities towards sustainable development (Cowell, 2001; Notten, 2001).

1.2. Statement of the Problem

Ghana produces a lot of fruits; and however loses most of it due to inadequate postharvest handling technology and low level of processing into more storable forms for the domestic and export markets. The Government of Ghana support for value addition to primary produce in

the last ten years has generated a lot of interest and consequently led to some appreciable level of investment in the fruit processing industry. Moreover, the influx of imported processed fruit products on the market has also thrown a lot of challenge to the local industry to stand up to the test. Blue Skies Products Ghana Limited where the study was conducted has been one of the companies that have been championing value addition of fruits for the domestic and export markets.

The gradual increase in processing of fruits is improving on the economic life of participants in the value chain as well as its impact on Ghanaian economy. However, concerns are also being raised on environmental impact of the fruit processing industry within the communities that they are located. There has been the need for the industry to invest in improving on the environment that their activities tend to have negative impact on. As indicated by Ehrenfeld and Gertler (1997), the products that companies market are only a small portion of what their processes turn out; a significant portion of their output eventually leave the economy as waste and returns to the environment in forms that may stress it unacceptably. This consequently calls for managing the balance between optimizing profit and minimizing environmental impact.

1.3. Objectives of the Study

The goal of this research is to demonstrate the use of Monte Carlo simulation within a LCA framework. The aims of this thesis could therefore be summarized in three points:

i. To discuss and propose some guidelines for scientists carrying out environmental assessment studies on fruit processing plants using emerging technologies and Monte Carlo analysis;

ii. To summarize some general recommendations on how to improve the environmental performance of fruit processing plants.

iii. Promote the development of LCA research and application in Ghana

1.4. Methodology

LCA is the tool used in this thesis in accessing environmental load of the fruit processing company. LCA is an ISO standardized methodology (ISO 14040, 1997); and is the only tool that examines the environmental impacts of a product or service throughout its life cycle. It provides a comprehensive overview of a product or service and avoids simply shifting the source of the pollution from one life cycle stage to another. Furthermore, LCA can, for example, guide a company's decision-making process (micro-economic level) and help governments define a public policy (macro-economic level). It challenges preconceived notions by distinguishing between the information that is relevant for objective quantification and the issues that pertain to policies, priorities, and social choices. However, according to Guinée (2001) and Dreyer *et al* (2006) LCA methodologies address only environmental aspects and impacts, therefore recommendations based on LCA's fail to address possible trade-offs between environmental protection and both social and economic concerns in the product life cycle. This raises questions about LCA's ability to support actual decision-making in companies, which aim for sustainability, and it creates an incentive for developing LCA methodology to include these other dimensions of sustainability (Dryer *et al*, 2006).

The study uses the Monte Carlo simulation method in the application of LCA in decision making process. This is because the Monte Carlo simulation method provides framework for multi criteria decision analysis. Thus management of anticipated environmental load from fruit processing activities of the company would need some level of decision to be made as per the type of raw materials as well as infrastructure and equipment options to be considered to increase productivity and improve on performance whilst reducing environmental load.

The Monte Carlo simulation method is the best known and simplest method for sampling from uncertain input domain (Notten, 2001, Int Panis *et al.* 2001; Int Panis *et al.* 2002; Sawilowsky, 2003). Monte Carlo simulation involves trying to simulate the conditions, which apply to a specific problem, by generating a large number of random samples using a random number generator from a computer. Thus the method allows several inputs to be used at the same time to create the probability distribution of one or more outputs.

SimaPro software (PhD Version) was used in analyzing the results of the study. It uses advanced process coupled sampling techniques when comparing the uncertainty in two LCA models. This means that if a certain process exists in both models, the same variation for this process is used in a single Monte Carlo sample for both models.

1.5. The Scope and Limitations of the Study

The scope of the study is to select applications of Monte Carlo analysis, which for different reasons are important for modeling the impact of fruit processing industry on the environment,

and perform different types of environmental assessment of the technology in the model. Even though it could be very useful for determining different risks and factors that affect forecasted variables and can also lead to more accurate predictions, it cannot wipe out uncertainty and risk, but it can make them easier to understand by ascribing probabilistic characteristics to the inputs and outputs of a model.

Moreover, LCA which was used in the study only assesses potential impacts and not real impacts. Hence, it does not provide any information on the consequences of not following regulations or on environmental risks. Thus, only known and quantifiable environmental impacts are considered.

CHAPTER 2

LITERATURE SURVEY/REVIEW

In this chapter some relevant literature on life cycle assessment and Monte Carlo analysis as well as optimization process have been discussed. This is to give insight into application of these tools and approaches as have been described and used by previous workers and researchers in the respective areas of discipline. A background to the pineapple industry and some of the key players in the processing function along the pineapple value chain have also been discussed.

2.1. Life Cycle Assessment

Life-cycle studies range from highly detailed and quantitative assessments that characterize, and sometimes assess the environmental impacts of energy use, raw material use, wastes and emissions over all life stages, to assessments that qualitatively identify and prioritize the types of impacts that might occur over a life cycle.

According to Baumann and Tillman (2004), life cycle concepts could be explained as indicated in Table 2.1.

Table 2.1: Life Cycle Concepts

Life Cycle Analysis (LCA):	A tool (or model) for calculating the environmental impact of a product (including services) from cradle to grave. LCA can also be seen as a procedure for carrying out such studies.
Life Cycle Thinking (LCT):	When individuals reflect upon the environmental impact of a product or activity in life cycle perspective. This 'way of thinking' does not have to go into as much details as an LCA study.
Life Cycle Management (LCM):	Managerial practices and organizational arrangements that are expressions of life cycle thinking.

Life cycle thinking proves the philosophical basis to the decision-making process in that it supports the process of defining the contribution of human activities to the environmental aspects of sustainable development (Cowell, 2001). Notten (2001) explained that, this it does by identifying and assessing the environmental impacts associated with services delivered to societies, regardless of their geographical and temporal location (where identifying the relative magnitude of these impact is a first step towards minimizing them). It is thus able to incorporate the issues of intra-generational equity (impacts occurring on different geographical scales) and inter-generational equity (impacts occurring on different time scales), integral to defining the contribution of human activities towards sustainable development (Cowell, 2001).

Products, services, and processes all have a life cycle. For products, the life cycle begins when raw materials are extracted or harvested. Raw materials then go through a number of manufacturing steps until the product is delivered to a customer. The product is used, then disposed of or recycled. Energy is consumed and wastes and emissions are generated in all of these lifecycle stages.

Processes also have a life cycle. The life cycle begins with planning, research and development. The products and processes are then designed and constructed and/or manufactured. A process will have an active lifetime, and then will be decommissioned and, if necessary, remediation and restoration may occur (Rooselot and Allen 2001).

Traditionally, product designers have been concerned primarily with product life cycles up to and including the manufacturing step. Chemical process designers have been primarily concerned with process life cycles up to and including the manufacturing step. That focus is changing; Rooselot and Allen (2001) emphasized that, chemical product designers must consider how their products will be recycled. They must consider how their customers will use their products and what environmental hazards might arise. Process designers must avoid contamination of the sites at which their processes are located. Simply stated, engineers must become stewards for their products and processes throughout their life cycles. These increased responsibilities for products and processes throughout their life cycles have been recognized by a number of professional organizations.

LCA has therefore been formally defined by The Society of Environmental Toxicology and Chemistry (SETAC) as "a process to evaluate the environmental burdens associated with a product, process or activity by identifying and quantifying energy and materials used and wastes released to the environment; to assess the impact of those energy and material uses and releases to the environment; and to identify and evaluate opportunities to effect environmental improvements. The assessment includes the entire life cycle of a product, process or activity, encompassing extracting and processing raw materials; manufacturing, transportation and distribution; use, re-use, maintenance; recycling, and disposal" (Consoli et al., 1993; Notten, 2001). This definition is consistent with that put forward in the International Organization for Standardizations (ISO) environmental management standard on LCA (ISO, 1997). The ISO 14040 standard defines an LCA as a compilation and evaluation of the inputs and outputs and the potential environmental impacts of a product system through its life cycle. In this definition, it is clear that impact assessment is an integral part of LCA.

Although the principles of LCA have been in use for around forty (40) years, it has only been since the early 1990s that it gained attention as a promising environmental management tool. The Society of Environmental Toxicology and Chemistry (SETAC) took the lead in trying to consolidate and standardize the emerging tool, which culminated in the formulation of a Code of Practice for LCA (Fava et al., 1991; Consoli et al., 1993; Notten, 2001).

LCA attempts to approximate the comprehensive treatment of the environmental, health and resource burdens associated with product systems. In theory, this comprehensiveness entails inclusion of "all significant" burdens (e.g., pollution releases, resource consumption flows, or

other impacts) from "all" causally-connected processes. Thus, the system boundary for a life cycle inventory model requires a series of choices along two dimensions: environment and supply chain. Which activities and operations along the supply chain should be included? How wide and how broad should the system boundaries be drawn? (e.g., should capital equipment be included? transport of workers and raw materials to the production sites? service sector inputs such as from researchers, designers, lawyers, accountants, advertising, etc.?)

Thus a Life-Cycle Assessment (LCA) is the most complete and detailed form of a life-cycle study. Rooselot and Allen (2001) explained that a life cycle assessment consists of four major steps: Scope and Boundary, Life Cycle Inventory, Life-Cycle Impact Assessment, Interpretation.

2.1.1 Scope and Boundary of Life Cycle Assessment

The first step in an LCA is to determine the scope and boundaries of the assessment. In this step, the reasons for conducting the LCA are identified; the product, process, or service to be studied is defined; a functional unit for that product is chosen; and choices regarding system boundaries, including temporal and spatial boundaries, are made (Rooselot and Allen 2001). The system boundaries are simply the limits placed on data collection for the study. The choice of system boundaries can influence the outcome of a life cycle assessment. A narrowly defined system requires less data collection and analysis, but may ignore critical features of a system. On the other hand, in a practical sense it is impossible to quantify all impacts for a process or product system. According to Rooselot and Allen (2001), what is included in the system and what is left out is generally based on engineering judgment and a desire to capture any parts of

the system that may account for 1% or more of the energy use, raw material use, wastes or emissions.

Thus boundaries of a system can be limited to certain life cycle stages or to certain impact categories or limited to the main contributors, identified according to expert opinion and experience. The analysis can also be performed in a strictly qualitative fashion or using secondary data only (generic data from the literature or from databases). Such simplifications can affect the accuracy and applicability of life cycle assessment results, but can nevertheless allow for the identification of potential impacts and, to a certain extent, their assessment.

Another critical part of defining the scope of a life cycle assessment is to specify the functional unit. The choice of functional unit is especially important when life-cycle assessments are conducted to compare products. This is because functional units are necessary for determining equivalence between the choices. The choice of functional unit is not always straightforward and can have a profound impact on the results of a study.

2.1.2 Life Cycle Inventory

The second step in a life-cycle assessment is to inventory the outputs that occur, such as products, byproducts, wastes and emissions, and the inputs, such as raw materials and energy that are used during the life-cycle. Thus a life-cycle inventory is a set of data as well as material and energy flow calculations that quantifies the inputs and outputs of a product life-cycle. Some of the values that are sought during the inventory process are objective quantities derived using tools such as material and energy balances. This step, shown conceptually in

Figure 2.1, is called a life-cycle inventory**,** and is often the most time consuming and data intensive portion of a life cycle assessment.

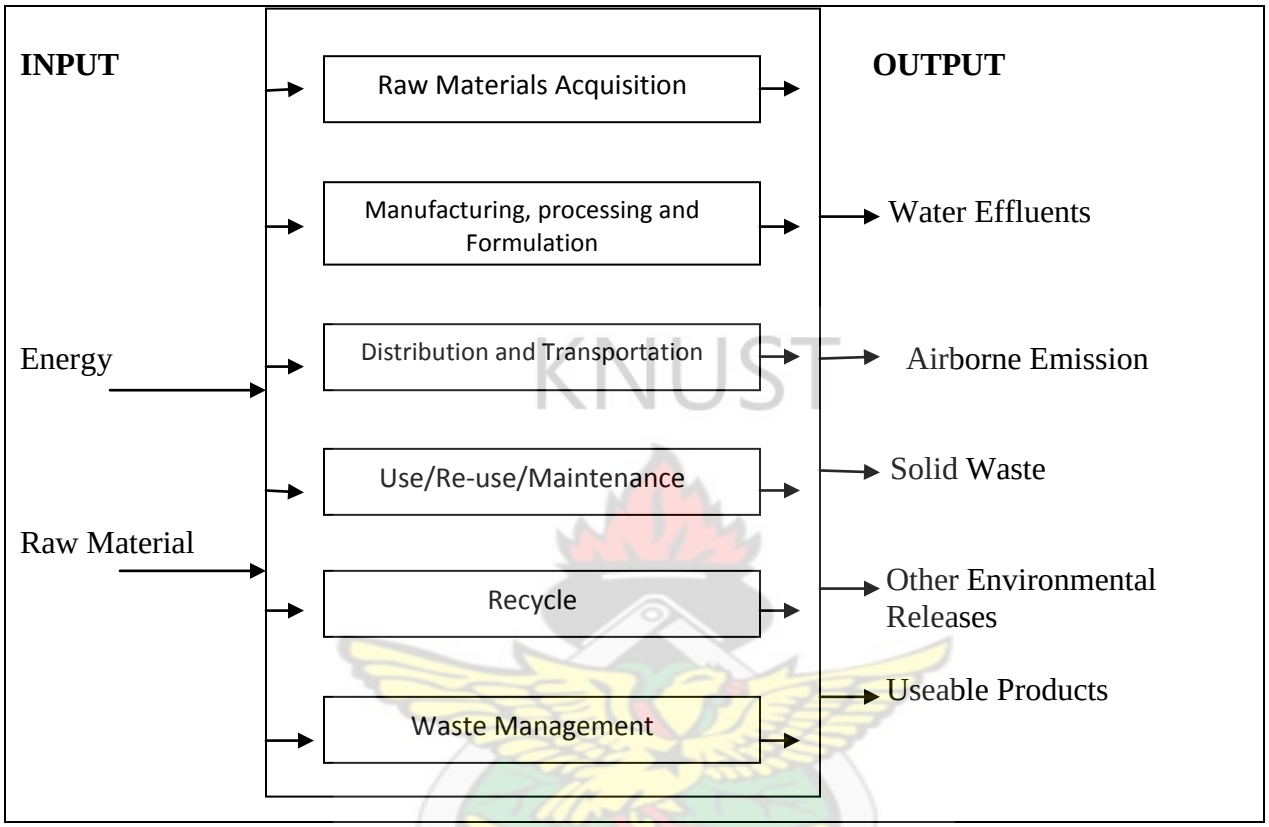


Figure 2.1: Life cycle inventory account for input and output

Figure 2.1 shows life cycle inventories account for material use, energy use, wastes, emissions and co-products over all of the stages of a product's life cycle (Rooselot and Allen 2001).

The first stage in a product life cycle, as shown in Figure 2.1 is raw material acquisition. Example of raw material acquisition is pineapple harvesting and transporting to the fruit processing plant. After raw material acquisition is the material manufacture stage, where raw materials are processed into the basic materials of product manufacture. These materials move

to the product manufacture stage where they are used to make the final product. The next stage of the life-cycle stage is use. Some products, such as automobiles, generate significant emissions and wastes during use, while other products, such as grocery sacks have negligible material and energy flows associated with the use of the product. The final life-cycle stage consists of disposal or recycling.

Recycling can occur in several ways. A product might be reused, which is what happens when a ceramic cup is washed and reused instead of being thrown away. The product could be remanufactured, where the materials it contains are used to make another product. A newspaper, for example, might be made into another newspaper or might be shredded and used for animal bedding (Rooselot and Allen 2001). Finally, products might be recycled to more basic materials, through processes such as plastics depolymerization or automobile disassembly which yield commodity materials such as monomers and steel.

Tracking material flows, over all of the stages of a life cycle, is required for a comprehensive lifecycle inventory. Even for a simple product made from a single raw material in one or two manufacturing steps, the data collection effort can be substantial.

The energy input requirements are the hydrocarbon fuels and electric power sources used in processing the raw materials and for running manufacturing process. The data on the main raw materials for processing and production are essential part of the LCI. Depending on the type of product industry, the raw material could either be reported in energy units or mass (a common

practice among life-cycle study practitioners) so that it can be combined with the energy or otherwise that are required in the production process (Rooselot and Allen, 2001).

The input and output data are often aggregated over the life cycle and reported as aggregate quantities. Thus, water use would include water used in the production process as well as steam used in other units of operation. Some of the entries may seem obscure, but only serve to point out the complex nature of product life cycles. For example, limestone used in ethylene production is due in part to acid gas scrubbing in various parts of the product life cycle.

A final set of inventory elements are the wastes and emissions. Some subjectivity is introduced in deciding which materials to report. For example, some life cycle inventories do not report the release of carbon dioxide, a global warming gas or the use of water. Neglecting these inventory elements implies that they are not important. More subtle subjectivity can arise in defining exactly what is and what is not a waste.

While most Life Cycle Inventory (LCI) data are specific to a particular study and its goal, there are data that are common in all LCIs, namely electricity, transportation and waste management (Rooselot and Allen, 2001; Curran *et al*, 2001). Curran *et al*, (2001) further stressed that electricity use, especially, features very prominently in the total LCA results for a majority of product life cycles. Therefore, the benefits of public LCI data on electricity generation would be high for those who undertake LCAs and for those who draw conclusions based on LCAs.

Electricity is therefore a major consideration in any LCA. It is important to accurately calculate and model resource use and pollutant releases for activities related to the generation and distribution of electricity, such as how and where electricity is produced, with what input requirements, and with what pollution and waste consequences (Curran *et.al*, 2001). As LCAs are being conducted more frequently as part of overall environmental management approaches within both the public and private sectors, it is becoming increasingly important that LCI data become more readily available. Also it is vital that data be used consistently between LCAs in order to lead to more fairly comparable results and reliable conclusions.

2.1.2.1 Attributional LCA

Current LCA modeling represents an allocation of the total environmental burdens of a macro system and the life cycles of individual products and services. All such LCAs are structured so that, theoretically, the results could be combined to form a total response. According to Curran *et* al., (2001) and Heijungs (1997), the goal is to answer the question: "If we were to assign the total environmental burdens caused by global demand for goods and services across all components of that demand, how much burden would we assign to each unit of good or service?" and this is referred to as "the attribution problem."

In attributional LCA, a co-product is defined as one that contributes to the income of the producer. According to Curran *et al*, 2001, when co-products are present, LCA practitioners must determine how much of the burdens associated with operating and supplying the multi-output process should be allocated to each co-product. There is the need to decide how to allocate environmental burdens across co-products when one is a waste stream that can be sold

for other uses. Rooselot and Allen (2001) indicated that, in most life cycle inventories, allocation of material use, energy use, and emissions among co-products is based on mass. Sometimes, however, the co-product is a byproduct that would not be produced solely for its own merit, and allocation based on value might be more appropriate.

Issues of co-product allocation can be complex, even when single inputs exist. The situation can become more complex when the number of inputs and emissions increases.

The ISO standards for LCA, particularly ISO 14041 on inventory analysis, provide methodological guidance on this issue. But they call for LCA practitioners to attempt to avoid allocation if possible; and secondly, to attempt modeling approaches which reflect the physical relationships between the process outputs and its inputs. Thus proper application of the ISO guidelines on allocation requires a physical understanding of the co-product production processes. There is the need to follow the guidance outlined in ISO 14041 for any systems under investigation. The following highlights some key issues related to allocation per ISO 14041.

ISO 14041 requires the following procedure be used for allocation in multifunction processes:

- Allocation should be avoided, wherever possible, either through division of the multifunction process into sub-processes, and collection of separate data for each sub-process, or through expansion of the systems investigated until the same functions is delivered by all systems compared.

- Where allocation cannot be avoided, the allocation should reflect the physical relationships between the environmental burdens and the functions, i.e., how the burdens are changed by quantitative changes in the functions delivered by the system.
- Where such physical causal relationships alone cannot be used as the basis for allocation, the allocation should reflect other relationships between the environmental burdens and the functions.

For allocation in open-loop recycling, ISO 14041 recommends the same procedure but allows a few additional options. If the recycling does not cause a change in the inherent properties of the material, the allocation may be avoided through calculating the environmental burdens as if the material was recycled back into the same product. Otherwise, the allocation can be based on physical properties, economic value, or the number of subsequent uses of the recycled material. The international standard does not include information on the effect of the different methods on the life cycle modeling, for example the feasibility of the methods, the amount of work required, or what type of information that results from the application of the methods. The choice of allocation method depends considerably upon whether the LCA is being performed from an attributional or a consequential point of view (Ekvall and Tillman, 1997; Curran *et al*, 2001; Weidema, 2001).

2.1.2.2. Average and Marginal Systems

An evolution is taking place within the field of life cycle assessment, away from models of "average" systems which support retrospective analyses, towards models of "marginal" systems which support prospective analyses. In contrast to attributional LCAs, prospective

LCAs explicitly attempt to characterize what the impacts will be of potential decisions. Thus, they are designed to provide insight about "what will happen if we decide A or B," rather than "which product is to blame for which burdens."

The processes whose levels of output will be impacted by a decision or a change in demand are referred to as the "marginal" processes – those producing "at the margin".

The marginal modeling underlying prospective LCA may appear more complex or data-intensive than the average modeling underlying attributional LCA. In practice, this is not necessarily the case, and in fact prospective LCA helps take some of the arbitrariness out of thorny LCI modeling issues such as allocation (Weidema, 2001). Advantage of the average (attributional) approach is that much statistical information is provided in a form suitable for this approach. Also, it may be easier to communicate to lay-people without an economic or system-analytical background.

Advantages of the marginal (prospective) approach is that it provides results that are meaningful in a decision-making context, it can reduce data collection efforts substantially (since only data for the marginal production is needed, not data for the entire system), and it avoids arbitrariness in setting of system boundaries, notably in relation to geographical and technological boundaries as well as in relation to co-product allocation. The average (attributional) approach may be warranted when seeking to allocate blame for past activities. The marginal (prospective) approach is warranted when analyzing the consequences of a decision, i.e. as a decision-support. The marginal approach can also be applied to allocate

blame for past activities, by using historical data valid at the time of the decision that led to the situation that you wish to allocate blame for. The applicability of using average or marginal modeling for electricity data is dependent on the purpose and scope of the LCA.

LCA results would inform decision makers about the consequences of decision options that they are evaluating. However, there remained a significant level of concern about switching from attributional to consequential LCI modeling. In most cases, the use of LCA for decision support appears to call for adopting the prospective approach as far as possible (Curran *et al.*, 2001; Weidema, 2001).

2.1.3 Life Cycle Impact Assessment

The ISO 14040 standard defines an LCA as a compilation and evaluation of the inputs and outputs and the potential environmental impacts of a product system through its life cycle. In this definition, it is clear that impact assessment is an integral part of LCA. Life cycle impact assessment is defined as the phase in the LCA aimed at understanding and evaluating the magnitude and significance of the potential environmental impacts of a product system.

The output from a life cycle inventory is an extensive compilation of specific materials used and emitted. Converting these inventory elements into an assessment of environmental performance requires that the emissions and material use be transformed into estimates of environmental impacts. Thus, the third step in a life cycle assessment is to assess the environmental impacts of the inputs and outputs compiled in the inventory.

Life-cycle inventories do not by themselves characterize the environmental performance of a product, process, or service. This is because overall quantities of wastes and emissions, and raw material and energy requirements must be considered in conjunction with their potency of effect on the environment. According to Rooselot and Allen (2001), a pound of lead emitted to the atmosphere has a different environmental impact from a pound of iron emitted to surface waters. To develop an overall characterization of the environmental performance of a product or process, throughout its life cycle, requires that life cycle inventory data be converted into estimates of environmental impact.

Fava *et al*., (1996) explained that the process of producing life cycle impact assessments is generally divided into three major steps. They are Classification, Characterization and Valuation.

2.1.3.1 Classification

Classification is where inputs and outputs determined during the inventory process are classified into environmental impact categories; for example, methane, carbon dioxide and CFCs would be classified as global warming gases. Thus, inputs and outputs that are the subject of the inventory are usually classified into environmental impact categories such as

- Global warming
- Stratospheric ozone depletion
- Photochemical smog formation
- Human carcinogenicity
- Atmospheric acidification

- Aquatic toxicity
- Terrestrial toxicity
- Habitat destruction
- Depletion of nonrenewable resources
- Eutrophication

The inventory result of an LCA usually contains hundreds of different emissions and resource extraction parameters. Once the relevant impact categories are determined, these LCI results must be assigned to these impact categories. For example CO_2 and CH_4 are both assigned to the impact category "Global warming", while SO_2 and NH_3 are both assigned to an impact category acidification. It is possible to assign emissions to more than one impact category at the same time; for example SO_2, may also be assigned to an impact category like Human health, or Respiratory diseases (Pré Consultants, 2008a).

In the Eco-indicator method, the damage caused by agricultural practices is determined by empirical data from botanists, who have studied the bio diversity of the land. It is impossible to say if a decrease in biodiversity is caused by the use of pesticides, fertilization or otherwise. If the impact category Land use is combined with the impact category Ecotoxicity and Eutrophication a double count can be introduced, that should preferably be avoided (Pre Consultants, 2008a).

Eco-Indicator 99 is a life cycle impact assessment tool developed by PRé Consultants B.V. Eco-Indicator 99 helps designers to make an environmental assessment of a product by calculating

eco-indicator scores for materials and processes used. The resulting scores provide an indication of areas for product improvements. The Eco-Indicator is split into three sections:

- production of raw materials (e.g. polystyrene), processing & manufacture (e.g. injection moulding)
- transportation of product (e.g. shipping), energy in use (e.g. electricity), consumables in use (e.g. paper)
- disposal

According to Pré Consultants (2008b) the default Eco-indicator 99 method is the Hierarchist version with average weighting set (average of the full panel). In the Eco-indicator 99 method normalisation and weighting are performed at damage category level (endpoint level in ISO terminology). There are three damage categories:

HH Human Health (unit: DALY= Disability adjusted life years; this means different disability caused by diseases are weighted) EQ Ecosystem Quality (unit: PDF*m2yr; PDF= Potentially Disappeared Fraction of plant species) R Resources (unit: MJ surplus energy Additional energy requirement to compensate lower future ore grade)

Eco-indicator 99 has a damage assessment step. This means that the impact category indicator results that are calculated in the Characterization step are added to form damage categories. Addition without weighting is justified here because all impact categories that refer to the same damage type (like human health) have the same unit (for instance DALY). This procedure can also be interpreted as grouping.

The damage categories (and not the impact categories) are normalized on an European level (damage caused by 1 European per year), mostly based on 1993 as base year, with some updates for the most important emissions. The normalisation set is however dependent on the perspective chosen. The normalized damage categories can also be used with the triangle tool. This is very useful if two products are to be compared without weighting, in case the damage indicators for Product A and B are conflicting (A is higher on Human health and B is higher on Ecosystem Quality). In such a case the answer is dependent on the weighting factors for Ecosystem quality, Resources and Human health (Pré Consultants (2008b).

The triangle is a way to show all possible combinations of weighting factors (represented as a percentage in such a way that they add up to 100%). If damage categories have conflicting values, the triangle will display two areas. One area represents all weighting sets for which product A has a lower environmental load, the other area will represent all weighting sets for which B has a lower load than A. The line in between is the line of indifference. These are the weighting sets for which the environmental load of A and B are the same. The benefit of using the triangle is that one does not always need to know which exact weighting set would want to use

2.1.3.2 Characterization

Characterization is where the potency of effect of the inputs and outputs on their environmental impact categories is determined; for example, the relative greenhouse warming potentials of methane, carbon dioxide and CFCs would be identified in this step. Characterization generally consists of assigning relative weights or potencies to different types of emissions, energy use

and material use. These potencies reflect the degree to which the inventory elements contribute to environmental impacts. For example, if the impact category is global warming, then relative global warming potentials can be used to weight the relative impact of emissions of different global warming gases (Rooselot and Allen, 2001). Other weighting factors could be presented for smog formation potential, atmospheric acidification potential, and other categories. Once these *potency factors* are established, the inventory values for inputs and outputs are combined with the potency factors to arrive at *impact scores*.

2.1.3.2.1 End Point and Mid Point

The ISO standard allows the use of impact category indicators that are somewhere between the inventory result (i.e. emission) and the "endpoint" (Pre Consultants, 2008a). The endpoints are human health, ecosystem quality and resource depletion. Indicators that are chosen between the inventory results and the "endpoints" are sometimes referred to as indicators at "midpoint level".

In general, indicators that are chosen close to the inventory result have a lower uncertainty, as only a small part of the environmental mechanism needs to be modeled, while indicators near endpoint level can have significant uncertainties (Pre Consultant, 2008a). However, indicators at endpoint level are much easier to understand and interpret by decision makers than indicators at midpoint.

The CML 92 methodology is a typical example of a midpoint method. The impact category indicators are chosen relatively close to the inventory result. For example, the impact categories for global warming and ozone layer depletion are based on the IPCC equivalency factors (Pre

Consultant, 2008a). The impact category on acidification is based on the number of protons H+ that could be released per kg of emitted substance. Such impact category indicators have usually rather abstract units. For example, the unit of global warming is kg CO_2 equivalence, and the unit for acidification is kg SO_2 equivalence.

In methods like the Eco-indicator 99, the indicator for climate change is expressed in Disability Adjusted Life Years (DALY). This is a unit used by the WHO and World Bank to evaluate health statistics. The impact category indicator for Acidification is expressed in the percentage of decreased biodiversity over an area during a certain period. These indicators are of course much more difficult to calculate, as the complete environmental model has to be taken into account, and in that model many assumptions have to be made (Pré Consultant, 2008a). They are thus more uncertain. On the other hand, their meaning is easier to understand and evaluate.

There is a typical trade-off between uncertainty in the model of the environmental mechanism and the uncertainty in the interpretation. It depends on the goal and scope and the ability of the targeted audiences to understand aggregated or disaggregated results, which choice is made.

2.1.3.2.2 Normalization

Normalization is a procedure needed to show to what extent an impact category has a significant contribution to the overall environmental problem. This is done by dividing the impact category indicators by a "Normal" value. There are different ways to determine the "Normal" value. The most common procedure is to determine the impact category indicators for a region during a year

and, if desired, divide this result by the number of inhabitants in that area (Pré Consultants, 2008a).

Normalization serves two purposes:

i. Impact categories that contribute only a very small amount compared to other impact categories can be left out of consideration, thus reducing the number of issues that need to be evaluated.

ii. The normalized results show the order of magnitude of the environmental problems generated by the products life cycle, compared to the total environmental loads in Europe.

2.1.3.2.3 Grouping and Ranking

In order to avoid weighting, while making results easier to interpret, impact category indicators may be grouped and ranked:

- Impact category indicators that have some common features may be presented as a group. For example, one can form a group of impact category indicators with Global, regional and local significance.
- Ranking refers to a procedure, where impact categories are sorted by a panel in a descending order of significance.
- Both procedures can be used to present the results.

2.1.3.2.4 Damage Assessment

The category indicators are defined close to one of the three endpoints to achieve an optimum environmental relevance. The impact category indicators that refer to the same endpoint are all defined in such a way that the unit of the indicator result is the same. This allows addition of the indicator results per group. This means that the indicator results can be presented as three indicators at endpoint level (human health, ecosystem quality and resources depletion) without any subjective weighting. Interpreting three instead of a multiple set of indicators is much easier.

The predicted diseases can now be expressed into damage unit, in this case the DALY (disability adjusted life years). According to Pre Consultants (2008a), this system is widely used in health statistics, and was originally developed for the World Health Organisation (WHO). The core is a list of weighting factors for each type of disability; the factors have been determined by several panels with doctors.

2.1.3.2.5 Weighting

Weighting is the most controversial and most difficult step in life cycle impact assessment, especially for midpoint methods (Pré Consultants, 2008b). Several solutions have been proposed to solve or simplify the weighting problem:

1. Use a panel that assesses the impact category and proposes default weights. There are several problems in this approach:

- It is very difficult to explain to a panel the meaning of the impact category indicators. They are too abstract ("CO2 equivalency" or "proton release").

- In a Midpoint approach, the number of indicators to be assessed is usually rather large (10 to 15).
- Panels tend to give a very small range of weights (usually between 1 and 3). This is called *framing* in social sciences. This is a problem in both endpoint and midpoint methods.

2. Distance to target. If it is possible to set a target for each impact category and its target can be used to derive at a weighting factor. If the difference is high, the weight is high. The Ecopoint method uses targets set by the Swiss government, the

Eco-indicator 95 method uses targets that reflect to necessary reduction to lower the damage to a certain level that is the same for all impact categories (this can also be interpreted as a damage approach). Also this approach has some difficulties:

- In the case policy targets are used, it is not clear if all targets are equally important.
- Policy targets are usually formed as a compromise between interest groups, and need not to reflect the "real" need to reduce environmental impacts.
- In case scientific targets are used, different types of damages need to be weighted.

2.1.3.3 Valuation

Valuation is where the relative importance of each environmental impact category is assessed, so that a single index indicating environmental performance can be calculated. Thus valuation consists of weighting the results of the characterization step so that the environmental impact categories of highest importance receive more attention than the impact categories of least concern. According to Rooselot and Allen, (2001), there is no generally accepted method for aggregating values obtained from the evaluations of different impact categories to obtain a

single environmental impact score. They further explained that some methods assign valuations of high, medium, or low to the impact categories based on the extent and irreversibility of effect, so that stratospheric ozone depletion might receive a high rating and water usage might receive a low rating.

Valuation schemes based on the A "footprint" of the inputs and outputs have been suggested (Rooselot and Allen, 2001). In these schemes, characterization would be conducted so that the air, water, land, and other resources required to absorb the inputs and outputs are quantified. These quantities could then be normalized according to the amount of each resource available, on either a local or global basis, and added within resource category. The resource with the highest combined normalized value is the one that is being most adversely impacted. In fact, it would be possible to arrive at a single value that represented the total fraction of the earth's resources required to buffer the inputs and outputs over the life cycle being studied (Rooselot and Allen, 2001).

Table 2.2: Strategies for valuing life cycle impacts (Christiansen, 1997)

Life cycle impact assessment approach	**Description**
Critical volumes	Emissions are weighted based on legal limits and are aggregated within each environmental medium (air, water, soil)
Environmental Priority System (Steen and Ryding, 1992)	Characterization and valuation steps combined using a single weighting factor for each inventory element. Valuation based on willingness-to-pay surveys
Ecological scarcities	Characterization and valuation steps combined using a single weighting factor for each inventory element. Valuation based on flows of emissions and resources relative to the ability of the environment to assimilate the flows or the extent of resources available
Distance to target method	Valuation based on target values for emission flows set in the Dutch national environmental plan

The classification and characterization steps are generally based on scientific data or models. The data may be incomplete or uncertain, but the process of classification and characterization is generally objective. In contrast, the valuation step is inherently subjective, and depends on the value society places on various environmental impact categories (Fava et al., 1996).

2.1.4 Interpretation

Probably the most readable and practical standard is the last of the four LCA standards on interpretation. In essence it describes a number of checks that need to be made in order to see if the conclusions to be drawn from the study are adequately supported by the data and by the procedures used.

The fourth step in a life cycle assessment which is also referred to as improvement analysis is to interpret the results of the impact assessment, suggesting improvements whenever possible. When life-cycle assessments are conducted to compare products, for example, this step might consist of recommending the most environmentally desirable product. Alternatively, if a single product were analyzed, specific design modifications that could improve environmental performance might be suggested.

While the process of a life-cycle assessment might seem simple enough in principle, in practice it is subject to a number of practical limitations (Rooselot and Allen, 2001). The authors further explained that, in performing the inventory, system boundaries must be chosen so that completion of the inventory is possible, given the resources that are available. Even if sufficient resources are available, the time required to perform a comprehensive life cycle inventory may be limiting. Then, even if the necessary time and resources are available, life-cycle data are subject to uncertainty.

The limitations of life-cycle inventories are then carried forward into the impact assessment stage of life-cycle studies, and the impact assessment methodologies add their own

uncertainties. For example, potency factors are not available for all compounds in all impact categories. There are also issues of temporal and spatial aggregation. Moreover valuation adds an element of subjectivity into the analyses.

This is not to say that life-cycle assessments are without value. Rather, despite the uncertainties involved, these assessments provide invaluable information for decision-making and product stewardship. They allow environmental issues to be evaluated strategically, throughout the entire product life cycle. The challenge is to take advantage of these valuable features of life cycle assessments while bearing in mind the difficulties and uncertainties.

2.1.5 Limitations of Life Cycle Assessment

According to Guinée et al (2001), the robustness of the end results of an LCA is subject to a large number of viability and reliability of issues and the value of the result of the results is not a single point but some kind of probability distribution.

Thus LCA has however certain limitations as has been overviewed below based on ISO (1996), Frankl & Rubik (2000), Wrisberg et al. (2002), Fawer (2001), supplemented:

- The degree of detail and time frame of an LCA may vary to a large extent, depending on the definition of goal and scope. The possibility to select different allocations, system boundaries and recycling concepts leads to data inconsistencies, as well as double counting and omittments. Therefore, (further) standardization of LCA after ISO is required

- Only known and quantifiable environmental impacts are considered. Value choices can be hidden in allocation rules
- The availability and quality of data is a big problem, which still requires a lot of methodological and scientific work. It is unclear what to do, if data is missing and how to deal with (large) differences in different LCA databases
- The results of a life cycle assessment are geographically dependent. Hence, the results of a life cycle assessment carried out in Europe cannot be applied to Ghana without taking into account the significant variations related to the geographical context (for example, Ghana relies mostly on hydroelectricity while Europe employ other sources of energy such as nuclear)
- LCA only assesses potential impacts and not real impacts. Hence, it does not provide any information on the consequences of not following regulations or on environmental risks
- The results of two LCAs on a same subject may differ according to the objectives, processes, quality of the data, and the impact assessment methods used. This is why ISO insists on transparency in life cycle assessment
- A detailed life cycle assessment requires inventory data of all of the elementary processes included within the parameters of the system. Databases, life cycle assessment software, and even human resources are required to analyze all the data

2.2 Monte Carlo Simulation Method

There are many things that faster computers have made possible in recent years. For scientists, engineers, statisticians, managers, investors, and others, computers have made it possible to

create models that simulate reality and aid in making predictions. One of the methods for simulating real systems is the ability to take into account randomness by investigating hundreds of thousands of different scenarios. The results are then compiled and used to make decisions. This is what Monte Carlo simulation is about.

Simulation can be defined as a numerical technique for conducting experiments on a digital computer, which involves certain types of mathematical and logical models that describe the behavior of a system over extended periods of real time. Simulation is, in a wide sense, a technique for performing sampling experiments on a model of the system. Stochastic simulation implies experimenting with the model over time including sampling stochastic variates from probability distributions.

Monte Carlo simulation is often used in business for risk and decision analysis, to help make decisions given uncertainties in market trends, fluctuations, and other uncertain factors. Thus when a system is too complex to be analyzed using ordinary methods, investment analysts frequently use Monte Carlo simulation. In the science and engineering communities, Monte Carlo simulation is used for uncertainty analysis, optimization, and reliability-based design. In manufacturing, Monte Carlo methods are used to help allocate tolerances in order to reduce cost. There are certainly other fields that employ Monte Carlo methods, and there are also times when Monte Carlo is not practical (for extremely large problems, computer speed is still an issue). However, Monte Carlo continues to gain popularity, and is often used as a benchmark for evaluating other statistical methods.

The term Monte Carlo method was coined in the 1940s by physicists working on nuclear weapon projects in the Los Alamos National Laboratory (Metropolis, 1987). It was coined by Ulam and Nicholas Metropolis in reference to games of chance, a popular attraction in Monte Carlo, Monaco (Hoffman, 1998; Metropolis and Ulam, 1949).

Monte Carlo methods are a class of computational algorithms that rely on repeated random sampling to compute their results. However, Monte Carlo simulation methods do not always require truly random numbers to be useful — while for some applications, such as primality testing, unpredictability is vital (Davenport, 1992). Monte Carlo methods are often used when simulating physical and mathematical systems. Because of their reliance on repeated computation and random or pseudo-random numbers, Monte Carlo methods are most suited to calculation by a computer. Monte Carlo methods tend to be used when it is unfeasible or impossible to compute an exact result with a deterministic algorithm (Hubbard, 2007).

In theory, data uncertainties are relatively easy to handle, as such uncertainties can be expressed as a range or standard deviation. Statistical methods, such as Monte Carlo techniques can be used to handle these types of uncertainties, and calculate the uncertainty in the LCA results (Pre Consultant, 2008a). Thus Monte Carlo Simulation (MCS) is a technique that converts uncertainties in input variables of a model into probability distributions. By combining the distributions and randomly selecting values from them, it recalculates the simulated model many times and brings out the probability of the output.

Sawilowsky (2003) distinguishes between a simulation, a Monte Carlo method, and a Monte Carlo simulation: a simulation is a fictitious representation of reality, a Monte Carlo method is a technique that can be used to solve a mathematical or statistical problem, and a Monte Carlo simulation uses repeated sampling to determine the properties of some phenomenon (or behavior)

There is no single Monte Carlo method; instead, the term describes a large and widely-used class of approaches. However, these approaches tend to follow a particular pattern (Kalos and Whitlock (2008).

Basic Characteristics

- It defines a domain of possible inputs. Monte Carlo simulation allows several inputs to be used at the same time to create the probability distribution of one or more outputs.
- It generates inputs randomly from the domain. Different types of probability distributions can be assigned to the inputs of the model. When the distribution is unknown, the one that represents the best fit could be chosen.
- It performs a deterministic computation using the inputs. The use of random numbers characterizes Monte Carlo simulation as a stochastic method. The random numbers have to be independent; no correlation should exist between them.
- It aggregates the results of the individual computations into the final result. Monte Carlo simulation generates the output as a range instead of a fixed value and shows how likely the output value is to occur in the range.

Furthermore, Sawilowsky (2003) lists the characteristics of a high quality Monte Carlo simulation:

- the (pseudo-random) number generator has certain characteristics (*e.g.*, a long "period" before the sequence repeats)
- the (pseudo-random) number generator produces values that pass tests for randomness
- there are enough samples to ensure accurate results
- the proper sampling technique is used
- the algorithm used is valid for what is being modeled
- it simulates the phenomenon in question

Random methods of computation and experimentation (generally considered forms of stochastic simulation) can be arguably traced back to the earliest pioneers of probability theory but are more specifically traced to the pre-electronic computing era. The general difference usually described about a Monte Carlo form of simulation is that it systematically "inverts" the typical mode of simulation; treating deterministic problems by first finding a probabilistic analog. Previous methods of simulation and statistical sampling generally did the opposite: using simulation to test a previously understood deterministic problem. Thus the use of random variables characterizes Monte Carlo Simulation as a stochastic method. Random variables are variables that behave in an uncertain way and a probability can be assigned to the possible values of the random variables. There are two types of random variables corresponding to the two types of distribution – discrete (probability distribution of variables that have certain discrete values) and continuous (probability distribution of variables that have values within infinite range). The discrete random variables take a specific number of real values and are

defined by probability frequency function. The probabilities take values from zero to one and they sum to one (Iordanova, 2007)

Monte Carlo simulation methods are especially useful in studying systems with a large number of coupled degrees of freedom, such as fluids, disordered materials, strongly coupled solids, and cellular structures. More broadly, Monte Carlo methods are useful for modeling phenomena with significant uncertainty in inputs, such as the calculation of risk in business. These methods are also widely used in mathematics: a classic use is for the evaluation of definite integrals, particularly multidimensional integrals with complicated boundary conditions. It is a widely successful method in risk analysis and when compared to alternative methods or human intuition. When Monte Carlo simulations have been applied in space exploration and oil exploration, actual observations of failures, cost overruns and schedule overruns are routinely better predicted by the simulations than by human intuition or alternative "soft" methods (Hubbard, 2009).

Monte Carlo simulation methods are especially useful for modeling phenomena with significant uncertainty in inputs and in studying systems with a large number of coupled degrees of freedom.

2.2.1 Monte Carlo Simulation versus "what if" Scenarios

The opposite of Monte Carlo simulation might be considered deterministic modeling using single-point estimates. Each uncertain variable within a model is assigned a "best guess" estimate. Various combinations of each input variable are manually chosen (such as best case,

worst case, and most likely case), and the results recorded for each so-called "what if" scenario (Vose, 2008).

By contrast, Monte Carlo simulations sample probability distribution for each variable to produce hundreds or thousands of possible outcomes. The results are analyzed to get probabilities of different outcomes occurring (Vose, 2008). By contrast, Monte Carlo simulation considers random sampling of probability distribution functions as model inputs to produce hundreds or thousands of possible outcomes instead of a few discrete scenarios. The results provide probabilities of different outcomes occurring. For example, a comparison of a spreadsheet cost construction model run using traditional "what if" scenarios, and then run again with Monte Carlo simulation and Triangular probability distributions shows that the Monte Carlo analysis has a narrower range than the "what if" analysis. This is because the "what if" analysis gives equal weight to all scenarios while Monte Carlo method hardly samples in the very low probability regions as have been explained earlier by Vose (2008) that Monte Carlo simulation considers random sampling of probability distribution functions as model inputs. The samples in regions in regions that are hardly selected are called "rare events".

According to Bieda (2009), the uncertainty stems from partial ignorance or lack of perfect knowledge. Based on the experiences regarding uncertainty in LCA/LCI studies, it seems that LCI must be performed from a probabilistic point of view, rather than by considering deterministic aspects. Among the probabilistic tools, in order to include the above aspects the

use of Monte Carlo analysis has been increasing in recent years, and is one of the most widespread stochastic model uncertainty analyses (Nadal *et al.,* 2008; Spath *et al.,* 2000).

Monte Carlo simulation uses these distributions, referred to as "assumptions", to automate the complex "what-if" process and generate realistic random values. The benefits of a simulation modeling approach are: (i) an understanding of the probability of specific outcomes (ii) the ability to pinpoint and test the driving variables within a model (iii) a far more flexible model; and (iv) clear summary charts and reports (Bieda, 2009; Sonnemann *et al.,* 2004).

2.2.2 Applications of Monte Carlo Simulations

As mentioned, Monte Carlo simulation methods are especially useful for modeling phenomena with significant uncertainty in inputs and in studying systems with a large number of coupled degrees of freedom. Specific areas of application include: Physical Sciences, Design and Visuals, Finance and Business, Telecommunications and Games.

Physical Sciences

Monte Carlo methods are very important in computational physics, physical chemistry, and related applied fields, and have diverse applications from complicated quantum chromodynamics calculations to designing heat shields and aerodynamic forms (Golden, 1979; MacGillivray and Dodd, 1982; Baeurle, 2009) The Monte Carlo method is widely used in statistical physics, particularly Monte Carlo molecular modeling as an alternative for computational molecular dynamics as well as to compute statistical field theories of simple particle and polymer models (Baeurle, 2009). In experimental particle physics, these methods

are used for designing detectors, understanding their behavior and comparing experimental data to theory, or on vastly large scale of the galaxy modeling (MacGillivray and Dodd, 1982).

Monte Carlo methods are also used in the ensemble models that form the basis of modern weather forecasting operations (Golden, 1979).

Design and Visuals

Monte Carlo methods have also proven efficient in solving coupled integral differential equations of radiation fields and energy transport, and thus these methods have been used in global illumination computations which produce photorealistic images of virtual 3D models, with applications in video games, architecture, design, computer generated films, special effects in cinema.

Finance and Business

Monte Carlo methods in finance are often used to calculate the value of companies, to evaluate investments in projects at a business unit or corporate level, or to evaluate financial derivatives. Monte Carlo methods used in these cases allow the construction of stochastic or probabilistic financial models as opposed to the traditional static and deterministic models, thereby enhancing the treatment of uncertainty in the calculation (Boyle, 1977, Boyle *et al* 1997; Boyle *et al*., 2002). The advantage of Monte Carlo methods over other techniques increases as the dimensions (sources of uncertainty) of the problem increase. It is also used in the insurance industry.

Telecommunications

When planning a wireless network, design must be proved to work for a wide variety of scenarios that depend mainly on the number of users, their locations and the services they want to use. Monte Carlo methods are typically used to generate these users and their states (Saarnisaari, 2012). The network performance is then evaluated and, if results are not satisfactory, the network design goes through an optimization process.

Games

Monte Carlo methods have recently been applied in game playing related artificial intelligence theory (Cormen *et al*, 2001; Berman and Paul, 2005). Most notably the game of Go has seen remarkably successful Monte Carlo algorithm based computer players. One of the main problems that this approach has in game playing is that it sometimes misses an isolated, very good move. These approaches are often strong strategically but weak tactically, as tactical decisions tend to rely on a small number of crucial moves which are easily missed by the randomly searching Monte Carlo algorithm.

2.2.3 Optimization

Another powerful and very popular application for random numbers in numerical simulation is in numerical optimization. These problems use functions of some often large-dimensional vector that are to be minimized (or maximized). Most Monte Carlo optimization methods are based on random walks. Essentially, the program will move around a marker in multi-dimensional space, tending to move in directions which lead to a lower function, but sometimes

moving against the gradient. There are also applications to engineering design, such as multidisciplinary design optimization (Int. Panis *et al*, 2001; Int Panis *et al*, 2002).

Multi-disciplinary Design Optimization (MDO) is a field of engineering that uses optimization methods to solve design problems incorporating a number of disciplines. It is also known as multidisciplinary optimization and multidisciplinary system design optimization (MSDO). MDO allows designers to incorporate all relevant disciplines simultaneously (Szirmay-Kalos 2008). The optimum of the simultaneous problem is superior to the design found by optimizing each discipline sequentially, since it can exploit the interactions between the disciplines. However, including all disciplines simultaneously significantly increases the complexity of the problem.

These techniques have been used in a number of fields, including automobile design, naval architecture, electronics, computers, and electricity distribution (Szirmay-Kalos, 2008; Madani and Lund, 2011). However, the largest number of applications has been in the field of aerospace engineering, such as aircraft and spacecraft design. For example, the proposed Boeing blended wing body (BWB) aircraft concept has used MDO extensively in the conceptual and preliminary design stages. The disciplines considered in the BWB design are aerodynamics, structural analysis, propulsion, control theory, and economics.

2.2.4 Uncertainty Assessment in LCI

Data collection for life cycle inventories (LCIs) remains a critical factor in the successful completion of a life cycle assessment (LCA). Access to reliable data continues to be a

significant barrier to the advancement and use of LCAs in environmental management (Curran *et al.,* 2001).

In the Commission Decision of 18 July 2007 establishing guidelines for the monitoring and reporting of greenhouse gas emissions pursuant to Directive 2003/87/EC of the European parliament and of the Council, uncertainty means: "a parameter, associated with the result of the determination of a quantity, that characterizes the dispersion of the values that could reasonably be attributed to the particular quantity, including the effects of systematic as well as of random factors and expressed in per cent and describes a confidence interval around the mean value comprising 95% of inferred values taking into account any asymmetry of the distribution of values" (COMMISSION DECISION, 2007).

Usually the overall uncertainty of a LCI is dominated by a few major uncertainties (Bieda, 2009). Likewise, the overall uncertainty of a specific process is typically dominated by one source of uncertainty and other sources of uncertainty may be ignored (Fress *et al.,* 2003). Information about uncertainty in LCI results cannot be fully captured within the LCI database, because a significant share of this uncertainty arises in practice, based on relationship between the data. When the main determining parameter of an uncertainty is known, it can be eliminated or at least reduced to the uncertainty by modeling (Bieda, 2009).

2.2.5 Measures of Uncertainty Importance

A *sensitivity analysis* is the simplest and most well established method for determining the influence of an uncertain parameter on the overall output (Notten, 2001). The model is run with

only one uncertain input, the other parameters remaining fixed at their most likely value. The analysis is repeated for each uncertain parameter and the resulting sensitivities compared. However, sensitivities calculated in this way do not take into account any interference or correlation between the various uncertainties. They can thus only be taken as an indication of relative sensitivity and not each parameter's actual contribution to the overall uncertainty (Meier, 1997).

An analytical measure of uncertainty importance, able to identify the key parameters contributing to the uncertainty in the results, is demonstrated by Heijungs (1996). Derived from Gaussian approximation, but using absolute error and not standard deviations to characterize the uncertainty, this method rests on the fact that the uncertainty of the results can be expressed as a sum of the individual contributions from the input data. Thus, for the function $y=f(x_1, x_{2,}\ldots.)$:

$$\frac{\Delta y}{|y|} = \left|\frac{\partial f}{\partial x_1}\right| \frac{\Delta x_1}{|y|} + \left|\frac{\partial f}{\partial x_2}\right| \frac{\Delta x_2}{|y|} + \ldots\ldots \qquad 2.1$$

The above equation is disaggregated, and the individual contributions arranged in decreasing order, so as to give a ranking of the parameters which have the highest influence on the uncertainty of the result (Heijungs, 1996). The method is subject to the same limitations as given for Gaussian Approximation (Section 2.2.6).

A powerful global measure of uncertainty importance, applicable to the methods of uncertainty analysis using simulation techniques, is the correlation of the sample output values with the corresponding sample of values for each input variable:

$$U_{\rho}(x, y) = \rho(x, y) \ldots\ldots\ldots \qquad 2.2$$

This estimates the effect of uncertainty in x on uncertainty in y, averaged over all possible combinations of values of the other inputs, weighted by their probabilities. Thus for m samples from the output, y_k, and a particular input, x_k, for $k = 1$ to m the sample correlation is given as:

$$U_{\rho}(x, y) = \frac{\sum_{k=1}^{m}(x_k - \bar{x})(y_k - \bar{y})}{\sqrt{\sum_{k=1}^{m}(x_k - \bar{x})^2 \times \sum_{k=1}^{m}(y_k - \bar{y})^2}} \ldots\ldots\ldots \qquad 2.3$$

This is truly a global measure of uncertainty because the effect of each input is averaged over the joint probability distribution for all other inputs. The correlation estimates the linear contribution of each input to the output uncertainty, and does not necessarily provide a good measure of non-linear relationships (Notten, 2001). Where the input or output distributions are far from normal, i.e. if they have long tails, distortion from the effect of outliers is likely to be a problem. Notten (2001) further explained that, to avoid this, rank-order correlations can be used, where the sample values for each input and for the output are rank ordered (i.e. placed in order of increasing magnitude) before computing the correlations. Related measures of uncertainty have been developed that extend the correlation approach, e.g. partial correlation coefficients and principal components, or employ regression coefficients. Scatter plots are also a useful and simple way of visualizing the relationship between model inputs and outputs.

2.2.6 The Theory of Monte Carlo Analysis

The main statistical method developed for the analysis of uncertainty is presented here. It is well established statistical method and details can be found in the extensive statistical literature. The most extensively used method for uncertainty analysis is Monte Carlo. An overview of theory of

Monte Carlo simulation method as initially published by Morgan and Henrion (1990) and reviewed by Notten (2001) is as described in this section.

The analysis of uncertainty involves measuring the degree to which each input contributes to the uncertainty in the output. Consider function ***f***, with two uncertain inputs, x_1 and x_2, and one output, *y*:

$$y = f(x_1, x_2) \ldots\ldots\ldots \qquad 2.4$$

The analysis of uncertainty is the degree to which *x* contributes to *y*. Methods to quantify this are termed *measures of uncertainty importance*, and are denoted by $U(x,y)$ (Notten, 2001).

The simplest measure of uncertainty importance is *sensitivity*. This is the rate of change of the output *y* with respect to variation in an input *x*, i.e. the partial derivatives of output *y* with respect to each input. The derivatives are evaluated at the nominal scenario, where the nominal scenario is defined as the vector of initial "best guess" or "most likely" values for the inputs. Sensitivity is thus defined as:

$$U_s(x, y) = \left[\frac{\partial y}{\partial x}\right]_{x^0} \quad \ldots\ldots\ldots \qquad 2.5$$

where $X^0 = (x_1^0, x_2^0)$

and x_1^0, x_2^0 denote the nominal input values (usually the mean, median or mode of the input probability distribution). A problem with using sensitivity for comparing the uncertainty importance of different inputs is that it depends on the scale of *x* and *y*, i.e. on the units of measurement. To avoid this, the sensitivity is often normalized, and the changes in *x* and *y*

defined in relative terms as a fraction of their nominal values, e.g. the percent change in *y* induced by a 1 percent change in *x*. This normalized sensitivity, defined as the ratio of the relative change in *y* induced by a unit relative change in *x*, is termed *elasticity*:

$$U_E(x,y) = \left[\frac{\partial y}{\partial x}\right]_{X^0} \times \frac{x^0}{y^0} \quad \ldots\ldots\ldots \qquad 2.6$$

Sensitivity and elasticity consider only the slopes of the response surface and do not consider the degree of uncertainty in each input. An input that has a small sensitivity but a large uncertainty may be just as important as an input with a larger sensitivity but smaller uncertainty. *Gaussian or first order approximation* is the simplest uncertainty analysis that considers both sensitivity and uncertainty. In this approach, a variable's uncertainty importance is measured as the product of its sensitivity and uncertainty, i.e. the product of the partial derivative and standard deviation, σ:

$$U_G(x,y) = \left[\frac{\partial y}{\partial x}\right]_{X^0} \times \sigma_x \ldots\ldots\ldots \qquad 2.7$$

Gaussian approximation can be used directly to measure the uncertainty propagation, i.e. to estimate the uncertainty of the output. The variance of the output, $\mathrm{Var}[y] \equiv \sigma_y^2$, is estimated as the sum of the squares of the contributions from each input where $\mathrm{Var}[x] \equiv \sigma_x^2$:

$$Var[y] \approx \left(\left[\frac{\partial y}{\partial x}\right]_{x^0}^2 Var[x_1]\right) + \left(\left[\frac{\partial y}{\partial x}\right]_{x^0}^2 Var[x_2]\right) \ldots\ldots\ldots \qquad 2.8$$

Gaussian approximation is a local approach in that it considers the behaviour of the function only in the vicinity of the nominal scenario. It is thus fairly accurate for smooth functions and small uncertainties, but is likely to produce misleading results for complicated functions and large uncertainties. In such cases, a global approach is required, that evaluates the function for scenarios distant from the nominal scenario. The *nominal range sensitivity* method computes the

effect on the output of varying each input from its low to high value, while keeping the other inputs at their nominal values:

$$U_R(x_1, y) = f(x_1^+, x_2^0) - f(x_1^-, x_2^0) \ldots\ldots\ldots \quad 2.9$$

$$U_R(x_2, y) = f(x_1^0, x_2^+) - f(x_1^0, x_2^-) \ldots\ldots\ldots \quad 2.10$$

where $[x_1^-, x_1^+]$ and $[x_2^-, x_2^+]$ denote the bounds of plausible variation for the inputs.

The nominal range sensitivity is more than a local approach, as it evaluates the model for extreme values of each input, but is not truly global, as it holds all the other inputs at their nominal values when looking at the effect of each input. The effect of one input may depend on the values of other inputs, so an approach is required that evaluates the effect of each parameter for several values of the other inputs. This can be obtained by a *parametric analysis* that evaluates *y* for a sequence of different values for each input, holding the others constant (Notten, 2001).

A *scenario tree*, an example of which is shown in Figure 2.2, is a useful way to represent possible combinations of inputs. Each node represents an uncertain quantity or event, and each branch from the node one of its possible outcomes. Each path through the tree represents a sequence of event outcomes determining a specific scenario. The number of scenarios increases exponentially with the number of uncertain inputs, so the computational effort to evaluate every scenario rapidly becomes infeasible with increasing numbers of inputs, as does the ability to display and analyze the results. For this reason, often only a few special interest scenarios are examined, e.g. “most likely”, “best case” and “worst case” scenarios, where the input parameters

are set to their nominal, best and worst values respectively. An extension of the scenario tree is the *probability tree*. Here a conditional probability is attached to each branch on the scenario tree. Each path through the tree represents a feasible scenario whose probability is the product of the conditional probabilities of the branches along that path. A discrete probability distribution for the output, or risk profile, can be obtained by calculating the probability and output value for each scenario (Notten, 2001).

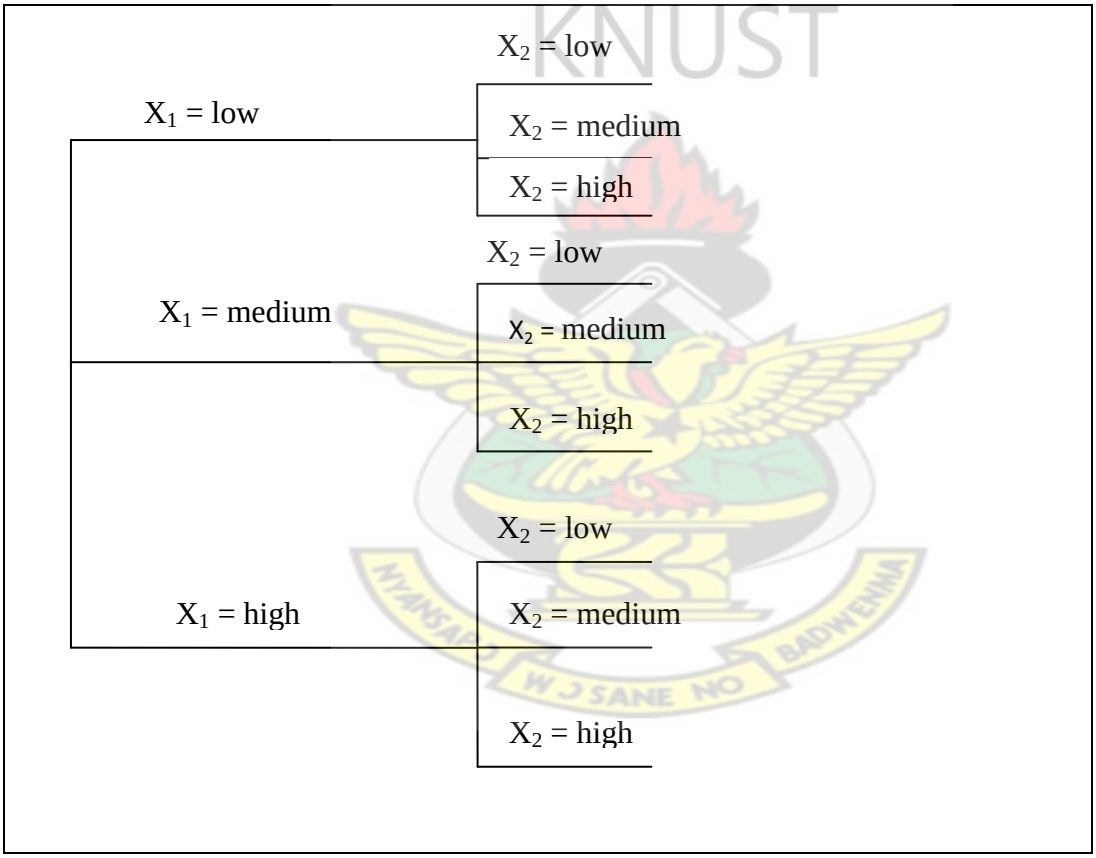


Figure 2.2 Scenario tree with three levels

The construction of a probability tree requires that the uncertainty in the input parameters be expressed as discrete probability distributions. However, uncertain quantities are often continuous rather than discrete. It is mathematically too complex for all but the simplest cases to

obtain an analytical solution for the probability distribution of a function of a set of continuous random variables. Where there are only a few uncertain variables, it is possible to approximate the continuous distributions by discrete ones and use the probability tree approach. An alternative approach is Monte Carlo simulation. In this method, all the combinatorial scenarios are considered by selecting a random sample of scenarios for evaluation. Each scenario is generated by selecting each branch at a node according to its assigned probability, and as the computational effort depends on sample size and not on the number of possible values for each parameter, the branch values may be generated directly from the underlying continuous distribution, avoiding the need to discretize (Notten, 2001).

The resulting output distribution is inevitably only an approximation of the actual distribution, but it does avoid the approximation due to discretising the continuous distributions. Also the accuracy of Monte Carlo simulation can simply be increased by increasing the sample size, and unlike the probability tree approach, its accuracy can easily be estimated using standard statistical techniques. The appropriate sample size depends on the accuracy required, and thus the application of the model. For models with a large number of uncertain variables, Monte Carlo methods are generally preferable to probability tree methods on the grounds of the computational effort required. In addition, Monte Carlo methods provide a simple measure of uncertainty importance, that of a correlation analysis (Notten, 2001).

Monte Carlo simulation is the best known and simplest method for sampling from the uncertain input domain. In this method, a value is drawn at random from the distribution for each uncertain input, producing a set of random values. This set, containing one value for each input, defines a

scenario used as input to the model, from which the corresponding output is computed. The process is repeated *m* times, producing *m* independent scenarios and their output values. The *m* output values constitute a random sample from the probability distribution over the output induced by the probability distributions over the inputs. Standard statistical techniques can then be used to estimate the precision of the output distribution derived from this random sample. The accuracy of the estimates of the output distribution's parameters depends on the sample size *m*, and not on the number of uncertain inputs *n*. This is because the output sample consists of independent random values from the output distribution, and how representative the sample is of the output distribution is irrespective of the number of uncertain inputs. The number of runs required, *m*, depends on the relative accuracy required of the output distribution. For a given degree of uncertainty, *m* is thus independent of *n*, the number of uncertain inputs, although the computational effort to run the model is typically proportional to *n*.

2.2.6.1 Selecting a Sample Size

A compromise needs to be found between the time for each model run and the precision of the results, and will usually be dictated by the application of the analysis. Using standard statistical techniques an estimate of the number of samples required to meet the desired precision can be calculated, either from stating the acceptable uncertainty about the mean, or from stating required confidence intervals for the fractiles. Where the random sample of *m* output variables is given by ($y_1, y_2, y_3, \ldots y_m$), the mean and standard deviation of *y* are estimated by:

$$\bar{y} = \sum_{i=1}^{m} \frac{y_i}{m} \quad \ldots\ldots\ldots \qquad 2.11$$

$$s^2 = \sum_{i=1}^{m} \frac{(y_i - \bar{y})^2}{(m-1)} \quad \ldots\ldots\ldots \qquad 2.12$$

The required confidence interval, with confidence α, is then given by:

$$\left(\bar{y} - c\frac{s}{\sqrt{m}}, \bar{y} + c\frac{s}{\sqrt{m}} \right) \quad \ldots\ldots\ldots \qquad 2.13$$

where *c* is the deviation for the unit normal enclosing probability α. To obtain an estimate of the mean of *y* with a confidence interval α smaller than *w* units wide, the width of the interval must be less than *w*, i.e

$$2c\frac{s}{\sqrt{m}} \prec w \quad \ldots\ldots\ldots \qquad 2.14$$

To obtain the required number of samples, *m*, this equation can simply be rearranged to yield:

$$m \succ \left(\frac{2cs}{w} \right)^2 \quad \ldots\ldots\ldots \qquad 2.15$$

To use this equation, a small number of runs (around ten) first need to be done, so that an initial estimate of the variance, *s*, can be obtained. The deviation, *c*, enclosing the specified probability, α, can be obtained from statistical tables, and the value substituted into the above equation, together with the specified interval width and the estimate of variance, to obtain the number of sample runs (Notten, 2001).

Alternatively, the number of samples required can be determined by specifying the required precision of the estimate of the median or of the other fractiles. Assuming the *m* sample values of *y* are relabelled to be in increasing order, i.e. $y_1 \leq y_2 \leq \ldots \leq y_m$ sample value *yi* is an estimate of fractile Y*p* where *p* = *i/m*. The confidence interval, α, for a pair of sample values can be shown to be given by (y_i, y_k), where:

$$i = mp - c\sqrt{mp(1-p)} \ldots\ldots\ldots \quad 2.16$$

$$k = mp + c\sqrt{mp(1-p)} \ldots\ldots\ldots \quad 2.17$$

and the values of *i* and *k* are rounded down and up respectively. Supposing confidence, α, of the fractile Yp is specified as being between the sample value estimates of the $p - \Delta p^{th}$ and $p + \Delta p^{th}$ fractile, i.e. $i = m(p - \Delta p)$ and $k = m(p + \Delta p)$. These expressions for *i* and *k* can be combined with the above equations for *i* and *k* to yield:

$$m = p(1-p)\left(\frac{c}{\Delta p}\right)^2 \ldots\ldots\ldots \quad 2.18$$

For this estimate of *m*, no previous sample runs need to be done and the number of samples can be obtained directly from the specified precision. For example, a 95% confidence interval for the 50th percentile to be plus or minus one estimated percentile, gives p=0.5, Δp=0.01 and *c*, the deviation enclosing 95% of the probability of the unit normal, approximately equal to 2 (read from statistical tables). To achieve this very high precision, approximately 10,000 runs are required. A reasonable estimate of the desired precision is thus necessary if the number of sample runs is to be kept to a manageable level. Where the empirical uncertainty from the input parameters is high, a very high degree of precision in the propagation of these uncertainties is probably worthless. In this case, the approximation uncertainty due to the number of runs will most probably be dominated by the empirical uncertainty from the input parameters, and a few hundred runs will probably suffice (Notten, 2001).

2.2.6.2 Selecting a Sampling Method

Monte Carlo sampling is the simplest sampling method, in which each of the sample points (m) for each uncertainty quantity (X) is generated at random from X, with probability proportional to the probability density for X. Using the inverse cumulative method, m uniform random variables (ui for i =1,2… m) between 0 and 1 are generated. The inverse of the cumulative probability distribution is then used to compute the corresponding values of X, i.e.

$$Xi \text{ where } \mathbf{P}(xi \leq Xi) \text{ for } i = 1,2 \ldots m.$$

In this simple Monte Carlo method, each value of every random variable X, including those calculated from other random variables, is a sample of m independent random values from the true probability distribution for X (Notten, 2001).

The value of the Monte Carlo methods lie primarily in their providing a uniform distribution of points in the parameter space, and not in the randomness of the sampling per se. Stratified sampling methods are able to enhance this primary objective by ensuring a more uniform sample over the input domain. In these methods the sample space for an input parameter is divided up into strata, and input values are obtained by sampling from within each stratum instead of from the whole distribution. One such method is *Latin Hypercube Sampling* (LHS), in which each input distribution is divided into m equiprobable intervals. A scenario is generated by selecting, without replacement, one value at random from the m samples for each of the inputs, resulting in m nominally independent scenarios. With Median Latin Hypercube sampling the sample points are the medians of the m intervals, that is, the fractiles:

$$Xi \text{ where } \mathbf{P}(xi \leq Xi) = (i\text{-}0.5)/m \text{ for } i = 1,2 \ldots m \ldots\ldots \qquad 2.19$$

To avoid non-random correlations among different quantities, the points are then randomly shuffled so that they are no longer in ascending order. Random Latin Hypercube sampling is similar to median Latin Hypercube sampling, except that the sample points are random samples taken from each of the *m* equiprobable intervals, instead of the medians of the intervals. Thus in random Latin Hypercube sampling each sample is a true independent sample from the distribution, although the samples are not totally independent (Notten, 2001).

The sample of *m* values obtained using LHS are for each distribution more uniform than would be obtained by purely random sampling (i.e. Monte Carlo sampling), with median LHS able to yield a still more even spread of sample scenarios over the input domain. LHS is thus able to represent the parameters of the output distribution more accurately than random Monte Carlo sampling, and with median LHS, the mean and variance are often almost exact. Stratified sampling is almost always better than truly random sampling, although for highly nonlinear models and those with a large number of uncertain inputs, the improvement may be slight. The sample scenarios, and hence the outputs, are not completely independent when using LHS. Standard statistical techniques are therefore not directly applicable, and more complex measures are required to compute the true precision of the output distribution. The equations presented in the preceding section are thus not able to accurately predict the number of required samples derived from LHS. However, as these equations typically underestimate the true precision, they are able to provide a useful minimum level of precision or maximum number of samples required. In general, median LHS is considerably better than standard LHS, although it is not able to accurately sample functions displaying high frequency periodicity. As such functions are

not at all likely to occur in LCA models, median LHS is the sampling method of choice in the uncertainty analysis of empirical quantities in LCA models (Notten, 2001).

A random sampling technique to generate the random samples, also needs to be chosen. A number of techniques exist, of which three common methods are:

- the *Minimal Standard* random number generator, an implementation of Park and Miller's Minimal Standard, based on a multiplicative congruential method, with a Bays-Durham shuffle;
- the *L'Ecuyer* random number generator, based on L'Ecuyer's algorithm. Also based on a multiplicative congruential method, it gives a series of random numbers with a much longer period but is slightly slower than the Minimal Standard method.
- *Knuth's algorithm*, based on a subtractive rather than a multiplicative congruential method, and is slightly faster than the Minimal Standard method.

The differences between the methods were found to be slight, so the simpler minimal standard method is used (Notten, 2001).

2.2.7 The Mathematics behind Monte Carlo Simulations

In general, Monte Carlo methods are used in mathematics to solve various problems by generating suitable random numbers and observing that fraction of the numbers which obeys some property or properties. Monte Carlo methods are particularly useful in the valuation of options with multiple sources of uncertainty or with complicated features which would make

them difficult to value. The method is useful for obtaining numerical solutions to problems which are too complicated to solve analytically.

Consider that we have a real-valued function g(X) with probability frequency function P(x), (if X is discrete), or probability density function f(x), (if X is continuous). Then we can define the expected value of g(X) in discrete and continuous terms respectively:

$$E(g(X))=\sum_{-\infty}^{+\infty} g(x)P(x), \quad \text{where P(x)>0 and } \sum_{-\infty}^{+\infty} P(x)=1 \ldots\ldots\ldots \quad 2.20$$

$$E(g(X))=\int_{-\infty}^{+\infty} g(x)f(x)dx, \quad \text{where f(x) >0 and } \int_{-\infty}^{+\infty} f(x)dx=1 \ldots\ldots\ldots \quad 2.21$$

Next, make n random drawings of X (x_1, …..,x_n), called trial runs or simulation runs, calculate g(x_1),….g(x_n) and find the mean of g(x) of the sample:

$$G_x(X)=\frac{1}{n}\sum_{i=1}^{n} g(x_i), \ldots\ldots\ldots \quad 2.22$$

which represents the final simulated value of $E(g(X))$

Therefore $G_n(X)=\frac{1}{n}\sum_{i=1}^{n} g(X)$ will be the Monte Carlo estimator of $E(g(X))$

As $n\to\infty, G_n(X)\to E(g(X))$, thus we are now able to compute the dispersion around the estimated mean the unbiased variance of $G_n(X)$

$$Var(G_n(X))=\frac{1}{n}\frac{1}{n-1}\sum_{i=1}^{n}(g(x_i)-G_n(x))^2 \ldots\ldots\ldots \quad 2.23$$

(Iordanova, 2007).

Defining the uncertainty of an input value by a probability distribution that does not correspond to the real one and sampling from it will give incorrect results.

In addition, the assumption that the input variables are independent might not be valid. Misleading results might come from inputs that are mutually exclusive or if significant correlation is found between two or more input distributions.

It is noted that the number of trials should not be too small, as it might not be sufficient to simulate the model, causing clustering of values to occur.

Three types of process modeling can be identified in LCA studies (Bieda, 2009; Klopffer, Hutzinger, 1997)

i. Black box models of processes. This is the mostly used type in LCA because this is the easiest way of process modeling.
ii. Models of processes with linear functional relations. In this concept linear relations (functions) between each input and output as well as between the different inputs are defined.
iii. Models of processes with non-linear and linear functional relations. In this concept linear or non-linear relations (functions) between each input and output as well as between the different inputs are defined.

2.2.8 Monte Carlo Approach in LCA

In order to apply the Monte Carlo approach in LCA, there is the need to translate the information on uncertainty to a standard distribution type. In SimaPro, it can use four different distributions as listed in the table below (Pre Consultants, 2008).

Table 2.3: Statistical Distributions

Distribution Range	Data Needed	Graphical presentation
Range	Min and Max value	
Triangular	Min and Max value plus best guess value	
Normal distribution	Standard deviation and best guess value	
Lognormal distribution	Standard deviation and best guess value	

The key characteristics are:

i. **Range.** It is used when there is an equal probability that a value lies between a minimum and a maximum value. A simple example is the result of throwing a single dice. The range is between 1 and 6, and there is an equally big chance on every outcome.

ii. **Triangular.** This distribution is sometimes used as alternative for the normal distribution. The advantage is that very high or low (even negative) values cannot occur. In SimaPro there is the need to specify the range as well as the best guess value, as this determines the point with the highest probability. This allows specifying an asymmetrical distribution that can also be used to simulate a lognormal distribution.

iii. **Normal distribution.** This distribution requires specifying the best guess value (the centre) and the standard deviation SD. However, in SimaPro it is asked to specify the 2xSD value. This is useful as the 95% confidence interval lies between – 2xSD and +2XSD. In practice this means that only 2.5% of the data points lie above or below these points, and 95% lie between these points. This means that if there is an estimate for the upper and lower value, it can often use these to estimate 2xSD.

iv. **Lognormal distribution**. This is the most important distribution for LCA. Lognormal distributions occur when values with a normal distribution are multiplied. As this happens often in LCA, this distribution can be considered as the default. The 95% confidence interval is defined by dividing or multiplying the best guess value with the squared geometric standard deviation. In SimaPro one is supposed to specify this square of the standard deviation, often written as $\sigma 2$.

2.2.9 Limitations of the Monte Carlo Simulation Method

Uses of Monte Carlo methods require large amounts of random numbers. It is a complement to analytical methods. It provides only statistical estimates, not exact results. It does not directly provide precise insights as analytical methods do. For example, it cannot reveal cause-and-effect relationships. Monte Carlo simulation uses a random number generator with a specified distribution. A drawback is that any risk not represented in the time period selected will not be reflected in the simulation.

Thus Monte Carlo simulation considers random sampling of probability distribution functions as model inputs (Vose, 2008). The samples in regions that are hardly selected are called "rare events". There is a real danger that Monte Carlo calculations overestimate uncertainty if products are compared where correlations are not observed.

According to Iordanova (2007), the assumption that the input variables are independent might not be valid and misleading results might come from inputs that are mutually exclusive or in case significant correlation is found between two or more input distributions.

2.2.10 Other Simulation Methods

Simulation is a way to model random events, such that simulated outcomes closely match real-world outcomes. By observing simulated outcomes, researchers gain insight on the real world. Some situations do not lend themselves to precise mathematical treatment. Others may be difficult, time-consuming, or expensive to analyze. In these situations, simulation may approximate real-world results; yet, require less time, effort, and/or money than other approaches Simulation-based assertional techniques and process algebraic techniques are two of the major methods that have been proposed for the verification of concurrent and distributed systems.

Before the Monte Carlo method was developed, simulations tested a previously understood deterministic problem and statistical sampling was used to estimate uncertainties in the simulations. Monte Carlo simulations invert this approach, solving deterministic problems using a probabilistic analog. Ripley (1987) defines most probabilistic modeling as stochastic

simulation, with Monte Carlo being reserved for Monte Carlo integration and Monte Carlo statistical tests

There is spectrum of simulation studies in statistics including:

- **Principal Component Analysis**. PCA is the simplest of the true eigenvector-based multivariate analyses. Often, its operation can be thought of as revealing the internal structure of the data in a way that best explains the variance in the data. If a multivariate dataset is visualized as a set of coordinates in a high-dimensional data space (1 axis per variable), PCA can supply the user with a lower-dimensional picture, a projection or "shadow" of this object when viewed from its (in some sense; see below) most informative viewpoint. This is done by using only the first few principal components so that the dimensionality of the transformed data is reduced
- **Simulations for Properties of Estimators** – It is used to compare three estimators for the mean μ of a distribution based on random sample $Y_{1,}Y2\ldots Y_n$. For instance the 3 estimators are Sample Mean, Sample Median and Sample 10% trimmed mean for Underlying distribution: N(0,1). Thus if the distribution of the data is symmetric, all three estimators indeed estimate the mean, and if the distribution is skewed, they do not. Thus it is used to compare 3 estimators for location through a simulation study.
- **Simulations for Properties of Hypothesis Tests** – Similarly using an example for illustration, considering size and power of the usual t-test for the mean H_0: $\mu = \mu_0$ vs. H_1: $\mu \neq m\mu_0$. To evaluate whether size/level of test achieves advertised α generate data under $\mu=\mu_0$ and calculate proportion of rejections of H_0. Approximates the true probability of rejecting H_0 when it is true. Proportion should be approximately equal to α. To evaluate

power then generate data under some alternative $\mu \neq \mu_0$, let say and calculate the proportion of rejections of H_0. Approximate the true probability of rejecting H_0 when the alternative is true

Principal Component Analysis (PCA) is one of the widely used simulation methods for complex situations aside Monte Carlo Simulation method

2.2.10.1. Principal Component Analyses

Principal component analysis (PCA) is a statistical procedure that uses an orthogonal transformation to convert a set of observations of possibly correlated variables into a set of values of linearly uncorrelated variables called principal components. The number of principal components is less than or equal to the number of original variables. This transformation is defined in such a way that the first principal component has the largest possible variance (that is, accounts for as much of the variability in the data as possible), and each succeeding component in turn has the highest variance possible under the constraint that it is orthogonal to (i.e., uncorrelated with) the preceding components. Principal components are guaranteed to be independent if the data set is jointly normally distributed. PCA is sensitive to the relative scaling of the original variables.

Principal component analysis (PCA) is a multivariate technique that analyzes a data table in which observations are described by several inter-correlated quantitative dependent variables. Its goal is to extract the important information from the table, to represent it as a set of new orthogonal variables called principal components, and to display the pattern of similarity of the

observations and of the variables as points in maps (Abdi and Williams, 2010). The quality of the PCA model can be evaluated using cross-validation techniques such as the bootstrap and the jackknife. PCA can be generalized as correspondence analysis (CA) in order to handle qualitative variables and as multiple factor analysis (MFA) in order to handle heterogeneous sets of variables. Mathematically, PCA depends upon the eigen-decomposition of positive semi-definite matrices and upon the singular value decomposition (SVD) of rectangular matrices

According to Abdi and Williams (2010), the method is mostly used as a tool in exploratory data analysis and for making predictive models. PCA can be done by eigenvalue decomposition of a data covariance (or correlation) matrix or singular value decomposition of a data matrix, usually after mean centering (and normalizing or using Z-scores) the data matrix for each attribute. Shaw (2003) also indicated that the results of a PCA are usually discussed in terms of component scores, sometimes called factor scores (the transformed variable values corresponding to a particular data point), and loadings (the weight by which each standardized original variable should be multiplied to get the component score)

Limitations of PCA

PCA is sensitive to the scaling of the variables. If there are just two variables and they have the same sample variance and are positively correlated, then the PCA will entail a rotation by 45° and the "loadings" for the two variables with respect to the principal component will be equal. But if all values of the first variable are multiplied by 100, then the first principal component will be almost the same as that variable, with a small contribution from the other variable, whereas the second component will be almost aligned with the second original variable. This means that

whenever the different variables have different units (like temperature and mass), PCA is a somewhat arbitrary method of analysis

2.3 Response Surface Methodology

Research and development are the heart and soul of improvement efforts in manufacturing, and it is fast becoming standard practice to employ design of experiments methods in industrial R&D. In the early stages of their work, experimenters typically use screening experiment designs that normally consist of trials run at the extreme lower- and upper-bound level setting combinations of the variable study ranges. They provide information on the direct additive effects of the study variables and on pairwise (two-variable) interaction effects. Screening designs enable experimenters to select the best materials and equipment from available alternatives and to focus on the correct variables and ranges for further study. In the later stages of experimental work, the goal shifts from screening to product and process optimization (Verseput, 2001).

Optimization or mathematical programming refers to choosing the best element from some set of available alternatives. In the simplest case, this means solving problems in which one seeks to minimize or maximize a real function by systematically choosing the values of real or integer variables from within an allowed set. More generally, it means finding "best available" values of some objective function given a defined domain, including a variety of different types of objective functions and different types of domains.

Generally, adding more than one objective to an optimization problem adds complexity. A typical example is in optimization of processing parameters to minimize environmental impact of

a processing plant. This could lead to a trade-off in some of these inlet parameters so as to achieve these prospective objectives conflict. Consequently, there will be one design with the highest of one of the inlet parameters or variables; another design with highest of the second inlet parameter as well as a couple of combinations of different levels of amounts of these parameters of the process design without compromising the quality of the final product of the processing plant. This set of trade-off designs is known as a Pareto set.

Multi-disciplinary design optimization (MDO) practitioners have investigated optimization methods in several broad areas in the past four decades. Response surface methodology is one of the prominent approaches that have been developed for optimizing parameters in process designs. The statistical experiment designs most widely used in optimization experiments are termed response surface designs. According to Verseput (2001) response surface designs contain trials in which one or more of the variables is set at the midpoint of the study range (other levels in the interior of the range may also be represented). Thus, these designs provide information on direct effects, pairwise interaction effects and curvilinear variable effects. Response surface methodology, one approach to product and process optimization work, derives its name from the use of these widely used optimization experiment designs

Response surface methodology (RSM), developed extensively by the operations research community, received much attention in the MDO community. A driving force for their use has been the development of massively parallel systems for high performance computing, which are naturally suited to distributing the function evaluations from multiple disciplines that are

required for the construction of response surfaces. Distributed processing is particularly suited to the design process of complex systems in which analysis of different disciplines may be accomplished naturally on different computing platforms and even by different teams.

Evolutionary methods led the way in the exploration of non-gradient methods for MDO applications. They also have benefited from the availability of massively parallel high performance computers, since they inherently require many more function evaluations than gradient-based methods. Their primary benefit lies in their ability to handle discrete design variables and the potential to find globally optimal solutions.

Box-Behnken designs (BBD) are a class of rotatable or nearly rotatable second order designs based on three-level incomplete factorial designs. According to Box and Behnken (1960) and Ferreira *et al* (2007) Box-Behnken design is a response surface methodology, which is a collection of mathematical and statistical techniques that are useful for the modeling and analysis of problems in which a response of interest is influenced by several variables and the objective is to optimize this response. This optimization process involves a series of steps: identify the problem to be solved, determine the factors and levels that affect the response variable, performing the statistically designed experiments, and data analysis (Takayama *et al*, 2003; Meltem and Aysegul, 2009).

Most practitioners of RSM now generate their experiment designs and analyze their data using a statistical software program running on a personal computer. Many of these software programs can generate many classes of RSM designs and, in some cases, offer several varieties of each

class (Verseput (2001). However, the central composite design is the most popular of the many classes of RSM designs due to the following three properties:

- A CCD can be run sequentially. It can be naturally partitioned into two subsets of points; the first subset estimates linear and two-factor interaction effects while the second subset estimates curvature effects. The second subset need not be run when analysis of the data from the first subset points indicates the absence of significant curvature effects.
- CCDs are very efficient, providing much information on experiment variable effects and overall experimental error in a minimum number of required runs.
- CCDs are very flexible. The availability of several varieties of CCDs enables their use under different experimental regions of interest and operability

Problem formulation

Problem formulation is normally the most difficult part of the process. It is the selection of design variables, constraints, objectives, and models of the disciplines. A further consideration is the strength and breadth of the interdisciplinary coupling in the problem.

Design variables

A design variable is a specification that is controllable from the point of view of the designer. For instance, the flow rate of a fluid in a process can be considered a design variable. Another might be the choice of equipment. Design variables can be continuous (such as a wing span), discrete (such as the number of ribs in a wing), or boolean (such as whether to build a monoplane or a biplane). Design problems with continuous variables are normally solved more easily.

Design variables are often bounded, that is, they often have maximum and minimum values. Depending on the solution method, these bounds can be treated as constraints or separately.

Constraints

A constraint is a condition that must be satisfied in order for the design to be feasible. An example of a constraint in aircraft design is that the lift generated by a wing must be equal to the weight of the aircraft. In addition to physical laws, constraints can reflect resource limitations, user requirements, or bounds on the validity of the analysis models. Constraints can be used explicitly by the solution algorithm or can be incorporated into the objective using Lagrange multipliers.

Objectives

An objective is a numerical value that is to be maximized or minimized. For example, a designer may wish to maximize profit or minimize weight. Many solution methods work only with single objectives. When using these methods, the designer normally weights the various objectives and sums them to form a single objective. Other methods allow multi objective optimization, such as the calculation of a Pareto front.

Models

The designer must also choose models to relate the constraints and the objectives to the design variables. These models are dependent on the discipline involved. They may be empirical models, such as a regression analysis of aircraft prices, theoretical models, such as from

computational fluid dynamics, or reduced-order models of either of these. In choosing the models the designer must trade off fidelity with analysis time.

The multidisciplinary nature of most design problems complicates model choice and implementation. Often several iterations are necessary between the disciplines in order to find the values of the objectives and constraints. As an example, the aerodynamic loads on a wing affect the structural deformation of the wing. The structural deformation in turn changes the shape of the wing and the aerodynamic loads. Therefore, in analyzing a wing, the aerodynamic and structural analyses must be run a number of times in turn until the loads and deformation converge.

Standard form

Once the design variables, constraints, objectives, and the relationships between them have been chosen, the problem can be expressed in the following form:

find $\boldsymbol{x}$ that minimizes $\boldsymbol{J(x)}$

subject to $\boldsymbol{g(x) \leq 0}$, $\boldsymbol{h(x) = 0}$ and $\boldsymbol{x_{lb} \leq x \leq x_{ub}}$

where $\boldsymbol{J}$ is an objective, $\boldsymbol{x}$ is a vector of design variables, $\boldsymbol{g}$ is a vector of inequality constraints, $\boldsymbol{h}$ is a vector of equality constraints, and $\boldsymbol{x_{lb}}$ and $\boldsymbol{x_{ub}}$ are vectors of lower and upper bounds on the design variables. Maximization problems can be converted to minimization problems by multiplying the objective by -1. Constraints can be reversed in a similar manner. Equality constraints can be replaced by two inequality constraints

2.4 Overview of Pineapple Industry in Ghana

In the last 20 years, Ghana has made considerable progress in the development of its horticulture export industry. Currently Ghana has the potential to become a world leader in horticulture production having made remarkable strides in pineapple, papaya, mango and vegetables production and exports.

Pineapple is one of the major crops that have made tremendous strides over the period. Ghanaian firms began exporting the Smooth Cayenne variety of fresh pineapple to Europe - which was and still is the major destination - by air in very small quantities in the mid nineteen eighties by sourcing from smallholder farmers in the Akuapim South District in Ghana. These smallholder farmers initially supplied the Nsawam Canneries Limited, a Government owned fruit processing firm engaged in canning pineapple juice for the local and export markets (Korboe 2012). The early nineteen eighties saw the development of commercial indigenous farms by Ghanaian entrepreneurs from diverse professional and business backgrounds. Korboe (2012) further indicated that the production of these commercial farms was principally to complement purchases from the smallholder farmers and focused on Smooth Cayenne variety of pineapple though the Sugar Loaf variety of pineapple existed but was only grown in small quantities in the Central Region of the country for local consumption. The Queen variety of pineapple was also introduced to Ghana in 1999 by Jei River Farms but, like the Sugar Loaf, was also very limited in production to a few commercial farmers having very limited market opportunities in Europe. Some of these farms were Combined Farmers Ltd located near Obodan in the Akuapim South District (which in the nineteen eighties and early nineteen

nineties was the largest producer and exporter of fresh pineapple in Ghana) and Jei River Farms Limited at Ofaakor in the Awutu Effutu Senya District

The export industry developed as a result of availability of commercial cargo airplanes delivering part accessories to the oil fields in Nigeria and flying northbound empty. This offered the opportunity for fresh pineapple exporters – led by Combined Farmers Limited, Koranco Farms Limited and Farmex Limited – to establish freight companies and charter cargo planes (Korboe, 2012). Ghana has, over the period, been the largest exporter of fresh pineapple by air due to this distinct advantage. The industry experienced growth in export from 1994 to 2004 at a cumulative annual growth rate of 172%. This resulted in increased market share of fresh Ghanaian pineapples in Europe from about 8% in 1999 to 10% in 2004 with an annual volume of 71,000 MT (SPEG, 2009).

Thus between 1990 and 2004, pineapple exports grew from 12,000 MT to 71,000 MT, becoming Ghana's main horticulture export product. There was however a sharp decline thereafter to 32,000 MT in 2008 (Figure 2.3) due to shift in the market preference for MD2 variety, which was then not available in Ghana. The variety was produced primarily in Costa Rica by Del Monte. There has since been introduction of this variety to the pineapple industry in Ghana and is catching up well.

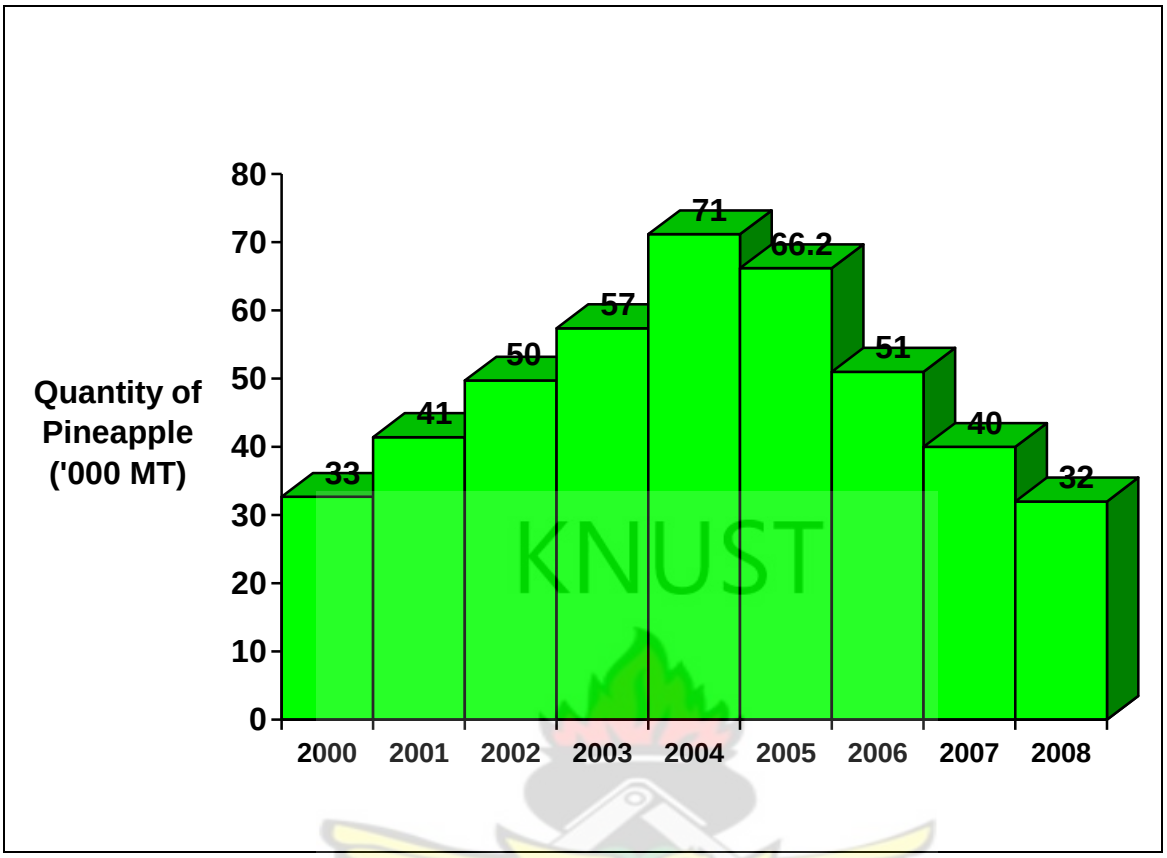


Figure 2.3: Ghana Pineapple Exports (2000 – 2008)
Source: Sea-Freight Pineapple Exporters of Ghana

Due to the specialized skill as well as high cost of MD2 production, its production is predominantly by large-scale pineapple estates in the country. The major ones are Bomart Farms Limited, Jei River Farms Limited, Unifruits, Golden Exotics Ghana Limited, Greenspan Farms, Georgefields Farms, Prudent Export Farms, Chartered Impress and Green Fields Farms. These companies have the requisite financial muscle as well as technical capacity to produce MD2. Consequently the price of MD2 is controlled by these companies and this restricts the major processors such as Blue Skies Products Ghana Limited to limited source options. Thus they virtually dictate the price and this makes it very difficult for processors to have enough to process. Thus the sector's growth has been driven principally by innovative entrepreneurs in the private sector.

Shipping of the commodity is either by air or sea freight. While airfreight is more expensive, it gets fruits to international markets faster and therefore in better condition. Sea freight on the other hand, moves bulk quantities at a cheaper rate but is slower in delivering fruits to target export markets. The pineapple industry trade is dominated by export of fresh fruits to the EU, mostly to France, Germany and Spain. The Sea-freight Pineapple Exporters of Ghana (SPEG) controls more than 70% of total pineapple export.

After positioning its production in the low-end European pineapple market, where Ghana defied its competitors with a low-cost approach, the country was soon losing ground against new competitors and market changes (Danielou and Ravry, 2005). The authors further explained that the industry had to face this serious crisis and take on these new challenges. A new market strategy was thus adopted by the industry founded on adaptability, diversification, and innovation. Ghana diversified toward other high-demand horticultural produce, such as fresh papaya, mango, and Asian vegetables, and facilitated the development of processed goods for export, in particular, sliced pineapple for fruit salads. These events have dramatically transformed the lives of growers and inversely contributed to the development of a new segment of the agricultural sector, whose dynamism now attracts significant investment. The country now faces important market changes, led in particular by the quick adoption in global markets of the new pineapple market variety, the MD2.

Box 1. Some Pineapple Varieties

Cayenne — big, cylindrical, deep orange fruit with flat eyes and a light yellow flesh. Its taste is sweet-sour. Smooth Cayenne is the most common variety worldwide, both for processing and fresh eating.

Queen or Victoria — small, conical, yellow fruit with pronounced eyes and a yellow flesh. Sweet and very aromatic, this variety is often used for growing "baby" pineapples.

Sugarloaf — large, heavy, and mildly sweet.

Pernambuco — sweet and medium-sized.

Variegated — sweet, white fleshed.

Baby — very sweet.

Red Spanish — medium-sized, purple-hued skin and light yellow flesh.

New varieties — the MD-2 is particularly rich in vitamin C and does not contain much acid.

Pineapple is grown primarily as cash crop mostly in the Greater Accra, Eastern and Central regions of Ghana. The popular varieties in Ghana are smooth cayenne and sugar loaf. The recent increase in demand for MD2, an exotic variety, in most of the pineapple importing countries has changed the landscape of the pineapple industry. Most of the farms are switching over to this preferred variety. Fresh pineapples are available year-round, with the peak period between March and July. The pineapple industry on the whole has four distinct groups of participants. These are identified as small-scale farmers, medium scale farmers, commercial farmers and large-scale farmers.

There are seven principal functions in the pineapple subsector. These functions are sucker production, production of pineapples, harvesting, postharvest handling, processing, storage and shipping.

Sucker production involves all activities including research and input supply that go into the production of planting material for the subsector. Cultivation of the pineapple fruits includes land preparation, planting and farm maintenance. New scientific plant technologies require major resource commitments and involve relatively high risks regarding payoff. Because these are worldwide problems, new funding sources and mechanisms of cooperative research and development (R&D) must be found (Rohrbach, 1997). Financial incentives were given to growers producing pineapples for export as part of the 1993 Economic Recovery Programme in Ghana, aimed at reducing dependence on cocoa as the country's principal export crop (Donkoh and Agboka, 1997)

Harvesting and post-harvest handling are treated as two distinct functions because pineapple is a horticultural crop which has to be managed in a specialized manner after harvesting if it is to meet stringent international export specifications for such crops. Processing involves transforming the fresh fruit into single strength juices, concentrates or into a high-value chopped fresh product.

There are six major pineapple processing companies: Blue Skies Products Ghana Limited, Milani Food Processing Company Limited, Peelco Limited, Pinora Limited, Akramang Processing Industries Limited and Athena Foods. Blue Skies and Peelco Limited are into

production of fresh cut pineapple for the export market whilst the rest are into production of juice and drink for the domestic and export markets. The demand from these companies is gradually reviving the pineapple industry and could encourage farmers to go back to Smooth Cayenne production. Moreover the two major projects (Trade Investment Program for Competitive Export Economy-TIPCEE, and Agricultural Development for Value Chain Enhancement-ADVANCE) that were financed by USAID played key roles during their respective project phases to support these processing companies in their activities especially in development of quality standards and linkages to farmers as well as introduction of farmers to improved pineapple production technologies and management of their activities to improve efficiency. The ADVANCE project has contracted one of the large pineapple estates, Bomarts Farms Limited, which is a private limited Ghanaian Company with shareholders from Ghana and Switzerland, to produce 20 million Smooth Cayenne suckers for farmers to enable them produce for that rejuvenated pineapple market. This became necessary because most of the farmers moved away from that variety and lost their planting materials as a result of the sudden shift of the market preference to MD2 in 2005.

PEELCO Limited

Peelco Limited is a fruit processing company located at Bawjiase in the Central Region of Ghana. It is about 50 km West of Accra, the national capital. It is a German and Ghanaian owned company operating under the Ghana Free Zones Board. The main focus of the company is processing and export of tropical fruits, predominantly pineapple for the export market with German market as the primary target.

Milani Food Processing Company Limited

It is a fruit processing company located at Abelenkpe in Accra. It processes pineapple into drink for the domestic market. It also exports fresh pineapple under the fair trade to the EU market where its produce earn US$0.05/kg of export. It exports pineapple under the Delighana brand name.

Pinora Limited

Pinora produces aseptic and frozen NFC juices as well as concentrates from oranges and pineapples. The company is SGF member and organically certified by IMO, Switzerland. It is located at Asamankese in Eastern Region and processes pineapple and oranges for the domestic and export markets. It sources fruits from outgrower farmers as well as medium and large scale commercial farmers. It sources 30% of its pineapple needs from its own nucleus farm.

Akramang Processing Industries Limited

Akramang Processing Industries Limited was established in 1995 and it processes pineapple, oranges, passion fruits, mangoes and banana into food drinks for the domestic market. Pineapple forms 55% of quantity of fruits processed for the market. It is located at Akramang in the Gomoa East District of the Central Region and sources its fruits from 20 outgrowers within a 10 km radius. Even though it is able to source all its fruits needs for processing from these farmers, it is however faced with the challenge of procuring enough bottles for packaging. It therefore resorts to the use of 5 liter plastic containers and target hospitality industries, especially hotels and restaurants.

Athena Foods

Athena Foods is a privately owned Ghanaian company that was incorporated in 1994. The company, which is located at Tema, processes and sells juices and concentrates made from tropical fruits including organic pineapple and oranges. Athena Foods sells its products beyond Ghana to several European markets, including Spain, France, and Germany. It sources fruits from farmers' groups and associations located within the major producing areas of pineapple and oranges.

Even though some of these processing companies have been operating for some time, they do have adequate records that were needed for the study. Moreover, Blue Skies Products Limited is the largest fruits processing company and had the best set up as well as records on parameters that were needed for the study. Furthermore, the latter was very much open and interested in the study than other companies.

2.5 Blue Skies Products Ghana Limited

Blue Skies Products Ghana Limited, which was established in Ghana in 1998 and currently having subsidiaries in Brazil, South Africa, Egypt and the Gambia, is a privately owned fruits processing company located at Dobro near Nsawam about twenty six (26) km north of Accra, the national capital of Ghana. It is the largest fruit processing company and contributes about 1% of Ghana's total export value of horticultural products exports; and in 2008 received the Queen's Award for Sustainable Development.

Fresh pineapple supplies to the Blue Skies processing plant meet Global GAP standards of certification. The raw materials are supplied by wide spectrum of farmers whose farms are inspected by the company's agronomist. It initially certified 18 farmers in 2002 to produce and supply the company with fresh pineapple fruits for processing. The number of certified farmers increased to 25 in 2003. The certification was done under the Global GAP which gives Blue Skies Products Ghana Limited opportunity to obtain a premium for its products. Thus its products are of good and consistent quality, safe and offer supply continuity. The company is also a certified Business Social Compliance Initiative and therefore very ethical on workers health and safety welfare. Moreover it is Fair Trade certified as well as LEAF (link environment and farmers) certified. The latter enhances standards to protect the environment to ensure that there is no environmental load, especially to water bodies. Under the Fair Trade regime the respective farmers gets guaranteed fair prices as well as premium for community development. The farmers are paid on weekly basis allowances that might have accrued from the company's sales under Fair trade

When the fruits arrive at the factory's main gate, the staff of the security department records the particulars of the vehicle, including that of driver and the type of fruit. This is to monitor the flow of vehicles, produce and people to and from the fruit processing plant.

Staffs from the quality assurance department then take samples of the fruits which are brought in plastic perforated containers in a vehicle for thorough inspection to find out whether it meets the specifications required. They have the liberty to reject all those fruits that fall outside the preferred parameters as per the suppliers' contract. This is to ensure uniformity and

consistency in the produce to the company. Minimum Residue Levels (MRL) of various elements and compounds in the fruits are determined to establish whether it meets international standards. There are also checks to establish the sugar-acid ratio as well as other pathological and mechanical damages to the fruits.

At the intake point, the fruits are counted and given batch numbers. The staff and the suppliers, who are usually farmers, sign a document to confirm the quantity and quality of fruits supplied. This is to facilitate tracing of fruits to the farm and location as well as farm management practice being followed by the respective farms.

The fruits are emptied on belt conveyor into the processing hall for sanitization by thoroughly washing in *Citrox BC* (Citric acid, Biflovinols) bath to disinfect the fruits from foreign material and microorganisms in the "low care" processing hall. The fruits are then washed in ascorbic acid solution to prevent browning.

The washing process is followed by peeling of the fruit. The peeling is done mechanically and manually depending on the type of fruit. For pineapple, peeling is done mechanically using tole cutter; and chunking is also done using mechanical chunking equipment which cuts the fruits into the right shape and size as required by the market.

Chunking, which is done in the "high care" processing hall, is usually to the specification as requested by the respective buyers. The chunked fruits are then moved to another section within the "high care" processing hall for packaging into small transparent plastic (PET)

containers, sealed and labeled. The content of the label depends and vary from buyer to buyer. This is to meet the standards and the specifications of the respective countries and preference. The containers and their contents are then conditioned (blast chilling) to attain the right temperatures so as to maintain the quality and freshness of the product before it leaves the factory. The containers are then packed into cartons and then into freight containers of airlines of the respective destinations in the European Union (EU). The freight containers are also kept in the cold room until the entire batch for export that day is ready. They are then rolled into a refrigerated container trucks to airport.

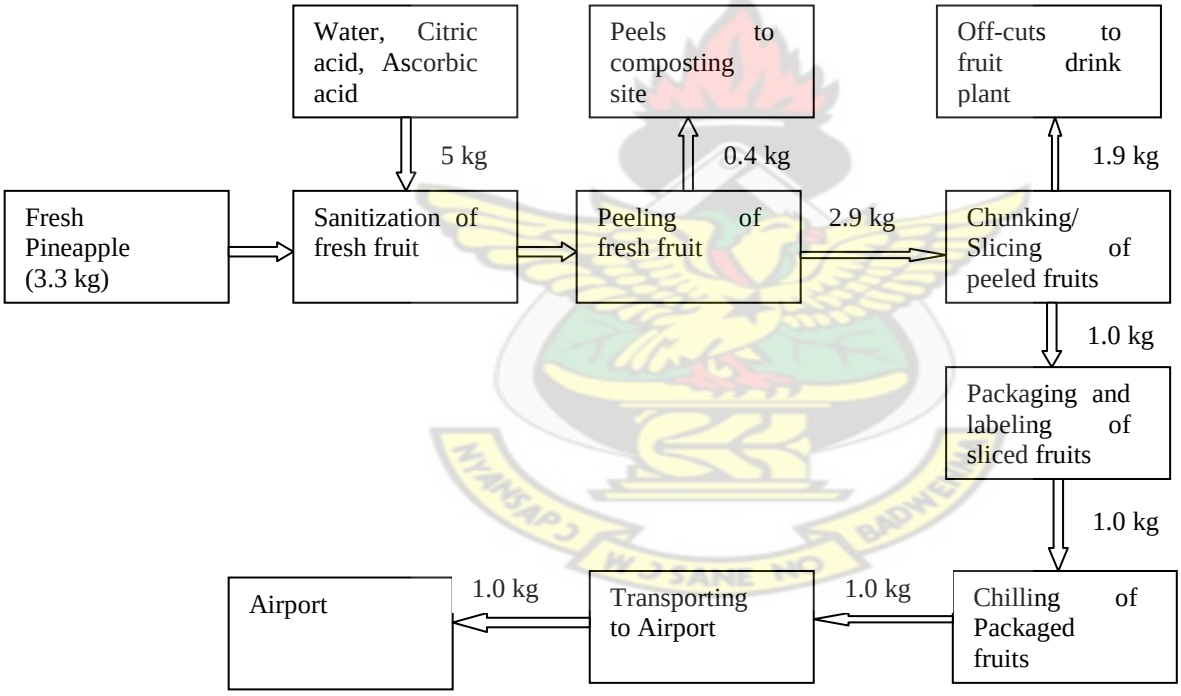


Figure 2.4: Flow Diagram for Sliced Pineapple Production

At the airport, the freight containers, with their contents are kept in a transit cold facility. It is kept in the cold room to ensure that the product maintains its temperature and freshness to prevent deterioration in quality. The containers are released 45 minutes before departure. All these are to maintain the quality and freshness of the fruits.

2.5.1 Source of Water and Energy

The company's source of water is from a borehole. The water is filtered, sterilized using an Ultra Violet (UV) sterilizer and then pumped into a surface storage tank. Booster pumps are used to pump water to service all the areas within the processing plant. This is what is used for all the processing activities.

The company primarily sources electric power from the national grid, which is a mix of hydropower and thermal power sources. It also has a stand-by 1,400 KVA diesel-electric power generating set. There are also 725 KVA and 700 KVA diesel-electric generating sets which are used as an alternative source when the 1,400 KVA diesel-electric generating set is faulty and there is power failure from the national grid source of electricity.

CHAPTER 3

METHODOLOGY

Life-cycle studies range from highly detailed and quantitative assessments that characterize, and sometimes assess the environmental impacts of energy use, raw material use, wastes and emissions over all life stages, to assessments that qualitatively identify and prioritize the types of impacts that might occur over a life cycle.

The methodology is proposed to systematically analyze the uncertainties involved in the entire procedure of LCA for pineapple fruit processing at the fruit processing plant. The methodology also explores the degree of uncertainty of various impact categories. The Monte Carlo simulation is used to analyze the uncertainties associated with LCI, LCIA, and the normalization and weighting processes. The uncertainty of the environmental performance for individual impact categories (e.g., carcinogens, respiratory organics, respiratory inorganics, climate change, radiation, ozone layer, ecotoxicity, acidification/eutrophication, land use, minerals and fossil fuels) is also calculated and compared.

The study is also to investigate impact on the environment in the use of only electricity from the national grid source or from diesel-electric generating set or a combination (hybrid) of the two, to establish optimum model that would minimize environmental burden. The use of PET containers in packing different weights of sliced pineapple and then packaging (different quantities of PET containers with sliced pineapple) in cardboard packaging boxes as part of the processes at the fruit processing plant and its consequential impact on the environment is also examined to ascertain environmental load of these processes.

There are several LCIA methods including many studies have evaluated the results of different LCIA methods that are applied to the same LCI data (Bovea and Gallardo 2006; Raluy et al., 2004, 2005; Seo et al., 2004). According to Hung and Ma (2009) Eco-indicator 99 LCIA method gives the lowest uncertainty and normalization step has lower uncertainty than weighting step using the same method. This research work is based on Eco-indicator 99 (H) LCIA methodology.

Furthermore, in a comparison of ecological scarcity, environmental theme, and EPS LCIA methods, Baumann and Rydberg (1994) pointed out that the different calculation outcomes resulted from differences of computation algorithms and background data. Brent and Hietkamp (2003) studied CML, Ecopoints, Eco-indicator 95, Eco-indicator 99, and EPS, organized the difference in terms of classification, characterization, normalization, and weighting of the five methods, and investigated the contribution of various pollutants to environmental impacts with empirical cases. It was discovered that different evaluation methods produce different results, and it is incorrect to directly apply normalization and weighting of the LCIA method without modification. The establishment of normalization and weighting for local conditions is necessary to make the evaluation meaningful (Hung and Ma, 2009).

Dreyer et al. (2003) also compared EDIP97, CML2001, and Eco-indicator 99 and discovered that in the same impact category, especially for human toxicity, different pollutants were identified as major contributors for different LCIA methods. The results led to the advice that a proper LCIA method should be selected based on professional judgment on the reasonableness

of assessment results. This buttresses the need to focus on an LCIA method for this research work: thus the use of Eco-indicator 99 (H).

The LCA methodology is ISO Standardized (ISO 14044) and has often been used to assess the environmental impact of agricultural products (e.g., Cederberg & Flysjö, 2004; Basset Mens & van der Werf, 2005; Williams et al., 2006; Dalgaard et al., 2007b).

This study was conducted in accordance with all requirements of the International Standards ISO 14040, 14041, 14042 and 14043 relating to Life Cycle Assessment (ISO, 1997, 1998, 2000a, 2000b, 2006, 2006). SimaPro 7.1.8 (PhD version) LCA software developed by the Pre Consultants (2008b) was used to analyze the data using the Eco-indicator 99 (H, Hierarchist version) method.

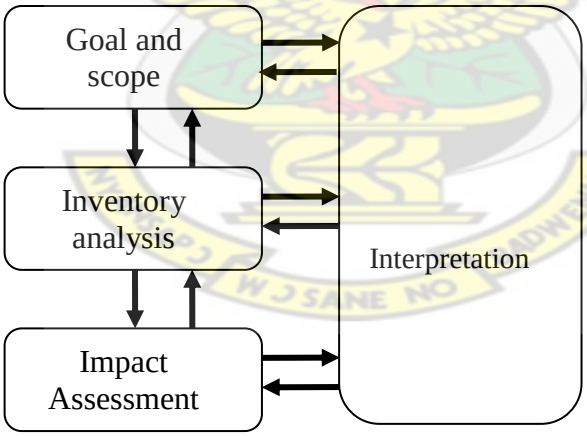


Figure 3.1: Components of a Life Cycle Assessment (ISO 14040, 1997)

3.1. Goal and Scope

Goal definition and scoping is perhaps the most important component of an LCA because the study is carried out according to the statements made in this phase, which defines the purpose

of the study, the expected product of the study, system boundaries, functional unit (FU) and assumptions (Roy *et.al.,* 2009).

3.1.1 Goal of the Study

The goals of this study are:

i. To discuss and propose some guidelines for scientists carrying out environmental assessment studies on fruits processing plants using emerging technologies and Monte Carlo analysis;

ii. To summarize some general recommendations on how to improve the environmental performance of fruits processing plants.

iii. Promote the development of LCA research and application in Ghana

The study therefore focused on the following three specific areas:

i. Conduct LCA on production of sliced pineapple at the fruit processing plant using Monte Carlo simulation method

ii. Compare environmental impact of different sources of electric energy in production of sliced pineapple at the fruits processing plant

iii. Optimize combination of electric energy sources, use of PET containers and cardboard packaging boxes to generate minimum environmental load

The study comprises the inventory corresponding to all process stages including the harvesting and transporting of fresh pineapple fruits, processing and packaging of pineapple fruit and transport of processed pineapple to the airport.

3.1.2. System Boundary

System boundaries of this study are presented in Figure 3.2. It does not include:

i. the production of pineapple,

ii. manufacture and disposal of packaging materials,

iii. manufacture of processing equipment,

iv. the use, end of life of processed pineapple fruit

v. disposal of solid and liquid waste

These aspects were excluded from the study due to lack of relevant data for the respective systems and processes.

The following assumptions were made in defining the boundary of the study.

i. The processing was done for twenty four (24) hours per day

ii. 94% of electric power at the factory is from national grid electricity and 6% is from diesel-electric generating set

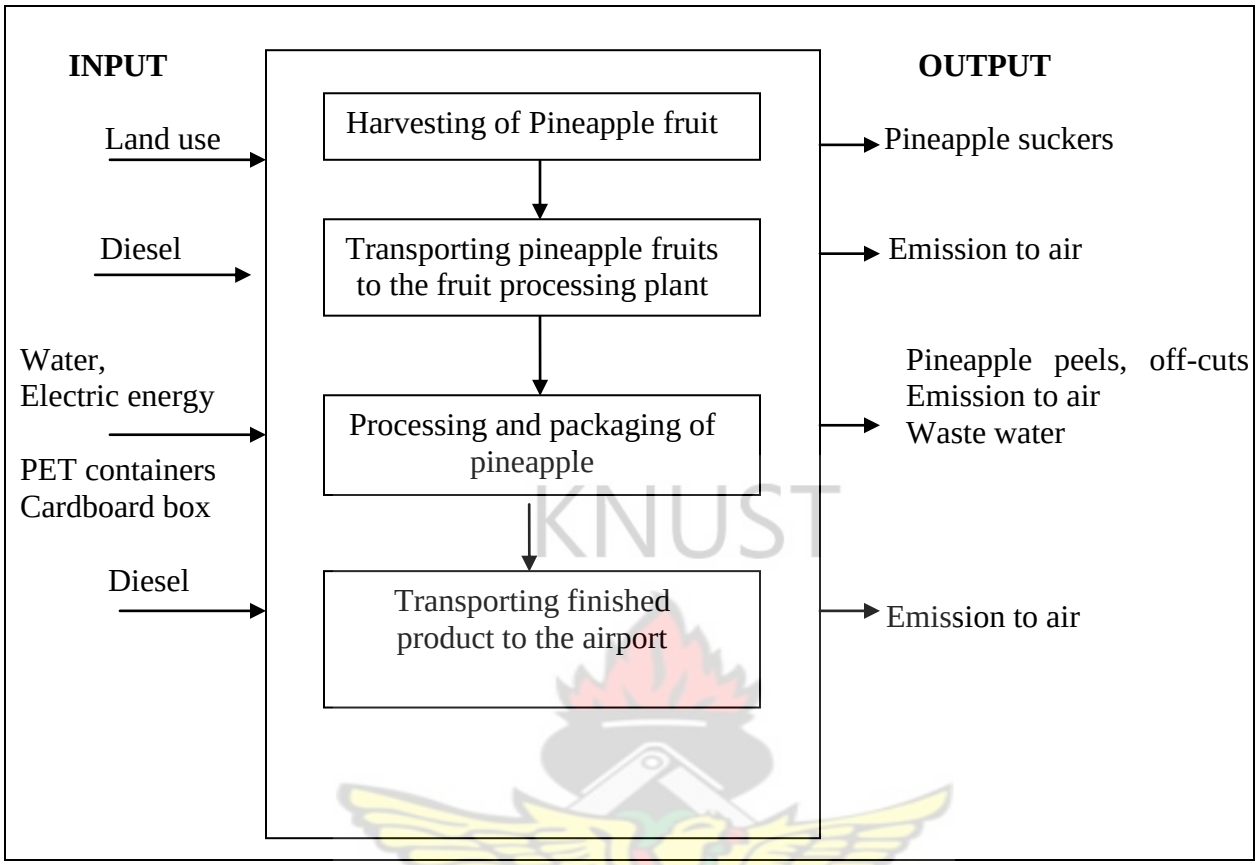


Figure 3.2: Flowchart for production of sliced pineapple at fruit processing plant (Blue Skies Products Ghana Limited)

The study is focused on these processes:

i. harvesting and transporting of fresh pineapple to the fruit processing plant,

ii. processing of pineapple,

iii. packaging of sliced pineapple in PET containers and then in cardboard packaging box

iv. transporting of finished product to the airport for export

Major activities at the fruit processing plant generally include fruit collection, processing, storage, transportation and waste disposal. The case study focused on the environmental impacts of pineapple transportation, processing and storage. The boundary set for the research

work was from when the fruits were harvested and transported to the premises of fruits processing plant to when the processed fruit leaves the processing plant and arrives at the airport. This includes all the processing activities that go on within the processing plant from fresh fruit to processed product. The research work is based on pineapple which is the main fruit that the company is handling.

Transportation is the process to transfer the pineapple fruits from farm to the processing plant; as well as transportation of finished products from processing plant to the airport. Main input at this stage is the amount of diesel and oil used in transportation of fresh fruits and finished product. Output is the air pollutants produced by burning diesel oil as well as dust and particulates from the wear-and-tear of the tyres during transportation.

Fruit processing is the stage whereby fresh pineapple is processed into products through various units of operation to meet the markets specification. The major inputs in this stage are the weight of pineapple entering into processing line and the energy provided by electric power. The outputs are the amount of air pollutants emitted by the source of energy; effluent and solid waste from the processing hall.

3.1.3 Functional Unit

This is taken as an average year's operation of the fruit processing plant, i.e. the amount of electricity, pineapple fruit, PET containers, cardboard packaging boxes, diesel, and water required by the average annual operation of the plant. An average year's operation of the fruits processing plant is chosen as this is most compatible with the data available for the study,

although a daily or monthly operating window is equally valid. The time period cannot be less than the monitoring time interval of the data. For this study, the data is predominantly available in monthly reports, so a time period of a year chosen in order to be sure that the variance of the data samples provides a sufficient estimate of annual variability (i.e. the monthly variation will provide an overestimate of annual variability, since the latter is typically lower due to averaging effects). The study is not able to address possible "spikes" in the operation of the processing plant (e.g. a sudden increase in volume or decrease in quantity of pineapple processes). The aim of this study is to capture the possible range in environmental effects, and make explicit the trade-offs that will have to be taken.

The annual data was processed to determine the processes and resources needed to produce 1 MT of sliced pineapple at the processing plant. The data was fed into the SimaPro software. The software processes input data and generates results based on one (1) kg of slice pineapple product produced.

3.1.4 Allocation

In the allocation process, environmental burden is attributed to the respective units of operation and other systems that use same resources for its activities. At the fruits processing plant, 20% of electricity consumed is assigned to non-production operations. The processing plant sources 94% of its electric energy from national grid (70% hydroelectric power and 30% light oil-fired power plant) and 6% from diesel-electric generating set.

3.1.5 Data Quality Requirements

Reliability of data in LCA is very crucial to determining the impact of the processes on the environment (ISO 14041, 1998).

- the data were crosschecked with different departments within the processing plant
- the data were processed into useful information and simulation was performed to ensure its reliability
- information that were not available were sourced from secondary data and confirmed with those responsible at the fruits processing plant

3.2 Life Cycle Inventory

The LCI provides a causal link between process design and performance, and potential environmental impact. This link is an important tool in the analysis and design of process systems for better overall environmental performance. LCI quantifies the energy and materials used and wastes released to the environment during all phases of the life of a product. Product life cycle is divided into raw material extraction, material preparation, manufacture, use, and final disposal (Gloria *et al*., 1995; McCleese and LaPuma, 2002). LCI is comprehensive because all phases of a product life cycle are considered.

According to U.S. Department of Transportation (1994), most emission models in widespread use, such as EPA's mobile source emissions model, MOBILE, rely on deterministic methods to characterize emissions. In other words, a single value is assigned to each input variable and a single value is computed for each output. The deterministic method produces an output that

does not address the variability or uncertainty inherent in each of the input variables. These deterministic estimates fail to place point estimates in the context of the uncertainty in which they were developed (Finkel, 1995).

One way of accounting for the variability and uncertainty of emissions and energy inputs for the processing and packaging of pineapple is to use probabilistic methods such as Monte Carlo simulation. Monte Carlo simulation is a technique of simulating real world behavior with variable distributions instead of point values. By using Monte Carlo simulation method to specify a distribution for emissions due to distances covered by vehicles as well as source of electricity, a range of probable estimates to include the high emitters will provide a better representation of reality.

The advantage with Monte Carlo simulation is that it allows the modeler to estimate the uncertainty in each input variable and predict the impact of that variable on the outputs. The Monte Carlo method provides the decision maker with a range of potential outcomes along with the predicted chance of their occurrence (Finley and Paustenbach 1994; McCleese and LaPuma, 2002).

In order to assign LCI results, LCI of the respective processes were conducted. The LCI study was conducted in accordance with all requirements of ISO 14041 (1998) relating to Life Cycle Inventory Analysis (LCI). The complete inventory was integrated by main environmental loads (inputs, outputs): energy and raw materials consumed, wastes produced, and emissions to air, water and soil.

Ghana's power supply sources are mainly from hydro-electricity and thermal from light crude oil. Currently the country has an installed generation capacity of 2,062 MW, with the Akosombo Dam generating 1,020 MW, while Kpong Dam produces 160 MW. In the case of thermal power generation, TAPCO (VRA) produces 330 MW; TICO, 220; the Mines Reserve Plant, 80 MW and the Tema Thermal Power Plant, 126 MW, while the Emergency Power Plant generates 126 MW (Marfo *et al.*, 2010). Currently the country's peak demand for power is about 1,350 MW. The hydro-power source contributes average of 70% of this amount of power distributed.

The fruit processing plant, Blue Skies Products Ghana Limited, electric energy source is average of 94% from the national electricity grid and 6% from 1,400 KVA diesel-electric generating set. In the research work, the percentage of power contribution from the national grid and diesel-electric generating set sources were varied using simulation. They were varied between 0% and 100% for each to make up the total 100% of power needed for production of sliced pineapple. This was to establish the environmental load for each of the combinations to make an informed decision on an optimized contribution that would minimize impact on the environment.

Pineapple fruits are sourced from farms between 6 km and 15 km away from the fruit processing plant. The fruits are transported in 5 MT capacity diesel engine trucks to the processing plant. The fruits are weighed and, various quality and other relevant analyses are

conducted to ascertain whether they meet the standards requirements expected for processing. Detail processes have been described in section 2.5.

The processed fruits are transported over 22 km to the airport in a 30 MT capacity refrigeration diesel engine truck.

Table 3.1: Input data for production of 1 kg of sliced pineapples

Input	**Amount**	**Units**
Fresh pineapple fruit	3.3000	Kg
Water	5.0000	Kg
Pet bottles (grade B250)	0.0600	Kg
Corrugated board double walled card box	0.1520	Kg
Total amount of electric power	0.8590	kWh
Transport from farm to processing plant	0.0347	Tkm
Transport from processing plant to airport	0.0220	Tkm

kWh – Kilowatt-hour; Tkm - Ton- kilometer
Source: Blue Skies Products Ghana Limited

Background data on PET bottle, corrugated cardboard box and water production as well as transportation and electricity generation were included using the eco-invent database and the SimaPro software. Thus background data on fuel consumption and emissions for the transportation as well as production of electricity were taken from the eoc-invent data base which is incorporated in the SimaPro Software. Thus it was assumed that the trucks used in Ghana are similar in condition to those used in Europe. Average distances of 10.5 km using 5 MT capacity diesel engine truck and 22 km using 30 MT truck were used to compute the inventory data for transportation of fresh from farm to processing plant and of finished product from the plant to airport, respectively. Foreground data on fresh pineapple fruit, water, weight

of PET bottle, corrugated board for packaging and the consumed electricity used in the simulation are given in Table 3.1. These data were input in the SimaPro Software (PhD version) installed on a computer for the analyses. The software among other options uses Monte Carlo simulations to analyze data for LCA.

3.2.1 Records on Operations

At each of these units of operation, records are taken on the type and variety of fruit, weight, quality and other parameters of the processing hall such as humidity and temperature. Some of the key data are:

Pre-Processing Data

- Brix level
- Maturity (age of fruit)
- Colon index of the fruit
- Mechanical damage (bruises)
- Pest infestation
- General hygiene of the fruit
- Quantity and weight of fruits
- Batch numbers

Washing Unit Data

- Strength of sanitizer

- Stock control to facilitate traceability and also to meet the quantity required in the 'high care' area

High Care Department Data

- Stock control to ensure that batches are not mixed
- Quantity and weight of fruit that enters the section
- Weight of final product
- Number of packaging
- Yield – product recovery rate
- Engineering data for repair and maintenance
- Quality defects
- Data on quantity of boxes per freight container
- Random quality check on the cut fruit to ascertain quality

Data on Waste

- Quality of effluent
- Weight of solid waste

3.3. Life Cycle Impact Assessment

Life Cycle Impact Assessment is quantitative and/or qualitative process to identify, characterize and assess the potential impacts of the environmental interventions identified in the inventory

analysis (Udo de Haes, 1996). The impact assessment methods themselves are described in ISO 14042. In this standard a distinction is made between:

- **Obligatory elements**, such as classification and characterization
- **Optional elements,** such as normalization, ranking, grouping and weighting

This means that according to ISO, every LCA must at least include classification and characterization. If such procedures are not applied, one may only refer to the study as a life cycle inventory (LCI). An important distinction is made between internal and external applications. If results are intended to compare (competing) products and they are to be presented to the public, weighting may not be used.

There is the need to select LCIA method that can integrate the impact categories into a single score. In this phase, the LCI results are translated into contributions to the single score using Eco-indicator 99 (H). Thus Eco-indicator 99 (H) method was used for the impact assessment. SimaPro 7.1.8 (PhD version) LCA software developed by Pre Consultants (2008b) was used for the LCIA.

The impact assessment of operations of the fruits processing plant was based on the Characterization, Damage Assessment, Normalization, Weighting and Single score. Under each of the impact assessment the contribution of some of the key processes involved in production of sliced pineapple to the various impact categories were determined.

The following processes involved in production of sliced pineapple were considered: harvesting and transportation of fresh pineapple fruits to the fruit processing plant, water, PET

containers, cardboard packaging boxes, transportation of finished products and electricity from national grid (70% hydro-electric power and 30% light oil-fired electric power plant) and diesel-electric generating set (generator), respectively. The impact categories considered were Carcinogens, Respiratory organic, Respiratory inorganic, Climate change, Radiation, Ozone layer, Ecotoxicity, Acidification/Eutrophication, Land use, Minerals and Fossil fuel.

Monte Carlo simulation is used to evaluate system uncertainty. One thousand sets of simulations were conducted. The rankings of processes based on overall performance of LCA assessed by distributions of LCI, normalization, and weighting are compared. An uncertainty index is derived to determine which parts of the LCA processes are primary contributors of uncertainty. The Monte Carlo simulation is used to analyze the uncertainties associated with LCI, LCIA, and the normalization and weighting processes. Thus Monte Carlo Simulation is a technique that converts uncertainties in input variables of a model into probability distributions. By combining the distributions and randomly selecting values from them, it recalculates the simulated model many times and brings out the probability of the output (Iordanova, 2007).

Moreover, the following damage categories: human health, ecosystem quality and resources; were analyzed under damage assessment, normalization and weighting using the Monte Carlo simulation method. The single score was used to ascertain the environmental load from the various processes involved in sliced pineapple production at the fruit processing plant.

Thus the Monte Carlo method is used to combine individual probability distributions of LCI parameters and variant methods of normalization, weighting, and LCIA models to produce probability distributions of impact performance estimates.

Further details on the LCIA application used in the study have been described in Chapter 4.

3.4. Life Cycle Interpretation

The life cycle interpretation is the last stage in ISO methodological framework for conducting research in LCA (ISO 14043, 2000b). This stage of the framework is to analyse and discuss the results of the LCI and LCIA and to serve as guide in decision making process by policy makers and business owners. This has been discussed in Chapters 4 and 5 where the outcomes of the LCI and LCIA of the fruits processing plant have been examined.

3.5 Optimization of Processes to minimize Environmental Load

The experimental design to optimize the key processes in the production of sliced pineapple at the fruit processing plant was divided into two major parts.

i. Single factor experiments were performed to determine the inlet conditions that would minimize climate change, ozone layer depletion and ecotoxicity. These processes were amount of PET containers used, amount of cardboard packaging boxes and percentage of electricity from the national grid that was sourced for the company's processing activities. Each independent variable was varied over a range whilst keeping the others constant.

ii. The optimization of processes to minimize impact of climate change, ozone layer depletion and ecotoxicity was carried out using Response Surface Methodology (RSM).

3.5.1 Response Surface Methodology

Experimental design for the response surface procedure

A 3 factor, 3 level central composite rotatable design (CCRD) was employed using Design-Expert 8.0 (Stat Ease, USA) optimization software to examine the optimum conditions of sliced pineapple production to minimize impact of climate change, ozone layer depletion and ecotoxicity. For each of the processes: use of PET containers, cardboard packaging boxes, and percentage of electricity from the national grid, the generated runs of the CCRD investigated in this work consisted of eighteen (18) experimental runs with twelve (12) factorial points, two star points and four replicates at the centre point (Appendix D). The low and high factor values were entered in terms of alpha as extreme points (star), thus all other design points were located within these extremes. The design variables were the PET containers, X_1, cardboard packaging boxes, X_2, and percentage of electricity from the national grid, X_3.

Determination of the optimum conditions

The Design-Expert 8.0. software was set to search the optimum desirability of the response variables, i.e., the minimum climate change, ozone layer depletion and ecotoxicity. Experimental data were fitted to the following second-order polynomial model (Eq. 3.1) and the regression coefficients (β's) obtained.

$$Y = \beta_0 + \sum_{i=1}^{k} \beta_i X_i + \sum_{i=1}^{k} \beta_{ii} X_i^2 + \sum_{i=1}^{k-1} \sum_{j=2}^{k} \beta_{ij} X_i X_j , \qquad i < j \quad \ldots\ldots\ldots \qquad 3.1$$

where X_1, X_2, . . ., X_k are the independent variables affecting the responses Y's; $\beta 0$, βi (i=1, 2, . . ., k), βii (i=1, 2, . . ., k), and βij (i=1,2, . . ., k; j=1,2, . . ., k) are the regression coefficients for intercept, linear, quadratic, and interaction terms, respectively; k is the number of variables.

Mathematical equation and response surface plots were used to relate the dependent and independent variables

CHAPTER 4

RESULTS AND DISCUSSION

There are a couple of approaches that have been developed for LCIA (see Appendix C) (Pre Consultants, 2008b). Many studies have evaluated the results of different LCIA methods that are applied to the same LCI data (Bovea and Gallardo, 2006; Raluy et al., 2004, 2005; Seo et al., 2004). According to Hung and Ma (2009) Eco-indicator 99 LCIA method gives the lowest uncertainty. The Eco-Indicator 99 (Hierarchist version, H) approach was used for this research work. SimaPro 7 software (PhD version) developed by Pre Consultants (2008b) based in the Netherlands was used to process all the data.

4.1 Monte Carlo Analyses of Life Cycle Impact Assessment of Sliced Pineapple Production at the Fruit Processing Plant

The fruit processing company sources electricity from the national grid and diesel-electric generating set. The electricity from the national grid is mainly from hydro-electric (70%) and light oil-fired electric power plant (30%). The processing plant uses the diesel-electric generating set when either there is a power cut or voltage from the nation grid is below what is required to operate the processing equipment. Generally, the processing plant accesses 94% of its electricity needs from the national grid and 6% from use of the diesel-electric generating set.

The LCIA on processes involved in the production of sliced pineapple at the fruit processing plant was analyzed to identify which of them has the highest impact on the impact categories as well as the damage categories. Monte Carlo simulation was performed on LCI of all the processes involved in production of sliced pineapple at the fruit processing plant.

Network of the respective processes involved in production of sliced pineapple at the fruit processing plant and their contribution is as shown in Figure 4.1. The network indicates that the use of PET containers has the highest impact (38.6%) on the environment followed by use of electricity from the national grid (34.5%), and then corrugated cardboard packaging boxes (19.1%). The rest are diesel-electric generating set, 3.7%, fresh pineapple supply, 3.1% and transporting of finished product from the factory to the airport contributes 0.435%.

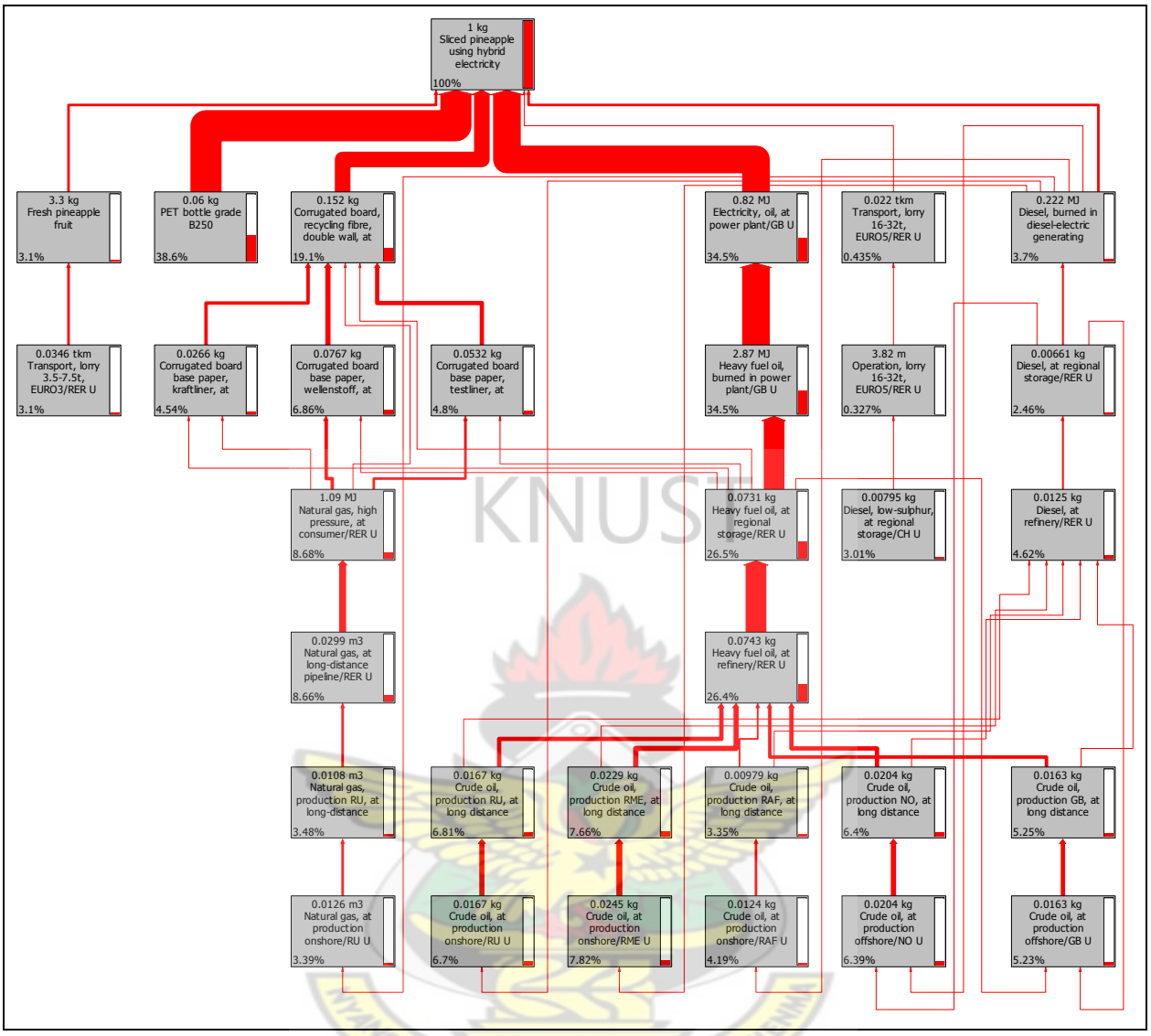


Figure 4.1: Network on Single Score Impact (cut off: 3%) on Environment by Processes in Production of Sliced Pineapple at the Fruit Processing Plant

4.1.1 Characterization Results on Production of Sliced Pineapple

Figure 4.2 depicts the presentation of the characterization results on production of sliced pineapple at the fruit processing plant. It indicates the impact on eleven (11) impact categories by the respective processes involved in production of sliced pineapple. Each of the impact categories is influenced by substances that are generated in processes involved in the

production of sliced pineapple (Appendix A). Some were also generated as a result of producing those materials and services.

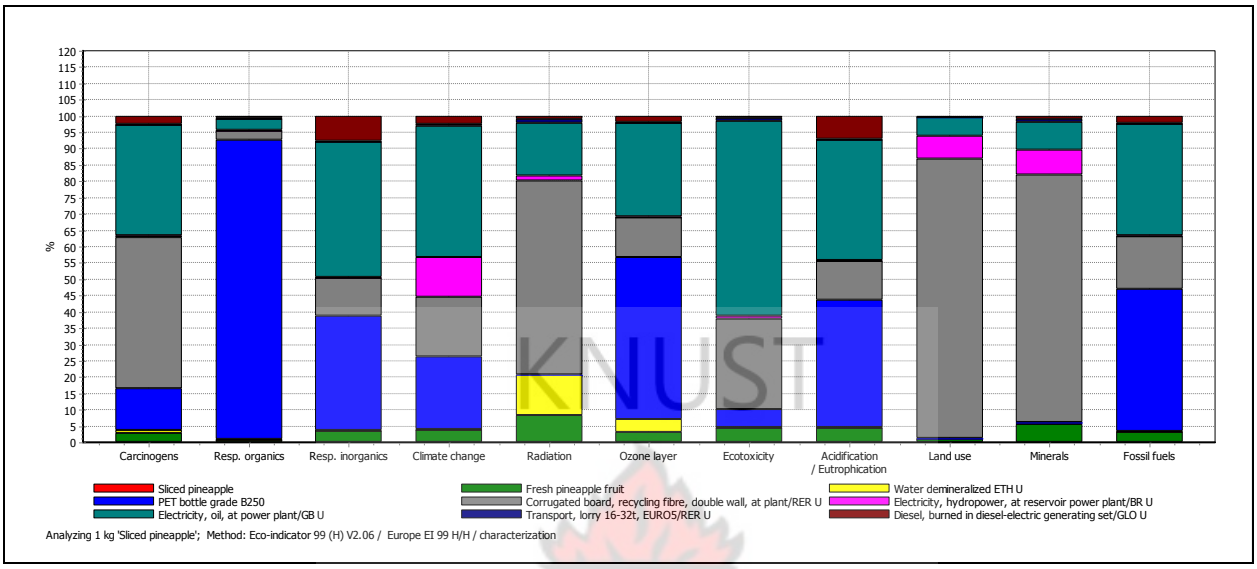


Figure 4.2: Characterization Scores on Production of Sliced Pineapple at the Fruit Processing Plant

Fresh pineapple appears to have contributed to impact categories that are caused by carbon. This has been collaborated by Ingwersen (2012) who indicated that pineapple likely has a higher energy demand and carbon footprint than common tree fruits such as apples and oranges because it is more input intensive. Earlier on West Africa Fair Fruit (2011) in a study had emphasized that the manufacture and use of fertilizers (including fertilizer derived N_2O emissions from soils) in pineapple production contribute 73% of total farm emissions. Almost all fertilizer related emissions are due to nitrogen fertilizer.

Some of the major substances that contribute to the respective impact categories are as shown in Table 4.1. Detail data are in Appendix A. The most significant contributors to global

warming potential are nitrous oxide, methane and CO2, and they are responsible for 44%, 32% and 20% of the greenhouse gas emissions respectively (Dalgaard et al, 2007a). The contributions to climate change from the respective inputs in production of sliced pineapple at the fruit processing plant are shown in Figure 4.2 and Table 4.2. Electricity from power plant fired by light crude oil (forms 30% of national grid electricity) is a major contributor of carbon dioxide from fossil fuel which is highest contributor to climate change.

Table 4.1: Major substances that cause impact categories

Impact category	**Major Substances**
Carcinogens	Arsenic, Cadmium Cadmium, ion; Particulates, <2.5µm; Metals
Respiratory organics	NMVOC, non-methane volatile organic compounds, unspecified origin; Hydrocarbons, unspecified; Methane, biogenic
Respiratory inorganics	Nitrogen oxides, Sulfur dioxide, Sulfur oxides Particulates, Ammonia, Sulfate
Climate change	Carbon dioxide (fossil, biogenic, land transformation); carbon dioxide; methane (biogenic, fossil); methane, dinitrogen monoxide.
Radiation	Radon-222; Carbon-14; Cesium-137
Ozone layer	Methane, bromotrifluor-, Halon 1301; Methane, bromochlorodifluoro-, Halon 1211; Methane, tetrachloro-, CFC-10; Ethane, 1,2-dichloro-1,1,2,2-tetrafluoro-, CFC114; Methane, dichlorofluoro-, HCFC-21
Ecotoxicity	Nickel, Nickel-ion, Zinc, Zinc-ion, Copper, Copper-ion, Chromium, Lead, Cadmium
Acidification/ Eutrophication	Nitrogen oxides, Sulfur dioxide, Sulfur oxides, Ammonia, Sulfate, Nitrate
Land use	Transformation (to arable, to forest, to water bodies, to dump site); Occupation (fruit, road network, industrial area)
Minerals	Nickel (in silicates, crude ore); Copper (in sulfide, ion); Aluminium (in bauxite, in crude ore); iron (in ore, crude ore); Molybdenum (in sulfide); Tin (in cassiterite, in crude ore); Chromium (in chromite, in crude ore)
Fossil fuels	Oils, crude in the ground; oil, crude, feedstock, in the ground; Gas, natural, in the ground

These substances, most of them radioactive, are as a result of the production and utilization of the inputs that were used in the production of sliced pineapple at the processing plant. Thus the production of PET containers, electricity, corrugated cardboard boxes as well as other input materials emitted these substances. Therefore the use of these items and services in the production of sliced pineapple at the processing plant contribute to the respective environmental loads. Thus when a unit product is produced at the processing plant and these items and services are used, the respective environmental loads that were caused during their production are attributed to the sliced pineapple production. Accordingly, when performing an LCA not only processes directly related to the products are assessed. Each input will have a prior history of environmental impacts, which must be included in the assessment

The climate change impact category is mainly caused by carbon dioxide from fossil which is as a result of the use of light crude oil at the power plant to generate electricity to feed into the national grid. This contributes 40% of the substances that cause climate change impact category. Moreover the use of diesel in the diesel-electric generating set at the processing plant is another source of carbon dioxide that contributed to the climate change impact category. The coefficient of variation from Monte Carlo simulation on the LCI for sliced pineapple production of 6.36% suggests that standard deviation of the inputs vary does not widely from the mean.

Methane, bromotrifluoro-, Halon 1301 is the major substance that contributed to ozone layer impact category as a result of the production of PET containers which are used to package slice pineapple at the processing plant. Moreover, the use of light crude oil at the power plant

contributed to emission of this major substance. Methane, bromochlorodifluoro-, Halon 1211; Methane, tetrachloro-, CFC-10; Ethane, 1,2-dichloro-1,1,2,2-tetrafluoro-, CFC114; Methane, dichlorofluoro-, HCFC-21 are other substances that caused ozone layer depletion. It is estimated that 50% of the substances that caused ozone layer depletion are from production of PET containers which are used in the processing activities at the fruits processing plant (Table 4.2). The Monte Carlo simulations show a coefficient of variation of 13.5% (Table 4.3) indicating that the LCIs variability is low. Thus there is not much difference between standard deviation of the substances that contributed to ozone layer depletion and their mean.

Nickel is a major substance emitted into air when light crude oil is used in the power plant to generate electricity that is fed into the national grid. Nickel emission into the air is a major contributor to the ecotoxicity impact category. Furthermore, the production of PET containers and corrugated cardboard double walled boxes emit nickel and other substances such as zinc that contribute to ecotoxicity. Thus the use of these materials and services in the production activities of the fruit processing plant has impact on the respective impact categories. The light crude oil used to generate electricity contributes 60% of substances that cause ecotoxicity. There is coefficient of variation of 60% indicating that standard deviation of the LCI that contribute to the ecotoxicity impact category does not vary widely from the mean.

Carcinogen impact category is mainly caused by these substances: Arsenic, Cadmium, ion; Particulates, <2.5µm; metals. Corrugated cardboard boxes and electricity from light oil-fired power plant which are used in sliced pineapple production are the main contributors to this impact category. They respectively contribute 46% and 34% of the volume of these substances

that cause carcinogen impact category. Production of electricity from light crude oil-fired power plant to supplement national grid emits arsenic and cadmium ion into the atmosphere. This could have adverse impact on human health. Moreover emission of cadmium ion and arsenic as well as particulates <2.5µm from production of corrugated cardboard boxes contributes to this impact category. The standard deviation of the LCI varies from the mean with coefficient of variation of 29.8%.

Nitrogen oxides, Sulfur dioxide, Sulfur oxides Particulates, Ammonia, Sulfate are the major substances that cause respiratory inorganic impact category. Production of electricity from light crude oil-fired power plant (41%) and PET containers (35%) are the foremost processes that contribute to this impact category. The power plant emits nitrogen oxides, sulfur dioxide and particulates <2.5µm that cause this impact category. PET container production also leads to emission of nitrogen oxides and sulfur oxides which also contribute to the respiratory inorganic impact category. The standard deviation of the LCI does not vary widely from the mean with coefficient of variation of 6%. The standard error of the mean is estimated as 0.0019 from the Monte Carlo simulation results.

For the respiratory organic impact category, non-methane volatile organic compounds (NMVOC), and other hydrocarbons; methane, biogenic are the major substances that cause it. These are emitted primarily from production of PET containers which is attributed with 92% of substance that are responsible for the impact category in sliced pineapple production at Blue Skies Products Ghana Limited. Thus the use of PET containers is the major cause of respiratory organic impact category. The standard deviation of the LCI does not widely vary from the

mean with coefficient of variation of 1.12%. This indicates some of level of consistency with the input data. There is the need for the company to critically explore avenues to reduce its impact on the environment as a result of its use as packaging material.

Radiation impact category is caused by Radon-222; Carbon-14; Cesium-137 which are emitted primarily from production of corrugated cardboard boxes (60%). However, light crude oil-fired power plant (16%), demineralized water (12%) and pineapple (8%) make low contribution to these substances. The coefficient of variation is 117% implying that the mean is less than the standard deviation with a resultant high uncertainty in the LCI. Thus the standard deviation varies widely from the mean.

The use of PET containers and light crude oil-fired power plant to generate electricity are the major contributors to the acidification/eutrophication impact category. They respectively contribute 39% and 37% of the substances that cause this impact category. Some of the major substances are nitrogen oxides, sulfur dioxide, sulfur oxides, ammonia, sulfate, and nitrate. Nitrogen oxides are responsible for 77% of the acidification/eutrophication followed by sulfur dioxide (14%), sulfur oxides (7%) and ammonia (2%). The production of PET containers emits nitrogen oxides, sulfur oxides and ammonia, whilst the power plant emits nitrogen oxides, sulfur dioxide and ammonia. The Monte Carlo simulation results (Table 4.3) indicates that standard deviation of the LCI does not vary widely from the mean with coefficient of variation of 8.93%.

The use of corrugated cardboard boxes is the major contributor to the land use impact category in the production of sliced pineapple at the fruit processing plant. It contributes 85% of these issues that cause this impact category. Some of the key ones are: Transformation (to arable, to forest, to water bodies, to dump site); Occupation (fruit, road network, industrial area). Electricity from hydropower at reservoir power plant is responsible for 7% of these causes. The standard deviation is more than the mean with coefficient of variation of 146% (Table 4.3). There is therefore high level of uncertainty of the LCI that cause land use impact category.

Minerals impact category is caused by Nickel (in silicates, crude ore); Copper (in sulfide, ion); Aluminium (in bauxite, in crude ore); iron (in ore, crude ore); Molybdenum (in sulfide); Tin (in cassiterite, in crude ore); Chromium (in chromite, in crude ore). The most important contributor to this impact category potential is nickel (62%) followed by copper (20%). Corrugated cardboard boxes which are used to package sliced pineapple at the fruit processing plant is the main contributor (76%) of these substances that cause this impact category. Other contributors are electricity from light crude oil-fired power plant (9%) and electricity from hydropower (7%) source. The coefficient of variation was determined as 26% indicating narrow variation of standard deviation from mean.

The main substances that cause fossil fuel impact category are Oils, crude in the ground; oil, crude, feedstock, in the ground; Gas, natural, in the ground. The measure of this impact category indicates the extra energy that future generations must use to excavate these scarce resources. PET containers (44%) and electricity from light crude oil-fire power plant (34%) are

the major contributors to this impact category. The standard deviation of LCI varies narrowly from the mean with coefficient of variation of 4.2%.

The use of Monte Carlo simulation to analyze environmental load of the production of sliced pineapple at the fruit processing plant indicates that the score for radiation, ecotoxicity and land use have very high uncertainty as shown in Figure 4.3. In a similar work by Hung and Ma (2009), uncertainty in ecotoxicity was also high at the level of 1,200 uncertainty index in a case study of a municipal waste management in Taiwan. Thus due to high uncertainty in impact on ecotoxicity, it should be of concern in the determination of environmental load of provision of goods and services in any enterprise.

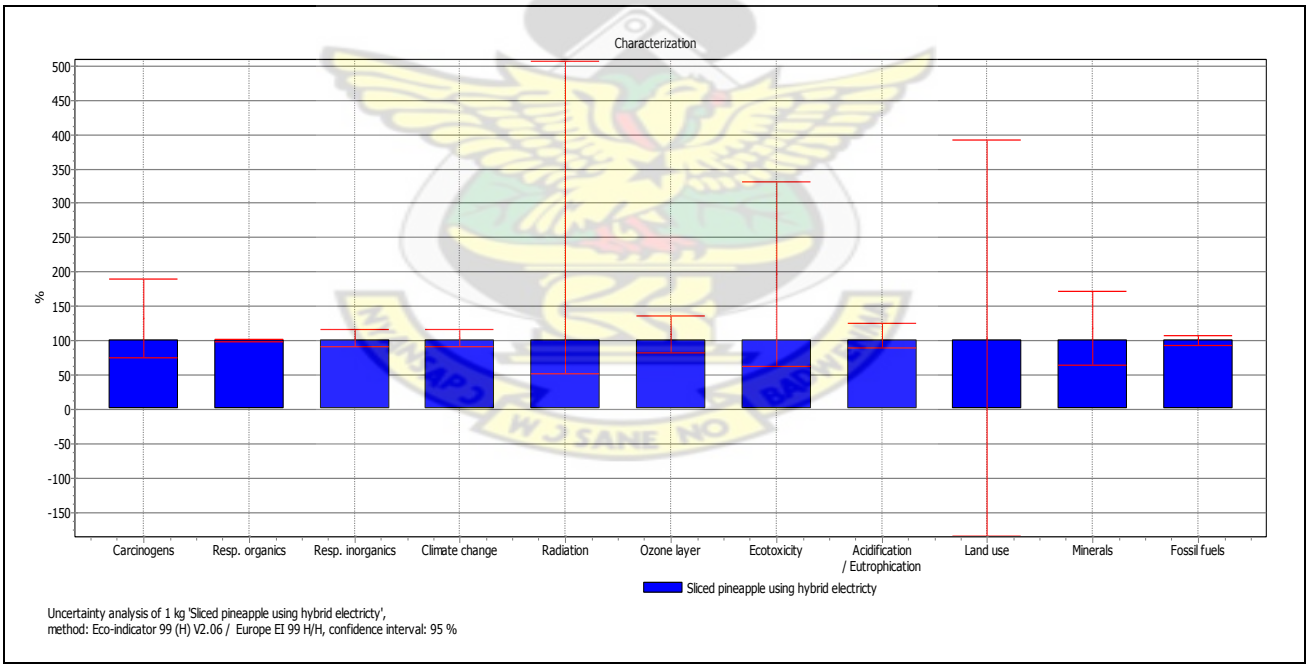
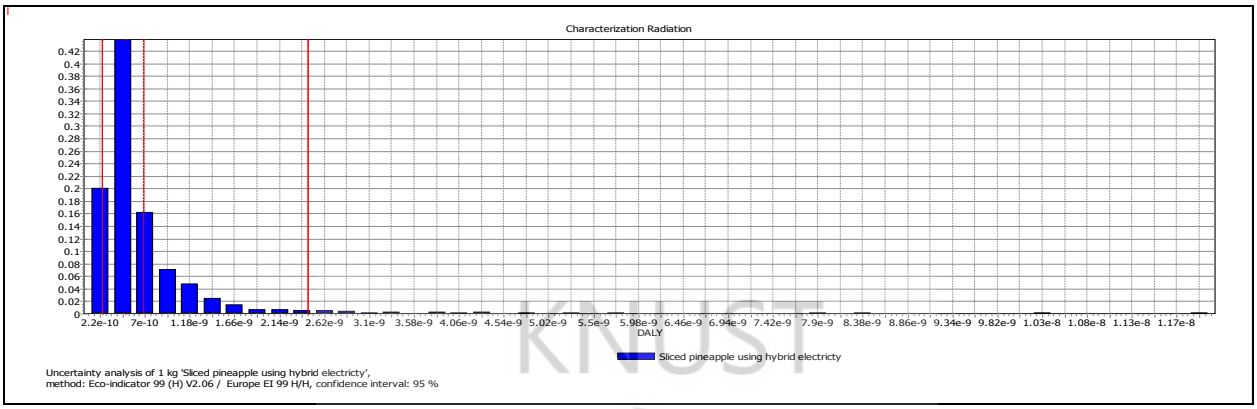


Figure 4.3: Monte Carlo Results on Impact Categories with Uncertainty Ranges

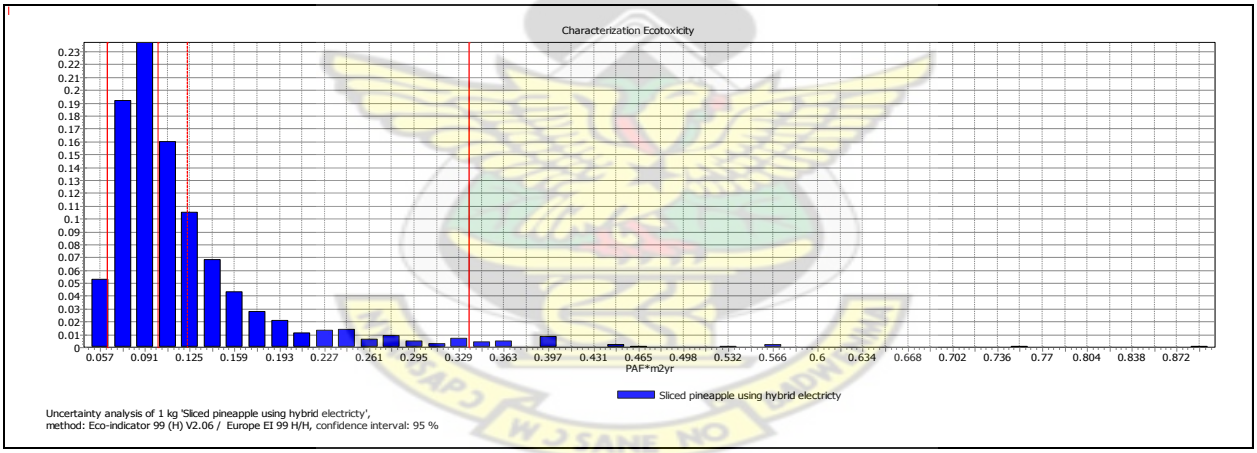
Most of the other scores have an uncertainty of about 100%, which is also high. In general, absolute uncertainties on the characterization level are quite high (Pre Consultants, 2008a).

Figure 4.4 shows distribution for the three impact categories that have very high uncertainty.

a)



b)



c)

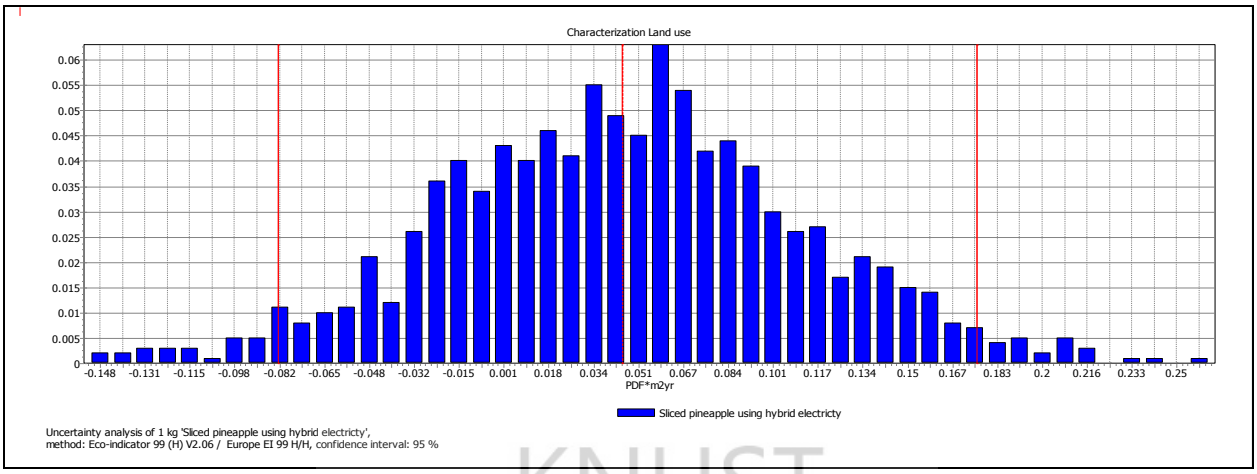


Figure 4.4: Uncertainty Distributions for Radiation, Ecotoxicity and Land Use Impact Categories a) Uncertainty distribution for Radiation Impact Category b) Uncertainty distribution for Ecotoxicity Impact Category; c) Uncertainty distribution for Land Use Impact Category

The cardboard packaging boxes, electricity (oil, at power plant) and PET containers have the highest impact on the carcinogens, respiratory organics, respiratory inorganics, ozone layer and climate change impact categories. These impact categories are classified as main causes of human health (Pre Consultants, 2008a).

These processes, cardboard packaging box, electricity (oil, at power plant) and PET containers, have the highest impact on ecotoxicity, acidification/eutrophication and land use impact categories in the sliced pineapple production processes. These impact categories are classified as ecosystem quality (Pre Consultants, 2008a).

Moreover, the effects on minerals and fossil fuel impact categories (resources) are highest with the use of cardboard packaging box, electricity (oil, at power plant) and PET containers (Table

4.2). The mean, median and standard deviation of these impact categories are as shown in Table 4.3.

The 3 key processes {cardboard packaging box, electricity (oil, at power plant) and PET containers} have high impact on the end points (human health, ecosystem quality and resources depletion) in environmental load in the production of sliced pineapple. It is important for the fruit processing plant to strategize to reduce the amount of cardboard packaging boxes and PET containers that are used for its production activities. This means that they should be producing sliced pineapple in heavier packs so that less PET containers would be used per MT of slice pineapple produced. Thus packaging in 300 g would be recommended against 250 g since the former would require less number of packaging materials per MT of pineapple processed.

Moreover, the management of the company should explore packing more PET containers filled with sliced pineapple in a cardboard packaging box than the current low numbers of between 4 and 6. This would facilitate the use of less number of cardboard packaging boxes which would consequently reduce the environmental load attributed to the use of cardboard packaging box, especially its contribution to climate change, ozone layer and carcinogens.

With respect to the use of electricity, there would be the need for advocacy to facilitate reduction in amount of national electricity production and distribution that come from light oil-fired electric power plant which is currently at 30%. This supplements what is produced from the hydroelectric power plant. There is therefore the need to increase capacity of hydroelectric power plants in the country to produce more electricity for distribution.

Table 4.2: Characterization Results on Production of Sliced Pineapple

Impact category	Unit	Total	Fresh pineapple fruit	Water deminer alized	PET Containers	Corrugate d cardboard box	Electricity, hydropow er plant	Electricity, oil, at power plant	Transport, lorry	Diesel, burned in diesel-electric generating set
Carcinogens	DALY	1.70E-08	4.41E-10	1.99E-10	2.14E-09	7.91E-09	9.80E-11	5.75E-09	7.12E-11	4.22E-10
Resp. organics	DALY	3.83E-09	2.74E-11	2.65E-12	3.51E-09	1.01E-10	1.50E-11	1.32E-10	4.67E-12	3.00E-11
Resp. inorganics	DALY	6.11E-07	2.11E-08	1.66E-09	2.13E-07	7.02E-08	3.19E-09	2.52E-07	1.93E-09	4.78E-08
Climate change	DALY	1.36E-07	4.77E-09	5.92E-10	3.03E-08	2.47E-08	1.67E-08	5.50E-08	7.11E-10	3.43E-09
Radiation	DALY	6.54E-10	5.36E-11	8.10E-11	0	3.90E-10	1.00E-11	1.06E-10	7.11E-12	6.50E-12
Ozone layer	DALY	1.16E-10	3.63E-12	4.53E-12	5.75E-11	1.40E-11	1.41E-13	3.32E-11	5.66E-13	2.12E-12
Ecotoxicity	PAF*m2yr	0.12263132	0.005246	0.000442	0.0065	0.034199	0.001229	0.073201	0.001016	0.000797
Acidification/ Eutrophication	PDF*m2yr	0.021581648	0.000907	4.92E-05	0.008418	0.002589	4.44E-05	0.007963	7.12E-05	0.00154
Land use	PDF*m2yr	0.04413678	0.000452	0.000117	0	0.037726	0.003124	0.002501	5.52E-05	0.000162
Minerals	MJ surplus	0.005733183	0.00032	2.51E-05	1.03E-05	0.004342	0.000428	0.000493	6.07E-05	5.32E-05
Fossil fuels	MJ surplus	1.4414553	0.044212	0.002067	0.630894	0.232489	0.001807	0.491782	0.006824	0.031381

DALY-Disability Adjusted Life Years (Years of disabled living or years of life lost due to the impacts)
PAF Potentially Affected Fraction (Animals affected by the impacts)
*PDF*m2yr-Potentially Disappeared Fraction (Plant species disappeared as result of the impacts)*
SE Surplus Energy (MJ) (Extra energy that future generations must use to excavate scarce resources)

Table 4.3: Monte Carlo Results on Characterization of Sliced Pineapple Production Processes

Impact category	Unit		Mean	Median	SD	CV (Coefficient of Variation)	2.50%	97.50%	Std.err.of mean
Acidification/ Eutrophication	PDF*m2yr	0.021581648	0.0216	0.0213	0.00193	8.93%	0.0188	0.0267	0.00282
Carcinogens	DALY	1.70E-08	1.72E-08	1.60E-08	5.11E-09	29.80%	1.20E-08	3.02E-08	0.00942
Climate change	DALY	1.36E-07	1.36E-07	1.35E-07	8.65E-09	6.36%	1.22E-07	1.57E-07	0.00201
Ecotoxicity	PAF*m2yr	0.12263132	0.123	0.101	0.0741	60.10%	0.0625	0.336	0.019
Fossil fuels	MJ surplus	1.4414553	1.44	1.43	0.0604	4.20%	1.33	1.56	0.00133
Land use	PDF*m2yr	0.04413678	0.0452	0.0447	0.0659	146%	-0.0823	0.176	0.0461
Minerals	MJ surplus	0.005733183	0.00579	0.00552	0.00151	26%	0.00354	0.00947	0.00822
Ozone layer	DALY	1.16E-10	1.16E-10	1.14E-10	1.56E-11	13.50%	9.24E-11	1.55E-10	0.00428
Radiation	DALY	6.54E-10	6.89E-10	4.82E-10	8.06E-10	117%	2.43E-10	2.44E-09	0.037
Resp. inorganics	DALY	6.11E-07	6.11E-07	6.06E-07	3.67E-08	6.01%	5.55E-07	7.05E-07	0.0019
Resp. organics	DALY	3.83E-09	3.83E-09	3.82E-09	4.28E-11	1.12%	3.75E-09	3.92E-09	0.000354

4.1.2 Damage Assessment of Sliced Pineapple Production Process

The Monte Carlo simulation on damage assessment of processes at the fruit processing plant shows that ecosystem quality results have very high uncertainty (Figure 4.5). However, the outcome of the Monte Carlo simulation shows low uncertainty for human health and resources.

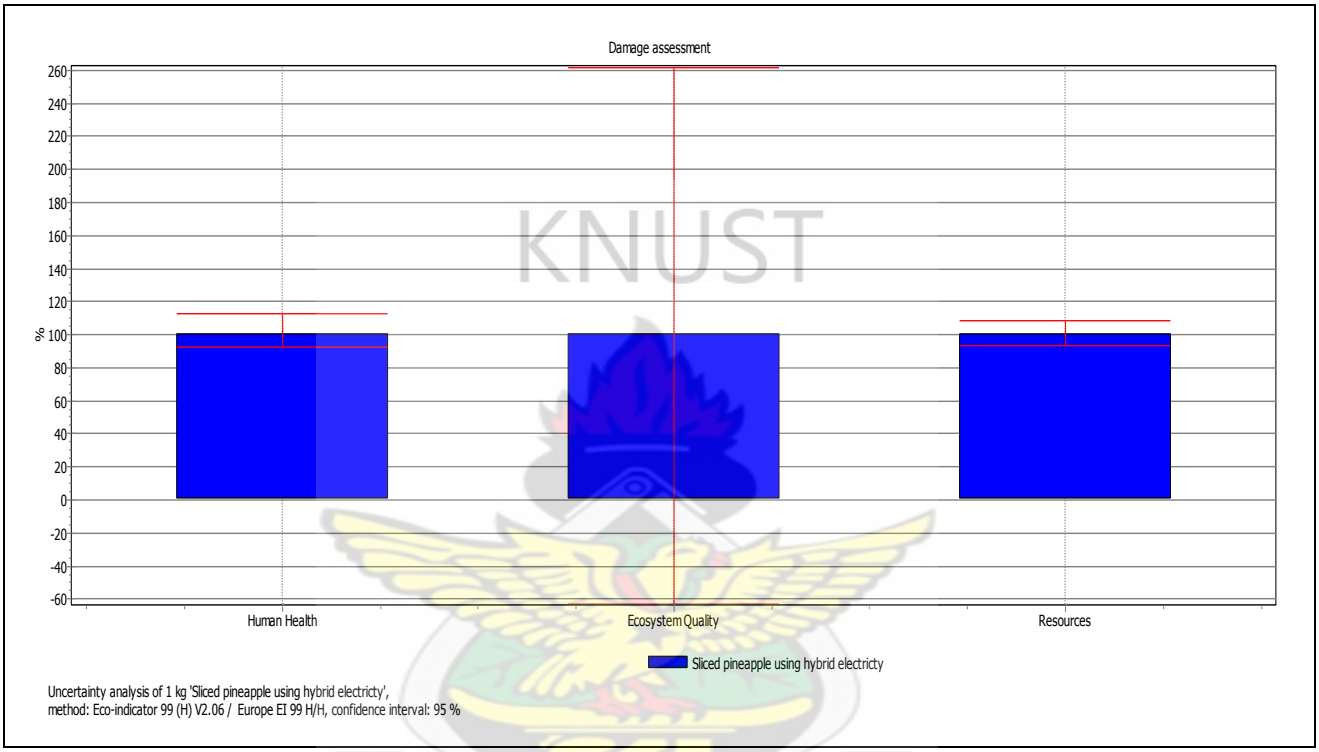


Figure 4.5: Uncertainty in Outcome of Damage Assessment of the Fruit Processing Plant

The high uncertainty in ecosystem quality has a coefficient of variation of 83.7% and standard deviation of 0.0662 as well as mean value of 0.0791 as shown in Table 4.4

Table 4.4: Monte Carlo Simulation Results on Damage Assessment

Damage category	Unit		Mean	Median	SD	CV (Coefficient of Variation)	2.50%	97.50%	Std.err.of mean
Ecosystem Quality	PDF*m2yr	0.07798	0.0791	0.08	0.0662	83.70%	-0.0504	0.209	0.0265
Human Health	DALY	7.69E-07	7.69E-07	7.64E-07	3.96E-08	5.15%	7.04E-07	8.63E-07	0.00163
Resources	MJ surplus	1.447	1.44	1.44	0.0605	4.19%	1.34	1.56	0.00132

The respective impact of processes involved in sliced pineapple production at the fruit processing plant (Table 4.5) shows that Electricity from light oil-fired power plant, use of PET containers and cardboard packaging boxes aggregately contributed 86.5%, 90.5%, 94% of the impact on human health, ecosystem quality and resources damage categories, respectively.

Table 4.5: Damage Assessment of Sliced Pineapple Production Processes on Damage Categories

	Human Health (DALY)	**Ecosystem Quality (PDF*m2yr)**	**Resources (MJ surplus)**
PET Containers	2.49E-07 **(32.4%)**	0.009068 **(11.6%)**	6.31E-01 **(43.6%)**
Electricity, oil, at power plant	3.13E-07 **(40.7%)**	0.017784 **(22.8%)**	0.492274933 **(34.0%)**
Electricity, hydropower	2.00E-08 **(2.6%)**	0.003291 **(4.2%)**	0.002235128 **(0.2%)**
Diesel-Electric generating set	5.17E-08 **(6.7%)**	1.782E-03 **(2.3%)**	3.14E-02 **(2.2%)**
Fresh Pineapple fruit supply to processing plant	2.64E-08 **(3.4%)**	1.884E-03 **(2.4%)**	0.044532707 **(3.1%)**
Water	2.54E-09 **(0.3%)**	2.100E-04 **(0.3%)**	2.09E-03 **(0.1%)**
Cardboard packaging box	1.03E-07 **(13.4%)**	4.374E-02 **(56.1%)**	0.236831068 **(16.4%)**
Transport finished product to airport	2.72E-09 **(0.4%)**	2.280E-04 **(0.3%)**	6.88E-03 **(0.5%)**
Total	**7.68684E-07**	**0.07798156**	**1.447188449**

Thus these three processes in the production of sliced pineapple have very high impact on the environment and the management of the fruits processing plant must initiate strategies to reduce impact on these damage categories.

4.1.3 Single Score Results on Production of Sliced Pineapple

The single score results on the processes for production of sliced pineapple at the fruit processing plants indicates that use of PET containers has the highest environmental load, and

this is followed by electricity from light crude oil-fired power plant and then corrugated cardboard boxes (Figure 4.6). Details on the results are in Appendix A.

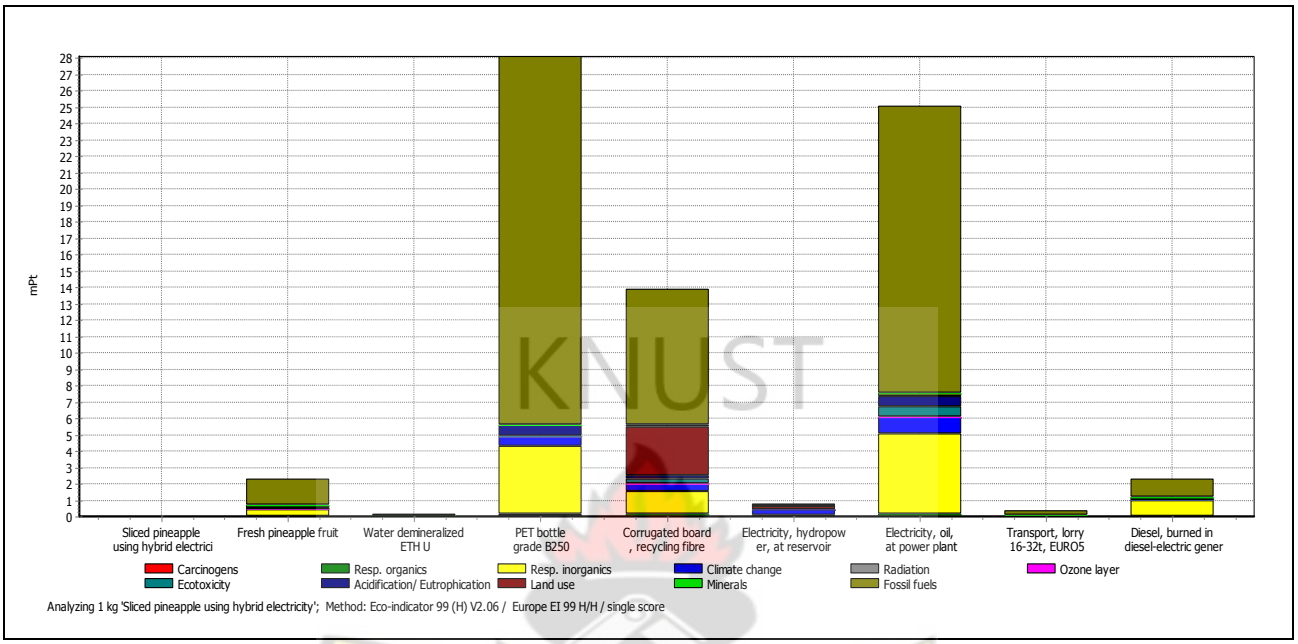


Figure 4.6: Single Score Results on Processes in Sliced Pineapple Production

It appears that fossil fuels and respiratory inorganics impact categories are caused by most of the input materials used at the fruits processing plant.

The Monte Carlo simulation on single score is graphically shown in Figure 4.7. It shows the uncertainty in the single score results of the processes.

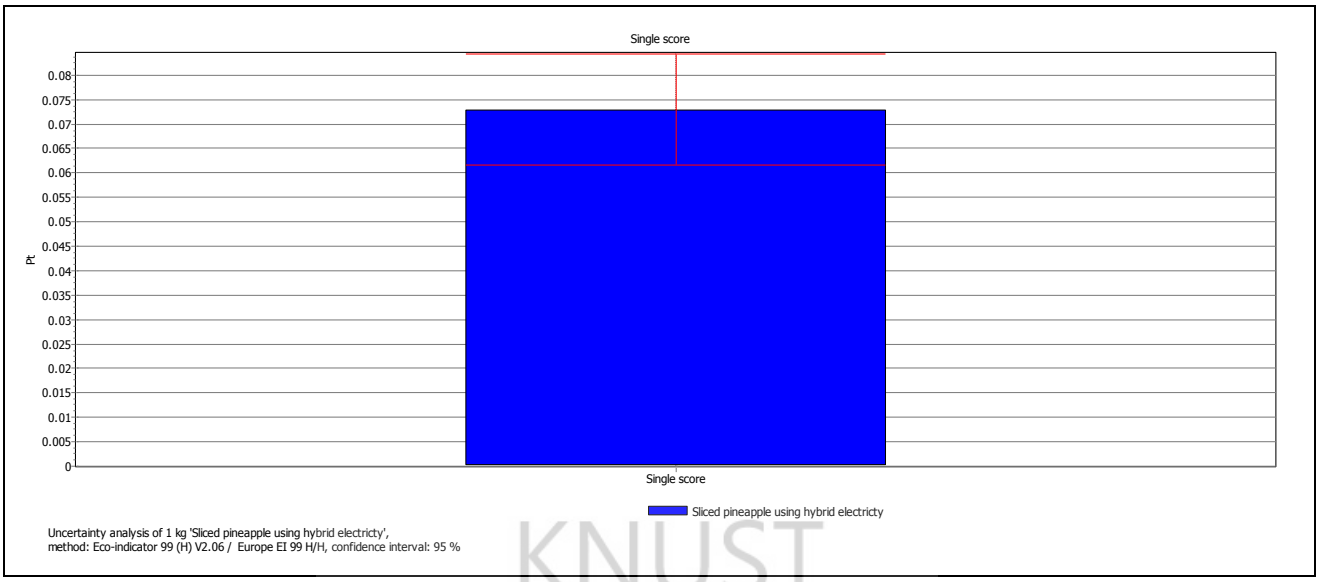


Figure 4.7: Uncertainty in Single Score Outcome for Sliced Pineapple Production Process

Table 4.6 shows the outcome of Monte Carlo simulation on single score of the production process. It shows a mean of 0.0727, which is close to single score value of 0.07276 and consequently resulted in a small standard deviation. This is further accentuated by the coefficient of variation of 7.87%, indicating that the standard deviation does not widely vary from the mean of the LCI.

Table 4.6: Monte Carlo Results on Single Score in Sliced Pineapple Production Process

Damage category	Unit		Mean	Median	SD	CV (Coefficient of Variation)	2.50%	97.50%	Std.err.of mean
Single score	Pt	0.07276	0.0727	0.0727	0.00572	7.87%	0.0617	0.0843	0.00249

Confidence interval: 95%

The thirty percent of the national electricity supply from light oil-fired electric power plant as well as uses of cardboard packaging boxes are also other sources of high impact on the environment.

Table 4.7 indicates that the three processes {cardboard box, electricity (oil, at power plant) and PET containers} involved in production of sliced pineapple contributes 92% of the total environmental load as per the single score results. These are all indications that the three key processes in production of sliced pineapple at the fruit processing plant must be managed to reduce environmental impact.

Table 4.7: Percentage Contribution of Processes in Sliced Pineapple Production to the Environment using Single Score Results

Processes	Units	Single Score	% Contribution
PET Containers	Pt	0.028102025	38.6%
Electricity, oil, at power plant	Pt	0.025066486	34.5%
Electricity, hydropower	Pt	0.000727612	1.0%
Diesel-Electric generating set	Pt	0.002270454	3.1%
Fresh Pineapple fruit supply to processing plant	Pt	0.00225204	3.1%
Water	Pt	0.000140659	0.2%
Corrugated Cardboard packaging box	Pt	0.013883595	19.1%
Transport finished product to airport	Pt	0.000316725	0.4%
Total		**0.072759596**	**100.0%**

The company needs to invest in exploring the use of alternative packaging materials, which are more environmentally friendly and/or reduce the amount of PET containers and cardboard packaging boxes. Moreover, management of the fruit processing plant needs to team up with environmental advocates to encourage the Government of Ghana to investment in hydropower

sources of electricity and reduce sourcing of electricity from light oil-fired electric power plants. These measures could reduce environmental load in the use of electricity from the national grid which is 30% from light oil-fired electric power plant.

4.1.4 Normalization of Impact Score on Production of Sliced Pineapple

The normalized values generated by calculating the LCI using SimaPro 7.1.8 is as shown in Table 4.8.

Table 4.8: Normalization of Impact Scores on Sliced Pineapple Production

Impact category	Single Impact Score	Normalized Impact Score
Carcinogens	0.000333	1.11E-06
Resp. organics	7.47E-05	2.49E-07
Resp. inorganics	0.01193	3.98E-05
Climate change	0.00266	8.87E-06
Radiation	1.28E-05	4.26E-08
Ozone layer	2.26E-06	7.53E-09
Ecotoxicity	0.000957	2.39E-06
Acidification/ Eutrophication	0.001683	4.21E-06
Land use	0.003443	8.61E-06
Minerals	0.000205	6.82E-07
Fossil fuels	0.05146	0.000171533

Monte Carlo simulation outcome on normalization of the processes shows that ecosystem quality damage category has high uncertainty (Figure 4.8).

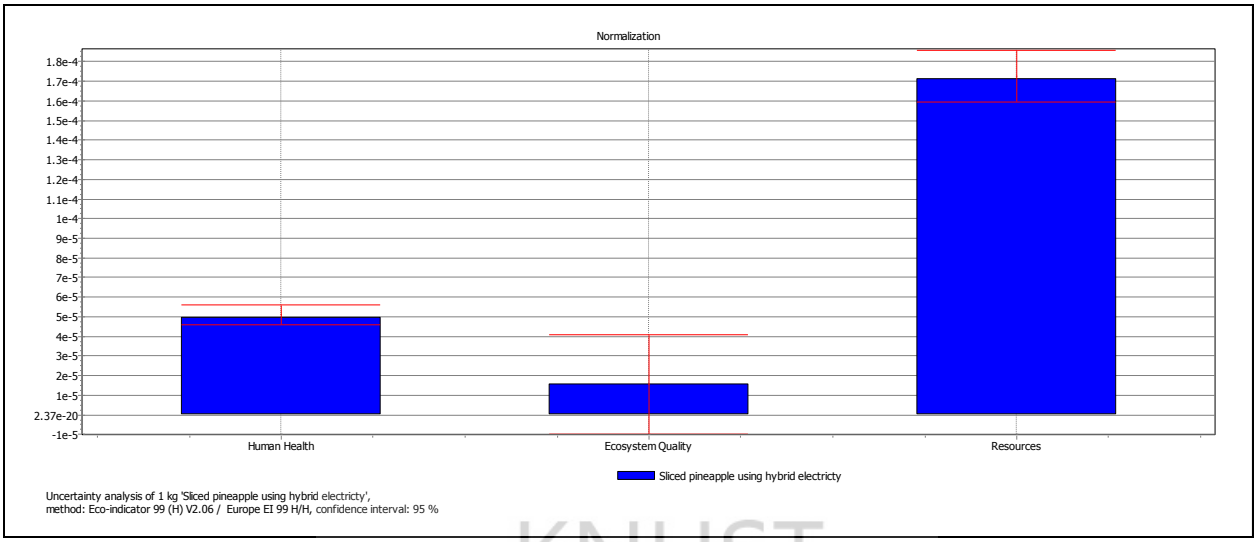


Figure 4.8: Uncertainty in outcome on Normalization of Sliced Pineapple Production Process

The least uncertainty is the score on resources with coefficient of variation of 4.19% (Table 4.9).

Table 4.9: Monte Carlo Results on Normalization of Sliced Pineapple Production Process

Damage category	Score	Mean	Median	SD	CV (Coefficient of Variation)	2.50%	97.50%	Std.err.of mean
Ecosystem Quality	1.52E-05	1.54E-05	1.56E-05	1.29E-05	83.70%	-9.83E-06	4.08E-05	0.0265
Human Health	5.00E-05	5.00E-05	4.97E-05	2.58E-06	5.15%	4.58E-05	5.62E-05	0.00163
Resources	1.72E-04	0.000172	0.000171	7.20E-06	4.19%	0.000159	0.000186	0.00132

Thus the Monte Carlo simulation results have indicated areas of uncertainty in evaluating the environmental load from the fruits processing plant as ecosystem quality. The coefficient of variation is 83.7% with a standard error of 0.0265 compared with coefficient of variation of 5.15% and 4.19% respectively for human health and resources damage categories. The high uncertainty in the ecosystem quality is attributed to the high uncertainty in ecotoxicity and land

use impact categories. They respectively have coefficient of variation of 60.1% and 146% when Monte Carlo simulation was run on the LCI (Table 4.3). The use of cardboard packaging boxes and production of electricity from light oil-fired electric power plant contributed 56.1% and 22.8% to the total impact on the ecosystem damage categories (Table 4.5). Thus LCI on these processes ostensibly have high uncertainty.

These normalized results are relative to the global environmental normalization values in the software's database. The results therefore show the relative contribution of the respective impact categories on the global environmental load.

The cardboard packaging box, electricity (oil, at power plant) and PET containers processes are the three highest scores on normalization (Appendix A)

4.1.5 Conclusions

The radiation, land use and ecotoxicity impact categories have very high uncertainties in the outcome of Monte Carlo simulation on characterization of the processes involved in sliced pineapple production at the fruits processing plant. The analyses results showed relatively high coefficient of variation implying that the respective standard deviations of the LCI are different from their means. Moreover, Monte Carlo simulation outcome established that ecosystem quality damage category has very high uncertainty.

The LCIA indicates that use of PET containers to package sliced pineapple; cardboard packaging boxes to package the filled PET containers; and the component of electricity from

national grid which is produced from light oil-fired power plant (this forms 30% of electricity supplied through the national grid); are the major sources of environmental load at the fruits process plant. They are the major contributors of the substances that cause all the 11 impact categories. Except in the case of land use, ecotoxicity and radiation impact categories, the standard deviation of their respective LCIs of the other 9 impact categories do not vary widely with the mean. These therefore have relatively low level of uncertainty.

The PET containers, corrugated cardboard boxes and electricity from light crude oil-fired power plant have high impact on the human health, ecosystem quality and resources depletion in the production of sliced pineapple. The company would need to strategize to reduce the amount of cardboard packaging boxes and PET containers that are used for its production activities. It should produce sliced pineapple in heavier packs so that less PET containers would be used per MT of slice pineapple produced. Thus packaging in 300 g would be recommended since it uses optimum quantity of packaging materials per MT of pineapple processed.

Moreover, the management of the company should explore packing more PET containers filled with sliced pineapple in a cardboard packaging box than the current low numbers of between 4 and 6. This would facilitate the use of less number of cardboard packaging boxes which would consequently reduce the environmental load attributed to the use of cardboard packaging box, especially its contribution to climate change, ozone layer and carcinogens

There is the need to invest in exploring the use of alternative packaging materials which are more environmental friendly and/or reduce the amount of PET containers and cardboard packaging boxes used at the fruits process plant. This means that instead of packaging 1.2 kg of pineapple in 200 g packs that would require 6 PET containers it should pack them in 300 g that would require 4 PET containers. This could be part of the company's marketing strategies to encourage the market to patronize larger packaging as part of their effort to reduce environmental load of its activities. Moreover, management of the fruits processing plant needs to team up with environmental advocates to encourage the Government of Ghana to investment in hydropower sources of electricity and reduce sourcing of electricity from light oil-fired electric power plants. These measures could reduce environmental load in the use of electricity from the national grid which is 30% from light oil-fired power plant.

4.2. Comparison of Different Electric Energy Sources

The fruit processing plant sources electricity from both the national grid and a standby 1,400 KVA diesel-electric generating set due to fluctuation in supply of electricity from the national grid. The diesel-electric generating set is used as a standby electricity source. Thus it is used when either power from the main national grid goes off or when the voltage drops below what is required to run the equipment at the processing plant. It sources average of 94% of power from the national grid and 6% from the diesel-electric generating set for its processing activities.

A simulation was performed to compare the environmental load from different sources of electricity for processing activities of a unit product. In addition to the normal sources

contribution of 94% from national grid and 6% from diesel-electric generating set, data on environmental load from 100% use of national grid as well as 100% source from diesel-electric generating set were gathered on producing 1 kg of sliced pineapple.

Eco-Indicator 99 (H), which is a life cycle impact assessment tool developed by PRé Consultants B.V. was used to make environmental assessment of electrical energy by calculating eco-indicator scores for the processes used. Moreover the resulting score from Eco-Indicator 99 provide indications of areas for improvement of the use of electrical energy to minimize impact on the environment.

4.2.1 Comparing Electricity Sources from Hybrid Electricity and 100% National Grid

The situation where the company is able to enjoy 100% source of electricity from the national grid for its processing activities and, where due to either low voltage or power failure from the national grid the company has to supplement its electrical energy requirements with electric power from the use of diesel-electric generating set were compared. For the latter, which is referred to as the hybrid electricity, 94% is from national grid and 6% is from the diesel-electric generating set.

The impact assessment using Eco-Indicator 99 (H) in SimaPro 7.1.8 gave the following results as shown in Table 4.10. The use of hybrid electricity for processing activities at the processing plant has higher impact on acidification/eutrophication and respiratory organic and respiratory inorganic than impact from the use of 100% electric power from the national grid. However the use of 100% national grid has higher impact on the carcinogens, ozone layer, radiation,

climate change, ecotoxicity, minerals, land use and fossil fuel than the impact from the use of hybrid electricity.

Table 4.10: Characterization of Comparing 100% National Grid and Hybrid Electricity

Impact category	Unit	Sliced Pineapple using national grid	Sliced pineapple using hybrid electricity
Carcinogens	DALY	1.74E-05	1.70E-05
Resp. organics	DALY	3.82E-06	3.83E-06
Resp. inorganics	DALY	0.000596647	0.000610867
Climate change	DALY	0.000142199	0.00013619
Radiation	DALY	6.63E-07	6.54E-07
Ozone layer	DALY	1.18E-07	1.16E-07
Ecotoxicity	PAF*m2yr	131.63961	122.63132
Acidification/ Eutrophication	PDF*m2yr	21.096652	21.581648
Land use	PDF*m2yr	44.715656	44.13678
Minerals	MJ surplus	5.8013872	5.7331832
Fossil fuels	MJ surplus	1475.097	1441.4553

DALY-Disability Adjusted Life Years (Years of disabled living or years of life lost due to the impacts)
PAF Potentially Affected Fraction (Animals affected by the impacts)
*PDF*m2yr-Potentially Disappeared Fraction (Plant species disappeared as result of the impacts)*
SE Surplus Energy (MJ) (Extra energy that future generations must use to excavate scarce resources)

Thus, the sourcing 100% electricity needs from national grid causes a lot of impact on more of the impact categories than supplementing it with the use of diesel-electric generating sets as shown in Figure 4.9.

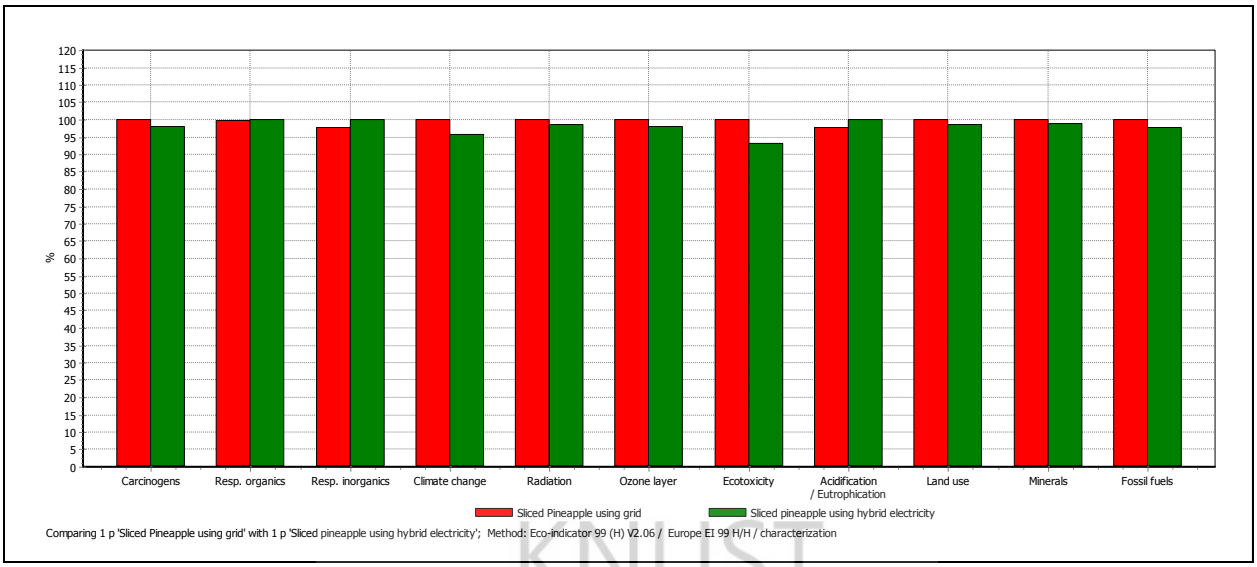


Figure 4.9: Characterization of 100% National Grid Electricity and Hybrid Electricity

The analysis of single score impact assessment on the use of these different sources of electrical energy for producing sliced pineapple for the export market indicates that the use of 100% national grid as a single source of electricity has higher impact on the environment than hybrid as shown in Figure 4.10.

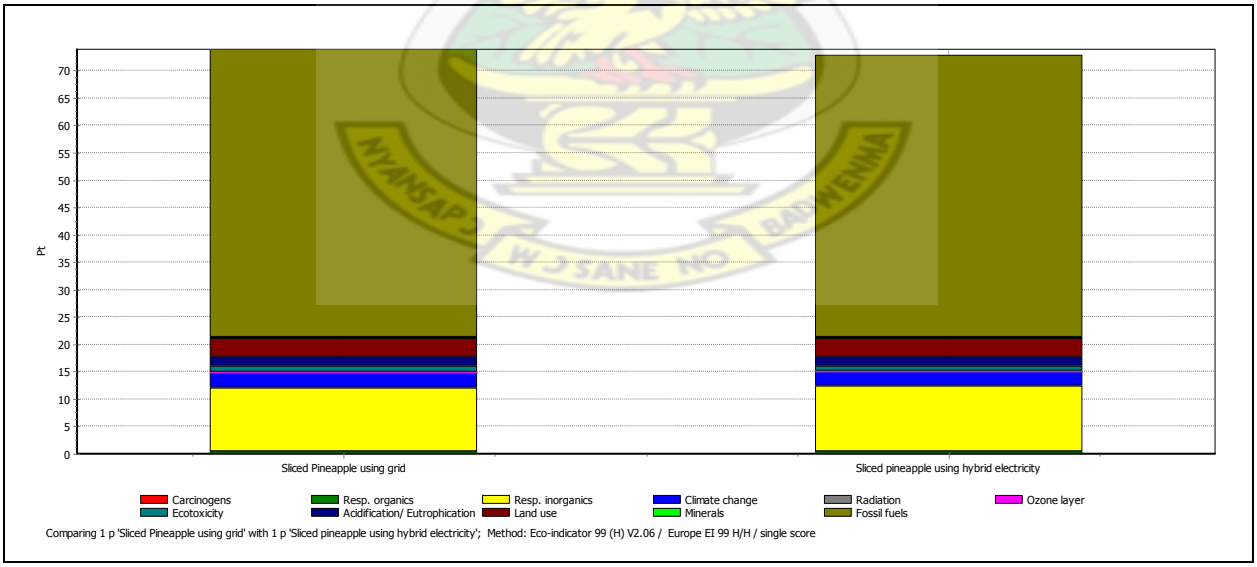


Figure 4.10: Single Score on 100% National Grid and Hybrid Electricity

The use of Monte Carlo simulation to analyze the environmental load of the 2 different electrical energy portfolios suggests that the use of 100% national grid made significant impact on the environment than sourcing electric energy as hybrid as shown in Table 4.11 and Figure 4.11. In this figure the number of outcomes where 100% national grid has a higher score than the hybrid is as shown per impact category.

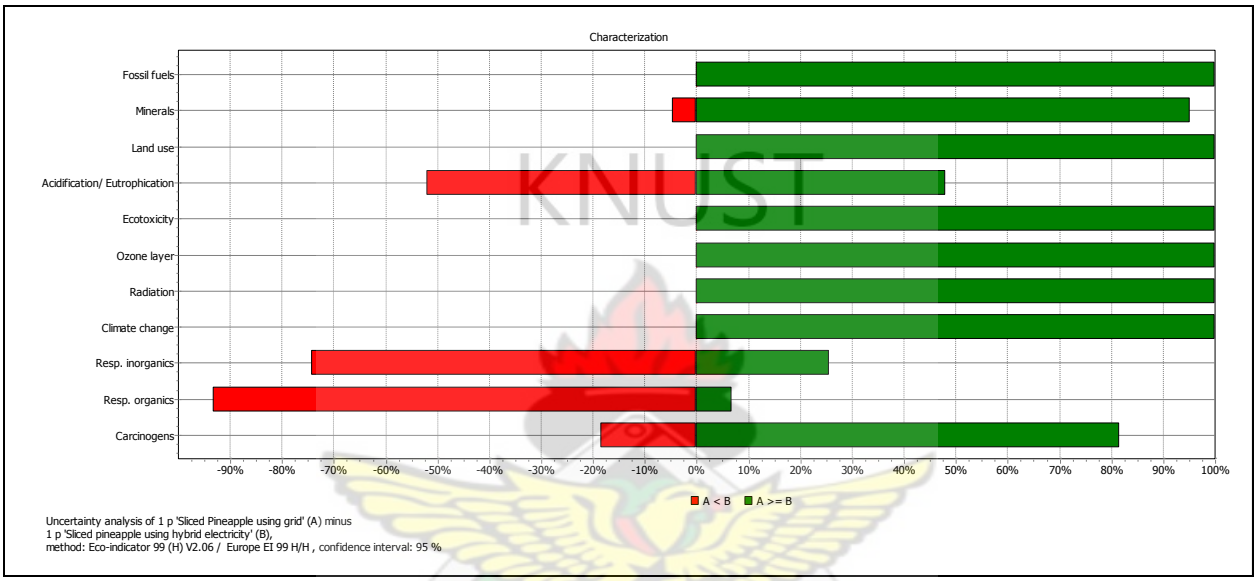


Figure 4.11: Monte Carlo Results on Comparing Characterization of 100% National Grid and Hybrid Electricity

This indicates that some of the differences shown in Figure 4.9 are significant. In general we can assume that if 90% to 95% of the Monte Carlo runs are favorable for a product, the difference may be considered significant (Pre Consultants, 2008a). This rule means that differences between the two processes (100% national grid and hybrid electricity) are not significant for carcinogens, respiratory inorganics and acidification/eutrophication. The table below also indicates that in 48% of the Monte Carlo runs, 100% national grid (A) has more impact on acidification/eutrophication than hybrid electricity (B) source. It is almost the same as the number of runs (52%) that the use of hybrid electricity has higher impact than 100%

national grid. Thus the difference in the impact is not significant for acidification/eutrophication. Similarly, for carcinogens and respiratory inorganics, the number of runs 81.5% and 25.6%, respectively do not fall within the assumed range for significant difference.

Table 4.11: Monte Carlo Results on comparing use of 100% National Grid with Hybrid Electricity on Impact categories

Impact category	A>= B	Mean	Median	SD	CV (Coefficient of Variation)	2.50%	97.50%	Std.err.of mean
Acidification/ Eutrophication	48%	-0.447	-0.0431	1.41	-315%	-4.04	0.79	-0.0997
Carcinogens	81.50%	3.27E-07	1.97E-07	4.76E-07	146%	-2.37E-07	1.60E-06	0.0461
Climate change	100%	6.04E-06	5.89E-06	1.06E-06	17.50%	4.35E-06	8.62E-06	0.00553
Ecotoxicity	100%	8.95	5.99	10.5	118%	1.62	33.8	0.0372
Fossil fuels	100%	33.6	33.5	5.88	17.50%	22	44.9	0.00553
Land use	100%	0.575	0.536	0.215	37.30%	0.267	1.11	0.0118
Minerals	95.30%	0.0654	0.0578	0.0518	79.10%	-0.0107	0.194	0.025
Ozone layer	100%	2.23E-09	2.07E-09	8.96E-10	40.10%	9.89E-10	4.54E-09	0.0127
Radiation	100%	8.83E-09	5.91E-09	1.04E-08	118%	2.05E-09	3.37E-08	0.0374
Resp. inorganics	25.60%	-1.40E-05	-8.72E-06	2.31E-05	-164%	-7.18E-05	1.21E-05	-0.052
Resp. organics	6.80%	-1.02E-08	-8.94E-09	8.11E-09	-79.50%	-2.81E-08	3.29E-09	-0.0251

Confidence level = 95%

The Monte Carlo runs indicates that in 6.8% of them the use of 100% national grid source have less impact on the respiratory organic than sourcing electrical energy from hybrid electricity. The Monte Carlo simulation confirms that use of 100% national grid has higher impact and the difference is significant on 7 impact categories (ozone layer, radiation, climate change, ecotoxicity, minerals, land use and fossil fuel) than impact on these impact categories from the use of hybrid electricity. Thus the use of 100% national grid causes more environmental load than hybrid source of electric energy and, the difference is very significant. It suggests that as

the company uses more electricity from the national grid it tends to cause more harm to the environment. Moreover, for every unit of product produced using 100% national grid depletes ozone layer and causes climate change as well as radiations and acidification more than if it would have been supplemented its source of energy with that of diesel generated electric power.

Damage Assessment, Normalization and Weighting

Table 4.12 indicates the respective impact on the damage categories by the use of 100% national grid (A) and hybrid electricity (B) source for production of 1 kg of sliced pineapple at the fruit processing plant. After 1,000 Monte Carlo runs, 100% and 82.8%, respectively of the results established that use of 100% national grid has higher impact on Resources depletion and Ecosystem quality, than the use of hybrid electricity source. However, 42.9% of the runs showed that 100% national grid has more impact on human health damage category. Thus in 57.1% of Monte Carlo simulation runs indicates that hybrid electricity source has higher impact on the human health damage category.

Table 4.12: Monte Carlo Results on comparing use of 100% National Grid with Hybrid Electricity for Damage Assessment

Damage category	A>=B	Mean	Median	SD	CV (Coefficient of Variation)	2.50%	97.50%	Std.err.of mean
Ecosystem Quality	82.80%	1.02	1.19	1.74	170%	-2.53	4.17	0.0538
Human Health	42.90%	-7.65E-06	-2.47E-06	2.32E-05	-303%	-6.53E-05	1.91E-05	-0.0957
Resources	100%	33.7	33.6	5.88	17.50%	22	45	0.00552

Confidence interval: 95%

The respective impact on the damage categories are as shown graphically in Figure 4.12. There is an indication that the difference between the two energy portfolios is not significant with

respect to human health and ecosystem quality under the damage category compared with differences in resources. However the difference is significant with respect to impact on resources depletion. Thus the use of 100% national grid electricity makes significant impact on resource depletion than use of hybrid electricity.

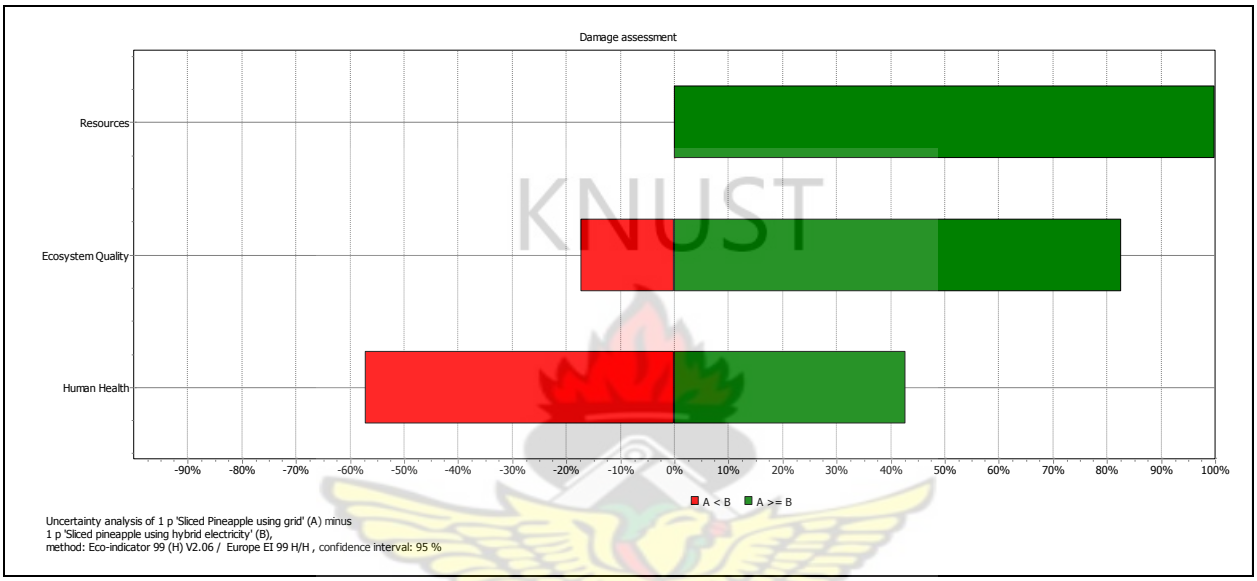


Figure 4.12: Monte Carlo Results on Comparing Damage Assessment of 100% National Grid and Hybrid Electricity

Monte Carlo results on normalization and weighting follow similar outcome as shown in Tables 4.13 and 4.14 as well as Figures 4.13 and 4.14, respectively.

Table 4.13: Monte Carlo Results on comparing use of 100% National Grid with Hybrid Electricity for Normalization

Damage category	A>=B	Mean	Median	SD	CV (Coefficient of Variation)	2.50%	97.50%	Std. err. of mean
Ecosystem Quality	82.8%	0.000199	0.000233	0.000339	170%	-0.00049	0.000814	0.0538
Human Health	42.9%	-0.0005	-0.00016	0.00151	-303%	-0.00425	0.00124	-0.0957
Resources	100%	0.00401	0.00399	0.0007	17.50%	0.00262	0.00535	0.00552

Confidence interval: 95%

Table 4.14: Monte Carlo Results on comparing use of 100% National Grid with Hybrid Electricity for Weighting

Damage category	A>= B	Mean	Median	SD	CV (Coefficient of Variation)	2.50%	97.50%	Std. err. of mean
Ecosystem Quality	82.80%	0.0798	0.0932	0.136	170%	-0.197	0.326	0.0538
Human Health	42.90%	-0.149	-0.0483	0.452	-303%	-1.28	0.373	-0.0957
Resources	100%	1.2	1.2	0.21	17.50%	0.787	1.61	0.00552

Confidence interval: 95%

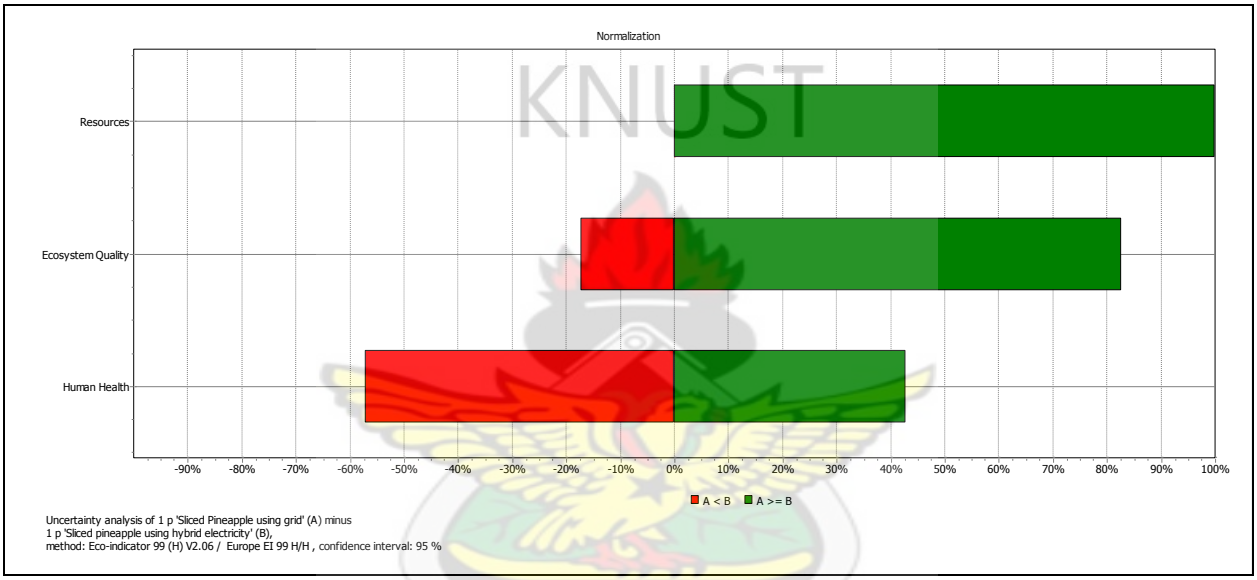


Figure 4.13: Monte Carlo Results on Comparing Normalization for 100% National Grid and Hybrid Electricity

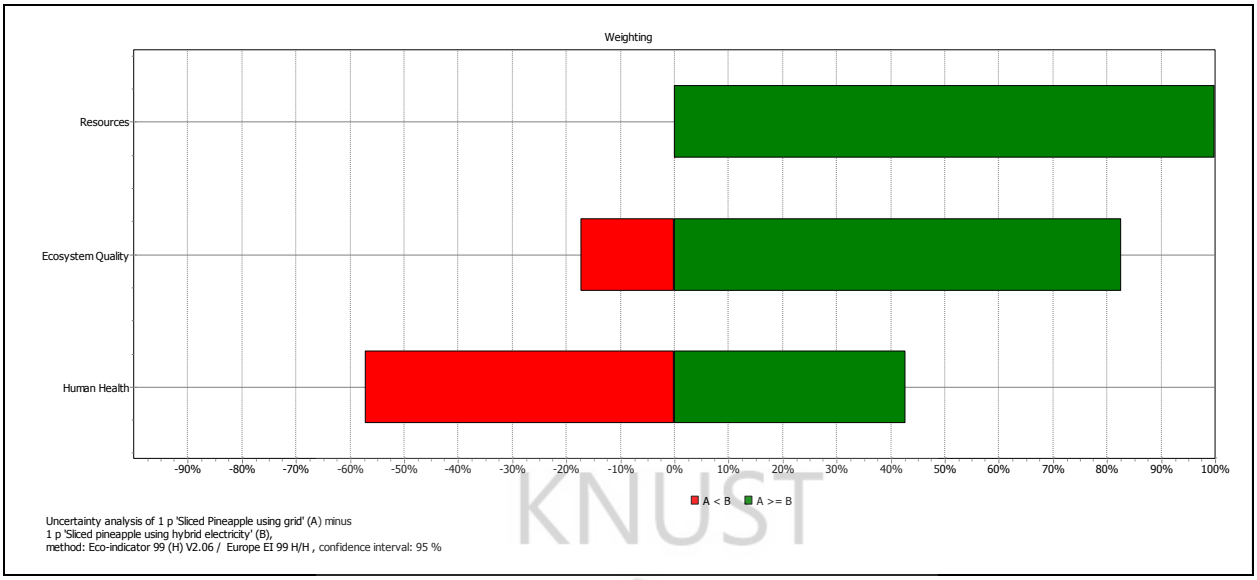


Figure 4.14: Monte Carlo Results on Comparing Weighting for 100% National Grid and Hybrid Electricity

Thus 1,000 runs of Monte Carlo simulations on values of components for damage assessment as well as normalization and weighting have similar results in each of the cases. They also show that use of 100% national grid electricity causes more harm to the environment than the hybrid source of electricity. This is similar to the outcome of characterization of impact categories.

Single Score

The number of outcomes where 100% national grid has higher score than hybrid electricity is shown in the Table 4.14 for single score.

Table 4.15: Monte Carlo Results on comparing use of 100% National Grid with Hybrid Electricity for Single Score

Damage category	A >= B	Mean	Median	SD	CV (Coefficient of Variation)	2.50%	97.50%	Std.err.of mean
Single score	95.40%	1.13	1.24	0.605	53.40%	-0.335	1.94	0.0169

The single score results indicates that for 95.4% of the Monte Carlo runs, 100% national grid has higher score on impact on total environment than impact from the use of hybrid electricity. Thus the single score for production of sliced pineapple using these two different electrical energy sources indicates that 100% national grid has higher impact on damage categories (ecosystem quality, human health and resources) than using hybrid electricity as shown in Figure 4.15.

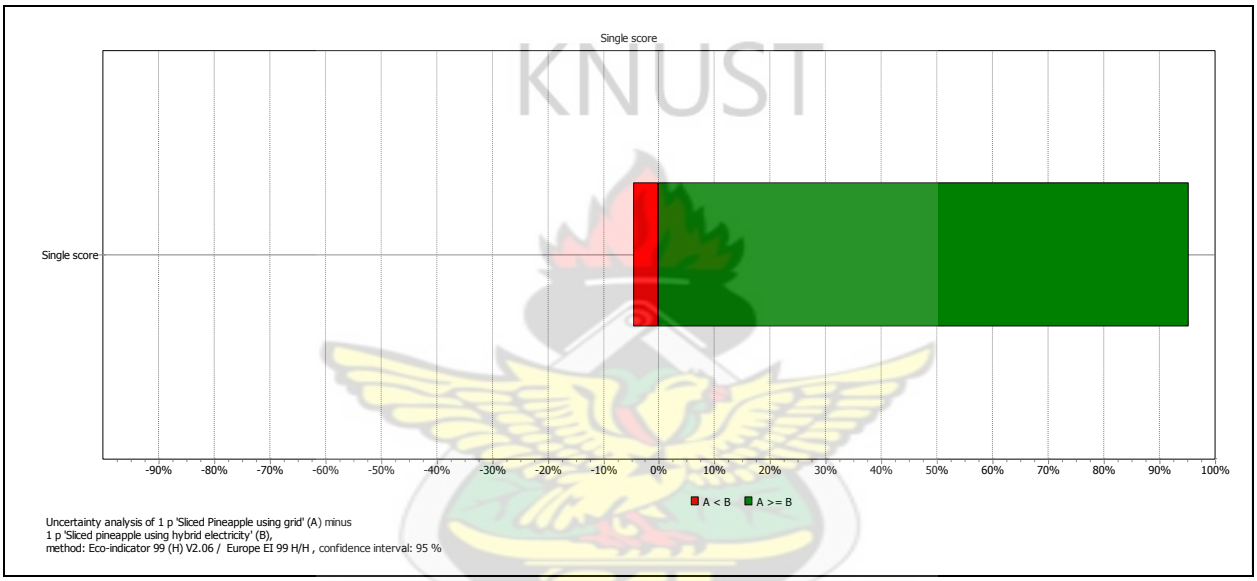


Figure 4.15: Monte Carlo Results on Comparing Single Score for 100% National Grid and Hybrid Electricity

4.2.2 Comparing Electricity Sources from Hybrid Electricity and 100% Diesel-Electric Generating Set

The circumstance where the fruit processing company would resort to sourcing electricity from only diesel-electric generating set for its production activities was compared with the use of electricity from a hybrid electricity (94% national grid and 6% diesel-electric generating set) source.

The impact assessment using Eco-Indicator 99 (H) in SimaPro 7.1.8 gave the following results as shown in Table 4.16. The use of hybrid electricity source has higher impact on climate change, radiation, ecotoxicity, land use and minerals than impact from sourcing electricity solely from diesel-electric generating set. However the diesel-electric generating set has higher impact on carcinogens, respiratory organic, respiratory inorganics and acidification/eutrophication than hybrid electricity source.

Table 4.16: Characterization of Comparing 100% National Grid and Hybrid Electricity

Impact category	**Unit**	**Sliced pineapple using generator**	**Sliced pineapple using hybrid electricity**
Carcinogens	DALY	1.78E-05	1.70E-05
Resp. organics	DALY	4.15E-06	3.83E-06
Resp. inorganics	DALY	0.001104726	0.000610867
Climate change	DALY	0.000118286	0.00013619
Radiation	DALY	6.40E-07	6.54E-07
Ozone layer	DALY	1.15E-07	1.16E-07
Ecotoxicity	PAF*m2yr	60.683267	122.63132
Acidification/ Eutrophication	PDF*m2yr	37.698408	21.581648
Land use	PDF*m2yr	41.05134	44.13678
Minerals	MJ surplus	5.6447513	5.7331832
Fossil fuels	MJ surplus	1439.4952	1441.4553

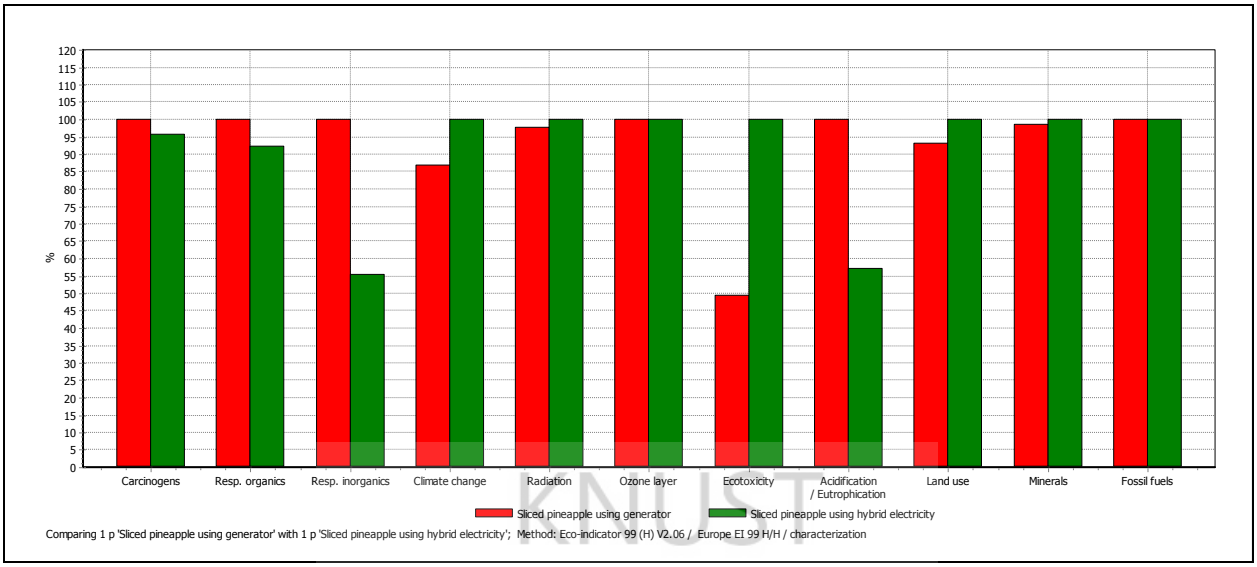


Figure 4.16: Characterization of Comparing 100% Diesel Electric Generating Set with Hybrid Electricity

The analysis of single score impact assessment on the use of these different sources of electric energy for producing sliced pineapple at the factory indicates that the use of 100% diesel-electric generating set as a single source of electric energy has higher impact on the environment than hybrid as shown in Figure 4.17.

Thus the use of 100% diesel-electric generating set by the fruit processing company for its production activities generates more environmental load than sourcing energy from the hybrid source.

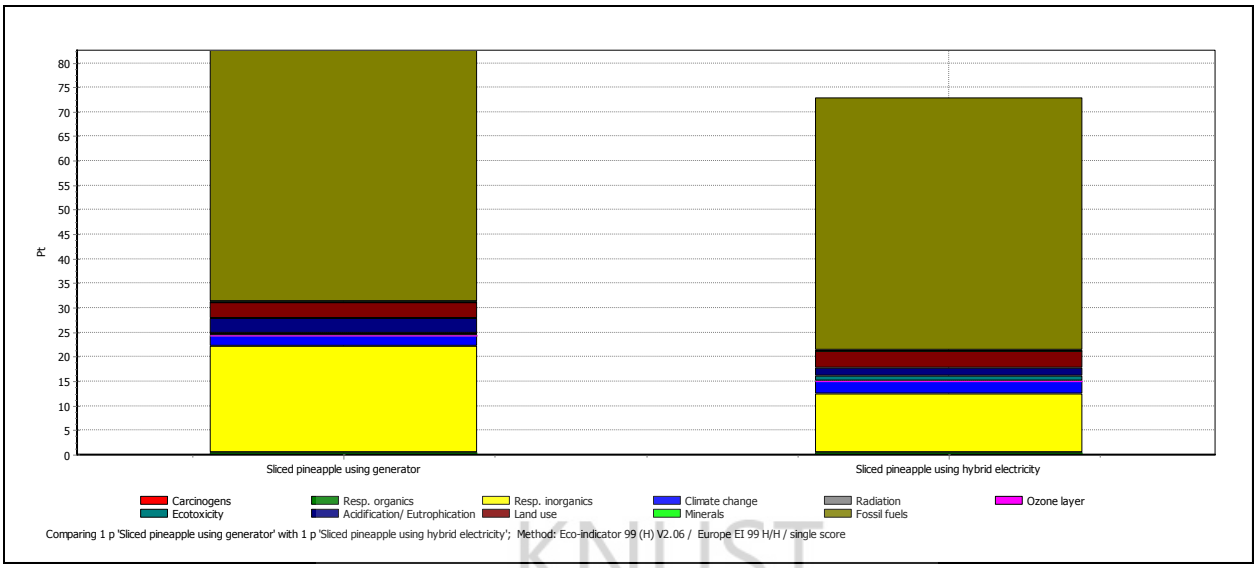


Figure 4.17: Single Score on 100% Diesel-Electric Generating Set and Hybrid Electricity

The use of Monte Carlo simulation to analyze the environmental load of the 2 different electricity portfolios suggests that the use of 100% diesel-electric generating set made significant impact on the environment than sourcing electric energy as hybrid electricity as shown in Table 4.17 and Figure 4.18. In this figure the number of outcomes where 100% diesel-electric generating set (A) has a higher score than the hybrid electricity (B) is shown per impact category.

Table 4.17: Monte Carlo Results on comparing use of 100% Diesel-Electric Generating Set with Hybrid Electricity on Impact categories

Impact category	A >= B	Mean	Median	SD	CV (Coefficient of Variation)	2.50%	97.50%	Std. err. of mean
Acidification/ Eutrophication	87.80%	16.1	10.3	20.4	127%	-3.9	70.2	0.04
Carcinogens	70.40%	6.25E-07	1.39E-06	5.09E-06	814%	-1.07E-05	6.75E-06	0.257
Climate change	0.10%	-1.80E-05	-1.70E-05	8.44E-06	-47%	-3.87E-05	-4.64E-06	-0.0149
Ecotoxicity	0.50%	-60.3	-36.6	97.8	-162%	-232	-5.69	-0.0513
Fossil fuels	46.70%	-4.22	-6.03	71.2	-1.69E+01	-135	137	-0.534
Land use	0.40%	-3.12	-2.9	1.53	-49%	-6.63	-0.919	-0.0155

Minerals	40.90%	-0.0887	-0.0804	0.45	-507%	-1.06	0.841	-0.16
Ozone layer	45.90%	-2.55E-10	-5.26E-10	5.17E-09	-2.02E+01	-9.93E-09	1.07E-08	-0.64
Radiation	16.80%	-1.46E-08	-9.50E-09	2.90E-08	-198%	-7.51E-08	1.72E-08	-0.0626
Resp. inorganics	99.40%	0.000491	0.00041	0.000343	69.80%	7.62E-05	0.00136	0.0221
Resp. organics	100%	3.21E-07	3.01E-07	1.25E-07	38.90%	1.44E-07	6.02E-07	0.0123

Confidence interval: 95%

This indicates that some of the differences shown in Figure 4.18 are significant. In general it could be assumed that if 90% to 95% of the Monte Carlo runs are favorable for a product, the difference may be considered significant (Pre Consultants, 2008).

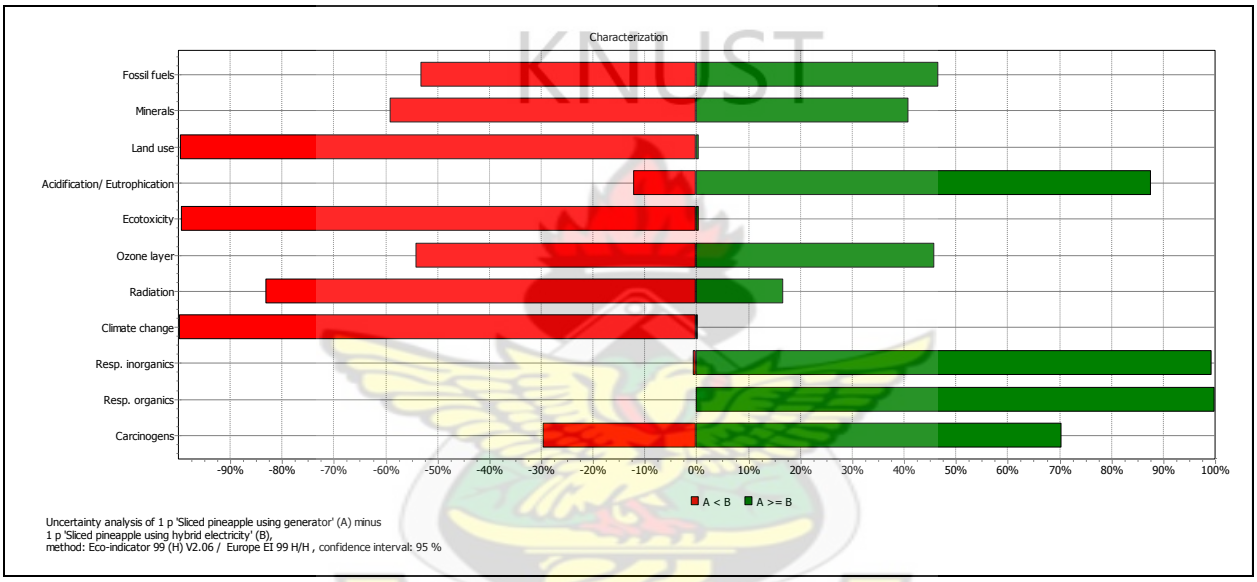


Figure 4.18: Monte Carlo Results on Comparing Characterization of 100% Diesel-Electric Generating Set and Hybrid Electricity

This rule means that differences between the two processes are not significant for fossil fuel, minerals, acidification/eutrophication, ozone layer, radiation and carcinogens. There is however significant difference in the impact on land use, ecotoxicity, and climate change by the use of hybrid electricity than diesel-electric generating set. Moreover, there is significant difference in the impact of 100% diesel-electric generating set on respiratory organics and respiratory inorganics than hybrid electricity as shown in Figure 4.18. Thus the continuous use

of 100% diesel-electric generating set could cause some respiratory ailments to the people who work at the processing plant.

Damage Assessment, Normalization and Weighting

The respective impact on damage categories by the use of 100% diesel-electric generating set (A) and hybrid electricity (B) source for production of 1 kg of sliced pineapple at the fruit processing plant are shown in Table 4.18. After 1,000 Monte Carlo simulation runs, 99% and 57.8%, respectively of the results established that use of 100% diesel-electric generating set has higher impact on human health and Ecosystem quality, than the use of hybrid electricity source. However, 46.5% of the runs showed that diesel-electric generating set source has higher impact on resources than hybrid electricity source. This implies that more Monte Carlo runs (53.5%) indicate that use of hybrid electricity has greater impact on resources in the damage category.

This confirms the earlier assertion that the continuous use of the diesel-electric generating set could affect the health of staff at the processing plant due to its significant impact on the respiratory organic and respiratory inorganics.

Table 4.18: Monte Carlo Results on comparing use of 100% Diesel-Electric Generating Set with Hybrid Electricity for Damage Assessment

Damage category	A >= B	Mean	Median	SD	CV (Coefficient of Variation)	2.50%	97.50%	Std.err.of mean
Ecosystem Quality	57.80%	6.97	2.08	23.1	332%	-19.1	63	0.105
Human Health	99%	0.000474	0.000392	0.000344	72.60%	5.71E-05	0.00135	0.023
Resources	46.50%	-4.3	-6.15	71.3	-1.66E+01	-136	137	-0.524

Confidence interval: 95%

The respective impact on the damage categories are as shown graphically in Figure 4.11. Thus for the damage assessment, the difference between the two energy portfolios is not significant with respect to resources and ecosystem quality under the damage category. The difference is however significant in human health as shown.

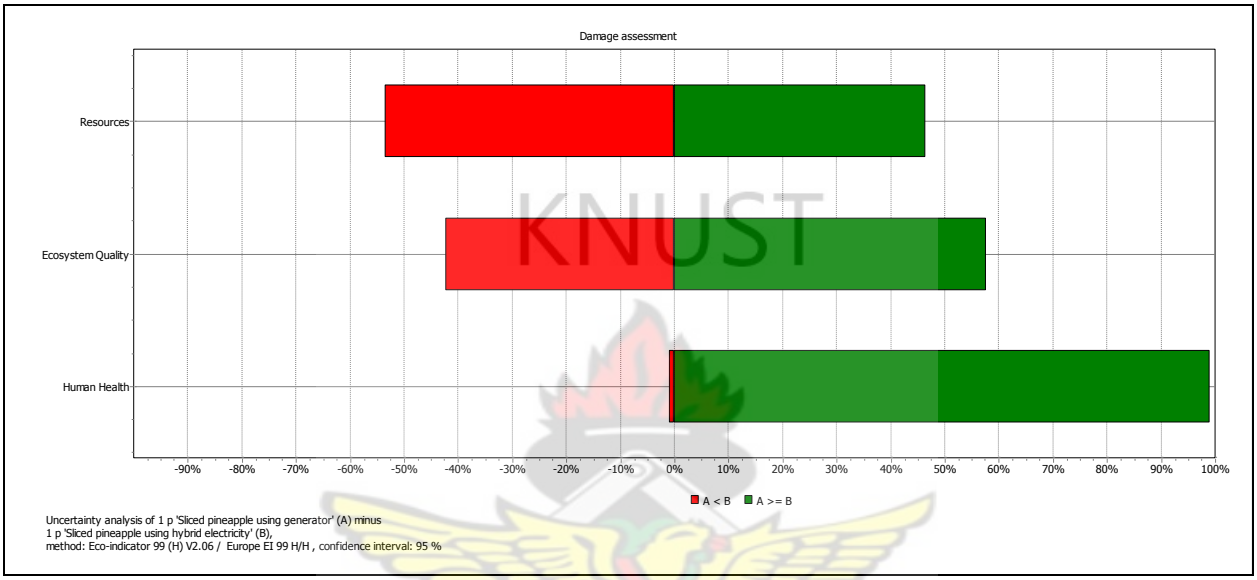


Figure 4.19: Monte Carlo Results on Comparing Damage Assessment of 100% Diesel-Electric Generating Set and Hybrid Electricity

The results of Monte Carlo simulation on the two energy sources as shown in Tables 4.19 and 4.20 as well as Figures 4.20 and 4.21, respectively indicate that normalization and weighting of the damage categories impact are similar to those of damage assessment as described above.

Table 4.19: Monte Carlo Results on comparing use of 100% Diesel-Electric Generating Set with Hybrid Electricity for Normalization

Damage category	A >= B	Mean	Median	SD	CV (Coefficient of Variation)	2.50%	97.50%	Std.err.of mean
Ecosystem Quality	57.80%	0.00136	0.000405	0.00451	332%	-0.00373	0.0123	0.105
Human Health	99%	0.0308	0.0255	0.0224	72.60%	0.00372	0.0879	0.023
Resources	46.50%	-0.00051	-0.00073	0.00848	-1.66E+01	-0.0161	0.0163	-0.524

Confidence interval: 95%

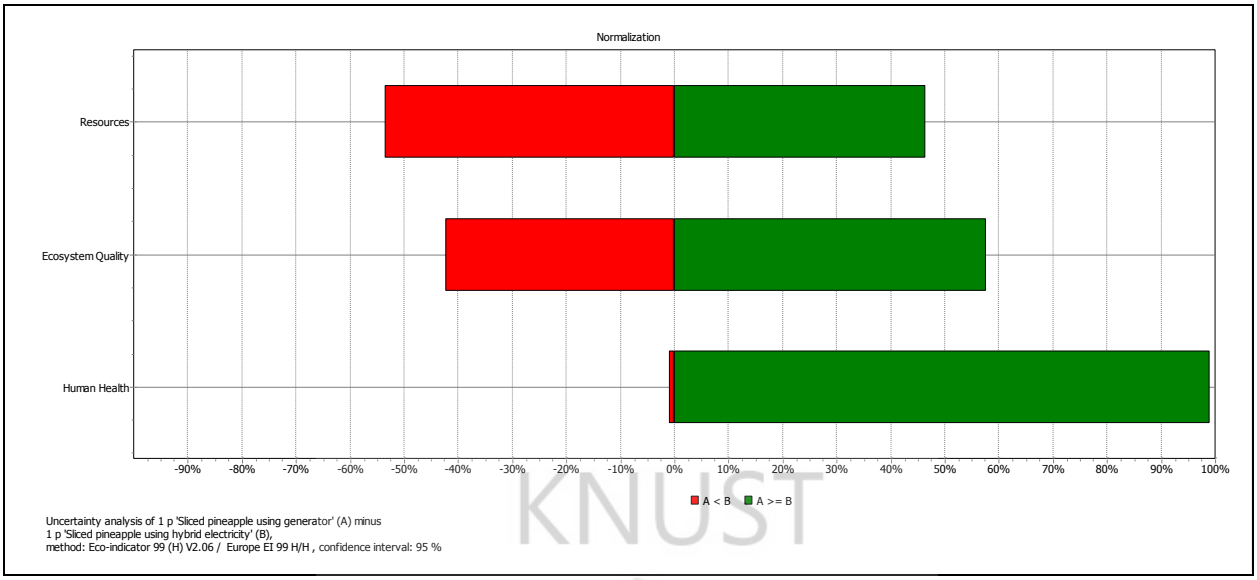


Figure 4.20: Monte Carlo Results on Comparing Normalization for 100% Diesel-Electric Generating Set and Hybrid Electricity

Table 4.20: Monte Carlo Results on comparing use of 100% Diesel-Electric Generating Set with Hybrid Electricity for Weighting

Damage category	A >= B	Mean	Median	SD	CV (Coefficient of Variation)	2.50%	97.50%	Std.err.of mean
Ecosystem Quality	57.80%	0.544	0.162	1.8	332%	-1.49	4.91	0.105
Human Health	99%	9.25	7.65	6.72	72.60%	1.12	26.4	0.023
Resources	46.50%	-0.154	-0.22	2.55	-1.66E+01	-4.84	4.89	-0.524

Confidence interval: 95%

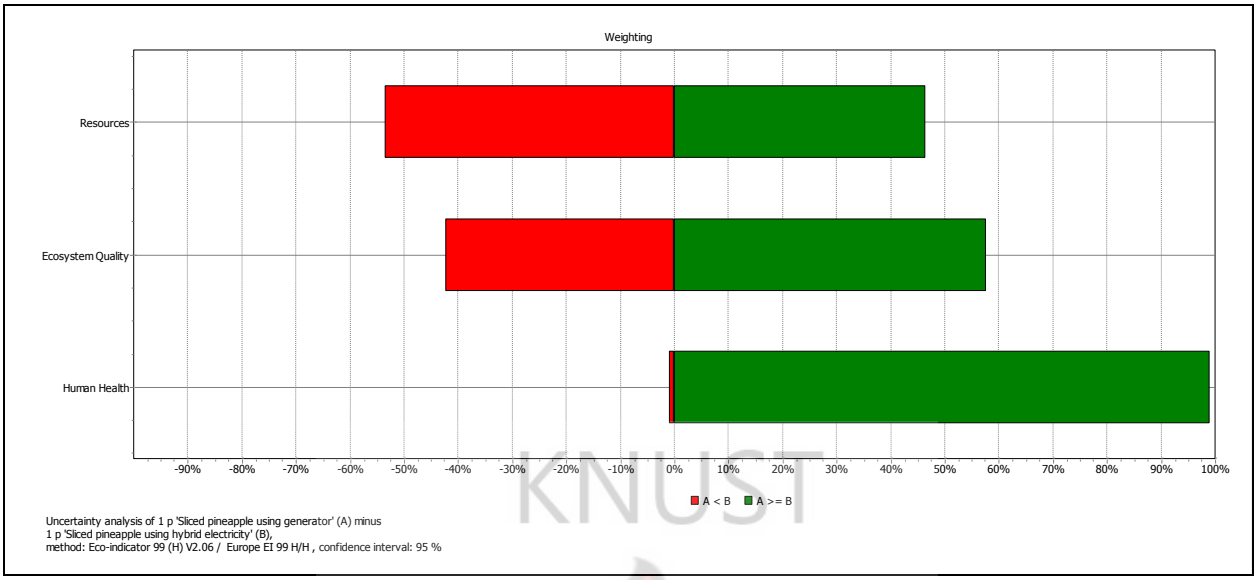


Figure 4.21: Monte Carlo Results on Comparing Weighting for 100% Diesel-Electric Generating Set and Hybrid Electricity

Single Score

The number of outcomes where use of 100% diesel-electric generating set has higher score than hybrid electricity is shown in the Table 4.21 for single score.

Table 4.21: Monte Carlo Results on comparing use of 100% Diesel-Electric Generating Set with Hybrid Electricity for Single Score

Damage category	A >= B	Mean	Median	SD	CV (Coefficient of Variation)	2.50%	97.50%	Std.err.of mean
Single score	93.20%	9.64	7.98	8.77	91%	-2.01	31.3	0.0288

Confidence interval: 95%

The single score results indicate that for 93.2% of the Monte Carlo simulation runs 100% diesel-electric generating set has higher score than use of hybrid electricity. Thus the single score for production of sliced pineapple using these two different electricity sources indicates

that 100% diesel-electric generating set has higher impact on damage categories (ecosystem quality, human health and resources) than using hybrid electricity as shown in Figure 4.22.

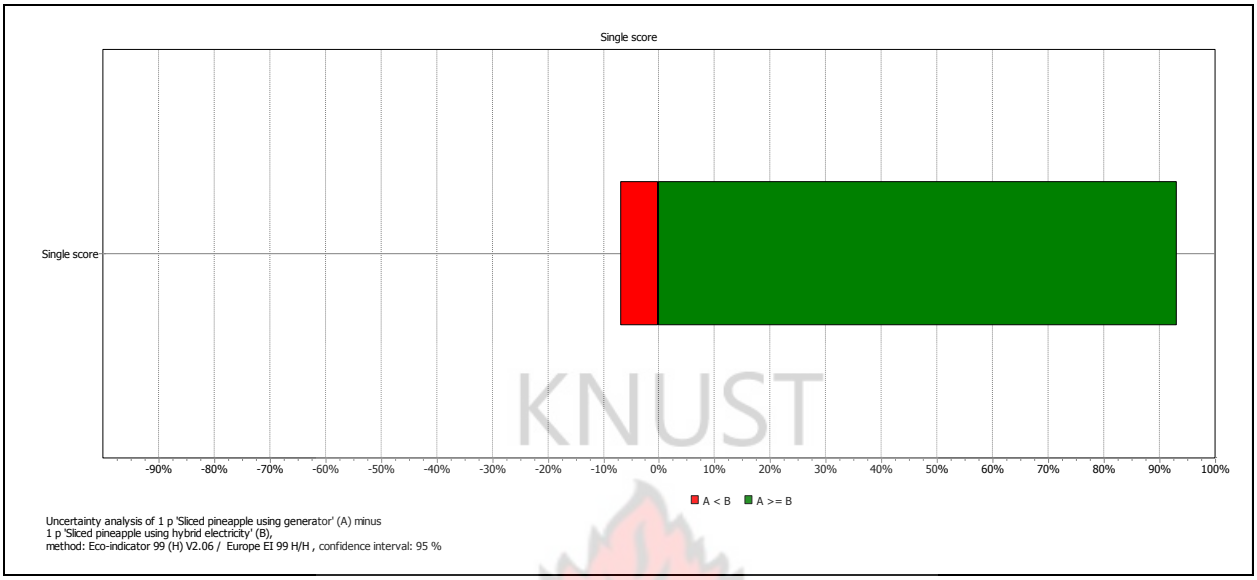


Figure 4.22: Monte Carlo Results on Comparing 100% Diesel-Electric Generating Set and Hybrid Electricity for Single Score

The figure indicates that the difference between the impacts on the environment by the two different sources of electric energy for the processing of pineapple is significant. Thus the use of 100% diesel-electric generating set made significant impact on the damage categories than the use of hybrid electricity source.

4.2.3 Comparing Energy Sources from 100% National Grid Electricity and 100% Diesel-Electric Generating Set

The prospects of the fruit processing company to explore the potential to put in place systems to facilitate continuous access to all its electricity needs from the national grid was investigated and compared with the environmental load that would be emanated in the use of diesel-electric generating set to provide all its electrical energy needs.

The impact assessment using Eco-Indicator 99 (H) in SimaPro 7.1.8 gave the following results as shown in Table 4.22. The access of all its electrical energy from the national grid led to higher impact on climate change, radiation, ozone layer, ecotoxicity, land use, minerals and fossil fuels than the impact from access of its electrical energy from the use of diesel-electric generating set. However, it has less impact on carcinogens, respiratory organics, respiratory inorganics and acidification/eutrophication than the impact from use of diesel-electric generating set.

Table 4.22: Characterization of Comparing 100% National Grid and 100% Diesel Electric Generating Sets

Impact category	Unit	Sliced pineapple using Diesel-Electric Generating Set	Sliced Pineapple using National Grid Electricity
Carcinogens	DALY	1.78E-05	1.74E-05
Resp. organics	DALY	4.15E-06	3.82E-06
Resp. inorganics	DALY	0.001104726	0.000596647
Climate change	DALY	0.000118286	0.000142199
Radiation	DALY	6.40E-07	6.63E-07
Ozone layer	DALY	1.15E-07	1.18E-07
Ecotoxicity	PAF*m2yr	60.683267	131.63961
Acidification/ Eutrophication	PDF*m2yr	37.698408	21.096652
Land use	PDF*m2yr	41.05134	44.715656
Minerals	MJ surplus	5.6447513	5.8013872
Fossil fuels	MJ surplus	1439.4952	1475.097

Thus access of all electrical energy from the national grid has higher impact on all the resources (minerals and fossil fuels) and most of the ecosystem quality than the impact from the use of diesel-electric generating set as shown in Figure 4.23.

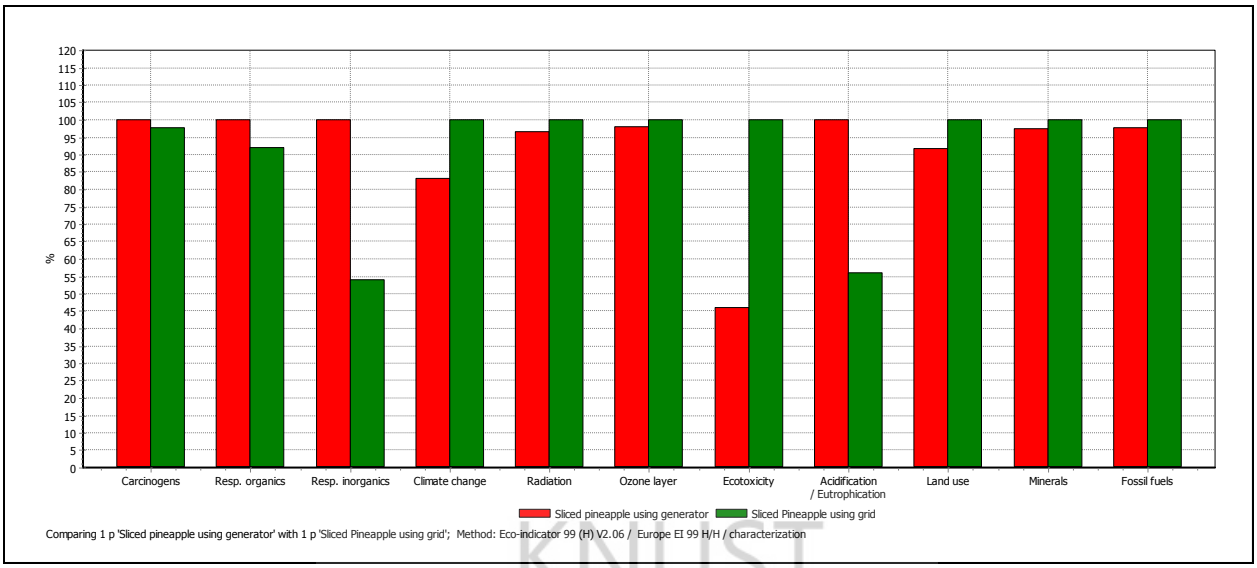


Figure 4.23: Characterization of Comparing 100% National Grid Electricity with 100% Diesel Electric Generating Set

The aggregate of the impact of accessing 100% of electrical energy from the use of diesel-electric generating set on all the impact categories is higher than aggregate impact on the categories from access of electrical energy from the national grid. Thus the single score indicator established that the use of diesel-electric generating set to produce sliced pineapple at the fruit processing factory has greater environmental load (Figure 4.24).

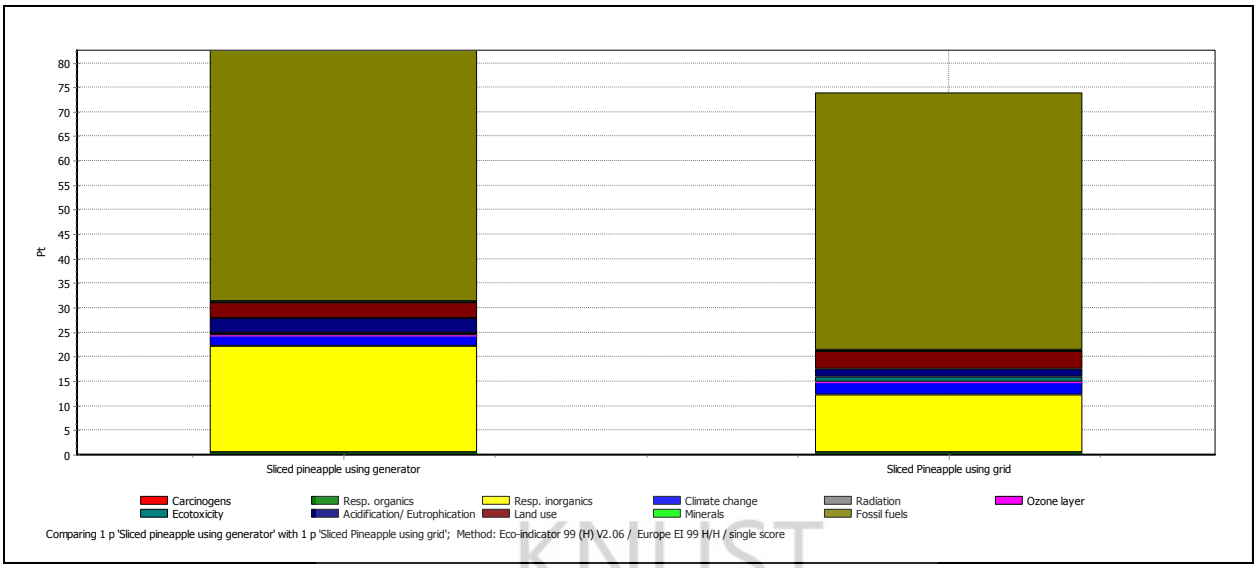


Figure 4.24: Single Score on 100% National Grid and 100% Diesel-Electric Generating Set

The 1,000 runs of Monte Carlo simulation to analyze the environmental load of the 2 different electrical energy portfolios suggests that access of electrical energy from 100% diesel-electric generating set made less impact on most of the impact categories than impact on these categories in accessing electrical energy from national grid to produce sliced pineapple as shown in Table 4.23.

Table 4.23: Monte Carlo Results on comparing use of 100% National Grid Electricity with 100% Diesel-Electric Generating Set on Impact categories

Impact category	A >= B	Mean	Median	SD	CV (Coefficient of Variation)	2.50%	97.50%	Std.err.of mean
Acidification/ Eutrophication	84%	18.2	10.1	26.8	148%	-4.74	89.9	0.0467
Carcinogens	64.90%	1.72E-07	1.04E-06	5.69E-06	3.30E+01	-1.25E-05	7.09E-06	1.04
Climate change	0%	-2.39E-05	-2.24E-05	9.98E-06	-41.80%	-4.68E-05	-8.79E-06	-0.0132
Ecotoxicity	0.20%	-73.3	-45.9	111	-152%	-286	-7.92	-0.048
Fossil fuels	28.10%	-42.2	-45.7	76.7	-182%	-178	117	-0.0575
Land use	0.20%	-3.65	-3.35	1.68	-46.10%	-7.57	-1.22	-0.0146
Minerals	35.90%	-0.17	-0.136	0.557	-328%	-1.29	0.806	-0.104
Ozone layer	26.60%	-2.91E-09	-2.74E-09	5.66E-09	-194%	-1.48E-08	7.97E-09	-0.0615
Radiation	8.70%	-2.44E-08	-1.60E-08	4.00E-08	-164%	-1.08E-07	9.17E-09	-0.0518
Resp. inorganics	99%	0.000535	0.00043	0.000442	82.60%	5.11E-05	0.00164	0.0261
Resp. organics	100%	3.32E-07	3.02E-07	1.36E-07	41.10%	1.46E-07	6.88E-07	0.013

Confidence interval: 95%

In Figure 4.25 the number of outcomes where 100% diesel-electric generating set (A) has a higher score than the national grid electricity (B) is shown per impact category. In general it could be assume that if 90% to 95% of the Monte Carlo runs are favorable for a product, the difference may be considered significant (Pre Consultants, 2008).

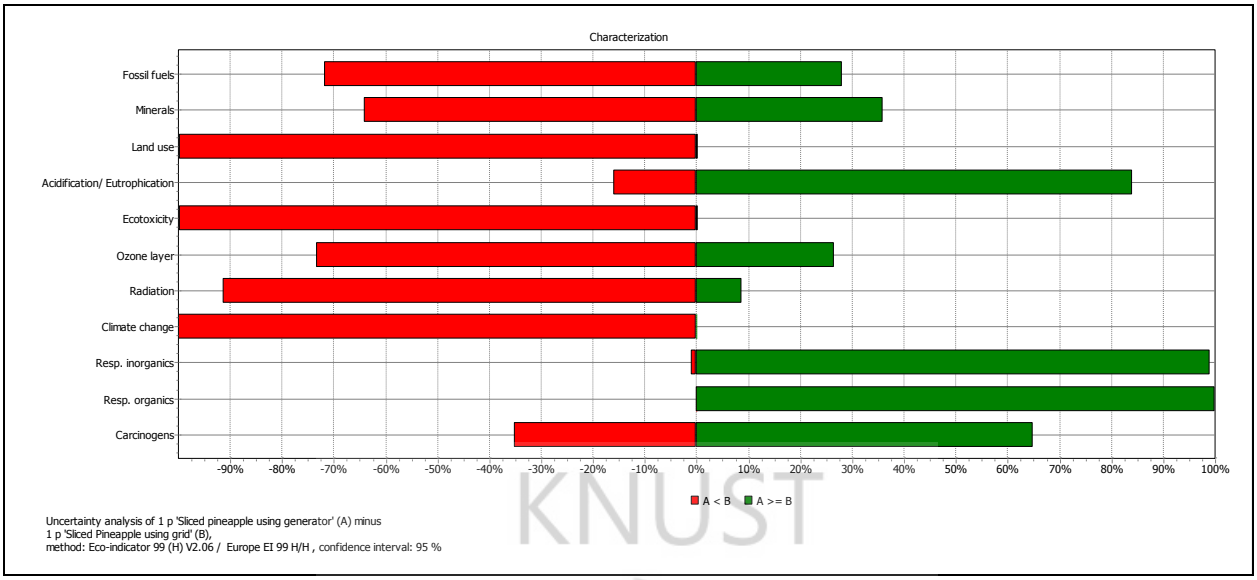


Figure 4.25: Monte Carlo Results on Comparing Characterization of 100% National Grid Electricity and 100% Diesel-Electric Generating Set

In using the assumptions by Pre Consultants (2008), differences in the higher impact of the use of electrical energy from diesel-electrical generating set on respiratory organics and respiratory inorganics are significant. However the differences in higher impact on acidification/eutrophication and carcinogens are not significant.

The access of electrical power solely from national grid at the fruit processing plant has higher impact on fossil fuels, minerals, land use, ecotoxicity, ozone layer, radiation, and climate change than impact on these categories by the use of 100% diesel-electric generating set (Figure 4.25). The difference in higher impact is significant on the land use, ecotoxicity, radiation and climate change impact categories.

Damage Assessment, Normalization and Weighting

The respective impact on damage categories by the use of 100% diesel-electric generating set (A) and 100% national grid electricity (B) source for production of 1 kg of sliced pineapple at the fruit processing plant are shown in Table 4.24. After 1,000 Monte Carlo simulation runs, 98.4% and 52.7%, respectively of the results established that use of 100% diesel-electric generating set has higher impact on human health and Ecosystem quality, than impact on these damage categories in the use of national grid electricity source. However, 28.1% of the runs showed that diesel-electric generating set source has higher impact on resources than impact in using national grid electricity source. This implies that more Monte Carlo simulation runs (71.9%) indicate that use of national grid electricity has greater impact on resources in the damage category.

Table 4.24: Monte Carlo Results on comparing use of 100% National Grid Electricity with 100% Diesel-Electric Generating Set for Damage Assessment

Damage category	A >= B	Mean	Median	SD	CV (Coefficient of Variation)	2.50%	97.50%	Std.err.of mean
Ecosystem Quality	52.70%	7.19	0.742	28.4	395%	-27.3	80.5	0.125
Human Health	98.40%	0.000511	0.000401	0.000443	86.60%	2.48E-05	0.00162	0.0274
Resources	28.10%	-42.4	-45.8	76.8	-181%	-179	117	-0.0573

Confidence interval: 95%

The respective impact on the damage categories are as shown graphically in Figure 4.18. Thus for the damage assessment, the difference in impact between the two energy portfolios is not significant with respect to resources and ecosystem quality under the damage category. However, the difference in higher impact of the use of diesel-electric generating set on human health is significant as shown.

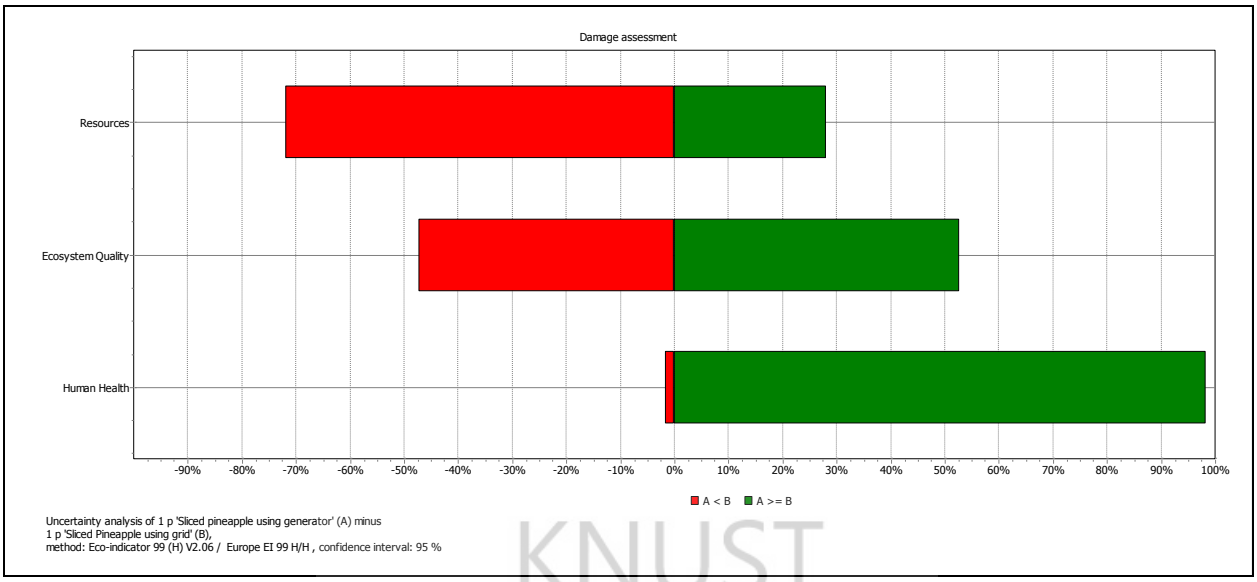


Figure 4.26: Monte Carlo Results on Comparing Damage Assessment of 100% National Grid Electricity and 100% Diesel-Electric Generating Set

The results of Monte Carlo simulation on the two energy sources as shown in Tables 4.25 and 4.26 as well as Figures 4.27 and 4.28, respectively indicate that normalization and weighting of the damage categories impact are similar to those of damage assessment as described above.

Table 4.25: Monte Carlo Results on comparing use of 100% National Grid Electricity with 100% Diesel-Electric Generating Set for Normalization

Damage category	A >= B	Mean	Median	SD	CV (Coefficient of Variation)	2.50%	97.50%	Std.err.of mean
Ecosystem Quality	52.70%	0.0014	0.000145	0.00554	395%	-0.00533	0.0157	0.125
Human Health	98.40%	0.0333	0.0261	0.0288	86.60%	0.00161	0.105	0.0274
Resources	28.10%	-0.00504	-0.00546	0.00914	-181%	-0.0212	0.014	-0.0573

Confidence interval: 95%

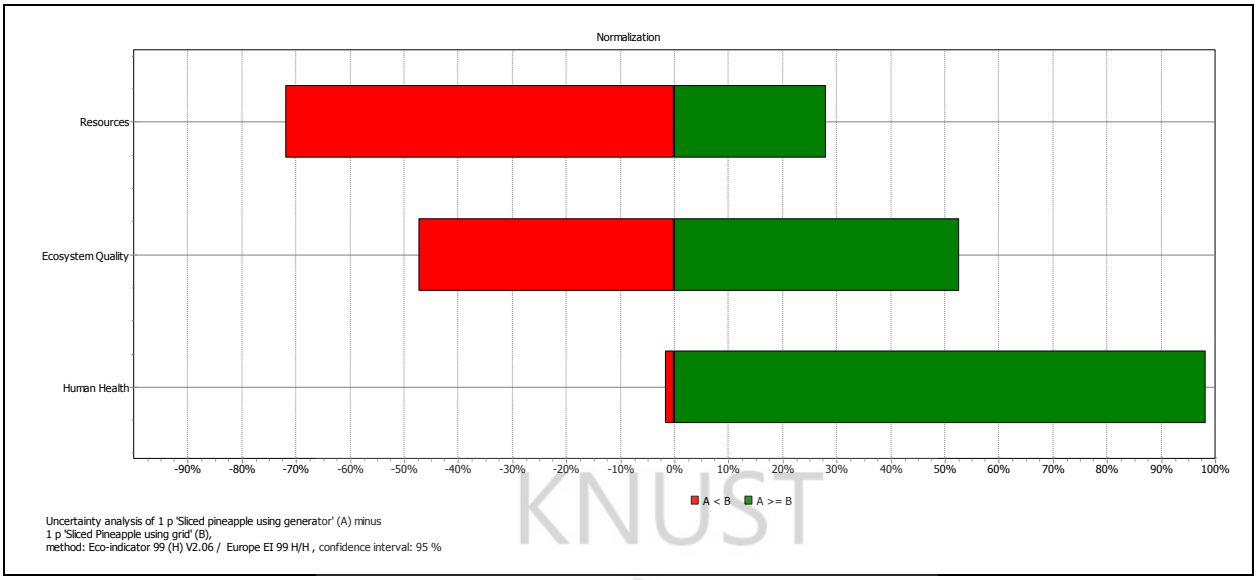


Figure 4.27: Monte Carlo Results on Comparing Normalization for 100% National Grid Electricity with 100% Diesel-Electric Generating Set

Table 4.26: Monte Carlo Results on comparing use of 100% National Grid Electricity with 100% Diesel-Electric Generating Set for Weighting

Damage category	A >= B	Mean	Median	SD	CV (Coefficient of Variation)	2.50%	97.50%	Std.err.of mean
Ecosystem Quality	52.70%	0.561	0.0578	2.22	395%	-2.13	6.28	0.125
Human Health	98.40%	9.99	7.82	8.65	86.60%	0.484	31.6	0.0274
Resources	28.10%	-1.51	-1.64	2.74	-181%	-6.37	4.19	-0.0573

Confidence interval: 95%

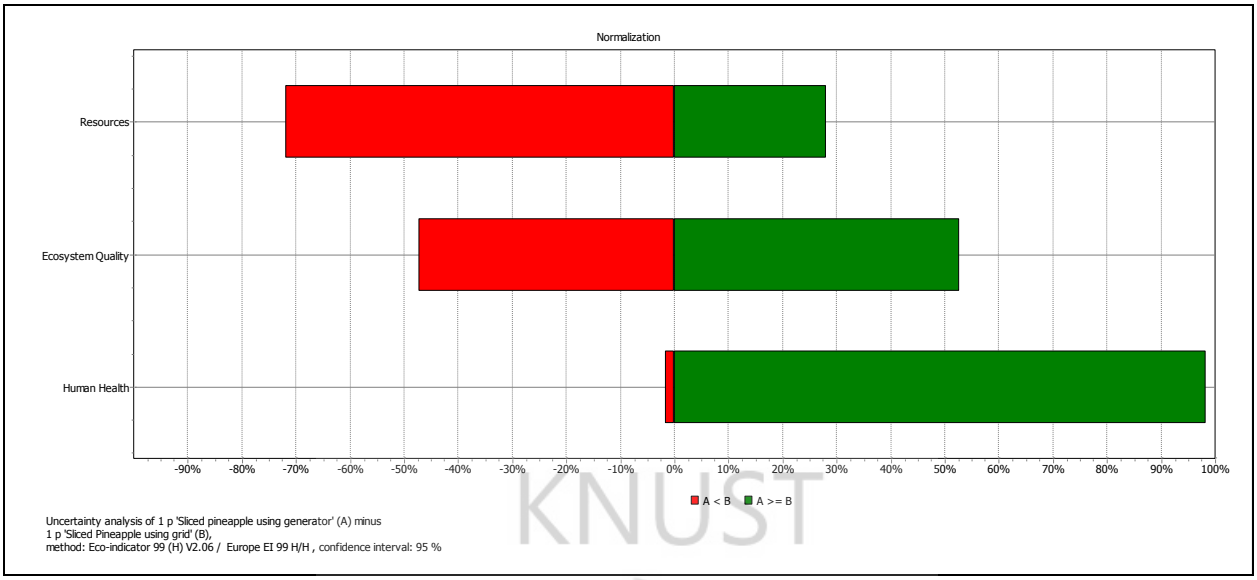


Figure 4.28: Monte Carlo Results on Comparing Weighting for 100% National Grid Electricity with 100% Diesel-Electric Generating Set

Single Score

The number of outcomes where use of 100% diesel-electric generating set has higher score than national grid electricity is shown in the Table 4.27 for single score.

Table 4.27: Monte Carlo Results on comparing use of 100% National Grid Electricity with 100% Diesel-Electric Generating Set for Single Score

Damage category	A >= B	Mean	Median	SD	CV (Coefficient of Variation)	2.50%	97.50%	Std.err.of mean
Single score	86.20%	9.04	6.54	11	122%	-4.23	37.5	0.0386

Confidence interval: 95%

The single score results indicate that for 86.2% of the Monte Carlo simulations runs 100% diesel-electric generating set has higher score than use of national grid electricity. Thus the single score for production of sliced pineapple using these two different electrical energy sources indicates that 100% diesel-electric generating set has higher impact on the aggregate

damage categories (ecosystem quality, human health and resources) than using national grid electricity as shown in Figure 4.29.

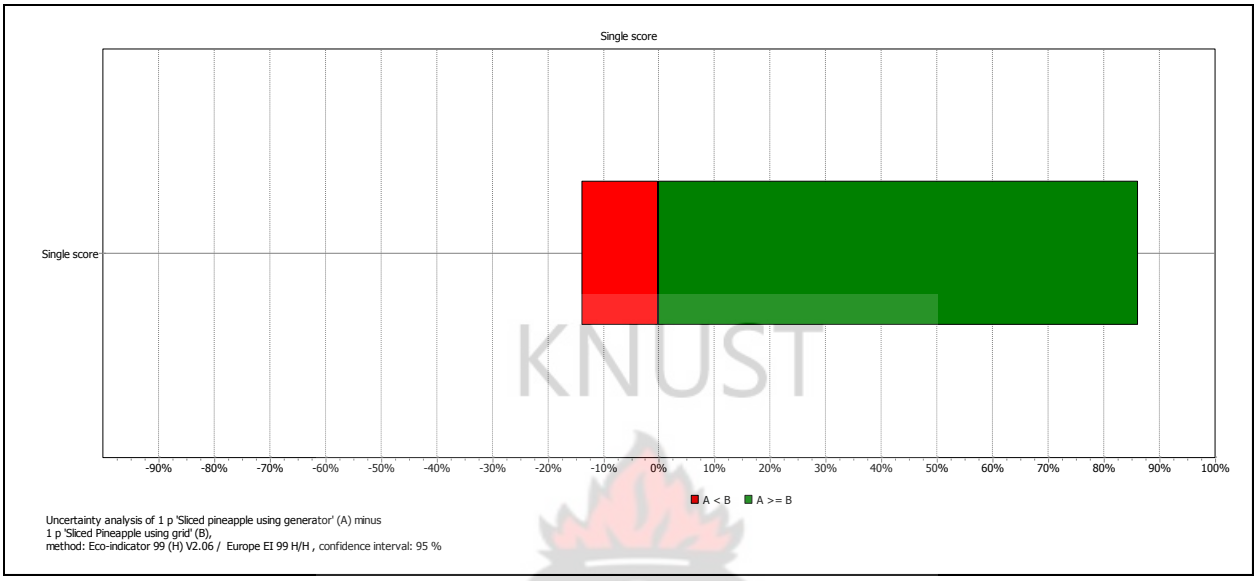


Figure 4.29: Monte Carlo Results on Comparing 100% national Grid Electricity with 100% Diesel-Electric Generating Set for Single Score

The figure indicates that the difference between the impacts on the environment by the two different sources of electrical energy for the processing of pineapple is not significant.

4.2.4. Comparing Electricity Sources from Hybrid Electricity, National Grid and Diesel-Electric Generating Set

These three different energy portfolios were compared to establish the respective impact on the environment. Table 4.28 shows the characterization results for the 3 different scenarios.

Table 4.28: Characterization impact score for three different sources of Electricity to produce 1 kg of Sliced Pineapple

Impact category	Unit	Sliced pineapple using Hybrid Electricity sources	Sliced pineapple using National Grid	Sliced pineapple using Diesel-Electric Generating Set
Carcinogens	DALY	1.70E-05	1.74E-05	1.78E-05
Resp. organics	DALY	3.83E-06	3.82E-06	4.15E-06
Resp. inorganics	DALY	0.000610867	0.000596647	0.001104726
Climate change	DALY	0.00013619	0.000142199	0.000118286
Radiation	DALY	6.54E-07	6.63E-07	6.40E-07
Ozone layer	DALY	1.16E-07	1.18E-07	1.15E-07
Ecotoxicity	PAF*m2yr	122.63132	131.63961	60.683267
Acidification/ Eutrophication	PDF*m2yr	21.581648	21.096652	37.698408
Land use	PDF*m2yr	44.13678	44.715656	41.05134
Minerals	MJ surplus	5.7331832	5.8013872	5.6447513
Fossil fuels	MJ surplus	1441.4553	1475.097	1439.4952

DALY-Disability Adjusted Life Years (Years of disabled living or years of life lost due to the impacts)
PAF Potentially Affected Fraction (Animals affected by the impacts)
*PDF*m2yr-Potentially Disappeared Fraction (Plant species disappeared as result of the impacts)*
SE Surplus Energy (MJ) (Extra energy that future generations must use to excavate scarce resources)

The results indicate that extensive use of diesel-electric generating set leads to high carcinogens, respiratory (organic and inorganic) and acidification. This is graphically depicted in Figure 4.30.

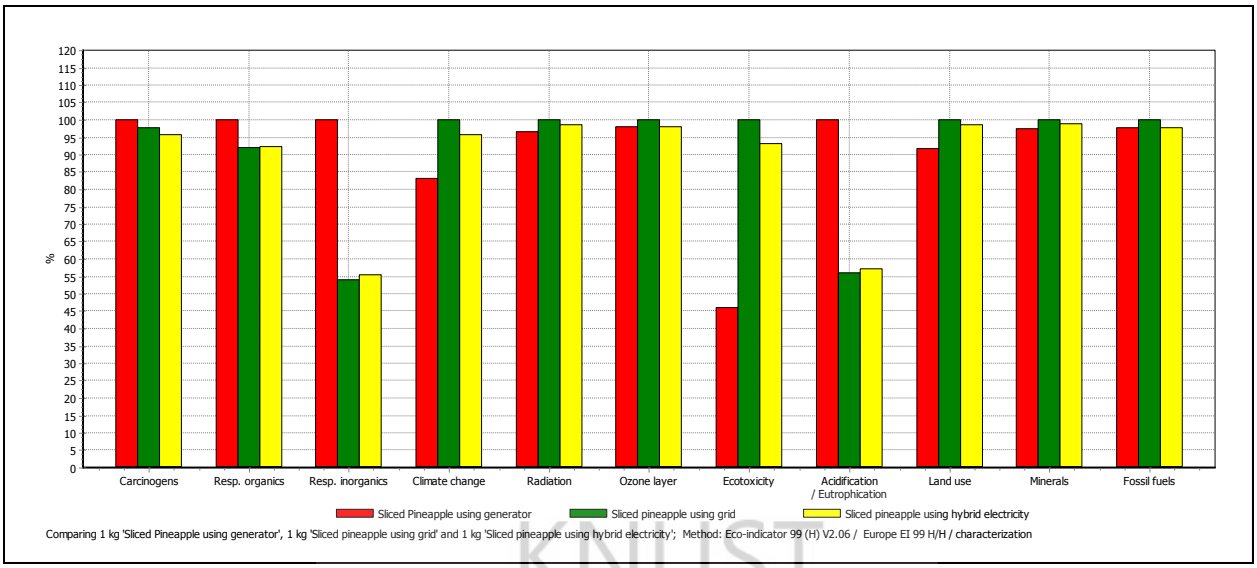


Figure 4.30: Characterization of Comparing 100% National Grid Electricity, 100% Diesel Electric Generating Set and Hybrid Electricity Sources

The access of electricity from the national grid as the main source of electrical energy to produce sliced pineapple at the fruit processing plant has the highest impact on climate change, radiation, ozone layer, ecotoxicity, land use, minerals and fossil fuel impact categories as shown in Figure 4.30.

The use of diesel-electric generating set has less impact on ozone layer depletion and climate change than impact on these categories by the use of hybrid electricity (94% national grid and 6% diesel-electric generating set) and 100% national grid in the ascending order. As the amount of energy sourced from national grid reduces, the impact on ozone layer depletion and climate change also decreases. Consequently sourcing of electricity from the national grid contributes more to depletion of the ozone layer and climate change. The 30% source of national power supply from light oil-fired electric power plant could be the main cause of substances that contribute to the depletion of the ozone layer and climate change. There is an

indication that the use of light oil power plant in the production of electricity in Ghana makes significant contribution to the depletion of the ozone layer and climate change.

The respective impact contributions from the use of these energy portfolio sources on human health, ecosystem quality and resource are summarized in Table 4.29.

Table 4.29: Impact of different Electric Energy Sources on Human health, Ecosystem and Resources Damage Categories

Damage Categories	Unit	Sliced Pineapple using generator	Sliced pineapple using grid	Sliced pineapple using hybrid electricity
Human Health	DALY	1.25E-06	7.61E-07	7.69E-07
Ecosystem Quality	PAF*m2yr	0.084818075	0.078976269	0.07798156
Resources	MJ surplus	1.445139951	1.480898387	1.447188483

The use of diesel-electric generating set has the highest impact on human health and ecosystem quality but the least impact on resources in the damage categories. The access of electrical energy from the hybrid electricity sources demonstrates the least impact on the ecosystem quality and resources. However, the use of 100% electricity from the national grid which comprises 70% hydro-electric and 30% light oil power plant sources has the highest impact on the resources but the least impact on human health.

These outcomes suggest that the diesel-electric generating set is the major cause of human health. This led to the higher impact on human health damage category by hybrid electricity than impact on the same damage category by use of electrical energy from national grid. Thus there is a significant difference in impact on human health by the use of diesel-electric generating set.

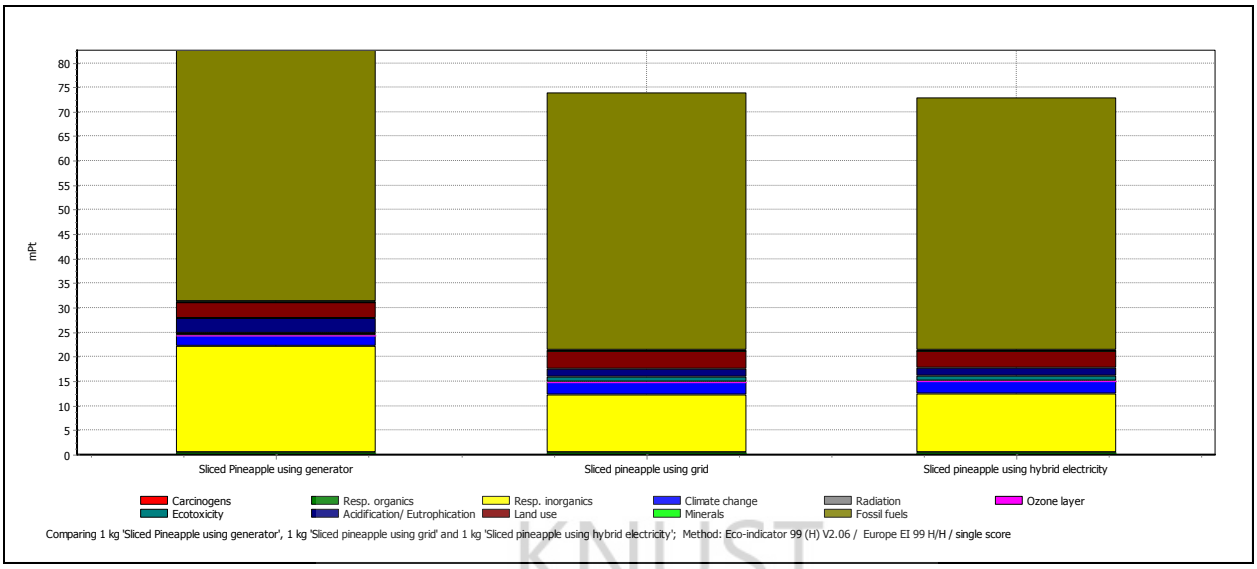


Figure 4.31: Single Score Outcome of Comparing 100% National Grid Electricity, 100% Diesel Electric Generating Set and Hybrid Electricity Sources

The single score outcome (Figure 4.31) of the respective electric energy portfolios indicates that the use of diesel-electric generating set has the highest impact on the environment. The use of hybrid electricity source has the least impact on the environment. These buttress the outcome of Monte Carlo simulation runs to establish the relative impact on damage categories in comparing these three different electric energy scenarios.

4.2.5 Conclusions

The impact of access of electrical energy from 100% diesel-electric generating set, 100% national grid, and hybrid (94% of national grid electricity and 6% of diesel-electric generating set) on the environment by fruit processing plant were investigated. Their respective impacts were compared using Monte Carlo simulations.

The outcome of the Monte Carlo simulation runs in systematic comparison of the different models of electrical energy sources suggests that the use of 100% of diesel-electric generating set to provide electricity in production of sliced pineapple at the fruit processing plant for the export market has the highest impact on the human health and ecosystem quality damage categories. These outcomes suggest that the diesel-electric generating set is the major cause of human health. This led to the higher impact on human health damage category by hybrid electricity (6% diesel-electric generating set and 94% electricity from national grid) than impact on the same damage category by use of electrical energy from national grid. There is a significant difference in impact on human health by the use of diesel-electric generating set. Sourcing of electrical energy solely from the national grid has the highest impact on resources in the damage category.

The use of electricity from hybrid source (94% from national grid and 6% from the diesel-electric generating source) generates the least environmental load. The use of 100% national grid causes more environmental load than hybrid source of electric energy and, the difference is very significant. As Blue Skies Products Ghana Limited uses more electricity from the national grid it tends to cause more harm to the environment. Moreover, for every unit of product produced using 100% national grid depletes ozone layer and causes climate change as well as radiations and acidification more than if it would have been supplemented its source of energy with that of diesel generated electric power.

The high levels of respiratory (organic and inorganic) in the use diesel-electric generating plant are main contributing factors to the human health. There is the need for the company to institute and enforce health and safety measures in the management of the power source.

4.3. Optimization of Processing Parameters to Minimize Life Cycle Impact Assessment

All the processes involved in the production of sliced pineapple at the fruit processing plant have some degree of impact on the environment. Moreover, the materials involved in the respective processes also contributed to the environmental load attributed to the product. Some of these processes and materials make more contributions to the respective impact categories than others. This is due to the processes and materials involved in production of those materials that are used in the sliced pineapple production process as well as the processes that they go through in the production of sliced pineapple at the factory.

In sliced pineapple production process at the fruit processing plant, some of the key processes are fresh pineapple supply from farms to the processing plant, use of water in washing fresh pineapple fruits, use of PET containers for the sliced pineapple, cardboard packaging boxes to pack the PET containers with sliced pineapple for export, electricity from national grid (70% hydroelectric power and 30% light oil-fired electric power plant) and diesel-electric generating set, and transporting of finished products to the airport for export. The use of electricity, PET containers and cardboard packaging boxes are the highest contributors to environmental load in processing of fresh pineapple into sliced pineapple at the fruit processing plant (Figure 4.32).

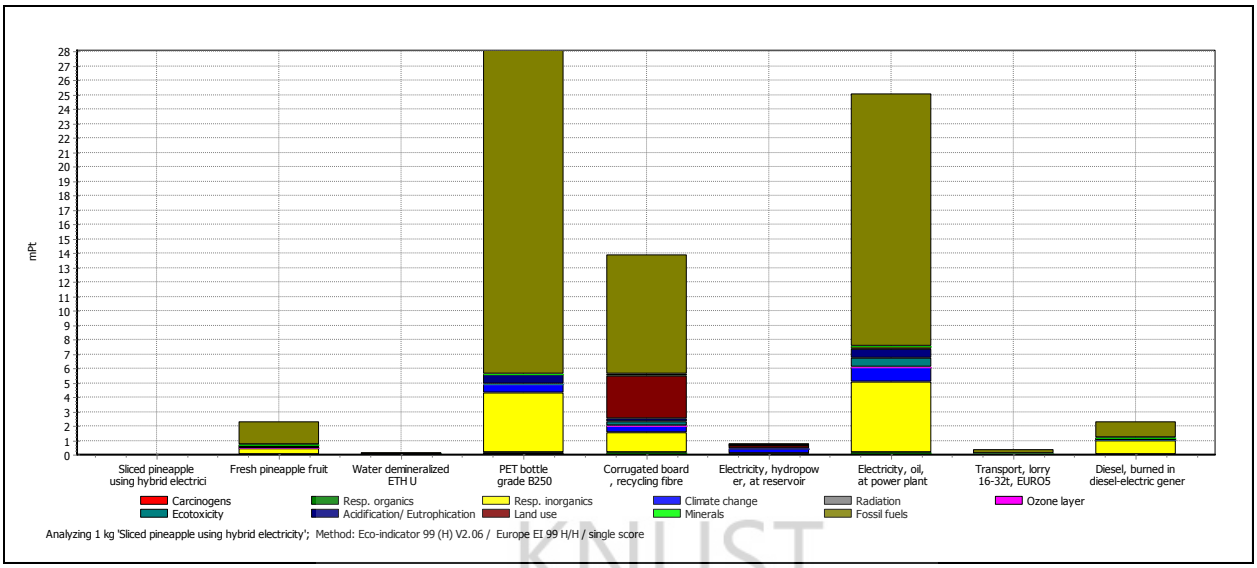


Figure 4.32: Single Score Impact of Processes in Sliced Pineapple Production

At the fruit processing plant, sliced pineapple is packed in PET cans at net weights of 100 g, 200 g, 250 g, 300 g and 350 g respectively for export. These PET cans are then packaged in numbers of 2, 4, 6, 8 or 12 in a cardboard packaging box. Thus for each weight of sliced pineapple, it could be packaged in any of these quantities in a box. In the study the number of PET cans that were used to package 1 MT of sliced pineapple in units of 100 g (net weight) was determined. Moreover the number of cardboard boxes that were used to pack up these "PET-canned" sliced pineapples was also determined. This was determined for when 1 MT of the "PET-canned" sliced pineapple of 100 g weight was packaged in numbers of 2 in a cardboard box. The weight of empty PET can was also determined to establish the total weight of empty PET can needed to package 1 MT of sliced pineapple. Moreover, the weight of empty cardboard box was determined to calculate the total weight of empty cardboard boxes needed for packing up 1 MT of "PET-canned" sliced pineapple.

Currently the fruit processing plants sources its power requirements from the national electricity grid (94%) and diesel-electric generating set (6%). It sources electricity from a standby 1,400 KVA diesel-electric generating set when voltage of power from the national grid falls below the expected voltage to operate the equipment or when there is a power failure. Different percentages of electricity (80%, 85%, 90%, 94% and 100%) accessed from the national grid were simulated to determine the optimized amount that would have the least impact on the climate change, ozone layer and ecotoxicity at different PET and cardboard box weights.

The two weights (empty PET cans and empty cardboard boxes) and different percentages of grid were used in the SimaPro 7.1.8 software to determine impact on climate change, ozone layer and ecotoxicity. Similar analyses were also conducted for when 100 g PET-canned sliced pineapple was packaged in numbers of 4, 6, 8 and 12 in cardboard boxes, respectively.

All these processes were also used to determine similar results for "PET-canned" sliced pineapple of 200 g, 250 g, 300 g and 350 g. Thus these processing parameters were varied to optimize the respective amount that would facilitate reduction in these impact categories (ozone layer depletion, climate change and ecotoxicity).

The Design-Expert 8 software was used to conduct the optimization analyses. The software was used to generate a second-order polynomial model equation from the variables as shown in Equations 4.1., 4.2., and 4.3. The regression coefficients and response surfaces were used to analyze the effect of respective variables on the ozone layer, climate change and ecotoxicity

impact categories. The analysis was to determine the combination of respective inlet variable that would generate minimum environmental load with respect to these three impact categories. Thus mathematical equation and response surface plots were used to relate the dependent and independent variables.

The respective derived equations represent the quantitative effect of process variables (PET Containers, Corrugated Cardboard box and Percentage of national grid) and their interaction on the respective responses - climate change, ozone layer and ecotoxicity. The values of the coefficient of process variables are related to the effect of these variables on the respective responses. Coefficient with more than one factor term and those with higher order terms represent interaction term. A positive sign represent a synergistic effect, while a negative sign indicate an antagonistic effect. The values of the respective coefficient of PET containers, corrugated cardboard box and percentage of national grid were substituted in the equation to obtain the respective theoretical values for climate change, ozone layer and ecotoxicity.

4.3.1 Optimization of Inlet Variable Conditions to Minimize Impact on Climate Change in the Production of Sliced Pineapple

The relationship between the processes (PET containers weights, packaging boxes weights and percentage grid electric energy) to minimize climate change in the production of sliced pineapple at the fruit processing plant is expressed in Equation 4.1.

$$CC = 1.29E\text{-}07 + 8.31E\text{-}09X_1 + 1.3E\text{-}08X_2 + 4.51E\text{-}09X_3 + 4.45E\text{-}09X_2^2 \quad \text{.....(4.1)}$$

Where

CC: Climate Change

X_1: PET Container weight

X_2: Cardboard Box Weight

X_3: Percentage of Grid Electrical Energy used

The equation indicates that the processes have positive correlation with climate change in the production of sliced pineapple at the fruit processing plant.

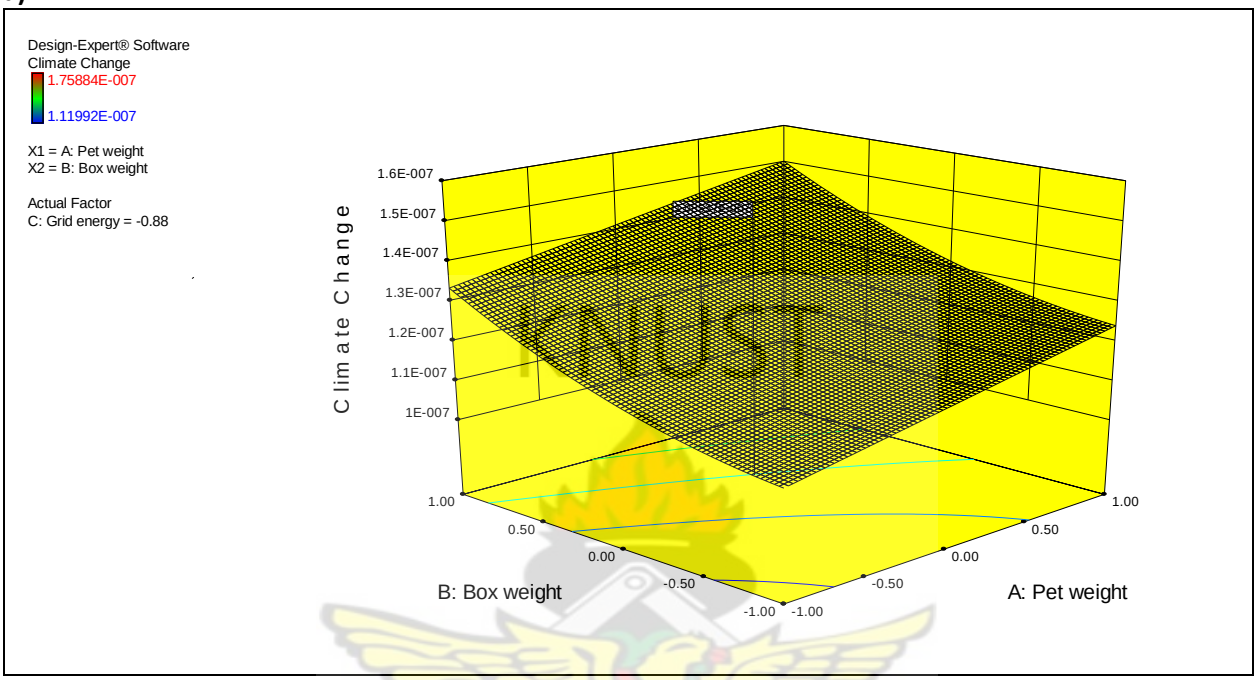
The effect of PET containers weight, cardboard box weight and percentage of grid electrical energy used on climate change is illustrated in the response surface plots (Figure4.33 a, b, c). In each of the plots one of the variables was maintained constant and the others were varied, respectively.

The minimized value for the climate change was determined as 1.08537E-07 DALY under the following optimized inlet variable conditions of: PET container weight of 40.05 kg/MT slice pineapple; cardboard box weight of 120 kg and 85.6% of national grid electricity. Thus 14.4% of electricity from diesel-electric generating set. At these conditions which seek to minimize climate change, values of the other two impact categories would be: ozone layer, 8.8583E-11 DALY; Ecotoxicity, 0.098969142 PDF*m2yr.

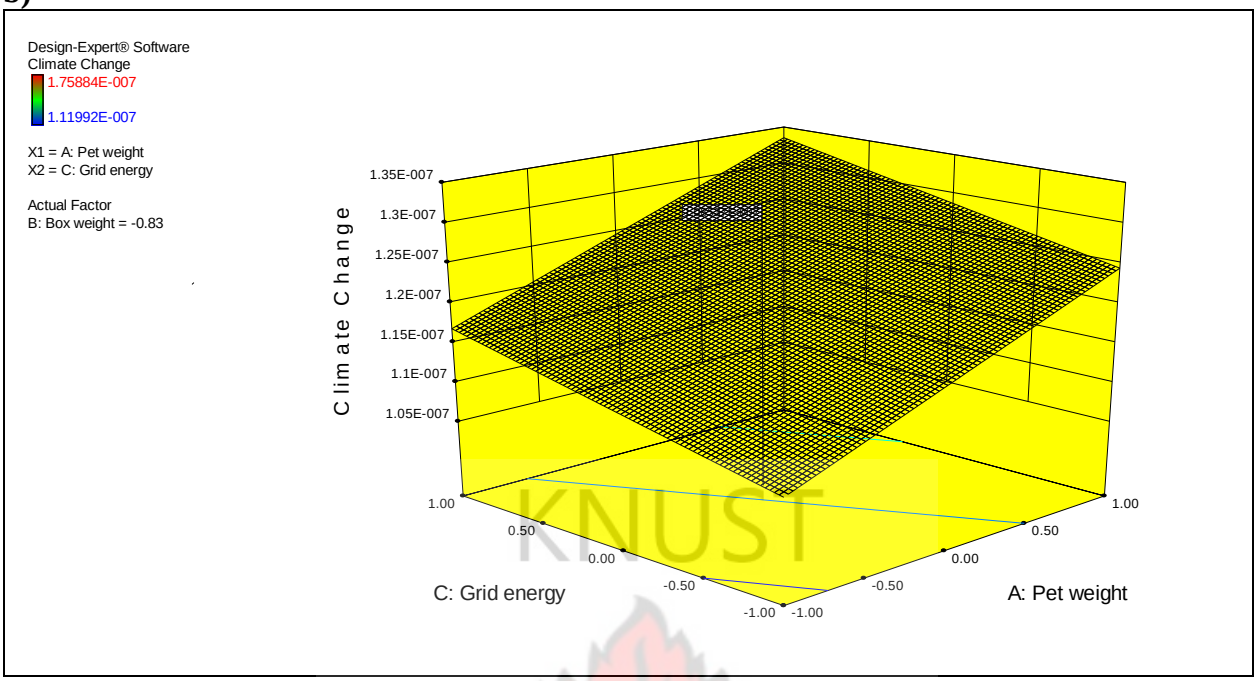
Thus for the fruits processing plant to optimize low impact on climate change category from its processing activities, it has to use a total weight of 40.05 kg of empty PET cans to package 1 MT of sliced pineapples. It means that it has to package net weight of 300 g sliced pineapple

for the market. Moreover, with an average weight of 185 g per empty cardboard box, the optimum number of PET-canned sliced pineapple per box should be 5.

a)



b)



c)

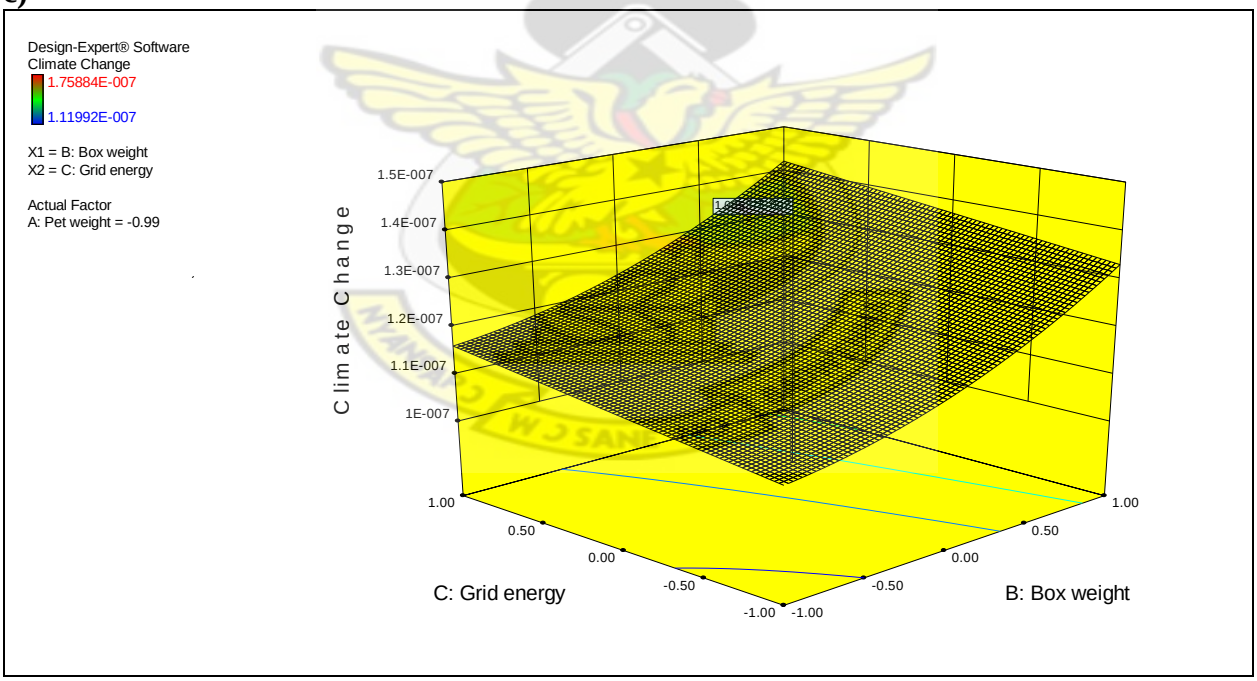


Figure 4.33: Effect of process variables on Climate change impact category a) PET weight and Box weight; b) Pet weight and Grid electrical energy; c) Box weight and Grid electrical energy

4.3.2 Optimization of Inlet Variable Conditions to Minimize Impact on Ozone Layer in the Production of Sliced Pineapple

The relationship between the processes (PET containers weights, packaging boxes weights and percentage grid electric energy) to minimize impact on ozone layer in the production of sliced pineapple at the fruit processing plant is expressed in Equation (4.2).

$$\mathbf{OL = 1.03E\text{-}10 + 1.58E\text{-}11X_1 + 7.39E\text{-}12X_2 + 7.72E\text{-}12X_1^2 \ldots\ldots\ldots (4.2)}$$

Where

OL: Ozone Layer

X_1: PET Container weight

X_2: Cardboard Box Weight

The equation indicates that the processes have positive correlation with impact on ozone layer in the production of sliced pineapple at the fruit processing plant. There is no correlation between impact on ozone layer and percentage of grid electrical energy used as shown in equation 4.2.

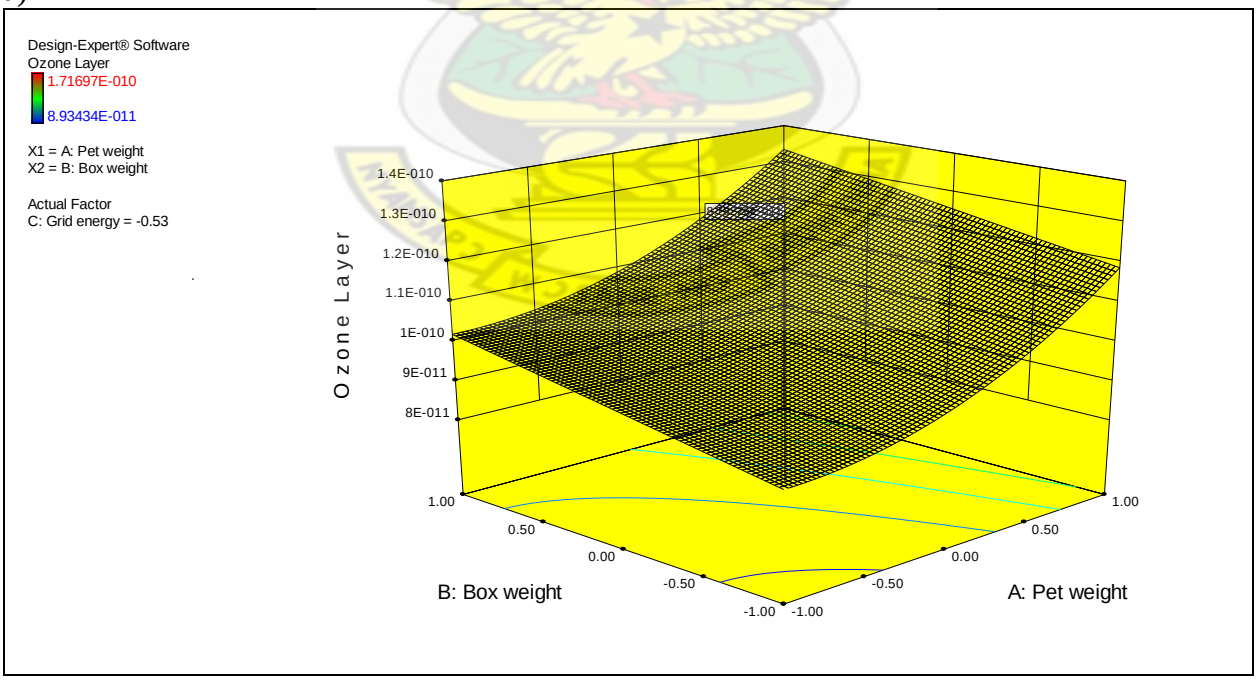
In each of the plots one of the variables was maintained constant and the others were varied, respectively. The response surface graphs (Figure 4.34 a, b, c) show impact on ozone layer depletion by the inlet parameters. Both Figures 4.34b and 4.34c confirm the ozone layer relationship in equation 4.2. Thus the impact on ozone layer is constant as the percentage in national grid electricity increases.

The optimal conditions of the inlet parameters that would minimize impact on ozone layer in the production of sliced pineapple at the fruit processing plant are: PET container weight of

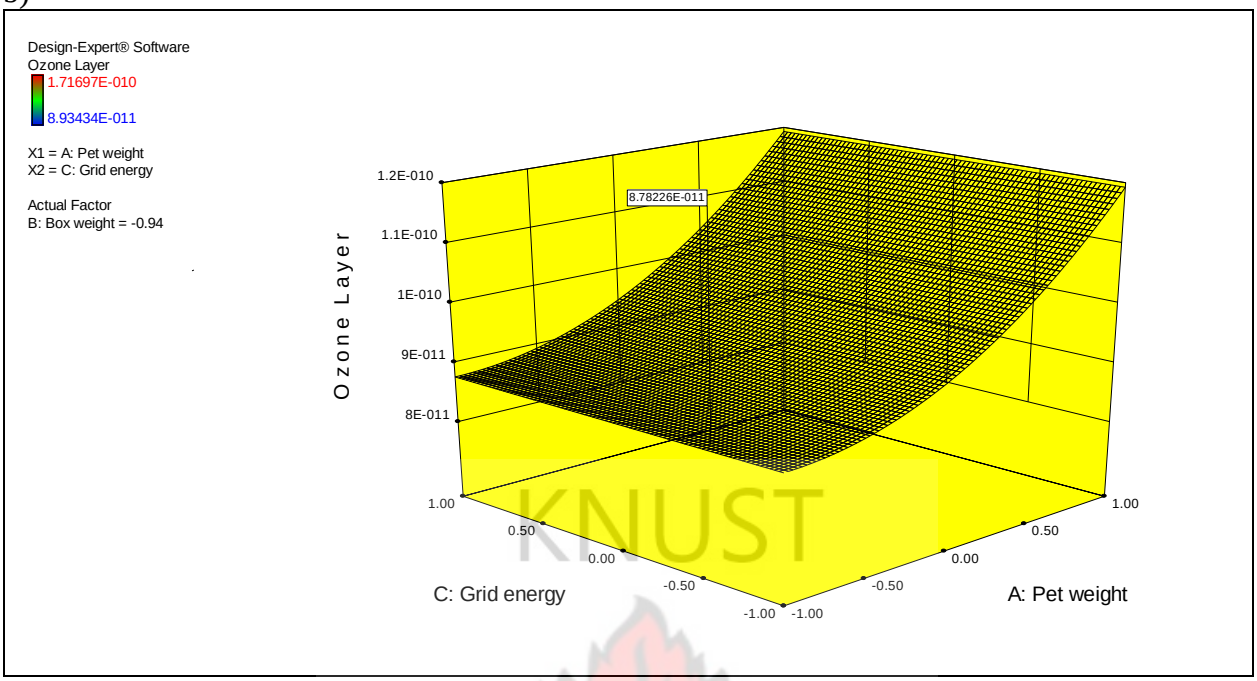
40.49 kg/MT sliced pineapple produced; cardboard box weight of 116 kg; and 87.3% electric energy from national grid source. The minimum impact on ozone layer depletion under these optimal conditions was determined as 8.78226E-11 DALY. Moreover at these optimal conditions of the processing plant which establish minimum impact on ozone layer, the impact on the climate change would be 1.10001E-07 DALY and that on ecotoxicity would be 0.100975718 PDF*m2yr.

For the fruit processing plant to have optimized PET container weight of 40.49 kg to package 1 MT of sliced pineapple, it has to package them in 295 g (net weight of "PET-canned" sliced pineapple) for the market. Five "PET-canned" sliced pineapples should be packaged in a cardboard box. Thus to achieve the minimum impact on ozone layer, the sliced pineapples should be packed in PET containers at net weight of 295 g and package 5 of them in a box.

a)



b)



c)

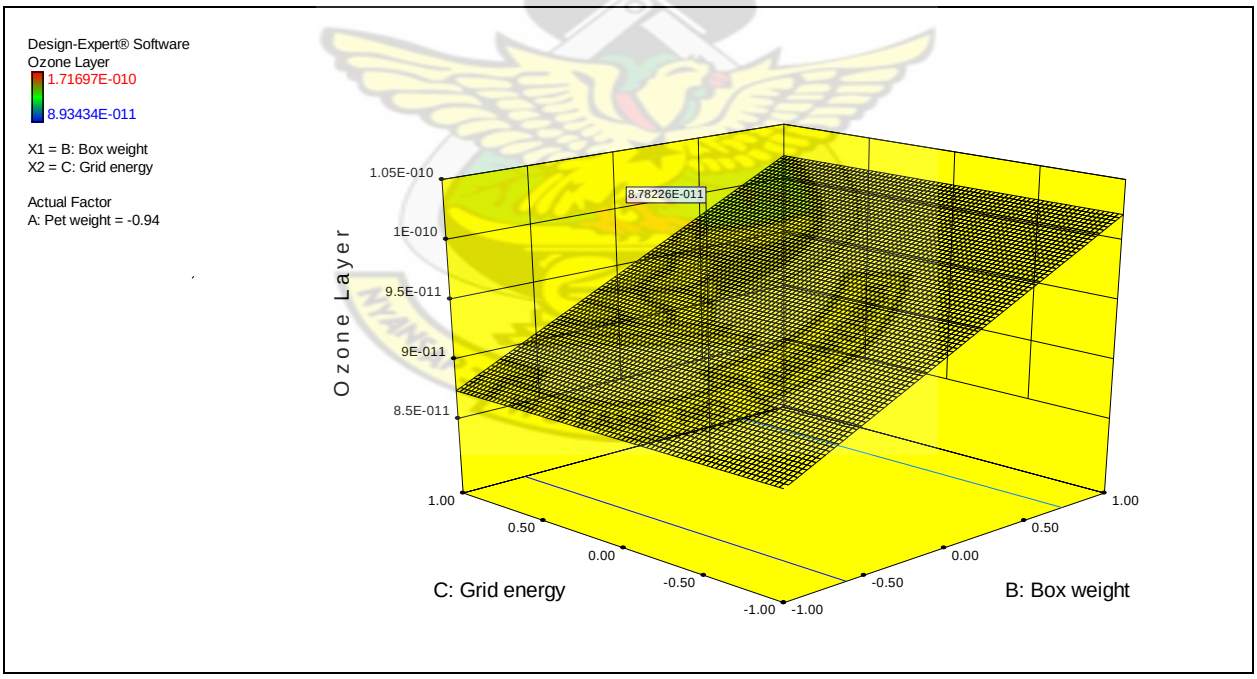


Figure 4.34: Effect of process variables on Ozone Layer impact category a) PET weight and Box weight; b) Pet weight and Grid electrical energy; c) Box weight and Grid electrical energy

4.3.3 Optimization of Inlet Variable Conditions to Minimize Impact on Ecotoxicity in the Production of Sliced Pineapple

The relationship between the processes (PET containers weights, packaging boxes weights and percentage grid electric energy) to minimize impact on ecotoxicity in the production of sliced pineapple at the fruit processing plant is expressed in Equation (4.3).

$$\mathbf{ET = 0.114724 + 0.018041X_1 + 0.007032X_2 + 0.007904X_1^2 \ldots\ldots\ (4.3)}$$

Where

ET: Ecotoxicity

X_1: Cardboard Box Weight

X_2: Percentage of Grid Electrical Energy used

The equation indicates that the processes have positive correlation with impact on ecotoxicity in the production of sliced pineapple at the fruit processing plant. There is no correlation between impact on ecotoxicity and PET container weight as shown Equation (4.3).

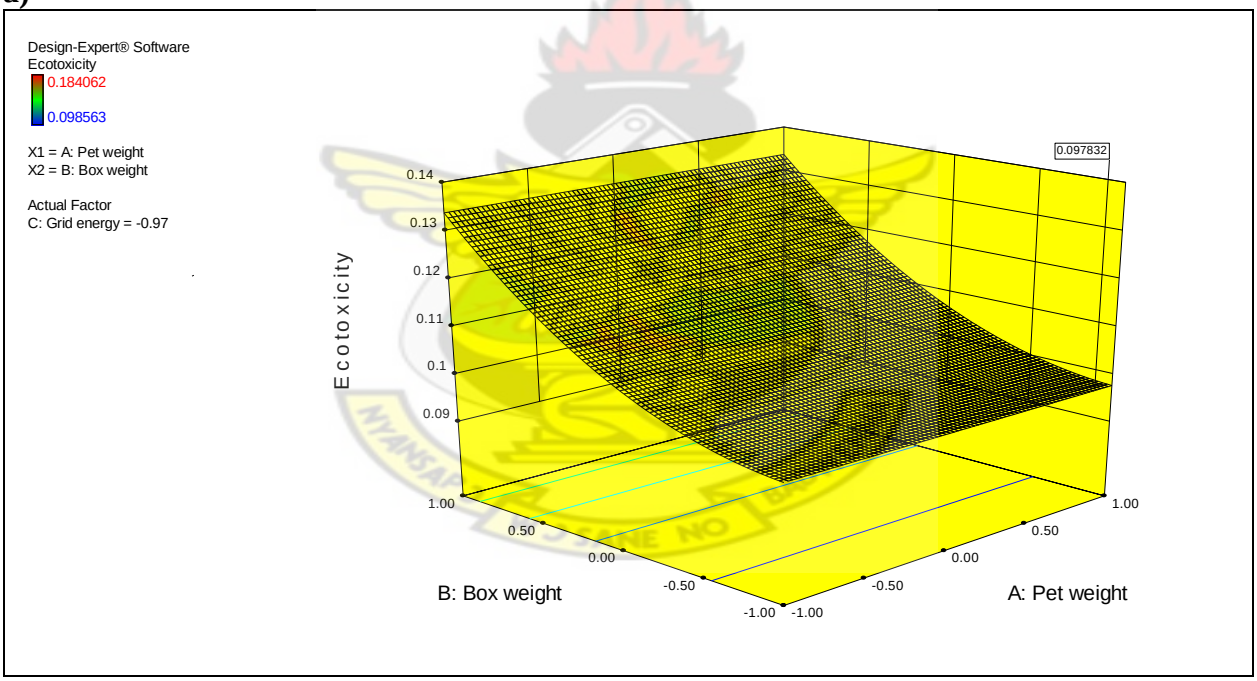
The response surface graphs (Figure 4.35 a, b, c) show the impact on ecotoxicity by the inlet parameters. Both Figures 4.35a and 4.35b confirm the ecotoxicity relationship in Equation (4.3). Thus the impact on ecotoxicity is constant as PET container weight increases.

The minimum impact on ecotoxicity under optimal conditions was determined as 0.097831954 PDF*m2yr. The outcome of the optimization analysis indicates that the minimum ecotoxicity could be achieved under the following optimal conditions of net variables: PET container weight of 58.9 kg/MT sliced pineapple; cardboard box weight of 114.8 kg/MT sliced pineapple and 85.2% electric energy from national gird source. Moreover at these optimal conditions of

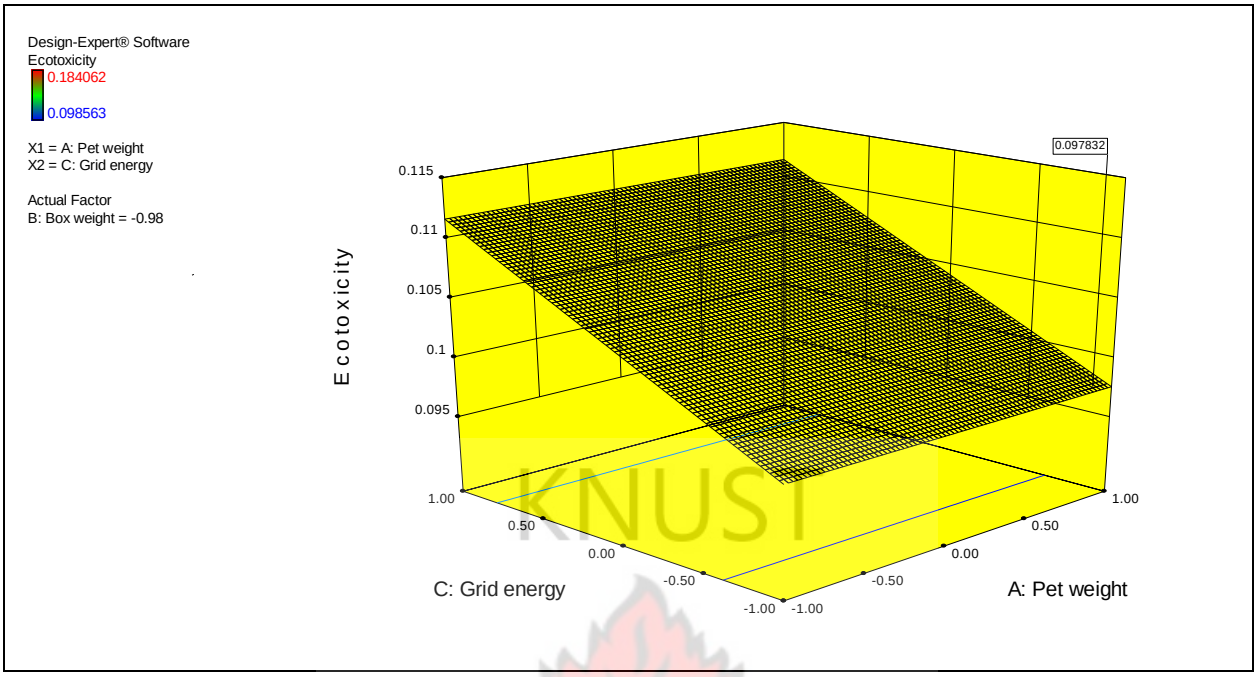
the processing plant which establish minimum impact on ecotoxicity, the impact on the climate change would be 1.23241E-07 DALY and that on ozone layer would be 1.16261E-10 DALY.

The fruit processing plant has to package sliced pineapple in 203 g net weight units to enable it achieve an optimized PET container weight of 58.9 kg to package 1 MT of sliced pineapple. Eight of such packs should be packaged in a cardboard box. Thus to achieve the minimum impact on ecotoxicity, the sliced pineapples should be packed in PET containers at net weight of 203 g and package eight of them in a box.

a)



b)



c)

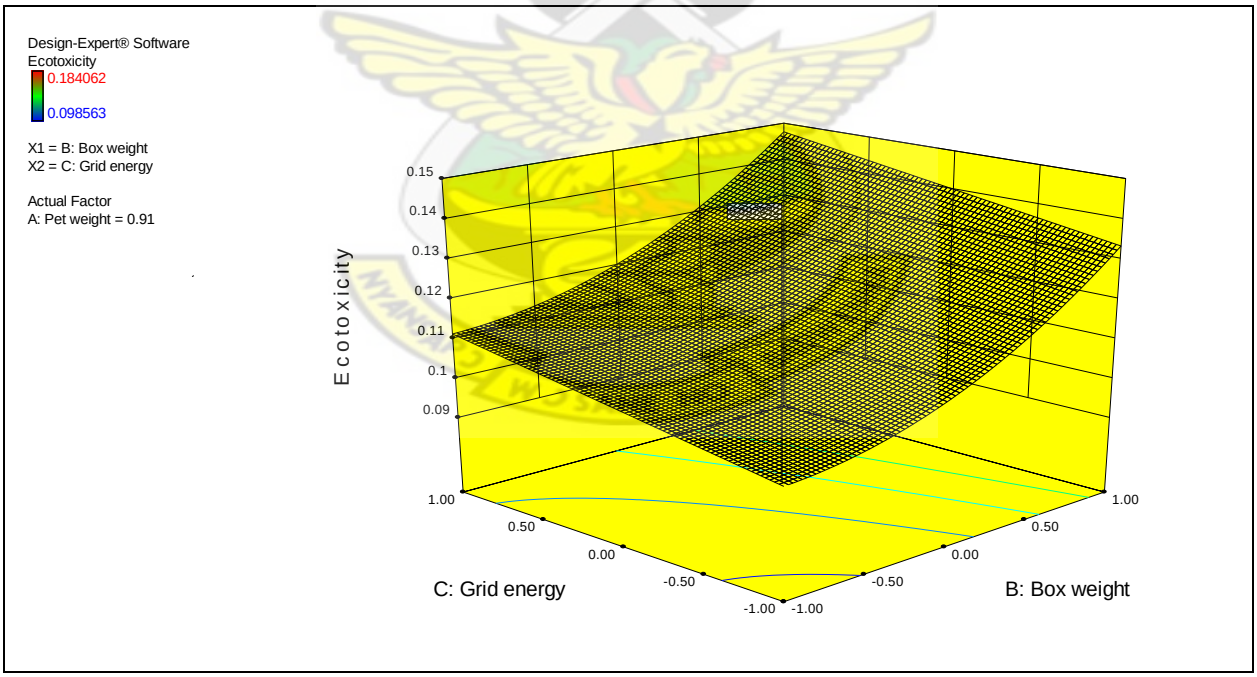


Figure 4.35: Effect of process variables on Ozone Layer impact category a) PET weight and Box weight; b) Pet weight and Grid electrical energy; c) Box weight and Grid electrical energy

The relationship between the dependent and independent variables was further elucidated using response surface plots. The effects of PET containers and corrugated cardboard boxes and their interaction on Ecotoxicity at a fixed level of percentage national grid are given in Figure 4.35a. At high level of corrugated cardboard boxes the impact on Ecotoxicity increases. In Figures 4.35b and 4.35c, respectively, fixed levels of corrugated cardboard boxes and PET containers were used whilst the other parameters were varied. The graphs (4.35a and 4.35b) collaborates the outcome of equation 4.3 which seeks to indicate that impact of Ecotoxicity is independent on levels of PET containers used in the sliced pineapple production at the fruits processing plant. Thus as the quantity of PET containers increase, the impact of Ecotoxicity are constant in these graphs. In similar research works by Shaji and Lodha (2008) and Mowafy (2009), the regression equation conforms to behavior of the respective graphs generated using the response surface methodology.

4.3.4 Conclusions

Optimization of PET container weight, cardboard packaging box weight and percentage of electricity that is sourced from national grid, which are the three key processes in the production of sliced pineapple at the fruit processing plant, to minimize impact on climate change, ozone layer and ecotoxicity was investigated.

It has been established that there are positive correlation between the impact on climate change and the three inlet processes. The minimum impact on climate change of 1.08537E-07 DALY at the processing plant could be achieved under certain optimal conditions. These conditions are that the sliced pineapple must be packed at 300 g net weight in PET containers and then

packaged as five in cardboard packaging box for the market. It should be sourcing 85.6% of electrical energy from the national grid and 14.4% from the diesel-electric generating set.

Under optimal conditions of packing sliced pineapple at 295 g net weight in PET containers and, then five of such containers in a cardboard box containers and sourcing 87.3% of its electricity from the national grid, the fruit processing plant would achieve a minimum impact on ozone layer (8.78226E-11 DALY).

The minimum impact on ecotoxicity of 0.097831954 PDF*m2yr would be achieved when the fruit processing plant packs sliced pineapple at 203 g net weight in PET containers and then package eight of that in a cardboard packaging box. The amount of electricity sourced from the national grid must be 85.2% and 14.8% from the diesel-electric generating set.

It is under inlet processing parameters for the minimum climate change regime that ozone layer and ecotoxicity do not have the highest impact on the environment. Thus they achieve their respective median impact results of 8.8583E-11 DALY and 0.098969142 PDF*m2yr among their 3 results from optimization.

The indications are that the company might need to consider adopting the parameters obtained under achieving minimum climate change impact. Thus the required 300 g net weight of sliced pineapple in PET cans which would also require 5 of the cans packed in a corrugated cardboard box for export would allow the company to sell more pineapple than under the minimum ozone

layer regime. In the latter regime, the net weight of pineapple would be 295 g per PET can and, 5 of the cans would be packed in a corrugated cardboard box.

Moreover with the PET can being the highest contributor to environmental load among all the inlet processing parameters at the processing plant, the minimum weight of 40.05 kg of it that would be required to package 1 MT is better than 40.49 kg that would be required under the optimization of inlet parameters to achieve minimum ozone layer impact.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1. Introduction

Life-cycle studies are a uniquely useful tool for assessing the impact of human activities. These impacts can only be fully understood by assessing them over a life cycle, from raw material acquisition to manufacture, use, and final disposal. Life-cycle techniques have been adopted in industry and the public sector to serve a variety of purposes, including product comparison, strategic planning, environmental labeling, and product design and improvement.

The LCA approach is based on a rigorous analysis of all material and energy flows occurring within the system boundary, and consequently has much in common with the conventional mass and energy balance approach to process technology assessment (Notten 2001). However, LCA only assesses potential impacts and not real impacts. Hence, it does not provide any information on the consequences of not following regulations or on environmental risks. Moreover, only known and quantifiable environmental impacts are considered. Value choices can be hidden in allocation rules. Guinée (2001) and Dreyer *et al* (2006) have indicated that LCA methodologies address only environmental aspects and impacts.

The environmental interventions are linked to the impacts to which they could potentially give rise, according to a pre-defined set of environmental impact factors. All stakeholders in the food production chain have to invest in food safety and control to regain the consumer confidence. So not only governmental organizations, but farmers, the food industry and traders must be aware of their responsibilities to provide healthy food. Consequently the processing

industry which plays a key role along the value chain has to minimize environmental load from its activities. The LCI associated with the processing activities are susceptible to uncertainties. Monte Carlo simulation method is widely used in establishing the level of uncertainties in the LCI.

The Monte Carlo simulation technique is straightforward and flexible. It cannot wipe out uncertainty and risk, but it can make them easier to understand by ascribing probabilistic characteristics to the inputs and outputs of a model. Moreover it does not directly provide precise insights and therefore could not reveal cause-and-effect relationships. However, it could be very useful for determining different risks and factors that affect forecasted variables and, therefore, it can lead to more accurate predictions.

The case study of the research work used Monte Carlo analysis to conduct life cycle assessment on a fruit processing plant (Blue Skies Products Ghana Limited) to propose some guidelines for scientists carrying out environmental assessment studies on fruit processing plants using emerging technologies and Monte Carlo analysis as well as develop and promote LCA research and application in Ghana. The study focused on:

i. Conduct LCA on production of sliced pineapple at the fruit processing plant using Monte Carlo simulation method
ii. Compare environmental impact of different sources of electric energy in production of sliced pineapple at the fruits processing plant
iii. Optimize combination of electric energy sources, use of PET containers and cardboard boxes

5.2. Monte Carlo Analysis on LCA

The network of the LCA indicates that the use of PET containers has the highest impact (38.6%) on the environment followed by use of electricity from the national grid (34.5%), and then corrugated cardboard packaging boxes (19.1%). The rest are diesel-electric generating set, 3.7%, fresh pineapple supply, 3.1% and transporting of finished product from the factory to the airport contributes 0.435%.

The use of Monte Carlo simulation to analyze environmental load of sliced pineapple production at the fruit processing plant indicates that the score for radiation, ecotoxicity and land use have very high uncertainty. Due to high uncertainty in impact on ecotoxicity, it should be of concern in the determination of environmental load of provision of goods and services in any processing enterprise.

The Monte Carlo simulation on damage assessment of processes at the fruit processing plant shows that ecosystem quality damage category has very high uncertainty. However, the outcome of the Monte Carlo simulation shows low uncertainty for human health and resources.

The respective impact of processes involved in sliced pineapple production at the fruit processing plant shows that aggregate of environmental load from the use of Electricity from light oil-fired power plant, use of PET containers and cardboard packaging boxes contributed 86.5%, 90.5%, 94% of the impact on human health, ecosystem quality and resources damage categories, respectively. They are the major contributors of the substances that cause all the 11

impact categories. Except in the case of land use, ecotoxicity and radiation impact categories, the standard deviation of their respective LCIs of the other 9 impact categories do not vary widely with the mean. These therefore have relatively low level of uncertainty.

These 3 key processes {cardboard packaging box, electricity (oil, at power plant) and PET containers} have high impact on the end points (human health, ecosystem quality and resources depletion) in environmental load in the production of sliced pineapple. It is therefore important for the fruit processing plant to strategize to reduce the amount of cardboard packaging boxes and PET containers that are used for its production activities. This means that the fruit processing plant should be producing sliced pineapple in heavier packs so that less PET containers would be used.

The package of 300 g is highly recommended for production; and the company is encouraged to formulate strategies that would facilitate marketing of this weight that would have low environmental load.

Moreover, the management of the company should explore packing more PET containers filled with sliced pineapple in a cardboard packaging box. This would facilitate the use of less number of cardboard packaging boxes which would consequently reduce the environmental load attributed to the use of cardboard packaging box. Investment is needed to explore the use of alternative packaging materials which are more environmental friendly and/or reduce the amount of PET containers and cardboard packaging boxes used at the fruits process plant.

With respect to the use of electricity, there would be the need for advocacy to facilitate reduction in amount of national electricity production and distribution that come from light oil-fired electric power plant which is currently at 30%. This supplements what is produced from the hydroelectric power plant. There is therefore the need to increase capacity of hydroelectric power plants in the country to produce more electricity for distribution. Management of the fruits processing plant needs to team up with environmental advocates to encourage the Government of Ghana to investment in hydropower sources of electricity and reduce sourcing of electricity from light oil-fired electric power plants. These measures could reduce environmental load in the use of electricity from the national grid which is 30% from light oil-fired power plant.

5.3. Comparison of sourcing Electricity from Hybrid, 100% National grid and 100% Diesel-electric generating set

The fruit processing plant sources electricity from both the national grid and a standby 1,400 KVA diesel-electric generating set. The latter is used when either power from the main national grid goes off or when the voltage drops below what is required to run the equipment at the processing plant. It sources average of 94% of power from the national grid and 6% from the diesel-electric generating set for its processing activities. A simulation was performed to compare the environmental load from different sources of electricity for processing activities of a unit product.

The difference in impact on human health and ecosystem quality under the damage category when the company uses either 100% national grid electricity or hybrid electricity is not

significant. However the use of 100% national grid electricity makes significant impact on resource depletion than use of hybrid electricity and there is therefore significant difference between these electricity source on resources depletion. Moreover the use of 100% national grid has higher impact on damage categories (ecosystem quality, human health and resources) than using hybrid electricity.

The use of 100% diesel-electric generating set has higher impact on human health and Ecosystem quality, than the use of hybrid electricity source. However, hybrid source of electricity has higher impact on resources depletion than that of 100% diesel-electric generating set.

The access of electricity from the national grid as the main source of electrical energy to produce sliced pineapple at the fruit processing plant has the highest impact on climate change, radiation, ozone layer, ecotoxicity, land use, minerals and fossil fuel impact categories. Thus the use of 100% national grid causes more environmental load than hybrid source of electric energy and, the difference is very significant. It suggests that as the company uses more electricity from the national grid it tends to cause more harm to the environment. Moreover, for every unit of product produced using 100% national grid depletes ozone layer and causes climate change as well as radiations and acidification more than if it would have been supplemented its source of energy with that of diesel generated electric power.

The use of electricity from 100% national grid has the highest impact on ozone layer depletion and climate change whilst the diesel-electric generating set has least impact on these impact

categories. Therefore as the amount of energy sourced from national grid reduces, the impact on ozone layer depletion and climate change also decreases. Consequently sourcing of electricity from the national grid contributes more to depletion of the ozone layer and climate change. The 30% source of national power supply from light oil-fired electric power plant could be the main cause of substances that contribute to the depletion of the ozone layer and climate change. There is an indication that the use of light oil power plant in the production of electricity in Ghana makes significant contribution to the depletion of the ozone layer and climate change.

The use of diesel-electric generating set has the highest impact on human health and ecosystem quality but the least impact on resources in the damage categories. The access of electrical energy from the hybrid sources demonstrates the least impact on the ecosystem quality and resources. However, the use of 100% electricity from the national grid which comprises 70% hydro-electric and 30% light oil electric power plant sources has the highest impact on the resources but the least impact on human health.

These outcomes suggest that the diesel-electric generating set is the major cause of human health. This contributed to the higher impact on human damage category by hybrid electricity than impact on the same damage category by use of electrical energy from national grid. Thus there is a significant difference in impact on human health by the use of diesel-electric generating set than the use of electricity from either 100% national grid or hybrid sources.

The single score outcome of the respective electric energy portfolios indicates that the use of diesel-electric generating set has the highest impact on the environment. The use of hybrid electricity source has the least impact on the environment.

The high levels of respiratory (organic and inorganic) impact categories in the use diesel-electric generating plant are main contributing factors to the human health. There is the need for the company to institute and enforce health and safety measures in the management of the power source. A diesel electric generator is a worthy addition, but it should be only an addition. It should not be relied upon as the main source of power. The main source of power should be the public utility national grid, since it provides continuous power at an affordable price (Oldhand, 2010). A diesel electric generator should only be used during power outages. Duplicating the power characteristics of the electric utility grid is very difficult, especially with a diesel generator.

Monte Carlo Simulation generates the output as a range instead of a fixed value and shows how likely the output value is to occur in the range. All these make the Monte Carlo Simulation method an appropriate and preferred for evaluation of the accuracy and performance of other models but it has a few drawbacks. Moreover, Monte Carlo Simulation cannot wipe out uncertainty. It only helps to better understand the uncertainty and how it affects the forecasted variables by ascribing probabilistic characteristics to the inputs and outputs of a model.

5.4. Optimization of Processing Conditions to minimize Environmental Load

The Design-Expert 8 software was used to conduct the optimization analyses. The software was used to generate a second-order polynomial model equation from the variables. The regression coefficients and response surfaces were used to analyze the effect of respective variables on the ozone layer, climate change and ecotoxicity impact categories. The analysis was to determine the combination of respective inlet variables that would generate minimum environmental load with respect to these three impact categories.

After generating the polynomial equation relating the dependent and independent variables, the process was optimized for the respective responses of climate change, ozone layer and ecotoxicity. Optimization was performed to obtain the levels of PET containers, corrugated cardboard boxes and percentage of national grid which minimize these impact categories. The minimized value for the climate change was determined as 1.08537E-07 DALY under the optimized inlet variable conditions. These conditions are that the sliced pineapple must be packed at 300 g net weight in PET containers (12 g) and then packaged as five in a cardboard packaging box for the market. It should be sourcing 85.6% of electrical energy from the national grid and 14.4% from the diesel-electric generating set. At these conditions which seek to minimize climate change, values of the other two impact categories would be: ozone layer, 8.8583E-11 DALY; and ecotoxicity, 0.098969142 PDF*m2yr.

The optimal conditions of the inlet parameters that would minimize impact on ozone layer in the production of sliced pineapple at the fruit processing plant are: packing sliced pineapple at 295 g net weight in PET containers and, then five of such containers in a cardboard box

containers and sourcing 87.3% of its electricity from the national grid, the fruit processing plant would achieve a minimum impact on ozone layer (8.78226E-11 DALY). At these optimal conditions of the processing plant which establish minimum impact on ozone layer, the impact on the climate change would be 1.10001E-07 DALY and that on ecotoxicity would be 0.100975718 PDF*m2yr.

The minimum impact on ecotoxicity under optimal conditions was determined as 0.097831954 PDF*m2yr. The outcome of the optimization analysis indicates that the minimum ecotoxicity could be achieved under the following optimal conditions of net variables: the fruit processing plant has to package sliced pineapple in 203 g net weight units of sliced pineapple. Eight of such packs should be packaged in a cardboard box, and 85.2% electric energy from national gird source. Moreover at these optimal conditions of the processing plant which establish minimum impact on ecotoxicity, the impact on the climate change would be 1.23241E-07 DALY and that on ozone layer would be 1.16261E-10 DALY.

The observed responses were found to be in close agreement with the predicted values of the optimized use of PET containers, corrugated cardboard boxes and percentage of electricity from national grid, thereby demonstrating the feasibility of the optimization procedure in minimizing impact of climate change, ozone layer and ecotoxicity as a result of producing sliced pineapple at the fruits processing plant for the export market.

5.5. Recommendations

Life cycle assessment has become an important tool for the environmental impact assessment of products and materials and businesses are increasingly relying on it for their decision-making. The information obtained from the life cycle assessment could also influence environmental policies and regulations. It is therefore highly recommended that food processing companies, especially fruit processing plants would adequately conduct LCA to incorporate its outputs in new products development processes. This could facilitate effective decision on options that would optimize processing paths that would consequently minimize environmental load. Thus a framework for technology selection is necessary and consequently the certainty with which technological systems can be evaluated.

Energy options, as have been simulated using Monte Carlo simulation in the case study, could be extended to other processing industries to ascertain the level of impact of the respective categories on the environment. Companies must critically consider the optimum energy combination that would optimize its cost of production and would also not jeopardize the healthiness of the environment. Thus there should be effective and efficient management of the balance between optimizing profit and minimizing environmental impact.

It is recommended that capacities of relevant institutions should be enhanced to facilitate assessment of life cycles of products that are being developed as well as processing plants that are being set up in the country to undertake life cycle studies to reduce environmental load. There is the need for processing industry to invest in improving on the environment that their activities tend to have negative impact on. If the enterprises have the tools to assess the most

important life cycle impacts of their products, then they will develop cleaner products. According to Ramjeawon et al (2005) this will require a substantial effort to develop a simplified language that communicates the concepts, tools and benefits of LCA to policy and decision-makers and the development of database relevant to domestic conditions. This has also been buttressed by Ntiamoah and Afrane (2008) that despite the general limitations regarding the application of the LCA tool in developing countries like Ghana, one cannot underestimate the environmental perspective offered by a method which makes it possible to identify key environmental issues in support of sustainability measures.

Increasing self-regulation, e.g. internalization of environmental responsibility in industry via environmental management (ISO14001), codes of conduct, sustainability reports would facilitate reduction of environmental load from the activities of processing industry. Moreover, there is the need to change from command-and-control regulation towards a facilitating role of governmental agencies.

It is proposed that further research work could be undertaken to explore alternative packaging materials to the use of PET and cardboard boxes using the processes prescribed in the thesis. The prospective alternatives should have lower environmental load than these packaging materials. Thus the study recommends that improvement activities along the slice pineapple production chain at Blue Skies Products Ghana Limited must be focused on the use of PET containers, corrugated cardboard boxes and percentage of electricity from the national grid.

Furthermore, it is recommended that a research work into investigating the environmental load of pineapple production by farmers using the Monte Carlo simulation and LCA as well as RSM approach. This would lead to optimizing agricultural inputs that could minimize environmental load.

It has been evidenced in the study that LCA is a useful tool to verify the extent of environmental load of processes in a fruit processing plant. The contribution of the respective inlet parameters on the impact categories as a result of the generation of major substances that consequently cause these impact could let management of processing companies and designers of processing systems for product development explore options of choosing processes and/or raw materials as well as other inputs that would not have grievous impact on the environment.

The use of Monte Carlo simulation method to establish the potential areas of high degree of uncertainty in some of the damage and impact categories is essential. This would let designers of processes identify the areas they should explore the options of managing the inputs as well as selection of processes that would have minimum environmental load. Consequently, the designers of processes could employ the response surface methodology (RSM) to optimize design variables to minimize effect of the identified impact categories on the environment.

Thus this approach which was employed in the study could be adopted for investigating environmental impact of processes.

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APPENDICES

APPENDIX A Inventory and Life Cycle Impact Assessment Results

Title:	Analyzing 1 kg 'Sliced pineapple' using hybrid electricity											
Method:	Eco-indicator 99 (H) V2.06 / Europe EI 99 H/H											
Per sub-compartment:	No											
Default units:	No											
Indicator:	Inventory											
Relative mode:	Non											
No	Substance	Compartment	Unit	Total	Fresh pineapple fruit	Water	PET containers	Cardboard box	Electricity, hydropower	Electricity, light oil, at power plant	Transport	Diesel-electric generating set
1	Aluminium, 24% in bauxite, 11% in crude ore, in ground	Raw	Mg	111.8674	12.58645	x	x	91.62939	1.459634	3.778729	2.20906	0.204151
2	Anhydrite, in ground	Raw	µg	1.554476	0.263858	x	x	1.018749	0.010048	0.196583	0.047332	0.017906
3	Barite, 15% in crude ore, in	Raw	mg	507.7811	24.1101	x	x	70.21165	0.849523	384.4517	3.608252	24.54987

	ground											
4	Baryte, in ground	Raw	mg	1.073804	x	1.073804	x	x	x	x	x	x
5	Basalt, in ground	Raw	mg	21.43894	0.997477	x	x	18.37458	0.131687	1.616352	0.189326	0.129522
6	Bauxite, in ground	Raw	mg	20.23356	x	1.633557	18.6	x	x	x	x	x
7	Borax, in ground	Raw	ng	266.2993	41.73948	x	x	143.7393	3.876992	67.09741	5.685654	4.160527
8	Cadmium, 0.30% in sulfide, Cd 0.18%, Pb, Zn, Ag, In, in ground	Raw	µg	82.33596	39.0444	x	x	33.87504	0.234818	1.331005	7.771292	0.079402
9	Calcite, in ground	Raw	g	9.084846	0.433417	x	x	2.142626	1.745591	4.625973	0.097464	0.039774
10	Carbon dioxide, in air	Raw	g	87.33301	0.066594	x	x	87.02185	0.017947	0.203444	0.010061	0.013119
11	Carbon, in organic matter, in soil	Raw	mg	5.8453	0.014324	x	x	5.751739	0.00041	0.071718	0.002543	0.004566
12	Cerium, 24% in bastnasite, 2.4% in crude ore, in ground	Raw	pg	-1.40E-08	-9.48E-10	x	x	-6.23E-09	-3.31E-11	-6.46E-09	-1.39E-10	-2.36E-10
13	Chromium, 25.5% in chromite, 11.6% in crude ore, in ground	Raw	mg	51.56401	0.729946	x	x	43.10352	5.44701	1.934904	0.135117	0.21351

14	Chromium, in ground	Raw	µg	66.62992	x	66.62992	x	x	x	x	x	x
15	Chrysotile, in ground	Raw	µg	14.88976	0.381771	x	x	13.68921	0.014227	0.699717	0.059831	0.045001
16	Cinnabar, in ground	Raw	µg	1.371915	0.033356	x	x	1.262397	0.001323	0.065356	0.005269	0.004214
17	Clay, bentonite, in ground	Raw	mg	72.06526	8.601256	0.809996	x	27.21088	1.566396	30.32553	1.629733	1.921474
18	Clay, unspecified, in ground	Raw	g	2.416805	0.118296	0.002821	x	1.440943	0.64428	0.172045	0.027663	0.010756
19	Coal, 18 MJ per kg, in ground	Raw	g	9.034672	x	0.634671	8.4	x	x	x	x	x
20	Coal, brown, 8 MJ per kg, in ground	Raw	g	8.564249	x	0.764249	7.8	x	x	x	x	x
21	Coal, brown, in ground	Raw	g	16.40865	0.42767	x	x	13.34037	0.161439	2.275056	0.064351	0.139767
22	Coal, hard, unspecified, in ground	Raw	g	12.71107	0.720615	x	x	9.653648	0.277083	1.816987	0.130274	0.112467
23	Cobalt, in ground	Raw	ng	479.1052	157.4066	0.112593	x	134.0566	3.139181	32.32246	22.93898	129.1288
24	Colemanite, in ground	Raw	µg	229.501	29.52741	x	x	182.7728	0.592215	10.98267	5.082041	0.54378
25	Copper, 0.99% in sulfide, Cu 0.36% and Mo 8.2E-3%	Raw	mg	2.481327	0.216597	x	x	1.932252	0.015577	0.244335	0.036475	0.036 09

	in crude ore, in ground											
26	Copper, 1.18% in sulfide, Cu 0.39% and Mo 8.2E-3% in crude ore, in ground	Raw	mg	13.64346	1.182819	x	x	10.62453	0.086159	1.351114	0.199031	0.199806
27	Copper, 1.42% in sulfide, Cu 0.81% and Mo 8.2E-3% in crude ore, in ground	Raw	mg	3.619121	0.31376	x	x	2.818307	0.022855	0.358402	0.052796	0.053001
28	Copper, 2.19% in sulfide, Cu 1.83% and Mo 8.2E-3% in crude ore, in ground	Raw	mg	18.10381	1.58338	x	x	14.09852	0.113516	1.778862	0.26664	0.262887
29	Copper, in ground	Raw	µg	580.3268	x	580.3268	x	x	x	x	x	x
30	Diatomite, in ground	Raw	ng	38.45036	26.49184	x	x	8.49672	0.089844	0.462804	2.880639	0.028513
31	Dolomite, in ground	Raw	mg	7.931802	0.820825	x	x	4.823269	0.306356	1.697215	0.177356	0.106782
32	Energy, gross calorific value, in	Raw	kJ	976.8832	0.693307	x	x	973.8305	0.176063	1.950744	0.105722	0.126905

	biomass											
33	Energy, gross calorific value, in biomass, primary forest	Raw	J	405.2427	0.993078	x	x	398.7563	0.028412	4.972043	0.176331	0.316523
34	Energy, kinetic (in wind), converted	Raw	kJ	4.795026	0.189932	x	x	3.517518	0.067437	0.934771	0.027942	0.057426
35	Energy, potential (in hydropower reservoir), converted	Raw	Wh	586.3209	1.385054	0.940634	9.166667	13.13984	559.7277	1.672707	0.184784	0.103569
36	Energy, solar, converted	Raw	J	61.82784	3.836354	x	x	42.16931	1.050253	13.41138	0.536685	0.823859
37	Feldspar, in ground	Raw	ng	20.54097	0.943828	x	x	18.29725	0.1622	0.93021	0.149087	0.058398
38	Fluorine, 4.5% in apatite, 1% in crude ore, in ground	Raw	mg	1.757455	0.017256	x	x	1.51411	0.001552	0.208427	0.002711	0.013399
39	Fluorine, 4.5% in apatite, 3% in crude ore, in ground	Raw	mg	1.775103	0.008627	x	x	1.6666	0.000701	0.091918	0.001349	0.005909
40	Fluorspar, 92%, in ground	Raw	mg	10.83496	0.511766	x	x	3.786854	0.045522	6.026431	0.077221	0.387163

41	Gadolinium, 0.15% in bastnasite, 0.015% in crude ore, in ground	Raw	pg	-4.89E-11	-5.02E-14	x	x	-4.88E-11	-2.78E-15	-8.92E-15	-8.27E-15	-5.77E-16
42	Gallium, 0.014% in bauxite, in ground	Raw	pg	176.7002	10.945	x	x	120.8675	2.983552	38.03745	1.530058	2.336631
43	Gas, mine, off-gas, process, coal mining/kg	Raw	mg	4.254403	x	4.254403	x	x	x	x	x	x
44	Gas, mine, off-gas, process, coal mining/m3	Raw	cm3	149.7722	7.009839	x	x	119.457	3.201496	17.73636	1.271047	1.096553
45	Gas, natural, 35 MJ per m3, in ground	Raw	cm3	135.8005	x	135.8005	x	x	x	x	x	x
46	Gas, natural, 36.6 MJ per m3, in ground	Raw	dm3	25.8	x	x	25.8	x	x	x	x	x
47	Gas, natural, feedstock, 35 MJ per m3, in ground	Raw	dm3	19.2	x	x	19.2	x	x	x	x	x
48	Gas, natural, in ground	Raw	dm3	40.19956	0.711074	x	x	35.02141	0.080164	4.025809	0.110737	0.25036
49	Gas, petroleum, 35	Raw	cm3	13.71144	x	13.71144	x	x	x	x	x	x

	MJ per m3, in ground											
50	Gold, Au 1.1E-4%, Ag 4.2E-3%, in ore, in ground	Raw	ng	117.5078	20.23397	x	x	91.95872	0.153319	1.50795	3.554697	0.099167
51	Gold, Au 1.3E-4%, Ag 4.6E-5%, in ore, in ground	Raw	ng	215.4679	37.10196	x	x	168.6199	0.281132	2.765052	6.518061	0.181838
52	Gold, Au 1.4E-4%, in ore, in ground	Raw	ng	257.9967	44.4251	x	x	201.9019	0.336622	3.310814	7.804589	0.217729
53	Gold, Au 2.1E-4%, Ag 2.1E-4%, in ore, in ground	Raw	ng	394.0572	67.85369	x	x	308.3794	0.514147	5.056848	11.92052	0.332554
54	Gold, Au 4.3E-4%, in ore, in ground	Raw	ng	97.66473	16.81713	x	x	76.43001	0.127428	1.253309	2.954429	0.082421
55	Gold, Au 4.9E-5%, in ore, in ground	Raw	ng	233.9195	40.27918	x	x	183.0596	0.305207	3.001836	7.076235	0.19741
56	Gold, Au 6.7E-4%, in ore, in ground	Raw	ng	362.1454	62.35872	x	x	283.406	0.47251	4.64733	10.95516	0.305622
57	Gold, Au 7.1E-4%, in ore, in ground	Raw	ng	408.3564	70.31591	x	x	319.5697	0.532804	5.240346	12.35308	0.344621
58	Gold, Au 9.7E-4%, Ag 9.7E-4%, Zn	Raw	ng	24.46922	4.213417	x	x	19.14901	0.031926	0.314008	0.740212	0.02065

	0.63%, Cu 0.38%, Pb 0.014%, in ore, in ground											
59	Granite, in ground	Raw	pg	283.4352	15.0219	x	x	254.9516	5.464436	4.810113	2.883083	0.304126
60	Gravel, in ground	Raw	g	71.92122	13.09957	0.358585	x	35.60386	15.69669	3.362043	3.609535	0.190938
61	Gypsum, in ground	Raw	µg	10.70023	1.389557	x	x	5.564035	0.083592	3.185879	0.243399	0.233767
62	Helium, 0.08% in natural gas, in ground	Raw	pg	892.0421	55.21776	x	x	610.1877	15.06109	192.0575	7.719974	11.79805
63	Indium, 0.005% in sulfide, In 0.003%, Pb, Zn, Ag, Cd, in ground	Raw	µg	1.380636	0.651248	x	x	0.570306	0.004056	0.024	0.129592	0.001435
64	Iron ore, in ground	Raw	mg	33	x	x	33	x	x	x	x	x
65	Iron, 46% in ore, 25% in crude ore, in ground	Raw	g	3.354766	0.573498	x	x	1.784382	0.120592	0.717805	0.113795	0.044694
66	Iron, in ground	Raw	mg	12.02977	x	12.02977	x	x	x	x	x	x
67	Kaolinite, 24% in crude ore, in ground	Raw	mg	263.6837	0.364388	x	x	263.1635	0.084327	0.028877	0.040672	0.001955
68	Kieserite,	Raw	mg	3.200	0.006	x	x	3.193	0.0002	0.0001	0.000	1.10E-

	25% in crude ore, in ground			884	689			06	23	71	73	05
69	Land use II-III	Raw	mm 2a	198.4 077	x	198.4 077	x	x	x	x	x	x
70	Land use II-III, sea floor	Raw	mm 2a	17.15 178	x	17.15 178	x	x	x	x	x	x
71	Land use II-IV	Raw	mm 2a	8.275 766	x	8.275 766	x	x	x	x	x	x
72	Land use II-IV, sea floor	Raw	mm 2a	1.769 879	x	1.769 879	x	x	x	x	x	x
73	Land use III-IV	Raw	mm 2a	7.668 864	x	7.668 864	x	x	x	x	x	x
74	Land use IV-IV	Raw	mm 2a	0.054 008	x	0.054 008	x	x	x	x	x	x
75	Lanthanum, 7.2% in bastnasite, 0.72% in crude ore, in ground	Raw	pg	2.70E -08	5.35E -09	x	x	9.71E-09	9.71E-11	1.04E-08	7.79E -10	6.18E-10
76	Lead, 5.0% in sulfide, Pb 3.0%, Zn, Ag, Cd, In, in ground	Raw	mg	7.671 936	5.082 257	x	x	1.761 342	0.0177 61	0.2403 78	0.555 11	0.015 088
77	Lead, in ground	Raw	µg	146.3 872	x	146.3 872	x	x	x	x	x	x
78	Limestone, in ground	Raw	mg	16.2	x	x	16.2	x	x	x	x	x
79	Magnesite, 60% in crude ore, in ground	Raw	mg	43.73 043	7.464 585	x	x	22.47 911	2.2905 7	9.5147 66	1.393 843	0.587 559

80	Magnesium, 0.13% in water	Raw	µg	3.686668	0.080303	x	x	3.497524	0.007068	0.083194	0.013335	0.005244
81	Manganese, 35.7% in sedimentary deposit, 14.2% in crude ore, in ground	Raw	mg	4.930101	0.293456	x	x	2.577594	1.118189	0.754631	0.067798	0.118433
82	Manganese, in ground	Raw	µg	19.47906	x	19.47906	x	x	x	x	x	x
83	Marl, in ground	Raw	mg	22.5292	x	22.5292	x	x	x	x	x	x
84	Metamorphous rock, graphite containing, in ground	Raw	µg	96.4155	18.54421	x	x	68.06131	1.504951	4.796559	3.250094	0.258372
85	Molybdenum, 0.010% in sulfide, Mo 8.2E-3% and Cu 1.83% in crude ore, in ground	Raw	µg	336.4358	29.42507	x	x	262.0027	2.109551	33.05784	4.955152	4.885418
86	Molybdenum, 0.014% in sulfide, Mo 8.2E-3% and Cu 0.81% in crude ore, in	Raw	µg	47.53744	4.121259	x	x	37.01868	0.300202	4.707642	0.693478	0.696179

	ground											
87	Molybdenum, 0.022% in sulfide, Mo 8.2E-3% and Cu 0.36% in crude ore, in ground	Raw	mg	1.719 71	0.100 95	x	x	0.895 23	0.3931 67	0.2651 92	0.023 447	0.041 724
88	Molybdenum, 0.025% in sulfide, Mo 8.2E-3% and Cu 0.39% in crude ore, in ground	Raw	µg	174.1 919	15.10 156	x	x	135.6 479	1.1000 33	17.250 25	2.541 117	2.551 014
89	Molybdenum, 0.11% in sulfide, Mo 4.1E-2% and Cu 0.36% in crude ore, in ground	Raw	mg	3.469 974	0.203 604	x	x	1.806 16	0.7934 99	0.5352 06	0.047 298	0.084 208
90	Molybdenum, in ground	Raw	pg	57.91 994	x	57.91 994	x	x	x	x	x	x
91	Neodymium, 4% in bastnasite, 0.4% in crude ore, in ground	Raw	pg	- 6.00E -09	- 3.35E -10	x	x	- 2.85E- 09	-1.26E- 11	- 2.65E- 09	- 4.93E -11	- 9.35E- 11
92	Nickel, 1.13% in sulfide, Ni 0.76% and Cu	Raw	µg	185.5 816	3.884 243	x	x	104.8 975	1.5740 95	74.149 03	0.648 286	0.428 499

	0.76% in crude ore, in ground											
93	Nickel, 1.98% in silicates, 1.04% in crude ore, in ground	Raw	mg	148.3185	4.827878	x	x	115.1244	14.94008	11.39212	1.010015	1.02408
94	Nickel, in ground	Raw	µg	41.86417	x	41.86417	x	x	x	x	x	x
95	Occupation, arable, non-irrigated	Raw	cm2a	113.8822	0.035289	x	x	113.8354	0.00153	0.004473	0.005177	0.00029
96	Occupation, construction site	Raw	mm2a	29.65581	0.769694	x	x	18.56561	0.748365	8.888406	0.125823	0.557911
97	Occupation, dump site	Raw	mm2a	148.4428	10.86848	x	x	103.2277	12.38336	18.3247	1.991577	1.647041
98	Occupation, dump site, benthos	Raw	mm2a	42.48811	1.533614	x	x	10.73644	0.062089	28.13491	0.225615	1.795434
99	Occupation, forest, intensive	Raw	m2a	0.170637	1.28E-05	x	x	0.170619	1.32E-06	1.72E-06	1.51E-06	1.61E-07
100	Occupation, forest, intensive, normal	Raw	cm2a	129.3531	0.693194	x	x	126.8799	0.200735	1.363727	0.11851	0.097033
101	Occupation, forest, intensive, short-cycle	Raw	mm2a	101.6551	0.249114	x	x	100.028	0.007127	1.247237	0.044233	0.0794

102	Occupation, industrial area	Raw	mm 2a	343.4139	17.39405	x	x	55.99448	1.322384	250.9505	2.580167	15.17234
103	Occupation, industrial area, benthos	Raw	mm 2a	0.349701	0.013595	x	x	0.102558	0.000569	0.217101	0.002028	0.013 85
104	Occupation, industrial area, built up	Raw	mm 2a	159.4452	3.645106	x	x	145.2179	0.914244	8.313051	0.597967	0.756896
105	Occupation, industrial area, vegetation	Raw	mm 2a	104.4876	2.684889	x	x	94.30277	1.952861	4.605618	0.5682	0.373253
106	Occupation, mineral extraction site	Raw	mm 2a	145.8428	7.651148	x	x	62.47901	44.17596	28.19958	1.631231	1.705892
107	Occupation, permanent crop, fruit, intensive	Raw	mm 2a	234.039	0.367445	x	x	231.6893	0.01007	1.793273	0.06474	0.114149
108	Occupation, shrub land, sclerophyllous	Raw	mm 2a	6.658742	0.328548	x	x	2.482865	3.384484	0.363859	0.081946	0.017041
109	Occupation, traffic area, rail embankment	Raw	mm 2a	34.21125	1.119383	x	x	29.61439	0.335376	2.788331	0.18003	0.173738
110	Occupation, traffic area, rail network	Raw	mm 2a	37.82975	1.237779	x	x	32.74669	0.370849	3.083251	0.199071	0.192114
111	Occupation, traffic area, road	Raw	cm 2a	30.19604	0.577109	x	x	29.53077	0.003703	0.01995	0.063139	0.001369

	embankment											
112	Occupation, traffic area, road network	Raw	mm 2a	498.1552	280.2273	x	x	116.7927	8.6079	55.20456	31.03874	6.284055
113	Occupation, urban, discontinuously built	Raw	mm 2a	26.18205	0.003299	x	x	26.17031	0.000333	0.007166	0.000488	0.000458
114	Occupation, water bodies, artificial	Raw	cm 2a	187.5535	0.126533	x	x	1.024741	186.1058	0.25214	0.028573	0.015663
115	Occupation, water courses, artificial	Raw	mm 2a	70.75991	9.964246	x	x	34.62111	0.883808	22.44973	1.439221	1.40179
116	Oil, crude, 42.6 MJ per kg, in ground	Raw	g	21.20032	x	0.200318	21	x	x	x	x	x
117	Oil, crude, feedstock, 41 MJ per kg, in ground	Raw	g	43.8	x	x	43.8	x	x	x	x	x
118	Oil, crude, in ground	Raw	g	96.08339	6.491551	x	x	7.89185	0.213746	75.65288	1.000407	4.832956
119	Olivine, in ground	Raw	ng	600.9204	118.1488	x	x	381.2811	4.449267	69.67053	21.11702	6.253619
120	Palladium, in ground	Raw	pg	59.72957	x	59.72957	x	x	x	x	x	x
121	Pd, Pd 2.0E-4%, Pt 4.8E-4%, Rh 2.4E-5%, Ni 3.7E-2%, Cu 5.2E-	Raw	ng	134.2616	9.653935	x	x	27.51449	0.20797	89.31158	1.539568	6.034037

	2% in ore, in ground											
122	Pd, Pd 7.3E-4%, Pt 2.5E-4%, Rh 2.0E-5%, Ni 2.3E+0%, Cu 3.2E+0% in ore, in ground	Raw	ng	322.6698	23.20123	x	x	66.12537	0.499813	214.6418	3.700033	14.50156
123	Peat, in ground	Raw	mg	209.6643	0.143491	x	x	209.4689	0.007255	0.018652	0.02475	0.001253
124	Phosphorus, 18% in apatite, 12% in crude ore, in ground	Raw	mg	7.086066	0.039694	x	x	6.647329	0.002916	0.366586	0.005968	0.023573
125	Phosphorus, 18% in apatite, 4% in crude ore, in ground	Raw	mg	7.029818	0.069023	x	x	6.056441	0.006209	0.833707	0.010843	0.053595
126	Platinum, in ground	Raw	pg	69.99289	x	69.99289	x	x	x	x	x	x
127	Praseodymium, 0.42% in bastnasite, 0.042% in crude ore, in ground	Raw	pg	3.66E-10	1.03E-10	x	x	6.17E-11	1.80E-12	1.73E-10	1.50E-11	1.11E-11
128	Pt, Pt 2.5E-4%, Pd 7.3E-4%, Rh 2.0E-	Raw	ng	3.174195	0.207598	x	x	0.637306	0.011812	2.144657	0.028482	0.144339

	5%, Ni 2.3E+0%, Cu 3.2E+0% in ore, in ground											
129	Pt, Pt 4.8E-4%, Pd 2.0E-4%, Rh 2.4E-5%, Ni 3.7E-2%, Cu 5.2E-2% in ore, in ground	Raw	ng	11.37902	0.744208	x	x	2.284649	0.042343	7.688281	0.102105	0.517435
130	Rh, Rh 2.0E-5%, Pt 2.5E-4%, Pd 7.3E-4%, Ni 2.3E+0%, Cu 3.2E+0% in ore, in ground	Raw	ng	2.591903	0.13075	x	x	0.249153	0.005093	2.049212	0.019323	0.138373
131	Rh, Rh 2.4E-5%, Pt 4.8E-4%, Pd 2.0E-4%, Ni 3.7E-2%, Cu 5.2E-2% in ore, in ground	Raw	ng	8.118172	0.409525	x	x	0.780379	0.015953	6.418393	0.060521	0.433401
132	Rhenium, in crude ore, in ground	Raw	ng	3.098629	0.236388	x	x	0.406569	0.006884	2.218469	0.035279	0.195041
133	Rhenium, in ground	Raw	pg	55.79918	x	55.79918	x	x	x	x	x	x
134	Rhodium, in ground	Raw	pg	64.03477	x	64.03477	x	x	x	x	x	x

135	Samarium, 0.3% in bastnasite, 0.03% in crude ore, in ground	Raw	pg	-1.82E-10	-4.05E-12	x	x	-6.56E-11	-3.28E-13	-1.08E-10	-5.98E-13	-3.20E-12
136	Sand and clay, unspecified, in ground	Raw	mg	1.2	x	x	1.2	x	x	x	x	x
137	Sand, unspecified, in ground	Raw	mg	4.53532	0.012213	4.40038	x	0.096541	0.001561	0.021139	0.002061	0.001424
138	Shale, in ground	Raw	µg	4.400474	0.747005	x	x	2.883809	0.028441	0.556527	0.134	0.050692
139	Silver, 0.007% in sulfide, Ag 0.004%, Pb, Zn, Cd, In, in ground	Raw	µg	2.611334	0.447601	x	x	2.041575	0.003708	0.037422	0.078585	0.002443
140	Silver, 3.2ppm in sulfide, Ag 1.2ppm, Cu and Te, in crude ore, in ground	Raw	µg	1.862828	0.319219	x	x	1.456422	0.002649	0.026743	0.056049	0.001746
141	Silver, Ag 2.1E-4%, Au 2.1E-4%, in ore, in ground	Raw	ng	171.9746	29.47183	x	x	134.4573	0.244278	2.465529	5.174771	0.160949

142	Silver, Ag 4.2E-3%, Au 1.1E-4%, in ore, in ground	Raw	ng	392.7696	67.31015	x	x	307.0844	0.557902	5.630974	11.81856	0.367588
143	Silver, Ag 4.6E-5%, Au 1.3E-4%, in ore, in ground	Raw	ng	384.9995	65.97857	x	x	301.0094	0.546865	5.519574	11.58476	0.360316
144	Silver, Ag 9.7E-4%, Au 9.7E-4%, Zn 0.63%, Cu 0.38%, Pb 0.014%, in ore, in ground	Raw	ng	254.0276	43.53351	x	x	198.6099	0.360829	3.64189	7.64377	0.237741
145	Silver, in ground	Raw	ng	628.1196	x	628.1196	x	x	x	x	x	x
146	Sodium chloride, in ground	Raw	g	3.390372	0.125095	2.290882	0.294	0.61483	0.001181	0.046849	0.014488	0.003048
147	Sodium nitrate, in ground	Raw	pg	146.4815	36.2747	x	x	95.76226	1.233066	6.132425	6.632054	0.446958
148	Sodium sulphate, various forms, in ground	Raw	mg	2.953356	0.129798	x	x	0.956235	0.009678	1.727162	0.019401	0.111083
149	Stibnite, in ground	Raw	ng	3.995822	2.753074	x	x	0.882992	0.009337	0.048095	0.299361	0.002963
150	Sulfur, in ground	Raw	µg	60.03709	8.865821	x	x	40.14595	0.462767	8.267298	1.574142	0.721109
151	Sylvite, 25 %	Raw	mg	169.4	0.054	x	x	169.2	0.0025	0.0543	0.009	0.003

	in sylvinite, in ground			129	702			886	91	55	131	469
152	Talc, in ground	Raw	mg	2.209 099	0.004 02	x	x	2.192 7	0.0088 95	0.0027 07	0.000 58	0.000 197
153	Tantalum, 81.9% in tantalite, 1.6E-4% in crude ore, in ground	Raw	µg	2.058 44	0.353 09	x	x	1.609 672	0.0028 77	0.0289 08	0.062 003	0.001 89
154	Tellurium, 0.5ppm in sulfide, Te 0.2ppm, Cu and Ag, in crude ore, in ground	Raw	ng	279.4 288	47.88 36	x	x	218.4 669	0.3973 32	4.0115 43	8.407 514	0.261 85
155	Tin, 79% in cassiterite, 0.1% in crude ore, in ground	Raw	µg	99.72 051	16.78 901	x	x	76.51 904	1.0544 76	2.1412 41	3.077 791	0.138 955
156	Tin, in ground	Raw	ng	348.9 553	x	348.9 553	x	x	x	x	x	x
157	TiO2, 54% in ilmenite, 2.6% in crude ore, in ground	Raw	mg	10.01 654	2.055 408	x	x	3.937 576	0.0374 22	3.4640 72	0.299 577	0.222 483
158	TiO2, 95% in rutile, 0.40% in crude ore, in ground	Raw	ng	57.55 689	21.89 7	x	x	30.30 067	0.1418 01	0.8543 07	4.310 655	0.052 468
159	Transformatio	Raw	mm	0.068	0.006	x	x	0.052	0.0009	0.0060	0.001	0.000

	n, from arable		2	022	578			982	26	86	086	363
160	Transformation, from arable, non-irrigated	Raw	cm 2	208.9 692	0.065 199	x	x	208.8 829	0.0028 11	0.0082 63	0.009 565	0.000 536
161	Transformation, from arable, non-irrigated, fallow	Raw	mm 2	0.013 574	0.001 527	x	x	0.011 118	0.0001 77	0.0004 58	0.000 268	2.47E-05
162	Transformation, from dump site, inert material landfill	Raw	mm 2	1.031 086	0.052 651	x	x	0.279 817	0.6683 3	0.0150 18	0.013 962	0.001 307
163	Transformation, from dump site, residual material landfill	Raw	mm 2	0.199 527	0.012 545	x	x	0.145 231	0.0085 11	0.0289 23	0.002 34	0.001 976
164	Transformation, from dump site, sanitary landfill	Raw	mm 2	0.081 099	0.000 178	x	x	0.052 115	2.93E-05	0.0286 4	2.66E-05	0.000 11
165	Transformation, from dump site, slag compartment	Raw	mm 2	0.019 717	0.000 316	x	x	0.019 178	1.23E-05	0.0001 43	5.65E-05	1.18E-05
166	Transformation, from forest	Raw	mm 2	249.6 392	6.162 476	x	x	16.56 673	122.45 82	97.315 93	0.924 036	6.211 762
167	Transformation, from forest,	Raw	cm 2	12.60 777	0.006 157	x	x	12.58 8	0.0015 5	0.0103 14	0.001 003	0.000 749

	extensive											
168	Transformation, from forest, intensive, clear-cutting	Raw	m2	3.630556	0.008897	x	x	3.572445	0.000255	0.044544	0.00158	0.002836
169	Transformation, from industrial area	Raw	m2	0.256404	0.008244	x	x	0.201873	0.001342	0.041217	0.001155	0.002573
170	Transformation, from industrial area, benthos	Raw	m2	0.001138	7.48E-06	x	x	0.001103	1.98E-06	2.34E-05	1.11E-06	1.26E-06
171	Transformation, from industrial area, built up	Raw	m2	0.002509	2.45E-05	x	x	0.002162	2.22E-06	0.000298	3.84E-06	1.91E-05
172	Transformation, from industrial area, vegetation	Raw	m2	0.00428	4.18E-05	x	x	0.003687	3.78E-06	0.000508	6.56E-06	3.26E-05
173	Transformation, from mineral extraction site	Raw	m2	3.839873	0.31698	x	x	1.761495	1.302463	0.360199	0.079478	0.019257
174	Transformation, from pasture and meadow	Raw	m2	3.144734	0.131617	x	x	1.705451	1.088606	0.179214	0.029898	0.009948
175	Transformation, from pasture and	Raw	m2	17.05392	0.00532	x	x	17.04687	0.000229	0.000674	0.00078	4.37E-05

	meadow, intensive											
176	Transformation, from sea and ocean	Raw	mm2	42.50693	1.535081	x	x	10.74341	0.062166	28.14437	0.225863	1.796038
177	Transformation, from shrub land, sclerophyllous	Raw	mm2	1.553645	0.086013	x	x	0.660312	0.681345	0.101609	0.019162	0.005204
178	Transformation, from tropical rain forest	Raw	mm2	3.630556	0.008897	x	x	3.572445	0.000255	0.044544	0.00158	0.002836
179	Transformation, from unknown	Raw	mm2	36.36251	5.510355	x	x	20.29714	5.467721	3.482078	1.373237	0.231984
180	Transformation, to arable	Raw	mm2	2.68676	0.039432	x	x	2.470397	0.019097	0.143111	0.006218	0.008505
181	Transformation, to arable, non-irrigated	Raw	cm2	209.1398	0.065253	x	x	209.0533	0.002813	0.008269	0.009572	0.000536
182	Transformation, to arable, non-irrigated, fallow	Raw	mm2	0.023503	0.002082	x	x	0.01728	0.002558	0.001126	0.000391	6.62E-05
183	Transformation, to dump site	Raw	mm2	1.033237	0.07903	x	x	0.752197	0.042743	0.132675	0.014123	0.012468
184	Transformation, to dump site, benthos	Raw	mm2	42.48811	1.533614	x	x	10.73644	0.062089	28.13491	0.225615	1.795434
185	Transformatio	Raw	mm	1.031	0.052	x	x	0.279	0.6683	0.0150	0.013	0.001

	n, to dump site, inert material landfill		2	086	651			817	3	18	962	307
186	Transformation, to dump site, residual material landfill	Raw	mm 2	0.199 529	0.012 545	x	x	0.145 233	0.0085 11	0.0289 23	0.002 34	0.001 976
187	Transformation, to dump site, sanitary landfill	Raw	mm 2	0.081 099	0.000 178	x	x	0.052 115	2.93E-05	0.0286 4	2.66E-05	0.000 11
188	Transformation, to dump site, slag compartment	Raw	mm 2	0.019 717	0.000 316	x	x	0.019 178	1.23E-05	0.0001 43	5.65E-05	1.18E-05
189	Transformation, to forest	Raw	mm 2	4.156 173	0.333 757	x	x	1.434 633	1.9605 08	0.3238 41	0.087 508	0.015 928
190	Transformation, to forest, intensive	Raw	cm 2	11.36 784	0.000 857	x	x	11.36 667	8.77E-05	0.0001 14	0.000 1	1.07E-05
191	Transformation, to forest, intensive, clear-cutting	Raw	mm 2	3.630 556	0.008 897	x	x	3.572 445	0.0002 55	0.0445 44	0.001 58	0.002 836
192	Transformation, to forest, intensive, normal	Raw	mm 2	100.9 833	0.517 22	x	x	99.17 765	0.1444 02	0.9844 8	0.088 106	0.071 44
193	Transformation, to forest,	Raw	mm 2	3.630 556	0.008 897	x	x	3.572 445	0.0002 55	0.0445 44	0.001 58	0.002 836

	intensive, short-cycle											
194	Transformation, to heterogeneous, agricultural	Raw	mm2	5.996794	0.302666	x	x	0.813141	0.011309	4.534906	0.046213	0.288559
195	Transformation, to industrial area	Raw	mm2	1.667701	0.093039	x	x	0.876205	0.02162	0.649824	0.014011	0.013003
196	Transformation, to industrial area, benthos	Raw	mm2	0.018824	0.001466	x	x	0.006968	7.68E-05	0.00946	0.000248	0.000604
197	Transformation, to industrial area, built up	Raw	mm2	4.472008	0.080224	x	x	2.908903	1.241075	0.210435	0.013117	0.018254
198	Transformation, to industrial area, vegetation	Raw	mm2	2.174156	0.059945	x	x	1.911088	0.039465	0.139774	0.012319	0.011565
199	Transformation, to mineral extraction site	Raw	mm2	140.9724	9.591623	x	x	24.90166	4.594987	93.99346	1.896569	5.994122
200	Transformation, to pasture and meadow	Raw	mm2	0.199056	0.001418	x	x	0.189718	0.000341	0.006955	0.000213	0.000411
201	Transformation, to permanent crop, fruit, intensive	Raw	mm2	3.294599	0.005173	x	x	3.261522	0.000142	0.025244	0.000911	0.001607
202	Transformation, to sea and	Raw	mm2	0.001138	7.48E-06	x	x	0.001103	1.98E-06	2.34E-05	1.11E-06	1.26E-06

	ocean											
203	Transformation, to shrub land, sclerophyllous	Raw	mm2	1.331429	0.06569	x	x	0.496341	0.676883	0.072725	0.016385	0.003405
204	Transformation, to traffic area, rail embankment	Raw	mm2	0.079607	0.002605	x	x	0.06891	0.00078	0.006488	0.000419	0.000404
205	Transformation, to traffic area, rail network	Raw	mm2	0.087502	0.002863	x	x	0.075745	0.000858	0.007132	0.00046	0.000444
206	Transformation, to traffic area, road embankment	Raw	mm2	19.9111	0.147318	x	x	19.73325	0.001943	0.011438	0.016332	0.000818
207	Transformation, to traffic area, road network	Raw	mm2	2.224158	0.480619	x	x	0.561514	0.426604	0.617089	0.063767	0.074566
208	Transformation, to unknown	Raw	mm2	0.255797	0.027661	x	x	0.161485	0.012484	0.046439	0.004773	0.002956
209	Transformation, to urban, discontinuously built	Raw	mm2	0.52153	6.57E-05	x	x	0.521296	6.63E-06	0.000143	9.72E-06	9.13E-06
210	Transformation, to water bodies, artificial	Raw	mm2	126.2791	0.824606	x	x	2.692078	122.1196	0.396429	0.222665	0.023682

211	Transformation, to water courses, artificial	Raw	mm2	0.738595	0.097153	x	x	0.395889	0.010279	0.208335	0.013933	0.013006
212	Ulexite, in ground	Raw	µg	9.763397	0.52727	x	x	7.207673	0.124315	1.716	0.082661	0.105478
213	Uranium, 451 GJ per kg, in ground	Raw	µg	108	x	x	108	x	x	x	x	x
214	Uranium, 560 GJ per kg, in ground	Raw	µg	51.90882	x	51.90882	x	x	x	x	x	x
215	Uranium, in ground	Raw	µg	497.0192	45.8087	x	x	339.5041	8.586828	91.38925	6.115333	5.614991
216	Vermiculite, in ground	Raw	µg	24.27819	0.35374	x	x	23.13627	0.307886	0.402488	0.053222	0.024588
217	Volume occupied, final repository for low-active radioactive waste	Raw	mm3	1.018345	0.093367	x	x	0.695008	0.017679	0.188313	0.012415	0.011563
218	Volume occupied, final repository for radioactive waste	Raw	mm3	0.253176	0.021691	x	x	0.173722	0.004327	0.047607	0.002905	0.002923
219	Volume occupied, reservoir	Raw	m3 day	29.60192	0.035368	0.02695	x	0.391604	29.10114	0.039842	0.00458	0.002441

220	Volume occupied, underground deposit	Raw	mm 3	4.904 168	0.586 94	x	x	2.534 256	0.0380 33	1.5251 31	0.104 842	0.114 965
221	Water, cooling, unspecified natural origin/m3	Raw	dm 3	87.80 635	0.078 517	x	x	1.241 75	0.0152 16	86.426 14	0.012 411	0.032 313
222	Water, lake	Raw	cm 3	25.47 915	0.368 729	x	x	24.28 449	0.3231 65	0.4217 15	0.055 23	0.025 818
223	Water, process and cooling, unspecified natural origin	Raw	cu.i n	64.07 495	x	x	64.07 495	x	x	x	x	x
224	Water, river	Raw	cu.i n	128.5 464	1.399 524	x	x	97.75 796	0.2986 87	28.528 97	0.196 488	0.364 759
225	Water, salt, ocean	Raw	cm 3	83.71 517	3.510 571	x	x	47.65 012	0.5778 29	29.609	0.495 921	1.871 73
226	Water, salt, sole	Raw	cm 3	74.36 167	4.207 686	x	x	5.529 802	0.1381 48	60.015 12	0.637 408	3.833 501
227	Water, turbine use, unspecified natural origin	Raw	cuft	165.9 669	1.178 805	0.629 819	x	9.891 866	152.27 53	1.7228 73	0.161 08	0.107 21
228	Water, unspecified natural origin/kg	Raw	kg	5.371 09	x	5.371 09	x	x	x	x	x	x
229	Water, unspecified	Raw	cm 3	480.1 989	42.85 861	x	x	194.1 029	25.791 8	195.92 7	9.066 68	12.45 198

	natural origin/m3											
230	Water, well, in ground	Raw	cm3	447.2812	8.112709	x	x	420.2178	1.610003	15.32752	1.059454	0.953706
231	Wood, dry matter	Raw	mg	7.957258	x	7.957258	x	x	x	x	x	x
232	Wood, hard, standing	Raw	cm3	14.99785	0.019027	x	x	14.91038	0.005455	0.056586	0.002879	0.003522
233	Wood, primary forest, standing	Raw	mm3	37.59078	0.092119	x	x	36.98909	0.002636	0.461212	0.016357	0.029361
234	Wood, soft, standing	Raw	cm3	70.24277	0.043805	x	x	70.04488	0.011295	0.127614	0.006647	0.008525
235	Wood, unspecified, standing/m3	Raw	mm3	0.006175	0.000927	x	x	0.003293	4.53E-05	0.001595	0.000164	0.00015
236	Zinc, 9.0% in sulfide, Zn 5.3%, Pb, Ag, Cd, In, in ground	Raw	mg	25.77281	2.359979	x	x	21.87122	0.09207	0.900399	0.449811	0.099322
237	Zinc, in ground	Raw	µg	1.805478	x	1.805478	x	x	x	x	x	x
238	Zirconium, 50% in zircon, 0.39% in crude ore, in ground	Raw	µg	2.816049	0.484711	x	x	2.203599	0.003701	0.036489	0.08515	0.002398
239	1-Propanol	Air	pg	802.5215	49.63769	x	x	548.9607	13.5487	172.8176	6.940679	10.61615

240	1,4-Butanediol	Air	pg	683.8551	117.5509	x	x	534.9861	0.921038	9.149834	20.64721	0.599997
241	2-Propanol	Air	µg	12.77111	2.199218	x	x	9.994473	0.016645	0.163653	0.386361	0.010763
242	Acenaphthene	Air	pg	76.71749	3.175808	x	x	55.09414	1.133473	15.8639	0.475168	0.975001
243	Acetaldehyde	Air	µg	964.876	81.86601	1.225405	x	123.4778	1.889646	754.6548	1.35724	0.405009
244	Acetic acid	Air	mg	3.448239	0.008637	0.0056	x	0.340205	0.000967	3.088646	0.001516	0.002668
245	Acetone	Air	µg	799.7588	3.248901	1.220489	x	42.32115	0.177713	751.988	0.558838	0.24364
246	Acetonitrile	Air	µg	3.947141	0.009673	x	x	3.883962	0.000277	0.048429	0.001717	0.003083
247	Acrolein	Air	ng	31.66468	1.786112	0.18261	x	21.349	0.887313	6.491687	0.359867	0.608087
248	Acrylic acid	Air	ng	33.04251	5.689648	x	x	25.85823	0.043116	0.42407	0.999555	0.027888
249	Actinides, radioactive, unspecified	Air	µBq	10.70096	1.160606	x	x	7.567701	0.154201	1.561637	0.15921	0.097602
250	Aerosols, radioactive, unspecified	Air	µBq	207.7862	14.22295	x	x	145.7256	3.341847	40.07999	1.954328	2.461507
251	Aldehydes, unspecified	Air	ng	925.1113	95.07709	41.43289	x	504.7617	9.159343	239.0788	15.61182	19.98965
252	Aluminum	Air	mg	3.532619	0.20916	0.04311	x	2.736607	0.095687	0.383688	0.03788	0.026488
253	Americium-241	Air	nBq	399.6213	x	399.6213	x	x	x	x	x	x
254	Ammonia	Air	mg	25.39	0.358	0.008	0.056	23.93	0.0936	0.8484	0.052	0.042

				688	984	757	4	611	29	23	541	032
255	Ammonium carbonate	Air	ng	21.77 592	2.185 672	x	x	13.62 232	0.2504 81	5.0697 21	0.312 184	0.335 543
256	Antimony	Air	µg	2.894 822	0.151 16	0.037 506	x	2.482 551	0.0140 91	0.1638 79	0.024 971	0.020 665
257	Antimony-124	Air	nBq	8.329 755	0.907 964	5.892 84	x	1.129 099	0.0788 09	0.1970 7	0.111 931	0.012 041
258	Antimony-125	Air	nBq	26.18 05	9.475 363	0.749 253	x	11.78 31	0.8224 38	2.0565 91	1.168 095	0.125 66
259	Argon-41	Air	mBq	145.1 579	5.399 315	46.64 943	x	68.30 053	1.6072 31	21.136 04	0.766 9	1.298 436
260	Arsenic	Air	µg	57.53 984	1.051 487	0.200 939	x	14.32 036	0.2334 17	41.306 9	0.175 809	0.250 929
261	Arsine	Air	pg	0.385 154	0.066 32	x	x	0.301 412	0.0005 03	0.0049 43	0.011 651	0.000 325
262	Barium	Air	µg	26.03 395	0.226 632	0.683 262	x	23.97 47	0.1203 81	0.9329 8	0.037 408	0.058 583
263	Barium-140	Air	µBq	1.738 075	0.616 358	0.083 811	x	0.766 473	0.0534 98	0.1337 78	0.075 983	0.008 174
264	Benzal chloride	Air	pg	0.005 296	0.000 989	x	x	0.003 952	1.74E-05	0.0001 78	0.000 142	1.81E-05
265	Benzaldehyde	Air	ng	13.97 54	0.762 967	0.062 609	x	9.358 12	0.4252 54	2.9144 25	0.163 947	0.288 081
266	Benzene	Air	mg	2.156 708	0.053 453	0.005 484	0.222	1.186 305	0.0046 55	0.6415 39	0.008 285	0.034 988
267	Benzene, ethyl-	Air	µg	133.4 155	8.780 555	3.611 009	x	12.43 013	0.2949 65	100.52 65	1.349 698	6.422 662
268	Benzene, hexachloro-	Air	ng	35.67 253	5.099 378	0.002 697	x	21.58 282	1.1742 18	6.4649 62	0.948 106	0.400 352
269	Benzene, pentachloro-	Air	ng	16.10 855	0.079 792	0.007 21	x	15.93 656	0.0052 71	0.0605 92	0.013 945	0.005 178

270	Benzo(a)pyrene	Air	µg	1.790762	0.069232	0.002021	x	1.487144	0.015223	0.178352	0.01199	0.026801
271	Beryllium	Air	ng	398.9113	2.329837	7.637689	x	219.6043	5.408511	163.2196	0.466905	0.244 36
272	Boron	Air	µg	877.285	10.79754	29.6711	x	768.7939	4.314134	58.46836	1.643166	3.59679
273	Boron trifluoride	Air	pg	0.002874	0.000495	x	x	0.002249	3.75E-06	3.69E-05	8.70E-05	2.43E-06
274	Bromine	Air	µg	37.12593	1.155968	3.082548	x	25.39037	0.457727	6.463306	0.177854	0.39816
275	Butadiene	Air	pg	397.8802	65.8091	x	x	297.3096	0.570245	21.24274	11.52568	1.422795
276	Butane	Air	mg	6.77843	0.390227	0.021693	x	1.55689	0.015057	4.450645	0.059843	0.284075
277	Butanol	Air	pg	2.119951	0.364408	x	x	1.658457	0.002855	0.028364	0.064006	0.00186
278	Butene	Air	µg	129.1492	8.752612	1.447808	x	10.43401	0.29057	100.4608	1.345765	6.417679
279	Butyrolactone	Air	pg	197.8955	34.01714	x	x	154.8154	0.266532	2.647798	5.974935	0.173628
280	Cadmium	Air	µg	28.91415	0.589781	0.085433	0.96	5.529132	0.047914	21.32721	0.093486	0.281191
281	Calcium	Air	mg	2.917419	0.004091	0.045812	x	2.760371	0.001302	0.103912	0.000644	0.001287
282	Carbon-14	Air	mBq	911.654	85.98173	32.16189	x	593.0596	15.70681	163.3381	11.37629	10.02954
283	Carbon dioxide	Air	g	140.667	x	2.667009	138	x	x	x	x	x
284	Carbon dioxide, biogenic	Air	g	58.01326	0.054559	x	x	57.7034	0.036267	0.197794	0.008357	0.012885

285	Carbon dioxide, fossil	Air	g	433.0125	21.6606	x	x	135.8176	2.227932	254.4701	3.242794	15.59344
286	Carbon dioxide, land transformation	Air	g	55.34847	0.000231	x	x	0.056727	55.29026	0.001137	3.87E-05	7.14E-05
287	Carbon disulfide	Air	µg	334.245	29.00504	x	x	234.8316	21.19555	38.59807	5.082168	5.532614
288	Carbon monoxide	Air	g	1.081127	x	0.001127	1.08	x	x	x	x	x
289	Carbon monoxide, biogenic	Air	mg	7.813365	1.001751	x	x	6.277871	0.083559	0.260581	0.175404	0.014198
290	Carbon monoxide, fossil	Air	mg	687.0342	53.43797	x	x	315.3423	5.341309	179.1091	4.237414	129.5661
291	Cerium-141	Air	nBq	403.0244	149.4192	1.993137	x	185.8104	12.96922	32.43086	18.41996	1.981567
292	Cerium-144	Air	µBq	4.249984	x	4.249984	x	x	x	x	x	x
293	Cesium-134	Air	µBq	15.207	0.007156	15.18779	x	0.008899	0.000621	0.001553	0.000882	9.49E-05
294	Cesium-137	Air	µBq	29.6514	0.126856	29.31093	x	0.157753	0.011011	0.027534	0.015638	0.001682
295	Chlorine	Air	µg	89.09165	7.658467	x	x	56.14485	0.394308	22.11694	1.356473	1.420618
296	Chloroform	Air	ng	40.64652	6.196191	1.26944	x	29.53464	0.245131	2.235996	1.025444	0.139676
297	Chlorosilane, trimethyl-	Air	pg	593.6037	102.2137	x	x	464.5393	0.774565	7.618357	17.95686	0.501002
298	Chromium	Air	µg	256.2633	3.237968	0.266366	x	155.8276	18.82239	76.44797	0.575207	1.085799

299	Chromium-51	Air	nBq	101.1416	9.574755	75.44357	x	11.9067	0.831065	2.078164	1.180348	0.126978
300	Chromium VI	Air	µg	5.562364	0.055224	x	x	3.93906	0.468252	1.070022	0.010115	0.01969
301	Cobalt	Air	µg	217.5951	0.338156	0.331336	x	7.291552	0.299708	209.0548	0.056188	0.223353
302	Cobalt-57	Air	nBq	0.036843	x	0.036843	x	x	x	x	x	x
303	Cobalt-58	Air	nBq	645.2554	13.33324	609.4698	x	16.58057	1.157293	2.893929	1.643683	0.176823
304	Cobalt-60	Air	µBq	1.223208	0.117787	0.907076	x	0.146474	0.010224	0.025565	0.01452	0.001562
305	Copper	Air	µg	134.8759	29.54703	0.79725	x	64.12346	1.468327	26.81079	3.793419	8.335608
306	Cumene	Air	µg	12.25062	1.803135	x	x	4.686217	0.074968	4.890662	0.337477	0.458157
307	Curium-242	Air	nBq	0.00211	x	0.00211	x	x	x	x	x	x
308	Curium-244	Air	nBq	0.019152	x	0.019152	x	x	x	x	x	x
309	Curium alpha	Air	nBq	634.3195	x	634.3195	x	x	x	x	x	x
310	Cyanide	Air	µg	60.75232	0.223628	0.006365	x	59.90157	0.222001	0.333113	0.038836	0.026814
311	Dinitrogen monoxide	Air	mg	27.82087	1.185524	0.121872	0.354	12.73324	0.058466	12.08074	0.134711	1.152316
312	Dioxins, measured as 2,3,7,8-tetrachlorodibenzo-p-dioxin	Air	pg	151.3119	5.501062	0.184551	x	75.72666	2.502051	65.81407	1.047462	0.536042

313	Ethane	Air	mg	8.753 737	0.164 776	0.029 264	x	6.782 893	0.0185 2	1.6303 65	0.025 051	0.102 868
314	Ethane, 1,1-difluoro-, HFC-152a	Air	ng	22.93 771	1.418 95	x	x	15.69 038	0.3872 54	4.9393 05	0.198 403	0.303 421
315	Ethane, 1,1,1-trichloro-, HCFC-140	Air	pg	103.3 218	11.21 015	x	x	73.06 935	1.4887 02	15.073 72	1.537 792	0.942 126
316	Ethane, 1,1,1,2-tetrafluoro-, HFC-134a	Air	ng	26.72 922	2.568 377	x	x	19.29 051	0.3691 24	3.8937 94	0.368 129	0.239 288
317	Ethane, 1,1,2-trichloro-1,2,2-trifluoro-, CFC-113	Air	ng	1.568 185	0.270 029	x	x	1.227 222	0.0020 46	0.0201 26	0.047 439	0.001 324
318	Ethane, 1,2-dichloro-	Air	µg	1.777 719	0.147 236	x	x	1.208 225	0.0091 89	0.3566 11	0.025 538	0.030 92
319	Ethane, 1,2-dichloro-1,1,2,2-tetrafluoro-, CFC-114	Air	ng	827.9 376	37.17 514	434.4 187	x	274.7 204	6.5339 18	66.127 51	4.901 737	4.060 219
320	Ethane, dichloro-	Air	ng	48.03 421	x	48.03 421	x	x	x	x	x	x
321	Ethane, hexafluoro-, HFC-116	Air	µg	1.665 758	0.317 629	0.017 756	x	1.175 807	0.0243 49	0.0707 56	0.055 71	0.003 751
322	Ethanol	Air	mg	1.564 359	0.000 841	0.002 452	x	0.027 083	0.0002 29	1.5332 55	0.000 13	0.000 369
323	Ethene	Air	mg	2.024	0.029	0.038	x	1.715	0.0040	0.2183	0.005	0.014

				289	427	174		272	26	24	015	051
324	Ethene, chloro-	Air	ng	883.6325	57.81295	7.82384	x	693.3941	4.919048	102.0615	9.525328	8.09571
325	Ethene, tetrachloro-	Air	pg	246.8605	26.24475	x	x	174.5265	3.533349	36.63309	3.63661	2.286218
326	Ethyl acetate	Air	µg	59.30941	10.20495	x	x	46.40722	0.078469	0.775202	1.792649	0.050915
327	Ethyl cellulose	Air	ng	119.957	20.6559	x	x	93.87558	0.156486	1.53901	3.628827	0.101212
328	Ethylene diamine	Air	pg	208.7481	137.6861	x	x	43.96919	8.106276	3.701071	15.04101	0.244399
329	Ethylene oxide	Air	µg	1.267663	0.027863	x	x	1.160626	0.005064	0.063108	0.005131	0.00587
330	Ethyne	Air	µg	279.9391	0.476938	0.278134	x	278.0009	0.282033	0.757968	0.090875	0.052279
331	Fluorine	Air	µg	4.77127	0.149699	x	x	4.083095	0.180084	0.297196	0.027315	0.033882
332	Fluosilicic acid	Air	µg	1.799129	0.349438	x	x	1.274924	0.028282	0.080932	0.061284	0.004269
333	Formaldehyde	Air	mg	2.890315	0.156555	0.008364	x	0.405067	0.004216	2.311531	0.003	0.001282
334	Formic acid	Air	µg	26.47418	0.077478	x	x	26.03548	0.001948	0.32486	0.013733	0.020683
335	Furan	Air	µg	7.496372	0.01837	x	x	7.376384	0.000526	0.091975	0.003262	0.005855
336	Heat, waste	Air	MJ	4.913538	0.331875	0.053165	x	2.349795	0.023628	1.877026	0.049021	0.229028
337	Helium	Air	µg	280.9646	34.24964	13.8191	x	33.04939	1.152851	181.6322	5.460719	11.60069
338	Heptane	Air	mg	1.280563	0.08749	0.003607	x	0.104335	0.002905	1.004598	0.013451	0.064177

339	Hexane	Air	mg	2.989 016	0.191 121	0.007 575	x	0.451 569	0.0074 48	2.1637 58	0.029 361	0.138 184
340	Hydrocarbons , aliphatic, alkanes, cyclic	Air	µg	2.108 733	0.033 071	x	x	1.971 393	0.0014 23	0.0890 09	0.005 944	0.007 893
341	Hydrocarbons , aliphatic, alkanes, unspecified	Air	mg	4.446 005	0.102	0.012 513	x	0.991 167	0.0167 59	3.2900 99	0.018 67	0.014 798
342	Hydrocarbons , aliphatic, alkenes, unspecified	Air	µg	3.790 775	x	3.790 775	x	x	x	x	x	x
343	Hydrocarbons , aliphatic, unsaturated	Air	µg	633.9 07	3.340 694	x	x	460.8 84	1.2535 92	167.02 83	0.513 667	0.886 638
344	Hydrocarbons , aromatic	Air	µg	928.0 493	26.77 863	0.555 233	540	279.0 408	5.0479 15	69.386 22	4.859 872	2.380 624
345	Hydrocarbons , chlorinated	Air	µg	3.301 769	0.192 984	x	x	2.911 197	0.0219 63	0.1259 96	0.036 184	0.013 443
346	Hydrocarbons , halogenated	Air	ng	14.4	x	x	14.4	x	x	x	x	x
347	Hydrocarbons , unspecified	Air	mg	564	x	x	564	x	x	x	x	x
348	Hydrogen	Air	mg	4.787 044	0.022 307	x	x	4.582 738	0.0016 35	0.1662 91	0.003 346	0.010 727
349	Hydrogen-3, Tritium	Air	Bq	5.258 664	0.377 175	0.331 686	x	3.412 863	0.0819 59	0.9457 49	0.051 153	0.058 081
350	Hydrogen chloride	Air	mg	13.42 148	0.141 042	0.910 538	6.6	4.904 76	0.0626 53	0.7359 64	0.024 216	0.042 303

351	Hydrogen fluoride	Air	mg	1.090784	0.029384	0.059713	0.348	0.44194	0.008161	0.192006	0.004869	0.00671
352	Hydrogen peroxide	Air	ng	88.8889	15.30107	x	x	69.55785	0.116675	1.149751	2.687987	0.075569
353	Hydrogen sulfide	Air	mg	1.85439	0.019634	0.003138	x	1.787309	0.004346	0.034389	0.003583	0.001991
354	Iodine	Air	µg	19.40012	0.595677	1.377806	x	13.45096	0.243977	3.429281	0.091648	0.210767
355	Iodine-129	Air	µBq	975.238	69.81305	114.1775	x	591.6206	14.62268	165.4316	9.413104	10.15937
356	Iodine-131	Air	mBq	38.80389	2.025519	0.012676	x	26.96864	0.627828	8.365405	0.289912	0.513915
357	Iodine-133	Air	µBq	10.27345	0.855214	7.102437	x	1.755112	0.082701	0.349595	0.106961	0.021426
358	Iodine-135	Air	µBq	13.22279	0.256456	10.63522	x	1.818963	0.040631	0.41131	0.034939	0.025273
359	Iron	Air	mg	1.235116	0.006381	0.028618	x	0.971696	0.00335	0.222254	0.001234	0.001583
360	Iron-59	Air	nBq	0.834727	x	0.834727	x	x	x	x	x	x
361	Isocyanic acid	Air	ng	676.8447	29.67936	x	x	543.0535	7.934025	86.50986	4.33492	5.333082
362	Isoprene	Air	ng	347.8617	0.852461	x	x	342.2938	0.024389	4.26802	0.151363	0.271705
363	Krypton-85	Air	Bq	1966.808	0.017319	1966.499	x	0.214038	0.005062	0.066161	0.002452	0.004064
364	Krypton-85m	Air	mBq	31.04491	9.121394	2.324719	x	14.45018	0.84916	2.98703	1.129569	0.182864
365	Krypton-87	Air	mBq	10.05557	2.161055	1.039617	x	5.04465	0.231155	1.233194	0.270285	0.075618
366	Krypton-88	Air	mB	102.7	2.755	92.83	x	5.270	0.2732	1.1957	0.342	0.073

			q	479	12	767		138	29	51	676	271
367	Krypton-89	Air	mBq	3.950894	1.122453	0.728862	x	1.549354	0.100264	0.293392	0.138625	0.017944
368	Lanthanum	Air	ng	19.53005	x	19.53005	x	x	x	x	x	x
369	Lanthanum-140	Air	nBq	194.4508	52.67772	53.06726	x	65.50745	4.572297	11.4335	6.493955	0.698601
370	Lead	Air	µg	122.846	8.117768	1.119185	5.46	51.55973	1.550728	52.76459	1.279217	0.994795
371	Lead-210	Air	mBq	10.54399	0.222039	0.373705	x	8.870939	0.085306	0.903334	0.032715	0.05595
372	m-Xylene	Air	µg	6.244749	0.039679	x	x	6.002125	0.012823	0.173595	0.005768	0.01076
373	Magnesium	Air	µg	670.0076	2.394189	15.33625	x	645.5449	1.928612	4.070328	0.446438	0.28687
374	Manganese	Air	µg	89.16918	0.948026	0.771526	1.86	18.21161	0.375275	66.66868	0.177442	0.156615
375	Manganese-54	Air	nBq	34.96143	4.903335	21.8012	x	6.097549	0.425597	1.06425	0.604469	0.065027
376	Mercury	Air	µg	11.93545	0.792489	1.883129	1.8	4.565023	0.221163	2.321695	0.142871	0.209075
377	Metals, unspecified	Air	µg	600	x	x	600	x	x	x	x	x
378	Methane	Air	mg	227.006	x	5.006022	222	x	x	x	x	x
379	Methane, biogenic	Air	g	1.061814	4.64E-05	x	x	0.01475	1.046827	0.000173	6.86E-06	1.06E-05
380	Methane, bromo-, Halon 1001	Air	pg	0.001212	0.000226	x	x	0.000904	3.98E-06	4.07E-05	3.25E-05	4.14E-06
381	Methane,	Air	µg	1.842	0.012	x	x	1.770	0.0033	0.0513	0.001	0.002

	bromochlorodifluoro-, Halon 1211			88	991			434	02	3	919	904
382	Methane, bromotrifluoro-, Halon 1301	Air	µg	8.044515	0.278798	0.077779	4.56	0.309008	0.009201	2.600103	0.043548	0.166078
383	Methane, chlorodifluoro-, HCFC-22	Air	µg	6.567817	0.062341	0.003891	x	6.263559	0.014626	0.202349	0.00946	0.011591
384	Methane, chlorotrifluoro-, CFC-13	Air	ng	2.221551	x	2.221551	x	x	x	x	x	x
385	Methane, dichloro-, HCC-30	Air	µg	11.60193	0.000376	11.59878	x	0.002277	3.18E-05	0.000372	5.78E-05	2.54E-05
386	Methane, dichlorodifluoro-, CFC-12	Air	ng	16.1797	0.752165	3.538025	x	11.13559	0.022884	0.570627	0.130294	0.030117
387	Methane, dichlorofluoro-, HCFC-21	Air	µg	16.78689	1.78E-06	16.78688	x	8.26E-06	1.92E-08	2.00E-07	3.12E-07	1.28E-08
388	Methane, fossil	Air	mg	473.9545	27.86571	x	x	285.8189	2.897366	144.7026	4.404862	8.265102
389	Methane, monochloro-, R-40	Air	ng	2.777323	0.301714	x	x	1.966201	0.039714	0.402981	0.04154	0.025174
390	Methane, tetrachloro-, CFC-10	Air	µg	2.054789	0.011505	1.934278	x	0.066325	0.000603	0.037575	0.002005	0.002498
391	Methane, tetrafluoro-,	Air	µg	14.01524	2.690932	0.159805	x	9.818401	0.217808	0.623476	0.471931	0.032891

	CFC-14											
392	Methane, trichlorofluoro-, CFC-11	Air	ng	16.47311	0.00289	16.45593	x	0.013404	3.12E-05	0.000324	0.000506	2.08E-05
393	Methane, trifluoro-, HFC-23	Air	ng	3.366439	0.566339	x	x	2.627154	0.006115	0.063483	0.099267	0.00408
394	Methanol	Air	mg	1.675728	0.00532	0.002587	x	0.105757	0.000558	1.55891	0.000948	0.001648
395	Methyl acrylate	Air	ng	37.48976	6.455429	x	x	29.33854	0.048919	0.481147	1.134087	0.031641
396	Methyl amine	Air	pg	71.33457	12.26202	x	x	55.80569	0.096076	0.954441	2.15376	0.062587
397	Methyl borate	Air	pg	0.012656	0.002179	x	x	0.009904	1.65E-05	0.000162	0.000383	1.07E-05
398	Methyl ethyl ketone	Air	µg	59.30933	10.20494	x	x	46.40716	0.078469	0.775201	1.792646	0.050915
399	Methyl formate	Air	pg	145.3964	25.03763	x	x	113.7849	0.1895	1.863159	4.398633	0.122539
400	Molybdenum	Air	µg	50.1957	0.1167	0.117702	x	3.808415	0.01375	46.02244	0.01765	0.099051
401	Monoethanolamine	Air	µg	266.494	0.339844	x	x	266.0229	0.006499	0.062614	0.057709	0.004486
402	Neptunium-237	Air	nBq	0.020933	x	0.020933	x	x	x	x	x	x
403	Nickel	Air	µg	954.4424	6.503058	2.804655	54	75.25834	0.885567	810.3669	1.034791	3.589133
404	Niobium-95	Air	nBq	5.416173	0.582069	3.853939	x	0.723832	0.050522	0.126336	0.071756	0.007719
405	Nitrate	Air	ng	165.8456	9.218067	x	x	64.25476	72.63195	16.9125	1.662713	1.165562

406	Nitrogen	Air	µg	37.19847	x	37.19847	x	x	x	x	x	x
407	Nitrogen oxides	Air	g	2.903719	0.153523	0.005607	1.2	0.35516	0.006968	0.90687	0.011669	0.263922
408	NMVOC, non-methane volatile organic compounds, unspecified origin	Air	g	2.370138	0.019514	0.001825	2.178	0.062556	0.001107	0.081279	0.003387	0.022471
409	Noble gases, radioactive, unspecified	Air	Bq	8274.696	670.8067	0.002781	x	5685.559	140.5133	1589.738	90.44798	97.62792
410	Ozone	Air	µg	321.9979	21.28551	x	x	232.9717	4.815644	56.52565	2.928758	3.470665
411	PAH, polycyclic aromatic hydrocarbons	Air	µg	27.2861	1.907397	0.098329	1.02	18.61365	0.412983	4.679203	0.367677	0.186858
412	Paraffins	Air	pg	89.25134	4.189701	x	x	76.38556	0.548583	6.784163	0.796743	0.546595
413	Particulates	Air	mg	228	x	x	228	x	x	x	x	x
414	Particulates, < 10 um (mobile)	Air	µg	76.11927	x	76.11927	x	x	x	x	x	x
415	Particulates, < 10 um (stationary)	Air	µg	645.0256	x	645.0256	x	x	x	x	x	x
416	Particulates, < 2.5 um	Air	mg	98.06864	6.424469	x	x	30.63641	1.520627	26.53947	0.628011	32.31964

417	Particulates, > 10 um	Air	mg	148.1657	6.240462	x	x	34.12448	7.553512	98.56984	1.017426	0.659963
418	Particulates, > 10 um (process)	Air	mg	1.206136	x	1.206136	x	x	x	x	x	x
419	Particulates, > 2.5 um, and < 10um	Air	mg	42.73225	4.445761	x	x	14.26986	3.563573	19.50081	0.67534	0.276908
420	Pentane	Air	mg	8.561368	0.489203	0.028496	x	2.121778	0.019813	5.4764	0.075424	0.350254
421	Phenol	Air	µg	28.62717	0.374572	0.003704	x	27.76635	0.036132	0.346927	0.071824	0.027663
422	Phenol, pentachloro-	Air	ng	218.0394	10.11803	0.001165	x	155.1436	3.330236	45.20367	1.465523	2.777191
423	Phosphine	Air	pg	28.56148	4.918053	x	x	22.35149	0.037269	0.36656	0.864002	0.024106
424	Phosphorus	Air	µg	25.41787	0.148888	x	x	24.50354	0.066936	0.634407	0.023538	0.040568
425	Phosphorus, total	Air	ng	596.7025	x	596.7025	x	x	x	x	x	x
426	Platinum	Air	pg	318.3005	0.793514	307.9701	x	6.826174	0.188656	2.273856	0.108452	0.13967
427	Plutonium-238	Air	nBq	0.165091	0.009524	0.047628	x	0.080707	0.001995	0.022568	0.001284	0.001386
428	Plutonium-241	Air	µBq	34.88757	x	34.88757	x	x	x	x	x	x
429	Plutonium-alpha	Air	µBq	1.268924	2.18E-05	1.268655	x	0.000185	4.57E-06	5.17E-05	2.94E-06	3.18E-06
430	Polonium-210	Air	mBq	18.82789	0.378089	0.5657	x	15.98782	0.150687	1.590953	0.056091	0.098558
431	Polychlorinate	Air	ng	51.43	8.881	x	x	26.96	1.9876	11.210	1.688	0.694

	d biphenyls			199	531			878	56	49	723	811
432	Potassium	Air	mg	1.393 712	0.008 506	0.007 585	x	1.335 971	0.0031 3	0.0350 66	0.001 27	0.002 186
433	Potassium-40	Air	mB q	2.672 249	0.041 316	0.066 051	x	2.323 888	0.0197 19	0.2023 56	0.006 359	0.012 56
434	Promethium-147	Air	µB q	10.78 343	x	10.78 343	x	x	x	x	x	x
435	Propanal	Air	ng	14.32 528	0.788 481	x	x	9.640 282	0.4322 18	3.0032 51	0.167 514	0.293 538
436	Propane	Air	mg	8.444 104	0.398 399	0.024 4	x	2.984 83	0.0177 84	4.6694 41	0.061 141	0.288 108
437	Propene	Air	µg	571.4 783	21.10 181	1.421 109	x	326.3 614	1.0175 75	205.07 4	3.343 421	13.15 896
438	Propionic acid	Air	µg	23.19 239	0.133 627	0.095 384	x	22.44 175	0.0362 89	0.4422 3	0.019 578	0.023 53
439	Propylene oxide	Air	µg	4.602 977	2.396 105	x	x	1.537 489	0.0114 29	0.2216 67	0.422 23	0.014 057
440	Protactinium-234	Air	µB q	134.6 147	11.15 782	12.69 966	x	83.35	2.1076 29	22.437 66	1.484 035	1.377 9
441	Radioactive species, other beta emitters	Air	mB q	61.67 593	42.49 11	2.69E -06	x	13.63 123	0.1441 78	0.7432 75	4.620 357	0.045 793
442	Radioactive species, unspecified	Air	kBq	9.6	x	x	9.6	x	x	x	x	x
443	Radium-226	Air	mB q	7.109 993	0.414 465	0.458 245	x	5.070 642	0.0895 05	0.9619 51	0.055 96	0.059 225
444	Radium-228	Air	mB q	5.304 133	0.030 634	0.032 454	x	5.089 411	0.0330 8	0.1063	0.005 096	0.007 157
445	Radon-220	Air	mB q	48.11 193	1.803 637	2.878 364	x	33.00 174	0.6445 08	8.9617 96	0.271 416	0.550 468

446	Radon-222	Air	Bq	1895 3.15	1471. 78	2855. 676	x	11002 .15	278.49 97	2967.1 1	195.7 188	182.2 188
447	Ruthenium-103	Air	nBq	0.560 988	0.127 884	0.217 755	x	0.159 031	0.0111	0.0277 57	0.015 765	0.001 696
448	Ruthenium-106	Air	µB q	126.8 639	x	126.8 639	x	x	x	x	x	x
449	Scandium	Air	ng	129.0 307	1.148 302	6.511 723	x	118.6 814	0.7107 31	1.6436 51	0.220 881	0.114 033
450	Selenium	Air	µg	39.66 038	0.342 36	0.411 654	x	7.456 849	0.0530 7	31.167 32	0.053 688	0.175 436
451	Silicon	Air	mg	7.027 561	0.012	0.148 037	x	6.839 665	0.0079 77	0.0164 95	0.002 217	0.001 171
452	Silicon tetrafluoride	Air	ng	53.12 884	0.518 462	x	x	45.77 397	0.0469 14	6.3029 23	0.081 384	0.405 188
453	Silver	Air	ng	3.726 657	0.229 554	x	x	2.548 684	0.0625 32	0.8045 83	0.032 17	0.049 133
454	Silver-110	Air	nBq	24.88 138	1.267 431	21.47 968	x	1.576 116	0.1100 1	0.2750 91	0.156 245	0.016 808
455	Sodium	Air	mg	1.272 734	0.006 231	0.007 783	x	0.334 346	0.0007 79	0.9181 09	0.000 957	0.004 528
456	Sodium chlorate	Air	µg	17.65 632	0.006 888	x	x	17.57 329	0.0006 11	0.0700 5	0.000 982	0.004 499
457	Sodium dichromate	Air	ng	310.7 432	11.08 639	x	x	270.1 312	1.3832 24	25.062 95	1.527 237	1.552 135
458	Sodium formate	Air	µg	12.01 766	0.000 25	x	x	12.01 687	0.0002 2	0.0002 52	4.51E -05	2.22E-05
459	Sodium hydroxide	Air	ng	331.4 515	57.06 578	x	x	259.3 789	0.4335 47	4.2675 4	10.02 515	0.280 581
460	Strontium	Air	µg	30.11 107	0.232 337	0.712 365	x	27.97 023	0.1464 14	0.9506 28	0.038 815	0.060 276
461	Strontium-89	Air	nBq	38.11	x	38.11	x	x	x	x	x	x

				477		477						
462	Strontium-90	Air	µBq	20.93975	x	20.93975	x	x	x	x	x	x
463	Styrene	Air	ng	647.5953	23.54873	x	x	567.4153	4.123911	42.57699	4.706071	5.224312
464	Sulfate	Air	mg	3.32425	0.067926	x	x	3.042319	0.003774	0.188729	0.009418	0.012084
465	Sulfur dioxide	Air	g	2.896549	0.023251	x	x	0.177	0.003053	2.659534	0.003563	0.030148
466	Sulfur hexafluoride	Air	µg	4.408598	0.231091	x	x	3.181014	0.060593	0.851348	0.032369	0.052183
467	Sulfur oxides	Air	g	1.516333	x	0.016333	1.5	x	x	x	x	x
468	Sulfuric acid	Air	ng	69.4137	11.94488	x	x	54.31462	0.091647	0.904799	2.098319	0.059438
469	t-Butyl methyl ether	Air	µg	1.067302	0.030795	0.00534	x	1.022942	0.001367	0.003106	0.003533	0.000219
470	Technetium-99	Air	nBq	0.888047	x	0.888047	x	x	x	x	x	x
471	Tellurium-123m	Air	nBq	95.84049	x	95.84049	x	x	x	x	x	x
472	Terpenes	Air	µg	3.289284	0.008061	x	x	3.236635	0.000231	0.040357	0.001431	0.002569
473	Thallium	Air	ng	161.2495	3.209189	4.893153	x	127.5752	19.19507	5.293934	0.766592	0.316377
474	Thorium	Air	ng	292.0963	1.311111	12.55333	x	274.8987	0.984679	1.958864	0.249989	0.139577
475	Thorium-228	Air	µBq	933.444	8.93677	27.469	x	845.056	5.188651	42.71978	1.396554	2.677239
476	Thorium-230	Air	µBq	728.2919	42.14052	141.2588	x	431.1588	7.869129	94.40643	5.627792	5.830411

477	Thorium-232	Air	µBq	753.9626	12.69289	17.43336	x	647.2468	5.948117	64.67858	1.955703	4.007154
478	Thorium-234	Air	µBq	134.6404	11.15999	12.69966	x	83.36828	2.108033	22.44193	1.484323	1.378162
479	Tin	Air	µg	3.187918	0.189983	0.013684	x	2.513233	0.164384	0.243494	0.034395	0.028745
480	Titanium	Air	µg	45.55228	0.60978	1.894796	x	42.34979	0.192178	0.368779	0.110491	0.026467
481	Toluene	Air	mg	1.262079	0.061067	0.004922	x	0.505742	0.00322	0.637218	0.009262	0.040648
482	Uranium	Air	ng	429.6228	1.068107	13.96245	x	411.3237	1.17003	1.766472	0.198633	0.133401
483	Uranium-234	Air	mBq	1.705395	0.130489	0.152192	x	1.091596	0.024585	0.272397	0.017376	0.01676
484	Uranium-235	Air	µBq	76.09514	6.282986	7.3766	x	46.97237	1.18904	12.66118	0.835496	0.777467
485	Uranium-238	Air	mBq	3.743074	0.16123	0.199958	x	2.861904	0.039731	0.431476	0.022148	0.026628
486	Uranium alpha	Air	mBq	7.072108	0.605294	0.454878	x	4.52224	0.11455	1.219756	0.08049	0.0749
487	Vanadium	Air	mg	2.906833	0.007053	0.009659	x	0.195391	0.000942	2.687616	0.001086	0.005086
488	water	Air	mg	3.308186	0.315951	x	x	2.180766	0.138878	0.575771	0.057117	0.039703
489	Xenon-131m	Air	mBq	48.26057	11.14969	4.796877	x	23.78933	1.151239	5.637056	1.390823	0.345559
490	Xenon-133	Air	Bq	2.875569	0.402385	1.413119	x	0.780748	0.040109	0.17822	0.050066	0.010921
491	Xenon-133m	Air	mBq	4.974575	0.525785	0.710759	x	2.744886	0.084295	0.791965	0.068256	0.048628
492	Xenon-135	Air	mB	834.4	161.3	240.9	x	318.2	16.178	73.156	20.08	4.483

			q	552	389	309		84	91	37	288	314
493	Xenon-135m	Air	mBq	383.6786	101.07	23.7731	x	190.6609	9.973864	42.99958	12.56647	2.634711
494	Xenon-137	Air	mBq	9.415603	3.072823	0.589733	x	4.245351	0.274555	0.804435	0.379506	0.0492
495	Xenon-138	Air	mBq	77.7445	23.17484	6.44148	x	35.492	2.134885	7.193134	2.867901	0.440268
496	Xylene	Air	mg	1.040691	0.059915	0.016449	x	0.47864	0.004345	0.445943	0.007002	0.028396
497	Zinc	Air	µg	378.224	34.1644	3.912608	22.2	142.4796	4.308236	160.5354	4.788085	5.835632
498	Zinc-65	Air	nBq	159.2349	24.48354	93.52264	x	30.44654	2.125112	5.314059	3.01826	0.324696
499	Zirconium	Air	ng	67.99507	10.14963	0.699518	x	39.63655	2.113157	12.60113	2.009952	0.785132
500	Zirconium-95	Air	nBq	65.62689	23.93174	1.395699	x	29.76034	2.077216	5.194291	2.950234	0.317378
501	1,4-Butanediol	Water	pg	273.544	47.0207	x	x	213.996	0.368418	3.659959	8.258944	0.24
502	4-Methyl-2-pentanone	Water	pg	31.4324	5.869257	x	x	23.45294	0.103293	1.055432	0.84416	0.107319
503	Acenaphthene	Water	ng	37.41093	2.229768	x	x	2.838166	0.073245	30.01315	0.33949	1.917105
504	Acenaphthylene	Water	ng	231.7972	0.13945	229.4575	x	0.177499	0.004581	1.877028	0.021232	0.119896
505	Acetaldehyde	Water	ng	392.9015	67.60668	x	x	307.4322	0.519418	5.13014	11.87616	0.336967
506	Acetic acid	Water	µg	3.870821	0.478349	x	x	2.125366	0.018781	1.060591	0.087784	0.099951
507	Acetone	Water	pg	74.91782	13.98913	x	x	55.89911	0.246195	2.51558	2.012019	0.255791

508	Acidity, unspecified	Water	µg	105.5795	0.297578	x	x	104.3116	0.010356	0.851762	0.052734	0.055489
509	Acids, unspecified	Water	ng	242.3132	x	242.3132	x	x	x	x	x	x
510	Acrylate, ion	Water	ng	78.20341	13.46599	x	x	61.20001	0.102044	1.003669	2.365699	0.066004
511	Actinides, radioactive, unspecified	Water	mBq	1.398601	0.113396	x	x	0.960956	0.023751	0.268707	0.015289	0.016502
512	Aluminum	Water	mg	98.01286	2.30784	1.046421	8.4	64.63161	0.67631	20.01751	0.38044	0.552727
513	Americium-241	Water	µBq	52.64852	x	52.64852	x	x	x	x	x	x
514	Ammonia, as N	Water	µg	20.2956	x	20.2956	x	x	x	x	x	x
515	Ammonium, ion	Water	mg	8.987569	0.055349	x	2.1	6.578766	0.004731	0.216272	0.007722	0.024073
516	Antimony	Water	µg	193.0348	2.014208	0.01605	x	187.2251	0.240423	2.99698	0.349895	0.192143
517	Antimony-122	Water	µBq	1.245497	0.366057	0.263025	x	0.45521	0.031773	0.079451	0.045126	0.004855
518	Antimony-124	Water	µBq	294.8704	30.38828	37.72273	x	171.8443	4.7427	43.54997	3.948941	2.673465
519	Antimony-125	Water	µBq	255.3137	28.12899	2.144777	x	174.9782	4.34956	39.62063	3.659544	2.432021
520	AOX, Adsorbable Organic Halogen as Cl	Water	µg	230.1664	0.686891	0.037191	3.72	207.8938	0.025051	17.45486	0.097735	0.250906
521	Arsenic, ion	Water	µg	88.5255	3.370437	2.066094	17.4	45.21555	0.897819	18.27504	0.593404	0.707156

522	Barite	Water	mg	26.6871	0.95556	0.213738	x	6.689629	0.038687	17.53022	0.140575	1.118693
523	Barium	Water	mg	9.749346	0.337693	0.106498	3.06	1.569643	0.018349	4.329466	0.051429	0.276269
524	Barium-140	Water	µBq	4.566775	1.603523	0.263025	x	1.994063	0.139182	0.348039	0.197678	0.021266
525	Benzene	Water	µg	436.4128	27.9903	1.336812	x	41.59819	0.937006	338.187	4.402669	21.96082
526	Benzene, 1,2-dichloro-	Water	ng	91.96536	15.80834	x	x	71.94534	0.123862	1.230476	2.776653	0.080688
527	Benzene, chloro-	Water	µg	1.899011	0.326429	3.18E-07	x	1.485614	0.002558	0.025408	0.057336	0.001666
528	Benzene, ethyl-	Water	µg	144.6062	8.604551	0.240727	x	10.95271	0.282647	115.8177	1.310073	7.397855
529	Beryllium	Water	µg	6.926943	0.170307	0.001852	x	5.670405	0.06808	0.93255	0.026413	0.057337
530	BOD5, Biological Oxygen Demand	Water	g	1.50409	0.05981	2.49E-06	0.06	0.251626	0.002342	1.054371	0.008917	0.067021
531	Boron	Water	µg	742.1255	27.65621	1.857415	x	522.439	8.935181	166.7318	4.149148	10.35666
532	Bromate	Water	µg	78.46432	1.921244	x	x	72.22843	0.074891	3.699492	0.302634	0.237626
533	Bromine	Water	mg	4.586238	0.25687	x	x	0.67705	0.009201	3.387141	0.039304	0.216671
534	Butanol	Water	ng	215.2181	37.03107	x	x	168.3995	0.284741	2.812999	6.505047	0.184756
535	Butene	Water	ng	89.49898	8.911718	x	x	75.59444	0.167611	3.155667	1.559487	0.11006
536	Butyl acetate	Water	ng	279.7	48.13	x	x	218.9	0.3701	3.6568	8.456	0.240

				804	986			169	6	59	468	18
537	Butyrolactone	Water	pg	474.9578	81.64261	x	x	371.5638	0.639688	6.354833	14.34011	0.416716
538	Cadmium-109	Water	nBq	1.520612	x	1.520612	x	x	x	x	x	x
539	Cadmium, ion	Water	µg	21.90537	0.484088	0.621288	1.5	15.59809	0.106159	3.390228	0.089293	0.116219
540	Calcium, ion	Water	mg	697.727	18.36909	88.78232	x	323.0586	2.57791	250.9341	2.891494	11.11348
541	Carbon-14	Water	mBq	2.664142	x	2.664142	x	x	x	x	x	x
542	Carbonate	Water	µg	49.03517	6.464319	x	x	34.93714	0.463403	5.663841	1.087412	0.41905
543	Carboxylic acids, unspecified	Water	mg	26.00967	1.487037	x	x	1.990726	0.048901	20.92113	0.225538	1.336339
544	Cerium-141	Water	µBq	1.760026	0.641115	0.039317	x	0.797259	0.055647	0.139151	0.079035	0.008502
545	Cerium-144	Water	mBq	1.205742	0.000195	1.205218	x	0.000243	1.69E-05	4.24E-05	2.41E-05	2.59E-06
546	Cesium	Water	µg	6.024803	0.358484	0.010185	x	0.456297	0.011776	4.825266	0.05458	0.308216
547	Cesium-134	Water	mBq	2.911437	0.014386	2.694478	x	0.158509	0.003159	0.036687	0.001966	0.002253
548	Cesium-136	Water	nBq	306.8034	113.7854	1.411018	x	141.4979	9.876289	24.69667	14.02712	1.508998
549	Cesium-137	Water	mBq	186.0344	13.20706	24.8067	x	110.69	2.744257	30.90949	1.778702	1.898179
550	Chlorate	Water	µg	994.6081	15.10313	x	x	942.6033	0.610025	31.86626	2.374959	2.050469
551	Chloride	Water	g	6.501	0.284	2.023	0.042	0.959	0.0115	2.9494	0.046	0.183

				648	337	882	6	592	92	84	367	794
552	Chlorinated solvents, unspecified	Water	ng	221.1596	10.17653	1.336367	x	188.4504	0.635341	17.45063	1.75769	1.352611
553	Chlorine	Water	µg	16.14636	0.530024	x	x	14.39279	0.22023	0.875073	0.07448	0.053764
554	Chloroform	Water	ng	19.46907	0.752401	15.09927	x	3.419671	0.005707	0.056146	0.132181	0.003692
555	Chromium	Water	µg	96	x	x	96	x	x	x	x	x
556	Chromium-51	Water	µBq	443.7637	122.3256	5.782536	x	240.9819	11.6703	45.05387	15.19066	2.758892
557	Chromium VI	Water	µg	634.7111	88.49793	0.002168	x	361.572	22.30628	136.9584	16.85942	8.51491
558	Chromium, ion	Water	µg	66.74845	1.539951	11.05277	x	29.48127	0.142176	23.40513	0.260143	0.867014
559	Cobalt	Water	µg	366.5511	9.359172	2.025732	x	302.4746	21.45438	27.30686	1.825721	2.104573
560	Cobalt-57	Water	µBq	9.96418	3.611976	0.269874	x	4.491678	0.313511	0.783966	0.445274	0.047901
561	Cobalt-58	Water	mBq	2.87074	0.561475	0.228385	x	1.586178	0.061269	0.341999	0.070464	0.02097
562	Cobalt-60	Water	mBq	13.81131	0.491667	11.65423	x	1.268821	0.051796	0.266906	0.061523	0.016362
563	COD, Chemical Oxygen Demand	Water	g	2.125515	0.063539	2.77E-05	0.198	0.712172	0.003152	1.070928	0.009567	0.068129
564	Copper, ion	Water	mg	7.408086	0.018133	0.012008	0.043 2	7.181138	0.005846	0.141952	0.003371	0.002439
565	Cumene	Water	µg	29.43798	4.3329	x	x	11.26086	0.180146	11.75218	0.810951	1.100943

566	Curium alpha	Water	µBq	69.77514	x	69.77514	x	x	x	x	x	x
567	Cyanide	Water	µg	55.52137	4.240897	0.11791	4.02	32.3684	1.152701	11.99093	0.744976	0.885552
568	Dichromate	Water	ng	431.9731	40.44821	x	x	282.1316	5.098112	92.98505	5.552003	5.758156
569	DOC, Dissolved Organic Carbon	Water	g	1.230556	0.020005	2.00E-06	0.78	0.082245	0.001029	0.323681	0.003027	0.020568
570	Ethane, 1,1,1-trichloro-, HCFC-140	Water	pg	125.4555	x	125.4555	x	x	x	x	x	x
571	Ethane, 1,2-dichloro-	Water	ng	439.6148	8.275634	x	x	379.0467	1.121589	46.97418	1.180043	3.016674
572	Ethane, dichloro-	Water	ng	24.70892	x	24.70892	x	x	x	x	x	x
573	Ethane, hexachloro-	Water	pg	0.548947	x	0.548947	x	x	x	x	x	x
574	Ethanol	Water	ng	495.2055	85.20655	x	x	387.4783	0.655173	6.472541	14.96777	0.425112
575	Ethene	Water	µg	12.82508	1.57576	x	x	5.557387	0.068439	4.866266	0.294827	0.462404
576	Ethene, chloro-	Water	ng	10.83459	0.577382	0.0185	x	9.129878	0.068235	0.886103	0.091046	0.063447
577	Ethene, tetrachloro-	Water	pg	65.18745	x	65.18745	x	x	x	x	x	x
578	Ethene, trichloro-	Water	ng	4.117102	x	4.117102	x	x	x	x	x	x
579	Ethyl acetate	Water	pg	33.77888	5.814089	x	x	26.43239	0.044409	0.437844	1.02137	0.028774

580	Ethylene diamine	Water	pg	506.0559	333.7845	x	x	106.592	19.65158	8.972293	36.46307	0.592483
581	Ethylene oxide	Water	ng	426.2135	6.434551	x	x	418.0269	0.054528	0.534397	1.127488	0.035684
582	Fatty acids as C	Water	µg	51.13	x	51.13	x	x	x	x	x	x
583	Fluoride	Water	mg	7.543838	1.014142	0.005432	x	5.141013	0.017098	1.152228	0.177589	0.036335
584	Fluosilicic acid	Water	µg	3.238433	0.628988	x	x	2.294863	0.050908	0.145678	0.110311	0.007685
585	Formaldehyde	Water	µg	2.104422	0.279969	0.000211	x	1.075347	0.010454	0.62856	0.051059	0.058822
586	Glutaraldehyde	Water	µg	3.294703	0.11797	0.026387	x	0.82588	0.004776	2.164224	0.017355	0.13811
587	Heat, waste	Water	kJ	880.8742	6.063174	0.586217	x	60.17571	0.725298	808.3042	0.920518	4.09904
588	Hydrocarbons, aliphatic, alkanes, unspecified	Water	µg	783.2243	46.60286	1.323914	x	59.31858	1.530842	627.2845	7.095452	40.06812
589	Hydrocarbons, aliphatic, alkenes, unspecified	Water	ng	122.1772	x	122.1772	x	x	x	x	x	x
590	Hydrocarbons, aliphatic, unsaturated	Water	µg	72.17542	4.301802	x	x	5.475561	0.141308	57.90319	0.654965	3.698595
591	Hydrocarbons, aromatic	Water	mg	4.06243	0.190895	0.006176	0.84	0.251019	0.006282	2.574551	0.029058	0.16445
592	Hydrocarbons, chlorinated	Water	µg	1.2	x	x	1.2	x	x	x	x	x

593	Hydrocarbons, unspecified	Water	µg	661.4386	21.1202	0.34422	x	158.5273	1.151849	455.5599	3.229111	21.50607
594	Hydrogen-3, Tritium	Water	Bq	448.461	29.99986	78.92223	x	254.0778	6.267227	70.80205	4.043717	4.348032
595	Hydrogen peroxide	Water	µg	49.5185	0.134629	x	x	49.34077	0.003445	0.015544	0.023101	0.001011
596	Hydrogen sulfide	Water	mg	1.378381	0.002397	4.24E-05	x	0.479244	0.000375	0.894578	0.000383	0.001362
597	Hydroxide	Water	µg	2.47541	0.423827	x	x	1.935033	0.003571	0.036208	0.074409	0.002361
598	Hypochlorite	Water	mg	2.034592	0.000709	0.00883	x	0.011823	0.000269	2.01262	0.000108	0.000234
599	Hypochlorous acid	Water	µg	8.432761	x	8.432761	x	x	x	x	x	x
600	Iodide	Water	µg	604.3528	35.92137	1.001793	x	47.0011	1.208336	482.9058	5.469373	30.84504
601	Iodine-129	Water	mBq	7.611834	x	7.611834	x	x	x	x	x	x
602	Iodine-131	Water	µBq	55.28988	6.934839	5.043479	x	33.097	0.964785	7.87609	0.890303	0.483386
603	Iodine-133	Water	µBq	3.905451	1.006656	1.203653	x	1.251829	0.087375	0.218491	0.124098	0.013 35
604	Iron	Water	mg	13.45189	x	2.05189	11.4	x	x	x	x	x
605	Iron-59	Water	nBq	747.4399	276.7513	4.657731	x	344.1544	24.02133	60.06781	34.11709	3.670219
606	Iron, ion	Water	mg	151.1712	1.793179	x	x	137.0202	0.781969	10.75826	0.281637	0.535 95
607	Kjeldahl-N	Water	µg	336	x	x	336	x	x	x	x	x
608	Lanthanum-140	Water	µBq	4.638372	1.707885	0.054523	x	2.123842	0.14824	0.37069	0.210543	0.022 65

609	Lead	Water	µg	540.1412	7.033791	9.793605	51.6	385.6165	0.89201	81.72928	1.241665	2.234339
610	Lead-210	Water	mBq	38.0655	0.291235	0.152343	x	34.5892	0.046045	2.765003	0.045034	0.17664
611	Lithium, ion	Water	µg	8.058983	1.504825	x	x	6.013121	0.026483	0.270603	0.216435	0.027516
612	m-Xylene	Water	pg	227.1168	42.40869	x	x	169.4607	0.74635	7.626094	6.099529	0.775441
613	Magnesium	Water	mg	80.3696	2.739177	0.864585	x	43.82977	0.338345	30.3204	0.422576	1.854749
614	Manganese	Water	mg	13.14317	0.048815	0.024806	x	12.65792	0.009607	0.374931	0.007972	0.01912
615	Manganese-54	Water	mBq	1.950454	0.033864	1.786744	x	0.09955	0.003718	0.021035	0.004253	0.00129
616	Mercury	Water	µg	2.578826	0.133434	0.167525	0.096	1.085244	0.033641	1.011052	0.026357	0.025573
617	Metallic ions, unspecified	Water	mg	7.2	x	x	7.2	x	x	x	x	x
618	Methane, dichloro-, HCC-30	Water	µg	73.65055	3.608386	0.097927	x	8.870957	0.125291	56.78101	0.540852	3.626123
619	Methane, tetrachloro-, CFC-10	Water	pg	99.49664	x	99.49664	x	x	x	x	x	x
620	Methanol	Water	µg	26.35513	0.472896	x	x	24.97813	0.048034	0.729605	0.079277	0.047189
621	Methyl acrylate	Water	ng	732.3735	126.1087	x	x	573.137	0.95564	9.399336	22.15473	0.618124
622	Methyl amine	Water	pg	171.1999	29.42832	x	x	133.9313	0.230578	2.290618	5.168933	0.150206
623	Methyl	Water	pg	58.04	9.996	x	x	45.42	0.0756	0.7438	1.756	0.048

	formate			841	083			777	56	52	121	923
624	Molybdenum	Water	µg	43.87 554	1.529 781	3.763 213	x	30.24 197	0.5019 25	7.1707 53	0.224 938	0.442 962
625	Molybdenum-99	Water	µBq	1.598 795	0.588 842	0.018 383	x	0.732 255	0.0511 1	0.1278 06	0.072 591	0.007 809
626	Neptunium-237	Water	µBq	3.361 893	x	3.361 893	x	x	x	x	x	x
627	Nickel, ion	Water	mg	2.582 428	0.065 507	0.005 175	0.044 4	1.336 687	0.0853 26	1.0210 17	0.012 951	0.011 364
628	Niobium-95	Water	µBq	26.17 373	2.591 128	0.149 321	x	19.22 458	0.3799 13	3.2899 44	0.336 959	0.201 882
629	Nitrate	Water	mg	435.4 425	0.270 971	0.031 572	0.84	433.6 017	0.0208 85	0.6014 32	0.037 261	0.038 719
630	Nitrite	Water	µg	112.3 957	1.357 568	2.042 189	x	107.2 65	0.0858 81	1.3859 39	0.165 403	0.093 706
631	Nitrogen	Water	mg	35.48 357	0.022 727	x	x	11.71 346	0.0045 08	23.722 36	0.003 358	0.017 151
632	Nitrogen, organic bound	Water	mg	1.181 263	0.033 742	0.001 541	x	0.141 218	0.0076 98	0.9690 32	0.005 298	0.022 733
633	Nitrogen, total	Water	µg	73.58 09	x	13.58 09	60	x	x	x	x	x
634	o-Xylene	Water	pg	165.4 337	30.89 083	x	x	123.4 365	0.5436 47	5.5549 08	4.442 945	0.564 837
635	Oils, unspecified	Water	mg	400.9 784	18.30 019	0.187 919	1.2	27.42 59	0.6097 86	329.51 94	2.710 531	21.02 462
636	PAH, polycyclic aromatic hydrocarbons	Water	µg	47.83 646	2.011 123	0.139 576	12.6	2.732 575	0.1174 71	28.125 13	0.306 107	1.804 478
637	Paraffins	Water	pg	259.0 161	12.15 892	x	x	221.6 784	1.5920 43	19.688 31	2.312 227	1.586 271

638	Phenol	Water	µg	581.4855	33.27591	x	x	43.91151	1.102195	468.6031	5.061371	29.53144
639	Phenols, unspecified	Water	µg	133.4086	x	1.408619	132	x	x	x	x	x
640	Phosphate	Water	mg	15.94986	0.326769	0.061077	0.402	14.06838	0.099576	0.871187	0.065885	0.054981
641	Phosphorus	Water	mg	1.995532	0.002918	x	x	1.912875	0.000198	0.077491	0.000482	0.001568
642	Phosphorus compounds, unspecified	Water	ng	7.892263	x	7.892263	x	x	x	x	x	x
643	Phthalate, dimethyl tere-	Water	pg	146.2792	x	146.2792	x	x	x	x	x	x
644	Phthalate, dioctyl-	Water	pg	3.137823	x	3.137823	x	x	x	x	x	x
645	Phthalate, p-dibutyl-	Water	pg	23.23257	x	23.23257	x	x	x	x	x	x
646	Plutonium-241	Water	mBq	5.20142	x	5.20142	x	x	x	x	x	x
647	Plutonium-alpha	Water	µBq	209.3254	x	209.3254	x	x	x	x	x	x
648	Polonium-210	Water	mBq	56.94082	0.400045	0.152343	x	51.99708	0.055468	4.016695	0.062089	0.2571
649	Potassium	Water	µg	354.7666	x	354.7666	x	x	x	x	x	x
650	Potassium-40	Water	mBq	7.073588	0.129569	0.191239	x	5.876045	0.037456	0.771516	0.019555	0.048208
651	Potassium, ion	Water	mg	71.21108	1.88012	x	x	43.68997	0.150999	23.7678	0.289891	1.432298
652	Propene	Water	µg	20.26542	6.093007	x	x	7.742084	0.088432	4.814647	1.090992	0.436258

653	Propylene oxide	Water	µg	11.07484	5.765444	x	x	3.698743	0.027499	0.53337	1.015959	0.033824
654	Protactinium-234	Water	mBq	2.480883	0.205326	0.235179	x	1.535045	0.038858	0.413764	0.027304	0.025407
655	Radioactive species, unspecified	Water	Bq	90	x	x	90	x	x	x	x	x
656	Radioactive species, alpha emitters	Water	µBq	73.89871	0.632569	0.017367	x	65.52342	0.056156	7.113646	0.098283	0.457262
657	Radioactive species, from fission and activation	Water	µBq	157.7361	x	157.7361	x	x	x	x	x	x
658	Radioactive species, Nuclides, unspecified	Water	mBq	838.9634	68.38522	0.000114	x	576.083	14.24408	161.1446	9.210395	9.896105
659	Radium-224	Water	mBq	301.2318	17.92418	0.500892	x	22.81484	0.588785	241.2633	2.72902	15.41081
660	Radium-226	Water	Bq	2.889822	0.156679	0.970155	x	1.029498	0.025149	0.6463	0.021394	0.040648
661	Radium-228	Water	mBq	602.4776	35.85096	1.001784	x	45.6401	1.177617	482.527	5.458415	30.82168
662	Rubidium	Water	µg	60.23298	3.592771	x	x	4.622297	0.119259	48.26865	0.546859	3.083145
663	Ruthenium	Water	ng	101.6124	x	101.6124	x	x	x	x	x	x
664	Ruthenium-103	Water	nBq	421.6558	124.251	88.17441	x	154.5124	10.78468	26.96819	15.31729	1.647791
665	Ruthenium-106	Water	mBq	12.68639	x	12.68639	x	x	x	x	x	x

666	Salts, unspecified	Water	mg	2.693 275	x	2.693 275	x	x	x	x	x	x
667	Scandium	Water	µg	9.406 769	0.353 894	x	x	6.667 342	0.1651 8	2.0395 12	0.054 972	0.125 869
668	Selenium	Water	µg	26.30 11	0.532 741	5.235 616	x	17.53 855	0.1444 87	2.6046 62	0.083 114	0.161 932
669	Silicon	Water	mg	545.5 507	33.50 648	0.000 457	x	413.9 6	22.194 65	65.511 37	5.948 479	4.429 294
670	Silver	Water	ng	7.038 425	x	7.038 425	x	x	x	x	x	x
671	Silver-110	Water	mB q	2.125 562	0.478 854	0.146 398	x	1.126 619	0.0498 15	0.2487 96	0.059 83	0.015 251
672	Silver, ion	Water	µg	4.987 357	0.337 908	x	x	0.481 516	0.0113 17	3.8581 52	0.051 989	0.246 474
673	Sodium-24	Water	µB q	20.05 855	4.455 335	8.100 726	x	5.540 438	0.3867 12	0.9670 13	0.549 241	0.059 086
674	Sodium formate	Water	µg	28.87 169	0.000 6	x	x	28.86 979	0.0005 28	0.0006 04	0.000 108	5.33E-05
675	Sodium, ion	Water	g	2.678 966	0.155 629	0.604 937	x	0.318 715	0.0040 33	1.4794 52	0.021 888	0.094 312
676	Solids, inorganic	Water	mg	64.31 591	1.800 852	x	x	52.35 249	0.6116 04	8.7349 36	0.277 425	0.538 603
677	Solved solids	Water	mg	5.146 52	0.272 248	x	x	3.883 279	0.3365 68	0.5505 33	0.050 082	0.053 808
678	Solved substances	Water	µg	431.0 917	x	431.0 917	x	x	x	x	x	x
679	Solved substances, inorganic	Water	mg	136.8	x	x	136.8	x	x	x	x	x
680	Strontium	Water	mg	11.93 957	0.672 602	0.072 798	x	1.638 387	0.0300 15	8.8577 72	0.102 51	0.565 482

681	Strontium-89	Water	µBq	43.40433	10.31646	0.594861	x	25.51222	1.018621	4.406535	1.285699	0.269931
682	Strontium-90	Water	Bq	1.075662	0.056017	0.002537	x	0.746304	0.017356	0.231225	0.008018	0.014205
683	Sulfate	Water	g	1.39464	0.011216	0.199947	0.108	0.40427	0.003504	0.662433	0.001753	0.003517
684	Sulfide	Water	µg	192.8583	0.487454	0.32849	30	2.030913	0.037148	159.5439	0.073797	0.356664
685	Sulfite	Water	mg	5.222703	0.001962	x	x	0.032887	0.000734	5.186187	0.000298	0.000635
686	Sulfur	Water	mg	2.196549	0.048722	x	x	1.199738	0.001611	0.882883	0.0072	0.056394
687	Sulfur trioxide	Water	µg	1.04641	x	1.04641	x	x	x	x	x	x
688	Suspended solids, unspecified	Water	mg	214.4517	4.047996	x	x	133.4533	0.21196	71.82481	0.60896	4.304624
689	Suspended substances, unspecified	Water	mg	36.6	x	x	36.6	x	x	x	x	x
690	t-Butyl methyl ether	Water	µg	12.69755	0.557142	0.000439	x	0.8643	0.018202	10.50439	0.081916	0.671156
691	Technetium-99	Water	mBq	1.332071	x	1.332071	x	x	x	x	x	x
692	Technetium-99m	Water	µBq	36.55549	13.53499	0.123957	x	16.90807	1.17622	2.962552	1.66868	0.181024
693	Tellurium-123m	Water	µBq	27.24241	2.120796	0.011096	x	19.36263	0.427971	4.743177	0.285488	0.291 25
694	Tellurium-132	Water	nBq	96.05716	34.09511	4.548137	x	42.39902	2.959372	7.400213	4.203145	0.452162
695	Thallium	Water	µg	13.56	0.031	x	x	2.630	0.0121	10.869	0.005	0.011

				028	687			484	01	57	217	216
696	Thorium-228	Water	Bq	1.205 367	0.071 699	0.002 004	x	0.091 665	0.0023 55	0.9650 82	0.010 916	0.061 645
697	Thorium-230	Water	mB q	343.1 714	28.01 478	36.76 704	x	209.4 419	5.3017 29	56.454 08	3.725 336	3.466 592
698	Thorium-232	Water	µB q	510.1 562	19.47 85	35.65 466	x	349.7 695	6.5793 3	90.220 43	2.912 709	5.541 042
699	Thorium-234	Water	mB q	2.483 132	0.205 35	0.237 154	x	1.535 24	0.0388 62	0.4138 1	0.027 307	0.025 41
700	Tin, ion	Water	µg	346.3 472	0.916 089	0.010 049	x	341.1 46	0.1978 71	3.7355 36	0.152 292	0.189 407
701	Titanium, ion	Water	mg	4.880 746	0.382 588	0.061 003	x	3.997 968	0.0340 65	0.3202 06	0.065 53	0.019 384
702	TOC, Total Organic Carbon	Water	mg	540.0 379	20.07 89	0.479 358	24	143.9 083	1.0318 9	326.90 05	3.037 496	20.60 15
703	Toluene	Water	µg	858.7 417	44.84 545	1.108 99	114	57.04 845	1.4682 68	594.34 58	6.818 209	39.10 654
704	Tributyltin	Water	ng	27.89 368	x	27.89 368	x	x	x	x	x	x
705	Tributyltin compounds	Water	µg	6.312 325	0.367 864	x	x	0.890 206	0.0228 24	4.6758 06	0.057 69	0.297 935
706	Triethylene glycol	Water	µg	22.26 112	0.131 477	2.003 933	x	19.61 111	0.0361 05	0.4352 75	0.019 591	0.023 627
707	Tungsten	Water	µg	7.497 362	0.277 846	0.050 02	x	5.436 057	0.1117 32	1.4879 25	0.042 218	0.091 564
708	Undissolved substances	Water	µg	796.0 402	x	796.0 402	x	x	x	x	x	x
709	Uranium-234	Water	mB q	3.009 146	0.246 392	0.314 301	x	1.842 054	0.0466 29	0.4965 17	0.032 765	0.030 489
710	Uranium-235	Water	mB	4.914	0.406	0.468	x	3.039	0.0769	0.8192	0.054	0.050

			q	79	546	296		389	38	53	062	307
711	Uranium-238	Water	mBq	26.98063	0.767327	0.795992	x	22.34596	0.140304	2.65901	0.105238	0.166793
712	Uranium alpha	Water	mBq	144.746	11.82934	15.36923	x	88.4339	2.238677	23.83799	1.573035	1.463784
713	Vanadium, ion	Water	mg	1.049836	0.031226	0.005491	x	0.368278	0.006615	0.629534	0.005621	0.003069
714	VOC, volatile organic compounds as C	Water	µg	3.506245	x	3.506245	x	x	x	x	x	x
715	VOC, volatile organic compounds, unspecified origin	Water	mg	2.110707	0.125966	x	x	0.163536	0.004217	1.689879	0.019169	0.107939
716	Xylene	Water	µg	616.4098	36.0023	0.962757	x	46.32151	1.182502	494.8769	5.471785	31.59201
717	Yttrium-90	Water	nBq	30.37616	x	30.37616	x	x	x	x	x	x
718	Zinc-65	Water	µBq	179.2242	60.40426	17.10317	x	75.1158	5.242942	13.11051	7.446461	0.801069
719	Zinc, ion	Water	mg	4.772761	0.851434	0.044347	0.09	2.090533	0.011242	1.450818	0.153418	0.080969
720	Zirconium-95	Water	µBq	109.748	0.699498	107.8706	x	0.869862	0.060715	0.151823	0.086232	0.009277
721	Mineral waste, from mining	Waste	g	1.8	x	x	1.8	x	x	x	x	x
722	pineapple peels	Waste	kg	2.3	x	x	x	x	x	x	x	x

723	Waste in bioactive landfill	Waste	mg	840	x	x	840	x	x	x	x	x
724	Waste in incineration	Waste	mg	66	x	x	66	x	x	x	x	x
725	Water	Waste	kg	5	x	x	x	x	x	x	x	x
726	2,4-D	Soil	µg	1.324 118	0.003 254	x	x	1.302 912	9.29E-05	0.0162 46	0.000 578	0.001 034
727	Aclonifen	Soil	ng	425.6 011	13.50 247	x	x	408.2 485	0.1002 81	1.6481 87	1.995 341	0.106 324
728	Aldrin	Soil	pg	849.8 408	146.3 163	x	x	665.0 467	1.1116 43	10.942 36	25.70 441	0.719 434
729	Aluminum	Soil	mg	2.972 809	0.144 428	0.014 054	x	0.396 16	0.0052 89	2.2477 15	0.021 611	0.143 553
730	Antimony	Soil	pg	111.7 775	10.96 727	x	x	94.94 601	0.3821 98	3.4157 44	1.901 263	0.165 003
731	Arsenic	Soil	µg	1.189 092	0.058 31	0.005 622	x	0.158 422	0.0020 86	0.8985 16	0.008 758	0.057 378
732	Atrazine	Soil	pg	222.9 479	38.38 474	x	x	174.4 689	0.2916 29	2.8706 27	6.743 314	0.188 737
733	Barium	Soil	mg	1.452 721	0.071 27	x	x	0.175 208	0.0024 75	1.1214 66	0.010 683	0.071 62
734	Benomyl	Soil	ng	8.440 918	0.020 685	x	x	8.305 811	0.0005 92	0.1035 64	0.003 673	0.006 593
735	Bentazone	Soil	ng	217.2 072	6.891 037	x	x	208.3 512	0.0511 79	0.8411 59	1.018 33	0.054 263
736	Boron	Soil	µg	31.88 899	1.701 064	x	x	5.308 447	0.0841 47	23.071 38	0.251 486	1.472 467
737	Cadmium	Soil	µg	1.146 493	0.031 816	0.000 337	x	1.102 232	0.0004 05	0.0040 09	0.007 435	0.000 26
738	Calcium	Soil	mg	12.35	0.585	0.056	x	1.996	0.0239	9.0314	0.087	0.576

				808	557	215		463	4	91	616	801
739	Carbetamide	Soil	µg	3.513 534	0.002 479	x	x	3.510 305	5.70E-05	0.0003 08	0.000 365	1.99E-05
740	Carbofuran	Soil	µg	4.627 633	0.011 34	x	x	4.553 562	0.0003 24	0.0567 78	0.002 014	0.003 615
741	Carbon	Soil	mg	13.71 672	0.440 745	0.043 342	x	5.974 942	0.0156 7	6.7452 89	0.065 649	0.431 081
742	Chloride	Soil	mg	106.7 08	65.15 239	x	x	25.15 872	0.1896 82	8.5630 01	7.098 845	0.545 408
743	Chlorothalonil	Soil	mg	3.387 892	3.97E -05	x	x	3.387 799	3.84E-05	9.83E-06	4.72E -06	6.78E-07
744	Chromium	Soil	µg	16.46 255	0.868 549	0.070 269	x	3.370 388	0.0286 31	11.262 79	0.142 583	0.719 337
745	Chromium VI	Soil	µg	15.92 549	1.550 759	x	x	10.17 881	0.1954 66	3.5667 97	0.212 793	0.220 865
746	Cobalt	Soil	ng	44.30 505	1.251 739	0.270 6	x	38.56 252	0.2770 41	3.5560 3	0.166 757	0.220 361
747	Copper	Soil	µg	82.63 649	2.931 892	0.001 354	x	76.45 769	0.1381 52	2.3566 02	0.603 096	0.147 704
748	Cypermethrin	Soil	ng	829.8 462	1.656 312	x	x	819.3 144	0.0481 85	8.0240 73	0.292 396	0.510 826
749	Fenpiclonil	Soil	µg	133.3 595	0.002 03	x	x	133.3 552	0.0015 14	0.0004 44	0.000 255	3.03E-05
750	Fluoride	Soil	µg	156.0 452	8.175 616	x	x	24.41 074	0.3797 8	114.55 59	1.212 131	7.311 034
751	Glyphosate	Soil	µg	13.72 594	1.635 218	x	x	11.54 314	0.0273 15	0.3172 31	0.183 127	0.019 911
752	Heat, waste	Soil	kJ	2.482 583	0.220 597	0.141 432	x	1.435 084	0.0206 24	0.5985 11	0.028 929	0.037 407
753	Iron	Soil	mg	10.40 807	0.443 186	0.028 108	x	4.646 6	0.0540 17	4.8579 31	0.067 932	0.310 293

754	Lead	Soil	µg	12.85808	1.183961	0.006194	x	11.32521	0.008407	0.046162	0.285194	0.002955
755	Linuron	Soil	µg	3.279095	0.104057	x	x	3.145367	0.000773	0.0127	0.015378	0.000819
756	Magnesium	Soil	mg	2.400814	0.115737	x	x	0.34752	0.004427	1.800802	0.01733	0.114999
757	Mancozeb	Soil	mg	4.400174	5.16E-05	x	x	4.400053	4.98E-05	1.28E-05	6.13E-06	8.80E-07
758	Manganese	Soil	µg	163.4208	6.546427	0.562152	x	55.26438	0.478578	93.61757	0.978308	5.973406
759	Mercury	Soil	ng	825.7466	0.19182	0.03965	x	825.4171	0.015793	0.053824	0.024985	0.003429
760	Metaldehyde	Soil	µg	1.528969	0.000477	x	x	1.528337	2.06E-05	6.05E-05	7.00E-05	3.92E-06
761	Metolachlor	Soil	µg	23.73248	0.752928	x	x	22.76486	0.005592	0.091907	0.111265	0.005929
762	Metribuzin	Soil	µg	154.9329	0.001817	x	x	154.9287	0.001755	0.00045	0.000216	3.10E-05
763	Molybdenum	Soil	ng	9.910881	0.456194	x	x	8.503722	0.066797	0.778962	0.056821	0.048384
764	Napropamide	Soil	µg	2.705094	0.000844	x	x	2.703976	3.64E-05	0.000107	0.000124	6.93E-06
765	Nickel	Soil	µg	14.94631	0.390605	0.002033	x	14.43166	0.003417	0.024411	0.092583	0.001601
766	Nitrogen	Soil	ng	12.48586	x	12.48586	x	x	x	x	x	x
767	Oils, biogenic	Soil	µg	536.6297	1.525012	0.12495	x	530.9269	0.41225	3.175283	0.248993	0.216325
768	Oils, unspecified	Soil	mg	419.186	18.42901	0.008807	x	27.30246	0.60168	347.9101	2.71099	22.22292
769	Orbencarb	Soil	µg	836.6	0.009	x	x	836.6	0.0094	0.0024	0.001	0.000

				533	815			302	77	28	166	167
770	Phosphorus	Soil	µg	168.7561	7.527648	0.725952	x	37.7027	0.384422	114.0109	1.127191	7.277218
771	Pirimicarb	Soil	ng	20.54638	0.651847	x	x	19.70866	0.004841	0.079568	0.096327	0.005133
772	Potassium	Soil	mg	1.143459	0.052116	x	x	0.234881	0.002494	0.795388	0.007805	0.050774
773	Silicon	Soil	µg	490.9771	19.58138	x	x	210.9337	1.746514	240.529	2.856986	15.32952
774	Sodium	Soil	mg	7.458939	0.49617	x	x	2.112813	0.010444	4.48707	0.065894	0.286549
775	Strontium	Soil	µg	29.25632	1.442369	x	x	3.522424	0.049929	22.57935	0.216128	1.446118
776	Sulfur	Soil	mg	1.777304	0.086891	0.008439	x	0.232073	0.003147	1.347704	0.012986	0.086063
777	Sulfuric acid	Soil	pg	42.84222	7.377079	x	x	33.52724	0.055903	0.54984	1.296002	0.036159
778	Tebutam	Soil	µg	6.409817	0.002	x	x	6.407168	8.62E-05	0.000253	0.000293	1.64E-05
779	Teflubenzuron	Soil	µg	10.32886	0.000121	x	x	10.32858	0.000117	3.00E-05	1.44E-05	2.07E-06
780	Thiram	Soil	ng	14.97519	0.036698	x	x	14.7355	0.00105	0.183735	0.006516	0.011697
781	Tin	Soil	ng	5.730796	1.299105	x	x	3.884459	0.064004	0.31459	0.148513	0.020127
782	Titanium	Soil	µg	3.205505	0.05648	x	x	2.842038	0.019288	0.263108	0.008309	0.016282
783	Vanadium	Soil	ng	91.75175	1.616644	x	x	81.34817	0.552081	7.530977	0.237838	0.46604
784	Zinc	Soil	µg	841.2304	82.55584	0.224357	x	699.5429	0.590142	36.22703	19.77358	2.316598

Title:	**Analyzing 1 kg 'Sliced pineapple using hybrid electricity**									
Method:	Eco-indicator 99 (H) V2.06 / Europe EI 99 H/H									
Indicator:	**Damage assessment**									
Per impact category:	Yes									
Skip categories:	Never									
Relative mode:	Non									
Impact category	Unit	Total	Fresh pineapple fruit	Water	PET containers	Cardboard box	Electricity, hydropower	Electricity, light oil, at power plant	Transport	Diesel-electric generating set
Carcinogens	DALY	1.70E-08	4.41E-10	1.99E-10	2.14E-09	7.91E-09	9.80E-11	5.75E-09	7.12E-11	4.22E-10
Resp. organics	DALY	3.83E-09	2.74E-11	2.65E-12	3.51E-09	1.01E-10	1.50E-11	1.32E-10	4.67E-12	3.00E-11
Resp. inorganics	DALY	6.11E-07	2.11E-08	1.66E-09	2.13E-07	7.02E-08	3.19E-09	2.52E-07	1.93E-09	4.78E-08
Climate change	DALY	1.36E-07	4.77E-09	5.92E-10	3.03E-08	2.47E-08	1.67E-08	5.50E-08	7.11E-10	3.43E-09
Radiation	DALY	6.54E-10	5.36E-11	8.10E-11	0	3.90E-10	1.00E-11	1.06E-10	7.11E-12	6.50E-12
Ozone layer	DALY	1.16E-10	3.63E-12	4.53E-12	5.75E-11	1.40E-11	1.41E-13	3.32E-11	5.66E-13	2.12E-12

Ecotoxicity	PDF* m2yr	0.0122 63132	0.0005 24639	4.42E-05	0.0006 49974	0.0034 19949	0.0001 2294	0.0073 2015	0.0001 01566	7.97E-05
Acidification/ Eutrophication	PDF* m2yr	0.0215 81648	0.0009 06939	4.92E-05	0.0084 17978	0.0025 89138	4.44E-05	0.0079 62931	7.12E-05	0.0015 39839
Land use	PDF* m2yr	0.0441 3678	0.0004 52302	0.0001 16557	0	0.0377 26026	0.0031 24094	0.0025 00505	5.52E-05	0.0001 62074
Minerals	MJ surplus	0.0057 33183	0.0003 20263	2.51E-05	1.03E-05	0.0043 42468	0.0004 27999	0.0004 93293	6.07E-05	5.32E-05
Fossil fuels	MJ surplus	1.4414 553	0.0442 12444	0.0020 67185	0.6308 94	0.2324 886	0.0018 07129	0.4917 8164	0.0068 2371	0.0313 80558

Title:	**Analyzing 1 kg 'Sliced pineapple using hybrid electricity**									
Method:	Eco-indicator 99 (H) V2.06 / Europe EI 99 H/H									
Indicator:	**Normalization**									
Per impact category:	Yes									
Skip categories:	Never									
Relative mode:	Non									
Impact category	Unit	Total	Fresh pineapple fruit	Water	PET containers	Cardboard box	Electricity, hydropower	Electricity, light oil, at power plant	Transport	Diesel-electric generating set
Carcinogens		1.11E-06	2.87E-08	1.29E-08	1.39E-07	5.15E-07	6.38E-09	3.74E-07	4.63E-09	2.74E-08
Resp. organics		2.49E-07	1.78E-09	1.73E-10	2.29E-07	6.56E-09	9.74E-10	8.60E-09	3.04E-10	1.95E-09
Resp. inorganics		3.98E-05	1.37E-06	1.08E-07	1.39E-05	4.57E-06	2.08E-07	1.64E-05	1.25E-07	3.11E-06
Climate change		8.87E-06	3.11E-07	3.85E-08	1.97E-06	1.61E-06	1.09E-06	3.58E-06	4.63E-08	2.23E-07
Radiation		4.26E-08	3.49E-09	5.27E-09	0	2.54E-08	6.52E-10	6.89E-09	4.63E-10	4.23E-10
Ozone layer		7.53E-09	2.37E-	2.95E-	3.74E-	9.12E-	9.17E-	2.16E-	3.69E-	1.38E-

			10	10	09	10	12	09	11	10
Ecotoxicity		2.39E-06	1.02E-07	8.63E-09	1.27E-07	6.67E-07	2.40E-08	1.43E-06	1.98E-08	1.55E-08
Acidification/ Eutrophication		4.21E-06	1.77E-07	9.59E-09	1.64E-06	5.05E-07	8.67E-09	1.55E-06	1.39E-08	3.00E-07
Land use		8.61E-06	8.82E-08	2.27E-08	0	7.36E-06	6.09E-07	4.88E-07	1.08E-08	3.16E-08
Minerals		6.82E-07	3.81E-08	2.98E-09	1.22E-09	5.17E-07	5.09E-08	5.87E-08	7.22E-09	6.33E-09
Fossil fuels		0.000171533	5.26E-06	2.46E-07	7.51E-05	2.77E-05	2.15E-07	5.85E-05	8.12E-07	3.73E-06

Title:	Analyzing 1 kg 'Sliced pineapple using hybrid electricity									
Method:	Eco-indicator 99 (H) V2.06 / Europe EI 99 H/H									
Indicator:	Weighting									
Per impact category:	Yes									
Skip categories:	Never									
Relative mode:	Non									
Impact category	Unit	Total	Fresh pineapple fruit	Water	PET containers	Cardboard box	Electricity, hydropower	Electricity, light oil, at power plant	Transport	Diesel-electric generating set
Total	Pt	0.072759595	0.00225204	0.000140659	0.028102025	0.013883595	0.000727612	0.025066486	0.000316725	0.002270454
Carcinogens	Pt	0.000332643	8.62E-06	3.88E-06	4.18E-05	0.000154485	1.91E-06	0.000112303	1.39E-06	8.23E-06
Resp. organics	Pt	7.47E-05	5.35E-07	5.18E-08	6.86E-05	1.97E-06	2.92E-07	2.58E-06	9.12E-08	5.85E-07
Resp. inorganics	Pt	0.011930224	0.000411799	3.24E-05	0.004168186	0.001370307	6.24E-05	0.004914194	3.76E-05	0.000933296
Climate change	Pt	0.002659784	9.32E-05	1.16E-05	0.000591693	0.00048274	0.000326305	0.00107336	1.39E-05	6.70E-05
Radiation	Pt	1.28E-	1.05E-	1.58E-	0	7.61E-	1.96E-	2.07E-	1.39E-	1.27E-

		05	06	06		06	07	06	07	07
Ozone layer	Pt	2.26E-06	7.10E-08	8.85E-08	1.12E-06	2.74E-07	2.75E-09	6.47E-07	1.11E-08	4.13E-08
Ecotoxicity	Pt	0.000956524	4.09E-05	3.45E-06	5.07E-05	0.000266756	9.59E-06	0.000570972	7.92E-06	6.21E-06
Acidification/ Eutrophication	Pt	0.001683369	7.07E-05	3.84E-06	0.000656602	0.000201953	3.47E-06	0.000621109	5.55E-06	0.000120107
Land use	Pt	0.003442669	3.53E-05	9.09E-06	0	0.00294263	0.000243679	0.000195039	4.31E-06	1.26E-05
Minerals	Pt	0.000204675	1.14E-05	8.95E-07	3.66E-07	0.000155026	1.53E-05	1.76E-05	2.17E-06	1.90E-06
Fossil fuels	Pt	0.051459953	0.001578384	7.38E-05	0.022522916	0.008299843	6.45E-05	0.017556604	0.000243606	0.001120286

Title:	**Analyzing 1 kg 'Sliced pineapple using hybrid Electricity**									
Method:	Eco-indicator 99 (H) V2.06 / Europe EI 99 H/H									
Indicator:	**Single score**									
Per impact category:	Yes									
Skip categories:	Never									
Relative mode:	Non				0.06705 2106	92%				
Impact category	Unit	Total	Fresh pineapple fruit	Water	PET containers	Cardboard box	Electricity, hydropower	Electricity, light oil, at power plant	Transport	Diesel-electric generating set
Total	Pt	0.0727595 95	0.00225 204	0.00014 0659	0.02810 2025	0.01388 3595	0.00072 7612	0.02506 6486	0.00031 6725	0.00227 0454
Carcinogens	Pt	0.0003326 43	8.62E-06	3.88E-06	4.18E-05	0.00015 4485	1.91E-06	0.00011 2303	1.39E-06	8.23E-06
Resp. organics	Pt	7.47E-05	5.35E-07	5.18E-08	6.86E-05	1.97E-06	2.92E-07	2.58E-06	9.12E-08	5.85E-07
Resp. inorganics	Pt	0.0119302 24	0.00041 1799	3.24E-05	0.00416 8186	0.00137 0307	6.24E-05	0.00491 4194	3.76E-05	0.00093 3296
Climate change	Pt	0.0026597 84	9.32E-05	1.16E-05	0.00059 1693	0.00048 274	0.00032 6305	0.00107 336	1.39E-05	6.70E-05
Radiation	Pt	1.28E-05	1.05E-	1.58E-	0	7.61E-	1.96E-	2.07E-	1.39E-	1.27E-

			06	06		06	07	06	07	07
Ozone layer	Pt	2.26E-06	7.10E-08	8.85E-08	1.12E-06	2.74E-07	2.75E-09	6.47E-07	1.11E-08	4.13E-08
Ecotoxicity	Pt	0.0009565 24	4.09E-05	3.45E-06	5.07E-05	0.00026 6756	9.59E-06	0.00057 0972	7.92E-06	6.21E-06
Acidification/ Eutrophication	Pt	0.0016833 69	7.07E-05	3.84E-06	0.00065 6602	0.00020 1953	3.47E-06	0.00062 1109	5.55E-06	0.00012 0107
Land use	Pt	0.0034426 69	3.53E-05	9.09E-06	0	0.00294 263	0.00024 3679	0.00019 5039	4.31E-06	1.26E-05
Minerals	Pt	0.0002046 75	1.14E-05	8.95E-07	3.66E-07	0.00015 5026	1.53E-05	1.76E-05	2.17E-06	1.90E-06
Fossil fuels	Pt	0.0514599 53	0.00157 8384	7.38E-05	0.02252 2916	0.00829 9843	6.45E-05	0.01755 6604	0.00024 3606	0.00112 0286

APPENDIX B Comparing 1 p 'Sliced pineapple using hybrid electricity', 1 p 'Sliced Pineapple using grid' and 1 p 'Sliced pineapple using generator'

Title: Comparing 1 p 'Sliced pineapple using hybrid', 1 p 'Sliced Pineapple using grid' and 1 p 'Sliced pineapple using generator'						
Method: Eco-indicator 99 (H) V2.06 / Europe EI 99 H/H						
Per sub-compartment: No						
Default units: No						
Indicator: Inventory						
Relative mode: Non						
No	**Substance**	**Compartment**	**Unit**	**Sliced pineapple using hybrid electricity**	**Sliced Pineapple using grid**	**Sliced pineapple using generator**
1	Aluminium, 24% in bauxite, 11% in crude ore, in ground	Raw	g	111.86741	112.35333	109.82741
2	Anhydrite, in ground	Raw	mg	1.5544764	1.5637906	1.628375
3	Barite, 15% in crude ore, in ground	Raw	g	507.78106	533.98838	507.09452
4	Baryte, in ground	Raw	g	1.0738039	1.0738039	1.0738039
5	Basalt, in ground	Raw	g	21.438943	21.539697	21.720081
6	Bauxite, in ground	Raw	g	20.233557	20.233557	20.233557
7	Borax, in ground	Raw	µg	266.29933	271.48854	260.50651
8	Cadmium, 0.30% in sulfide, Cd 0.18%, Pb, Zn, Ag, In, in ground	Raw	mg	82.335957	82.462827	82.014101
9	Calcite, in ground	Raw	kg	9.0848455	9.8844217	3.3364121
10	Carbon dioxide, in air	Raw	kg	87.333012	87.349058	87.317152
11	Carbon, in organic matter, in soil	Raw	g	5.8452995	5.8502356	5.8446997
12	Cerium, 24% in bastnasite, 2.4% in crude ore, in ground	Raw	pg	-1.40E-05	-1.47E-05	-1.12E-05
13	Chromium, 25.5% in chromite, 11.6% in crude ore, in ground	Raw	g	51.564006	52.322944	47.527085
14	Chromium, in ground	Raw	mg	66.629915	66.629915	66.629915
15	Chrysotile, in ground	Raw	mg	14.889758	14.938808	14.880833
16	Cinnabar, in ground	Raw	mg	1.3719148	1.3764848	1.3712538
17	Clay, bentonite, in ground	Raw	g	72.06526	74.345031	70.276432

18	Clay, unspecified, in ground	Raw	kg	2.4168045	2.5135865	1.7689845
19	Coal, 18 MJ per kg, in ground	Raw	kg	9.0346715	9.0346715	9.0346715
20	Coal, brown, 8 MJ per kg, in ground	Raw	kg	8.5642493	8.5642493	8.5642493
21	Coal, brown, in ground	Raw	kg	16.408651	16.589853	16.161836
22	Coal, hard, unspecified, in ground	Raw	kg	12.711074	12.874467	12.378985
23	Cobalt, in ground	Raw	mg	0.47910521	0.35464791	2.4666614
24	Colemanite, in ground	Raw	mg	229.50097	230.48199	226.4453
25	Copper, 0.99% in sulfide, Cu 0.36% and Mo 8.2E-3% in crude ore, in ground	Raw	g	2.4813265	2.4794758	2.7868239
26	Copper, 1.18% in sulfide, Cu 0.39% and Mo 8.2E-3% in crude ore, in ground	Raw	g	13.643455	13.632986	15.336481
27	Copper, 1.42% in sulfide, Cu 0.81% and Mo 8.2E-3% in crude ore, in ground	Raw	g	3.6191214	3.6163444	4.0682208
28	Copper, 2.19% in sulfide, Cu 1.83% and Mo 8.2E-3% in crude ore, in ground	Raw	g	18.103806	18.090209	20.329994
29	Copper, in ground	Raw	mg	580.32681	580.32681	580.32681
30	Diatomite, in ground	Raw	µg	38.45036	38.494649	38.344421
31	Dolomite, in ground	Raw	g	7.931802	8.0889576	7.6011549
32	Energy, gross calorific value, in biomass	Raw	MJ	976.88319	977.03646	976.74456
33	Energy, gross calorific value, in biomass, primary forest	Raw	kJ	405.24267	405.58487	405.20108
34	Energy, kinetic (in wind), converted	Raw	MJ	4.7950256	4.869624	4.6924967
35	Energy, potential (in hydropower reservoir), converted	Raw	kWh	586.32093	660.17277	26.543128
36	Energy, solar, converted	Raw	kJ	61.827837	62.909064	60.273326
37	Feldspar, in ground	Raw	µg	20.540967	20.626477	20.363453

38	Fluorine, 4.5% in apatite, 1% in crude ore, in ground	Raw	g	1.7574545	1.771717	1.7573912
39	Fluorine, 4.5% in apatite, 3% in crude ore, in ground	Raw	g	1.7751034	1.7813956	1.7750557
40	Fluorspar, 92%, in ground	Raw	g	10.834958	11.247676	10.828564
41	Gadolinium, 0.15% in bastnasite, 0.015% in crude ore, in ground	Raw	pg	-4.89E-08	-4.89E-08	-4.89E-08
42	Gallium, 0.014% in bauxite, in ground	Raw	ng	176.70012	179.76734	172.28635
43	Gas, mine, off-gas, process, coal mining/kg	Raw	g	4.2544027	4.2544027	4.2544027
44	Gas, mine, off-gas, process, coal mining/m3	Raw	dm3	149.77224	151.43392	146.01371
45	Gas, natural, 35 MJ per m3, in ground	Raw	dm3	135.80049	135.80049	135.80049
46	Gas, natural, 36.6 MJ per m3, in ground	Raw	m3	25.8	25.8	25.8
47	Gas, natural, feedstock, 35 MJ per m3, in ground	Raw	m3	19.2	19.2	19.2
48	Gas, natural, in ground	Raw	m3	40.199556	40.490091	40.015896
49	Gas, petroleum, 35 MJ per m3, in ground	Raw	cu.in	836.72334	836.72334	836.72334
50	Gold, Au 1.1E-4%, Ag 4.2E-3%, in ore, in ground	Raw	µg	117.50782	117.6275	117.40018
51	Gold, Au 1.3E-4%, Ag 4.6E-5%, in ore, in ground	Raw	µg	215.46792	215.68737	215.27054
52	Gold, Au 1.4E-4%, in ore, in ground	Raw	µg	257.99674	258.2595	257.76039
53	Gold, Au 2.1E-4%, Ag 2.1E-4%, in ore, in ground	Raw	µg	394.05719	394.45853	393.6962
54	Gold, Au 4.3E-4%, in ore, in ground	Raw	µg	97.664725	97.764194	97.575257
55	Gold, Au 4.9E-5%, in ore, in ground	Raw	µg	233.91949	234.15773	233.7052

56	Gold, Au 6.7E-4%, in ore, in ground	Raw	µg	362.14537	362.5142	361.81361
57	Gold, Au 7.1E-4%, in ore, in ground	Raw	µg	408.35643	408.77233	407.98234
58	Gold, Au 9.7E-4%, Ag 9.7E-4%, Zn 0.63%, Cu 0.38%, Pb 0.014%, in ore, in ground	Raw	µg	24.469223	24.494144	24.446807
59	Granite, in ground	Raw	ng	283.43524	284.48462	277.92532
60	Gravel, in ground	Raw	kg	71.921223	74.240965	55.853845
61	Gypsum, in ground	Raw	mg	10.700228	10.897161	11.093108
62	Helium, 0.08% in natural gas, in ground	Raw	ng	892.04214	907.52861	869.7597
63	Indium, 0.005% in sulfide, In 0.003%, Pb, Zn, Ag, Cd, in ground	Raw	mg	1.3806361	1.3828971	1.3750595
64	Iron ore, in ground	Raw	g	33	33	33
65	Iron, 46% in ore, 25% in crude ore, in ground	Raw	kg	3.3547658	3.4205174	3.2165682
66	Iron, in ground	Raw	g	12.029767	12.029767	12.029767
67	Kaolinite, 24% in crude ore, in ground	Raw	g	263.6837	263.69666	263.60113
68	Kieserite, 25% in crude ore, in ground	Raw	g	3.2008835	3.2009245	3.2006608
69	Land use II-III	Raw	m2a	0.19840771	0.19840771	0.19840771
70	Land use II-III, sea floor	Raw	cm2a	171.51783	171.51783	171.51783
71	Land use II-IV	Raw	cm2a	82.757656	82.757656	82.757656
72	Land use II-IV, sea floor	Raw	cm2a	17.698785	17.698785	17.698785
73	Land use III-IV	Raw	cm2a	76.688639	76.688639	76.688639
74	Land use IV-IV	Raw	mm2a	54.008139	54.008139	54.008139
75	Lanthanum, 7.2% in bastnasite, 0.72% in crude ore, in ground	Raw	pg	2.70E-05	2.78E-05	2.61E-05
76	Lead, 5.0% in sulfide, Pb 3.0%, Zn, Ag, Cd, In, in ground	Raw	g	7.6719358	7.6908537	7.6501715
77	Lead, in ground	Raw	mg	146.38717	146.38717	146.38717
78	Limestone, in ground	Raw	g	16.2	16.2	16.2
79	Magnesite, 60% in crude ore, in ground	Raw	g	43.730432	44.698034	41.130192

80	Magnesium, 0.13% in water	Raw	mg	3.6866679	3.6933145	3.6785608
81	Manganese, 35.7% in sedimentary deposit, 14.2% in crude ore, in ground	Raw	g	4.9301007	5.0583816	4.9127288
82	Manganese, in ground	Raw	mg	19.479057	19.479057	19.479057
83	Marl, in ground	Raw	g	22.529201	22.529201	22.529201
84	Metamorphous rock, graphite containing, in ground	Raw	mg	96.415496	96.987246	94.161812
85	Molybdenum, 0.010% in sulfide, Mo 8.2E-3% and Cu 1.83% in crude ore, in ground	Raw	mg	336.43577	336.18309	377.80659
86	Molybdenum, 0.014% in sulfide, Mo 8.2E-3% and Cu 0.81% in crude ore, in ground	Raw	mg	47.537444	47.500968	53.4364
87	Molybdenum, 0.022% in sulfide, Mo 8.2E-3% and Cu 0.36% in crude ore, in ground	Raw	g	1.7197101	1.7647144	1.715026
88	Molybdenum, 0.025% in sulfide, Mo 8.2E-3% and Cu 0.39% in crude ore, in ground	Raw	mg	174.19186	174.0582	195.80745
89	Molybdenum, 0.11% in sulfide, Mo 4.1E-2% and Cu 0.36% in crude ore, in ground	Raw	g	3.4699736	3.5608014	3.4605208
90	Molybdenum, in ground	Raw	ng	57.919938	57.919938	57.919938
91	Neodymium, 4% in bastnasite, 0.4% in crude ore, in ground	Raw	pg	-6.00E-06	-6.25E-06	-4.79E-06
92	Nickel, 1.13% in sulfide, Ni 0.76% and Cu 0.76% in crude ore, in ground	Raw	mg	185.58162	195.12841	116.57164
93	Nickel, 1.98% in silicates, 1.04% in crude ore, in ground	Raw	g	148.31853	150.76329	138.03025
94	Nickel, in ground	Raw	mg	41.864167	41.864167	41.864167

95	Occupation, arable, non-irrigated	Raw	m2a	11.388218	11.388268	11.388072
96	Occupation, construction site	Raw	cm2a	296.55811	303.67389	287.59653
97	Occupation, dump site	Raw	m2a	0.1484428	0.15084105	0.14353838
98	Occupation, dump site, benthos	Raw	cm2a	424.88108	444.07173	424.19566
99	Occupation, forest, intensive	Raw	m2a	170.63688	170.63712	170.63638
100	Occupation, forest, intensive, normal	Raw	m2a	12.935313	12.946219	12.930886
101	Occupation, forest, intensive, short-cycle	Raw	m2a	0.10165512	0.10174096	0.10164468
102	Occupation, industrial area	Raw	m2a	0.34341393	0.36147446	0.32884096
103	Occupation, industrial area, benthos	Raw	mm2a	349.70069	364.52465	349.02203
104	Occupation, industrial area, built up	Raw	m2a	0.15944521	0.15990386	0.16207594
105	Occupation, industrial area, vegetation	Raw	m2a	0.10448757	0.10497829	0.10377671
106	Occupation, mineral extraction site	Raw	m2a	0.14584281	0.15367122	0.10019291
107	Occupation, permanent crop, fruit, intensive	Raw	m2a	0.234039	0.23416241	0.23402398
108	Occupation, shrub land, sclerophyllous	Raw	cm2a	66.587418	71.354846	31.773683
109	Occupation, traffic area, rail embankment	Raw	cm2a	342.11252	344.49011	338.09439
110	Occupation, traffic area, rail network	Raw	cm2a	378.29751	380.92658	373.85439
111	Occupation, traffic area, road embankment	Raw	m2a	3.0196041	3.0197788	3.0193834
112	Occupation, traffic area, road network	Raw	m2a	0.49815519	0.5002774	0.53279292
113	Occupation, urban, discontinuously built	Raw	cm2a	261.82052	261.82581	261.81731
114	Occupation, water bodies, artificial	Raw	m2a	18.755345	21.208743	0.14408916
115	Occupation, water courses, artificial	Raw	cm2a	707.59909	724.31935	693.87748
116	Oil, crude, 42.6 MJ	Raw	kg	21.200318	21.200318	21.200318

	per kg, in ground					
117	Oil, crude, feedstock, 41 MJ per kg, in ground	Raw	kg	43.8	43.8	43.8
118	Oil, crude, in ground	Raw	kg	96.083388	101.24463	95.933078
119	Olivine, in ground	Raw	µg	600.92035	604.43082	624.77392
120	Palladium, in ground	Raw	ng	59.728827	59.728827	59.728827
121	Pd, Pd 2.0E-4%, Pt 4.8E-4%, Rh 2.4E-5%, Ni 3.7E-2%, Cu 5.2E-2% in ore, in ground	Raw	µg	134.26158	140.0203	139.27528
122	Pd, Pd 7.3E-4%, Pt 2.5E-4%, Rh 2.0E-5%, Ni 2.3E+0%, Cu 3.2E+0% in ore, in ground	Raw	µg	322.66984	336.50972	334.71922
123	Peat, in ground	Raw	g	209.66427	209.66643	209.658
124	Phosphorus, 18% in apatite, 12% in crude ore, in ground	Raw	g	7.0860661	7.1111686	7.0858808
125	Phosphorus, 18% in apatite, 4% in crude ore, in ground	Raw	g	7.029818	7.0868679	7.0295647
126	Platinum, in ground	Raw	ng	69.992886	69.992886	69.992886
127	Praseodymium, 0.42% in bastnasite, 0.042% in crude ore, in ground	Raw	pg	3.66E-07	3.78E-07	3.65E-07
128	Pt, Pt 2.5E-4%, Pd 7.3E-4%, Rh 2.0E-5%, Ni 2.3E+0%, Cu 3.2E+0% in ore, in ground	Raw	µg	3.1741945	3.3139351	3.2790405
129	Pt, Pt 4.8E-4%, Pd 2.0E-4%, Rh 2.4E-5%, Ni 3.7E-2%, Cu 5.2E-2% in ore, in ground	Raw	µg	11.379021	11.87997	11.754878
130	Rh, Rh 2.0E-5%, Pt 2.5E-4%, Pd 7.3E-4%, Ni 2.3E+0%, Cu 3.2E+0% in ore, in ground	Raw	µg	2.5919031	2.7241519	2.7054366

131	Rh, Rh 2.4E-5%, Pt 4.8E-4%, Pd 2.0E-4%, Ni 3.7E-2%, Cu 5.2E-2% in ore, in ground	Raw	µg	8.1181724	8.5323925	8.4737739
132	Rhenium, in crude ore, in ground	Raw	µg	3.0986294	3.1967431	3.9289116
133	Rhenium, in ground	Raw	ng	55.799175	55.799175	55.799175
134	Rhodium, in ground	Raw	ng	64.03485	64.03485	64.03485
135	Samarium, 0.3% in bastnasite, 0.03% in crude ore, in ground	Raw	pg	-1.82E-07	-1.93E-07	-1.24E-07
136	Sand and clay, unspecified, in ground	Raw	g	1.2	1.2	1.2
137	Sand, unspecified, in ground	Raw	g	4.5353199	4.5368864	4.5349275
138	Shale, in ground	Raw	mg	4.4004744	4.4268422	4.6096854
139	Silver, 0.007% in sulfide, Ag 0.004%, Pb, Zn, Cd, In, in ground	Raw	mg	2.6113341	2.6143093	2.6084772
140	Silver, 3.2ppm in sulfide, Ag 1.2ppm, Cu and Te, in crude ore, in ground	Raw	mg	1.8628275	1.8649538	1.8607838
141	Silver, Ag 2.1E-4%, Au 2.1E-4%, in ore, in ground	Raw	µg	171.97464	172.17067	171.78637
142	Silver, Ag 4.2E-3%, Au 1.1E-4%, in ore, in ground	Raw	µg	392.76955	393.21725	392.33956
143	Silver, Ag 4.6E-5%, Au 1.3E-4%, in ore, in ground	Raw	µg	384.99947	385.43831	384.57798
144	Silver, Ag 9.7E-4%, Au 9.7E-4%, Zn 0.63%, Cu 0.38%, Pb 0.014%, in ore, in ground	Raw	µg	254.0276	254.31716	253.7495
145	Silver, in ground	Raw	µg	628.11962	628.11962	628.11962
146	Sodium chloride, in ground	Raw	kg	3.3903722	3.3936513	3.3900961
147	Sodium nitrate, in ground	Raw	ng	146.48146	147.00479	146.11831
148	Sodium sulphate,	Raw	g	2.9533556	3.0710733	2.9568127

	various forms, in ground					
149	Stibnite, in ground	Raw	µg	3.9958217	4.0004243	3.9848124
150	Sulfur, in ground	Raw	mg	60.037086	60.466021	62.604403
151	Sylvite, 25 % in sylvinite, in ground	Raw	g	169.41285	169.41688	169.41025
152	Talc, in ground	Raw	g	2.2090993	2.2104312	2.2005753
153	Tantalum, 81.9% in tantalite, 1.6E-4% in crude ore, in ground	Raw	mg	2.0584399	2.0607375	2.056258
154	Tellurium, 0.5ppm in sulfide, Te 0.2ppm, Cu and Ag, in crude ore, in ground	Raw	µg	279.42878	279.74773	279.12221
155	Tin, 79% in cassiterite, 0.1% in crude ore, in ground	Raw	mg	99.720511	100.00254	98.701762
156	Tin, in ground	Raw	µg	348.95534	348.95534	348.95534
157	TiO2, 54% in ilmenite, 2.6% in crude ore, in ground	Raw	g	10.016537	10.25532	10.000605
158	TiO2, 95% in rutile, 0.40% in crude ore, in ground	Raw	µg	57.556893	57.635647	57.382779
159	Transformation, from arable	Raw	mm2	68.021786	68.582103	66.702802
160	Transformation, from arable, non-irrigated	Raw	m2	20.896924	20.897016	20.896655
161	Transformation, from arable, non-irrigated, fallow	Raw	mm2	13.573844	13.632798	13.326165
162	Transformation, from dump site, inert material landfill	Raw	cm2	10.310859	11.197994	3.6820818
163	Transformation, from dump site, residual material landfill	Raw	mm2	199.5266	202.48166	193.05463
164	Transformation, from dump site, sanitary landfill	Raw	mm2	81.09909	84.76567	54.155478
165	Transformation, from dump site, slag compartment	Raw	mm2	19.717475	19.726201	19.746489
166	Transformation, from	Raw	sq.in	386.94148	422.18843	197.13344

	forest					
167	Transformation, from forest, extensive	Raw	m2	1.2607772	1.2608586	1.2607636
168	Transformation, from forest, intensive, clear-cutting	Raw	cm2	36.305561	36.336219	36.301835
169	Transformation, from industrial area	Raw	mm2	256.40398	259.4373	254.15733
170	Transformation, from industrial area, benthos	Raw	mm2	1.1382752	1.1403552	1.1326917
171	Transformation, from industrial area, built up	Raw	mm2	2.5088621	2.529229	2.5087726
172	Transformation, from industrial area, vegetation	Raw	mm2	4.2798235	4.3145672	4.2796708
173	Transformation, from mineral extraction site	Raw	cm2	38.398724	40.396437	24.789112
174	Transformation, from pasture and meadow	Raw	cm2	31.447343	33.018008	20.327704
175	Transformation, from pasture and meadow, intensive	Raw	cm2	170.53916	170.53991	170.53697
176	Transformation, from sea and ocean	Raw	cm2	425.06932	444.2665	424.38315
177	Transformation, from shrub land, sclerophyllous	Raw	cm2	15.536451	16.51583	8.5221422
178	Transformation, from tropical rain forest	Raw	cm2	36.305561	36.336219	36.301835
179	Transformation, from unknown	Raw	cm2	363.62513	373.0952	310.47126
180	Transformation, to arable	Raw	cm2	26.867596	26.996228	26.577971
181	Transformation, to arable, non-irrigated	Raw	m2	20.913976	20.914069	20.913708
182	Transformation, to arable, non-irrigated, fallow	Raw	mm2	23.502553	23.921657	20.855599
183	Transformation, to dump site	Raw	cm2	10.332366	10.438776	10.53144
184	Transformation, to dump site, benthos	Raw	cm2	424.88108	444.07173	424.19566

185	Transformation, to dump site, inert material landfill	Raw	cm2	10.310859	11.197994	3.6820818
186	Transformation, to dump site, residual material landfill	Raw	mm2	199.5287	202.48377	193.05668
187	Transformation, to dump site, sanitary landfill	Raw	mm2	81.09909	84.76567	54.155478
188	Transformation, to dump site, slag compartment	Raw	mm2	19.717475	19.726201	19.746489
189	Transformation, to forest	Raw	cm2	41.561734	44.411718	21.213569
190	Transformation, to forest, intensive	Raw	m2	1.1367836	1.1367852	1.1367802
191	Transformation, to forest, intensive, clear-cutting	Raw	cm2	36.305561	36.336219	36.301835
192	Transformation, to forest, intensive, normal	Raw	sq.in	156.52442	156.64419	156.50946
193	Transformation, to forest, intensive, short-cycle	Raw	cm2	36.305561	36.336219	36.301835
194	Transformation, to heterogeneous, agricultural	Raw	cm2	59.967939	63.071249	59.713412
195	Transformation, to industrial area	Raw	cm2	16.677013	17.431501	11.999721
196	Transformation, to industrial area, benthos	Raw	mm2	18.824249	19.476678	18.748861
197	Transformation, to industrial area, built up	Raw	cm2	44.72008	46.449669	33.064792
198	Transformation, to industrial area, vegetation	Raw	cm2	21.741554	21.862018	21.761081
199	Transformation, to mineral extraction site	Raw	sq.in	218.50769	229.34734	211.25284
200	Transformation, to pasture and meadow	Raw	mm2	199.05553	199.60545	198.20147

201	Transformation, to permanent crop, fruit, intensive	Raw	cm2	32.945986	32.963359	32.943872
202	Transformation, to sea and ocean	Raw	mm2	1.1382752	1.1403552	1.1326917
203	Transformation, to shrub land, sclerophyllous	Raw	cm2	13.314291	14.26773	6.3516478
204	Transformation, to traffic area, rail embankment	Raw	mm2	79.606951	80.1602	78.671965
205	Transformation, to traffic area, rail network	Raw	mm2	87.501862	88.109979	86.47415
206	Transformation, to traffic area, road embankment	Raw	cm2	199.11097	199.12041	199.10537
207	Transformation, to traffic area, road network	Raw	cm2	22.241584	22.870824	23.486597
208	Transformation, to unknown	Raw	mm2	255.7973	260.60341	243.18479
209	Transformation, to urban, discontinuously built	Raw	mm2	521.52958	521.54013	521.52319
210	Transformation, to water bodies, artificial	Raw	sq.in	195.73297	220.71255	6.4077793
211	Transformation, to water courses, artificial	Raw	mm2	738.59528	754.38849	723.73652
212	Ulexite, in ground	Raw	mg	9.763397	9.9003508	9.5755692
213	Uranium, 451 GJ per kg, in ground	Raw	mg	108	108	108
214	Uranium, 560 GJ per kg, in ground	Raw	mg	51.908818	51.908818	51.908818
215	Uranium, in ground	Raw	mg	497.01921	504.57445	485.01133
216	Vermiculite, in ground	Raw	mg	24.278187	24.34718	23.95302
217	Volume occupied, final repository for low-active radioactive waste	Raw	cm3	1.0183454	1.0339179	0.99351479
218	Volume occupied, final repository for radioactive waste	Raw	mm3	253.17565	257.09364	247.0428

219	Volume occupied, reservoir	Raw	m3y	81.10039	91.611006	1.3676255
220	Volume occupied, underground deposit	Raw	cm3	4.9041682	4.9951246	5.1421254
221	Water, cooling, unspecified natural origin/m3	Raw	m3	87.806348	99.161285	1.8712199
222	Water, lake	Raw	dm3	25.479146	25.551454	25.138741
223	Water, process and cooling, unspecified natural origin	Raw	m3	1.05	1.05	1.05
224	Water, river	Raw	m3	2.1064974	2.1627512	1.7277416
225	Water, salt, ocean	Raw	dm3	83.715166	85.820062	82.852101
226	Water, salt, sole	Raw	dm3	74.36167	78.452389	74.266576
227	Water, turbine use, unspecified natural origin	Raw	m3	4699.66	5271.0813	386.47989
228	Water, unspecified natural origin/kg	Raw	tn.lg	5.286261	5.286261	5.286261
229	Water, unspecified natural origin/m3	Raw	dm3	480.19894	496.95483	453.56111
230	Water, well, in ground	Raw	dm3	447.28115	448.55869	445.28503
231	Wood, dry matter	Raw	g	7.9572582	7.9572582	7.9572582
232	Wood, hard, standing	Raw	cu.in	915.22494	915.50875	914.8062
233	Wood, primary forest, standing	Raw	cm3	37.590777	37.622521	37.58692
234	Wood, soft, standing	Raw	dm3	70.242768	70.252542	70.237412
235	Wood, unspecified, standing/m3	Raw	mm3	6.1750154	6.2411823	6.883455
236	Zinc, 9.0% in sulfide, Zn 5.3%, Pb, Ag, Cd, In, in ground	Raw	g	25.772806	25.804225	26.336388
237	Zinc, in ground	Raw	mg	1.805478	1.805478	1.805478
238	Zirconium, 50% in zircon, 0.39% in crude ore, in ground	Raw	mg	2.8160485	2.8189449	2.813427
239	1-Propanol	Air	ng	802.52153	816.45613	782.47495
240	1,4-Butanediol	Air	ng	683.85508	684.58175	683.18416
241	2-Propanol	Air	mg	12.771114	12.784102	12.759442
242	Acenaphthene	Air	ng	76.717488	77.981615	74.995133
243	Acetaldehyde	Air	g	0.96487596	1.0641334	0.21467663
244	Acetic acid	Air	g	3.4482391	3.8525774	0.4004282
245	Acetone	Air	mg	799.75876	898.60079	51.410043

246	Acetonitrile	Air	mg	3.9471405	3.9504737	3.9467355
247	Acrolein	Air	µg	31.664677	32.028654	33.812367
248	Acrylic acid	Air	µg	33.042505	33.076161	33.01223
249	Actinides, radioactive, unspecified	Air	mBq	10.700956	10.829388	10.514215
250	Aerosols, radioactive, unspecified	Air	mBq	207.78623	211.04484	202.928
251	Aldehydes, unspecified	Air	µg	925.11133	937.82304	990.04439
252	Aluminum	Air	g	3.5326194	3.5692818	3.4682159
253	Americium-241	Air	µBq	399.62128	399.62128	399.62128
254	Ammonia	Air	g	25.396878	25.478947	25.113325
255	Ammonium carbonate	Air	µg	21.775923	22.14123	21.712557
256	Antimony	Air	mg	2.8948224	2.8976019	3.0406061
257	Antimony-124	Air	µBq	8.3297548	8.3540561	8.2425216
258	Antimony-125	Air	µBq	26.180502	26.434107	25.270151
259	Argon-41	Air	Bq	145.15788	146.8555	142.75678
260	Arsenic	Air	mg	57.539839	62.761175	19.930741
261	Arsine	Air	pg	385.15413	385.54643	384.80123
262	Barium	Air	mg	26.033945	26.114125	25.898391
263	Barium-140	Air	mBq	1.7380754	1.7545721	1.6788585
264	Benzal chloride	Air	pg	5.296327	5.3039641	5.3843857
265	Benzaldehyde	Air	µg	13.975403	14.12727	15.148999
266	Benzene	Air	g	2.1567083	2.206846	2.0586573
267	Benzene, ethyl-	Air	mg	133.41553	140.27446	133.21576
268	Benzene, hexachloro-	Air	µg	35.672532	36.278518	34.305534
269	Benzene, pentachloro-	Air	µg	16.10855	16.112049	16.123804
270	Benzo(a)pyrene	Air	mg	1.7907623	1.7894612	2.017076
271	Beryllium	Air	µg	398.91128	420.88095	234.11144
272	Boron	Air	mg	877.28503	881.95882	870.85224
273	Boron trifluoride	Air	pg	2.8744807	2.8774086	2.871847
274	Bromine	Air	mg	37.125931	37.639505	36.442743
275	Butadiene	Air	ng	397.88018	399.33089	398.35765
276	Butane	Air	g	6.7784299	7.0826388	6.7632377
277	Butanol	Air	ng	2.1199507	2.1222034	2.1178709
278	Butene	Air	mg	129.1492	136.00388	128.94152
279	Butyrolactone	Air	ng	197.89547	198.10576	197.70132
280	Cadmium	Air	mg	28.914149	31.448786	11.944344
281	Calcium	Air	g	2.9174187	2.9299914	2.8323752
282	Carbon-14	Air	Bq	911.65398	925.2107	889.73859
283	Carbon dioxide	Air	kg	140.66701	140.66701	140.66701

284	Carbon dioxide, biogenic	Air	kg	58.013257	58.031206	57.981058
285	Carbon dioxide, fossil	Air	kg	433.01249	451.23487	420.61161
286	Carbon dioxide, land transformation	Air	lb	122.02247	138.08023	0.12827974
287	Carbon disulfide	Air	mg	334.24502	336.58924	361.12901
288	Carbon monoxide	Air	kg	1.0811273	1.0811273	1.0811273
289	Carbon monoxide, biogenic	Air	g	7.8133646	7.8445019	7.6916537
290	Carbon monoxide, fossil	Air	oz	24.234421	20.521211	89.329644
291	Cerium-141	Air	µBq	403.02437	407.02353	388.66884
292	Cerium-144	Air	mBq	4.2499844	4.2499844	4.2499844
293	Cesium-134	Air	mBq	15.206997	15.207188	15.206309
294	Cesium-137	Air	mBq	29.651399	29.654795	29.639211
295	Chlorine	Air	mg	89.091649	90.636524	88.836745
296	Chloroform	Air	µg	40.64652	40.833691	40.353657
297	Chlorosilane, trimethyl-	Air	ng	593.60373	594.20836	593.05985
298	Chromium	Air	mg	256.26334	267.72787	178.00384
299	Chromium-51	Air	µBq	101.14158	101.39784	100.22168
300	Chromium VI	Air	mg	5.5623639	5.7453163	4.332572
301	Cobalt	Air	mg	217.59513	244.95085	11.739777
302	Cobalt-57	Air	nBq	36.842704	36.842704	36.842704
303	Cobalt-58	Air	µBq	645.25535	645.61221	643.97435
304	Cobalt-60	Air	mBq	1.2232078	1.2263603	1.2118914
305	Copper	Air	mg	134.87589	130.2656	237.18796
306	Cumene	Air	mg	12.250616	12.4466	14.462776
307	Curium-242	Air	nBq	2.1095305	2.1095305	2.1095305
308	Curium-244	Air	nBq	19.151564	19.151564	19.151564
309	Curium alpha	Air	µBq	634.31949	634.31949	634.31949
310	Cyanide	Air	mg	60.752324	60.798637	60.617298
311	Dinitrogen monoxide	Air	g	27.82087	28.267698	33.734618
312	Dioxins, measured as 2,3,7,8-tetrachlorodibenzo-p-dioxin	Air	ng	151.31189	159.7754	91.393761
313	Ethane	Air	g	8.7537365	8.8680822	8.7164528
314	Ethane, 1,1-difluoro-, HFC-152a	Air	µg	22.937711	23.335979	22.36474
315	Ethane, 1,1,1-trichloro-, HCFC-140	Air	ng	103.32184	104.56154	101.5194

316	Ethane, 1,1,1,2-tetrafluoro-, HFC-134a	Air	µg	26.729221	27.051503	26.215152
317	Ethane, 1,1,2-trichloro-1,2,2-trifluoro-, CFC-113	Air	µg	1.5681846	1.5697819	1.5667478
318	Ethane, 1,2-dichloro-	Air	mg	1.7777185	1.7949866	1.896333
319	Ethane, 1,2-dichloro-1,1,2,2-tetrafluoro-, CFC-114	Air	µg	827.93759	833.44933	818.88625
320	Ethane, dichloro-	Air	µg	48.034205	48.034205	48.034205
321	Ethane, hexafluoro-, HFC-116	Air	mg	1.665758	1.6745351	1.6294264
322	Ethanol	Air	g	1.5643589	1.7660019	0.036651148
323	Ethene	Air	g	2.024289	2.0395291	2.02207
324	Ethene, chloro-	Air	µg	883.63249	889.62973	903.48473
325	Ethene, tetrachloro-	Air	ng	246.86052	249.86558	242.5115
326	Ethyl acetate	Air	mg	59.309412	59.370954	59.253404
327	Ethyl cellulose	Air	µg	119.95701	120.07916	119.84717
328	Ethylene diamine	Air	ng	208.74806	210.05909	200.76964
329	Ethylene oxide	Air	mg	1.267663	1.2707732	1.29146
330	Ethyne	Air	mg	279.93912	280.02384	279.71815
331	Fluorine	Air	mg	4.7712703	4.8002624	4.8248058
332	Fluosilicic acid	Air	mg	1.7991294	1.8092475	1.756799
333	Formaldehyde	Air	g	2.8903146	3.1940944	0.59465805
334	Formic acid	Air	mg	26.474182	26.496551	26.471405
335	Furan	Air	mg	7.4963722	7.5027025	7.4956028
336	Heat, waste	Air	MWh	1.3648717	1.3708028	1.8336093
337	Helium	Air	mg	280.9646	293.44289	279.92367
338	Heptane	Air	g	1.2805626	1.3491082	1.2784924
339	Hexane	Air	g	2.9890164	3.1368539	2.9826889
340	Hydrocarbons, aliphatic, alkanes, cyclic	Air	mg	2.1087328	2.1127533	2.1419502
341	Hydrocarbons, aliphatic, alkanes, unspecified	Air	g	4.4460048	4.8668322	1.3709752
342	Hydrocarbons, aliphatic, alkenes, unspecified	Air	mg	3.7907747	3.7907747	3.7907747
343	Hydrocarbons,	Air	mg	633.90695	655.18873	479.5157

	aliphatic, unsaturated					
344	Hydrocarbons, aromatic	Air	mg	928.04933	935.4742	890.91164
345	Hydrocarbons, chlorinated	Air	mg	3.3017685	3.3078166	3.364419
346	Hydrocarbons, halogenated	Air	µg	14.4	14.4	14.4
347	Hydrocarbons, unspecified	Air	g	564	564	564
348	Hydrogen	Air	g	4.7870437	4.7984384	4.7871722
349	Hydrogen-3, Tritium	Air	kBq	5.2586639	5.3359668	5.1408913
350	Hydrogen chloride	Air	g	13.421475	13.484376	13.285614
351	Hydrogen fluoride	Air	g	1.0907836	1.1104423	0.99573986
352	Hydrogen peroxide	Air	µg	88.888895	88.980157	88.806389
353	Hydrogen sulfide	Air	g	1.85439	1.8575014	1.846853
354	Iodine	Air	mg	19.400116	19.673241	19.028871
355	Iodine-129	Air	mBq	975.23795	988.79781	954.34717
356	Iodine-131	Air	Bq	38.803891	39.474689	37.861989
357	Iodine-133	Air	mBq	10.273445	10.308968	10.176821
358	Iodine-135	Air	mBq	13.22279	13.257054	13.16679
359	Iron	Air	g	1.2351158	1.2632528	1.0343077
360	Iron-59	Air	nBq	834.72694	834.72694	834.72694
361	Isocyanic acid	Air	µg	676.84469	683.95306	665.95242
362	Isoprene	Air	µg	347.86173	348.15548	347.82603
363	Krypton-85	Air	kBq	1966.8082	1966.8136	1966.8007
364	Krypton-85m	Air	Bq	31.044914	31.367405	30.073598
365	Krypton-87	Air	Bq	10.055574	10.17286	9.7759001
366	Krypton-88	Air	Bq	102.74786	102.8681	102.42679
367	Krypton-89	Air	Bq	3.9508937	3.9848075	3.838361
368	Lanthanum	Air	µg	19.530045	19.530045	19.530045
369	Lanthanum-140	Air	µBq	194.45078	195.86068	189.38973
370	Lead	Air	mg	122.84601	129.00638	84.115827
371	Lead-210	Air	Bq	10.543988	10.618275	10.4319
372	m-Xylene	Air	mg	6.2447486	6.2585464	6.2268992
373	Magnesium	Air	mg	670.00758	670.51097	668.50294
374	Manganese	Air	mg	89.169177	97.844518	24.578861
375	Manganese-54	Air	µBq	34.961426	35.092662	34.490335
376	Mercury	Air	mg	11.935445	12.06135	12.668097
377	Metals, unspecified	Air	mg	600	600	600
378	Methane	Air	g	227.00602	227.00602	227.00602
379	Methane, biogenic	Air	oz	37.454395	42.31919	0.52844487

380	Methane, bromo-, Halon 1001	Air	pg	1.2115246	1.2132715	1.2316678
381	Methane, bromochlorodifluoro-, Halon 1211	Air	mg	1.8428799	1.8471731	1.8337373
382	Methane, bromotrifluoro-, Halon 1301	Air	mg	8.0445146	8.2221703	8.0370982
383	Methane, chlorodifluoro-, HCFC-22	Air	mg	6.5678167	6.584809	6.532429
384	Methane, chlorotrifluoro-, CFC-13	Air	µg	2.2215507	2.2215507	2.2215507
385	Methane, dichloro-, HCC-30	Air	mg	11.601925	11.601953	11.60192
386	Methane, dichlorodifluoro-, CFC-12	Air	µg	16.179703	16.227771	16.058022
387	Methane, dichlorofluoro-, HCFC-21	Air	mg	16.786886	16.786886	16.786886
388	Methane, fossil	Air	g	473.95449	485.13329	455.84113
389	Methane, monochloro-, R-40	Air	µg	2.7773229	2.8104668	2.7290192
390	Methane, tetrachloro-, CFC-10	Air	mg	2.054789	2.0573206	2.055743
391	Methane, tetrafluoro-, CFC-14	Air	mg	14.015243	14.093177	13.689246
392	Methane, trichlorofluoro-, CFC-11	Air	µg	16.473108	16.473133	16.473079
393	Methane, trifluoro-, HFC-23	Air	µg	3.3664386	3.3715266	3.3607679
394	Methanol	Air	g	1.6757276	1.8795146	0.14207197
395	Methyl acrylate	Air	µg	37.489763	37.527949	37.455413
396	Methyl amine	Air	ng	71.334565	71.410367	71.26458
397	Methyl borate	Air	pg	12.655798	12.668688	12.644202
398	Methyl ethyl ketone	Air	mg	59.309327	59.37087	59.25332
399	Methyl formate	Air	ng	145.39639	145.54425	145.26351
400	Molybdenum	Air	mg	50.195703	56.161174	5.7113207
401	Monoethanolamine	Air	mg	266.49403	266.49865	266.4952
402	Neptunium-237	Air	nBq	20.932543	20.932543	20.932543

403	Nickel	Air	g	0.95444239	1.0577226	0.19941973
404	Niobium-95	Air	µBq	5.4161727	5.4317516	5.3602502
405	Nitrate	Air	µg	165.84555	176.47602	94.561568
406	Nitrogen	Air	mg	37.198474	37.198474	37.198474
407	Nitrogen oxides	Air	kg	2.903719	2.7601801	6.124663
408	NMVOC, non-methane volatile organic compounds, unspecified origin	Air	kg	2.3701384	2.3585203	2.6398003
409	Noble gases, radioactive, unspecified	Air	kBq	8274.6957	8405.0005	8073.9482
410	Ozone	Air	mg	321.99792	326.60798	315.03037
411	PAH, polycyclic aromatic hydrocarbons	Air	mg	27.286096	27.770052	25.121345
412	Paraffins	Air	ng	89.251342	89.670719	90.481911
413	Particulates	Air	g	228	228	228
414	Particulates, < 10 um (mobile)	Air	mg	76.119265	76.119265	76.119265
415	Particulates, < 10 um (stationary)	Air	mg	645.02562	645.02562	645.02562
416	Particulates, < 2.5 um	Air	g	98.068635	69.445457	576.34959
417	Particulates, > 10 um	Air	g	148.16569	161.48576	52.381755
418	Particulates, > 10 um (process)	Air	g	1.2061357	1.2061357	1.2061357
419	Particulates, > 2.5 um, and < 10um	Air	g	42.732251	45.493703	24.006084
420	Pentane	Air	g	8.5613683	8.9351512	8.5524709
421	Phenol	Air	mg	28.62717	28.649969	28.677491
422	Phenol, pentachloro-	Air	µg	218.0394	221.65576	213.01482
423	Phosphine	Air	ng	28.561482	28.590574	28.535312
424	Phosphorus	Air	mg	25.417872	25.469695	25.352096
425	Phosphorus, total	Air	µg	596.70251	596.70251	596.70251
426	Platinum	Air	ng	318.30045	318.48517	318.02609
427	Plutonium-238	Air	nBq	165.09104	166.94082	162.24119
428	Plutonium-241	Air	mBq	34.887572	34.887572	34.887572
429	Plutonium-alpha	Air	mBq	1.268924	1.2689283	1.2689175
430	Polonium-210	Air	Bq	18.827894	18.958769	18.630331
431	Polychlorinated biphenyls	Air	µg	51.431993	52.475825	49.119221
432	Potassium	Air	g	1.3937123	1.3965583	1.3897587
433	Potassium-40	Air	Bq	2.6722491	2.6889435	2.6469537

434	Promethium-147	Air	mBq	10.783431	10.783431	10.783431
435	Propanal	Air	µg	14.325284	14.484314	15.488577
436	Propane	Air	g	8.4441037	8.7734614	8.270575
437	Propene	Air	mg	571.47825	585.46852	571.54368
438	Propionic acid	Air	mg	23.19239	23.231897	23.082514
439	Propylene oxide	Air	mg	4.6029772	4.6196268	4.5901074
440	Protactinium-234	Air	mBq	134.61471	136.47026	131.65652
441	Radioactive species, other beta emitters	Air	Bq	61.675932	61.747047	61.505903
442	Radioactive species, unspecified	Air	kBq	9600	9600	9600
443	Radium-226	Air	Bq	7.109993	7.1892803	6.9863957
444	Radium-228	Air	Bq	5.3041329	5.3153367	5.2768838
445	Radon-220	Air	Bq	48.111926	48.826933	47.129616
446	Radon-222	Air	kBq	18953.151	19198.488	18562.302
447	Ruthenium-103	Air	nBq	560.98789	564.41067	548.70134
448	Ruthenium-106	Air	mBq	126.8639	126.8639	126.8639
449	Scandium	Air	µg	129.03069	129.22681	128.46283
450	Selenium	Air	mg	39.66038	43.597726	11.188491
451	Silicon	Air	g	7.0275612	7.0296138	7.0214378
452	Silicon tetrafluoride	Air	µg	53.128843	53.560144	53.126948
453	Silver	Air	µg	3.7266566	3.7917516	3.6292972
454	Silver-110	Air	µBq	24.881378	24.9153	24.759609
455	Sodium	Air	g	1.2727341	1.3892545	0.42478872
456	Sodium chlorate	Air	mg	17.656323	17.661132	17.656145
457	Sodium dichromate	Air	µg	310.74318	312.6749	308.61378
458	Sodium formate	Air	mg	12.017656	12.017696	12.017532
459	Sodium hydroxide	Air	µg	331.4515	331.79021	331.14618
460	Strontium	Air	mg	30.111068	30.195309	29.958346
461	Strontium-89	Air	µBq	38.114773	38.114773	38.114773
462	Strontium-90	Air	mBq	20.939747	20.939747	20.939747
463	Styrene	Air	µg	647.59531	648.52309	682.74197
464	Sulfate	Air	g	3.3242497	3.3375243	3.32107
465	Sulfur dioxide	Air	oz	102.17278	113.48179	24.913158
466	Sulfur hexafluoride	Air	mg	4.4085984	4.476549	4.314188
467	Sulfur oxides	Air	kg	1.516333	1.516333	1.516333
468	Sulfuric acid	Air	µg	69.4137	69.485528	69.348444
469	t-Butyl methyl ether	Air	mg	1.0673022	1.0676729	1.0662538
470	Technetium-99	Air	nBq	888.04729	888.04729	888.04729
471	Tellurium-123m	Air	µBq	95.840493	95.840493	95.840493

472	Terpenes	Air	mg	3.2892838	3.2920614	3.2889462
473	Thallium	Air	µg	161.24951	164.15916	141.71708
474	Thorium	Air	µg	292.09629	292.34448	291.33945
475	Thorium-228	Air	mBq	933.44401	937.07793	927.47899
476	Thorium-230	Air	mBq	728.29186	735.9346	717.35941
477	Thorium-232	Air	mBq	753.9626	759.25937	746.11464
478	Thorium-234	Air	mBq	134.64038	136.49628	131.68162
479	Tin	Air	mg	3.1879184	3.2129045	3.2303828
480	Titanium	Air	mg	45.552276	45.599706	45.405973
481	Toluene	Air	g	1.262079	1.3057985	1.2584591
482	Uranium	Air	µg	429.62282	429.87625	428.77627
483	Uranium-234	Air	Bq	1.7053949	1.7277574	1.670988
484	Uranium-235	Air	mBq	76.095141	77.142217	74.425228
485	Uranium-238	Air	Bq	3.7430741	3.77852	3.6890401
486	Uranium alpha	Air	Bq	7.0721083	7.1729818	6.9112318
487	Vanadium	Air	g	2.9068331	3.2559213	0.29795389
488	water	Air	g	3.3081859	3.3626265	3.2155493
489	Xenon-131m	Air	Bq	48.260574	48.809263	46.886033
490	Xenon-133	Air	kBq	2.8755686	2.8934086	2.8283401
491	Xenon-133m	Air	Bq	4.974575	5.0413805	4.8601478
492	Xenon-135	Air	Bq	834.45522	841.74039	815.35854
493	Xenon-135m	Air	Bq	383.67858	388.02226	371.98227
494	Xenon-137	Air	Bq	9.4156034	9.5085427	9.1074165
495	Xenon-138	Air	Bq	77.744499	78.533047	75.314008
496	Xylene	Air	g	1.0406908	1.0716135	1.0352661
497	Zinc	Air	mg	378.22401	394.10386	304.80525
498	Zinc-65	Air	µBq	159.23485	159.89015	156.88258
499	Zirconium	Air	µg	67.995071	69.148307	65.581197
500	Zirconium-95	Air	µBq	65.626893	66.267419	63.327638
501	1,4-Butanediol	Water	ng	273.54401	273.83468	273.27564
502	4-Methyl-2-pentanone	Water	ng	31.432397	31.477722	31.955004
503	Acenaphthene	Water	µg	37.410925	39.457216	37.359178
504	Acenaphthylene	Water	µg	231.79718	231.92516	231.79395
505	Acetaldehyde	Water	µg	392.90151	393.30878	392.53111
506	Acetic acid	Water	mg	3.8708214	3.9130597	4.3573562
507	Acetone	Water	ng	74.91782	75.025848	76.163431
508	Acidity, unspecified	Water	mg	105.57953	105.63761	105.58675
509	Acids, unspecified	Water	µg	242.31315	242.31315	242.31315
510	Acrylate, ion	Water	µg	78.203407	78.283063	78.131754
511	Actinides, radioactive,	Water	Bq	1.3986011	1.420626	1.3646686

	unspecified					
512	Aluminum	Water	g	98.012862	100.18621	85.978434
513	Americium-241	Water	mBq	52.648518	52.648518	52.648518
514	Ammonia, as N	Water	mg	20.295599	20.295599	20.295599
515	Ammonium, ion	Water	g	8.9875688	8.9919525	9.1539988
516	Antimony	Water	mg	193.03477	193.2691	192.8076
517	Antimony-122	Water	mBq	1.245497	1.2552944	1.2103279
518	Antimony-124	Water	mBq	294.8704	298.55871	288.46201
519	Antimony-125	Water	mBq	255.31368	258.67402	249.44516
520	AOX, Adsorbable Organic Halogen as Cl	Water	mg	230.16644	232.21823	216.61739
521	Arsenic, ion	Water	mg	88.525497	90.344054	80.431426
522	Barite	Water	g	26.687097	27.882822	26.64439
523	Barium	Water	g	9.7493464	10.045831	9.7297524
524	Barium-140	Water	mBq	4.5667747	4.6096925	4.4127153
525	Benzene	Water	mg	436.41276	459.12604	441.34171
526	Benzene, 1,2-dichloro-	Water	µg	91.965355	92.063079	91.87513
527	Benzene, chloro-	Water	mg	1.8990114	1.9010293	1.8971483
528	Benzene, ethyl-	Water	mg	144.60623	152.50272	144.40565
529	Beryllium	Water	mg	6.9269432	7.0014227	6.8245978
530	BOD5, Biological Oxygen Demand	Water	kg	1.5040895	1.5762736	1.4973673
531	Boron	Water	mg	742.12547	754.9101	728.71275
532	Bromate	Water	mg	78.464315	78.723903	78.412736
533	Bromine	Water	g	4.5862376	4.8169795	4.584411
534	Butanol	Water	µg	215.21807	215.44139	215.01483
535	Butene	Water	µg	89.498977	89.826706	87.899966
536	Butyl acetate	Water	µg	279.78044	280.07076	279.51624
537	Butyrolactone	Water	ng	474.95779	475.46249	474.49182
538	Cadmium-109	Water	µBq	1.5206121	1.5206121	1.5206121
539	Cadmium, ion	Water	mg	21.905369	22.249743	20.229738
540	Calcium, ion	Water	g	697.72697	720.0096	618.32611
541	Carbon-14	Water	Bq	2.6641419	2.6641419	2.6641419
542	Carbonate	Water	mg	49.035167	49.423283	49.473035
543	Carboxylic acids, unspecified	Water	g	26.009673	27.435796	25.975612
544	Cerium-141	Water	mBq	1.7600263	1.7771855	1.6984308
545	Cerium-144	Water	Bq	1.2057421	1.2057473	1.2057233
546	Cesium	Water	mg	6.0248027	6.3537884	6.0164832
547	Cesium-134	Water	Bq	2.9114371	2.9144334	2.9068843
548	Cesium-136	Water	µBq	306.80337	309.8488	295.87138

549	Cesium-137	Water	Bq	186.03436	188.56952	182.11876
550	Chlorate	Water	mg	994.6081	996.83585	994.25583
551	Chloride	Water	kg	6.5016478	6.7079278	6.4200075
552	Chlorinated solvents, unspecified	Water	µg	221.15961	222.18954	224.26454
553	Chlorine	Water	mg	16.146362	16.236886	15.893358
554	Chloroform	Water	µg	19.46907	19.473526	19.465058
555	Chromium	Water	mg	96	96	96
556	Chromium-51	Water	mBq	443.76372	448.47731	430.2622
557	Chromium VI	Water	mg	634.71106	647.17669	608.84666
558	Chromium, ion	Water	mg	66.748452	68.983415	56.784362
559	Cobalt	Water	mg	366.55108	370.87001	350.76148
560	Cobalt-57	Water	mBq	9.9641796	10.060853	9.617157
561	Cobalt-58	Water	Bq	2.8707402	2.9028941	2.7960043
562	Cobalt-60	Water	Bq	13.811309	13.836931	13.74894
563	COD, Chemical Oxygen Demand	Water	kg	2.1255149	2.1988786	2.1187879
564	Copper, ion	Water	g	7.4080857	7.425117	7.298494
565	Cumene	Water	mg	29.437979	29.908926	34.753769
566	Curium alpha	Water	mBq	69.775144	69.775144	69.775144
567	Cyanide	Water	mg	55.521368	56.367277	56.251387
568	Dichromate	Water	µg	431.97314	439.13585	424.10108
569	DOC, Dissolved Organic Carbon	Water	kg	1.2305561	1.2527637	1.2280742
570	Ethane, 1,1,1-trichloro-, HCFC-140	Water	ng	125.45551	125.45551	125.45551
571	Ethane, 1,2-dichloro-	Water	µg	439.61479	442.93395	438.78024
572	Ethane, dichloro-	Water	µg	24.708923	24.708923	24.708923
573	Ethane, hexachloro-	Water	pg	548.94696	548.94696	548.94696
574	Ethanol	Water	µg	495.20547	495.71931	494.73783
575	Ethene	Water	mg	12.825083	13.012747	15.13471
576	Ethene, chloro-	Water	µg	10.83459	10.896862	10.874257
577	Ethene, tetrachloro-	Water	ng	65.187452	65.187452	65.187452
578	Ethene, trichloro-	Water	µg	4.1171022	4.1171022	4.1171022
579	Ethyl acetate	Water	ng	33.778875	33.81363	33.747412
580	Ethylene diamine	Water	ng	506.05591	509.23416	486.71427
581	Ethylene oxide	Water	µg	426.2135	426.2554	426.18363
582	Fatty acids as C	Water	mg	51.129999	51.129999	51.129999
583	Fluoride	Water	g	7.5438382	7.6615426	6.9437667
584	Fluosilicic acid	Water	mg	3.2384329	3.2566454	3.1622382
585	Formaldehyde	Water	mg	2.1044216	2.129779	2.3869567

586	Glutaraldehyde	Water	mg	3.2947034	3.4423238	3.2894309
587	Heat, waste	Water	MJ	880.87418	983.35168	136.06294
588	Hydrocarbons, aliphatic, alkanes, unspecified	Water	mg	783.22428	825.99241	782.14274
589	Hydrocarbons, aliphatic, alkenes, unspecified	Water	µg	122.17723	122.17723	122.17723
590	Hydrocarbons, aliphatic, unsaturated	Water	mg	72.175418	76.123245	72.075584
591	Hydrocarbons, aromatic	Water	g	4.06243	4.2379632	4.0579767
592	Hydrocarbons, chlorinated	Water	mg	1.2	1.2	1.2
593	Hydrocarbons, unspecified	Water	mg	661.4386	700.0969	541.65536
594	Hydrogen-3, Tritium	Water	kBq	448.46095	454.26555	439.51085
595	Hydrogen peroxide	Water	mg	49.518501	49.519992	49.515349
596	Hydrogen sulfide	Water	g	1.3783809	1.4949147	0.50476248
597	Hydroxide	Water	mg	2.4754097	2.4782893	2.4726142
598	Hypochlorite	Water	g	2.0345921	2.2995239	0.025364748
599	Hypochlorous acid	Water	mg	8.4327613	8.4327613	8.4327613
600	Iodide	Water	mg	604.35278	637.28194	603.47761
601	Iodine-129	Water	Bq	7.6118339	7.6118339	7.6118339
602	Iodine-131	Water	mBq	55.28988	55.971136	54.02206
603	Iodine-133	Water	mBq	3.9054513	3.9323941	3.8087362
604	Iron	Water	g	13.45189	13.45189	13.45189
605	Iron-59	Water	µBq	747.4399	754.84707	720.85086
606	Iron, ion	Water	g	151.17116	152.15545	148.02749
607	Kjeldahl-N	Water	mg	336	336	336
608	Lanthanum-140	Water	mBq	4.6383721	4.6840831	4.4742862
609	Lead	Water	mg	540.14121	548.79089	492.52456
610	Lead-210	Water	Bq	38.0655	38.25917	38.021819
611	Lithium, ion	Water	mg	8.0589831	8.0706038	8.1929747
612	m-Xylene	Water	ng	227.1168	227.44429	230.89292
613	Magnesium	Water	g	80.369603	82.553647	78.768595
614	Manganese	Water	g	13.143169	13.174706	13.058175
615	Manganese-54	Water	Bq	1.9504542	1.9524253	1.945908
616	Mercury	Water	mg	2.5788264	2.6908744	1.934783
617	Metallic ions, unspecified	Water	g	7.2	7.2	7.2

618	Methane, dichloro-, HCC-30	Water	mg	73.650549	77.52091	73.553507
619	Methane, tetrachloro-, CFC-10	Water	ng	99.496637	99.496637	99.496637
620	Methanol	Water	mg	26.355134	26.410387	26.316789
621	Methyl acrylate	Water	µg	732.37349	733.11947	731.70246
622	Methyl amine	Water	ng	171.19993	171.38185	171.03197
623	Methyl formate	Water	ng	58.048406	58.10744	57.995355
624	Molybdenum	Water	mg	43.875543	44.443333	43.142596
625	Molybdenum-99	Water	mBq	1.5987954	1.6145556	1.5422221
626	Neptunium-237	Water	mBq	3.3618933	3.3618933	3.3618933
627	Nickel, ion	Water	g	2.5824276	2.716806	1.6541273
628	Niobium-95	Water	mBq	26.173728	26.455291	25.66669
629	Nitrate	Water	g	435.44254	435.4858	435.42683
630	Nitrite	Water	mg	112.39568	112.49586	112.39192
631	Nitrogen	Water	g	35.483565	38.592045	12.025393
632	Nitrogen, organic bound	Water	g	1.1812633	1.2871985	0.56068749
633	Nitrogen, total	Water	mg	73.580899	73.580899	73.580899
634	o-Xylene	Water	ng	165.43367	165.67222	168.18423
635	Oils, unspecified	Water	g	400.97837	423.44293	400.23492
636	PAH, polycyclic aromatic hydrocarbons	Water	mg	47.836457	49.752484	47.864012
637	Paraffins	Water	ng	259.01613	260.2332	262.58736
638	Phenol	Water	mg	581.48554	613.83017	574.4394
639	Phenols, unspecified	Water	mg	133.40862	133.40862	133.40862
640	Phosphate	Water	g	15.949855	16.022757	15.840461
641	Phosphorus	Water	g	1.995532	2.0041984	1.9424079
642	Phosphorus compounds, unspecified	Water	µg	7.8922632	7.8922632	7.8922632
643	Phthalate, dimethyl tere-	Water	ng	146.27915	146.27915	146.27915
644	Phthalate, dioctyl-	Water	ng	3.1378227	3.1378227	3.1378227
645	Phthalate, p-dibutyl-	Water	ng	23.232571	23.232571	23.232571
646	Plutonium-241	Water	Bq	5.2014198	5.2014198	5.2014198
647	Plutonium-alpha	Water	mBq	209.32543	209.32543	209.32543
648	Polonium-210	Water	Bq	56.940819	57.22016	56.896559
649	Potassium	Water	mg	354.76662	354.76662	354.76662
650	Potassium-40	Water	Bq	7.0735876	7.1319482	7.0198796
651	Potassium, ion	Water	g	71.211083	72.9297	69.731618

652	Propene	Water	mg	20.26542	20.475063	22.197052
653	Propylene oxide	Water	mg	11.074839	11.114901	11.043873
654	Protactinium-234	Water	Bq	2.4808829	2.5151011	2.4263106
655	Radioactive species, unspecified	Water	kBq	90	90	90
656	Radioactive species, alpha emitters	Water	mBq	73.898707	74.38595	73.892672
657	Radioactive species, from fission and activation	Water	mBq	157.7361	157.7361	157.7361
658	Radioactive species, Nuclides, unspecified	Water	Bq	838.96344	852.17196	818.61377
659	Radium-224	Water	Bq	301.2318	317.68108	300.81582
660	Radium-226	Water	kBq	2.8898217	2.9376267	2.8551848
661	Radium-228	Water	Bq	602.47757	635.37615	601.64585
662	Rubidium	Water	mg	60.232978	63.524157	60.147674
663	Ruthenium	Water	µg	101.61235	101.61235	101.61235
664	Ruthenium-103	Water	µBq	421.65575	424.98129	409.71827
665	Ruthenium-106	Water	Bq	12.68639	12.68639	12.68639
666	Salts, unspecified	Water	g	2.6932746	2.6932746	2.6932746
667	Scandium	Water	mg	9.4067687	9.5713326	9.1740185
668	Selenium	Water	mg	26.301101	26.501325	26.088884
669	Silicon	Water	g	545.55073	552.67528	527.23698
670	Silver	Water	µg	7.0384251	7.0384251	7.0384251
671	Silver-110	Water	Bq	2.1255624	2.1496489	2.0658789
672	Silver, ion	Water	mg	4.9873573	5.2506229	4.9793199
673	Sodium-24	Water	mBq	20.058551	20.177796	19.630502
674	Sodium formate	Water	mg	28.871686	28.871782	28.871388
675	Sodium, ion	Water	kg	2.6789655	2.7800792	2.6730277
676	Solids, inorganic	Water	g	64.315911	65.008563	63.407481
677	Solved solids	Water	g	5.1465195	5.2095722	5.1024177
678	Solved substances	Water	mg	431.0917	431.0917	431.0917
679	Solved substances, inorganic	Water	g	136.8	136.8	136.8
680	Strontium	Water	g	11.939566	12.544906	11.910994
681	Strontium-89	Water	mBq	43.40433	43.849076	42.208085
682	Strontium-90	Water	kBq	1.075662	1.0942036	1.0496246
683	Sulfate	Water	oz	49.194486	52.164875	27.648019
684	Sulfide	Water	mg	192.85833	213.52389	38.865053
685	Sulfite	Water	g	5.2227027	5.9053609	0.045724847

686	Sulfur	Water	g	2.1965485	2.2566724	2.195559
687	Sulfur trioxide	Water	mg	1.0464102	1.0464102	1.0464102
688	Suspended solids, unspecified	Water	g	214.45167	219.63673	209.854
689	Suspended substances, unspecified	Water	g	36.6	36.6	36.6
690	t-Butyl methyl ether	Water	mg	12.697545	13.41257	12.689729
691	Technetium-99	Water	Bq	1.3320709	1.3320709	1.3320709
692	Technetium-99m	Water	mBq	36.555487	36.919679	35.252764
693	Tellurium-123m	Water	mBq	27.24241	27.632375	26.634182
694	Tellurium-132	Water	µBq	96.057161	96.969707	92.781454
695	Thallium	Water	mg	13.560276	14.982544	2.8543262
696	Thorium-228	Water	kBq	1.2053672	1.2711663	1.2037032
697	Thorium-230	Water	Bq	343.17143	347.84016	335.72557
698	Thorium-232	Water	mBq	510.15619	517.36695	500.16609
699	Thorium-234	Water	Bq	2.483132	2.5173539	2.4285536
700	Tin, ion	Water	mg	346.34722	346.67598	345.38119
701	Titanium, ion	Water	g	4.8807458	4.908031	4.8301618
702	TOC, Total Organic Carbon	Water	g	540.03793	562.63622	534.86236
703	Toluene	Water	mg	858.74169	898.124	875.5968
704	Tributyltin	Water	µg	27.893682	27.893682	27.893682
705	Tributyltin compounds	Water	mg	6.312325	6.6333586	6.281341
706	Triethylene glycol	Water	mg	22.261119	22.299589	22.159898
707	Tungsten	Water	mg	7.497362	7.6165268	7.3322091
708	Undissolved substances	Water	mg	796.04017	796.04017	796.04017
709	Uranium-234	Water	Bq	3.0091462	3.050208	2.9436594
710	Uranium-235	Water	Bq	4.9147896	4.9825416	4.8067364
711	Uranium-238	Water	Bq	26.980625	27.182597	26.794399
712	Uranium alpha	Water	Bq	144.74595	146.71735	141.60191
713	Vanadium, ion	Water	g	1.0498356	1.1305689	0.46176921
714	VOC, volatile organic compounds as C	Water	mg	3.506245	3.506245	3.506245
715	VOC, volatile organic compounds, unspecified origin	Water	g	2.1107068	2.2259372	2.1076597
716	Xylene	Water	mg	616.40977	650.16556	615.29177
717	Yttrium-90	Water	µBq	30.376155	30.376155	30.376155
718	Zinc-65	Water	mBq	179.22422	180.84092	173.42084
719	Zinc, ion	Water	g	4.7727608	4.8843944	4.5792171

720	Zirconium-95	Water	mBq	109.74802	109.76675	109.68082
721	Mineral waste, from mining	Waste	kg	1.8	1.8	1.8
722	pineapple peels	Waste	tn.lg	2.2636748	2.2636748	2.2636748
723	Waste in bioactive landfill	Waste	g	840	840	840
724	Waste in incineration	Waste	g	66	66	66
725	Water	Waste	tn.lg	4.9210322	4.9210322	4.9210322
726	2,4-D	Soil	mg	1.3241176	1.3252358	1.3239817
727	Aclonifen	Soil	µg	425.60113	425.72514	425.51841
728	Aldrin	Soil	ng	849.84083	850.70932	849.05797
729	Aluminum	Soil	g	2.972809	3.1260526	2.9688059
730	Antimony	Soil	ng	111.77749	112.11281	110.5646
731	Arsenic	Soil	mg	1.189092	1.2503536	1.1874146
732	Atrazine	Soil	ng	222.94792	223.17576	222.74254
733	Barium	Soil	g	1.4527214	1.5291627	1.4508225
734	Benomyl	Soil	µg	8.4409181	8.4480461	8.4400519
735	Bentazone	Soil	µg	217.20715	217.27043	217.16493
736	Boron	Soil	mg	31.888989	33.466888	31.802106
737	Cadmium	Soil	mg	1.1464925	1.1468144	1.1461449
738	Calcium	Soil	g	12.358083	12.974188	12.339199
739	Carbetamide	Soil	mg	3.5135338	3.513562	3.5134807
740	Carbofuran	Soil	mg	4.6276327	4.6315405	4.6271578
741	Carbon	Soil	g	13.716717	14.176283	13.709353
742	Chloride	Soil	g	106.70804	107.31566	106.50009
743	Chlorothalonil	Soil	g	3.3878921	3.3878978	3.3878545
744	Chromium	Soil	mg	16.462549	17.230674	16.440739
745	Chromium VI	Soil	mg	15.925485	16.200237	15.623445
746	Cobalt	Soil	µg	44.305048	44.589633	43.924293
747	Copper	Soil	mg	82.636485	82.817424	82.455759
748	Cypermethrin	Soil	µg	829.84623	830.39879	829.7769
749	Fenpiclonil	Soil	mg	133.35946	133.35969	133.35798
750	Fluoride	Soil	mg	156.04519	163.87507	155.64906
751	Glyphosate	Soil	mg	13.725937	13.751415	13.693324
752	Heat, waste	Soil	MJ	2.4825833	2.5267376	2.4494878
753	Iron	Soil	g	10.408067	10.744843	10.35738
754	Lead	Soil	mg	12.85808	12.862314	12.849809
755	Linuron	Soil	mg	3.2790948	3.2800504	3.2784573
756	Magnesium	Soil	g	2.4008142	2.5236253	2.3972307
757	Mancozeb	Soil	g	4.4001738	4.4001812	4.400125

758	Manganese	Soil	mg	163.42082	169.84306	162.90802
759	Mercury	Soil	µg	825.74658	825.75232	825.73068
760	Metaldehyde	Soil	mg	1.5289692	1.528976	1.5289496
761	Metolachlor	Soil	mg	23.732481	23.739395	23.727868
762	Metribuzin	Soil	mg	154.93294	154.9332	154.93122
763	Molybdenum	Soil	µg	9.9108807	9.9739121	9.8231324
764	Napropamide	Soil	mg	2.7050938	2.7051058	2.7050591
765	Nickel	Soil	mg	14.946313	14.948378	14.943561
766	Nitrogen	Soil	µg	12.485862	12.485862	12.485862
767	Oils, biogenic	Soil	mg	536.62966	536.88594	536.43122
768	Oils, unspecified	Soil	g	419.18597	442.87384	418.83325
769	Orbencarb	Soil	mg	836.65326	836.65466	836.64398
770	Phosphorus	Soil	mg	168.75607	176.54859	168.37046
771	Pirimicarb	Soil	µg	20.546378	20.552365	20.542385
772	Potassium	Soil	g	1.1434589	1.1977928	1.1410387
773	Silicon	Soil	mg	490.97706	507.56341	488.86414
774	Sodium	Soil	g	7.458939	7.7648647	7.4506927
775	Strontium	Soil	mg	29.256317	30.79124	29.282888
776	Sulfur	Soil	g	1.7773044	1.8691941	1.7747751
777	Sulfuric acid	Soil	ng	42.842222	42.88586	42.802968
778	Tebutam	Soil	mg	6.4098166	6.4098449	6.4097344
779	Teflubenzuron	Soil	mg	10.328863	10.32888	10.328748
780	Thiram	Soil	µg	14.975194	14.987839	14.973657
781	Tin	Soil	µg	5.7307963	5.7605433	5.667519
782	Titanium	Soil	mg	3.2055052	3.2264243	3.178193
783	Vanadium	Soil	µg	91.751751	92.350523	90.969989
784	Zinc	Soil	mg	841.2304	843.76387	840.7066

Title: Comparing 1 p 'Sliced pineapple using hybrid electricity ', 1 p 'Sliced Pineapple using grid' and 1 p 'Sliced pineapple using generator'						
Method: Eco-indicator 99 (H) V2.06 / Europe EI 99 H/H						
Per sub-compartment: No						
Skip unused: Yes						
Indicator: Characterization						
Category: Carcinogens						
Cut-off: 0.60%						
Relative mode: Non						
No	**Substance**	**Compartment**	**Unit**	**Sliced pineapple using hybrid**	**Sliced Pineapple using grid**	**Sliced pineapple using generator**
	Total		DALY	1.70E-05	1.74E-05	1.78E-05
	Remaining substances		DALY	1.51E-07	1.60E-07	9.84E-08
1	Arsenic	Air	DALY	1.42E-06	1.54E-06	4.90E-07
2	Cadmium	Air	DALY	3.90E-06	4.25E-06	1.61E-06
3	Metals, unspecified	Air	DALY	4.18E-07	4.18E-07	4.18E-07
4	Particulates, < 2.5 um	Air	DALY	9.59E-07	6.79E-07	5.64E-06
5	Arsenic, ion	Water	DALY	5.82E-06	5.94E-06	5.28E-06
6	Cadmium, ion	Water	DALY	1.56E-06	1.58E-06	1.44E-06
7	Metallic ions, unspecified	Water	DALY	3.08E-07	3.08E-07	3.08E-07
8	PAH, polycyclic aromatic hydrocarbons	Water	DALY	1.24E-07	1.29E-07	1.24E-07
9	Cadmium	Soil	DALY	2.38E-06	2.38E-06	2.38E-06

Title: Comparing 1 p 'Sliced pineapple using hybrid electricity', 1 p 'Sliced Pineapple using grid' and 1 p 'Sliced pineapple using generator'						
Method: Eco-indicator 99 (H) V2.06 / Europe EI 99 H/H						
Per sub-compartment: No						
Skip unused: Yes						
Indicator: Characterization						
Category: Resp. organics						
Cut-off: 0.60%						
Relative mode: Non						
No	**Substance**	**Compartment**	**Unit**	**Sliced pineapple using hybrid**	**Sliced Pineapple using grid**	**Sliced pineapple using generator**
	Total		DALY	3.83E-06	3.82E-06	4.15E-06
	Remaining substances		DALY	7.07E-08	7.50E-08	4.81E-08
1	NMVOC, non-methane volatile organic compounds, unspecified origin	Air	DALY	3.03E-06	3.02E-06	3.38E-06
2	Hydrocarbons, unspecified	Air	DALY	7.22E-07	7.22E-07	7.22E-07

Title: Comparing 1 p 'Sliced pineapple using hybrid electricity', 1 p 'Sliced Pineapple using grid' and 1 p 'Sliced pineapple using generator'						
Method: Eco-indicator 99 (H) V2.06 / Europe EI 99 H/H						
Per sub-compartment: No						
Skip unused: Yes						
Indicator: Characterization						
Category: Resp. inorganics						
Cut-off: 0.60%						
Relative mode: Non						
No	**Substance**	**Compartment**	**Unit**	**Sliced pineapple using hybrid**	**Sliced Pineapple using grid**	**Sliced pineapple using generator**
	Total		DALY	0.000610867	0.000596647	0.001104726
	Remaining substances		DALY	2.61E-06	2.62E-06	2.59E-06
1	Nitrogen oxides	Air	DALY	0.0002575 6	0.000244828	0.000543258
2	Sulfur dioxide	Air	DALY	0.000158152	0.000175657	3.86E-05
3	Sulfur oxides	Air	DALY	8.28E-05	8.28E-05	8.28E-05
4	Particulates, < 2.5 um	Air	DALY	6.86E-05	4.86E-05	0.000403445
5	Particulates	Air	DALY	2.51E-05	2.51E-05	2.51E-05
6	Particulates, > 2.5 um, and < 10um	Air	DALY	1.60E-05	1.71E-05	9.00E-06

Title: Comparing 1 p 'Sliced pineapple using hybrid electricity', 1 p 'Sliced Pineapple using grid' and 1 p 'Sliced pineapple using generator'						
Method: Eco-indicator 99 (H) V2.06 / Europe EI 99 H/H						
Per sub-compartment: No						
Skip unused: Yes						
Indicator: Characterization						
Category: Climate change						
Cut-off: 0.60%						
Relative mode: Non						
No	**Substance**	**Compartment**	**Unit**	**Sliced pineapple using hybrid**	**Sliced Pineapple using grid**	**Sliced pineapple using generator**
	Total		DALY	0.00013619	0.000142199	0.000118286
	Remaining substances		DALY	5.75E-07	5.41E-07	1.17E-06
1	Carbon dioxide, fossil	Air	DALY	9.09E-05	9.48E-05	8.83E-05
2	Carbon dioxide	Air	DALY	2.95E-05	2.95E-05	2.95E-05
3	Carbon dioxide, biogenic	Air	DALY	1.22E-05	1.22E-05	1.22E-05
4	Carbon dioxide, land transformation	Air	DALY	1.16E-05	1.32E-05	1.22E-08
5	Methane, biogenic	Air	DALY	4.67E-06	5.28E-06	6.59E-08
6	Methane, fossil	Air	DALY	2.09E-06	2.13E-06	2.01E-06
7	Dinitrogen monoxide	Air	DALY	1.92E-06	1.95E-06	2.33E-06
8	Methane	Air	DALY	9.99E-07	9.99E-07	9.99E-07
9	Carbon dioxide, in air	Raw	DALY	-1.83E-05	-1.83E-05	-1.83E-05

Title: Comparing 1 p 'Sliced pineapple using hybrid electricity', 1 p 'Sliced Pineapple using grid' and 1 p 'Sliced pineapple using generator'						
Method: Eco-indicator 99 (H) V2.06 / Europe EI 99 H/H						
Per sub-compartment: No						
Skip unused: Yes						
Indicator: Characterization						
Category: Radiation						
Cut-off: 0.60%						
Relative mode: Non						
No	**Substance**	**Compartment**	**Unit**	**Sliced pineapple using hybrid**	**Sliced Pineapple using grid**	**Sliced pineapple using generator**
	Total		DALY	6.54E-07	6.63E-07	6.40E-07
	Remaining substances		DALY	3.06E-09	3.09E-09	3.02E-09
1	Radon-222	Air	DALY	4.55E-07	4.61E-07	4.45E-07
2	Carbon-14	Air	DALY	1.91E-07	1.94E-07	1.87E-07
3	Cesium-137	Water	DALY	4.39E-09	4.40E-09	4.39E-09

Title: Comparing 1 p 'Sliced pineapple using hybrid electricity', 1 p 'Sliced Pineapple using grid' and 1 p 'Sliced pineapple using generator'						
Method: Eco-indicator 99 (H) V2.06 / Europe EI 99 H/H						
Per sub-compartment: No						
Skip unused: Yes						
Indicator: Characterization						
Category: Ozone layer						
Cut-off: 0.60%						
Relative mode: Non						
No	**Substance**	**Compartment**	**Unit**	**Sliced pineapple using hybrid**	**Sliced Pineapple using grid**	**Sliced pineapple using generator**
	Total		DALY	1.16E-07	1.18E-07	1.15E-07
	Remaining substances		DALY	3.12E-10	3.12E-10	3.10E-10
1	Methane, bromotrifluoro-, Halon 1301	Air	DALY	1.01E-07	1.04E-07	1.01E-07
2	Methane, bromochlorodifluoro-, Halon 1211	Air	DALY	9.90E-09	9.92E-09	9.85E-09
3	Methane, tetrachloro-, CFC-10	Air	DALY	2.59E-09	2.59E-09	2.59E-09
4	Ethane, 1,2-dichloro-1,1,2,2-tetrafluoro-, CFC-114	Air	DALY	7.41E-10	7.46E-10	7.33E-10
5	Methane, dichlorofluoro-, HCFC-21	Air	DALY	7.05E-10	7.05E-10	7.05E-10

Title: Comparing 1 p 'Sliced pineapple using hybrid electricity', 1 p 'Sliced Pineapple using grid' and 1 p 'Sliced pineapple using generator'						
Method: Eco-indicator 99 (H) V2.06 / Europe EI 99 H/H						
Per sub-compartment: No						
Skip unused: Yes						
Indicator: Characterization						
Category: Ecotoxicity						
Cut-off: 0.60%						
Relative mode: Non						
No	**Substance**	**Compartment**	**Unit**	**Sliced pineapple using hybrid**	**Sliced Pineapple using grid**	**Sliced pineapple using generator**
	Total		PAF*m2yr	122.63132	131.63961	60.683267
	Remaining substances		PAF*m2yr	2.9988383	3.0984825	2.6767329
1	Nickel	Air	PAF*m2yr	67.76541	75.098307	14.158801
2	Zinc	Air	PAF*m2yr	10.930674	11.389602	8.8088718
3	Copper, ion	Water	PAF*m2yr	10.889886	10.914922	10.728786
4	Chromium	Air	PAF*m2yr	10.583676	11.057161	7.3515586
5	Zinc	Soil	PAF*m2yr	5.5811161	5.655302	5.5633875
6	Nickel, ion	Water	PAF*m2yr	3.6928715	3.8850326	2.365402
7	Lead	Air	PAF*m2yr	3.1202888	3.2767621	2.136542
8	Cadmium	Air	PAF*m2yr	2.7902154	3.0348078	1.1526291
9	Copper	Air	PAF*m2yr	1.969188	1.9018778	3.4629442
10	Metals, unspecified	Air	PAF*m2yr	1.5312	1.5312	1.5312
11	Zinc, ion	Water	PAF*m2yr	0.77796001	0.79615629	0.74641238

Title: Comparing 1 p 'Sliced pineapple using hybrid electricity', 1 p 'Sliced Pineapple using grid' and 1 p 'Sliced pineapple using generator'						
Method: Eco-indicator 99 (H) V2.06 / Europe EI 99 H/H						
Per sub-compartment: No						
Skip unused: Yes						
Indicator: Characterization						
Category: Acidification/ Eutrophication						
Cut-off: 0.60%						
Relative mode: Non						
No	**Substance**	**Compartment**	**Unit**	**Sliced pineapple using hybrid**	**Sliced Pineapple using grid**	**Sliced pineapple using generator**
	Total		PDF*m2yr	21.581648	21.096652	37.698408
	Remaining substances		PDF*m2yr	0.003461491	0.003475371	0.003457774
1	Nitrogen oxides	Air	PDF*m2yr	16.588947	15.768909	34.9902
2	Sulfur dioxide	Air	PDF*m2yr	3.0153077	3.3490576	0.73523339
3	Sulfur oxides	Air	PDF*m2yr	1.5785026	1.5785026	1.5785026
4	Ammonia	Air	PDF*m2yr	0.3954294	0.3967072	0.39101447

Title: Comparing 1 p 'Sliced pineapple using hybrid electricity', 1 p 'Sliced Pineapple using grid' and 1 p 'Sliced pineapple using generator'						
Method: Eco-indicator 99 (H) V2.06 / Europe EI 99 H/H						
Per sub-compartment: No						
Skip unused: Yes						
Indicator: Characterization						
Category: Land use						
Cut-off: 0.60%						
Relative mode: Non						
No	**Substance**	**Compartment**	**Unit**	**Sliced pineapple using hybrid**	**Sliced Pineapple using grid**	**Sliced pineapple using generator**
	Total		PDF*m2yr	44.13678	44.715656	41.05134
	Remaining substances		PDF*m2yr	1.5979061	1.6215498	1.5667071
1	Transformation, to arable, non-irrigated	Raw	PDF*m2yr	719.02251	719.02569	719.01329
2	Occupation, forest, intensive	Raw	PDF*m2yr	18.770057	18.770083	18.770001
3	Occupation, arable, non-irrigated	Raw	PDF*m2yr	13.096451	13.096508	13.096283
4	Transformation, to forest, intensive	Raw	PDF*m2yr	3.7513858	3.7513911	3.7513747
5	Transformation, to water bodies, artificial	Raw	PDF*m2yr	3.627998	4.0910057	0.11877105
6	Transformation, to mineral extraction site	Raw	PDF*m2yr	3.546866	3.7228177	3.4291038
7	Occupation, traffic area, road embankment	Raw	PDF*m2yr	2.5364674	2.5366142	2.5362821
8	Occupation, forest,	Raw	PDF*m2yr	1.4228845	1.4240841	1.4223975

	intensive, normal					
9	Transformation, to dump site, benthos	Raw	PDF*m2yr	1.2206833	1.2758181	1.2187141
10	Transformation, to traffic area, road embankment	Raw	PDF*m2yr	0.50096319	0.50098695	0.5009491
11	Occupation, traffic area, road network	Raw	PDF*m2yr	0.41845036	0.42023301	0.44754605
12	Transformation, to forest, intensive, normal	Raw	PDF*m2yr	0.33324487	0.33349987	0.33321303
13	Occupation, industrial area	Raw	PDF*m2yr	0.2884677	0.30363855	0.27622641
14	Occupation, permanent crop, fruit, intensive	Raw	PDF*m2yr	0.26914485	0.26928677	0.26912758
15	Transformation, from pasture and meadow, intensive	Raw	PDF*m2yr	-0.58017422	-0.58017678	-0.58016678
16	Transformation, from forest	Raw	PDF*m2yr	-0.82380924	-0.898851	-0.4197026
17	Transformation, from unknown	Raw	PDF*m2yr	-1.044695	-1.0719025	-0.89198392
18	Transformation, from sea and ocean	Raw	PDF*m2yr	-1.2212242	-1.2763776	-1.2192528
19	Transformation, from forest, extensive	Raw	PDF*m2yr	-4.1605646	-4.1608333	-4.1605198
20	Transformation, from arable, non-irrigated	Raw	PDF*m2yr	-718.43623	-718.43941	-718.42702

Title: Comparing 1 p 'Sliced pineapple using hybrid electricity', 1 p 'Sliced pineapple using generator' and 1 p 'Sliced Pineapple using grid'						
Method: Eco-indicator 99 (H) V2.06 / Europe EI 99 H/H						
Per sub-compartment: No						
Skip unused: Yes						
Indicator: Characterization						
Category: Minerals						
Cut-off: 0.60%						
Relative mode: Non						
No	**Substance**	**Compartment**	**Unit**	**Sliced pineapple using hybrid**	**Sliced pineapple using generator**	**Sliced Pineapple using grid**
	Total		MJ surplus	5.7331832	5.6447513	5.8013872
	Remaining substances		MJ surplus	0.064401938	0.065581705	0.064652248
1	Nickel, 1.98% in silicates, 1.04% in crude ore, in ground	Raw	MJ surplus	3.5225651	3.2782185	3.5806281
2	Copper, 2.19% in sulfide, Cu 1.83% and Mo 8.2E-3% in crude ore, in ground	Raw	MJ surplus	0.66440969	0.74611079	0.66391068
3	Copper, 1.18% in sulfide, Cu 0.39% and Mo 8.2E-3% in crude ore, in ground	Raw	MJ surplus	0.5007148	0.56284886	0.50033059
4	Aluminium, 24% in bauxite, 11% in crude ore, in ground	Raw	MJ surplus	0.26624443	0.26138923	0.26740092
5	Iron, 46% in ore, 25% in crude ore, in ground	Raw	MJ surplus	0.17109305	0.16404498	0.17444639

6	Molybdenum, 0.11% in sulfide, Mo 4.1E-2% and Cu 0.36% in crude ore, in ground	Raw	MJ surplus	0.14226892	0.14188135	0.14599286
7	Copper, 1.42% in sulfide, Cu 0.81% and Mo 8.2E-3% in crude ore, in ground	Raw	MJ surplus	0.13282176	0.1493037	0.13271984
8	Copper, 0.99% in sulfide, Cu 0.36% and Mo 8.2E-3% in crude ore, in ground	Raw	MJ surplus	0.091064684	0.10227644	0.090996761
9	Molybdenum, 0.022% in sulfide, Mo 8.2E-3% and Cu 0.36% in crude ore, in ground	Raw	MJ surplus	0.070508116	0.070316067	0.072353288
10	Tin, 79% in cassiterite, 0.1% in crude ore, in ground	Raw	MJ surplus	0.059832307	0.059221057	0.060001524
11	Chromium, 25.5% in chromite, 11.6% in crude ore, in ground	Raw	MJ surplus	0.047258412	0.043558574	0.047953978

Title: Comparing 1 p 'Sliced pineapple using hybrid electricity', 1 p 'Sliced pineapple using generator' and 1 p 'Sliced Pineapple using grid'						
Method: Eco-indicator 99 (H) V2.06 / Europe EI 99 H/H						
Per sub-compartment: No						
Skip unused: Yes						
Indicator: Characterization						
Category: Fossil fuels						
Cut-off: 0.60%						
Relative mode: Non						
No	**Substance**	**Compartment**	**Unit**	**Sliced pineapple using hybrid**	**Sliced pineapple using generator**	**Sliced Pineapple using grid**
	Total		MJ surplus	1441.4553	1439.4952	1475.097
	Remaining substances		MJ surplus	5.0443375	4.9693219	5.0802371
1	Oil, crude, in ground	Raw	MJ surplus	597.63868	596.70374	629.74161
2	Oil, crude, feedstock, 41 MJ per kg, in ground	Raw	MJ surplus	258.42	258.42	258.42
3	Gas, natural, in ground	Raw	MJ surplus	207.9523	207.00223	209.45524
4	Gas, natural, 36.6 MJ per m3, in ground	Raw	MJ surplus	141.642	141.642	141.642
5	Oil, crude, 42.6 MJ per kg, in ground	Raw	MJ surplus	129.95795	129.95795	129.95795
6	Gas, natural, feedstock, 35 MJ per m3, in ground	Raw	MJ surplus	100.8	100.8	100.8

APPENDIX C Different Life Cycle Assessment Methods

(Pre Consultants, SimaPro 7.1.8, PhD Version, 2008)

CML 2 Baseline 2000

CML 2001 (baseline).
Baseline impact categories taken from Ecoinvent 2.0 and extended with most important missing substances.
The original SimaPro name "CML 2 baseline 2000" has not been adjusted.

The impact categories presented in this CML baseline method are the recommended methods according to the Handbook on Life Cycle Assessment
Impact category names used in SimaPro are different according to the ones mentioned in the 'CML 2001 (all impact categories)' method:

Name in 'all impact categories' version	Name in 'baseline' version
-Ozone layer depletion steady state	-Ozone layer depletion (ODP)
-Human toxicity infinite	-Human toxicity
-Fresh water aquatic ecotox. infinite	-Fresh water aquatic ecotox.
-Marine aquatic ecotoxicity infinite	-Marine aquatic ecotoxicity
-Terrestrial ecotoxicity infinite	-Terrestrial ecotoxicity
-Photochemical oxidation	-Photochemical oxidation
-Global warming 100a	-Global warming (GWP100)
-Acidification	-Acidification
-Abiotic depletion	-Abiotic depletion
-Eutrophication	-Eutrophication

This method is an update from the CML 1992 method, based on the spreadsheet version 3.2 (December 2007) as published on the CML web site. It replaces the preliminary version.

Version v2 is adapted for SimaPro 7.1. All characterisation factors in this method are entered for the 'unspecified' subcompartment of each compartment (Raw materials, air, water, soil) and thus applicable on all subcompartments, where no specific characterization value is specified.

In case the original method only reported a characterization value for one specific subcompartment, this value is taken as the characterization value for all subcompartments in this compartment. In case two different characterization values for emissions to agricultural and industrial soil are available, the value for industrial soil is taken as the characterization value for all other subcompartments to soil. In case two different characterization values for emissions to fresh water and to marine water are available, the value for fresh water is taken as the characterization value for all other subcompartments to water. Marine water is represented by the compartment water (ocean).

Other adaptations (June 2004, v2.1):

- Carbon dioxide, biogenic and uptake from carbon dioxide from air (Carbon dioxide, in air) are added to the methodology. Similar for 'Carbon monoxide, fossil' and 'Carbon monoxide, biogenic'.

Other adaptations (August 2004):
- Raw materials: minerals from ecoinvent with additional information in name and missing fossil fuels are added to the methodology. To obtain the characterisation factor of Energy, from sulphur, the characterisation factor of Sulphur, in ground has been divided by the energy content of sulphur, as given in the cumulative energy demand (V1.2) method. To obtain the characterisation factor of Energy, from uranium, the characterisation factor of the uranium with the lowest energy content has been divided by the energy content of that uranium (worst case scenario). Oil, crude: assumed energy content 42 MJ/kg. Uranium ore, in ground: assumed that ratio characterisation factor uranium ore - uranium, in ground is the same as in EPS 2000 V2.2 method
- Global warming, Photochemical oxidation: Methane, biogenic and Methane, fossil added.
- Euthrophication: nitrogen compounds completed. Nitrogen is replaced by Nitrogen, total, with same characterisation factor.
- "Particulates, > 2.5 um, and < 10um" added with the assumption that the characterization factor is the same as for "Particulates, < 10 um"
- Human toxicity: Chromium (soil) -> Chromium (VI) (soil, agricultural)
- Fresh water aquatic ecotox., Marine aquatic ecotoxicity, Terrestrial ecotoxicity: Chromium (soil) deleted.
- Human toxicity, Fresh water aquatic ecotox. Marine aquatic ecotoxicity, Terrestrial ecotoxicity: Characterisation factors Naphthalene and Naphthalene (subcompartment Ocean) corrected.

Other adaptations (March 2005, v2.02):
- Raw materials: minerals from ecoinvent with additional information in name added and corrected
- Global warming, human toxicity, fresh water aquatic ecotoxicity, marine aquatic ecotoxicity, terrestrial ecotoxicity, photochemical oxidation: updated from version 2.02 to version 2.7.
- Eutrophication: Dinitrogen monoxide removed. Nitrogen, to water added (equal to nitrogen, total, to water).

Other adaptations (August 2005, v 2.03):
-Entry for airborne emission "Chromium" (6,47E2 kg 1,4-DB equivalents) in impact category Human Toxicity removed following ecoinvent 1.2 update recommendation.
-Entry for resource "Chrysotile, in Ground" in impact category "Abiotic Depletion" changed from 7,05E-9 to 9.88E-10 kg antimony-Eq/kg

Other adaptations (February 2008, v 2.04):
- Harmonised unit names:
    kg ethylene is renamed to kg C2H4
    kg formed ozone is renamed to kg formed O3
    kg 1,4-DCB-Eq is renamed to kg 1,4-DB eq

- Euthrophication: Nitrogen and Nitrogen, total can both be used, they have the same characterisation factor.
- Human toxicity: Chromium (soil) and Chromium (VI) (soil, agricultural) are both present, they have the same characterisation factor.
- Entry for Hydrogen Fluoride corrected according to Ecoinvent report No. 3 table 1.3 p. 27 for the following impact categories:

Human Toxicity: compartment air from 2.85E+03 to 1.30E+02, water from 3.64E+03 to 4.90E+01, water (ocean) from 3.64E+03 to 4.70E+01, soil from 1.82E+03 to 2.40E+01, soil (agricultural) from 1.85E+03 to 5.10E+01

Marine aquatic ecotoxicity: compartment air from 4.07E+07 to 5.20E+05, water from 5.38E+07 to 6.80E+05, soil from 2.69E+07 to 3.40E+05

- Global warming (GWP100): added characterisation factors from the IPCC 2001 GWP 100a method for Methane, bromodifluoro-, Halon 1201, Methane, dichlorofluoro-, HCFC-21, and Methane, iodotrifluoro-. For carbon monoxide; carbon monoxide, biogenic and carbon monoxide, fossil the characterization factors from Ecoinvent are taken. See Ecoinvent report No 3. Par 2.2
- Acidification: only characterization factors including fate were used for the CML baseline method. The method was extended with Nitric oxide, air (is nitrogen monoxide).
- Acidification: Corrected the characterisation factor for Sulphur dioxide from 1 to 1,2 SO2 eq . This factor of 1,2 SO2 eq for SO2 is including fate.
- Corrected the normalisation factor for Human toxicity infinite in the Netherlands 1997 set from 5,31E-12 to 5,32E-12

This method is NOT fully adapted for inventory data from the USA Input Output Database 98, and therefore omits emissions that could have been included in impact assessment.

The CML 2001 (baseline) method elaborates the problem-oriented (midpoint) approach. The CML Guide provides a list of impact assessment categories grouped into
A: Obligatory impact categories (Category indicators used in most LCAs)
B: Additional impact categories (operational indicators exist, but are not often included in LCA studies)
C: Other impact categories (no operational indicators available, therefore impossible to include quantitatively in LCA)

In case several methods are available for obligatory impact categories a baseline indicator is selected, based on the principle of best available practice. These baseline indicators are category indicators at "mid-point level" (problem oriented approach)". Baseline indicators are recommended for simplified studies. The guide provides guidelines for inclusion of other methods and impact category indicators in case of detailed studies and extended studies.
Only baseline indicators are available in the CML method in SimaPro (based on CML Excel spreadsheet with characterisation and normalisation factors). In general, these indicators do not deviate from the ones in the spreadsheet. In case the spreadsheet contained synonyms of substance names already available in the substance list of the SimaPro database, the existing names are used. A distinction is made for emissions to agricultural soil and industrial soil, indicated with respectively (agr.) or (ind.) behind substance names emitted to soil. Emissions to

seawater are indicated with (sea), while emissions to fresh water have no addition behind their substance name (we assume that all emissions to water in existing process records are emissions to fresh water).

Depletion of abiotic resources

This impact category indicator is related to extraction of minerals and fossil fuels due to inputs in the system. The Abiotic Depletion Factor (ADF) is determined for each extraction of minerals and fossil fuels (kg antimony equivalents/kg extraction) based on concentration reserves and rate of deaccumulation.

Climate change

The characterisation model as developed by the Intergovernmental Panel on Climate Change (IPCC) is selected for development of characterisation factors. Factors are expressed as Global Warming Potential for time horizon 100 years (GWP100), in kg carbon dioxide/kg emission.

Stratospheric Ozone depletion

The characterisation model is developed by the World Meteorological Organisation (WMO) and defines ozone depletion potential of different gasses (kg CFC-11 equivalent/ kg emission).

Human toxicity

Characterisation factors, expressed as Human Toxicity Potentials (HTP), are calculated with USES-LCA, describing fate, exposure and effects of toxic substances for an infinite time horizon. For each toxic substance HTP's are expressed as 1,4-dichlorobenzene equivalents/ kg emission.

CML 2001 (All Impact Categories)

CML 2001 is a LCA methodology developed by the Center of Environmental Science of Leiden Universit (CML)y
This method is an update from the CML 1992 method, based on the spreadsheet version 3.2 (December 2007) as published on the CML web site. It replaces the preliminary version.

CML 2001 (all impact categories)
Extended CML 2001 baseline, version 2.04 (original SimaPro name: CML 2 baseline 2000). Containing alternative impact categories, recommended for extended LCAs, which were taken from Ecoinvent 2.0.

Version v2 is adapted for SimaPro 7.1. All characterisation factors in this method are entered for the 'unspecified' subcompartment of each compartment (Raw materials, air, water, soil) and thus applicable on all subcompartments, where no specific characterisation value is specified.

In case the original method only reported a characterisation value for one specific subcompartment, this value is taken as the characterisation value for all subcompartments in this compartment. In case two different characterisation values for emissions to agricultural and industrial soil are available, the value for industrial soil is taken as the characterisation value for all other subcompartments to soil. In case two different characterisation values for emissions to fresh water and to marine water are available, the value for fresh water is taken as the characterisation value for all other subcompartments to water. Marine water is represented by the compartment water (ocean).

Other adaptations (June 2004, v2.1):
- Carbon dioxide, biogenic and uptake from carbon dioxide from air (Carbon dioxide, in air) are added to the methodology. Similar for 'Carbon monoxide, fossil' and 'Carbon monoxide, biogenic'.

Other adaptations (August 2004):
- Raw materials: minerals from ecoinvent with additional information in name and missing fossil fuels are added to the methodology. To obtain the characterisation factor of Energy, from sulphur, the characterisation factor of Sulphur, in ground has been divided by the energy content of sulphur, as given in the cumulative energy demand (V1.2) method. To obtain the characterisation factor of Energy, from uranium, the characterisation factor of the uranium with the lowest energy content has been divided by the energy content of that uranium (worst case scenario). Oil, crude: assumed energy content 42 MJ/kg. Uranium ore, in ground: assumed that ratio characterisation factor uranium ore - uranium, in ground is the same as in EPS 2000 V2.2 method
- Global warming, Photochemical oxidation: Methane, biogenic and Methane, fossil added.
- Euthrophication: nitrogen compounds completed. Nitrogen is replaced by Nitrogen, total, with same characterisation factor.
- "Particulates, > 2.5 um, and < 10um" added with the assumption that the characterization factor is the same as for "Particulates, < 10 um"
- Human toxicity: Chromium (soil) -> Chromium (VI) (soil, agricultural)

- Fresh water aquatic ecotox., Marine aquatic ecotoxicity, Terrestrial ecotoxicity: Chromium (soil) deleted.
- Human toxicity, Fresh water aquatic ecotox. Marine aquatic ecotoxicity, Terrestrial ecotoxicity: Characterisation factors Naphthalene and Naphthalene (subcompartment Ocean) corrected.

Other adaptations (March 2005, v2.02):
- Raw materials: minerals from ecoinvent with additional information in name added and corrected
- Global warming, human toxicity, fresh water aquatic ecotoxicity, marine aquatic ecotoxicity, terrestrial ecotoxicity, photochemical oxidation: updated from version 2.02 to version 2.7.
- Eutrophication: Dinitrogen monoxide removed. Nitrogen, to water added (equal to nitrogen, total, to water).

Other adaptations (August 2005, v 2.03):
-Entry for airborne emission "Chromium" (6,47E2 kg 1,4-DB equivalents) in impact category Human Toxicity removed following ecoinvent 1.2 update recommendation.
-Entry for resource "Chrysotile, in Ground" in impact category "Abiotic Depletion" changed from 7,05E-9 to 9.88E-10 kg antimony-Eq/kg

Other adaptations (February 2008, v 2.04):
- Harmonised unit names:
    kg ethylene is renamed to kg C2H4
    kg formed ozone is renamed to kg formed O3
    kg 1,4-DCB-Eq is renamed to kg 1,4-DB eq
- Eutrophication: Nitrogen and Nitrogen, total can both be used, they have the same characterisation factor.
- Human toxicity: Chromium (soil) and Chromium (VI) (soil, agricultural) are both present and can both be used, they have the same characterisation factor.
- Entry for Hydrogen Fluoride corrected according to Ecoinvent report No. 3 table 1.3 p. 27 for the following impact categories:
    Human Toxicity: compartment air from 2.85E+03 to 1.30E+02, water from 3.64E+03 to 4.90E+01, water (ocean) from 3.64E+03 to 4.70E+01, soil from 1.82E+03 to 2.40E+01, soil (agricultural) from 1.85E+03 to 5.10E+01
    Marine aquatic ecotoxicity: compartment air from 4.07E+07 to 5.20E+05, water from 5.38E+07 to 6.80E+05, soil from 2.69E+07 to 3.40E+05
    Marine sediment ecotoxicity: compartment air from 1.34E+07 to 1.70E+05, water from 1.77E+07 to 2.20E+05, soil from 8.86E+06 to 1.10E+05
- Global warming 100a: added characterisation factors from the IPCC 2001 GWP 100a method for Methane, bromodifluoro-, Halon 1201, Methane, dichlorofluoro-, HCFC-21, and Methane, iodotrifluoro-. For carbon monoxide; carbon monoxide, biogenic and carbon monoxide, fossil the characterization factors from Ecoinvent are taken. See Ecoinvent report No 3. Par 2.2
- Acidification: Characterization factors including fate were used when available, when not available, the factors excluding fate were used (In the CML baseline version only factors including fate were used). The method was extended for Nitric Acid, soil, water and air;

Sulphuric acid, water; Sulphur trioxide, air; Hydrogen chloride, water, soil; Hydrogen fluoride, water, soil; Phosphoric acid, water, soil; Hydrogen sulfide, soil, all not including fate. Nitric oxide, air (is nitrogen monoxide) was added including fate.
- Acidification: Corrected the characterisation factor for Sulphur dioxide from 1 to 1,2 SO2 eq . This factor of 1,2 SO2 eq for SO2 is including fate.
- Corrected the normalisation factor for Human toxicity infinite in the Netherlands 1997 set from 5,31E-12 to 5,32E-12

CML 2001 (all impact categories) has the following extra impact categories compared to CML 2001 (baseline). Some of the original Ecoinvent 2.0 names were changed to be clearer to the user:

competition, renamed to land competition
average European, renamed to average European (kg NOx eq)
malodourous air
MSETP 20a, renamed to Marine sediment ecotox. 20a
MSETP 100a, renamed to Marine sediment ecotox. 100a
MSETP 500a, renamed to Marine sediment ecotox. 500a
MSETP infinite, renamed to Marine sediment ecotox. Infinite
FSETP 20a, renamed to Freshwater sediment ecotox. 20a
FSETP 100a, renamed to Freshwater sediment ecotox. 100a
FSETP 500a, renamed to Freshwater sediment ecotox. 500a
FSETP infinite, renamed to Freshwater sediment ecotox. Infinite
low NOx POCP, renamed to Photochemical oxidation (low NOx)
EBIR, renamed to Equal benefit incremental reactivity
MIR, renamed to Max. incremental reactivity
MOIR, renamed to Max. ozone incremental reactivity
GWP 20a, renamed to Global warming 20a
GWP 500a, renamed to Global warming 500a
Upper limit of net global warming
Lower limit of net global warming
TAETP 20a, renamed to Terrestrial ecotoxicity 20a
TAETP 100a, renamed to Terrestrial ecotoxicity 100a
TAETP 500a, renamed to terrestrial ecotoxicity 500a
Ionising radiation
MAETP 20a, renamed to Marine aquatic ecotox. 20a
MAETP 100a, renamed to Marine aquatic ecotox. 100a
MAETP 500a, renamed to Marine aquatic ecotox. 500a
FAETP 20a, renamed to Freshwater aquatic ecotox. 20a
FAETP 100a, renamed to Freshwater aquatic ecotox. 100a
FAETP 500a, renamed to Freshwater aquatic ecotox. 500a
ODP 5a, renamed to Ozone layer depletion 5a
ODP 10a, renamed to Ozone layer depletion 10a
ODP 20a, renamed to Ozone layer depletion 20a
ODP 30a, renamed to Ozone layer depletion 30a
ODP 40a, renamed to Ozone layer depletion 40a

ODP 15a, renamed to Ozone layer depletion 15a
ODP 25a, renamed to Ozone layer depletion 25a
HTP 20a, renamed to Human toxicity 20a
HTP 100a, renamed to Human toxicity 100a
HTP 500a, renamed to Human toxicity 500a
20a stands for a time horizon of 20 years

There are no references available for normalization factors of Equal benefit incremental reactivity, Max. incremental reactivity, Max. ozone incremental reactivity and Malodours air.

This method is NOT fully adapted for inventory data from the USA Input Output Database 98, and therefore omits emissions that could have been included in impact assessment.

The CML 2001 (baseline) method elaborates the problem-oriented (midpoint) approach. The CML Guide provides a list of impact assessment categories grouped into
A: Obligatory impact categories (Category indicators used in most LCAs)
B: Additional impact categories (operational indicators exist, but are not often included in LCA studies)
C: Other impact categories (no operational indicators available, therefore impossible to include quantitatively in LCA)

In case several methods are available for obligatory impact categories a baseline indicator is selected, based on the principle of best available practice. These baseline indicators are category indicators at "mid-point level" (problem oriented approach)". Baseline indicators are recommended for simplified studies. The guide provides guidelines for inclusion of other methods and impact category indicators in case of detailed studies and extended studies.
Only baseline indicators are available in the CML method in SimaPro (based on CML Excel spreadsheet with characterisation and normalisation factors). In general, these indicators do not deviate from the ones in the spreadsheet. In case the spreadsheet contained synonyms of substance names already available in the substance list of the SimaPro database, the existing names are used. A distinction is made for emissions to agricultural soil and industrial soil, indicated with respectively (agr.) or (ind.) behind substance names emitted to soil. Emissions to seawater are indicated with (sea), while emissions to fresh water have no addition behind their substance name (we assume that all emissions to water in existing process records are emissions to fresh water).

Depletion of abiotic resources
This impact category indicator is related to extraction of minerals and fossil fuels due to inputs in the system. The Abiotic Depletion Factor (ADF) is determined for each extraction of minerals and fossil fuels (kg antimony equivalents/kg extraction) based on concentration reserves and rate of deaccumulation.

Climate change

The characterisation model as developed by the Intergovernmental Panel on Climate Change (IPCC) is selected for development of characterisation factors. Factors are expressed as Global Warming Potential for time horizon 100 years (GWP100), in kg carbon dioxide/kg emission.

Stratospheric Ozone depletion
The characterisation model is developed by the World Meteorological Organisation (WMO) and defines ozone depletion potential of different gasses (kg CFC-11 equivalent/ kg emission).

Human toxicity
Characterisation factors, expressed as Human Toxicity Potentials (HTP), are calculated with USES-LCA, describing fate, exposure and effects of toxic substances for an infinite time horizon. For each toxic substance HTP's are expressed as 1,4-dichlorobenzene equivalents/ kg emission.

Eco-indicator 99 (E)

Eco-indicator 99 method, egalitarian version.
Evaluation: "A" refers to the average weighting set. "E" refers to the weighting set belonging to the egalitarian perspective (recommended).
The default Eco-indicator 99 method is the Hierarchist version with average weighting set (average of the full panel).

This V2 version is adapted for SimaPro 6.0. All characterisation factors in this method are entered for the 'unspecified' subcompartment of each compartment (Raw materials, air, water, soil) and thus applicable on all subcompartments, where no specific characterisation value is specified.

In case the original method only reported a characterisation value for one specific subcompartment, this value is taken as the characterisation value for all subcompartments in this compartment.

In case two different characterisation values for emissions to agricultural and industrial soil are available, the value for industrial soil is taken as the characterisation value for all other subcompartments to soil.

Other adaptations (V2.1):
- Factors for Nickel and Chromium IV updated for the category carcinogenics (see ecoinvent report).
- Method expanded with all factors from ecoinvent (all categories), except for 'particulates >10 um' for respiratory damage.
- '0' (zero) factors applied for emissions to ocean or 'unspecied' water in case no characterisation factors area available for respectively 'ocean' and 'river, lake'.
- The characterisation values for pesticides to soil are taken from the original values for emission to agricultural soil. In these characterisation values, the damage on the agricultural land itself was not included. Therefore the characterization factor for emission of pesticides to other subcompartments of soil is heavily underestimated.

Other adaptations (August 2004):
- Characterisation factors category Minerals: "Nickel, 1.13% in sulfides, 0.76% in crude ore, in ground"; "Nickel, 1.98% in silicates, 1.04% in crude ore, in ground"; "Zinc 9%, Lead 5%, in sulfide, in ground" updated, according to updated characterisation factors in EI99 for Nickel, in ore and Zinc, in ore.
- Characterisation factor category Minerals corrected for Zinc, in ore.
- Characterisation factor category Respiratory inorganics added for Particulate matter, unspecified.

Other adaptations (March 2005):
- Raw materials: minerals from ecoinvent with additional information in name added and corrected.
- Carcinogens: Particulates, < 2.5 um added (same value as particulates, diesel soot).

- Resp. inorganics: Particulates, diesel soot added (same value as particulates, < 2.5 um).
- Characterisation factors category Carcinogenics added for dichromate to water.
- Characterisation factors ecotoxicity added for emissions to agricultural soil (pesticides) or industrial soil (metals and industrial compounds).

Other adaptations (August 2005):
- Characterisation factors fossil fuels updated according to ecoinvent 1.2.

Other adaptations (V2.04, June 2007):
- Characterisation factor added for raw material "Oil, crude, 38400 MJ per m3, in ground" to impact category "Fossil fuels" of 3190 MJ surplus / m3.

Other adaptations (V2.05, January 2008):
- Correction subcompartment of soil emissions for ecotoxicity.

Other adaptations (V2.06, April 2008)
- The impact category 'Climate change' is adapted. The substance 'carbon dioxide, land transformation' is added, with the same characterisation factor of 'carbon dioxide'.

In the Eco-indicator 99 method normalisation and weighting are performed at damage category level (endpoint level in ISO terminology). There are three damage categories:
HH Human Health (unit: DALY= Disability adjusted life years; this means different disability caused by diseases are weighted)
EQ Ecosystem Quality (unit: PDF*m2yr; PDF= Potentially Disappeared Fraction of plant species)
R Resources (unit: MJ surplus energy Additional energy requirement to compensate lower future ore grade)

Eco-indicator 99 has a damage assessment step. This means that the impact category indicator results that are calculated in the Characterisation step, are added to form damage categories. Addition without weighting is justified here because all impact categories that refer to the same damage type (like human health) have the same unit (for instance DALY). This procedure can also be interpreted as grouping.
The damage categories (and not the impact categories) are normalised on an European level (damage caused by 1 European per year), mostly based on 1993 as base year, with some updates for the most important emissions. Please note that the normalisation set is dependent on the perspective chosen.

The normalised damage categories can also be used with the triangle tool. This is very useful if two products are to be compared without weighting, in case the damage indicators for Product A and B are conflicting (A is higher on Human health and B is higher on Ecosystem Quality). In such a case the answer is dependent on the weighting factors for Ecosystem quality, Resources and Human health.
The triangle must be understood as a way to show all possible combinations of weighting factors (represented as a percentage in such a way that they add up to 100%). If damage

categories have conflicting values, the triangle will display two area's. One area represents all weighting sets for which product A has a lower environmental load, the other area will represent all weighting sets for which B has a lower load than A. The line in between is the line of indifference. These are the weighting sets for which the environmental load of A and B are the same.
The benefit of using the triangle is that you do not always need to know which exact weighting set you want to use. The stakeholders only have to decide in which area (on which side of the line of indifference) the weighting set may be. See also help file

Uncertainties
It is very important to pay attention to the uncertainties in the methodology. We distinguish two types:
* Data uncertainties
* Uncertainties about the correctness of the models used

Data uncertainties are specified for most damage factors as squared geometric standard deviation in the original reports, but not in the software. It is not useful to express the uncertainties of the model as a distribution. Uncertainties about the model are related to subjective choices in the model. In order to deal with them we developed three different versions of the methodology, using the archetypes specified in the
* Egalitarian perspective
* Hierarchist perspective
* Individualist perspective.

In the egalitarian perspective the chosen time perspective is extremely long-term.
Substances are included if there is just any indication regarding their effect. For instance all carcinogenic substances in IARC class 1, 2a, 2b and 3 are included, as far as information was available. In the egalitarian perspective, damages cannot be avoided and may lead to catastrophic events. In the case of fossil fuels the assumption is made that fossil fuels cannot be substituted. Oil, coal and gas are to be replaced by a future mix of brown coal and shale. In the DALY calculations age weighting is not included.

For further information see the Eco-indicator 99 reports, available from our web site www.pre.nl or our CD-ROM. Due to ongoing adjustments of the method and/or inventory data sets the Eco-indicator 99 in SimaPro might not give the same result as mentioned the printed version.

Eco-indicator 99 (H)

Eco-indicator 99 method, hierarchist version.
Evaluation: "A" refers to the average weighting set (recommended),
"H" refers to the weighting set belonging to the hierarchist perspective.

This V2 version is adapted for SimaPro 6.0. All characterisation factors in this method are entered for the 'unspecified' subcompartment of each compartment (Raw materials, air, water, soil) and thus applicable on all subcompartments, where no specific characterisation value is specified.

In case the original method only reported a characterisation value for one specific subcompartment, this value is taken as the characterisation value for all subcompartments in this compartment. In case two different characterisation values for emissions to agricultural and industrial soil are available, the value for industrial soil is taken as the characterisation value for all other subcompartments to soil.

Other adaptations (V2.1):
- Method expanded with factors implemented by ecoinvent, except for 'particulates >10 um' for respiratory damage.
- Chromium/ nickel correction for carcinogenics (see ecoinvent).
- factors 0 (zero) for radiation added forwater emissions 'unspecied' subcompartment or ocean if factors were lacking for respectively for emissions to 'river/lake' or 'oceans'.
- The characterisation values for pesticides to soil are taken from the original values for emission to agricultural soil. In this characterisation values, the damage on the agricultural land itself was not included. Therefore the characterization factor for emission of pesticides to other subcompartments of soil is heavily underestimated.

Other adaptations (August 2004):
- Characterisation factors category Minerals: "Nickel, 1.13% in sulfides, 0.76% in crude ore, in ground"; "Nickel, 1.98% in silicates, 1.04% in crude ore, in ground"; "Zinc 9%, Lead 5%, in sulfide, in ground" updated, according to updated characterisation factors in EI99 for Nickel, in ore and Zinc, in ore.
- Characterisation factor category Respiratory inorganics added for Particulate matter, unspecified and Particulates, > 2,5 um, and <10 um.

Other adaptations (March 2005):
- Raw materials: minerals from ecoinvent with additional information in name added and corrected.
- Carcinogens: Particulates, < 2.5 um added (same value as particulates, diesel soot).
- Resp. inorganics: Particulates, diesel soot added (same value as particulates, < 2.5 um).
- Characterisation factors category Carcinogenics added for sodium dichromate to air.
- Characterisation factors ecotoxicity added for emissions to agricultural soil (pesticides) or industrial soil (metals and industrial compounds).

Other adaptations (August 2005, v2.03):

- In impact category Fossil fuels the characterisation value for "Gas, natural in ground" has been changed to 5,173 MJ surplus/m3 following the ecoinvent 1.2 update.

Other adaptations (V2.04, June 2007):
- Characterisation factor added for raw material "Oil, crude, 38400 MJ per m3, in ground" to impact category "Fossil fuels" of 5530 MJ surplus / m3.

Other adaptations (V2.05, January 2008):
- Correction subcompartment of soil emissions for ecotoxicity.

Other adaptations (V2.06, April 2008)
- The impact category 'Climate change' is adapted. The substance 'carbon dioxide, land transformation' is added, with the same characterisation factor of 'carbon dioxide'.

The default Eco-indicator 99 method is the Hierarchist version with average weighting set (average of the full panel). In the Eco-indicator 99 method normalisation and weighting are performed at damage category level (endpoint level in ISO terminology). There are three damage categories:
HH Human Health (unit: DALY= Disability adjusted life years; this means different disability caused by diseases are weighted)
EQ Ecosystem Quality (unit: PDF*m2yr; PDF= Potentially Disappeared Fraction of plant species)
R Resources (unit: MJ surplus energy Additional energy requirement to compensate lower future ore grade)

Eco-indicator 99 has a damage assessment step. This means that the impact category indicator results that are calculated in the Characterisation step are added to form damage categories. Addition without weighting is justified here because all impact categories that refer to the same damage type (like human health) have the same unit (for instance DALY). This procedure can also be interpreted as grouping.

The damage categories (and not the impact categories) are normalised on an European level (damage caused by 1 European per year), mostly based on 1993 as base year, with some updates for the most important emissions. Please note that the normalisation set is dependent on the perspective chosen.
The normalised damage categories can also be used with the triangle tool. This is very useful if two products are to be compared without weighting, in case the damage indicators for Product A and B are conflicting (A is higher on Human health and B is higher on Ecosystem Quality). In such a case the answer is dependent on the weighting factors for Ecosystem quality, Resources and Human health.
The triangle must be understood as a way to show all possible combinations of weighting factors (represented as a percentage in such a way that they add up to 100%). If damage categories have conflicting values, the triangle will display two area's. One area represents all weighting sets for which product A has a lower environmental load, the other area will represent all weighting sets for which B has a lower load than A. The line in between is the line

of indifference. These are the weighting sets for which the environmental load of A and B are the same.
The benefit of using the triangle is that you do not always need to know which exact weighting set you want to use. The stakeholders only have to decide in which area (on which side of the line of indifference) the weighting set may be. See also help file

Uncertainties
Of course it is very important to pay attention to the uncertainties in the methodology. We distinguish two types:
* Data uncertainties
* Uncertainties about the correctness of the models used

Data uncertainties are specified for most damage factors as squared geometric standard deviation in the original reports, but not in the software. It is not useful to express the uncertainties of the model as a distribution. Uncertainties about the model are related to subjective choices in the model. In order to deal with them we developed three different versions of the methodology, using the archetypes specified in the
* Egalitarian perspective
* Hierarchist perspective
* Individualist perspective.

In the hierarchist perspective the chosen time perspective is long-term, substances are included if there is consensus regarding their effect. For instance all carcinogenic substances in IARC class 1, 2a and 2b are included, while class 3 has deliberately been excluded. In the hierarchist perspective damages are assumed to be avoidable by good management. For instance the danger people have to flee from rising water levels is not included. In the case of fossil fuels the assumption is made that fossil fuels cannot easily be substituted. Oil and gas are to be replaced by shale, while coal is replaced by brown coal. In the DALY calculations age weighting is not included.

For further information see the Eco-indicator 99 reports, available from our web site www.pre.nl
Due to adjustments of the method and/or inventory data sets the Eco-indicator 99 in SimaPro might not give the same result as the printed version.

Eco-indicator 99 (I)

Eco-indicator 99 method, individualist version.
Evaluation: "A" refers to the average weighting set. "I" refers to the weighting set belonging to the individualist perspective (recommended).
The default Eco-indicator 99 method is the Hierarchist version with average weighting set (average of the full panel).

This V2 version is adapted for SimaPro 6.0. All characterisation factors in this method are entered for the 'unspecified' subcompartment of each compartment (Raw materials, air, water, soil) and thus applicable on all subcompartments, where no specific characterisation value is specified.

In case the original method only reported a characterisation value for one specific subcompartment, this value is taken as the characterisation value for all subcompartments in this compartment. In case two different characterisation values for emissions to agricultural and industrial soil are available, the value for industrial soil is taken as the characterisation value for all other subcompartments to soil.

Other adaptations (V2.1):
- Method expanded with all factors applied by ecoinvent (all categories), except for 'particulates >10 um' for respiratory damage.
- Chromium/nickel factors for carcinogenics adapted (see ecoinvent).
- Factor '0' (zero) added for emssions to the 'long-term' subcompartment of air and water.

Other adaptations (August 2004):
- Characterisation factors category Minerals: "Nickel, 1.13% in sulfides, 0.76% in crude ore, in ground"; "Nickel, 1.98% in silicates, 1.04% in crude ore, in ground"; "Zinc 9%, Lead 5%, in sulfide, in ground" updated, according to updated characterisation factors in EI99 for Nickel, in ore and Zinc, in ore.
- Characterisation factor category Respiratory inorganics added for Particulate matter, Particulate matter, unspecified and Particulates, > 2,5 um, and <10 um.

Other adaptations (March 2005):
- Raw materials: minerals from ecoinvent with additional information in name added and corrected.
- Resp. inorganics: Particulates, diesel soot added (same value as particulates, < 2.5 um).
- Characterisation factors category Carcinogenics added for dichromate to water.
- Characterisation factors ecotoxicity added for emissions to agricultural soil (pesticides) or industrial soil (metals and industrial compounds).

Other adaptations (V2.03, January 2008):
- Correction subcompartment of soil emissions for ecotoxicity.

Other adaptations (V2.04, April 2008)

- The impact category 'Climate change' is adapted. The substance 'carbon dioxide, land transformation' is added, with the same characterisation factor of 'carbon dioxide'.

In the Eco-indicator 99 method normalisation and weighting are performed at damage category level (endpoint level in ISO terminology). There are three damage categories:
HH Human Health (unit: DALY= Disability adjusted life years; this means different disability caused by diseases are weighted)
EQ Ecosystem Quality (unit: PDF*m2yr; PDF= Potentially Disappeared Fraction of plant species)
R Resources (unit: MJ surplus energy Additional energy requirement to compensate lower future ore grade)

Eco-indicator 99 has a damage assessment step. This means that the impact category indicator results that are calculated in the Characterisation step are added to form damage categories. Addition without weighting is justified here because all impact categories that refer to the same damage type (like human health) have the same unit (for instance DALY). This procedure can also be interpreted as grouping.
The damage categories (and not the impact categories) are normalised on an European level (damage caused by 1 European per year), mostly based on 1993 as base year, with some updates for the most important emissions. Please note that the normalisation set is dependent on the perspective chosen.

The normalised damage categories can also be used with the triangle tool. This is very useful if two products are to be compared without weighting, in case the damage indicators for Product A and B are conflicting (A is higher on Human health and B is higher on Ecosystem Quality). In such a case the answer is dependent on the weighting factors for Ecosystem quality, Resources and Human health.
The triangle must be understood as a way to show all possible combinations of weighting factors (represented as a percentage in such a way that they add up to 100%). If damage categories have conflicting values, the triangle will display two area's. One area represents all weighting sets for which product A has a lower environmental load, the other area will represent all weighting sets for which B has a lower load than A. The line in between is the line of indifference. These are the weighting sets for which the environmental load of A and B are the same.
The benefit of using the triangle is that you do not always need to know which exact weighting set you want to use. The stakeholders only have to decide in which area (on which side of the line of indifference) the weighting set may be. See also help file

Uncertainties
Of course it is very important to pay attention to the uncertainties in the methodology. We distinguish two types:
* Data uncertainties
* Uncertainties about the correctness of the models used
Data uncertainties are specified for most damage factors as squared geometric standard deviation in the original reports, but not in the software. It is not useful to express the

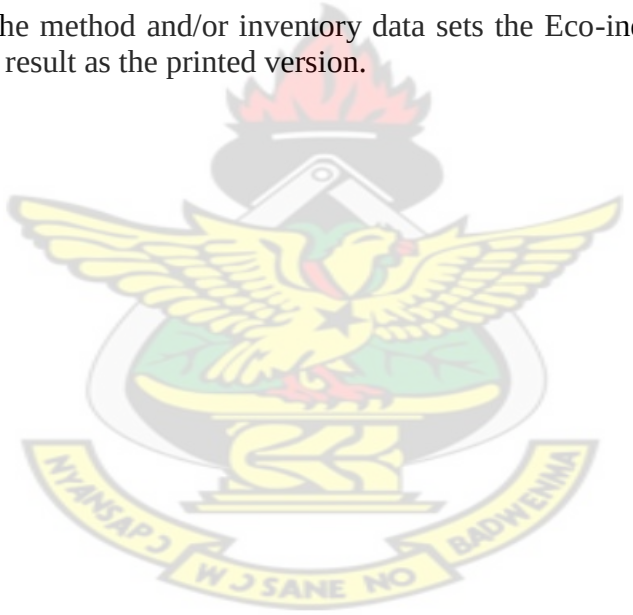
uncertainties of the model as a distribution. Uncertainties about the model are related to subjective choices in the model. In order to deal with them we developed three different versions of the methodology, using the archetypes specified in the

* Egalitarian perspective
* Hierarchist perspective
* Individualist perspective.

In the individualist perspective the chosen time perspective is short term (100 years or less), Substances are included if there is complete proof regarding their effect. For example, only proven carcinogenic substances in IARC class 1 included, while classes 2a, 2b and 3 have deliberately been excluded. In the individualist perspective damages are assumed to be recoverable by technological and economic development. In the case of fossil fuels the assumption is made that fossil fuels cannot really be depleted. Therefore they are left out in weighting. In the DALY calculations age weighting is included.

For further information see the Eco-indicator 99 reports, available from our web site www.pre.nl

Due to adjustments of the method and/or inventory data sets the Eco-indicator 95 in SimaPro might not give the same result as the printed version.



Ecological Scarcity 2006

The Ecological Scarcity 2006. Method is taken from http://www.esu-services.ch/cms/index.php?id=ubp06 (23-May 2008), with adaptations by PRé Consultants as described below. The characterisation factors have been implemented by ESU-services Ltd. All files are provided without liability.

Ecological Scarcity 2006 is a follow up of the Ecological scarcity 1997 method, which is called Ecopoints 97 (CH) in the SimaPro method library.
The Eco-invent implementation contains seven specific impact categories, with for each substance a final UBP (environmental loading points) score as characterisation factor . Because all impact categories are expressed in the same unit UBP, PRé consultants added a weighting step. The "weighting" step simply adds up the scores.
For more information see the Database manual.

Other adaptation (February 2008; v1.00):
-The substances present in this method are compatible with the EI 2.0 database.
-This method is extended for the impact category "emission to air" with:

- carbon dioxide
- carbon dioxide, biogenic
- carbon monoxide and
- carbon monoxide, biogenic

Other adaptation (April 2008; v1.01)
- Substances emitted to the subcompartment unspecified, with characterization factor zero are excluded from the method
- Substances emitted to a specific subcompartment with characterization factor zero while a non zero factor is provided for the subcompartment unspecified remain in the list
- Substances emitted to the subcompartment agricultural (i) are replaced by the subcompartment unspecified with the same characterization factor of subcompartment agricultural and (ii) a subcompartment industrial with characterization factor zero is added
-The impact category 'emissions into air' is adapted. The substance 'carbon dioxide, in air' is added, with the negative characterisation factor of carbon dioxide.
- This method is extended for the impact category "natural resources" with:

Water, barrage*
Water, cooling drinking
Water, cooling, surface
Water, cooling, unspecified natural origin/kg
Water, cooling, well, in ground
Water, fresh
Water, process and cooling, unspecified natural origin
Water, process, drinking
Water, process, surface
Water, process, unspecified natural origin/kg
Water, process, unspecified natural origin/m3
Water, process, well, in ground

Water, turbine use, unspecified natural origin*
Water, unspecified natural origin/kg
* see below under correction

Correction (June 2008;v1.02)
The following water parameters have been deleted from the impact category "Natural resources", as water used for energy production is not considered in this method.
Water, barrage
Water, turbine use, unspecified natural origin.
On the request of the method creators (ESU-services) we have changed the way biotic CO2 is calculated, this is different from the normal procedure in SimaPro.
The following factors have been deleted in the impact category "Emissions to air":
Raw material "Carbon dioxide, biogenic, in air" (factor was -3.10E-2, reflecting the carbon uptake)
Airborne emission Carbon dioxide", biogenic (factor was 3.10E-2, reflecting the release)
Airborne emission Carbon monoxide, biogenic (factor was 4.90E-2, reflecting the release)
Please note that airborne emission "Methane, biogenic" is not deleted! Airborne emission "Methane" was added with characterisation factor 7,1 E3 UBP/kg.

EDIP 2003

EDIP2003 is a Danish LCA methodology, that is presented as an alternative to the EDIP97 methodology. The EDIP2003 version is adapted for SimaPro 7.1.

The main innovation of EDIP2003 lies in the consistent attempt to include exposure in the characterisation modelling of the main non-global impact categories. EDIP2003 can originally be used both with and without spatial differentiation. Only characterisation factor for site-generic effects, which does not take spatial variation into account, are implemented in SimaPro 7.1.

The EDIP2003 methodology represents 18 different impact categories. Some of them are directly taken from EDIP97, some are updated versions of EDIP97, whereas others are modelled totally different. The table underneath gives an overview of the EDIP2003 impact categories. The choices made for implementing the methodology into SimaPro 7.0, are summed up for each impact category

Impact categories:	Implemented in original form	Choices made during implementation
Global warming		Time horizon of 100 years is used and extended with extra factors from EI 2.0
Ozone depletion	x	
Acidification	x	
Terrestrial eutrophication	x	
Aquatic eutrophication (N-eq)		Only emissions to inland waters are included. Emissions to air included
Aquatic eutrophication (P-eq)		
Ozone formation (human)	x	Extended with extra factors from EI 2.0
Ozone formation (vegetation)	x	Extended with extra factors from EI 2.0
Human toxicity (exposure route via air)		Release height of 25m
Human toxicity (exposure route via water)	x	
Human toxicity (exposure route via soil)	x	
Ecotoxicity (water acute)	x	
Ecotoxicity (water chronic)	x	
Ecotoxicity (soil chronic)	x	
Resources		Taken directly from EDIP 97 (updated in 2004)
Waste		Taken directly from EDIP 97 (updated in 2004)

In the EDIP 2003 method, characterisation factors for aquatic eutrophication are developed for two impact categories: Aquatic eutrophication EP(N) and Aquatic eutrophication EP(P). In

each impact category, characterisation factors for emissions effecting inland waters and emissions effecting marine waters are developed. This double set of characterisation factors reflect the fact that, in general, eutrophication is limited by Nitrate in fresh waters, and Phosphate in marine waters.
In order to avoid double counting, that would occur if both emission types are implemented simultaneously, only the characterisation factors for inland water are implemented in SimaPro 7.0. When characterisation factors for marine water are needed, see guidline EDIP 2003 or database manual.

The emission to soil only takes into account the effects after plant uptake. For this impact category the topsoil is part of the techno sphere.
Emission to air are also included in the model. The data needed for this compartment is not present in the guideline, but is received from Michael Hauschild.

The EDIP2003 characterisation factors for human toxicity, exposure route via air, are enhanced. The new exposure factors are established for:
- Two different kinds of substances: short-living (hydrogen chloride) and long-living (benzene)
- Actual variation in regional and local population densities: added for each substance
- Different release heights: 1m, 25m and 100m.
The release height of 25m is presented as default in EDIP2003 and is used in SimaPro 7.0.

For global warming a time horizon of 100 years is recommended by EDIP2003 and is used in SimaPro 7.0.

In the impact categories "ozone formation", for the substance isobutene, two synonyms with the same cas-number and a different characterisation factor are found. Next characterisation factors are used: Ozone formation (human): Isobutene: 9,44E-05
Ozone formation (vegetation): Isobutene: 1,168

The impact category resources is not mentioned and considered in EDIP2003. For calculating effects of within this impact category, the method EDIP/UMP 97 (resources only), available in SimaPro 7.0, can be used. The impact categories waste are directly taken from EDIP 1997 (with updated factors from 2004).

Normalisation:
Except for ecotoxicity, all the different impact categories are normalized in the same way as in EDIP97, only using EDIP2003 normalisation references. Due to lack of data, no EDIP2003 normalisation references for any of the ecotoxicity categories is calculated. Therefore, in SimaPro, the normalisation reference for ecotoxicity is nought.
For the impact categories waste normalization factors of EDIP 1997 are used.

Weighting:
The weighting factors of EDIP97, which were updated in 2004, are also used in EDIP2003. Because ecotoxicity has no normalisation factors, also for weighting the value is nought. For

the impact categories waste weighting factors of EDIP 1997 (with updated factors from 2004) are used.

For more information see the Database manual.

Reference:
M. Hauschild and Potting, J., 2003.Spatial differentiation in Life Cycle impact assessment - The EDIP2003 methodology. Institute for Product Development Technical University of Denmark.

Other adaptations (February 2008, v1.00):
- The name of impact category global warming (GWP100) was changed to Global warming 100a
- Expanded with extra substances.
- The folowing "substances" were removed from the method because they were not compatible with the SimaPro substance list:

Chemical cleaning of clothes
Coal mining
Combustion of wood
Diesel-powered car, exhaust
EP-2 syre
Farming
Food industry
Iso MP-1 syre
Landfilling household waste
Petrol-powered car, exhaust
Petrol-powered car, vapour
Power plants
Refining and distribution of oil
Surface coating

Other adaptation (April 2008, v1.01):
-The impact category 'Global warming 100a' is adapted.

The substance 'carbon dioxide, in air' is added, with the negative characterisation factor of carbon dioxide.

The substance 'carbon dioxide, land transformation' is added, with the same characterisation factor of 'carbon dioxide'.
- The characterisation factors for resources were updated according to the update of EDIP97 issued in 2004. Except for Cerium and Lanthanum.
- The normalisation (1994) and weighting (2004) factors for all categories were updated according to the update of EDIP97 issued in 2004.
- Added the substances: Uranium, Chromium, Selenium, Strontium, Tellurium, Thallium, Titanium, Tungsten, Vanadium, Yttrium, Zirconium.
- For PGM the average CF of platinum and palladium is used.

EPD 2007

This method is to be used for the creation of Environmental Product Declarations or (EPDs), as published on the website Swedish Environmental Management Council (SEMC) www.environdec.com. The original document is titled: "Revision of the EPD®system into an International EPD®" We used the draft version that was to be commented before March 2007, but that was still on the site when we compiled this method in June 2007. It is possible the final version will have other characterization factors.

In the standard EPDs one only has to report on the following impact categories. Specific product category guidelines may require extra information.
- Gross Calorific Values (GCV) (also referred to as the "Higher Heating Values")
- Greenhouse gases
- Ozone-depleting gases
- Acidifying compounds
- Gases creating ground-level ozone (Photochemical Ozone creation)
- Eutrophicating compounds

Except for the Gross Calorific Value (GVC) impact categories, all impact categories are taken directly from the CML 2 baseline 2000 method, also found in SimaPro (we used release 2.03).

Please note that there are some differences between the SimaPro implementation and the EPD document for the Gross Calorific Values. See the methods section in the Database manuals (available under the Help menu)

Acknowledgement: We thank Leo Breedveld from 2B (www.to-be.it) for his advise and support.

Mark Goedkoop, June 2007

Other adaptations (February 2008, v1.01):
- Minor adaptations in Unit names and Impact category names (capitals, points) for more consistency with other categories.

Other adaptation (April 2008, v1.02)
- The impact category 'Global warming (GWP100)' is adapted. The substance 'carbon dioxide, land transformation' is added, with the same characterisation factor of 'carbon dioxide'.

For further information see the database manual.

EPS 2000

EPS 2000 default methodology. Environmental Priority Strategies in product design. Adjusted to include a damage assessment step.

This V2 version is adapted for SimaPro 6.0. All characterisation factors in this method are entered for the 'unspecified' subcompartment of each compartment (Raw materials, air, water, soil) and thus applicable on all subcompartments, where no specific characterisation value is specified.

This method is NOT fully adapted for inventory data from the ecoinvent library and the USA Input Output Database 98, and therefore omits emissions that could have been included in impact assessment. Carbon dioxide, biogenic and uptake from carbon dioxide from air (Carbon dioxide, in air) are added to the methodology. Similar for 'Carbon monoxide, fossil' and 'Carbon monoxide, biogenic'.

The EPS system is mainly aimed to be a tool for a company's internal product development process. The top-down development of the EPS system has led to an outspoken hierarchy among its principles and rules. The general principles of its development are:
1. The top-down principle (highest priority is given to the usefulness of the system); 2. The index principle (ready made indices represent weighted and aggregated impacts)
3. The default principle (an operative method as default is required)
4. The uncertainty principle (uncetainty of input data has to be estimated)
5. Choice of default data and models to determine them

The EPS 2000 default method is an update of the 1996 version. The impact categories are identified from five safe guard subjects: human health, ecosystem production capacity, abiotic stock resource, biodiversity and cultural and recreational values. Human Health indicators are:
* Life expectancy, expressed in Years of life lost (person year)
* Severe morbidity and suffering, in person year, including starvation
* Morbidity, in person year, like cold or flue
* Severe nuisance, in person year, which would normally cause a reaction to avoid the nuisance
* Nuisance, in person year, irritating, but not causing any direct action

The default impact categories of production capacity of ecosystems are:
* Crop production capacity, in kg weight at harvest
* Wood production capacity, in kg dry weight
* Fish and meat production capacity, in kg full weight of animals
* Base cat-ion capacity, in H+ mole equivalents (used only when models including the other indicators are not available)
* Production capacity of (irrigation) water, in kg which is acceptable for irrigation, with respect to persistant toxic substances
* Production capacity of (drinking) water, in kg of water fulfilling WHO criteria on drinking water.

Abiotic stock resource indicators are depletion of elemental or mineral reserves and depletion of fossil reserves. Note some classification factors are defined 0 (zero).

NOTE: Adaption by PRé Consultants: The characterisation value as given in abiotic depletion is both the value for depletion PLUS the ELU's as a result of impacts due extraction of the element/mineral or resource. Default impact category for biodiversity is extinction of species, expressed in Normalised Extinction of species (NEX).

Changes in cultural and recreational values are difficult to describe by general indicators as they are highly specific and qualitative in nature. Indicators should be defined when needed.

Classification
Emissions and resources are assigned to impact categories when actual effects are likely to occur in the environment, based on likely exposure. Characterisation
Empirical, equivalency and mechanistic models are used to calculate default characterisation values.

Weighting
In the EPS default method, weighting is made through valuation. Weighting factors represent the willingness to pay to avoid changes. The environmental reference is the present state of the environment. The indicator unit is ELU (Environmental Load Unit).

Disclaimer
The models and data are intended to improve environmental performance of products. The choice and design of the models and data are made from an anticipated utility perspective of a product developer. They are, for instance not intended to be used as a basis for environmental protection strategies for single substances, or as a sole basis for environmental product declarations. In most of those cases additional site-specific information and modelling is necessary.

References:
Bengt Steen (1999) A systematic approach to environmental strategies in product development (EPS). Version 2000 - General system characteristics. Centre for Environmental Assessment of Products and Material Systems. Chalmers University of Technology, Technical Environmental Planning. CPM report 1999:4.

Bengt Steen (1999) A systematic approach to environmental strategies in product development (EPS). Version 2000 - Models and data of the default methods. Centre for Environmental Assessment of Products and Material Systems. Chalmers University of Technology, Technical Environmental Planning. CPM report 1999:5.

Download links for these reports can be found on http://www.pre.nl/simapro/impact_assessment_methods.htm

NOTE: Adaption by PRé Consultants: The characterisation value as given in abiotic depletion is both the value for depletion PLUS the ELU's as a result of impacts due extraction of the element/mineral or resource. Default impact category for biodiversity is extinction of species, expressed in Normalised Extinction of species (NEX).

30/05/01. Update characterization factors. Factors for air emissions of metals were added.

Update August 2004:
- Raw materials: minerals from ecoinvent with additional information in name and missing fossil fuels are added to the methodology. To obtain the characterisation factor of Energy, from sulphur, the characterisation factor of Sulphur, in ground has been divided by the energy content of sulphur, as given in the cumulative energy demand (V1.2) method. To obtain the characterisation factor of Energy, from uranium, the characterisation factor of the uranium with the lowest energy content has been divided by the energy content of that uranium (worst case scenario). Oil, crude: assumed energy content 42 MJ/kg.
- Life expectancy, Severe morbidity, Morbidity, Crop growth capacity, Wood growth capacity, Species extinction: Methane, biogenic and Methane, fossil added.
- Species extinction: Land occupation with additional information in name added. Assumptions:
  * Land occupations in same category (e.g. Arable, Industrial area) have the same characterisation factors
  * Construction site -> Industrial area
  * Dump site -> Industrial area
  * Permanent crop -> Arable
  * Shrub lands -> Forest
  * Occupation, unknown -> not characterized
- Acidification: nitrogen compounds completed.
- Acidification: sulphur compounds completed.
- "Particulates, > 2.5 um, and < 10um" added with the assumption that the characterization factor is the same as for "Particulates, < 10 um"
- "Particulates, < 10 um (mobile)" and "Particulates, < 10 um (stationary)" added to categories "Crop Growth Capacity", "Wood Growth Capacity" and "Species Extinction"
- "Particulates, unspecified"added with same characterization factors as "Particulates"

Other adaptations (February 2005):
- Raw materials: minerals from ecoinvent with additional information in name added and corrected.
- Life expextancy and Severe morbidity: Characterisation factors for Benzo(a)pyrene and for Polychlorinated biphenyls added (equal to characterisation factors for PAH, polycyclic aromatic hydrcarbons).
- Raw materials: Characterisation factors for (energy from) coal, brown corrected.
- Fish and Meat production and Species Extinction: Nitrogen, to water added (equal to nitrogen, total, to water).

Other adaptations (February 2008, v2.03):

- Minor adaptations in Unit names and Impact category names (capitals, points) for more consistency with other categories

Other adaptations (April 2008, v2.04):
- The impact categories 'Life expectancy, Severe morbidity, Morbidity, Crop growth capacity, Wood growth capacity, Species extinction' are addapted. The substance 'carbon dioxide, land transformation' is added, with the same characterisation factor of 'carbon dioxide'.

IMPACT 2002+

IMPACT 2002+ is mainly a combination between IMPACT 2002 (Pennington et al. 2005), Eco-indicator 99 (Goedkoop and Spriensma. 2000, 2nd version, Egalitarian Factors), CML (Guinée et al. 2002) and IPCC.

IMPACT 2002 factors mainly replace Human Health cancer and non-cancer factors and Aquatic and Terrestrial ecotoxicity factors. Eco-indicator 99 factors mainly replace Respiratory effects, Ionizing radiations, Terrestrial acid/nutri, Land use and Mineral extraction. CML factors mainly replace Aquatic acidification and Aquatic eutrophication. The Aquatic eutrophication CF implemented in this method are the one for a P-limited watershed.

The respective midpoint units are the following: kgeq chloroethylene into air (written "kg C2H3Cl eq") for Carcinogens and Non-carcinogens, kgeq PM2.5 into air (written "kg PM2.5 eq") for Respiratory inorganics, Bqeq C-14 into air (written "Bq C-14 eq") for Ionizing radiation, kgeq CFC-11 into air (written "kg CFC-11 eq") for Ozone layer depletion, kgeq ethylene into air (written "kg C2H4 eq") for Respiratory organics, kgeq triethylene glycol into water (written "kg TEG water") for Aquatic ecotoxicity, kgeq triethylene glycol into soil (written "kg TEG soil") for Terrestrial ecotoxicity, kgeq SO2 into air (written "kg SO2 eq") for Terrestrial acidi/nutri, m2eq organic arable land (written "m2org.arable") for Land occupation, kgeq SO2 into air (written "kg SO2 eq") for Aquatic acidification, kgeq PO4--- into a P-limited water (written "kg PO4 P-lim") for Aquatic eutrophication, kgeq CO2 into air (written "kg CO2 eq") for Global warming, MJ primary non-renewable (written "MJ primary") for Non-renewable energy and MJ surplus (written "MJ surplus") for Mineral extraction. The respective damage units are DALY for Human health, PDF*m2*yr for Ecosystem quality, kgeq CO2 into air (written "kg CO2 eq") for Climate change and MJ primary non-renewable (written "MJ primary") for Resources. These characterization factors are from the file "IMPACT2002+_v2.1_CF_1a.xls".

The supporting documents for IMPACT 2002+ (Jolliet et al. 2003, Humbert et al. 2005) and the factors can be downloaded at http://www.epfl.ch/impact. This version has been formatted and released in October 2005. By Sébastien Humbert, sebastien_humbert@berkeley.edu, EPFL, October 2005. This file takes into account the updates regarding the flows Molybdenum (should be non-cancer), Chlordane (and its isomers), Cyhalothrin (and lambda- and gamma-) and Phthalate ("Phthalate, dioctyl-" has been changed by "Phthalate, di(2-ethylhexyl)-"). Characterization factors for "groundwater", "groundwater, long-term" and "ocean" emissions for carcinogens, non-carcinogens, aquatic ecotoxicity and terrestrial ecotoxicity have been set to 0. However, this does not indicate that no impacts will occur, but that currently we do not have available CF for groundwater emissions.

Impact categories Aquatic acidification and Aquatic eutrophication are midpoint indicators, and therefore are not included in the endpoint.

Normalization:

The damage factor reported in ecoinvent are normalized by dividing the impact per unit of emission by the total impact of all substances of the specific category for which characterization factors exist, per person per year (for Europe).

Weighting:
Use default weighting factor of one, unless other social weighting values are available.

Ref: Jolliet O, Margni M, Charles R, Humbert S, Payet J, Rebitzer G and Rosenbaum R (2003). "IMPACT 2002+: A New Life Cycle Impact Assessment Methodology." Int J LCA 8 (6) 324-330.

Update version 2.01:
IMPACT 2002+ version 2.01 (October 2005) is the same as version 2.00 (March 2004) with the DALY per case of cancer and non-cancer updated from 6.7 and 0.67 to 13 and 1.3 respectively (in accordance with Keller (2005)).

Update version 2.02:
Version 2.02 replaces version 2.01 which contained an error in the damage assessment.

Update version 2.03:
Substances under non material emissions are appended with corresponding substances in raw, air and water compartments.

Other adaptations (February 2008, v2.04):
- Minor adaptations in Unit names and Impact category names (capitals, points) for more consistency with other categories.

Other adaptation (April 2008, v2.05)
- The impact category 'Global warming' is adapted.The substance 'carbon dioxide, land transformation' is added, with the same characterisation factor of 'carbon dioxide'.

APPENDIX D Parameters for Optimization Experiment

Design-Expert Software Coded values

Run	PET Weight (kg)	Box Weight (kg)	Grid Energy (%)
1	0	0	0
2	1	1	1
3	0	0	-1.681792831
4	1	-1	-1
5	0	0	1.681792831
6	0	0	0
7	1	-1	1
8	-1	-1	-1
9	1.681792831	0	0
10	1	1	-1
11	0	-1.681792831	0
12	-1.681792831	0	0
13	-1	1	-1
14	0	0	0
15	-1	1	1
16	0	1.681792831	0
17	0	0	0
18	-1	-1	1

Real Values for Optimization Analysis

	PET Weight (kg)	Box Weight (kg)	Grid Energy (%)	Climate Change	Ozone Layer	Ecotoxicity
1	48	152	90%	1.26449E-07	1.0275E-10	0.11566279
2	60	228	94%	1.48549E-07	1.22606E-10	0.13973107
3	48	152	80%	1.1838E-07	9.98701E-11	0.10267064
4	60	114	85%	1.22091E-07	1.09206E-10	0.1017062
5	48	152	100%	1.3614E-07	1.06383E-10	0.13033967
6	48	152	90%	1.26449E-07	1.0275E-10	0.11566279
7	60	114	94%	1.3001E-07	1.12103E-10	0.11408145
8	40	114	85%	1.11992E-07	9.00538E-11	0.099539625
9	120	152	90%	1.62805E-07	1.71697E-10	0.12346248
10	60	228	85%	1.4063E-07	1.19709E-10	0.12735582
11	48	76	90%	1.1409E-07	9.57475E-11	0.09856305
12	34	152	90%	1.19379E-07	8.93434E-11	0.11414619
13	40	228	85%	1.30531E-07	1.00557E-10	0.12518924
14	48	152	90%	1.26449E-07	1.0275E-10	0.11566279
15	40	228	94%	1.3845E-07	1.03454E-10	0.13756449
16	48	456	90%	1.75884E-07	1.30759E-10	0.18406177
17	48	152	90%	1.26449E-07	1.0275E-10	0.11566279
18	40	114	94%	1.19911E-07	9.29507E-11	0.11191487

APPENDIX E Pineapple Nutrition Information

Nutrient	Units	1 fruit ------- 472 g	1 slice (3-1/2" dia x 3/4" thick) ------- 84 g
Proximates			
Water	g	408.280	72.660
Energy	kcal	231.280	41.160
Energy	kj	967.600	172.200
Protein	g	1.841	0.328
Total lipid (fat)	g	2.030	0.361
Ash	g	1.369	0.244
Carbohydrate, by difference	g	58.481	10.408
Fiber, total dietary	g	5.664	1.008
Minerals			
Calcium, Ca	mg	33.040	5.880
Iron, Fe	mg	1.746	0.311
Magnesium, Mg	mg	66.080	11.760
Phosphorus, P	mg	33.040	5.880
Potassium, K	mg	533.360	94.920
Sodium, Na	mg	4.720	0.840
Zinc, Zn	mg	0.378	0.067
Copper, Cu	mg	0.519	0.092
Manganese, Mn	mg	7.783	1.385
Selenium, Se	mcg	2.832	0.504
Vitamins			

Vitamin C, total ascorbic acid	mg	72.688	12.936
Thiamin	mg	0.434	0.077
Riboflavin	mg	0.170	0.030
Niacin	mg	1.982	0.353
Pantothenic acid	mg	0.755	0.134
Vitamin B-6	mg	0.411	0.073
Folate, total	mcg	51.920	9.240
Folic acid	mcg	0.000	0.000
Folate, food	mcg	51.920	9.240
Folate, DFE	mcg_DFE	51.920	9.240
Vitamin B-12	mcg	0.000	0.000
Vitamin A, IU	IU	108.560	19.320
Retinol	mcg	0.000	0.000
Vitamin A, RAE	mcg_RAE	4.720	0.840
Vitamin E	mg_ATE	0.472	0.084
Tocopherol, alpha	mg	0.472	0.084

Lipids			
Fatty acids, total saturated	g	0.151	0.027
4:0	g	0.000	0.000
6:0	g	0.000	0.000
8:0	g	0.000	0.000
10:0	g	0.000	0.000
12:0	g	0.000	0.000
14:0	g	0.000	0.000
16:0	g	0.090	0.016
18:0	g	0.052	0.009
Fatty acids, total monounsaturated	g	0.227	0.040
16:1 undifferentiated	g	0.014	0.003
18:1 undifferentiated	g	0.212	0.038
20:1	g	0.000	0.000
22:1 undifferentiated	g	0.000	0.000
Fatty acids, total polyunsaturated	g	0.689	0.123
18:2 undifferentiated	g	0.396	0.071
18:3 undifferentiated	g	0.293	0.052
18:4	g	0.000	0.000
20:4 undifferentiated	g	0.000	0.000
20:5 n-3	g	0.000	0.000
22:5 n-3	g	0.000	0.000
22:6 n-3	g	0.000	0.000
Cholesterol	mg	0.000	0.000
Phytosterols	mg	28.320	5.040
Amino acids			
Tryptophan	g	0.024	0.004
Threonine	g	0.057	0.010
Isoleucine	g	0.061	0.011
Leucine	g	0.090	0.016
Lysine	g	0.118	0.021
Methionine	g	0.052	0.009
Cystine	g	0.009	0.002

Phenylalanine	g	0.057	0.010
Tyrosine	g	0.057	0.010
Valine	g	0.076	0.013
Arginine	g	0.085	0.015
Histidine	g	0.042	0.008
Alanine	g	0.080	0.014
Aspartic acid	g	0.269	0.048
Glutamic acid	g	0.212	0.038
Glycine	g	0.080	0.014
Proline	g	0.061	0.011
Serine	g	0.118	0.021

Source: USDA National Nutrient Database for Standard Reference Release 18, 2006 - Nutrition and Diet Data