University of Southern Queensland

Faculty of Engineering and Surveying

Life Cycle Assessment of a Personal Computer

A dissertation submitted by

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Abstract

This research project aims to assess the components parts of a PC to determine which parts contribute most adverse to environmental impacts, and to make recommendations about the potential for recycling and recovery of materials at the end-of-life of a PC. The investigation is performed by implementing LCA methodology on the PC. This paper summarizes the methodology generated. A PC used is the Pentium IV ABA PC including the Compaq monitor, keyboard and mouse. The procedure of the LCA follows the ISO 14040 series. System boundary includes the entire life cycle of the product, including raw material acquisition, material processing, transportation, use and disposal. The LCI and impact database for a PC is constructed using SimaPro software version 6.0 after disassembling the PC and taking an inventory of its component parts.

The results of the study show that the production and the use stages are the most contributing phases. In the production phase, PC manufacturing consists of simple processes such as assembly and packaging. Assembly processes of the computer parts such as PCB assembly, CRT assembly, and ICs assembly are the most contributing in this phase. The use stage has a significant potential due to electricity consumption. The disposal stage's contribution is very small in comparison. Possible ways of improving the environmental burden, such as reduction of power consumption of the PC, are also outlined in this paper. This paper concludes by outlining the main achievements and some future work of this project.

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Certification

I certify that the ideas, designs and experimental work, results, analyses and conclusions set out in this dissertation are entirely my own effort, except where otherwise indicated and acknowledged.

I further certify that the work is original and has not been previously submitted for assessment in any other course or institution, except where specifically stated.

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CHAPTER 1

Introduction

Electric and electronic goods constitute one of the fastest growing categories of consumer goods in the world today (US EPA 1999). Often being the very symbols of material welfare, they have become intimately connected to our modern way of life and several have become indispensable everyday aids. More so, computer technology has had a substantial impact on the development of several technological and scientific disciplines, besides the field of communication itself. One of these disciplines is the modeling of complex meteorological and climatic patterns in the earth's atmosphere, crucial for our understanding of our own human impact on the climate, which is heavily dependent on powerful computer technology. The modern "communication society" would not be what it is today without the aid of advanced electronic appliances.

Apart from the importance of these products in facilitating modern life, and being important tools to combat today's environmental and societal problems, they also bring about significant health and environmental hazards. The PC, of which this project focuses, is no exception. Some of these aspects, such as solvent releases, hazardous waste generation and water and energy consumption, occur as a result of production processes, whereas others, such as the emission of electromagnetic radiation and consumption of energy, occur during the use phase of the products. Still others, related to end-of-life treatment, occur due to the product content. Examples of the latter are the occurrence of halogenated flame retardants and toxic metals in PC components. With new substances continuously being incorporated into the products and with the volumes of personal computers entering the market each year ever increasing, new health and environmental aspects are occurring and are likely to continue to do so.

According to Matthews (2003, p.1760), little attention is placed upon the potential environmental impacts of Information and Communications Technology (ICT) around the world. These negative environmental impacts arise from among others, a globallypolluting supply chain and from producing the electricity needed to power computers. Table 1 below gives an approximate value of the environmental impact of Computer/Office Equipment in USA in 1997 by Matthews (2003). The direct component is defined as the environmental effect that can be attributed directly to an industry's operations, while the indirect component results from a corresponding change in demand for all other industries in the economy associated with the supply chain for an industry.

Table 1: Direct and Indirect Effects of providing $1 million of products in the Computer/Office Equipment (US, 1997)

Effects	**Units**	**Computer/Office Equipment**		
		Total	**Direct**	**Indirect**
Electricity used	10^6 kW-hr	0.436	0.093	0.343
Energy used	Terajoule	8.5	0.275	8.225
Conventional pollutants released	Metric tons	6.838	0.057	6.781
Fatalities	Lives	0.001	0.000	0.001
CO_2 equivalent gases released	Metric tons	585	13	572
Hazardous waste generated	Metric tons	39	25	14
Toxic releases and transfers	Metric tons	0.939	0.039	0.9
Weighted toxic releases	Metric tons	7.712	0.093	7.619

From the table the most effects generally occur from indirect purchases in the supply chain. The energy used to produce $1 million of computers is approx. 97% in the indirect purchases.

Matthews (2003, p.1762) furthers says this about electronic devices:

> Most electronic devices consume power even when turned off, because they leak energy in standby and sleep modes. They also generate heat which must be dissipated by ventilation (of which this is an indirect source of electricity demand).

Hence this project aims to analyze a PC specifically in more detail. This is done by the use of life cycle assessment (LCA) methods which are incorporated into the SimaPro software. Further analyses is conducted on which of the PC parts contribute most to adverse environmental impacts of the whole PC system. The results obtained will be compared to previous studies that have been conducted on the same product, such as "Life Cycle Assessment; An Approach to Environmentally Friendly PCs" by Tekwawa et al. (1997).

1.1 Outline of the project

Chapter 2 covers the background and literature of LCA, and further summarizes the four components of a LCA study. Chapter 3 provides an introduction to the methodology used in this study and some current technologies associated with SimaPro software as well as a short review of the studies that have been done on a particular PC. Chapter 4 covers the goal and scope of this project in more detail. In Chapter 5, an overview of the system description and its lifecycle inventory is given. Chapter 6 contains the central analysis of the project, that is, the lifecycle inventory (LCI) is categorized and characterized as potential environmental impacts. The results of the environmental load are given and discussed in this chapter. Ways of reducing some potential impacts are also discussed in here. In Chapter 7 some conclusions on what is being achieved and future work is provided here. Chapter 8 gives some details of the study in the form of Appendices. Appendix A presents a copy of the Project Specification, and Appendix B presents detailed input/output data from the LCI.

CHAPTER 2

Life Cycle Assessment

2.1 Background Information of LCA

Life cycle assessment (LCA) is the calculation and evaluation of the environmentally relevant inputs and outputs, and the potential environmental impacts of the life cycle of a product, material or service (ISO, 1997). Environmental inputs & outputs refer to demand for natural resources, and to emissions and solid waste.

LCAs evaluate the environmental impacts from each of the following major life cycle stages, raw material acquisition; material processing; transport; product manufacture; product use; and final disposition (ISO 14040). All processes start with the extraction of raw materials and energy from the environment. They proceed through the stages of production and consumption. And they end with disposal, when the product may be transported to a municipal waste treatment plant where it is dismantled. Parts of the product may be recovered for recycling and other parts are incinerated. Thus disposal also involves several processes which require materials, energy and services. Ultimately, all material inputs from the environment are transformed by economic processes and re-enter the environment as emissions to water, air and land. LCA is sometimes called a “cradle-to-grave” assessment.

2.2 The Components of LCA

LCA generally has four components (ISO 1997). These include:

(i) Defining the goal and scope of the study.
(ii) Making a model of the product life cycle with all environmental inflows and outflows. This data collection effort is usually referred to as the life-cycle inventory (LCI) stage.
(iii) Understanding the environmental relevance of all inflows and outflows; this is referred to as the life-cycle impact assessment (LCIA) phase.
(iv) The interpretation of the study.

2.2.1 Goal and Scope

The goal and scope definition is the first step in a LCA study. In this phase the purpose of the study is described. This description includes the intended application and audience, and reasons for carrying out the study (Udo de Haes et al. 2002, p.1). Furthermore, the scope of the study is described. This includes a description of the limitations of the study, the functions of the systems investigated, the functional unit, the systems investigated, the system boundaries, the allocation approaches, the data requirements, data quality requirements, the key assumptions, the impact assessment method, the interpretation method, and the type of reporting.

2.2.2 Life Cycle Inventory

The main technique used in LCA is that of modeling. In the inventory phase, a model is made of the complex technical system that is used to produce, transport use and dispose of a product. This results in a flow sheet or process tree with all the relevant processes. For each process, all the relevant inflows and the outflows are collected. Emissions, energy requirements and material flows are calculated for each process. These data will then be adapted and/or weighted to the functional unit, which is defined in the goal and scope, so that the whole life cycle of the product can be taken into account (Pre Consultants, 2002).

2.2.3 Life Cycle Impact Assessment

Life-cycle impact assessment (LCIA) is the process in which the input and the output data from an LCI are aggregated across all life cycle stages and translated into impacts and examined from an environmental perspective using category indicators (Udo de Haes et. 2002, p.2). In the life cycle impact assessment phase, a completely different model is used to describe the relevance of inflows and outflows. For this, a model of an environmental mechanism is used. For example, an emission of SO_2 could result in an increased acidity, which can cause changes in soils that result in dying trees, etc (Goedkoop & Oele 2004). By using several environmental mechanisms, the LCI result can be translated into a number of impact categories such as acidification, climate changes etc. The LCIA also provides information for the interpretation phase.

According to ISO (International Organization for Standardization 14040 series (1997, 2000), life-cycle impact assessment (LCIA) consists of two mandatory elements, classification and characterization, and three optional elements, normalization, grouping, and weighting.

2.2.4 Interpretation

The Life Cycle Interpretation is the phase where the results are analyzed in relation to the scope definition, where conclusions are reached, the limitations of the results are presented and where recommendations are provided based on the findings of the preceding phases of the LCA.

2.3 LCA Standards

LCA approaches are generally guided by standards; and from a standard perspective they are dealt with under the umbrella of the ISO 14000 series. The main documents are as follows:

- ISO 14040 – Life Cycle Assessment – General principles, framework and requirements for the LCA of products and services (1997)
- ISO 14041 – Life Cycle Inventory analysis (1998)
- ISO 14042 – Life Cycle Impact Assessment (2000)
- ISO 14043 – Life Cycle Interpretation (2000)

2.4 Types of LCA

There are three different types of LCA. They are conceptual, simplified and detailed LCA. According to UNEP (1996), these three different types can be used in different ways depending upon the context in which they are used.

2.4.1 Conceptual LCA

The conceptual LCA is the simplest form of LCA and is used at a very basic level to make an assessment of environmental aspects, based upon a limited and usually qualitative inventory. The results of a conceptual LCA can usually be presented using qualitative statements, graphics, flow diagrams or simple scoring systems which indicate which components or materials have the largest environmental impacts and why.

2.4.2 Simplified LCA

Simplified LCA applies the LCA method for screening assessment (i.e. covering the whole life cycle). Screening is made using already available data or estimated data that is already in the database (Goedkoop & Oele 2004). For missing data, provisional alternatives are taken. For example, if you need nickel production, and you only have data on some other non-ferro metals, you use these alternatives to get an impression of the importance of this process.

2.4.3 Detailed LCA

Detailed LCAs involve the full process of undertaking LCAs and require extensive and in-depth data collection, specifically focused upon the target of the LCA, which if only available generically, must be collected specifically on the product or service under review.

Of the three types of LCA discussed, simplified (screening) is used in this study.

2.5 Literature

The energy crises in the 1970s and the resource depletion concerns raised by publications such as “Limits to Growth” (Meadows, et al., 1972) set a trend where more thought began to be given to ways and means of optimizing resource usage. Rising energy costs triggered the need for more systematic and detailed energy usage planning. (UNEP-IE, 1996) LCA was developed in parallel to energy planning initiatives and the need for detailed energy analyses within it.

During the 1980s a growing focus upon global warming and resource depletion influenced an increased interest in LCA. This was accompanied by more LCA studies being made available publicly. It was at this stage that databases began to be developed to meet the complex inventory and assessment data needs of the studies.

A confusing situation arose towards the end of the 1980s when environmental reports on similar products often contained conflicting results because they were based on different methods, data and terminology. It soon became clear that there was a need for standardization in environmental reporting. Hence by 1997, the first LCA standard was developed, ISO 14040, which deals with principles and framework of LCA.

Today, knowledge of how to carry out an LCA is improving rapidly. The value of the technique is being increasingly recognized and it is now being used for strategic decision making and for designing environmental policies.

CHAPTER 3

Project Methodology

The methodology of the project involved a study of the literature and background information to develop an understanding of the current LCA technology and its associated standards, as well as an understanding of the current methodology associated with SimaPro and its usage. To analyze and assess the environmental impacts of a PC, a few things were carried out, that is, a particular PC was disassembled and an inventory of its components parts was constructed. Weights of the different parts of the computer, together with packaging were also taken, to aggregate the total weight of the PC. Then measurements of energy consumption were taken from a typical similar PC under a variety of conditions (i.e. when the monitor is on and the control unit and keyboard off; when control unit and keyboard on but monitor off; and when control unit and keyboard and monitor are all on). A model of the lifecycle of the PC from raw material to ultimate disposal was further constructed. Then various analyses using SimaPro software were performed. The broad analysis of LCA performed by the software incorporates categories such as human health, ecosystem quality and natural resource use etc into the impact assessment. The analyses were further supported by a study of relevant literature for comparison of results to similar products.

3.1 How the Methodology was conducted

This is how the methodology was carried out in detail. First, data was prepared for the different stages of the life cycle of a PC. Data prepared were product composition data; production stage data; distribution stage data; use stage data; and the disposal stage data.

3.1.1 Product Composition Data

The PC that is being evaluated in this study is a desktop PC that comprises a cathode ray tube (CRT) monitor, control unit, keyboard and mouse. The monitor is a Compaq and the control unit is an ABA model, both of which were manufactured in early 1997 in Malaysia, Asia. To prepare the product composition data, the desktop PC was disassembled into components such as the hard disk drive (HDD), floppy disk drive (FDD), CD-ROM drive, power supply, etc, and the weight of each component was measured. The components were further dismantled, and the weight and number of the materials in them determined. Tabulated results for the disassembled PC are in chapter 5.

3.1.2 Production Stage Data

The production stage data comprised parts manufacturing, material manufacturing and the assembly processes. Most of the background data such as fuels, aluminum sheet, copper sheet, packaging materials, glass, electricity, emissions, energy, waste management, materials production, transport, etc, are readily available in LCA databases such as SimaPro software.

The inventory data for electronic parts such as semiconductor devices, resistors, capacitors, transformers and coils, printed circuit boards, and cables were obtained after disassembling the PC, and from LCA reports on similar product such as “Life Cycle Assessment; An Approach to Environmentally Friendly PCs, by Tekawa M, etal., 1996”.

3.1.3 Distribution Stage Data

Distribution stage data were obtained by assuming the PC is transported from Malaysia to Brisbane by ship; and from Brisbane to Toowoomba by a 28-ton truck; and from Toowoomba wholesale to University of Southern Queensland (USQ) by a delivery van.

The carrying capacity of each transportation stage was obtained by multiplying the distance traveled by the weight of the PC. For example, the distance from Malaysia to Brisbane is approx. 6000km, and the weight of the PC is approx. 29kg (0.029 tonnes), therefore the carrying capacity of the ship for this PC is about 174tkm.

3.1.4 Use Stage Data

The power consumption for the PC was measured. The computer's life was assumed to be 5 years, being operated 8hrs/day and 240days/year. Hence the use stage data for this PC was calculated by multiplying the power consumption by the operating time. More detail on the use stage is on section 5.2.

3.1.5 Disposal Stage Data

The disposal stage data were obtained assuming that 30% of the used products from PCs are recycled; and that 70% of the used products from PCs are broken into fragments and landfilled.

3.2 LCA Methodology with SimaPro

The main technique used in LCA is that of modeling. In the inventory phase, a model is made of the complex technical system that is used to produce, transport, use and dispose of a product. This results in a flow sheet or process tree with all the relevant processes. For each process, all the relevant inflows and the outflows are collected. The result is usually a long list of inflows and outflows that is often difficult to interpret. In the life cycle impact assessment phase, a completely different model is used to describe the relevance of inflows and outflows. For this, a model of an environmental mechanism is used. For example, SO_2, could result in an increased acidity, increased acidity can cause changes in soils that result in dying trees, etc.

So the inventory data for each life cycle stage including the product composition data were input into SimaPro and a life cycle inventory and impact analysis for the desktop PC was conducted. The impact assessment method used is Eco-indicator 99 (E) V2.1 Australian substances. The impact analysis categories analyzed were climate change (which is often called global warming), resource consumption (which includes minerals and fossil fuels), respiratory effects (in-organics), acidification/eutrophication, land use, carcinogens, eco-toxicity and respiratory effects (organics).

There are three types of environmental damages associated with this methodology:

- Human Health
- Ecosystem Quality
- Resources

A detailed description of each damage category is given below:

3.2.1 The Damage to Human Health

The health of any human individual, being a member of the present or a future generation, may be damaged either by reducing its duration of life by a premature death, or by causing a temporary or permanent reduction of body function (disabilities). According to the current knowledge, the environmental sources for such damages are mainly the following:

- Infectious diseases, cardiovascular and respiratory diseases, as well as forced displacement due to the climate change.
- Cancer as a result of ionizing radiation.
- Cancer and eye damage due to ozone layer depletion.

- Respiratory diseases and cancer due to toxic chemicals in air, drinking water and food.

These damages represent the most important damages to human health caused by emissions from product systems. To aggregate different types of damages to human health, the DALY (Disability Adjusted Life Years) scale is used. The core of the DALY is a disability weighting scale. The scale lists many different disabilities on a scale between 0 and 1 (0 meaning being perfectly health and 1 meaning death).

Example: Carcinogenic substances cause a number of deaths each year. In the DALY health scale, death has a disability rating of 1. If a type of cancer is (on average) fatal ten years prior to the normal life expectancy, we would count 10 lost life years for each case. This means that each case has a value of 10 DALYs.

3.2.2 The Damage to Ecosystem Quality

The species diversity is used as an indicator for ecosystem quality. This damage category is expressed as a percentage of species that are threatened or disappear from a given area during a certain time due to environmental load. Impact categories associated with this damage category are explained in the following paragraph:

- Eco-toxicity is expressed as the percentage of all species present in the environment living under toxic stress (PAF – Potentially Affected Fraction).
- Acidification and eutrophication are treated as a single score. Here the damage to target species (vascular plants) in natural areas is modeled.
- Land use and land transformation is based on empirical of the occurrence of vascular plants as a function of the land-use type and the area size. Both the local damage on the occupied or transformed area as well as the regional damage on ecosystems is taken into account.

The unit for damages to Ecosystem Quality is the PDF times area affected times years on which this applies [PDF*m^2.yr], where PDF stands for potentially disappeared fraction.

3.2.3 The Damage to Resources

In Eco-indicator 99 methodology, only mineral resources and fossil fuels are modeled. In this category the concentration of a resource is the main element of resource quality. That is, as more minerals are extracted, the energy requirements for future mining will increase. The damage is the energy needed to extract a kg of a mineral in the future. For fossil fuels the concept of surplus energy is used.

The unit of resources damage category is the "surplus energy" in MJ per kg extracted material. This is the expected increase of extraction energy per kg extracted material when mankind has extracted an amount that is N times the cumulative extracted materials since the beginning of extraction. Surplus energy is used to add the damages from extracting different resources.

Figure 3-1 below, which is taken from Goedkoop and Spriensma (2001), gives a general representation of the Eco-indicator methodology as used in LCA databases such as SimaPro software. A limiting assumption is that in principle all emissions and land uses are occurring in Europe and that all subsequent damages occur in Europe; except for the damages to resources and the damages created by climate change, ozone layer depletion, air emissions of persistent carcinogenic substances, inorganic air pollutants that have long-range dispersion, and some radioactive substances.

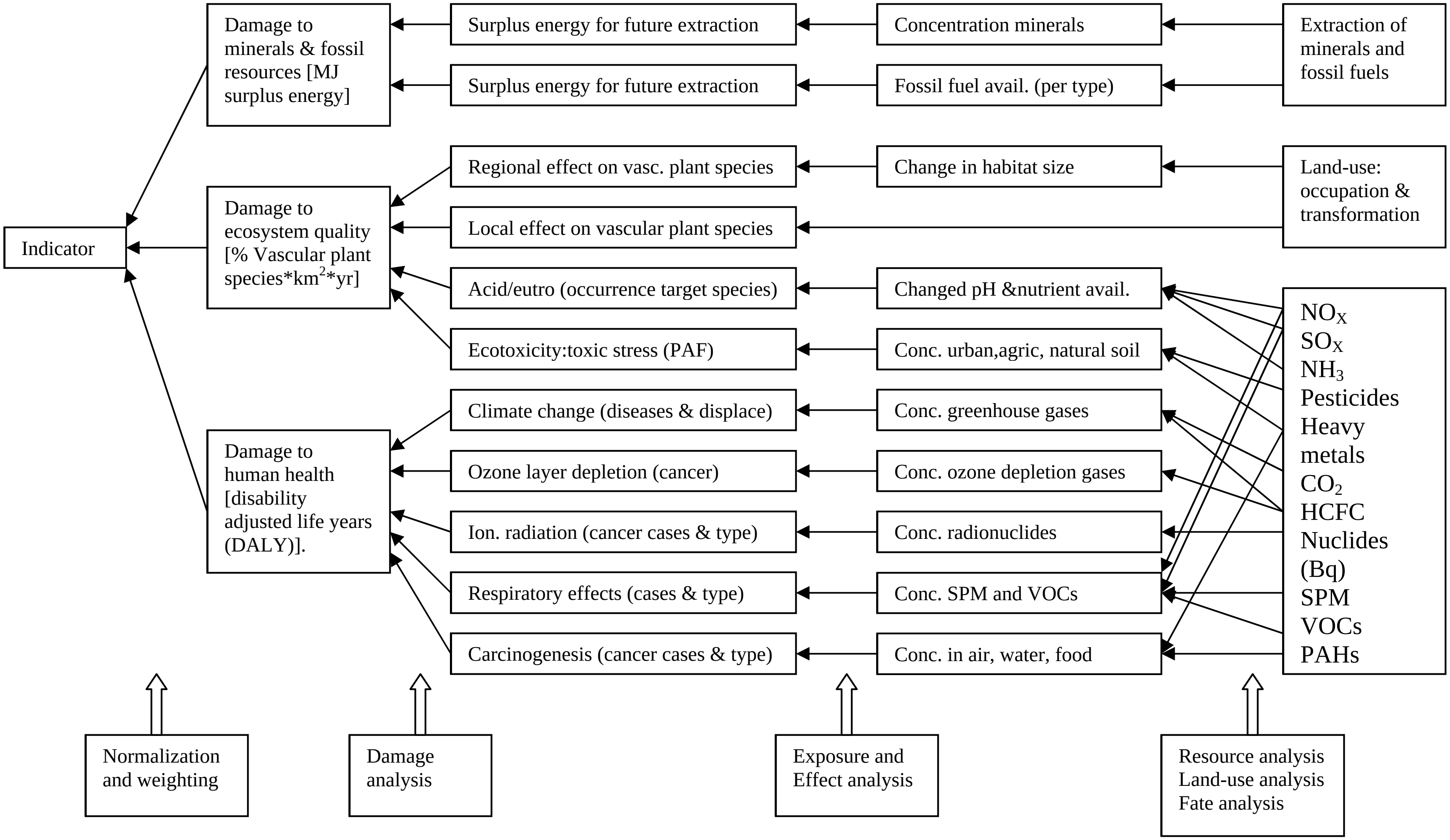


Figure 3-1: General representation of the Eco-indicator methodology. The boxes at the bottom of the figure (those with block arrows on top) refer to procedures; while the other boxes refer to intermediate results.

CHAPTER 4

Goal and Scope of the Project

4.1 Goal of this project

The goal of this project is to identify and assess the most significant environmental impacts of a personal computer through a lifecycle inventory analysis (LCI) and impact assessment. This includes having to disassemble a particular PC and construct a life cycle inventory of its component parts; to construct a model of the lifecycle of particular PC from raw material to ultimate disposal, and hence determine which parts contribute most adverse environmental impacts. The LCA technologies analysis provide the opportunity to use the model as a stepping stone for further analyses and improvement assessments for this personal computer.

4.2 Scope of the project

Scope is defined by the system boundaries, the functional unit (which is the structure of the personal computer) and input/output species. These are described in the following subsections.

4.2.1 Product and Functional Unit

The product system being analyzed in this study is a standard personal computer with five years of lifetime. Though the technical lifetime of the computer may be longer than five years, the USQ ITS keeps them for service for 5 years. The product system includes the central processing unit (CPU) or control unit, a CRT monitor, keyboard and a mouse.

In an LCA, product systems are evaluated on a functionally equivalent basis. The functional unit is used as the basis for the inventory and impact assessment to provide a reference to which the inputs and outputs are related.

4.2.1.1 The structure of a personal computer (functional unit)

A standard, modern personal computer is comprised of four different units; the control unit (CU), the visual display unit (VDU), which is the CRT monitor, the keyboard and the mouse. Brief overviews of the different sections of the personal computer are outlined below.

- **The Control Unit**

The control unit (CU) is the central unit of a PC; this is where information is processed and stored. The CU contains the motherboard on which are mounted the electronic circuits necessary for the functioning of the computer. The most central part of the CU is the processor circuit, which is the “brain” of the computer, directing all the information flows between the different parts of the computer. Mounted on the motherboard are graphical cards, and working memory or RAM (Random Access Memory) as it is also called.

All these units consist predominantly of transistors made from semi-conducting materials, mainly silicon. The motherboard is what is called a printed wiring board (a laminated plate with electric circuits) on which is mounted semiconductor components.
The memory units of the CU can be divided into working memory and the disc memories. The RAM is a temporary storage place, intimately connected to the processor, for information being used when the PC is in the “on-mode”. When the computer is shut down the RAM is emptied. The disc memories, on the other hand, are permanent storage facilities for information. There are three main types of disc memories two based on

magnetic technology, the hard disc and the floppy disc, and one using optical technology, the CD-ROM. The hard disc is permanently installed in the CU and has the highest storage capacity, while the other two are inserted temporarily into special disc drive units.

- **Mouse and Keyboard**

The mouse and the keyboard are both tools to transform external information into a form that can be stored in either of the PC's memory units. That is, they are both "input devices".

Both mouse and keyboard basically contain plastics and a few electronic circuits to transfer the information provided by the PC operator. Thus they contain no parts that differ significantly in production related environmental aspects from the CU.

- **The Visual Display Unit**

The VDU is, on the other hand, an "output device". This is where information is presented to the operator in an understandable fashion. In this project the type of VDU assessed is the cathode ray tube (CRT) monitor. This uses the same technology as the traditional TV set, i.e., a current of electrons creates an image on a glass panel, projected by electric and magnetic fields.

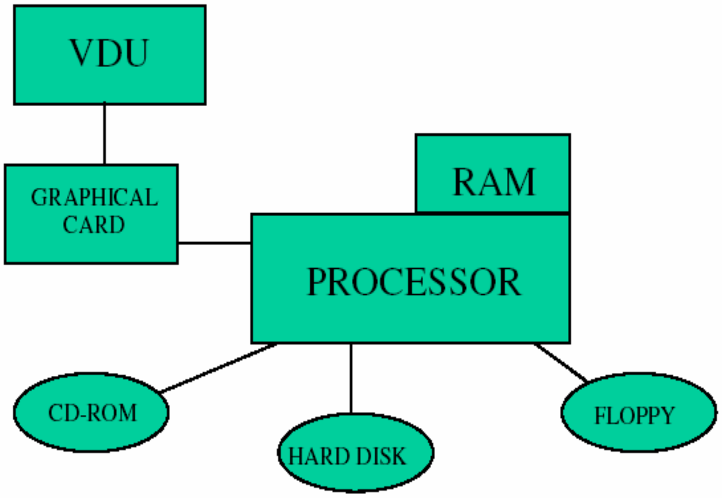


Figure 1. The basic structure of a personal computer

4.2.2 System Boundaries

Since a model of the lifecycle of a PC is constructed from raw material to ultimate disposal, the boundaries of this study are where raw materials are extracted from the ground/environment; emissions to ambient air occur from operations, after treatment; residual wastes are landfilled, with exception of wastewater emissions from landfills, which are included for metals. The product system studied is scoped to focus on relevant impact categories as defined in SimaPro, from direct production, transport, use and disposal operations that comprise the life cycle. Figure 1-1 briefly describes each of the stages for a computer product system. The inputs (e.g., resources and energy) and outputs (e.g., product and waste within each life cycle stage, as well as the interaction between each stage (e.g., transportation) are evaluated to determine the environmental impacts.

INPUTS	**LIFE-CYCLE STAGES**	**OUTPUTS**
Materials → Energy → Resources	**RAW MATERIALS EXTRACTION** Activities related to the acquisition of natural resources, including mining non-renewable material, harvesting biomass, and transporting raw materials to processing facilities.	→ Wastes Products →
	MATERIALS PROCESSING Processing natural resources by reaction, separation, purification, and alteration steps in preparation for the manufacturing stage; and transporting processed materials to product manufacturing facilities.	
	PRODUCT MANUFACTURE Processing materials and assembling components parts to make a computer (that is, control unit, CRT monitor, keyboard and the mouse).	
	PRODUCT USE, MAINTENANCE, AND REPAIR Computers are transported to and used by customers. Maintenance and repair may be conducted either at the customer's location or taken back to a service center or manufacturing facility.	
	FINAL DISPOSITION At the end of its useful life, the computer is retired. If reuse and recycle of usable parts is feasible, the product can be transported to an appropriate facility and disassembled. Parts and materials that are not recoverable are then transported to appropriate facilities and treated (if required or necessary) and/or disposed of.	

Figure 4-1: Life cycle stages of a computer

(Source: http://www.epa.gov/dfe/pubs/comp-dic/lca)

4.3 Using thresholds in SimaPro

Many inventories apply so-called ‘cut-off’ rules, whereby those individual inputs that constitute very small percentages of total inputs to the system are ignored. The effect of using cut-off criteria can be analyzed in the process tree or network window in SimaPro. In many LCAs process trees become very large, up to about 2000 processes. Some of these processes do not contribute much to the load. To illustrate this, a cut-off threshold can be set for displaying processes in the process tree at any percentage, say, 2.2%, and 0.5%, of the environmental load (for a single score or an impact category). In most cases only a few processes turn out to have a contribution that is above the threshold. In this project, no cut-off rules have been applied, that is, an attempt has been made to represent the entire life cycle of the system. For some inputs where emissions/energy data is unavailable, an assumption has been used, usually the closest analogous process for which data are available.

4.4 Allocation

Many processes usually perform more than one function or output. The environmental load of that process needs to be allocated over different functions and outputs. In general, the best solution to allocation is to avoid it in the first place. In SimaPro each process can have multiple outputs and avoided outputs at the same time. This means you can combine system boundary expansion and direct allocation in a way that best suit your project. For most unit operations in the system, the generally accepted convention of allocating resource consumptions and emissions according to the proportional mass of the economically useful products has been applied. For instance, if a process’s output is 20 kg of A, 20 kg of B, A and B each are credited with half of the emissions. That is, for each multiple output, you can add a percentage that indicates the allocation share.

In the use phase, allocation is assumed in such a way that the personal computer is operated 8 hours a day, 240 days a year for 5 years. The power consumption rate for this computer was tested for a similar typical PC.

In the disposal stage, it is assumed that 70% and 30% of the used products from the PC are landfilled and recycled respectively. In the waste management of this PC, the large assemblies such as cathode ray tube (CRT), printed circuit boards (PCBs), cabinet, power cords, cables are assumed to be manually separated at the end of the product life cycle, and then recycled. The packaging materials such as cardboard, plastic inserts, foam are usually recycled. Other components such as electrical cables, cable clamp, etc are landfilled.

CHAPTER 5

Life Cycle Inventory

This chapter contains a summary of the pollutants emitted and resources consumed in delivering, using and disposing of a personal computer. The goal, scope and methodology that has already been outlined in the preceding chapters, show that the life-cycle inventory of a personal computer has been compiled.

To generate the inventory, a particular PC was disassembled, its components parts constructed into an inventory and its life-cycle described.

5.1 Disassembly of the PC

As already mentioned in the preceding chapters, the personal computer consists of four main parts; control unit, monitor, keyboard and mouse. The different subparts and their weights are shown in the next tables. For the printed circuit boards with components, weights for different components in the board were taken and hence the weight of the PCB with components aggregated, except for the electrolytic capacitors, choking coils and transformers which were excluded from the weight of the printed circuit board with components.

Table 5-1A shows different parts and weights of the control unit. The motherboard consists of the motherboard PCI, the Cache RAM, controller port, printed circuit board (PCB) with components for the CPU and the BUS-print plus for the cooling body for the CPU.

Figure 5-1A: shows the motherboard and the daughter board of the PC

The hard disk drive consists of a cover, casing, hard disk plate and printed circuit board (PCB) with components as shown in figure 5-1B. The hard disk plate is assumed to be made from alloyed aluminum which is coated (*LCA Study of the Personal Group Personal Computers in the EU Ecolabel Scheme 1998)*. Personal observation after disassembly confirms this.

Figure 5-1B shows the disassembled hard disk drive (HDD)

The floppy drive consists of two mechanical parts which is made of steel, a cover and printed circuit board with components.

Figure 5-1C: a disassembled floppy disk from a PC system

The power supply as shown in figure 5-1D consists of a cabinet, ventilator, sockets, cooling body, cable plus plug and printed circuit board with components plus electrolytic capacitors, choking coils, and transformers. It is assumed that the ventilator and sockets are made of polystyrene (PS). There is absolutely no information pertaining to electrolytic capacitors in SimaPro database. So it is assumed that the electrolytic capacitors contain PS, and the choking coils and transformers contain PVC (*LCA Study of the Product Group Personal Computers in the EU Ecolabel Scheme March 1998).*

Figure 5-1D: a power supply of a PC system pulled apart

The CD-ROM drive consists of the mechanical part, aluminum sheet casing, front cover and the printed circuit board with components which unfortunately is not included in figure 5-1E.

Figure 5-1E: shows the CD-ROM drive of the PC disassembled

The desktop cabinet is made from metal frame, hard disk socket, a cover and a front.

Figure 5-1F shows the desktop cabinet disassembled.

There are two types of cables, assumed to be made, one from copper and PS and the other made of PVC and copper.

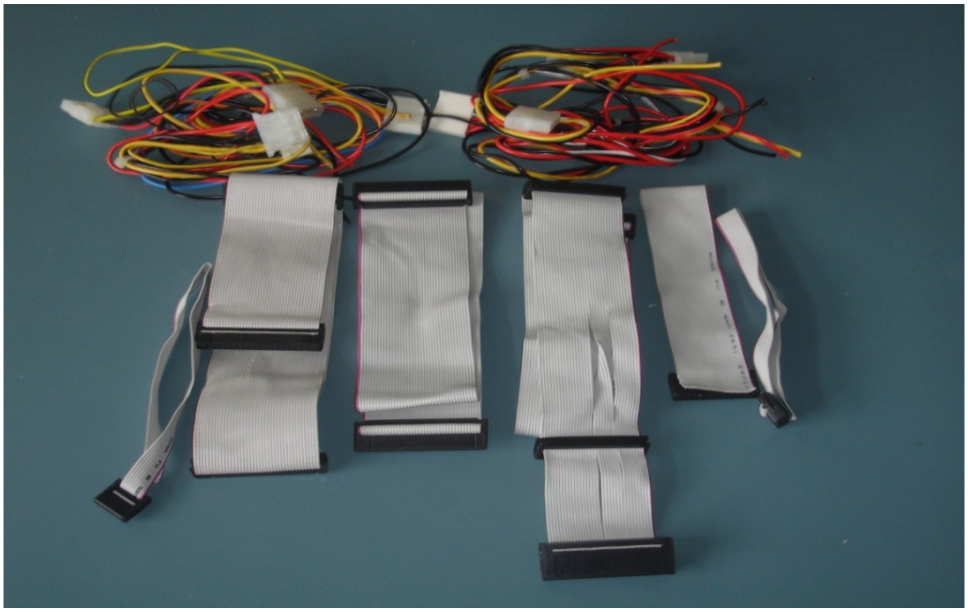


Figure 5-1G: data cables and the mains cables from a PC system

Packaging for the control unit is a cardboard box and insert plus sponge. Since William et al. (2003) show that ICs are significant, I treated them separately from the PCB. All the ICs weights were taken together for each PC element.

Table 5-1A: Parts and Materials in the Control Unit

Parts	**Weight (g)**	**Material**
Motherboard		
Printed circuit board with components	930	Polyester/Al/PVC/Steel/Phenol/Epoxy/Cu/Pb/Ceramic/PP/ Si_2O_3
Cooling body for processor	40	Aluminum
SUM	970	
1.44MB, 3.5" floppy drive		
Casing	340.2	Aluminum sheet
Mechanical part	234.42	Steel
Rotating wheel	57.34	Assumption: alloy aluminum with coating
Front cover	7.98	Aluminum
Printed circuit board with components	31.14	Polyester/Al/PVC/Steel/Phenol/Epoxy/Cu/Pb/Ceramic/PP/ Si_2O_3
SUM	671.08	
Hard disk drive		
Printed circuit board with components	31.39	Polyester/Al/PVC/Steel/Phenol/Epoxy/Cu/Pb/Ceramic/ Si_2O_3
Hard disk plates	101.21	Assumption: alloy aluminum with coating
Casing	307.92	Aluminum
SUM	440.52	
Disk drive/CDROM		
Mechanical part	286.56	Steel
PCB with components	144.91	Polyester/Al/PVC/Steel/Phenol/Epoxy/

		Cu/Pb/Ceramic/PP/ Si_2O_3
Casing	433.43	Aluminum
Front cover (plastic)	18.83	ABS
SUM	883.73	
ASTEC Power supply		
Electrolytic capacitors	53.16	Al/Cu/Phenolic resin paper/PS
Inductor coils	64.78	PVC/insulated Cu^+ Ferrite
Transformers	121.78	PVC/insulated Cu^+ Ferrite
Cabinet	560.51	Steel
Cooling body	80.77	Aluminum
Heat sink	54.49	Aluminum
PCB with components	79.47	Polyester/Al/PVC/Steel/Phenol/Epoxy/ Cu/Pb/Ceramic/PP/ Si_2O_3
Cable and plug	115.96	Cu/PVC/PS
SUM	1130.92	
Desktop cabinet		
Metal frame	2735.65	Electroplated steel
Hard disk socket	263.26	Steel, electroplated
Cover	2200	Steel
Front	272.19	ABS
SUM	5471.1	
Cables		
Flat band cable	181.37	Cu/PS
Mains cable	181.14	Cu/PVC
SUM	362.51	
Packaging for Control Unit		
Box	1800	Cardboard
Insert	414.5	Cardboard
Packaging Material	175	EPS/Sponge
SUM	2389.5	

ICs	38.91	
TOTAL	12358.27	

Table 5-1B shows the different parts and weights of the monitor. These are a cabinet that is made of flame retarded ABS, foot and socket, CRT with electronic gun, cables and printed circuits boards with components, electrolytic capacitors, choking coils and transformers. Materials used in the parts of the PC monitor were obtained from a report by Kim et al. (2000) and from own personal comparison, assumptions and knowledge. A table from Huisman et al. (2004, p.14) on the product composition of 17-inch CRT monitor is included in Appendix C which confirms the data that I used at least in part.

Figure 5-2A: shows the printed circuit board with components and some of the electrolytic capacitors, transformers, choking coils being pulled off the board

The CRT consists of panel and funnel glass, shadow mask, frame, inner shield, mount, deflection yoke and a shrinking band for protection. The electronic gun consists of steel, glass pillar, hollow nickel tubes and tungsten wire. Figure 5-2B shows these internal components of a CRT monitor.

CRT glass material is a very special type with a lot of lead in it. “There is approximately 2-3 kg of insoluble lead encapsulated in the glass matrix of the funnel and faceplate in each CRT (representing approximately 27% of content of the glass screen). There is an additional 15-100 gm of lead present as soluble lead oxide in the ‘frit’, which is a type of glass solder used to join the faceplate and funnel sections of CRTs” (*Computer and Peripherals Material Project 2001)*.

The database for SimaPro does not have adequate data on lead glass. Due to lack of data for this type of glass for the CRT monitor life cycle, the impact potentials that have been calculated do not bear the exact load, but probably a small fraction of the total contribution from the life cycle of this monitor.

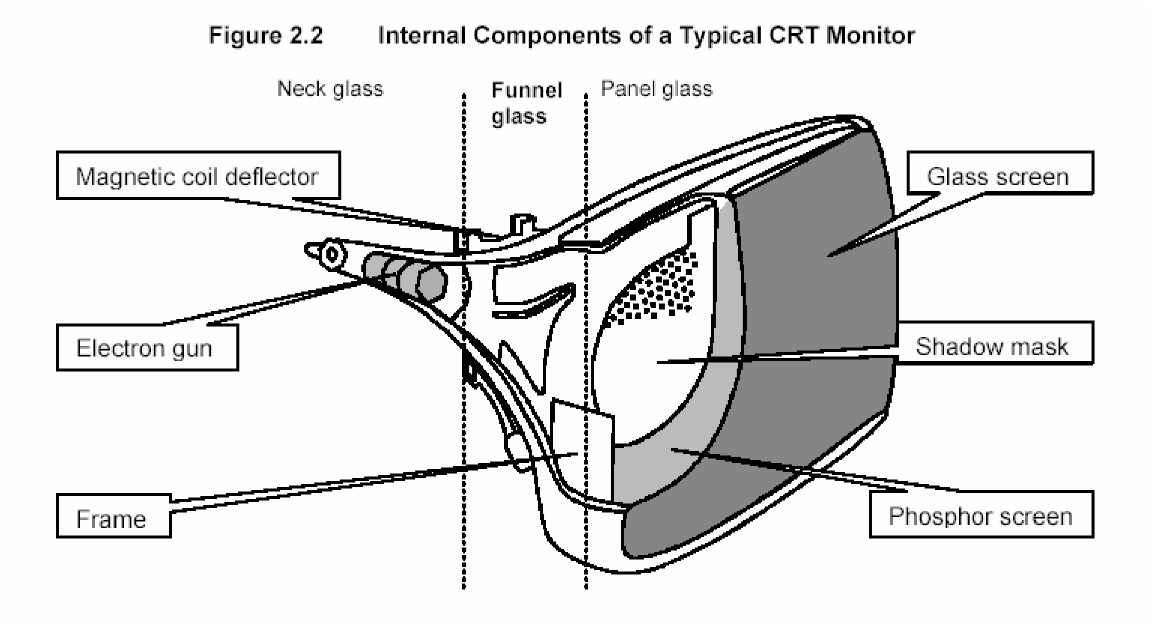


Figure 5-2B: Internal components of a CRT monitor

(Source: http://www.deh.gov.au/settlements/publications/waste/electricals/computer-report/production.html)

The packaging of the monitor is made of the cardboard box with a foam insert.

Table 5-1B: Parts and weights in the monitor

Parts	**Weight (g)**	**Material**
Monitor cable	290.4	Cu/PVC
Foot/socket	338.37	ABS
PCB casing	105.21	Brass/Steel
PCB with components	107.15	Al/Steel/PP/Cu/Polyester/ Ceramic/Phenol/Epoxy/ Si_2O_3
Heat sink	280.96	Al
Electrolytic capacitors	152.82	Al/Cu/Phenolic resin paper
ICs	13.86	Al
Inductor coils	93.81	PVC/Ferrite/Cu
Transformers	509.39	Ferrite/Cu
PCB with components	538.32	Al/Steel/PP/Cu/Polyester/ Ceramic/Phenol/Epoxy/ Si_2O_3
Cabinet	2480	ABS/PVC
Frame	439	Steel
CRT	7749	Glass/Steel/Cu/PVC/Paper
SUM	13872.29	
Packaging for the monitor		
Box	1780	Cardboard box
Foam insert	535	EPS/Sponge/LDPE/HDPE
SUM	2315	
TOTAL	16187.29	

Table 5-1C shows the different parts and weights of the keyboard. They are the cover, base and 102 keys, the base shielding and a cable with plugs and printed circuit board with components. The disassembly of the keyboard as shown on figure 5-3A, shows that it contains only a few components. On the PCB, there is one IC, two diodes, two resistors, three LEDs and one small electrolytic capacitor.

The packaging for the keyboard is a cardboard box with a plastic insert.

Figure 5-3A: shows the different parts of a keyboard

Table 5-1C: Parts and weights in the keyboard

Parts	**Weight (g)**	**Material**
PCB with components	14.22	Cu/Epoxy/Si_2O_3
Base shielding	59.58	Steel sheet
Base	259.88	ABS
Cover	143.53	ABS
Keys	265.85	ABS
Cable and plug	68.96	Cu/PVC
SUM	812.02	
Packaging for keyboard		
Box	310	Cardboard
Plastic insert	35	Assumption: PS
SUM	345	
TOTAL	1157.02	

Table 5-1D shows the parts and weights of the few components that are in the PC mouse. These are the 225mm^2 PCB with only three components, the mouse ball, base, cover and the cable and plug. The packaging for the mouse is cardboard box.

Figure 5-4A: shows all the parts in the mouse

Table 5-1D: Parts and weights in the mouse

Parts	**Weight (g)**	**Material**
PCB with components	6.97	Cu/Epoxy/ Si_2O_3
Cover	24.95	ABS
Base	25.32	ABS
Mouse ball	31.25	Rubber
Cable and plug	43.57	Cu/PVC
SUM	132.06	
Packaging for the mouse		
Cardboard box	45	Cardboard
TOTAL	177.06	

5.2 Calculation of the Environmental load of the PC

In order to calculate the environmental load of the PC, a model of the life cycle was constructed as shown on figure 5-5A.

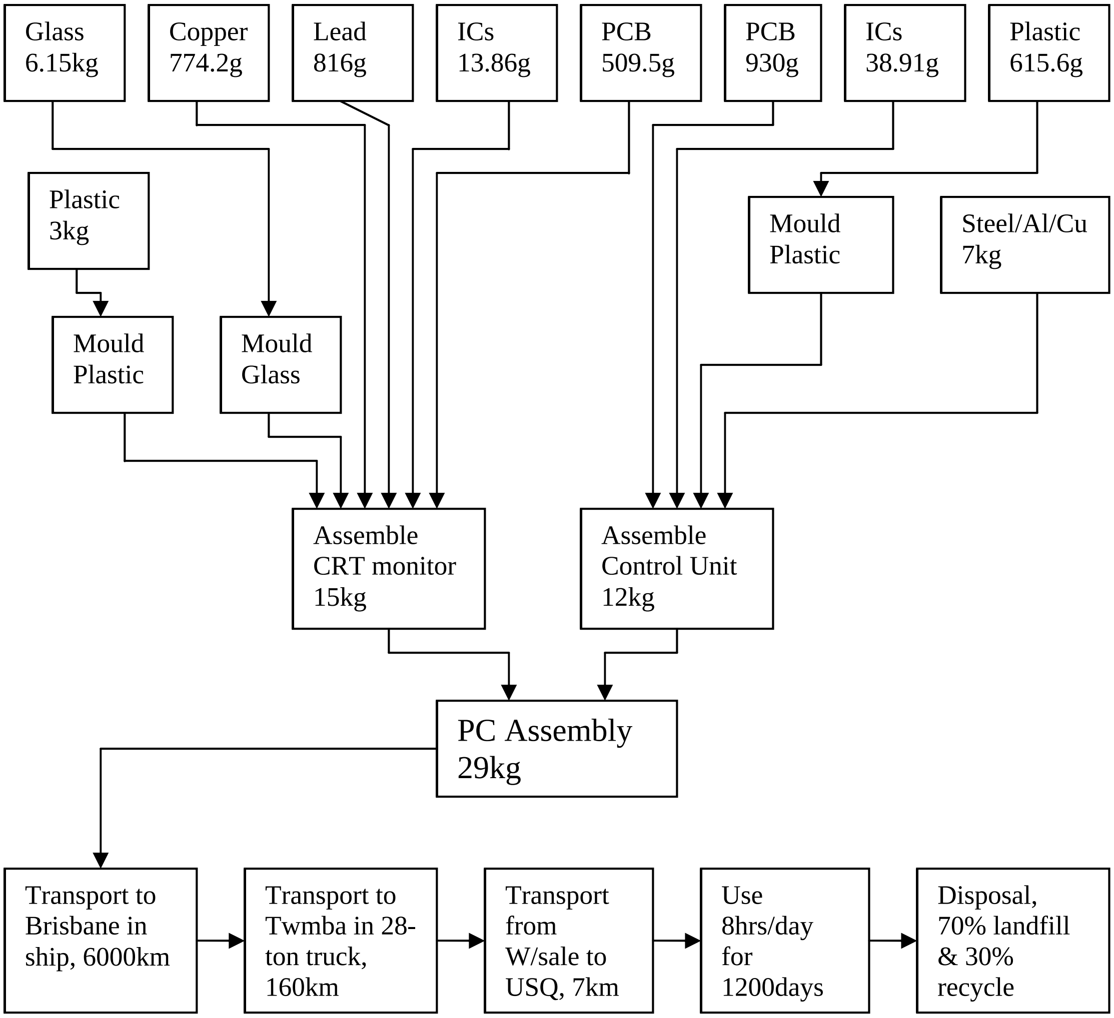


Figure 5-5A: shows the model of the life cycle of a PC from raw materials to disposal

5.2.1 Description of Life Cycle Stages

A primary concept of LCA is that life cycles are collections of stages. In theory, an infinite number of stages might be defined. In practice, 4-6 stages usually are defined.

In this study the life cycle is defined as five stages: production of raw materials, manufacturing, distribution, use and disposal. Transport will be considered within each stage.

5.2.1.1 Production of Raw Materials

The extraction and refining of raw materials like oil, natural gas, iron and other metals are included here. So are extractions of raw materials for production of e.g. metal casing, glass etc. The productions of some materials like glass, glass fibre, glass textile, copper foil, and laminates for printed circuit boards are also included in the raw material stage.

5.2.1.2 Manufacturing

The manufacturing includes all processes for manufacturing the PC. These are metal coating processes such as electroplating, injection molding of plastics; production of the CRT (which includes the glass production but excluding the extraction of the raw materials for the glass); production of the printed circuit board (from laminate) and semiconductors, wave soldering etc.

5.2.1.3 Distribution

The PC is transported from a European/Asian PC manufacturer to the salesroom with a truck larger than 16 tons. From the salesroom to the office it is transported by a van.
The driving distance for the truck is more kilometers as compared to van. For example, the PC being studied here is transported from Malaysia to Brisbane by ship for a distance of approx. 6000 km; and from Brisbane to Toowoomba at a distance of approx.160 km by a 16-ton truck; and finally from a wholesale in Toowoomba to USQ office by a delivery van. In each case the carrying capacity of transportation is calculated. For instance, transporting this PC from Malaysia, the carrying capacity is 6000 km * 0.029 tonnes = 174 tonne*km.

5.2.1.4 Use

Power consumption for the monitor is 104.5 Watts and 39.13 Watts for control unit, which includes power consumption of the keyboard. The base case PC has no energy saving facilities and therefore consumes 143.63 Watts when turned on. The lifetime of the PC is set to 5 years. This time span is the one companies use for writing off a PC in their accounts. After 5 years in an office the first user of the PC is likely to get a new computer. Then the PC is either thrown out or passed on to another user in the office or given to an employee and used at home. Only the first "life" of the PC is considered in this LCA. After 5 years, the PC is disposed. The PC is estimated to be turned on for 8 hours per day, 240 days per year (Byrre, T. 2005, pers.comm. 15 July). Altogether it runs for 9600 hours during its lifetime. Therefore the energy that is consumed is around 1.3788MWh during its use.

5.2.1.5 Disposal

Disposal routes of general household waste in Australia have been used to estimate PC disposal routes (*Computer & Peripheral Material Project*). According to this scenario, 63% of the PCs are sent to landfills, 22% to incineration and 15% to recycling. The same pattern is assumed for the packaging. PCs sent to landfills are assumed to be disposed of in landfills for household waste (bulk waste). Emissions to waste water from the leachates of metals within the first hundred years are taken into account. Emissions of methane from decomposition of cardboard in landfills are included.

Representing an average recycling situation in the European Union countries the metals and the PCB with components is assumed sent to secondary metal works where steel, aluminum, copper, lead, zinc, and silver and gold are reclaimed. The recovery is 97% for steel, 95% for aluminum and 100% for the other metals. Metals not mentioned above are lost in the recovery process. The glass/silicon oxide from the PCB is landfilled as hazardous waste.

All other parts of the computer are landfilled (*LCA Study of the Product Group Personal Computers in the EU Ecolabel Scheme 1998*).

All the above data for all the stages was used in SimaPro to perform a life cycle assessment of the PC.

CHAPTER 6

Life Cycle Impact Assessment

The impact assessment method used in this study is the Eco-indicator 99 method that has already been discussed in chapter 3 (outlined in SimaPro software - methods). In this method normalization and weighting are performed at damage category level. There are three damage category levels, human health, ecosystem quality and resources. The units that are used in human health are DALY (disability adjusted life years; which means different disability caused by diseases are weighted); in ecosystem quality PDF*m2yr is used as the unit where PDF means potentially disappeared fraction of plant species; and finally MJ surplus are used in the resources. The impact categories and the characterization factors in this method are; acidification/eutrophication, fossil fuels, land use, ozone layer, radiation, minerals, climate change, respiratory in-organics, respiratory organics, eco-toxicity and carcinogens.

Impact assessment may be broken down into two steps: *classification* and *characterization*. Classification in SimaPro V6.0 is defined as the grouping of inputs and outputs of the life cycle system, usually reported by weight, under categories of environmental impact that these input/output engender. For instance, air emissions that are believed to contribute to acid rains are classified under acidification, while those that are believed to be greenhouse gases are classified under global warming. Fossil fuels on the other hand are classified under the abiotic resources. It is also 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.

With characterization, inputs/outputs are aggregated in a category into a single indicator that is meant to reflect the sum environmental burden for that category. Aggregation is done on the basis of common units that are agreed to represent an equivalent impact to the environment; these are known as equivalence factors. These factors should reflect the relative contribution of an LCI result to the impact category indicator result. For example, on a time scale of 100 years the contribution of 1 kg CH_4 to global warming is 42 times as high as the emission of 1 kg CO_2. This means that if characterization factor of CO_2 is 1, the characterization factor of CH_4 is 42. Thus, the impact category indicator result for global warming can be calculated by multiplying the LCI result with the characterization factor. Table 6-1A and 6-1B show the classification of emissions to air and the possible categories to be included in characterization, respectively.

Table 6-1A: Classifications of emissions to Air

Substance	**Global warming**	**Respiratory effects (in-organics)**	**Acidification/ Eutrophication**	**Ecotoxicity**	**Ozone layer depletion**
Ammonia		+	+		
Arsenic				+	
Benzene				+	
Benzo(a)pyrene				+	
Butane	+				
Cadmium				+	
Carbon dioxide	+				
Carbon monoxide	+	+			
Chloroform	+			+	
Chromium				+	
Chromium VI				+	
Dinitrogen monoxide	+				
Dioxins				+	
Ethane	+				+
Fluoranthene				+	
Heavy metals, unspecified				+	
Lead				+	
Mercury				+	
Metals, unspecified				+	
Methane	+				+
Nickel				+	
Nitric oxide		+			
Nitrogen dioxide			+		
Nitrogen oxides		+	+		
Polycyclic aromatic hydrocarbons (PAH)				+	

Particulates		+			
Phenol				+	
Sulphur hexafluoride	+				
Sulphur dioxide		+	+		
Sulphur oxides		+	+		
Toluene				+	
Zinc				+	

+ means contribution to that category

Table 6-1B: Environmental Impact Categories

Classification Category	**Examples of species included**	**Equivalence factor for characterization**	**Comment**
Abiotic resources	Fossil fuels and minerals	Weight (MJ per kg extraction)	Fuels are split into renewable and non-renewable resources
Climate change (Global warming)	CO_2, CO, CH_4	100-year GWP as defined by IPCC, with CO_2 as the reference	
Ozone layer depletion	CFCs, Halons, HCFCs and other chloro/bromo compounds	ODP as defined by the WMO, with CFC-11 as the reference.	
Eco-toxicity	Heavy metals	m^3 air, water or soil	The amount of air, water or soil needed for dilution to no effect level
Acidification/Eutrophication	SO_2, NO_x, NO_3^-, NO_2	Acid and nitrogen contents with SO_2 and NO_3^- as references	

Respiratory effects	In-organic compounds		

(Source: Atlantic Consulting and IPU, *LCA Study of the Product Group Personal Computers in the EU Ecolabel Scheme*)

The current state of life cycle inventory analysis and the available databases (in SimaPro) is such that while consumption of energy and resources is well covered, data are still very incomplete for the emissions of most environmentally hazardous substances such as lead which is used in CRT glass. Due to lack of data for these types of emissions from the large majority of processes of the life cycle, the impact potentials for some of the impact categories end up not representing the total contribution from the life cycle to these impact categories. As a result of this, the results obtained from this study will be compared to the other products of the same and to other methods that has been used on the same products.

6.1 Validation of the Eco-indicator 99 Methodology

In comparison of the Eco-indicator methodology with other methods that can be used for the assessment, Luo et al. (2001) have analyzed laptops, office telephones and alternative part designs using four different methods. These are Eco-indicator 95, Eco-indicator 99, Ecological Footprint and Eco Pro. In each case the results are broadly similar from each method and all agree about which of the two alternative products are environmentally better.

This evidence suggests that the Eco-indicator 99 is as valid as the other methods in deriving measures of environmental damage to any product. Hence the results obtained from this methodology will be as sound as the others.

6.2 Results and Discussions from the Inventory Analysis

There are so many environmental parameters that are included in the life cycle analysis. A few of those are selected here for discussion. Figures 6-1A and 6-1B show the consumption of resources in terms of fossil fuels and minerals. Contribution ratio of each environmental burden as a percentage is also shown on the figures.

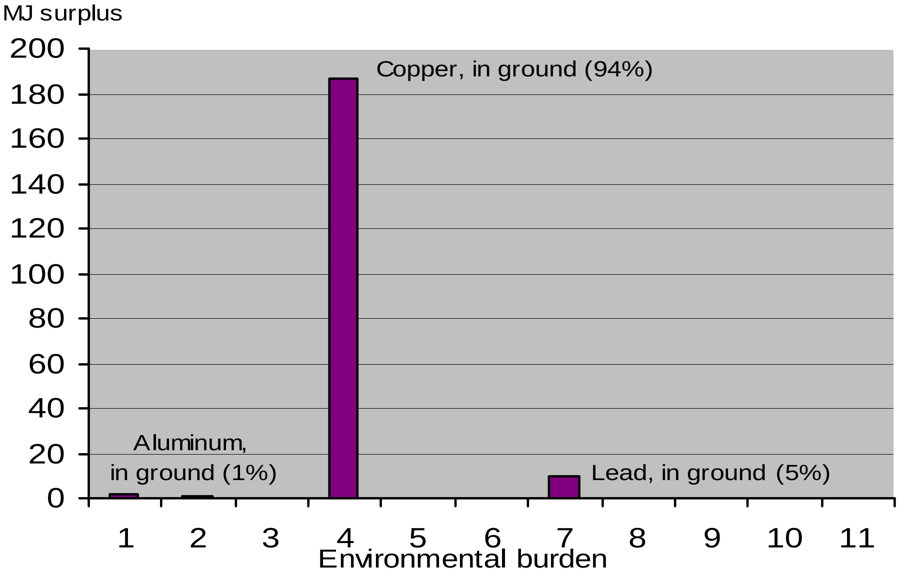


Figure 6-1A: Consumption of resources in life cycle of a PC (minerals).

The use of copper in ground is approx. 187 MJ surpluses which is 94% of the total consumption of minerals for the PC life cycle. Lead contributes 5% of total load.

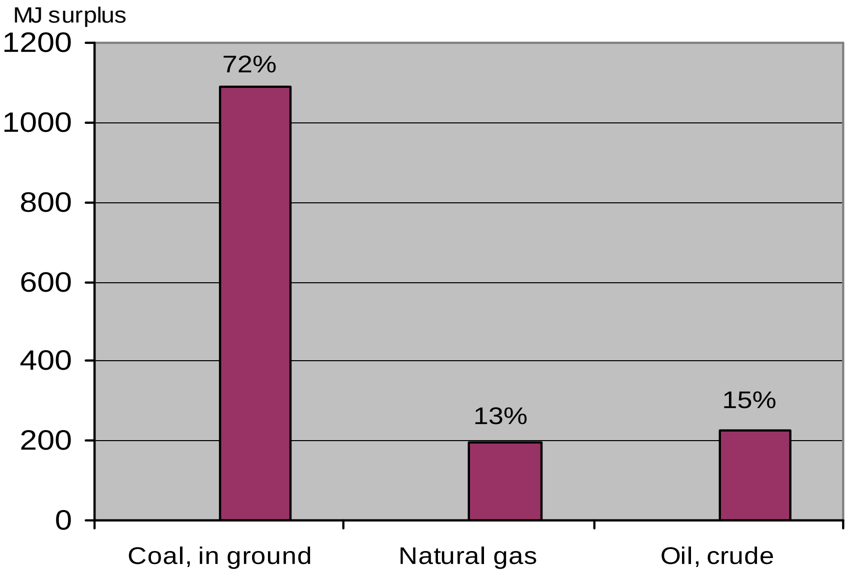


Figure 6-1B: Consumption of fossil fuel resources in the life cycle of a PC

The energy-related resources like coal, natural gas and crude oil are shown in figure 6-1B with their contributions to the total load on the consumption of fossil fuels on the PC life cycle. Coal which is used for generating electricity is consumed at a ratio of 72%, while crude oil is used at a rate of 13% of the total fossil fuels consumption.

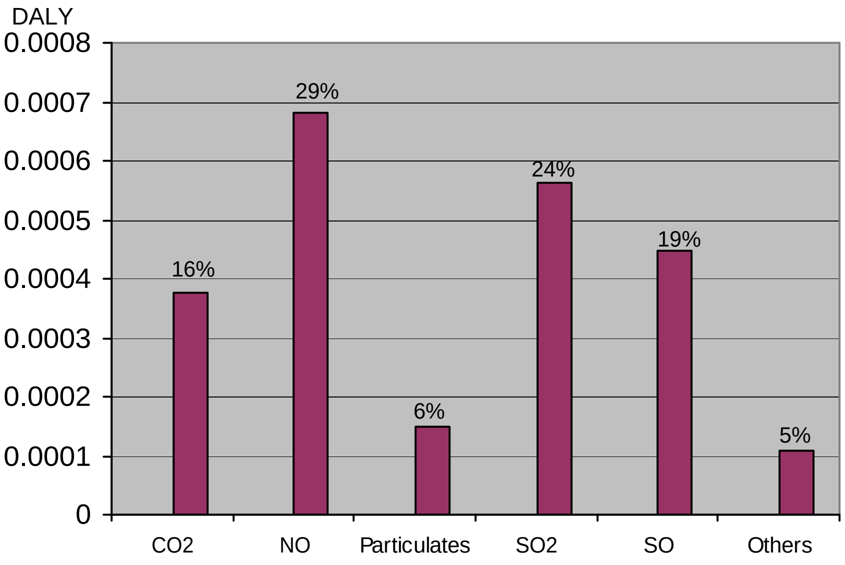


Figure 6-1C: Environmental emissions in the life cycle of a PC

Figure 6-1C shows a contribution of 16% of carbon dioxide emissions on the environment throughout the life cycle of the PC. These emissions are harmful to human health. Nitrogen oxides NO_x are the ones with the largest emissions (29%) followed by sulfur dioxide (SO_2) with 24% of total emissions to the environment.

6.3 Results and Discussions from Impact Assessment

The results of the classified and characterized inventory of the whole PC are presented and discussed here. This section is divided into sub-sections in which the results of the whole PC and all its peripherals (control unit, monitor, keyboard and mouse) will each be discussed.

6.3.1 The Whole PC

Figure 6-2A shows the whole characterized results of the environmental impact of a PC including packaging on a single score. A single score is where the data of the inventory table is transformed into damage scores which can be aggregated. All the category impacts of the impact assessment method used are represented. The characterized data shows that use of resources caused by depletion of fossil fuels have the largest contributions of about 45%, followed by the respiratory in-organics with 32%, climate change having 7.5% and minerals with a contribution of about 6% on the environmental performance of the PC.

Since there are many impact categories associated with this assessment method, some of them, mostly those that contribute more to the total environmental impact of the PC are selected and presented. Tabulated results for all of the impact categories are presented in Appendix B.

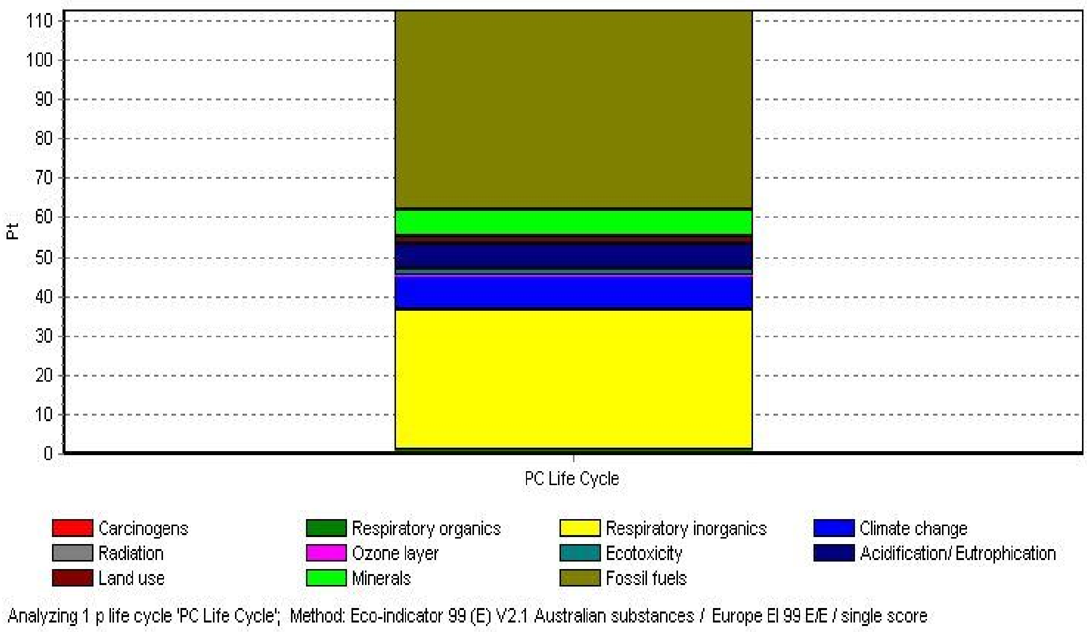


Figure 6-2A: Characterization results of the environmental impact of whole PC system

In figure 6-2B and similar networks they follow, the top yellow box is a product stage called the PC life cycle. The life cycle can link up to:

- One assembly (which may have subassemblies). For instance, the sub-assemblies of the PC assembly (blue box) are the control unit, CRT monitor, keyboard and mouse.
- One or more use process (grey box), in this case electricity.
- A waste or disposal scenario (red box).

Processes (such as printed circuit board assembling process) are linked to the product stage by a flow of arrows (note the direction of the waste scenario process). The thickness of the line represents the contribution to the environmental load from a process, sub-assembly or assembly stage. The small bar chart in a block indicates contribution to an indicator.

The characterized results for the use of fossil fuels in figure 6-2B shows that the largest contributions of impact come from the use phase where they are caused by the electricity consumption during use. This constitutes 61.3% of the total performance, while the second most contributing factor is the PC assembly which includes the production and the manufacture stages. These stages contribute 35.8% of the total contributions of the use of fossil fuels. The disposal stage only contributes a small amount of less than 3%. In the PC assembly process, the control unit contributes approximately 25% of the environmental impacts, which mainly comes from the ICs and the printed boards; while the CRT monitor contributes only about 10%. The keyboard and the mouse both have a small impact contribution less than 1%.

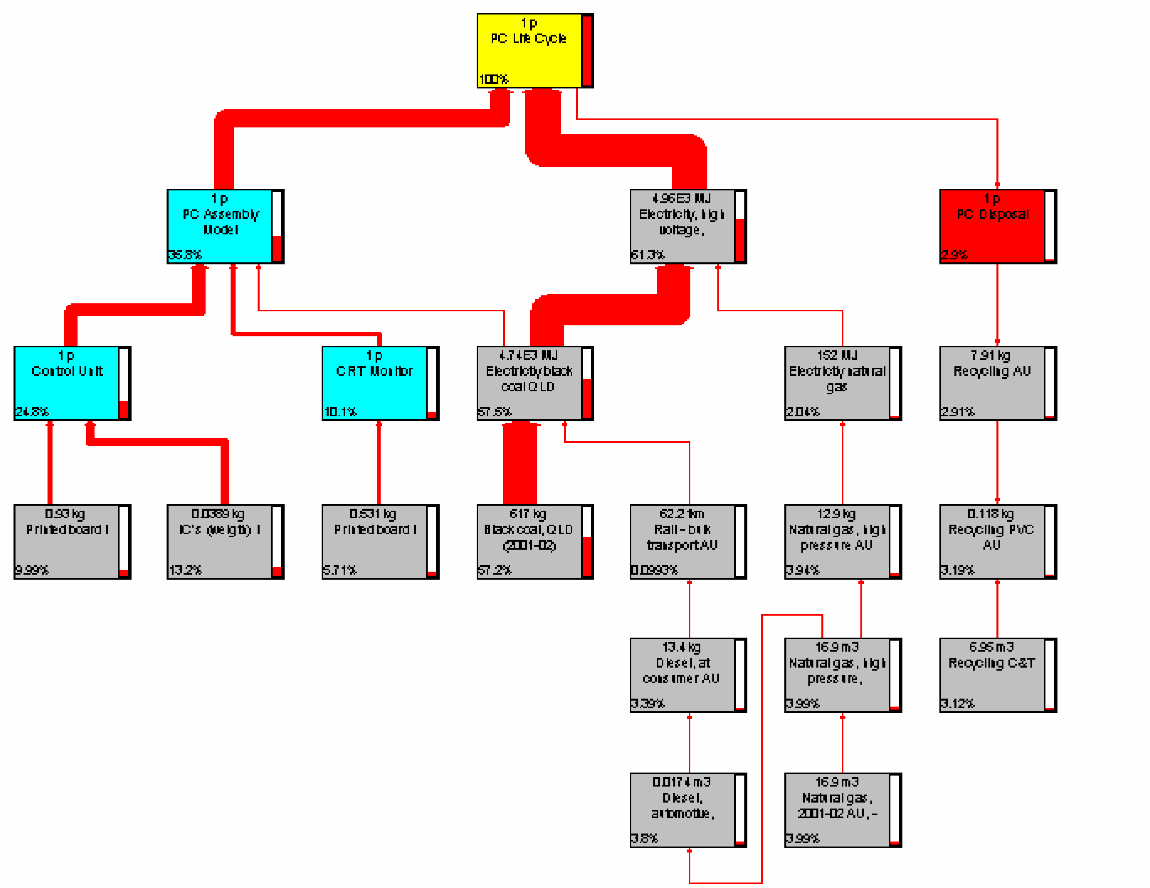


Figure 6-2B: Characterized network shows aspects of PC life cycle and relative use of fossil fuels

The impact category climate change which is also known as global warming includes effect of gases such as carbon dioxide, carbon monoxide, dinitrogen monoxide, ethane, and methane and sulfur hexafluoride. Tabulated results are at Appendix B. The data shows that carbon dioxide (CO_2) is the most contributing environmental impact with approximately 87%. Figure 6-2C shows that the electricity consumption in the use phase contributes a fair amount to environmental burdens. A percentage of 63.7 are contributed from this phase. CO_2 emission in the air is as a result of more energy that is consumed in the use phase. The PC assembly process only contributes approximately half of the contribution by the use phase, with the ICs from the control unit contributing more than any other material/parts.

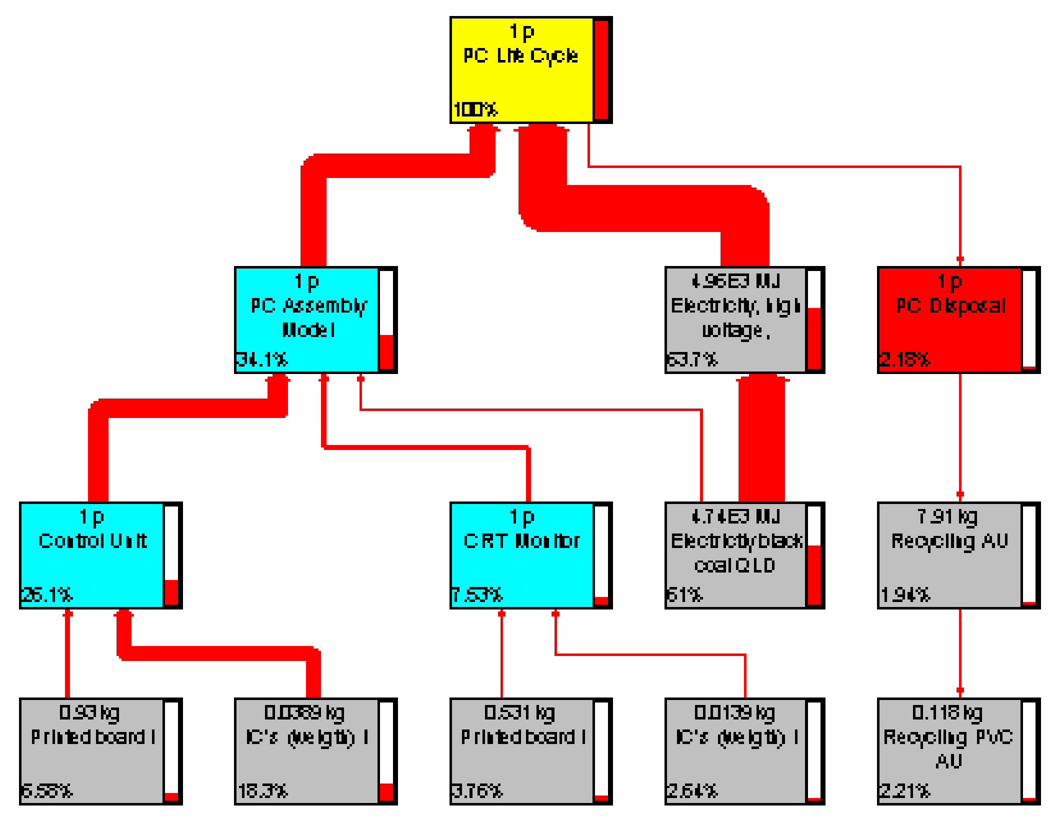


Figure 6-2C: Characterized network showing the aspect of climate change (global warming) as a result of the life cycle of a PC

The characterized network for the depletion of minerals shown on figure 6-2D, shows that the PC assembly contributes significantly to the burden; the printed boards, copper and lead being the main contributors on all of the PC elements. A table showing the results of the substances that contribute to the characterized minerals category is in Appendix A. The results show that the most contributing substance is copper with 93.5%, lead 4.8% and aluminum with 1%. The control unit assembly shows to be contributing more than the CRT monitor assembly with contributions coming from the printed boards and copper.

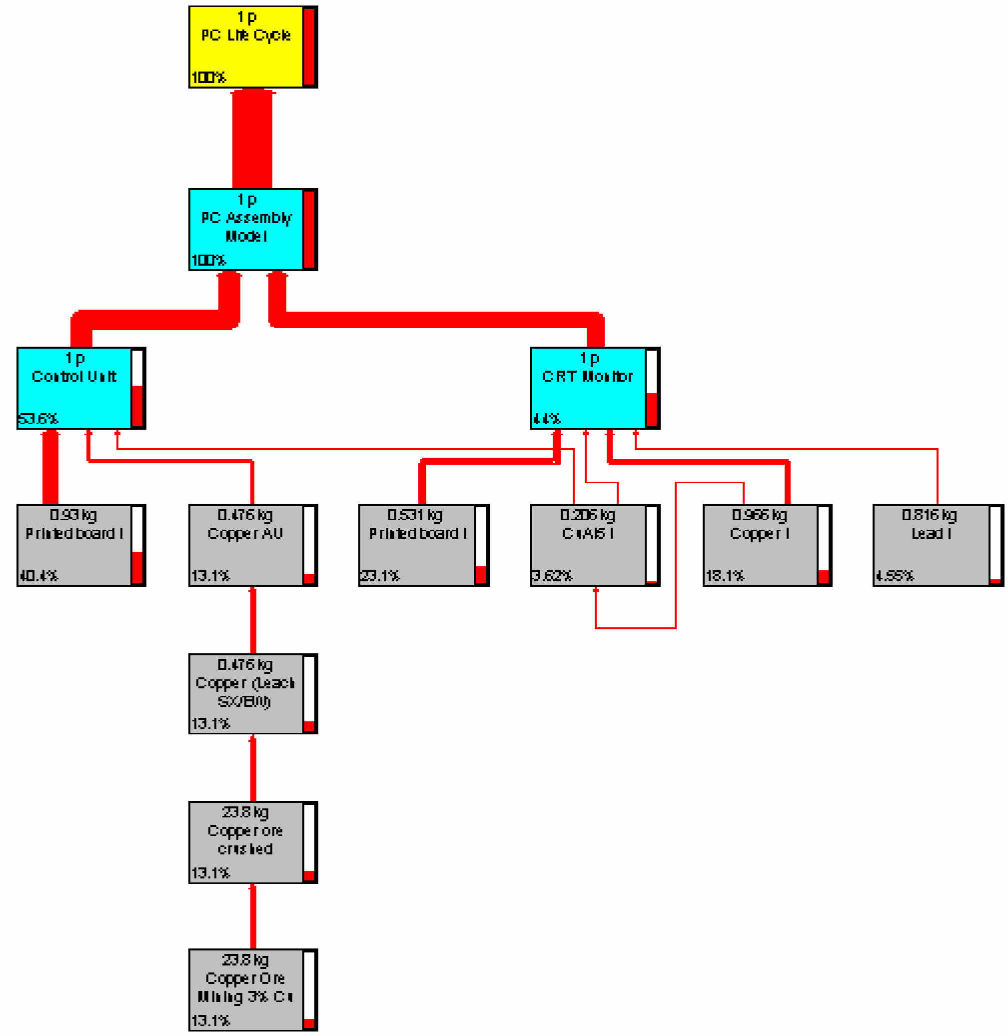


Figure 6-2D: Characterized network shows aspects of PC life cycle and resource consumption (use of mineral resources)

The respiratory in-organics category also shows that the use phase is the largest contributor of burden. This contribution is caused by the amount of electricity that is consumed during use. The consumption of energy amounts to more than 65% of the total burden as can be seen from figure 6-2E. The PC assembly accounts to approximately 30%, with the control unit contributing almost twice the CRT monitor assembly. The keyboard and the mouse again contribute a small amount of less than a percentage. The parts that have the most contributing impacts are the printed boards which quadruple the burdens from ICs. With the substances, nitrogen oxides (NO_x) seemed to be having the most common environmental impacts, with 37% being contributed. Sulfur dioxide (SO_2) was the next followed by sulfur oxides, with 31% and 24% contribution respectively.

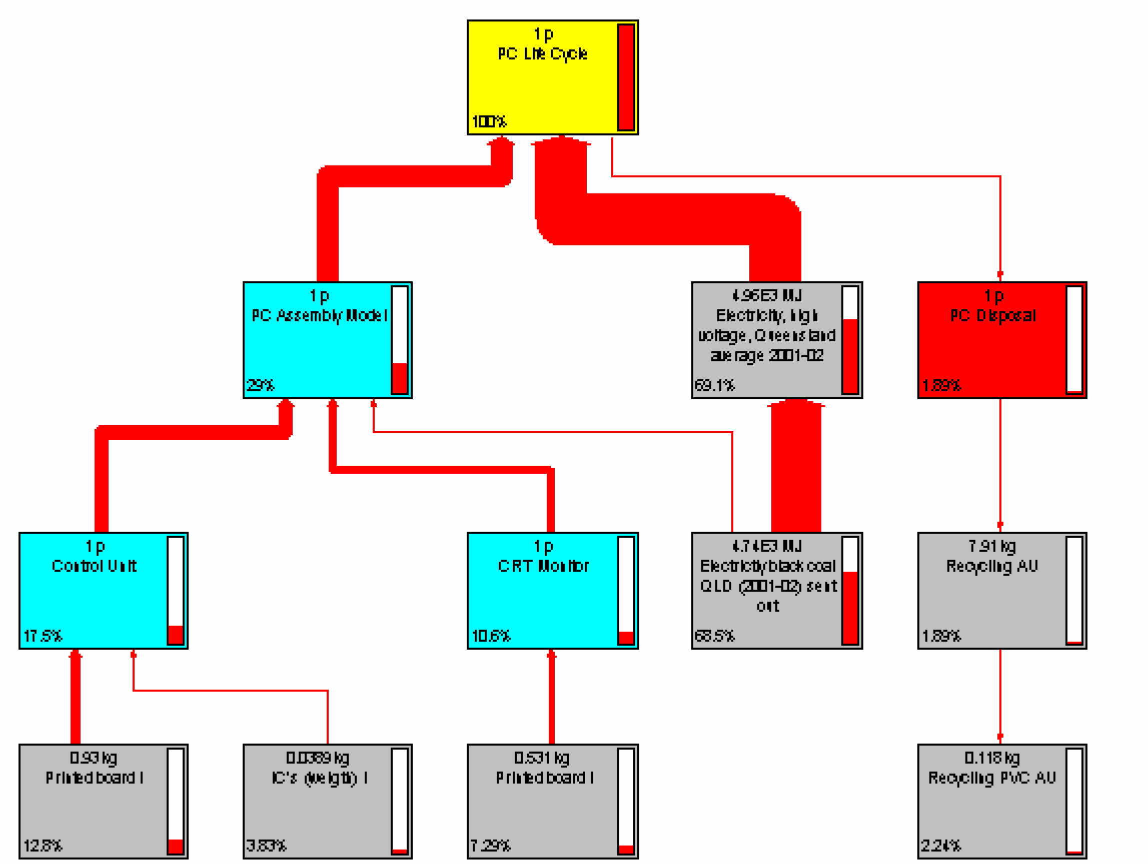


Figure 6-2E: Network shows aspects of PC life cycle and relative contributions to respiratory in-organics

Another category that the PC system has environmental impacts on is acidification and eutrophication. Examples of species in these categories are nitrogen oxides (NO_x), sulfur dioxide (SO_2) and nitric oxide (NO_3). The results of which are tabulated in Appendix B show that nitrogen oxides are the most environmental impact contributors with approximately 70%, followed by sulfur dioxide with approx. 17 %. Sulfur oxides contribute 13% of the total load in acidification/eutrophication. Electricity consumption in the use phase is the largest contributor, with 69.8% contribution, while the PC assembly which includes production and manufacture stages contributes 26.7%; and the disposal (waste) stage has 3.5% contribution. Figure 6-2F shows that the assembly of the control unit (16.7%) is the next contributor after electricity consumption, and the CRT monitor assembly accounts for less than 9%. The printed board is the dominating contributor in all the elements of the PC, followed by the ICs. The ICs contribute almost one half of the printed board contribution.

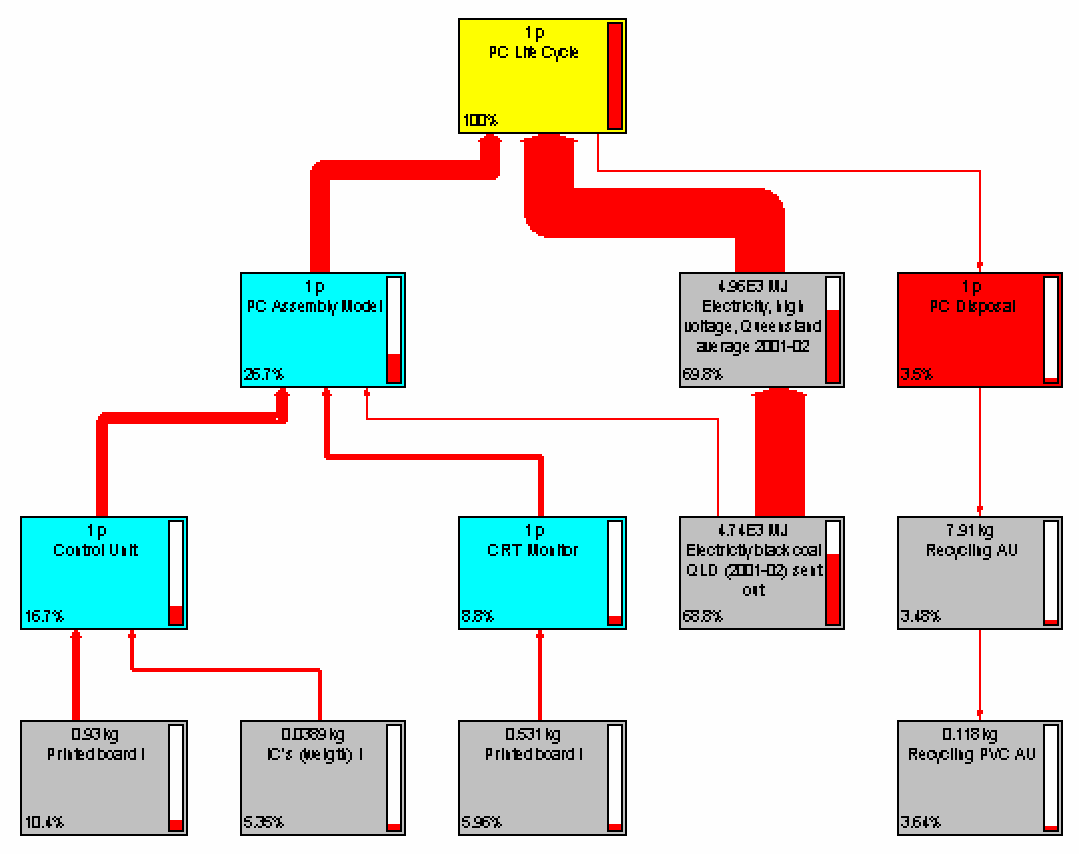


Figure 6-2F: Characterization network of acidification/eutrophication

Eco-toxicity includes species such as heavy metals. In this category copper that is used in the production and manufacture of the PC assembly is the most environmental contributor with more than 70% of total contribution of the PC; nickel 13%; and lead 7%. The PC assembly in this category contributes more environmental burden than the use phase. The contribution is illustrated in figure 6-2G where the PC assembly accounts for 90%, while the use accounts for 10%. The control unit is the most contributor with 55.9%; most of the impact coming from the printed board. The control unit is the next contributing element with 32.6%; again most of the impact coming from the printed board (27.9%) and the glass (4.41%) because lead is used as a raw material in the glass tube. Energy consumption during the PC assembly contributes approx. 10%. Once again the keyboard and the mouse have little impact.

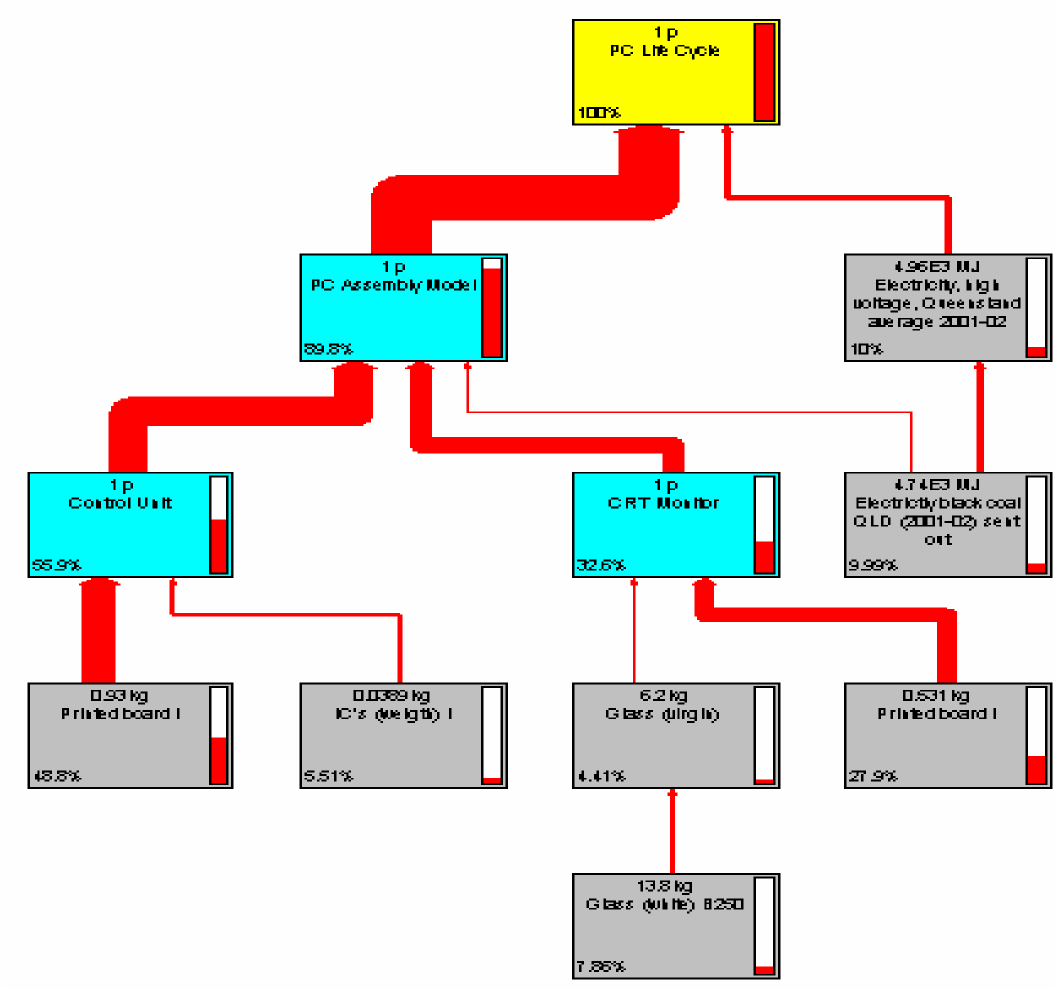


Figure 6-2G: Characterization network on the results on eco-toxicity in the life cycle of a PC

The assessment shows that of the impact categories discussed, electricity consumption during use is the main issue to most of the category impacts that are caused by the PC, except of course for eco-toxicity and minerals where the PC assembly is the most contributing factor. As such the use phase is seen as the most contributing phase to environmental performance of the PC. The printed board assembly on the other hand is one of the most contributing components in the PC assembly on all the category impacts.

6.3.1.1 Normalization

Normalization is a procedure needed to show to what extent an impact category has a significant contribution to the overall environmental problem (Goedkoop & Oele 2004). 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 that is used in SimaPro is to determine the impact category indicators for a region during a year, and if desired, divide the result by the number of inhabitants in that area.

Normalization serves two purposes:

1. 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.

2. 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 a specific region.

The three damage categories and the eleven impact categories in Eco-indictor 99 have different units. In order to use a set of dimensionless weighting factors, these categories are made dimensionless. Hence the normalized data/results for the PC were also taken. Figure 6-2H shows the normalized results of the impact categories. The contributions to fossil fuels from a PC are almost 57% of the total contributions of impact categories. Contribution to climate change accounts to approx. 7% of the total contributions.

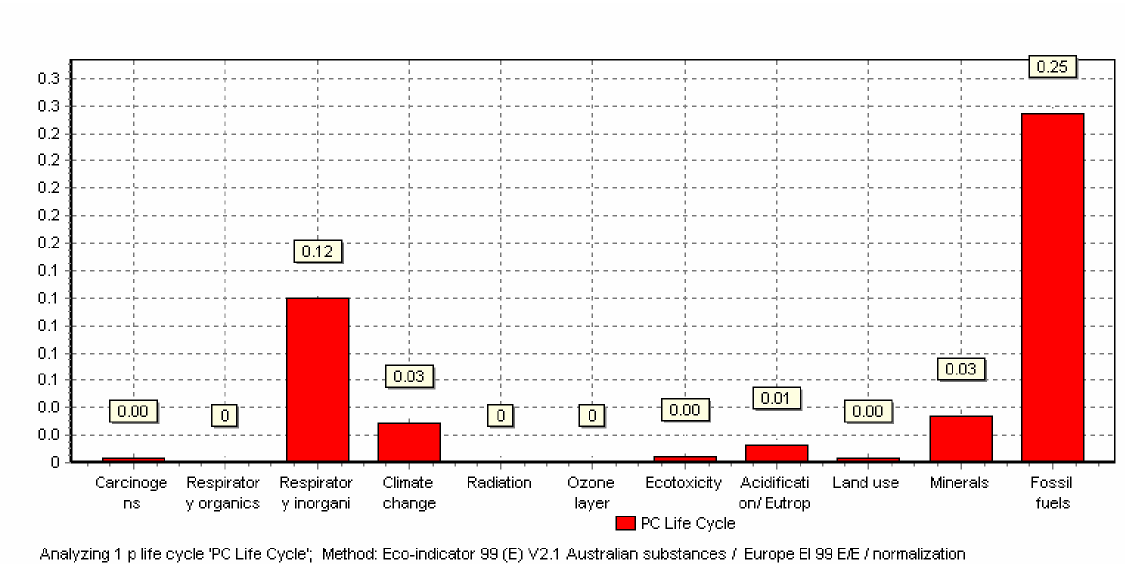


Figure 6-2H: Normalization of environmental impact potentials of the whole PC

6.3.1.2Damage assessment

The final step of assessment in Eco-indicator 99 method is the damage assessment, as has already been mentioned in chapter 3 (Project Methodology). In this step the impact category indicator results that are calculated in the characterization step are added to form the damage categories. Impact categories are grouped according to the same damage type they have (like human health have the same unit DALY).

Figure 6-2I shows that the damage to resources is the most contributing in the environmental performance of the PC. Depletion of resources contributes approx. 51% done by the PC; human health comes next with 40% and ecosystem quality with 9%. Resources depletion includes the electricity/energy consumption during extraction of materials, production and manufacture, and the use of the PC.

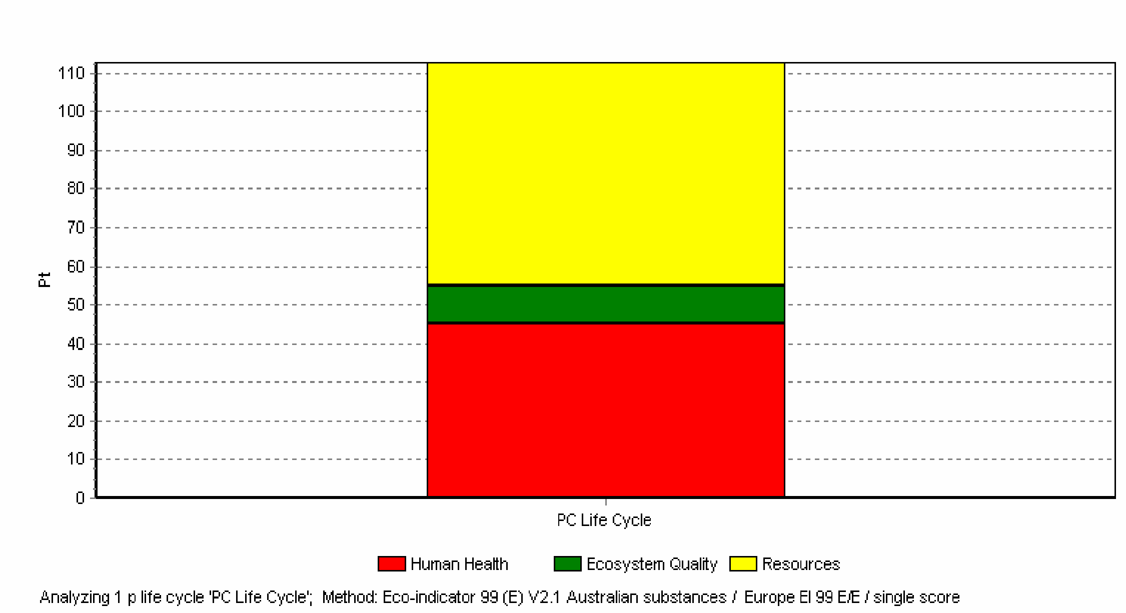


Figure 6-2I: Damage assessment of the life cycle of a PC on a single score

The damage categories are also normalized as can be seen on figure 6-2J. The damage categories are normalized on a European load (damage divided by population per year). Normalized results on resources show a contribution of 29% of one person's contribution (0.29 MJ energy surpluses) per year. The contribution to human health from one person is 15% per year, while 2% contribution per year from one person is caused on ecosystem quality.

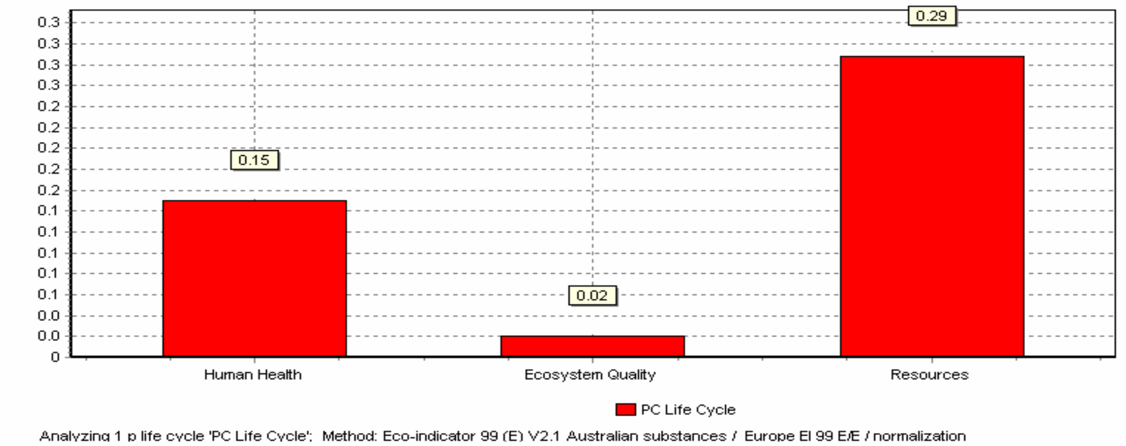


Figure 6-2J: Normalized damage category results

Figure 6-2K shows that the damage to resources accounts to 51% of the total damage by the PC whole life cycle. Damage to human health is 40% and to ecosystem quality is 9% on a weighted scale of the whole life cycle.

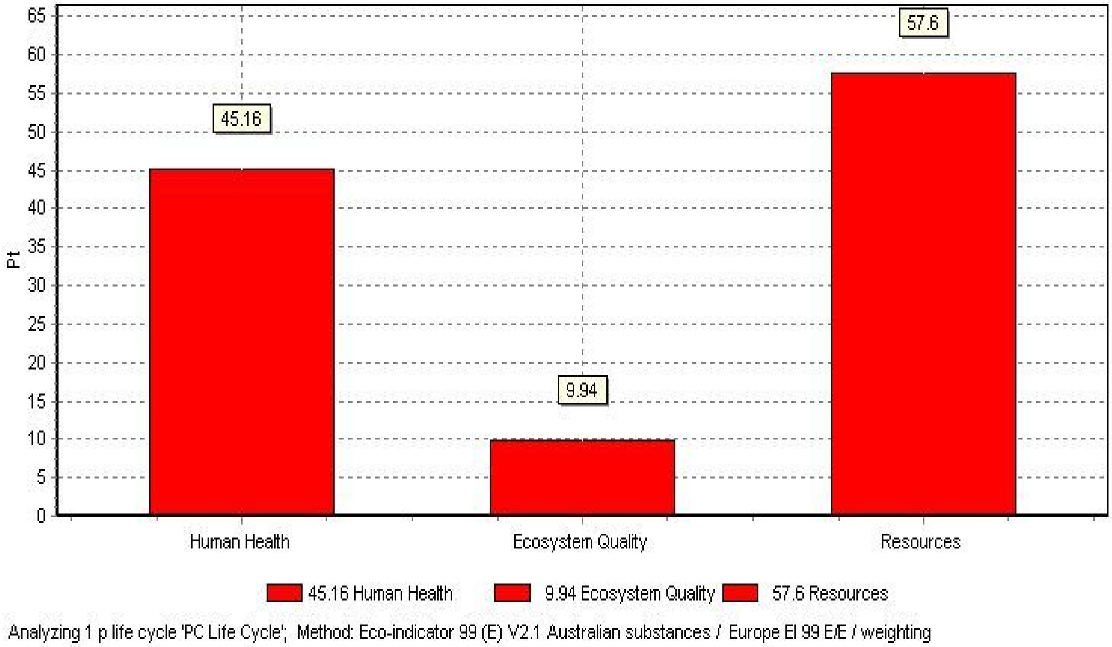
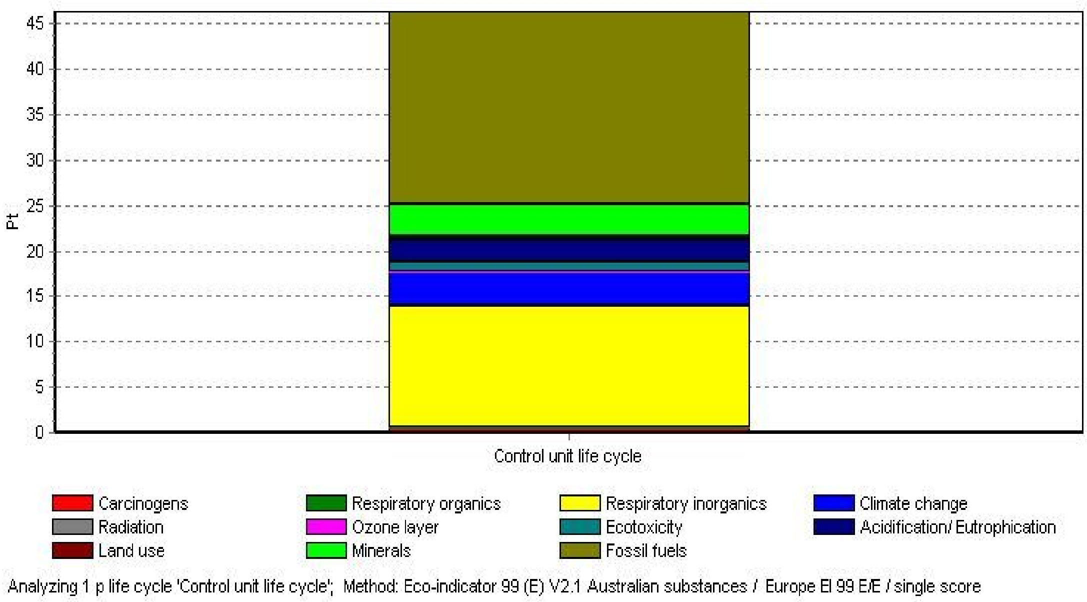


Figure 6-2K: Damage assessment results of the PC life cycle on a weighted scale

6.3.2 Control Unit

Figure 6-3A shows the characterized emissions for the control unit including packaging. Results are given for all the lifecycle stages on a single score. Some of the impact categories are also represented in figures 6-3B to 6-3E. The normalized data for the environmental impacts is shown on figure 6-3F. The normalized damage categories results are shown on figure 6-3G, followed by the weighted damage assessment results on figure 6-3H. The damage assessment figure on a single score for the control unit is shown on figure 6-3I.



Analyzing 1 p life cycle 'Control unit life cycle'; Method: Eco-indicator 99 (E) V2.1 Australian substances / Europe EI 99 E/E / single score

Figure 6-3A: shows the characterized results of the environmental impacts for the control unit

The figure shows that the use of fossil resources has the largest environmental load, followed by respiratory effects (in-organics), and the global warming potential (climate change) and mineral resources.

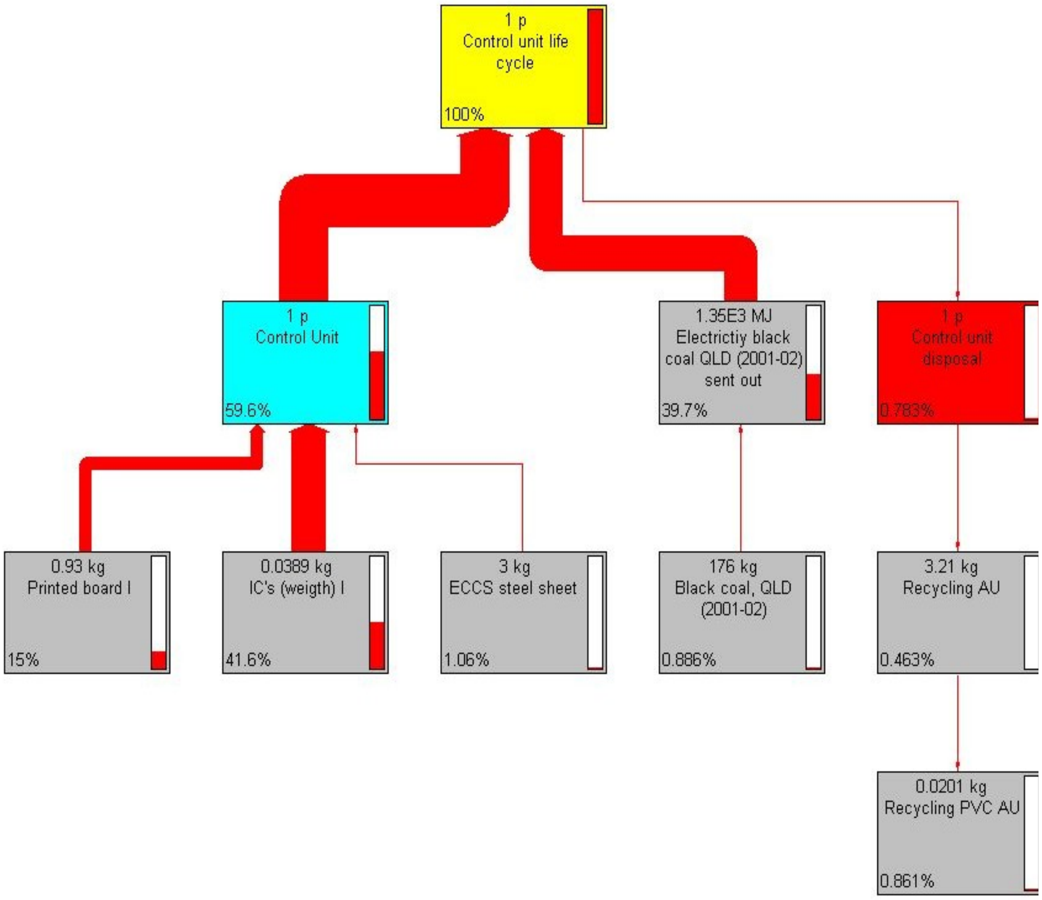


Figure 6-3B: shows the characterized effects of global warming due to climate change caused by the control unit

The results show that the effect on global warming potential due to climate change for the control unit was largest in the production stage, and second largest in the use stage. The effects in the disposal stage are very small (less than 1%).

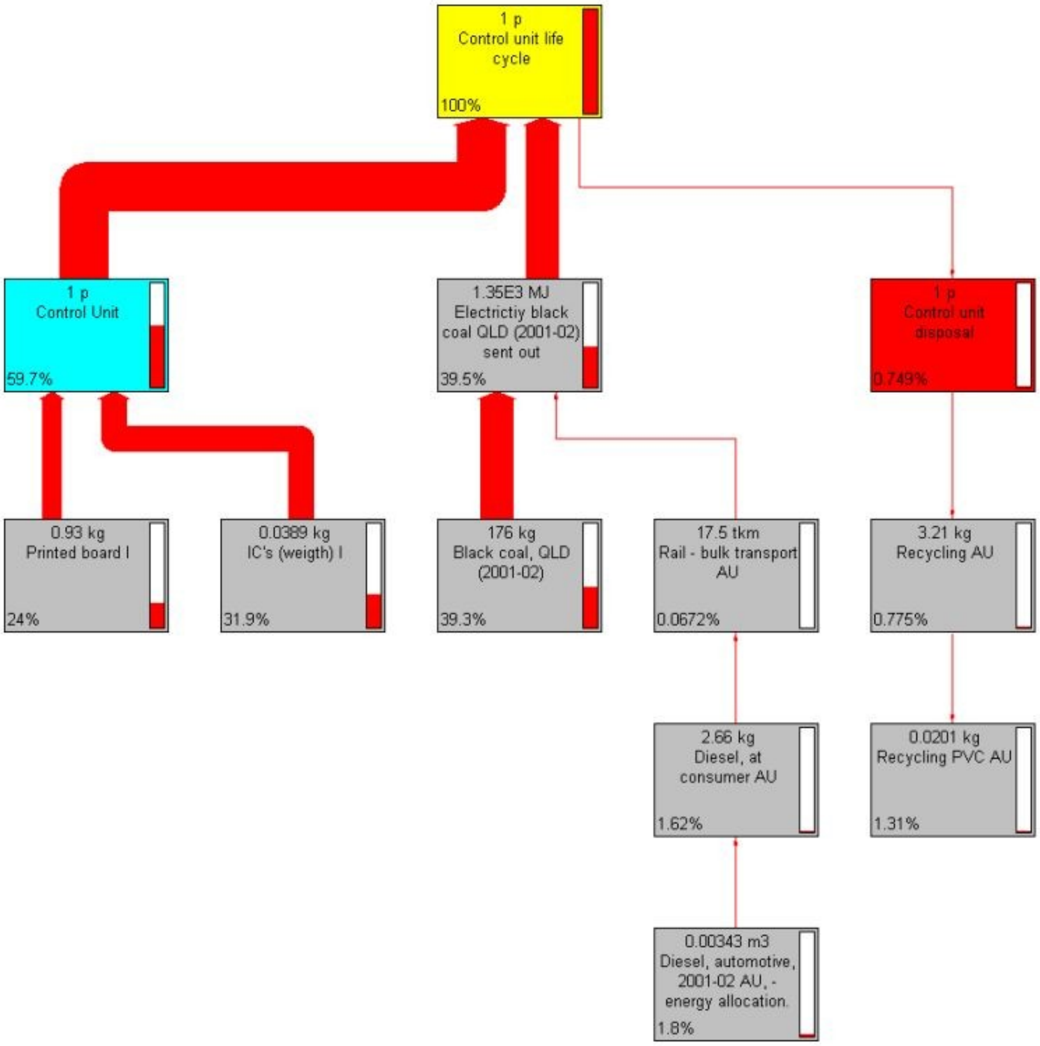


Figure 6-3C: shows the aspects of the control unit life cycle and the relative use of fossil fuels (resources)

Depletion of fossil resources is largest in the production phase followed by the use phase with a contribution of approx. 40%. The largest contribution on the control unit came from the ICs with approx. 32% and then the printed circuit board with about 24%. The disposal stage once again poses little effect.

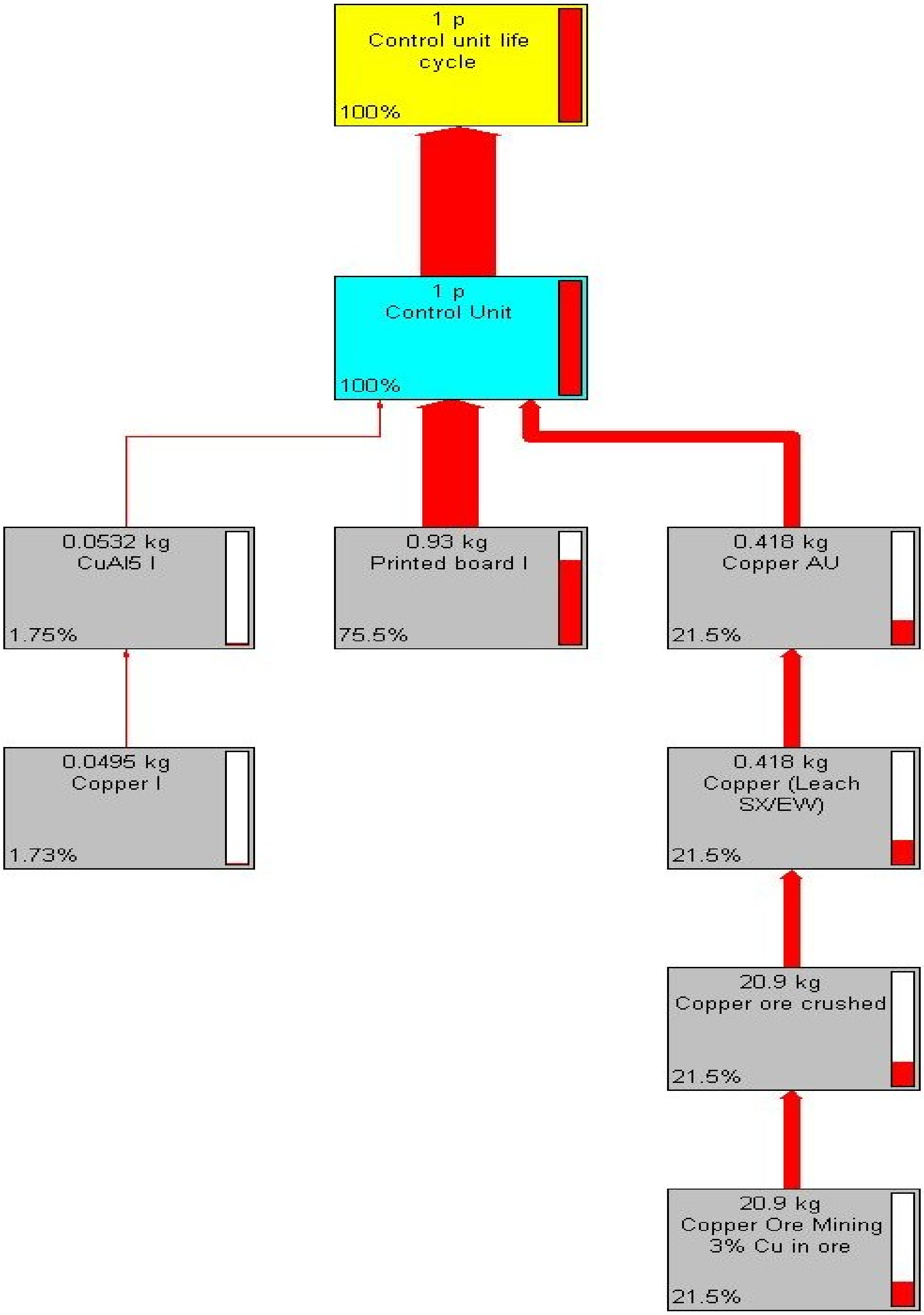


Figure 6-3D: Characterized results of mineral resources potential due to the control unit life cycle

Figure 6-3D shows that almost all of the environmental impact was produced in the production stage. In this stage the largest index on the use of mineral resources was in the printed circuit boards of the control unit. This is because of the energy used in extracting the mineral metals used to assemble the PCB. The second largest contribution is from copper with approx. 22%.

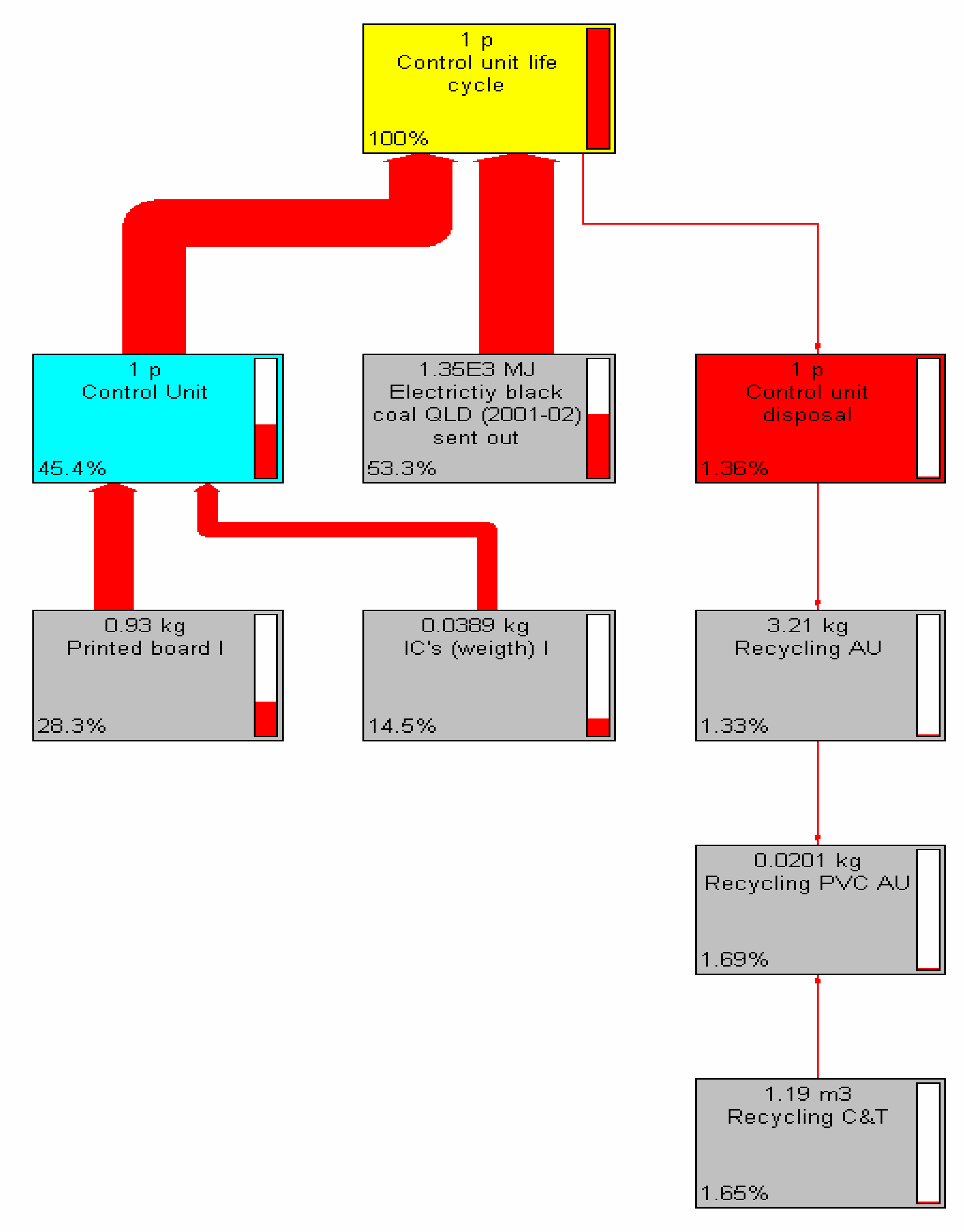
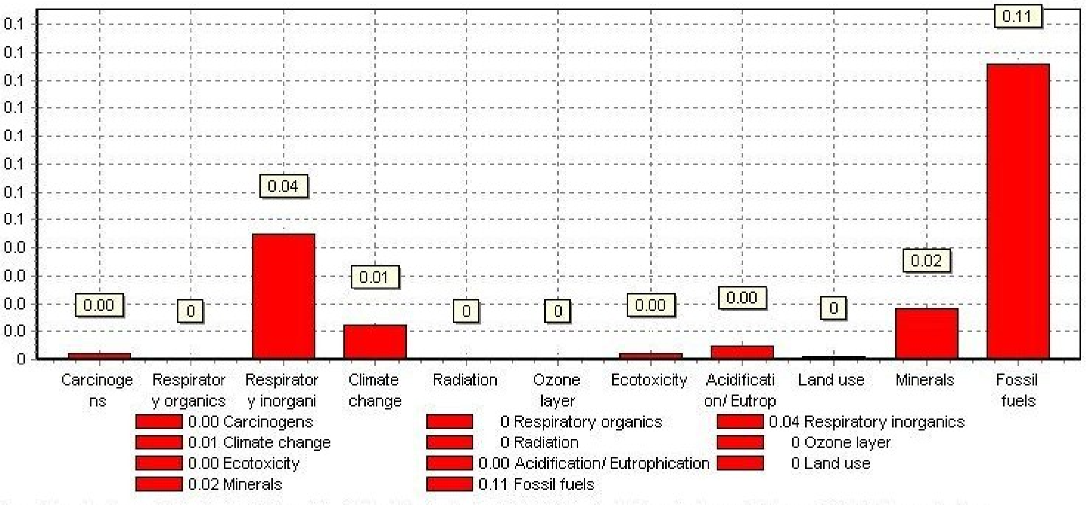


Figure 6-3E: Characterization results of acidification/eutrophication index in the life cycle for the control unit.

Environmental impact in figure 6-3E is largest in the use and production stages in acidification/eutrophication analysis for the control unit, with the largest contribution coming form the printed circuit boards, then the ICs.



Analyzing 1 p life cycle 'Control unit life cycle'; Method: Eco-indicator 99 (E) V2.1 Australian substances / Europe EI 99 E/E / normalization

Figure 6-3F: Normalized environmental potentials for control unit with packaging

Figure 6-3F shows that the consumption of resources (that is, fossil fuels and minerals) by one person's relative share per year is approx. 13%, while effects of climate change contribute only 1% to one person per year.

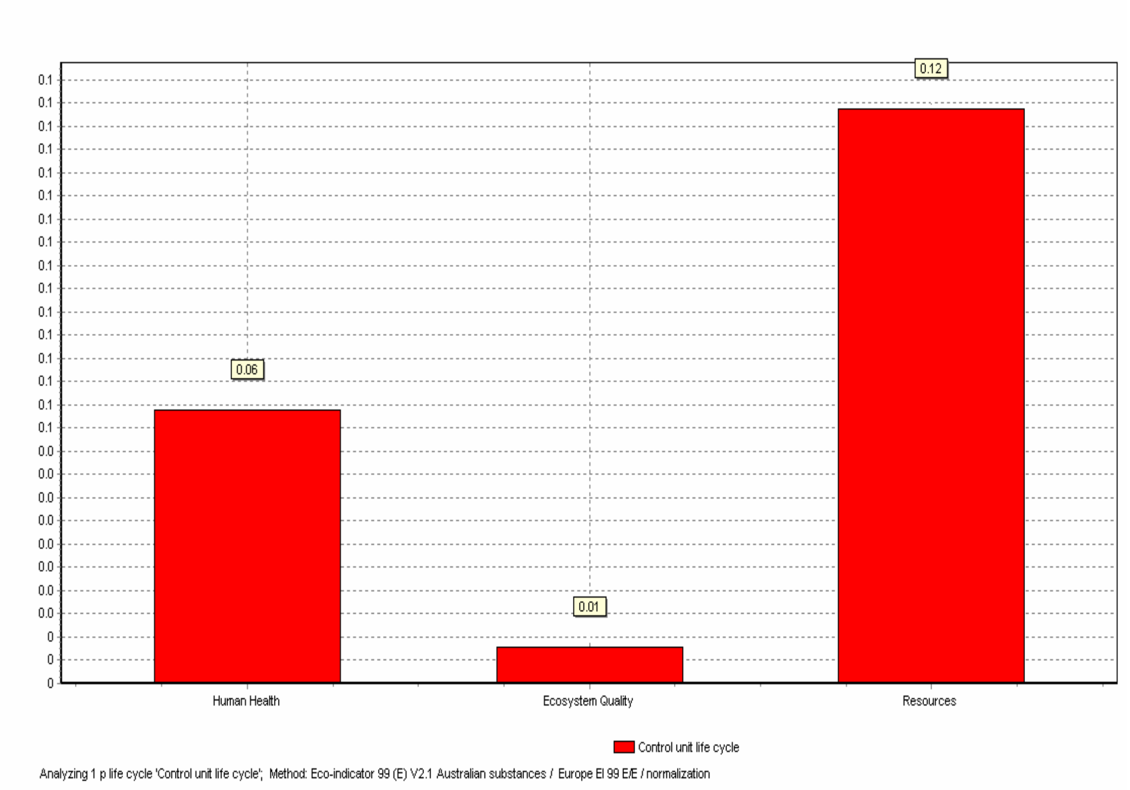


Figure 6-3G: shows the normalized damage categories of the control unit with packaging

Figure 6-3G shows that the contribution of damage to human health from one person is 6% per year; on ecosystem quality is 1%; and on damage to resources is 12% of one person per year.

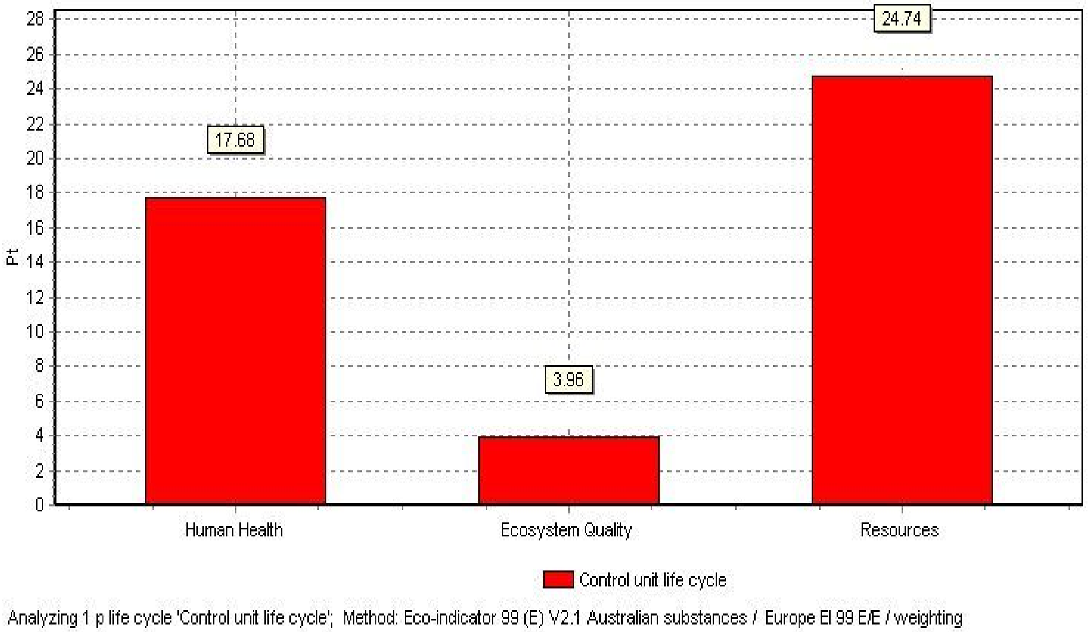


Figure 6-3H: shows the weighted damage assessment results for the control unit life cycle

The results on a weighted scale show that the damage to ecosystem quality is approx. 9%, and to human health is 38% of the total contribution from the life cycle of the control unit. Similar results are shown on a single score on figure 6-3I.

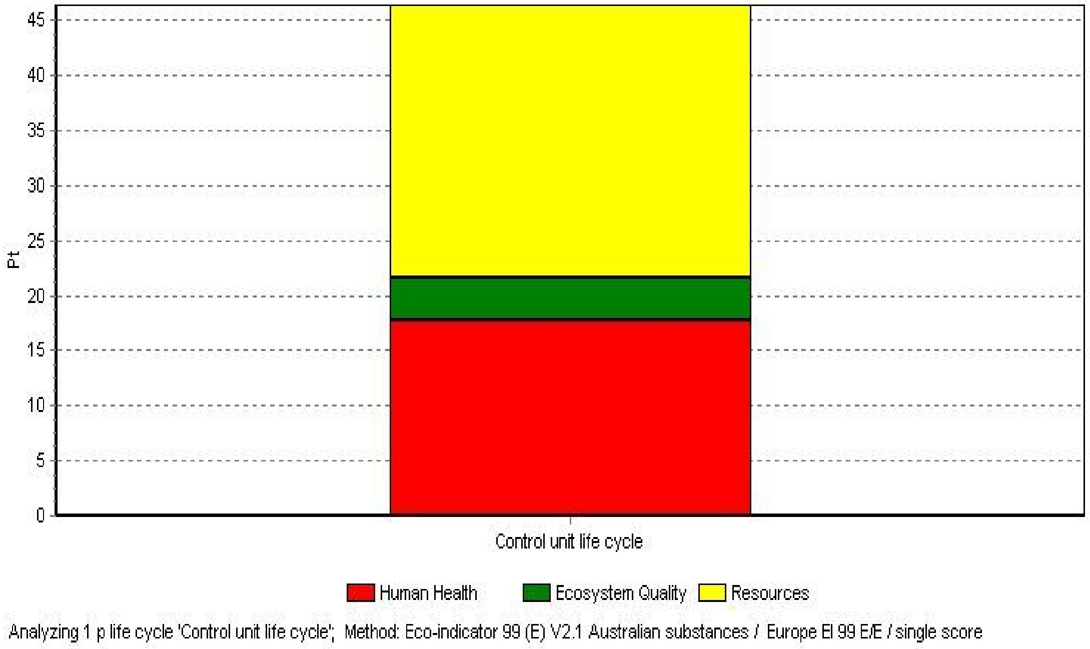


Figure 6-3I: Damage assessment for the control unit on a single score

6.3.3 CRT Monitor

Figure 6-4A shows the characterized results of the environmental load of a CRT monitor life cycle with packaging on a single score. Like the control unit, only a few of the impact categories are presented. As previously pointed out in chapter 5, the results of the CRT monitor do not represent the total contribution as assumptions for glass in the CRT were made. The lead glass of which the CRT glass consists is not available in SimaPro database. These are presented on figures 6-4B to 6-4E. The normalized environmental impact potential is represented on figure 6-4F. The damage category figures for the CRT monitor are presented on figures 6-4G to 6-4H.

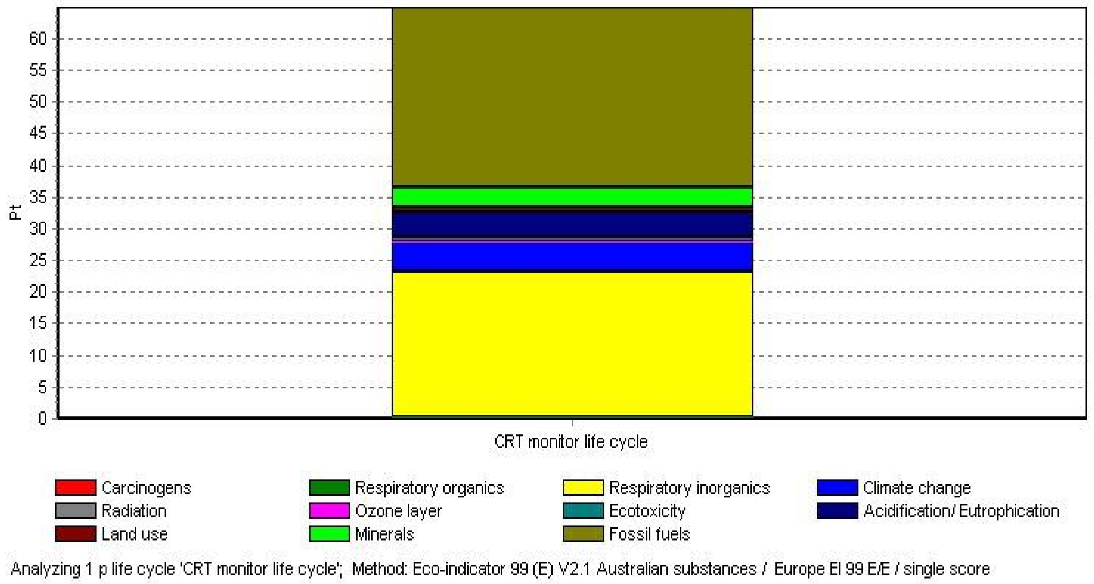


Figure 6-4A: the characterized environmental impact potentials of the CRT monitor

The figure shows that the use of resources (fossil fuels and minerals) has the largest environmental load, followed by respiratory effects (in-organics), and the global warming potential due to climate change.

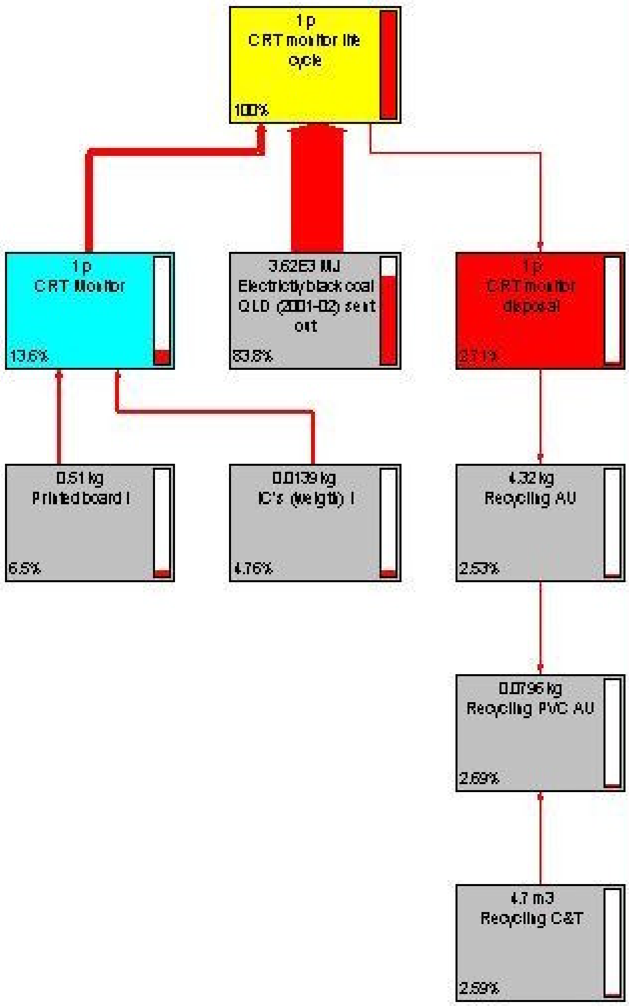


Figure 6-4B: Characterized results shows aspects of the CRT monitor life cycle and effect on climate change (global warming potential)

The results show that most of the global warming potential comes from the use stage followed by the production stage. The printed circuit board and the ICs are the most contributing parts in the life cycle of the CRT monitor in this case.

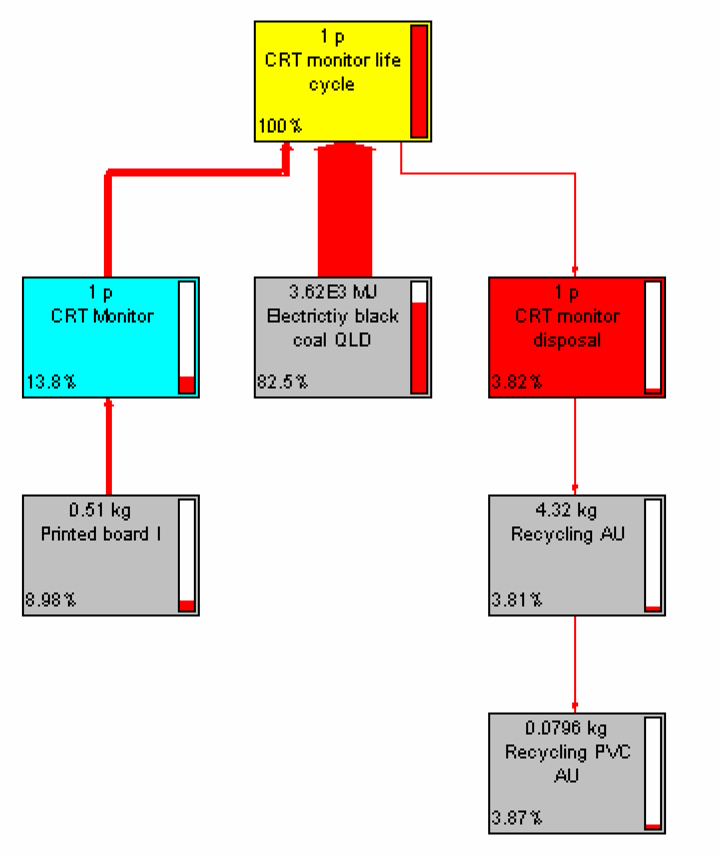


Figure 6-4C: Characterized results of acidification/eutrophication index for the monitor

The results obtained for acidification/eutrophication analysis show that the environmental impact is large in the use and production stages, with the printed circuit board having the largest load in the production stage.

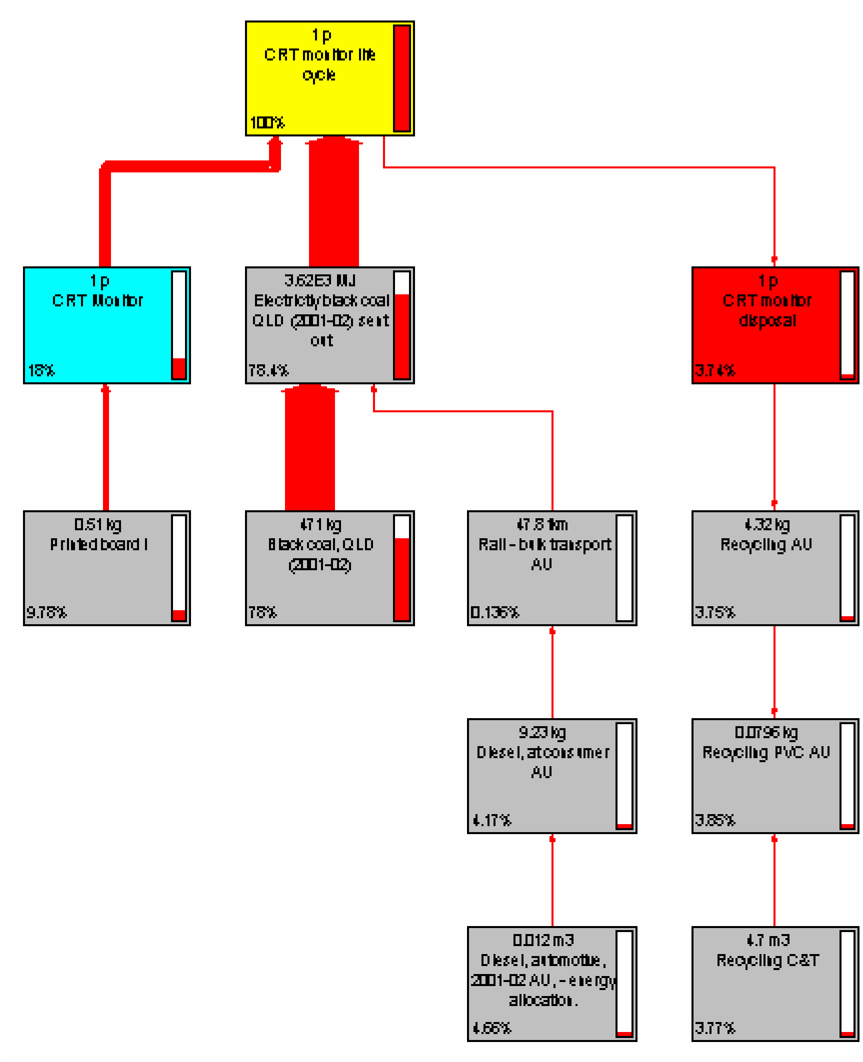


Figure 6-4D: shows the aspects of the life cycle for the CRT monitor and relative use of fossil fuels (resource consumption index of fossil fuels)

Figure 6-4D shows that the use of fossil resources is largest in the use stage of the life cycle of a monitor.

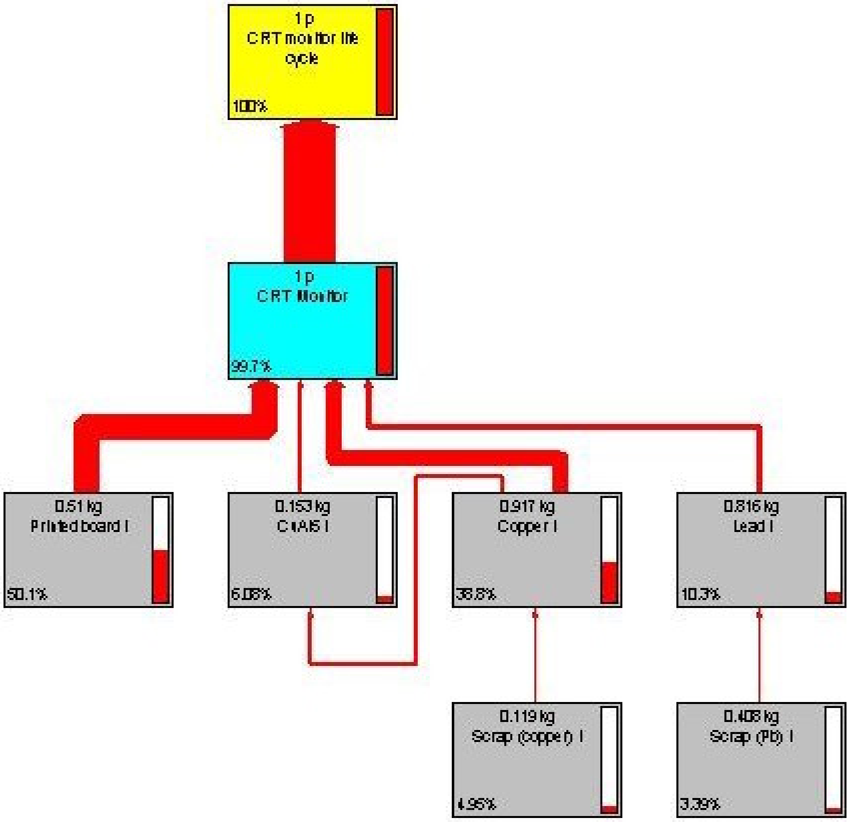
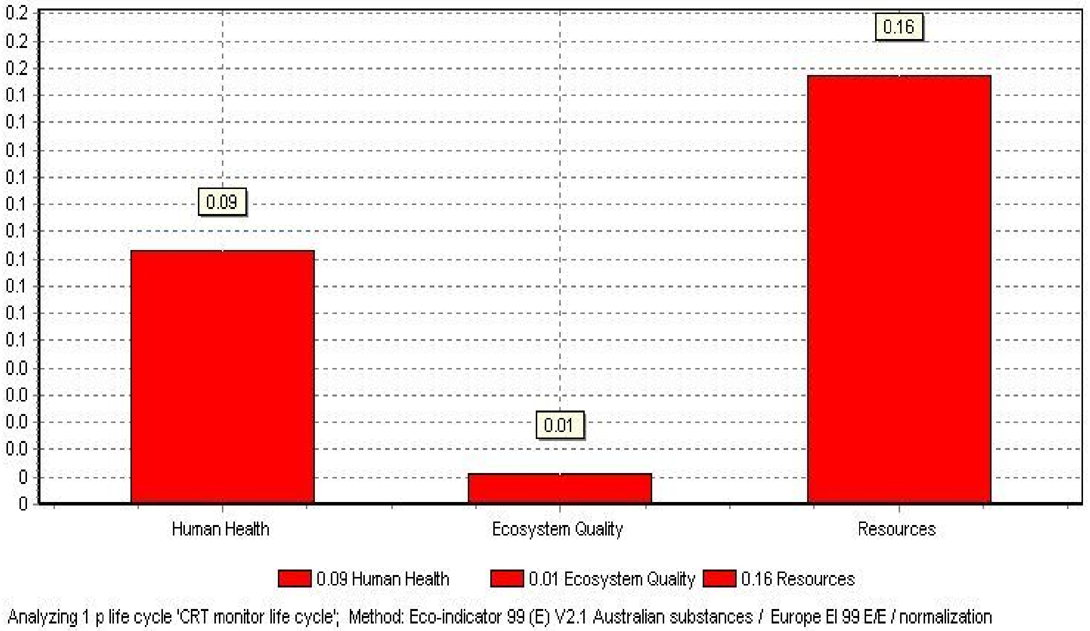


Figure 6-4E: shows characterized minerals resources index for the life cycle of the CRT monitor

The above figure shows that almost the entire load on mineral extraction is produced in the production stage. The largest index was on the printed circuit board, followed by copper and lead.

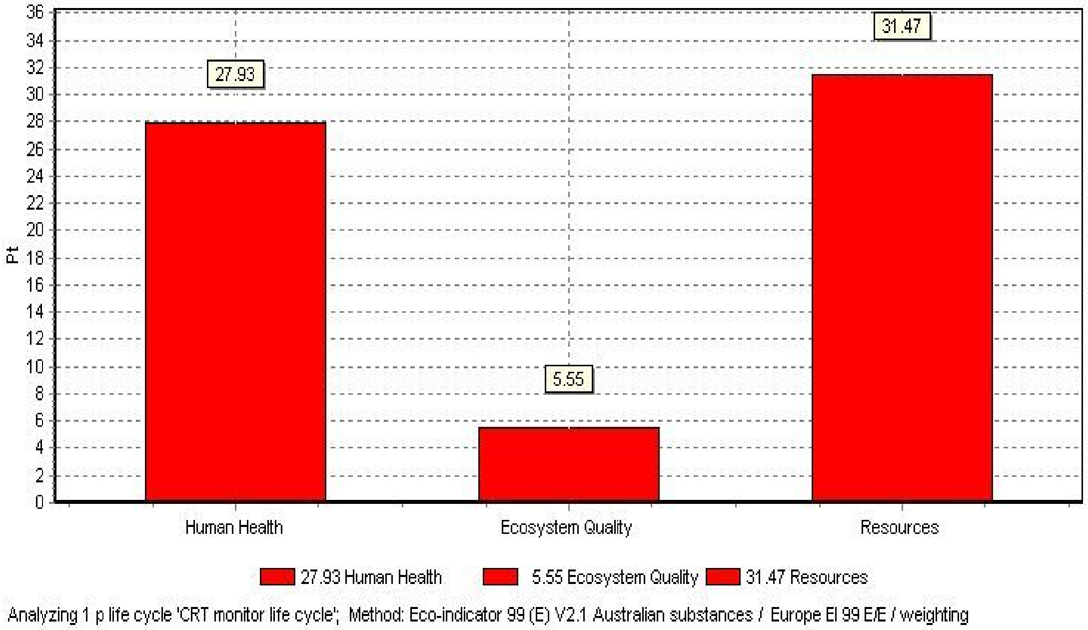


Analyzing 1 p life cycle 'CRT monitor life cycle'; Method: Eco-indicator 99 (E) V2.1 Australian substances / Europe EI 99 E/E / normalization

Figure 6-4F: Normalized damage assessment for CRT monitor life cycle

A 16% contribution of one person per year to damage to resources is observed in the normalized results of the monitor life cycle. The relative share of damages to human health is 9% per person per year.

Figure 6-4G shows the weighted results of the damage categories of the life cycle of the CRT monitor. Damage to human health is approx. 43% of the total environmental load of the life cycle of the CRT monitor. The damage to ecosystem quality amounts to 9% of the total load. The same results are presented on a single score on figure 6-4H.



Analyzing 1 p life cycle 'CRT monitor life cycle'; Method: Eco-indicator 99 (E) V2.1 Australian substances / Europe EI 99 E/E / weighting

Figure 6-4G: Weighting of the damage categories for the CRT monitor life cycle

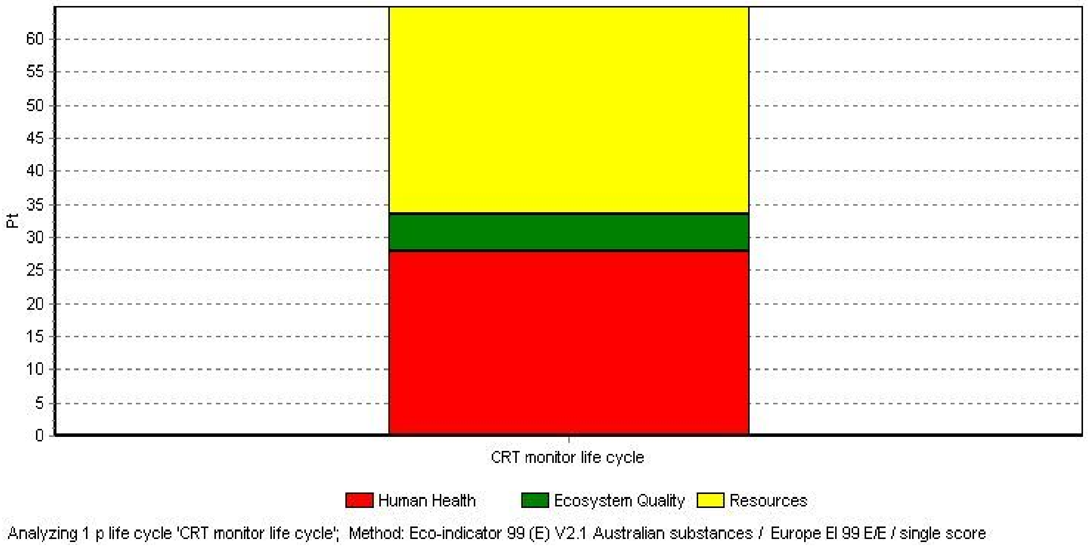


Figure 6-4H: Damage assessment of the life cycle for the CRT monitor on a single score

Results on a single score same as in figure 6-4G.

6.3.4 Relative Contributions of the PC Elements

The following tables show the relative contributions of the elements of the PC to the environmental impact potential and the damage potential. Detailed tables for the whole PC contributions and each element's contributions to both environmental impact potential and categorized damage potential are on Appendix B.

Table 6-1C: Contributions to Environmental Impact Potential, PC by Element

Environmental impact categories	**Control Unit**	**CRT Monitor**	**Keyboard & Mouse**	**Total**
Fossil fuels	41.5%	56%	2.5%	100%
Minerals	53.5%	44%	2.5%	100%
Ozone layer	44%	47%	9%	100%

Eco-toxicity	58.4%	40.6%	1%	100%
Acidification/Eutrophication	36.8%	62.2%	1%	100%
Climate change	43.9%	55.5%	0.6%	100%
Radiation	0%	100%	0%	100%
Land use	28.4%	45.6%	26%	100%
Carcinogens	69%	30.5%	0.5%	100%
Respiratory in-organics	37%	63%	0%	100%
Respiratory organics	54%	37.4%	8.6%	100%

From the above table the largest contributions to environmental impact are from the control unit and the monitor. Environmental load of the PC to climate change is more on the monitor than the other elements, i.e. 55% of total environmental load of the PC to climate change comes from the monitor.

Table 6-1D: Contributions to Damage, PC by Element

Damage categories	**Control unit**	**CRT Monitor**	**Keyboard & Mouse**	**Total**
Human Health	39%	60%	1%	100%
Ecosystem Quality	39.8%	55.8%	4.4%	100%
Resources	43%	55%	2%	100%

Again, the control unit and the monitor have the largest contributions to damage categories. Depletion of resources for the monitor is approx. 55% of the total damage to resources.

6.4 Discussion of Overall Results

The results obtained from the analysis of climate change, acidification/eutrophication, use of minerals and fossil fuels, eco-toxicity, ozone layer depletion and respiratory inorganics show that the environmental impact on the PC was large in the use and production stages. This means that if we would like to improve the environmental impact, then focus should be on these stages of the PC life cycle. The disposal stage in all cases has very little effect to the environmental impact. As already seen on the figures on the results, the environmental impact in the use stage was generated as a result of electricity consumption during use. The electricity consumption in the use stage for almost all the environmental impact categories, show a much higher percentage on electricity consumption than on the production processes of the PC life cycle. In the production phases the most environmental impact potential came from the control unit and the cathode ray tube monitor. The impact potentials are due to various causes. These causes include among others the printed circuit board, ICs, steel, copper, lead, cathode ray tube assembly etc. The loads in the keyboard and mouse are relatively small.

The cathode ray tube monitor is the heaviest assembly in the PC monitor having materials such as glass, steel, copper, coating materials, etc. This makes the manufacturing process of the cathode ray tube to be energy-intensive. The overall results for the cathode ray tube monitor do not reflect to exact contribution to environmental load as assumption on the glass was made since the data for the lead glass that is used in the CRT monitor was not available in the SimaPro database.

The environmental potential for the printed circuit board production and ICs is assumed to be mainly produced in the assembling process. Also the PCB has a large number of parts mounted onto it which are assumed to be also contributing to the environmental load. Kim et al. (2000, p.6) has the following to say about the printed circuit board assembly process:

> In the assembly process where the electronic devices are inserted onto the phenol resin board, some of the electronic devices are arranged and attached to a paper roll and cut automatically to the proper size for an inserting machine. Therefore, the inserting process generates a large amount of paper and steel wire waste. After inserting electronic devices, the board moves to the soldering process, followed by the cleaning process where steam is used as a cleaning agent. The printed circuit board assembly is also energy intensive.

Metal cabinet (steel) which is used in the housing of most of the components such as the hard disk drive (HDD), CD-ROM drive, and for the control unit itself, seems to have a large contribution to the environmental impact than the plastic material casing.

It is therefore recommended that to reduce (improve) the environmental impact potential of the PC, the following points should be considered:

- Reduction of power consumption of the PC (this includes the monitor and control unit) in the use stage. The energy consumption of the CRT monitor holds a strong improvement potential as compared to the control unit, as it consumes almost twice the energy consumed by the control unit. Needless to say, the energy consumption of the control unit is also significant.

- The printed circuit board assembling process and the ICs should be improved. This can be achieved by reducing the number of parts on the board and miniaturizing the boards.

- Use of low power consuming displays such as LCDs.

- Recovery of materials and re-use: this extends the use-life of the PC as the motherboard, hard disk, etc may be upgraded. After upgrading the PC may be used for another 3-5 years. A PC may also be bought at point of disposal and again be used for another 3-5 years.

CHAPTER 7

Conclusions

7.1 Main Achievements of Objectives

This project was conducted with the aim of assessing the environmental impact of the life cycle of a PC. This PC was manufactured in 1997 in Asia, and has been used for almost 5 years before being put in storage, awaiting disposal. The parts that contribute more to the environmental load and possible ways of environmental improvements were to be identified. This study shows that the use and production phases are the most contributing stages in the life cycle. Of these two stages, the use stage was the most contributing to the environmental impact than the production stage. The use stage shows that the impact was generated as a result of electricity consumption during use; and in the production stage the control unit and the CRT monitor assembly processes are the most contributors. The parts contributing most from the control unit and the monitor are the printed circuit board, ICs, cabinet housing that is made of steel, copper, and the cathode ray tube assembly.

It is therefore based on the results of this study that the possible ways of reducing the environmental burden of the life cycle of the PC are:

1. Reduce PC energy consumption – the monitor as observed from the power consumption measurements taken, consumes more power than the control unit. It is also understood that even in stand-by mode, electronic devices consume power. As a result the energy consumption of the monitor holds very strong improvement potential than that of the control unit.

2. Improving the PCB and ICs assembling processes – many different materials of which are of environmental concern are used in the construction of the PCBs such as cadmium and lead. Flame retardants including organic halogenated or brominated compounds and inorganic compounds (e.g. antimony compounds) are used in the epoxy of resin of PCBs to prevent fires (*Computer & Peripherals Material Project 2001*). Of course the brominated flame retardants are of principal concern with regard to environmental and health risks. This is the area that needs attention (getting rid of the brominated flame retardants or replacement with non-toxic or problematic materials).

3. Extending the lifetime by allowing for the exchange of motherboard and the upgrading of the memories.

4. Use of plastic materials in the housing of components.

5. Using low power consuming displays such as LCDs. LCDs are understood to be consuming less power than the CRT monitor because of the fact that they have a smaller amount of materials and a smaller number of components than the CRT monitor.

The software (SimaPro 6) used in this study is user-friendly and a very powerful tool in assessing the environmental impacts of products. With this software only the foreground data (such as data for semiconductor devices, cathode ray tube resistors capacitors, etc.) has to be collected; most of the background data such as glass, electricity, aluminum, energy, materials production, packaging materials etc. are already available in the software. The software is valuable as it uses diagrams to illustrate the flows, stages and processes of life cycle of product. The use of scores, with reliable data sets and impact categories in the software enables effective comparisons to be made between products and processes. Of course any software has its on merits and de-merits. Most data on some of the materials is not available on the database; limited data, questionable data quality and varying regional relevancy (data is based on European data) is also a constricting factor, as such the lack of confidence in data in these areas means the environmental scores could be unreliable.

The impact assessment method (Eco-indicator 99) used is as valid as any other method in SimaPro. A comparison of these methods by Luo et al. confirms this. Aggregation of impact categories into damage categories (human heath, ecosystem quality and resources) makes the analysis of the results more easily using this method than the other methods.

7.2 Further Work

There are some uncertainties with regard to the software package, because of the imprecision of available data. As such sensitivities can be identified and varied to check whether the results will have any change. Therefore suggestions in future are that the assumptions that were made (such as weight of some of the PC components and its life time), be changed; materials data for some parts such as the glass that was assumed to be used in the CRT be improved to see whether these will have any effect on the conclusions made from the analysis. It is also suggested that other impact assessment methods be applied to verify the validity of the results obtained with Eco-indicator 99.

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10 Appendix A

University of Southern Queensland
FACULTY OF ENGINEERING AND SURVEYING

ENG 4111/2 Research Project
PROJECT SPECIFICATION

FOR: Baipaki Pakson **HIKWAMA**

TOPIC: Life cycle assessment of a personal computer

SUPERVISOR: Mr. David Parsons

ENROLMENT: ENG 4111 – S1, D, 2005;
ENG 4112 – S2, D, 2005

SPONSORSHIP: Faculty of Engineering and Surveying, USQ

PROJECT AIM: This project aims to assess the environmental impact of a PC by using LCA methods. Specifically, it aims to determine which parts contribute most to adverse environmental impacts, and to make recommendations about the potential for recycling and recovery of materials and any other action as a means of environmental improvement.

PROGRAMME: **<u>Issue A, 21st March 2005</u>**

1. Research background information of the current LCA technology and its associated standards.
2. Understand current methodology associated with the SimaPro software and its proper usage.
3. Disassemble a particular PC and construct an inventory of its component parts, and measure the energy use of a typical similar PC under a variety of conditions.
4. Construct a model of the life cycle of a particular PC from raw material to ultimate disposal.
5. Perform various analyses using SimaPro software.
6. Study relevant literature for comparison of results to similar products.

As time permits:
7. Design methods to achieve environmental gains with respect to computers. This might include research on the current status of recycling technologies and markets.

AGREED:

__________________________ (Student) _________________________(Supervisor)
____ /____ /_____ _____ /______ /_____

11 Appendix B

LCI Input/Output Tables

The inventory input/output for the whole PC, control unit and CRT monitor are presented in this appendix. Section 11.1 presents the inventory results for the whole PC; section 11.2 presents the results for the control unit while section 11.2 presents inventory results for the CRT monitor.

11.1 The Whole PC

Table 11-1A: Damage Assessment to Ecosystem Quality in the PC system

NO	SUBSTANCE	COMPARTMENT	UNIT	PC LIFE CYCLE
	Total		PDF*m2yr	102
1	Occupation, arable	Raw	PDF*m2yr	2.09
2	Occupation, construction site	Raw	PDF*m2yr	0.0169
3	Occupation, forest	Raw	PDF*m2yr	-0.148
4	Occupation, industrial area	Raw	PDF*m2yr	1.11
5	Occupation, industrial area, vegetation	Raw	PDF*m2yr	0.445
6	Occupation, mineral extraction site	Raw	PDF*m2yr	0.0093
7	Occupation, traffic area	Raw	PDF*m2yr	5.44
8	Occupation, urban, continuously built	Raw	PDF*m2yr	0.214
9	Occupation, urban, green areas	Raw	PDF*m2yr	3.03
10	Transformation, from forest,	Raw	PDF*m2yr	-0.207
11	Transformation, from mineral extraction site	Raw	PDF*m2yr	-0.00912
12	Transformation, from unknown	Raw	PDF*m2yr	-8.57
13	Transformation, to arable	Raw	PDF*m2yr	6.54
14	Transformation, to industrial area	Raw	PDF*m2yr	1.67
15	Transformation, to industrial area, vegetation	Raw	PDF*m2yr	0.444
16	Transformation, to	Raw	PDF*m2yr	0.00912

	mineral extraction site			
17	Transformation, to shrub land, sclerophyllous	Raw	PDF*m2yr	0.0012
18	Transformation, to urban, continuously built	Raw	PDF*m2yr	3.2
19	Transformation, to water bodies, artificial	Raw	PDF*m2yr	2.44
20	Ammonia	Air	PDF*m2yr	0.0678
21	Arsenic	Air	PDF*m2yr	0.0594
22	Benzene	Air	PDF*m2yr	3.4E-6
23	Benzene, hexachloro-	Air	PDF*m2yr	6.87E-13
24	Benzo(a)pyrene	Air	PDF*m2yr	0.000137
25	Cadmium	Air	PDF*m2yr	0.0934
26	Chromium	Air	PDF*m2yr	0.647
27	Chromium VI	Air	PDF*m2yr	0.153
28	Copper	Air	PDF*m2yr	0.253
29	Dioxins,	Air	PDF*m2yr	4.31E-5
30	Fluoranthene	Air	PDF*m2yr	7.5E-8
31	Heavy metals, unspecified	Air	PDF*m2yr	-2.3E-7
32	Lead	Air	PDF*m2yr	1.39
33	Mercury	Air	PDF*m2yr	0.0199
34	Metals, unspecified	Air	PDF*m2yr	0.106
35	Nickel	Air	PDF*m2yr	2.08
36	Nitric oxide	Air	PDF*m2yr	0.0142
37	Nitrogen dioxide	Air	PDF*m2yr	0.368
38	Nitrogen oxides	Air	PDF*m2yr	43.8
39	PAH, polycyclic aromatic hydrocarbons	Air	PDF*m2yr	5.06E-8
40	Phenol, pentachloro-	Air	PDF*m2yr	1.01E-13
41	Sulfur dioxide	Air	PDF*m2yr	10.7
42	Sulfur oxides	Air	PDF*m2yr	8.54
43	Toluene	Air	PDF*m2yr	1.24E-6
44	Zinc	Air	PDF*m2yr	0.537
45	Arsenic, ion	Water	PDF*m2yr	0.00527
46	Benzene	Water	PDF*m2yr	2.95E-6
47	Benzo(a)pyrene	Water	PDF*m2yr	-8.43E-9
48	Cadmium, ion	Water	PDF*m2yr	0.0592
49	Chromium	Water	PDF*m2yr	0.125
50	Chromium VI	Water	PDF*m2yr	3.44E-5
51	Chromium, ion	Water	PDF*m2yr	7.42E-6
52	Copper, ion	Water	PDF*m2yr	14.4
53	DNOC	Water	PDF*m2yr	-1.65E-10

54	Fluoranthene	Water	PDF*m2yr	-6.09E-9
55	Lead	Water	PDF*m2yr	0.134
56	Mercury	Water	PDF*m2yr	0.000129
57	Metallic ions, unspecified	Water	PDF*m2yr	0.00346
58	Nickel, ion	Water	PDF*m2yr	0.444
59	PAH, polycyclic aromatic hydrocarbons	Water	PDF*m2yr	1.73E-8
60	Phenol, pentachloro-	Water	PDF*m2yr	-1.27E-8
61	Phthalate, dioctyl-	Water	PDF*m2yr	4.14E-13
62	Toluene	Water	PDF*m2yr	1.23E-5
63	Zinc, ion	Water	PDF*m2yr	0.0648
64	Arsenic	Soil	PDF*m2yr	0.000975
65	Cadmium	Soil	PDF*m2yr	0.00201
66	Chromium	Soil	PDF*m2yr	0.000336
67	Chromium VI	Soil	PDF*m2yr	0.000241
68	Copper	Soil	PDF*m2yr	0.00482
69	Lead	Soil	PDF*m2yr	5.21E-5
70	Mercury	Soil	PDF*m2yr	0.000101
71	Nickel	Soil	PDF*m2yr	0.106
72	Zinc	Soil	PDF*m2yr	0.0181

Table 11-1B: Damage Assessment to Human Resources for the PC system

NO	SUBSTANCE	COMPARTMENT	UNIT	PC LIFE CYCLE
	Total		DALY	0.00233
1	2-Propanol	Air	DALY	5.88E-10
2	Acetaldehyde	Air	DALY	7.5E-11
3	Acetic acid	Air	DALY	1.07E-10
4	Acetone	Air	DALY	6.88E-9
5	Acrolein	Air	DALY	4.62E-14
6	Acrylonitrile	Air	DALY	2.85E-9
7	Alcohols, unspecified	Air	DALY	1.05E-7
8	Aldehyde, unspecified	Air	DALY	6.17E-10
9	Arsenic	Air	DALY	2.47E-6
10	Benzaldehde	Air	DALY	1.3E-14
11	Benzene	Air	DALY	3.67E-9
12	Benzene, ethyl-	Air	DALY	5.55E-10
13	Benzene, hexachloro-	Air	DALY	1.46E-15
14	Benzene, pentachloro-	Air	DALY	9.91E-20
15	Benzo(a)pyrene	Air	DALY	3.84E-9
16	Butane	Air	DALY	3.93E-9
17	Butene	Air	DALY	3.38E-11

18	Cadmium	Air	DALY	1.31E-6
19	Carbon-14	Air	DALY	1.37E-11
20	Carbon dioxide	Air	DALY	0.000108
21	Carbon dioxide, biogenic	Air	DALY	3.98E-6
22	Carbon dioxide, fossil	Air	DALY	0.000265
23	Carbon monoxide	Air	DALY	1.07E-6
24	Carbon monoxide, biogenic	Air	DALY	7.55E-18
25	Carbon monoxide, fossil	Air	DALY	4.75E-10
26	Cesium-134	Air	DALY	2.94E-16
27	Cesium-137	Air	DALY	6.24E-16
28	Chloroform	Air	DALY	1.18E-13
29	Chromium VI	Air	DALY	2.17E-7
30	Cobalt-58	Air	DALY	2.43E-19
31	Cobalt-60	Air	DALY	1.98E-17
32	Cumene	Air	DALY	7.98E-12
33	Cyclohexane	Air	DALY	1.84E-11
34	Dinitrogen monoxide	Air	DALY	1.07E-6
35	Dioxins,	Air	DALY	5.85E-8
35	Ethane	Air	DALY	2.64E-9
36	Ethane, HCFC-140	Air	DALY	2.29E-9
37	Ethane, HFC-134a	Air	DALY	7.78E-10
38	Ethane, 1,2-dichloro-	Air	DALY	3.54E-9
39	Ethane, CFC-114	Air	DALY	2.16E-12
40	Ethane, hexafluoro-, HFC-116	Air	DALY	1.1E-8
41	Ethanol	Air	DALY	1.05E-9
42	Ethene	Air	DALY	8.46E-10
43	Ethene, chloro-	Air	DALY	9.33E-12
44	Ethene, tetrachloro-	Air	DALY	1.73E-15
45	Ethyne	Air	DALY	2.51E-12
46	Fluorine	Air	DALY	6.46E-11
47	Formaldehyde	Air	DALY	5.15E-9
48	Heavy metals, unspecified	Air	DALY	-6.27E-13
49	Heptane	Air	DALY	1.51E-10
50	Hexane	Air	DALY	5.06E-10
51	Hydrocarbons, unspecified	Air	DALY	4.92E-10
52	Hydrocarbons, unspecified	Air	DALY	7.18E-10
53	Hydrocarbons, aromatic	Air	DALY	6.48E-9
54	Hydrocarbons,	Air	DALY	1.05E-10

	chlorinated			
55	Hydrocarbons, halogenated	Air	DALY	7.38E-16
56	Hydrocarbons, unspecified	Air	DALY	4.55E-7
57	Hydrogen-3, Tritium	Air	DALY	5.45E-15
58	Iodine-129	Air	DALY	1.77E-13
59	Iodine-131	Air	DALY	1.6E-17
60	Iodine-133	Air	DALY	6.95E-20
61	Krypton-85	Air	DALY	4.52E-13
62	Lead-210	Air	DALY	7.05E-16
63	Metals, unspecified	Air	DALY	2.91E-7
64	Methane	Air	DALY	1.12E-5
65	Methane, biogenic	Air	DALY	4.58E-8
66	Methane, Halon 1301	Air	DALY	1.38E-8
67	Methane, HCFC-22	Air	DALY	2.01E-15
68	Methane, CFC-13	Air	DALY	1.41E-9
69	Methane, dichloro-, HCC-30	Air	DALY	8.14E-10
70	Methane, CFC-12	Air	DALY	2.71E-8
71	Methane, HCFC-21	Air	DALY	8.05E-13
72	Methane, fossil	Air	DALY	2.14E-10
73	Methane, CFC-10	Air	DALY	2.35E-10
74	Methane, tetrafluoro-, FC-14	Air	DALY	1.63E-6
75	Methane, CFC-11	Air	DALY	1.61E-8
76	Methanol	Air	DALY	2.54E-11
77	Methyl ethyl ketone	Air	DALY	2.36E-14
78	Nickel	Air	DALY	1.26E-8
79	Nitric oxide	Air	DALY	2.21E-7
80	Nitrogen dioxide	Air	DALY	5.74E-6
81	Nitrogen oxides	Air	DALY	0.000683
82	NMVOC, non-methane volatile organic compounds, unspecified origin	Air	DALY	2.56E-7
83	o-Xylene	Air	DALY	9.67E-14
84	PAH, polycyclic aromatic hydrocarbons	Air	DALY	1.12E-8
85	Particulates	Air	DALY	7.4E-6
86	Particulates, < 10 um	Air	DALY	0.000136
87	Particulates, < 10 um (mobile)	Air	DALY	4.54E-8
88	Particulates, < 10 um (stationary)	Air	DALY	2.93E-9

89	Particulates, < 2.5 um	Air	DALY	4.74E-7
90	Particulates, > 2.5 um, and < 10um	Air	DALY	1.34E-7
91	Particulates, SPM	Air	DALY	3.62E-6
92	Pentane	Air	DALY	2.87E-9
93	Phenol	Air	DALY	1.55E-11
94	Phenol, pentachloro-	Air	DALY	5.5E-17
95	Plutonium-238	Air	DALY	2.85E-21
96	Plutonium-alpha	Air	DALY	1.73E-16
97	Polonium-210	Air	DALY	1E-15
98	Propane	Air	DALY	4.72E-9
99	Propene	Air	DALY	2.9E-9
100	Propionic acid	Air	DALY	1.34E-11
101	Radium-226	Air	DALY	6.45E-16
102	Radon-222	Air	DALY	1.11E-10
103	Styrene	Air	DALY	2.23E-14
104	Sulfur dioxide	Air	DALY	0.000562
105	Sulfur hexafluoride	Air	DALY	4.25E-5
106	Sulfur oxides	Air	DALY	0.000448
107	t-Butyl methyl ether	Air	DALY	2.74E-16
108	Thorium-230	Air	DALY	1.03E-14
109	Toluene	Air	DALY	7.04E-9
110	Uranium-234	Air	DALY	2.4E-14
111	Uranium-235	Air	DALY	2.52E-16
112	Uranium-238	Air	DALY	2.43E-15
113	VOC, volatile organic compounds	Air	DALY	5.34E-8
114	Xenon-133	Air	DALY	3E-16
115	Xenon-133m	Air	DALY	8.9E-20
116	Xylene	Air	DALY	3.43E-9
117	Acrylonitrile	Water	DALY	-1.09E-13
118	Antimony-124	Water	DALY	8.69E-17
119	Arsenic, ion	Water	DALY	3.03E-5
120	Benzene	Water	DALY	2.53E-10
121	Benzo(a)anthracene	Water	DALY	-2.58E-10
122	Benzo(a)pyrene	Water	DALY	-6.85E-10
123	Cadmium, ion	Water	DALY	8.78E-6
124	Cesium-134	Water	DALY	6.23E-13
125	Cesium-137	Water	DALY	7E-12
126	Chloroform	Water	DALY	-2.05E-15
127	Chromium VI	Water	DALY	4.14E-16
128	Cobalt-58	Water	DALY	8.36E-17
129	Cobalt-60	Water	DALY	9.64E-13
130	Ethane, 1,1,2-trichloro-	Water	DALY	2.61E-21
131	Ethane, 1,2-dichloro-	Water	DALY	1.51E-11

132	Ethane, hexachloro-	Water	DALY	2.14E-19
133	Ethene, chloro-	Water	DALY	5.32E-14
134	Ethene, tetrachloro-	Water	DALY	5.66E-19
135	Ethene, trichloro-	Water	DALY	7.38E-15
136	Formaldehyde	Water	DALY	8.4E-14
137	Hydrogen-3, Tritium	Water	DALY	5.8E-14
138	Iodine-131	Water	DALY	1.28E-17
139	Manganese-54	Water	DALY	9.37E-16
140	Metallic ions, unspecified	Water	DALY	4.13E-7
141	Methane, dichloro-, HCC-30	Water	DALY	5.76E-13
142	Methane, tetrachloro-, CFC-10	Water	DALY	1.53E-15
143	Nickel, ion	Water	DALY	2.15E-13
144	PAH, polycyclic aromatic hydrocarbons	Water	DALY	2.15E-8
145	Phenol, 2,4,6-trichloro-	Water	DALY	-8.59E-16
146	Phenol, pentachloro-	Water	DALY	-1.16E-11
147	Phthalate, dioctyl-	Water	DALY	4.32E-16
148	Radium-226	Water	DALY	2.28E-13
149	Silver-110	Water	DALY	7.5E-17
150	Styrene	Water	DALY	5.18E-22
151	Uranium-234	Water	DALY	1.23E-15
152	Uranium-235	Water	DALY	1.75E-15
153	Uranium-238	Water	DALY	2.87E-15
154	Arsenic	Soil	DALY	2.11E-8
155	Cadmium	Soil	DALY	8.05E-10
156	Chromium VI	Soil	DALY	2.09E-14
157	Nickel	Soil	DALY	6.07E-14

Table 11-1C: Damage Assessment to Resources for the Whole PC system

No	**Substance**	**Compartment**	**Unit**	**PC Life Cycle**
	Total		MJ surplus	1.71E3
1	Aluminum, in ground	Raw	MJ surplus	2.02
2	Bauxite, in ground	Raw	MJ surplus	0.862
3	Chromium, in ground	Raw	MJ surplus	0.0497
4	Coal, 13.3 MJ per kg, in ground	Raw	MJ surplus	0.142
5	Coal, 18 MJ per kg, in ground	Raw	MJ surplus	6.3
6	Coal, 18.0 MJ per kg,	Raw	MJ surplus	0.16

	in ground			
7	Coal, 18.5 MJ per kg, in ground	Raw	MJ surplus	0.245
8	Coal, 19.5 MJ per kg, in ground	Raw	MJ surplus	0.0113
9	Coal, 20.5 MJ per kg, in ground	Raw	MJ surplus	857
10	Coal, 21.5 MJ per kg, in ground	Raw	MJ surplus	1.59
11	Coal, 22.1 MJ per kg, in ground	Raw	MJ surplus	2.25
12	Coal, 22.6 MJ per kg, in ground	Raw	MJ surplus	0.0724
13	Coal, 24.0 MJ per kg, in ground	Raw	MJ surplus	-0.597
14	Coal, 28.0 MJ per kg, in ground	Raw	MJ surplus	0.193
15	Coal, 29.3 MJ per kg, in ground	Raw	MJ surplus	219
16	Coal, brown, 10 MJ per kg, in ground	Raw	MJ surplus	0.427
17	Coal, brown, 10.0 MJ per kg, in ground	Raw	MJ surplus	1.12
18	Coal, brown, 14.1 MJ per kg, in ground	Raw	MJ surplus	0.0916
19	Coal, brown, 8 MJ per kg, in ground	Raw	MJ surplus	0.364
20	Coal, brown, 8.0 MJ per kg, in ground	Raw	MJ surplus	0.000893
21	Coal, brown, 8.1 MJ per kg, in ground	Raw	MJ surplus	1.41
22	Coal, brown, 8.2 MJ per kg, in ground	Raw	MJ surplus	1.07
23	Copper, in ground	Raw	MJ surplus	187
24	Energy, from coal	Raw	MJ surplus	0.0647
25	Energy, from coal, brown	Raw	MJ surplus	0.0101
26	Energy, from gas, natural	Raw	MJ surplus	0.664
27	Energy, from oil	Raw	MJ surplus	0.391
28	Gas, mine, off-gas, process, coal mining/kg	Raw	MJ surplus	4.13E-5
29	Gas, natural, 35 MJ per m3, in ground	Raw	MJ surplus	0.076
30	Gas, natural, 35.0 MJ per m3, in ground	Raw	MJ surplus	0.175

31	Gas, natural, 35.9 MJ per m3, in ground	Raw	MJ surplus	63.9
32	Gas, natural, 36.6 MJ per m3, in ground	Raw	MJ surplus	3.23
33	Gas, natural, 50.3 MJ per kg, in ground	Raw	MJ surplus	95.6
34	Gas, natural, 51.3 MJ per kg, in ground	Raw	MJ surplus	33.1
35	Gas, natural, feedstock, 35 MJ per m3, in ground	Raw	MJ surplus	0.191
36	Gas, natural, feedstock, 35.0 MJ per m3, in ground	Raw	MJ surplus	0.00421
37	Gas, off-gas, 35.0 MJ per m3, oil production, in ground	Raw	MJ surplus	1.19
38	Gas, petroleum, 35 MJ per m3, in ground	Raw	MJ surplus	0.00797
39	Iron ore, in ground	Raw	MJ surplus	0.225
40	Iron, in ground	Raw	MJ surplus	0.201
41	Lead, in ground	Raw	MJ surplus	9.63
42	Manganese, in ground	Raw	MJ surplus	0.00113
43	Molybdenum, in ground	Raw	MJ surplus	4.52E-8
44	Nickel, in ground	Raw	MJ surplus	0.251
45	Oil, crude, 41.0 MJ per kg, in ground	Raw	MJ surplus	19.2
46	Oil, crude, 42.0 MJ per kg, in ground	Raw	MJ surplus	37.7
47	Oil, crude, 42.6 MJ per kg, in ground	Raw	MJ surplus	8.93
48	Oil, crude, 42.7 MJ per kg, in ground	Raw	MJ surplus	131
49	Oil, crude, 42.8 MJ per kg, in ground	Raw	MJ surplus	0.0434
50	Oil, crude, 43.4 MJ per kg, in ground	Raw	MJ surplus	23.9
51	Oil, crude, feedstock, 41 MJ per kg, in ground	Raw	MJ surplus	0.327
52	Oil, crude, in ground	Raw	MJ surplus	2.89
53	Zinc, in ground	Raw	MJ surplus	0.000156

Table 11-1D: Characterized Climate Change for the Whole PC

NO	SUBSTANCE	COMPARTMENT	UNIT	PC LIFE CYCLE
	Total		DALY	0.000434
1	Butane	Air	DALY	1.78E-9
2	Carbon dioxide	Air	DALY	0.000108
3	Carbon dioxide, biogenic	Air	DALY	3.98E-6
4	Carbon dioxide, fossil	Air	DALY	0.000265
5	Carbon monoxide	Air	DALY	3.29E-7
6	Carbon monoxide, biogenic	Air	DALY	2.31E-18
7	Carbon monoxide, fossil	Air	DALY	1.45E-10
8	Chloroform	Air	DALY	3.66E-15
9	Dinitrogen monoxide	Air	DALY	1.07E-6
10	Ethane, 1,1,1-trichloro-, HCFC-140	Air	DALY	-1.19E-9
11	Ethane, 1,1,1,2-tetrafluoro-, HFC-134a	Air	DALY	7.78E-10
12	Ethane, 1,2-dichloro-1,1,2,2-tetrafluoro-, CFC-114	Air	DALY	1.53E-12
13	Ethane, hexafluoro-, HFC-116	Air	DALY	1.1E-8
14	Methane	Air	DALY	1.12E-5
15	Methane, biogenic	Air	DALY	4.57E-8
16	Methane, bromotrifluoro-, Halon 1301	Air	DALY	-1.78E-8
17	Methane, chlorodifluoro-, HCFC-22	Air	DALY	1.74E-15
18	Methane, chlorotrifluoro-, CFC-13	Air	DALY	1.05E-9
19	Methane, dichloro-, HCC-30	Air	DALY	6.23E-10
20	Methane, dichlorodifluoro-, CFC-12	Air	DALY	1.68E-8
21	Methane, dichlorofluoro-, HCFC-21	Air	DALY	4.1E-13
22	Methane, fossil	Air	DALY	2.14E-10

23	Methane, tetrachloro-, CFC-10	Air	DALY	-3.33E-11
24	Methane, tetrafluoro-, FC-14	Air	DALY	1.63E-6
25	Methane, trichlorofluoro-, CFC-11	Air	DALY	2.79E-9
26	Sulfur hexafluoride	Air	DALY	4.25E-5

Table 11-1E: Characterization results of fossil fuels for the Whole PC

NO	SUBSTANCE	COMPARTMENT	UNIT	PC LIFE CYCLE
	Total		MJ surplus	1.51E3
1	Coal, 13.3 MJ per kg, in ground	Raw	MJ surplus	0.142
2	Coal, 18 MJ per kg, in ground	Raw	MJ surplus	6.3
3	Coal, 18.0 MJ per kg, in ground	Raw	MJ surplus	0.16
4	Coal, 18.5 MJ per kg, in ground	Raw	MJ surplus	0.245
5	Coal, 19.5 MJ per kg, in ground	Raw	MJ surplus	0.0113
6	Coal, 20.5 MJ per kg, in ground	Raw	MJ surplus	857
7	Coal, 21.5 MJ per kg, in ground	Raw	MJ surplus	1.59
8	Coal, 22.1 MJ per kg, in ground	Raw	MJ surplus	2.25
9	Coal, 22.6 MJ per kg, in ground	Raw	MJ surplus	0.0724
10	Coal, 24.0 MJ per kg, in ground	Raw	MJ surplus	-0.597
11	Coal, 28.0 MJ per kg, in ground	Raw	MJ surplus	0.193
12	Coal, 29.3 MJ per kg, in ground	Raw	MJ surplus	219
13	Coal, brown, 10 MJ per kg, in ground	Raw	MJ surplus	0.427
14	Coal, brown, 10.0 MJ per kg, in ground	Raw	MJ surplus	1.12
15	Coal, brown, 14.1 MJ per kg, in ground	Raw	MJ surplus	0.0916
16	Coal, brown, 8 MJ per	Raw	MJ surplus	0.364

	kg, in ground			
17	Coal, brown, 8.0 MJ per kg, in ground	Raw	MJ surplus	0.000893
18	Coal, brown, 8.1 MJ per kg, in ground	Raw	MJ surplus	1.41
19	Coal, brown, 8.2 MJ per kg, in ground	Raw	MJ surplus	1.07
20	Energy, from coal	Raw	MJ surplus	0.0647
21	Energy, from coal, brown	Raw	MJ surplus	0.0101
22	Energy, from gas, natural	Raw	MJ surplus	0.664
23	Energy, from oil	Raw	MJ surplus	0.391
24	Gas, mine, off-gas, process, coal mining/kg	Raw	MJ surplus	4.13E-5
25	Gas, natural, 35 MJ per m3, in ground	Raw	MJ surplus	0.076
26	Gas, natural, 35.0 MJ per m3, in ground	Raw	MJ surplus	0.175
27	Gas, natural, 35.9 MJ per m3, in ground	Raw	MJ surplus	63.9
28	Gas, natural, 36.6 MJ per m3, in ground	Raw	MJ surplus	3.23
29	Gas, natural, 50.3 MJ per kg, in ground	Raw	MJ surplus	95.6
30	Gas, natural, 51.3 MJ per kg, in ground	Raw	MJ surplus	33.1
31	Gas, natural, feedstock, 35 MJ per m3, in ground	Raw	MJ surplus	0.191
32	Gas, natural, feedstock, 35.0 MJ per m3, in ground	Raw	MJ surplus	0.00421
33	Gas, off-gas, 35.0 MJ per m3, oil production, in ground	Raw	MJ surplus	1.19
34	Gas, petroleum, 35 MJ per m3, in ground	Raw	MJ surplus	0.00797
35	Oil, crude, 41.0 MJ per kg, in ground	Raw	MJ surplus	19.2
36	Oil, crude, 42.0 MJ per kg, in ground	Raw	MJ surplus	37.7
37	Oil, crude, 42.6 MJ per kg, in ground	Raw	MJ surplus	8.93
38	Oil, crude, 42.7 MJ per kg, in ground	Raw	MJ surplus	131

39	Oil, crude, 42.8 MJ per kg, in ground	Raw	MJ surplus	0.0434
40	Oil, crude, 43.4 MJ per kg, in ground	Raw	MJ surplus	23.9
41	Oil, crude, feedstock, 41 MJ per kg, in ground	Raw	MJ surplus	0.327
42	Oil, crude, in ground	Raw	MJ surplus	2.89

Table 11-1F: Characterization results of Eco-toxicity in the Whole PC

No	**Substance**	**Compartment**	**Unit**	**PC Life Cycle**
	Total		PAF*m2yr	207
1	Copper, ion	Water	PAF*m2yr	144
2	Nickel	Air	PAF*m2yr	20.8
3	Lead	Air	PAF*m2yr	13.9
4	Chromium	Air	PAF*m2yr	6.47
5	Zinc	Air	PAF*m2yr	5.37
6	Nickel, ion	Water	PAF*m2yr	4.44
7	Copper	Air	PAF*m2yr	2.53
8	Chromium VI	Air	PAF*m2yr	1.53
9	Lead	Water	PAF*m2yr	1.34
10	Chromium	Water	PAF*m2yr	1.25
11	Metals, unspecified	Air	PAF*m2yr	1.06
12	Nickel	Soil	PAF*m2yr	1.06
13	Cadmium	Air	PAF*m2yr	0.934
14	Zinc, ion	Water	PAF*m2yr	0.648
15	Arsenic	Air	PAF*m2yr	0.594
16	Cadmium, ion	Water	PAF*m2yr	0.592
17	Mercury	Air	PAF*m2yr	0.199
18	Zinc	Soil	PAF*m2yr	0.181
19	Arsenic, ion	Water	PAF*m2yr	0.0527
20	Copper	Soil	PAF*m2yr	0.0482
21	Metallic ions, unspecified	Water	PAF*m2yr	0.0346
22	Cadmium	Soil	PAF*m2yr	0.0201
23	Arsenic	Soil	PAF*m2yr	0.00975
24	Chromium	Soil	PAF*m2yr	0.00336
25	Chromium VI	Soil	PAF*m2yr	0.00241
26	Benzo(a)pyrene	Air	PAF*m2yr	0.00137
27	Mercury	Water	PAF*m2yr	0.00129
28	Mercury	Soil	PAF*m2yr	0.00101
29	Lead	Soil	PAF*m2yr	0.000521

30	Dioxins,	Air	PAF*m2yr	0.000431
31	Chromium VI	Water	PAF*m2yr	0.000344
32	Toluene	Water	PAF*m2yr	0.000123
33	Chromium, ion	Water	PAF*m2yr	7.42E-5
34	Benzene	Air	PAF*m2yr	3.4E-5
35	Benzene	Water	PAF*m2yr	2.95E-5
36	Toluene	Air	PAF*m2yr	1.24E-5
37	Fluoranthene	Air	PAF*m2yr	7.5E-7
38	PAH, polycyclic aromatic hydrocarbons	Air	PAF*m2yr	5.06E-7
39	PAH, polycyclic aromatic hydrocarbons	Water	PAF*m2yr	1.73E-7
40	Benzene, hexachloro-	Air	PAF*m2yr	6.87E-12
41	Phthalate, dioctyl-	Water	PAF*m2yr	4.14E-12
42	Phenol, pentachloro-	Air	PAF*m2yr	1.01E-12
43	Benzene, hexachloro-	Water	PAF*m2yr	0
44	DNOC	Water	PAF*m2yr	-1.65E-9
45	Fluoranthene	Water	PAF*m2yr	-6.09E-8
46	Benzo(a)pyrene	Water	PAF*m2yr	-8.43E-8
47	Phenol, pentachloro-	Water	PAF*m2yr	-1.27E-7
48	Heavy metals, unspecified	Air	PAF*m2yr	-2.3E-6

Table 11-1G: Characterization results for Acidification/Eutrophication in the PC system

NO	SUBSTANCE	COMPARTMENT	UNIT	PC LIFE CYCLE
	Total		PDF*m2yr	63.5
1	Nitrogen oxides	Air	PDF*m2yr	43.8
2	Sulfur dioxide	Air	PDF*m2yr	10.7
3	Sulfur oxides	Air	PDF*m2yr	8.54
4	Nitrogen dioxide	Air	PDF*m2yr	0.368
5	Ammonia	Air	PDF*m2yr	0.0678
6	Nitric oxide	Air	PDF*m2yr	0.0142

Table 11-1H: Characterization of consumption of mineral resources

NO	SUBSTANCE	COMPARTMENT	UNIT	PC LIFE CYCLE
	Total		MJ surplus	200
1	Aluminium, in ground	Raw	MJ surplus	2.02
2	Bauxite, in ground	Raw	MJ surplus	0.862
3	Chromium, in ground	Raw	MJ surplus	0.0497

4	Copper, in ground	Raw	MJ surplus	187
5	Iron ore, in ground	Raw	MJ surplus	0.225
6	Iron, in ground	Raw	MJ surplus	0.201
7	Lead, in ground	Raw	MJ surplus	9.63
8	Manganese, in ground	Raw	MJ surplus	0.00113
9	Molybdenum, in ground	Raw	MJ surplus	4.52E-8
10	Nickel, in ground	Raw	MJ surplus	0.251
11	Zinc, in ground	Raw	MJ surplus	0.000156

Table 11-1I: Characterization of respiratory effects (in-organics)

NO	SUBSTANCE	COMPARTMENT	UNIT	PC LIFE CYCLE
	Total		DALY	0.00185
1	Nitrogen oxides	Air	DALY	0.000683
2	Sulfur dioxide	Air	DALY	0.000562
3	Sulfur oxides	Air	DALY	0.000448
4	Particulates, < 10 um	Air	DALY	0.000136
5	Particulates	Air	DALY	7.4E-6
6	Nitrogen dioxide	Air	DALY	5.74E-6
7	Particulates, SPM	Air	DALY	3.62E-6
8	Carbon monoxide	Air	DALY	7.46E-7
9	Particulates, < 2.5 um	Air	DALY	4.74E-7
10	Ammonia	Air	DALY	3.7E-7
11	Nitric oxide	Air	DALY	2.21E-7
12	Particulates, > 2.5 um, and < 10um	Air	DALY	1.34E-7
13	Particulates, < 10 um (mobile)	Air	DALY	4.54E-8
14	Particulates, < 10 um (stationary)	Air	DALY	2.93E-9
15	Carbon monoxide, fossil	Air	DALY	3.3E-10
16	Carbon monoxide, biogenic	Air	DALY	5.24E-18

Table 11-1J: Characterized environmental impacts of a PC per impact category

IMPACT CATEGORY	UNIT	PC LIFE CYCLE
Carcinogens	DALY	4.4E-5
Respiratory organics	DALY	9.48E-7
Respiratory inorganics	DALY	0.00185
Climate change	DALY	0.000434
Radiation	DALY	1.35E-10
Ozone layer	DALY	5.92E-8
Ecotoxicity	PAF*m2yr	207
Acidification/ Eutrophication	PDF*m2yr	63.5
Land use	PDF*m2yr	17.7
Minerals	MJ surplus	200
Fossil fuels	MJ surplus	1.51E3

Table 11-1K: Normalization of environmental load of a PC per impact category

IMPACT CATEGORY	UNIT	PC LIFE CYCLE
Carcinogens		0.00284
Respiratory organics		6.13E-5
Respiratory inorganics		0.12
Climate change		0.0281
Radiation		8.71E-9
Ozone layer		3.83E-6
Ecotoxicity		0.00404
Acidification/ Eutrophication		0.0124
Land use		0.00346
Minerals		0.0336
Fossil fuels		0.254

Table 11-1L: Weighted environmental load of a PC per impact category

IMPACT CATEGORY	UNIT	PC LIFE CYCLE
Total	Pt	113
Carcinogens	Pt	0.853
Respiratory organics	Pt	0.0184
Respiratory in-organics	Pt	35.9
Climate change	Pt	8.43
Radiation	Pt	2.61E-6
Ozone layer	Pt	0.00115
Eco-toxicity	Pt	2.02
Acidification/ Eutrophication	Pt	6.19
Land use	Pt	1.73

Minerals	Pt	6.73
Fossil fuels	Pt	50.9

Table 11-1M: Damage Assessment Results of the Whole PC

DAMAGE CATEGORY	UNIT	PC LIFE CYCLE
Human Health	DALY	0.00233
Ecosystem Quality	PDF*m2yr	102
Resources	MJ surplus	1.71E3

Table 11-1N: Normalized Damage Assessment of the PC system

DAMAGE CATEGORY	UNIT	PC LIFE CYCLE
Human Health		0.151
Ecosystem Quality		0.0199
Resources		0.288

Table 11-1O: Weighting of Damage Assessment Results of the PC

DAMAGE CATEGORY	UNIT	PC LIFE CYCLE
Total	Pt	113
Human Health	Pt	45.2
Ecosystem Quality	Pt	9.94
Resources	Pt	57.6

11.2 Control Unit

The following tables show the inventory results of the control unit including packaging.

Table 11-2A: Damage Assessment to Ecosystem Quality

NO	SUBSTANCE	COMPARTMENT	UNIT	CONTROL UNIT LIFE CYCLE
	Total		PDF*m2yr	40.6
1	Occupation, arable	Raw	PDF*m2yr	1.33
2	Occupation, construction site	Raw	PDF*m2yr	0.0046
3	Occupation, forest	Raw	PDF*m2yr	-0.0752
4	Occupation, industrial area	Raw	PDF*m2yr	0.283
5	Occupation, industrial area, vegetation	Raw	PDF*m2yr	0.127

6	Occupation, mineral extraction site	Raw	PDF*m2yr	0.00265
7	Occupation, traffic area	Raw	PDF*m2yr	0.986
8	Occupation, urban, continuously built	Raw	PDF*m2yr	0.149
9	Occupation, urban, green areas	Raw	PDF*m2yr	0.00319
10	Transformation, from forest, intensive, clear-cutting	Raw	PDF*m2yr	-0.775
11	Transformation, from mineral extraction site	Raw	PDF*m2yr	-0.0026
12	Transformation, from unknown	Raw	PDF*m2yr	-2.97
13	Transformation, to arable	Raw	PDF*m2yr	3.33
14	Transformation, to industrial area	Raw	PDF*m2yr	0.845
15	Transformation, to industrial area, vegetation	Raw	PDF*m2yr	0.127
16	Transformation, to mineral extraction site	Raw	PDF*m2yr	0.0026
17	Transformation, to shrub land, sclerophyllous	Raw	PDF*m2yr	0.000341
18	Transformation, to urban, continuously built	Raw	PDF*m2yr	1.68
19	Transformation, to water bodies, artificial	Raw	PDF*m2yr	0.00109
20	Ammonia	Air	PDF*m2yr	0.0391
21	Arsenic	Air	PDF*m2yr	0.0209
22	Benzene	Air	PDF*m2yr	2.35E-6
23	Benzo(a)pyrene	Air	PDF*m2yr	0.000119
24	Cadmium	Air	PDF*m2yr	0.0436
25	Chromium	Air	PDF*m2yr	0.247
26	Chromium VI	Air	PDF*m2yr	0.0437
27	Copper	Air	PDF*m2yr	0.154
28	Fluoranthene	Air	PDF*m2yr	6.95E-8
29	Lead	Air	PDF*m2yr	0.322
30	Mercury	Air	PDF*m2yr	0.00848
31	Metals, unspecified	Air	PDF*m2yr	0.0565
32	Nickel	Air	PDF*m2yr	1.17
33	Nitric oxide	Air	PDF*m2yr	0.0102

34	Nitrogen dioxide	Air	PDF*m2yr	0.292
35	Nitrogen oxides	Air	PDF*m2yr	15.5
36	PAH, polycyclic aromatic hydrocarbons	Air	PDF*m2yr	3.17E-8
37	Sulfur dioxide	Air	PDF*m2yr	5.05
38	Sulfur oxides	Air	PDF*m2yr	2.52
39	Toluene	Air	PDF*m2yr	1E-6
40	Zinc	Air	PDF*m2yr	0.293
41	Arsenic, ion	Water	PDF*m2yr	0.00394
42	Benzene	Water	PDF*m2yr	2.3E-6
43	Benzo(a)pyrene	Water	PDF*m2yr	4.33E-12
44	Cadmium, ion	Water	PDF*m2yr	0.0387
45	Chromium	Water	PDF*m2yr	0.0985
46	Chromium VI	Water	PDF*m2yr	2.21E-5
47	Chromium, ion	Water	PDF*m2yr	1.3E-6
48	Copper, ion	Water	PDF*m2yr	9.18
49	Lead	Water	PDF*m2yr	0.0864
50	Metallic ions, unspecified	Water	PDF*m2yr	0.00114
51	Nickel, ion	Water	PDF*m2yr	0.303
52	Zinc, ion	Water	PDF*m2yr	0.0456
53	Arsenic	Soil	PDF*m2yr	0.000187
54	Cadmium	Soil	PDF*m2yr	0.000393
55	Chromium	Soil	PDF*m2yr	8.02E-5
56	Chromium VI	Soil	PDF*m2yr	4.64E-5
57	Copper	Soil	PDF*m2yr	0.000943
58	Lead	Soil	PDF*m2yr	1.01E-5
59	Mercury	Soil	PDF*m2yr	1.95E-5
60	Nickel	Soil	PDF*m2yr	0.0203

Table 11-2B: Damage Assessment to Human Health

NO	SUBSTANCE	COMPARTMENT	UNIT	CONTROL UNIT LIFE CYCLE
	Total		DALY	0.000911
1	2-Propanol	Air	DALY	5.14E-10
2	Acetaldehyde	Air	DALY	5.89E-11
3	Acetic acid	Air	DALY	8.43E-11
4	Acetone	Air	DALY	6.01E-9
5	Acrolein	Air	DALY	3.62E-14
6	Acrylonitrile	Air	DALY	1.94E-10
7	Alcohols, unspecified	Air	DALY	9.2E-8
8	Aldehyde, unspecified	Air	DALY	3.9E-10
9	Arsenic	Air	DALY	8.7E-7
10	Benzaldehde	Air	DALY	1.02E-14

11	Benzene	Air	DALY	2.54E-9
12	Benzene, ethyl-	Air	DALY	4.16E-10
13	Benzo(a)pyrene	Air	DALY	3.34E-9
14	Butane	Air	DALY	3.08E-9
15	Butene	Air	DALY	2.63E-11
16	Cadmium	Air	DALY	6.09E-7
17	Carbon dioxide	Air	DALY	7.19E-5
18	Carbon dioxide, biogenic	Air	DALY	-4.53E-8
19	Carbon dioxide, fossil	Air	DALY	7.37E-5
20	Carbon monoxide	Air	DALY	3.31E-7
21	Carbon monoxide, biogenic	Air	DALY	9.52E-20
22	Carbon monoxide, fossil	Air	DALY	8.8E-11
23	Chloroform	Air	DALY	1.57E-14
24	Chromium VI	Air	DALY	6.18E-8
25	Cumene	Air	DALY	1.76E-12
26	Cyclohexane	Air	DALY	3.72E-12
27	Dinitrogen monoxide	Air	DALY	3.74E-7
28	Dioxins	Air	DALY	5.38E-8
29	Ethane	Air	DALY	2.08E-9
30	Ethane	Air	DALY	1.95E-9
31	Ethane, HFC-134a	Air	DALY	1.72E-10
32	Ethane, 1,2-dichloro-	Air	DALY	6.27E-10
33	Ethane, hexafluoro-, HFC-116	Air	DALY	9.62E-9
34	Ethanol	Air	DALY	9.13E-10
35	Ethene	Air	DALY	6.19E-10
36	Ethene, chloro-	Air	DALY	3.17E-12
37	Ethene, tetrachloro-	Air	DALY	2.33E-16
38	Ethyne	Air	DALY	1.97E-12
39	Fluorine	Air	DALY	5.89E-11
40	Formaldehyde	Air	DALY	4.01E-9
41	Heptane	Air	DALY	1.18E-10
42	Hexane	Air	DALY	2.79E-10
43	Hydrocarbons	Air	DALY	3.86E-10
44	Metals, unspecified	Air	DALY	1.54E-7
45	Methane	Air	DALY	6.04E-6
46	Methane, biogenic	Air	DALY	9.4E-9
47	Methane, bromotrifluoro-, Halon 1301	Air	DALY	9.05E-9
48	Methane, chlorotrifluoro-, CFC-	Air	DALY	1.23E-9

	13			
49	Methane, dichloro-, HCC-30	Air	DALY	5.35E-10
50	Methane, dichlorodifluoro-, CFC-12	Air	DALY	2.38E-9
51	Methane, fossil	Air	DALY	4.24E-11
52	Methane, tetrachloro-, CFC-10	Air	DALY	2.05E-10
53	Methane, tetrafluoro-, FC-14	Air	DALY	1.43E-6
54	Methane, trichlorofluoro-, CFC-11	Air	DALY	1.31E-9
55	Methanol	Air	DALY	2E-11
56	Methyl ethyl ketone	Air	DALY	3.13E-15
57	Nickel	Air	DALY	7.09E-9
58	Nitric oxide	Air	DALY	1.59E-7
59	Nitrogen dioxide	Air	DALY	4.56E-6
60	Nitrogen oxides	Air	DALY	0.000242
61	NMVOC, unspecified origin	Air	DALY	1.05E-7
62	o-Xylene	Air	DALY	2.68E-14
63	PAH, polycyclic aromatic hydrocarbons	Air	DALY	6.99E-9
64	Particulates	Air	DALY	4.51E-6
65	Particulates, < 10 um	Air	DALY	3.84E-5
66	Particulates, < 2.5 um	Air	DALY	9.82E-8
67	Styrene	Air	DALY	1.95E-15
68	Sulfur dioxide	Air	DALY	0.000265
69	Sulfur hexafluoride	Air	DALY	3.71E-5
70	Sulfur oxides	Air	DALY	0.000132
71	Toluene	Air	DALY	5.67E-9
72	VOC, volatile organic compounds	Air	DALY	3.4E-8
73	Xylene	Air	DALY	2.54E-9
74	Acrylonitrile	Water	DALY	5.59E-17
75	Arsenic, ion	Water	DALY	2.27E-5
76	Benzene	Water	DALY	1.98E-10
77	Benzo(a)anthracene	Water	DALY	1.33E-13
78	Benzo(a)pyrene	Water	DALY	3.52E-13
79	Cadmium, ion	Water	DALY	5.74E-6
80	Chloroform	Water	DALY	4.87E-18
81	Chromium VI	Water	DALY	2.66E-16
82	Ethane, 1,1,2-trichloro-	Water	DALY	7.28E-22

83	Ethane, 1,2-dichloro-	Water	DALY	2.58E-12
84	Ethene, chloro-	Water	DALY	9.1E-15
85	Ethene, trichloro-	Water	DALY	5.8E-15
86	Formaldehyde	Water	DALY	6.59E-14
87	Metallic ions, unspecified	Water	DALY	1.36E-7
88	Methane, dichloro-, HCC-30	Water	DALY	4.47E-13
89	Nickel, ion	Water	DALY	1.46E-13
90	PAH, polycyclic aromatic hydrocarbons	Water	DALY	1.44E-8

Table 11-2C: Damage Assessment to Resources

No	Substance	Compartment	Unit	Control unit life cycle
1	Total		MJ surplus	736
2	Aluminum, in ground	Raw	MJ surplus	1.28
3	Bauxite, in ground	Raw	MJ surplus	0.816
4	Chromium, in ground	Raw	MJ surplus	0.00175
5	Coal, 13.3 MJ per kg, in ground	Raw	MJ surplus	0.0261
6	Coal, 18 MJ per kg, in ground	Raw	MJ surplus	4.71
7	Coal, 18.0 MJ per kg, in ground	Raw	MJ surplus	0.0956
8	Coal, 18.5 MJ per kg, in ground	Raw	MJ surplus	0.0746
9	Coal, 19.5 MJ per kg, in ground	Raw	MJ surplus	0.0112
10	Coal, 20.5 MJ per kg, in ground	Raw	MJ surplus	245
11	Coal, 21.5 MJ per kg, in ground	Raw	MJ surplus	0.314
12	Coal, 22.1 MJ per kg, in ground	Raw	MJ surplus	2.25
13	Coal, 22.6 MJ per kg, in ground	Raw	MJ surplus	0.0575
14	Coal, 24.0 MJ per kg, in ground	Raw	MJ surplus	-0.948
15	Coal, 28.0 MJ per kg, in ground	Raw	MJ surplus	0.0162
16	Coal, 29.3 MJ per kg, in ground	Raw	MJ surplus	170
17	Coal, brown, 10.0 MJ	Raw	MJ surplus	1.12

	per kg, in ground			
18	Coal, brown, 14.1 MJ per kg, in ground	Raw	MJ surplus	0.0907
19	Coal, brown, 8 MJ per kg, in ground	Raw	MJ surplus	0.218
20	Coal, brown, 8.0 MJ per kg, in ground	Raw	MJ surplus	0.000534
21	Coal, brown, 8.1 MJ per kg, in ground	Raw	MJ surplus	0.271
22	Coal, brown, 8.2 MJ per kg, in ground	Raw	MJ surplus	1.06
23	Copper, in ground	Raw	MJ surplus	104
24	Energy, from coal	Raw	MJ surplus	0.0109
25	Energy, from coal, brown	Raw	MJ surplus	0.00173
26	Energy, from gas, natural	Raw	MJ surplus	0.114
27	Energy, from oil	Raw	MJ surplus	0.0669
28	Gas, natural, 35 MJ per m3, in ground	Raw	MJ surplus	0.017
29	Gas, natural, 35.0 MJ per m3, in ground	Raw	MJ surplus	0.118
30	Gas, natural, 35.9 MJ per m3, in ground	Raw	MJ surplus	1.05
31	Gas, natural, 36.6 MJ per m3, in ground	Raw	MJ surplus	2.28
32	Gas, natural, 50.3 MJ per kg, in ground	Raw	MJ surplus	94.1
33	Gas, natural, 51.3 MJ per kg, in ground	Raw	MJ surplus	1.19
34	Gas, natural, feedstock, 35 MJ per m3, in ground	Raw	MJ surplus	0.16
35	Gas, natural, feedstock, 35.0 MJ per m3, in ground	Raw	MJ surplus	0.00421
36	Gas, off-gas, 35.0 MJ per m3, oil production, in ground	Raw	MJ surplus	0.934
37	Iron ore, in ground	Raw	MJ surplus	0.18
38	Iron, in ground	Raw	MJ surplus	0.177
39	Lead, in ground	Raw	MJ surplus	0.325
40	Manganese, in ground	Raw	MJ surplus	0.000272
41	Molybdenum, in ground	Raw	MJ surplus	2.94E-8

42	Nickel, in ground	Raw	MJ surplus	0.0209
43	Oil, crude, 41.0 MJ per kg, in ground	Raw	MJ surplus	18.7
44	Oil, crude, 42.0 MJ per kg, in ground	Raw	MJ surplus	7.06
45	Oil, crude, 42.6 MJ per kg, in ground	Raw	MJ surplus	2.32
46	Oil, crude, 42.7 MJ per kg, in ground	Raw	MJ surplus	72.4
47	Oil, crude, 42.8 MJ per kg, in ground	Raw	MJ surplus	0.00463
48	Oil, crude, 43.4 MJ per kg, in ground	Raw	MJ surplus	4.48
49	Oil, crude, feedstock, 41 MJ per kg, in ground	Raw	MJ surplus	0.287
50	Oil, crude, in ground	Raw	MJ surplus	0.0026

Table 11-2D: Characterized Climate Change, the Control Unit

No	Substance	Compartment	Unit	Control unit life cycle
	Total		DALY	0.000191
1	Carbon dioxide, fossil	Air	DALY	7.37E-5
2	Carbon dioxide	Air	DALY	7.19E-5
3	Sulfur hexafluoride	Air	DALY	3.71E-5
4	Methane	Air	DALY	6.02E-6
5	Methane, tetrafluoro-, FC-14	Air	DALY	1.43E-6
6	Dinitrogen monoxide	Air	DALY	3.74E-7
7	Carbon monoxide	Air	DALY	1.01E-7
8	Ethane, hexafluoro-, HFC-116	Air	DALY	9.62E-9
9	Methane, biogenic	Air	DALY	9.38E-9
10	Propane	Air	DALY	1.93E-9
11	Methane, dichlorodifluoro-, CFC-12	Air	DALY	1.47E-9
12	Butane	Air	DALY	1.4E-9
13	Methane, chlorotrifluoro-, CFC-13	Air	DALY	9.18E-10
14	Methane, dichloro-, HCC-30	Air	DALY	4.1E-10

15	Methane, trichlorofluoro-, CFC-11	Air	DALY	2.27E-10
16	Ethane, 1,1,1,2-tetrafluoro-, HFC-134a	Air	DALY	1.72E-10
17	Methane, fossil	Air	DALY	4.23E-11
18	Carbon monoxide, fossil	Air	DALY	2.69E-11
19	Chloroform	Air	DALY	4.85E-16
20	Carbon monoxide, biogenic	Air	DALY	2.91E-20
21	Methane, tetrachloro-, CFC-10	Air	DALY	-2.9E-11
22	Ethane, 1,1,1-trichloro-, HCFC-140	Air	DALY	-1.01E-9
23	Methane, bromotrifluoro-, Halon 1301	Air	DALY	-1.17E-8
24	Carbon dioxide, biogenic	Air	DALY	-4.53E-8

Table 11-2E: Characterized Fossil Fuels, Control Unit

No	Substance	Compartment	Unit	Control unit life cycle
	Total		MJ surplus	629
1	Coal, 20.5 MJ per kg, in ground	Raw	MJ surplus	245
2	Coal, 29.3 MJ per kg, in ground	Raw	MJ surplus	170
3	Gas, natural, 50.3 MJ per kg, in ground	Raw	MJ surplus	94.1
4	Oil, crude, 42.7 MJ per kg, in ground	Raw	MJ surplus	72.4
5	Oil, crude, 41.0 MJ per kg, in ground	Raw	MJ surplus	18.7
6	Oil, crude, 42.0 MJ per kg, in ground	Raw	MJ surplus	7.06
7	Coal, 18 MJ per kg, in ground	Raw	MJ surplus	4.71
8	Oil, crude, 43.4 MJ per kg, in ground	Raw	MJ surplus	4.48
9	Oil, crude, 42.6 MJ per kg, in ground	Raw	MJ surplus	2.32
10	Gas, natural, 36.6 MJ	Raw	MJ surplus	2.28

	per m3, in ground			
11	Coal, 22.1 MJ per kg, in ground	Raw	MJ surplus	2.25
12	Gas, natural, 51.3 MJ per kg, in ground	Raw	MJ surplus	1.19
13	Coal, brown, 10.0 MJ per kg, in ground	Raw	MJ surplus	1.12
14	Coal, brown, 8.2 MJ per kg, in ground	Raw	MJ surplus	1.06
15	Gas, natural, 35.9 MJ per m3, in ground	Raw	MJ surplus	1.05
16	Gas, off-gas, 35.0 MJ per m3, oil production, in ground	Raw	MJ surplus	0.934
17	Coal, 21.5 MJ per kg, in ground	Raw	MJ surplus	0.314
18	Oil, crude, feedstock, 41 MJ per kg, in ground	Raw	MJ surplus	0.287
19	Coal, brown, 8.1 MJ per kg, in ground	Raw	MJ surplus	0.271
20	Coal, brown, 8 MJ per kg, in ground	Raw	MJ surplus	0.218
21	Gas, natural, feedstock, 35 MJ per m3, in ground	Raw	MJ surplus	0.16
22	Gas, natural, 35.0 MJ per m3, in ground	Raw	MJ surplus	0.118
23	Energy, from gas, natural	Raw	MJ surplus	0.114
24	Coal, 18.0 MJ per kg, in ground	Raw	MJ surplus	0.0956
25	Coal, brown, 14.1 MJ per kg, in ground	Raw	MJ surplus	0.0907
26	Coal, 18.5 MJ per kg, in ground	Raw	MJ surplus	0.0746
27	Energy, from oil	Raw	MJ surplus	0.0669
28	Coal, 22.6 MJ per kg, in ground	Raw	MJ surplus	0.0575
29	Coal, 13.3 MJ per kg, in ground	Raw	MJ surplus	0.0261
30	Gas, natural, 35 MJ per m3, in ground	Raw	MJ surplus	0.017
31	Coal, 28.0 MJ per kg, in ground	Raw	MJ surplus	0.0162
32	Coal, 19.5 MJ per kg,	Raw	MJ surplus	0.0112

	in ground			
33	Energy, from coal	Raw	MJ surplus	0.0109
34	Oil, crude, 42.8 MJ per kg, in ground	Raw	MJ surplus	0.00463
35	Gas, natural, feedstock, 35.0 MJ per m3, in ground	Raw	MJ surplus	0.00421
36	Oil, crude, in ground	Raw	MJ surplus	0.0026
37	Energy, from coal, brown	Raw	MJ surplus	0.00173
38	Coal, brown, 8.0 MJ per kg, in ground	Raw	MJ surplus	0.000534
39	Coal, 24.0 MJ per kg, in ground	Raw	MJ surplus	-0.948

Table 11-2F: Characterization of Mineral resources, Control Unit

No	Substance	Compartment	Unit	Control unit life cycle
	Total		MJ surplus	107
1	Copper, in ground	Raw	MJ surplus	104
2	Aluminum, in ground	Raw	MJ surplus	1.28
3	Bauxite, in ground	Raw	MJ surplus	0.816
4	Lead, in ground	Raw	MJ surplus	0.325
5	Iron ore, in ground	Raw	MJ surplus	0.18
6	Iron, in ground	Raw	MJ surplus	0.177
7	Nickel, in ground	Raw	MJ surplus	0.0209
8	Tin, in ground	Raw	MJ surplus	0.0061
9	Chromium, in ground	Raw	MJ surplus	0.00175
10	Manganese, in ground	Raw	MJ surplus	0.000272
11	Zinc, in ground	Raw	MJ surplus	0.000123
12	Molybdenum, in ground	Raw	MJ surplus	2.94E-8

Table 11-2G: Characterized Respiratory Effects (in-organics) – Control Unit

No	Substance	Compartment	Unit	Control unit life cycle
	Total		DALY	0.00069
1	Sulfur dioxide	Air	DALY	0.000265
2	Nitrogen oxides	Air	DALY	0.000242
3	Sulfur oxides	Air	DALY	0.000132
4	Particulates, < 10 um	Air	DALY	3.84E-5
5	Nitrogen dioxide	Air	DALY	4.56E-6

6	Particulates	Air	DALY	4.51E-6
7	Particulates, SPM	Air	DALY	2.37E-6
8	Carbon monoxide	Air	DALY	2.3E-7
9	Ammonia	Air	DALY	2.13E-7
10	Nitric oxide	Air	DALY	1.59E-7
11	Particulates, < 2.5 um	Air	DALY	9.82E-8
12	Particulates, > 2.5 um, and < 10um	Air	DALY	2.65E-8
13	Carbon monoxide, fossil	Air	DALY	6.11E-11
14	Carbon monoxide, biogenic	Air	DALY	6.61E-20

Table 11-2H: Characterized Environmental Load - Control Unit

IMPACT CATEGORY	UNIT	CONTROL UNIT LIFE CYCLE
Carcinogens	DALY	3.04E-5
Respiratory organics	DALY	5.08E-7
Respiratory in-organics	DALY	0.00069
Climate change	DALY	0.000191
Radiation	DALY	x
Ozone layer	DALY	2.61E-8
Eco-toxicity	PAF*m2yr	121
Acidification/ Eutrophication	PDF*m2yr	23.4
Land use	PDF*m2yr	5.05
Minerals	MJ surplus	107
Fossil fuels	MJ surplus	629

Table 11-2I: Normalized Environmental Load per Impact Category - Control Unit

IMPACT CATEGORY	UNIT	CONTROL UNIT LIFE CYCLE
Carcinogens		0.00197
Respiratory organics		3.29E-5
Respiratory in-organics		0.0446
Climate change		0.0123
Radiation		x
Ozone layer		1.69E-6
Eco-toxicity		0.00237
Acidification/ Eutrophication		0.00457
Land use		0.000984
Minerals		0.018
Fossil fuels		0.106

Table 11-2J: Weighted Environmental Load per Impact Category - Control Unit

IMPACT CATEGORY	UNIT	CONTROL UNIT LIFE CYCLE
Total	Pt	46.4
Carcinogens	Pt	0.59
Respiratory organics	Pt	0.00987
Respiratory in-organics	Pt	13.4
Climate change	Pt	3.7
Radiation	Pt	x
Ozone layer	Pt	0.000507
Eco-toxicity	Pt	1.18
Acidification/ Eutrophication	Pt	2.28
Land use	Pt	0.492
Minerals	Pt	3.6
Fossil fuels	Pt	21.1

Table 11-2K: Damage Assessment Results for the Control Unit

DAMAGE CATEGORY	UNIT	CONTROL UNIT LIFE CYCLE
Human Health	DALY	0.000911
Ecosystem Quality	PDF*m2yr	40.6
Resources	MJ surplus	736

Table 11-2L: Normalized Damage Assessment for the Control Unit

DAMAGE CATEGORY	UNIT	CONTROL UNIT LIFE CYCLE
Human Health		0.0589
Ecosystem Quality		0.00792
Resources		0.124

Table 11-2M: Weighting of Damage Assessment for the Control Unit

DAMAGE CATEGORY	UNIT	CONTROL UNIT LIFE CYCLE
Total	Pt	46.4
Human Health	Pt	17.7
Ecosystem Quality	Pt	3.96
Resources	Pt	24.7

11.3 CRT Monitor

Table 11-3A to 11-3P show the results obtained from the inventory results of the CRT monitor.

Table 11-3A: Damage Assessment to Ecosystem Quality

NO	SUBSTANCE	COMPARTMENT	UNIT	CRT MONITOR LIFE CYCLE
	Total		PDF*m2yr	56.9
1	Occupation, arable	Raw	PDF*m2yr	0.73
2	Occupation, construction site	Raw	PDF*m2yr	0.0123
3	Occupation, forest	Raw	PDF*m2yr	-0.0606
4	Occupation, industrial area	Raw	PDF*m2yr	0.248
5	Occupation, industrial area, vegetation	Raw	PDF*m2yr	0.339
6	Occupation, mineral extraction site	Raw	PDF*m2yr	0.00709
7	Occupation, traffic area	Raw	PDF*m2yr	3.68
8	Occupation, urban, continuously built	Raw	PDF*m2yr	0.0626
9	Occupation, urban, green areas	Raw	PDF*m2yr	0.0107
10	Transformation, from forest, intensive, clear-cutting	Raw	PDF*m2yr	0.474
11	Transformation, from mineral extraction site	Raw	PDF*m2yr	-0.00696
12	Transformation, from unknown	Raw	PDF*m2yr	-2.8
13	Transformation, to arable	Raw	PDF*m2yr	2.68
14	Transformation, to industrial area	Raw	PDF*m2yr	0.805
15	Transformation, to industrial area, vegetation	Raw	PDF*m2yr	0.339
16	Transformation, to mineral extraction site	Raw	PDF*m2yr	0.00696
17	Transformation, to shrub land, sclerophyllous	Raw	PDF*m2yr	0.000912
18	Transformation, to urban, continuously built	Raw	PDF*m2yr	1.48
19	Transformation, to water bodies, artificial	Raw	PDF*m2yr	0.0622
20	Ammonia	Air	PDF*m2yr	0.0277

21	Arsenic	Air	PDF*m2yr	0.0409
22	Benzene	Air	PDF*m2yr	9.15E-7
23	Benzene, hexachloro-	Air	PDF*m2yr	6.87E-13
24	Benzo(a)pyrene	Air	PDF*m2yr	1.75E-5
25	Cadmium	Air	PDF*m2yr	0.0514
26	Chromium	Air	PDF*m2yr	0.424
27	Chromium-51	Air	PDF*m2yr	-
28	Chromium VI	Air	PDF*m2yr	0.117
29	Copper	Air	PDF*m2yr	0.0995
30	Dioxins, measured as 2,3,7,8-tetrachlorodibenzo-p-dioxin	Air	PDF*m2yr	3.43E-6
31	Fluoranthene	Air	PDF*m2yr	5.52E-9
32	Heavy metals, unspecified	Air	PDF*m2yr	-2.9E-8
33	Lead	Air	PDF*m2yr	1.07
34	Mercury	Air	PDF*m2yr	0.012
35	Metals, unspecified	Air	PDF*m2yr	0.0422
36	Nickel	Air	PDF*m2yr	0.929
37	Niobium-95	Air	PDF*m2yr	-
38	Nitric oxide	Air	PDF*m2yr	0.00389
39	Nitrogen dioxide	Air	PDF*m2yr	0.0732
40	Nitrogen oxides	Air	PDF*m2yr	28.2
41	Sulfur dioxide	Air	PDF*m2yr	5.74
42	Sulfur oxides	Air	PDF*m2yr	6.37
43	Zinc	Air	PDF*m2yr	0.251
44	Arsenic, ion	Water	PDF*m2yr	0.00128
45	Benzene	Water	PDF*m2yr	6.25E-7
46	Cadmium, ion	Water	PDF*m2yr	0.0197
47	Chromium	Water	PDF*m2yr	0.0255
48	Chromium VI	Water	PDF*m2yr	7.83E-6
49	Chromium, ion	Water	PDF*m2yr	5.69E-6
50	Copper, ion	Water	PDF*m2yr	5
51	DNOC	Water	PDF*m2yr	-1.65E-10
52	Lead	Water	PDF*m2yr	0.0458
53	Mercury	Water	PDF*m2yr	4.66E-5
54	Metallic ions, unspecified	Water	PDF*m2yr	0.00192
55	Nickel, ion	Water	PDF*m2yr	0.136
56	PAH, polycyclic aromatic hydrocarbons	Water	PDF*m2yr	5.14E-9
57	Phenol, pentachloro-	Water	PDF*m2yr	-1.27E-8
58	Phthalate, dioctyl-	Water	PDF*m2yr	4.14E-13
59	Toluene	Water	PDF*m2yr	3.63E-6
60	Zinc, ion	Water	PDF*m2yr	0.0185
61	Arsenic	Soil	PDF*m2yr	0.000608
62	Cadmium	Soil	PDF*m2yr	0.00125

63	Chromium	Soil	PDF*m2yr	0.000229
64	Chromium VI	Soil	PDF*m2yr	0.00015
65	Copper	Soil	PDF*m2yr	0.00301
66	Lead	Soil	PDF*m2yr	3.25E-5
67	Mercury	Soil	PDF*m2yr	6.31E-5
68	Nickel	Soil	PDF*m2yr	0.0658
69	Zinc	Soil	PDF*m2yr	0.0114

Table 11-3B: Damage Assessment to Human Health

NO	SUBSTANCE	COMPARTMENT	UNIT	CRT MONITOR LIFE CYCLE
	Total		DALY	0.00144
1	2-Propanol	Air	DALY	7.44E-11
2	Acetaldehyde	Air	DALY	1.57E-11
3	Acetic acid	Air	DALY	2.24E-11
4	Acetone	Air	DALY	8.71E-10
5	Acrolein	Air	DALY	9.72E-15
6	Acrylonitrile	Air	DALY	2.14E-9
7	Alcohols, unspecified	Air	DALY	1.33E-8
8	Aldehyde, unspecified	Air	DALY	2.19E-10
9	Ammonia	Air	DALY	1.51E-7
10	Arsenic	Air	DALY	1.7E-6
11	Benzaldehde	Air	DALY	2.72E-15
12	Benzene	Air	DALY	9.88E-10
13	Benzene, ethyl-	Air	DALY	1.32E-10
14	Benzene, hexachloro-	Air	DALY	1.46E-15
15	Benzene, pentachloro-	Air	DALY	9.91E-20
16	Benzo(a)pyrene	Air	DALY	4.91E-10
17	Butane	Air	DALY	8.22E-10
18	Butene	Air	DALY	7.26E-12
19	Cadmium	Air	DALY	7.19E-7
20	Carbon-14	Air	DALY	1.37E-11
21	Carbon dioxide	Air	DALY	3.26E-5
22	Carbon dioxide, biogenic	Air	DALY	-5.64E-8
23	Carbon dioxide, fossil	Air	DALY	0.000197
24	Carbon monoxide	Air	DALY	3.38E-7
25	Carbon monoxide, biogenic	Air	DALY	2.82E-19
26	Carbon monoxide, fossil	Air	DALY	3.3E-10
27	Cesium-134	Air	DALY	2.94E-16
28	Cesium-137	Air	DALY	6.24E-16
29	Chloroform	Air	DALY	9.13E-14

30	Chromium VI	Air	DALY	1.65E-7
31	Cobalt-58	Air	DALY	2.43E-19
32	Cobalt-60	Air	DALY	1.98E-17
33	Cumene	Air	DALY	5.56E-12
34	Cyclohexane	Air	DALY	1.26E-11
35	Dinitrogen monoxide	Air	DALY	6.53E-7
35	Dioxins, measured as 2,3,7,8-tetrachlorodibenzo-p-dioxin	Air	DALY	4.65E-9
37	Ethane	Air	DALY	5.51E-10
38	Ethane, 1,1,1-trichloro-, HCFC-140	Air	DALY	3.4E-10
39	Ethane, 1,1,1,2-tetrafluoro-, HFC-134a	Air	DALY	5.09E-10
40	Ethane, 1,2-dichloro-	Air	DALY	2.38E-9
41	Ethane, 1,2-dichloro-1,1,2,2-tetrafluoro-, CFC-114	Air	DALY	2.16E-12
42	Ethane, hexafluoro-, HFC-116	Air	DALY	1.29E-9
43	Ethanol	Air	DALY	1.39E-10
44	Ethene	Air	DALY	2.12E-10
45	Ethene, chloro-	Air	DALY	5.18E-12
46	Ethene, tetrachloro-	Air	DALY	1.33E-15
47	Ethyne	Air	DALY	5.23E-13
48	Fluorine	Air	DALY	5.42E-12
49	Formaldehyde	Air	DALY	1.11E-9
50	Formaldehyde (methyl aldehyde)	Air	DALY	-
51	furans	Air	DALY	-
52	Heat, waste	Air	DALY	-
53	Heavy metals, unspecified	Air	DALY	-7.93E-14
54	Helium	Air	DALY	-
55	Heptane	Air	DALY	3.23E-11
56	Hexane	Air	DALY	1.96E-10
57	Hydrocarbons, aliphatic, alkanes, unspecified	Air	DALY	1.03E-10
58	Hydrocarbons, aliphatic, alkenes, unspecified	Air	DALY	1.5E-10
59	Hydrocarbons, aromatic	Air	DALY	1.66E-9
60	Hydrocarbons, chlorinated	Air	DALY	3.63E-11
61	Hydrocarbons,	Air	DALY	3.76E-16

	halogenated			
62	Hydrocarbons, unspecified	Air	DALY	1.96E-7
63	Hydrogen-3, Tritium	Air	DALY	5.45E-15
64	Iodine-129	Air	DALY	1.77E-13
65	Iodine-131	Air	DALY	1.6E-17
66	Iodine-133	Air	DALY	6.95E-20
67	Krypton-85	Air	DALY	4.52E-13
68	Lead-210	Air	DALY	7.05E-16
69	Metals, unspecified	Air	DALY	1.15E-7
70	Methane	Air	DALY	5.01E-6
71	Methane, biogenic	Air	DALY	6.71E-9
72	Methane, bromotrifluoro-, Halon 1301	Air	DALY	4.27E-9
73	Methane, chlorodifluoro-, HCFC-22	Air	DALY	2.01E-15
74	Methane, chlorotrifluoro-, CFC-13	Air	DALY	1.78E-10
75	Methane, dichloro-, HCC-30	Air	DALY	2.68E-10
76	Methane, dichlorodifluoro-, CFC-12	Air	DALY	1.99E-8
77	Methane, dichlorofluoro-, HCFC-21	Air	DALY	8.05E-13
78	Methane, fossil	Air	DALY	1.43E-10
79	Methane, tetrachloro-, CFC-10	Air	DALY	3.01E-11
80	Methane, tetrafluoro-, FC-14	Air	DALY	2.01E-7
81	Methane, trichlorofluoro-, CFC-11	Air	DALY	1.19E-8
82	Methanol	Air	DALY	5.3E-12
83	Methyl ethyl ketone	Air	DALY	1.82E-14
84	Nickel	Air	DALY	5.62E-9
85	Nitric oxide	Air	DALY	6.07E-8
86	Nitrogen dioxide	Air	DALY	1.14E-6
87	Nitrogen oxides	Air	DALY	0.000441
88	PAH, polycyclic aromatic hydrocarbons	Air	DALY	4.1E-9
89	Particulates	Air	DALY	2.41E-6
90	Particulates, < 10 um	Air	DALY	0.000103
91	Pentane	Air	DALY	6.07E-10
92	Phenol	Air	DALY	5.59E-12
93	Phenol, pentachloro-	Air	DALY	5.5E-17

94	Plutonium-238	Air	DALY	2.85E-21
95	Plutonium-alpha	Air	DALY	1.73E-16
96	Polonium-210	Air	DALY	1E-15
97	Propane	Air	DALY	1.44E-9
98	Propene	Air	DALY	2.08E-9
99	Propionic acid	Air	DALY	2.8E-12
100	Radium-226	Air	DALY	6.45E-16
101	Radon-222	Air	DALY	1.11E-10
102	Styrene	Air	DALY	1.77E-14
103	Sulfur dioxide	Air	DALY	0.000301
104	Sulfur hexafluoride	Air	DALY	5.37E-6
105	Sulfur oxides	Air	DALY	0.000334
106	t-Butyl methyl ether	Air	DALY	2.74E-16
107	Thorium-230	Air	DALY	1.03E-14
108	Toluene	Air	DALY	1.35E-9
109	Uranium-234	Air	DALY	2.4E-14
110	Uranium-235	Air	DALY	2.52E-16
111	Uranium-238	Air	DALY	2.43E-15
112	VOC, volatile organic compounds	Air	DALY	1.86E-8
113	Xenon-133	Air	DALY	3E-16
114	Xenon-133m	Air	DALY	8.9E-20
115	Xylene	Air	DALY	8.42E-10
116	Acrylonitrile	Water	DALY	-1.09E-13
117	Antimony-124	Water	DALY	8.69E-17
118	Arsenic, ion	Water	DALY	7.37E-6
119	Benzo(a)pyrene	Water	DALY	-6.85E-10
120	Cadmium, ion	Water	DALY	2.93E-6
121	Chloroform	Water	DALY	-2.05E-15
122	Chromium VI	Water	DALY	9.42E-17
123	Cobalt-58	Water	DALY	8.36E-17
124	Cobalt-60	Water	DALY	9.64E-13
125	Ethane, 1,1,2-trichloro-	Water	DALY	1.95E-21
126	Ethane, 1,2-dichloro-	Water	DALY	1.02E-11
127	Ethane, hexachloro-	Water	DALY	2.14E-19
128	Ethene, chloro-	Water	DALY	3.6E-14
129	Ethene, tetrachloro-	Water	DALY	5.66E-19
130	Ethene, trichloro-	Water	DALY	1.54E-15
131	Manganese-54	Water	DALY	9.37E-16
132	Metallic ions, unspecified	Water	DALY	2.3E-7
133	Methane, dichloro-, HCC-30	Water	DALY	1.26E-13
134	Methane, tetrachloro-, CFC-10	Water	DALY	1.53E-15

135	Nickel, ion	Water	DALY	6.59E-14
136	PAH, polycyclic aromatic hydrocarbons	Water	DALY	6.36E-9
137	Phenol, 2,4,6-trichloro-	Water	DALY	-8.59E-16
138	Phenol, pentachloro-	Water	DALY	-1.16E-11
139	Phthalate, dioctyl-	Water	DALY	4.32E-16
140	Radium-226	Water	DALY	2.28E-13
141	Silver-110	Water	DALY	7.5E-17
142	Uranium-234	Water	DALY	1.23E-15
143	Uranium-235	Water	DALY	1.75E-15
144	Uranium-238	Water	DALY	2.87E-15
145	Chromium VI	Soil	DALY	1.31E-14

Table 11-3C: Damage Assessment to Resources

No	Substance	Compartment	Unit	CRT monitor life cycle
	Total		MJ surplus	936
1	Aluminum, in ground	Raw	MJ surplus	0.704
2	Bauxite, in ground	Raw	MJ surplus	0.0379
3	Chromium, in ground	Raw	MJ surplus	0.0479
4	Coal, 13.3 MJ per kg, in ground	Raw	MJ surplus	0.0896
5	Coal, 18 MJ per kg, in ground	Raw	MJ surplus	1.48
6	Coal, 18.0 MJ per kg, in ground	Raw	MJ surplus	0.0366
7	Coal, 18.5 MJ per kg, in ground	Raw	MJ surplus	0.129
8	Coal, 19.5 MJ per kg, in ground	Raw	MJ surplus	4.94E-5
9	Coal, 20.5 MJ per kg, in ground	Raw	MJ surplus	654
10	Coal, 21.5 MJ per kg, in ground	Raw	MJ surplus	0.983
11	Coal, 22.1 MJ per kg, in ground	Raw	MJ surplus	0.00338
12	Coal, 22.6 MJ per kg, in ground	Raw	MJ surplus	0.0068
13	Coal, 24.0 MJ per kg, in ground	Raw	MJ surplus	0.366
14	Coal, 28.0 MJ per kg, in ground	Raw	MJ surplus	0.158
15	Coal, 29.3 MJ per kg, in ground	Raw	MJ surplus	47.9

16	Coal, brown, 10 MJ per kg, in ground	Raw	MJ surplus	0.413
17	Coal, brown, 14.1 MJ per kg, in ground	Raw	MJ surplus	0.000399
18	Coal, brown, 8 MJ per kg, in ground	Raw	MJ surplus	0.14
19	Coal, brown, 8.0 MJ per kg, in ground	Raw	MJ surplus	0.000205
20	Coal, brown, 8.1 MJ per kg, in ground	Raw	MJ surplus	0.879
21	Coal, brown, 8.2 MJ per kg, in ground	Raw	MJ surplus	0.00468
22	Copper, in ground	Raw	MJ surplus	78
23	Energy, from coal	Raw	MJ surplus	0.0439
24	Energy, from coal, brown	Raw	MJ surplus	0.00685
25	Energy, from gas, natural	Raw	MJ surplus	0.45
26	Energy, from oil	Raw	MJ surplus	0.265
27	Gas, mine, off-gas, process, coal mining/kg	Raw	MJ surplus	4.13E-5
28	Gas, natural, 35 MJ per m3, in ground	Raw	MJ surplus	0.0143
29	Gas, natural, 35.0 MJ per m3, in ground	Raw	MJ surplus	0.0203
30	Gas, natural, 35.9 MJ per m3, in ground	Raw	MJ surplus	4.3
31	Gas, natural, 36.6 MJ per m3, in ground	Raw	MJ surplus	0.902
32	Gas, natural, 50.3 MJ per kg, in ground	Raw	MJ surplus	1.26
33	Gas, natural, 51.3 MJ per kg, in ground	Raw	MJ surplus	29.9
34	Gas, natural, feedstock, 35 MJ per m3, in ground	Raw	MJ surplus	0.0306
35	Gas, off-gas, 35.0 MJ per m3, oil production, in ground	Raw	MJ surplus	0.248
36	Gas, petroleum, 35 MJ per m3, in ground	Raw	MJ surplus	0.00797
37	Iron ore, in ground	Raw	MJ surplus	0.0412
38	Iron, in ground	Raw	MJ surplus	0.0239
39	Lead, in ground	Raw	MJ surplus	9.29
40	Manganese, in ground	Raw	MJ surplus	0.000853
41	Molybdenum, in ground	Raw	MJ surplus	1.56E-8
42	Nickel, in ground	Raw	MJ surplus	0.23
43	Oil, crude, 41.0 MJ per	Raw	MJ surplus	0.486

	kg, in ground			
44	Oil, crude, 42.0 MJ per kg, in ground	Raw	MJ surplus	26.1
45	Oil, crude, 42.6 MJ per kg, in ground	Raw	MJ surplus	5.51
46	Oil, crude, 42.7 MJ per kg, in ground	Raw	MJ surplus	52.2
47	Oil, crude, 42.8 MJ per kg, in ground	Raw	MJ surplus	0.0172
48	Oil, crude, 43.4 MJ per kg, in ground	Raw	MJ surplus	16.5
49	Oil, crude, feedstock, 41 MJ per kg, in ground	Raw	MJ surplus	0.034
50	Oil, crude, in ground	Raw	MJ surplus	2.89
51	Zinc, in ground	Raw	MJ surplus	3.28E-5

Table 11-3D: Characterized mineral resources

No	Substance	Compartment	Unit	CRT monitor life cycle
	Total		MJ surplus	88.4
1	Aluminum, in ground	Raw	MJ surplus	0.704
2	Bauxite, in ground	Raw	MJ surplus	0.0379
3	Chromium, in ground	Raw	MJ surplus	0.0479
4	Copper, in ground	Raw	MJ surplus	78
5	Iron ore, in ground	Raw	MJ surplus	0.0412
6	Iron, in ground	Raw	MJ surplus	0.0239
7	Lead, in ground	Raw	MJ surplus	9.29
8	Manganese, in ground	Raw	MJ surplus	0.000853
9	Molybdenum, in ground	Raw	MJ surplus	1.56E-8
10	Nickel, in ground	Raw	MJ surplus	0.23
11	Zinc, in ground	Raw	MJ surplus	3.28E-5

Table 11-3E: Characterized Climate Change – CRT Monitor

No	Substance	Compartment	Unit	CRT monitor life cycle
	Total		DALY	0.000241
1	Carbon dioxide	Air	DALY	3.26E-5
2	Carbon dioxide, biogenic	Air	DALY	-5.64E-8
3	Carbon dioxide, fossil	Air	DALY	0.000197
4	Carbon monoxide	Air	DALY	1.04E-7
5	Carbon monoxide, biogenic	Air	DALY	8.62E-20
6	Carbon monoxide, fossil	Air	DALY	1.01E-10

7	Chloroform	Air	DALY	2.82E-15
8	Dinitrogen monoxide	Air	DALY	6.53E-7
9	Ethane, 1,1,1-trichloro-, HCFC-140	Air	DALY	-1.76E-10
10	Ethane, 1,1,1,2-tetrafluoro-, HFC-134a	Air	DALY	5.09E-10
11	Ethane, CFC-114	Air	DALY	1.53E-12
12	Ethane, hexafluoro-, HFC-116	Air	DALY	1.29E-9
13	Methane	Air	DALY	5E-6
14	Methane, biogenic	Air	DALY	6.69E-9
15	Methane, bromotrifluoro-, Halon 1301	Air	DALY	-5.51E-9
16	Methane, chlorodifluoro-, HCFC-22	Air	DALY	1.74E-15
17	Methane, chlorotrifluoro-, CFC-13	Air	DALY	1.33E-10
18	Methane, dichloro-, HCC-30	Air	DALY	2.06E-10
19	Methane, dichlorodifluoro-, CFC-12	Air	DALY	1.23E-8
20	Methane, dichlorofluoro-, HCFC-21	Air	DALY	4.1E-13
21	Methane, fossil	Air	DALY	1.43E-10
22	Methane, tetrachloro-, CFC-10	Air	DALY	-4.26E-12
23	Methane, tetrafluoro-, FC-14	Air	DALY	2.01E-7
24	Methane, trichlorofluoro-, CFC-11	Air	DALY	2.07E-9
25	Sulfur hexafluoride	Air	DALY	5.37E-6

Table 11-3F: Characterized results on the use of fossil fuels

NO	SUBSTANCE	COMPARTMENT	UNIT	CRT MONITOR LIFE CYCLE
	Total		MJ surplus	848
1	Coal, 13.3 MJ per kg, in ground	Raw	MJ surplus	0.0896
2	Coal, 18 MJ per kg, in ground	Raw	MJ surplus	1.48
3	Coal, 18.0 MJ per kg, in ground	Raw	MJ surplus	0.0366
4	Coal, 18.5 MJ per kg, in	Raw	MJ surplus	0.129

	ground			
5	Coal, 19.5 MJ per kg, in ground	Raw	MJ surplus	4.94E-5
6	Coal, 20.5 MJ per kg, in ground	Raw	MJ surplus	654
7	Coal, 21.5 MJ per kg, in ground	Raw	MJ surplus	0.983
8	Coal, 22.1 MJ per kg, in ground	Raw	MJ surplus	0.00338
9	Coal, 22.6 MJ per kg, in ground	Raw	MJ surplus	0.0068
10	Coal, 24.0 MJ per kg, in ground	Raw	MJ surplus	0.366
11	Coal, 28.0 MJ per kg, in ground	Raw	MJ surplus	0.158
12	Coal, 29.3 MJ per kg, in ground	Raw	MJ surplus	47.9
13	Coal, brown, 10 MJ per kg, in ground	Raw	MJ surplus	0.413
14	Coal, brown, 14.1 MJ per kg, in ground	Raw	MJ surplus	0.000399
15	Coal, brown, 8 MJ per kg, in ground	Raw	MJ surplus	0.14
16	Coal, brown, 8.0 MJ per kg, in ground	Raw	MJ surplus	0.000205
17	Coal, brown, 8.1 MJ per kg, in ground	Raw	MJ surplus	0.879
18	Coal, brown, 8.2 MJ per kg, in ground	Raw	MJ surplus	0.00468
19	Energy, from coal	Raw	MJ surplus	0.0439
20	Energy, from coal, brown	Raw	MJ surplus	0.00685
21	Energy, from gas, natural	Raw	MJ surplus	0.45
22	Energy, from oil	Raw	MJ surplus	0.265
23	Gas, mine, off-gas, process, coal mining/kg	Raw	MJ surplus	4.13E-5
24	Gas, natural, 35 MJ per m3, in ground	Raw	MJ surplus	0.0143
25	Gas, natural, 35.0 MJ per m3, in ground	Raw	MJ surplus	0.0203
26	Gas, natural, 35.9 MJ per m3, in ground	Raw	MJ surplus	4.3
27	Gas, natural, 36.6 MJ per m3, in ground	Raw	MJ surplus	0.902
28	Gas, natural, 50.3 MJ per kg, in ground	Raw	MJ surplus	1.26

29	Gas, natural, 51.3 MJ per kg, in ground	Raw	MJ surplus	29.9
30	Gas, natural, feedstock, 35 MJ per m3, in ground	Raw	MJ surplus	0.0306
31	Gas, off-gas, 35.0 MJ per m3, oil production, in ground	Raw	MJ surplus	0.248
32	Gas, petroleum, 35 MJ per m3, in ground	Raw	MJ surplus	0.00797
33	Oil, crude, 41.0 MJ per kg, in ground	Raw	MJ surplus	0.486
34	Oil, crude, 42.0 MJ per kg, in ground	Raw	MJ surplus	26.1
35	Oil, crude, 42.6 MJ per kg, in ground	Raw	MJ surplus	5.51
36	Oil, crude, 42.7 MJ per kg, in ground	Raw	MJ surplus	52.2
37	Oil, crude, 42.8 MJ per kg, in ground	Raw	MJ surplus	0.0172
38	Oil, crude, 43.4 MJ per kg, in ground	Raw	MJ surplus	16.5
39	Oil, crude, feedstock, 41 MJ per kg, in ground	Raw	MJ surplus	0.034
40	Oil, crude, in ground	Raw	MJ surplus	2.89

Table 11-3G: Characterized Results on the Extraction of Mineral Resources

NO	SUBSTANCE	COMPARTMENT	UNIT	CRT MONITOR LIFE CYCLE
	Total		MJ surplus	88.4
1	Aluminum, in ground	Raw	MJ surplus	0.704
2	Bauxite, in ground	Raw	MJ surplus	0.0379
3	Chromium, in ground	Raw	MJ surplus	0.0479
4	Copper, in ground	Raw	MJ surplus	78
5	Iron ore, in ground	Raw	MJ surplus	0.0412
6	Iron, in ground	Raw	MJ surplus	0.0239
7	Lead, in ground	Raw	MJ surplus	9.29
8	Manganese, in ground	Raw	MJ surplus	0.000853
9	Molybdenum, in ground	Raw	MJ surplus	1.56E-8
10	Nickel, in ground	Raw	MJ surplus	0.23
11	Zinc, in ground	Raw	MJ surplus	3.28E-5

Table 11-3H: Characterized Eco-toxicity – CRT Monitor

NO	SUBSTANCE	COMPARTMENT	UNIT	CRT MONITOR LIFE CYCLE
1	Total		PAF*m2yr	83.8
2	Arsenic	Air	PAF*m2yr	0.409
3	Benzene	Air	PAF*m2yr	9.15E-6
4	Benzene, hexachloro	Air	PAF*m2yr	6.87E-12
5	Benzo(a)pyrene	Air	PAF*m2yr	0.000175
6	Cadmium	Air	PAF*m2yr	0.514
7	Chromium	Air	PAF*m2yr	4.24
8	Chromium VI	Air	PAF*m2yr	1.17
9	Copper	Air	PAF*m2yr	0.995
10	Dioxins	Air	PAF*m2yr	3.43E-5
11	Fluoranthene	Air	PAF*m2yr	5.52E-8
12	Heavy metals, unspecified	Air	PAF*m2yr	-2.9E-7
13	Lead	Air	PAF*m2yr	10.7
14	Mercury	Air	PAF*m2yr	0.12
15	Metals, unspecified	Air	PAF*m2yr	0.422
16	Nickel	Air	PAF*m2yr	9.29
17	Phenol, pentachloro-	Air	PAF*m2yr	1.01E-12
18	Toluene	Air	PAF*m2yr	2.38E-6
19	Zinc	Air	PAF*m2yr	2.51
20	Arsenic, ion	Water	PAF*m2yr	0.0128
21	Chromium	Water	PAF*m2yr	0.255
22	Chromium VI	Water	PAF*m2yr	7.83E-5
23	Chromium, ion	Water	PAF*m2yr	5.69E-5
24	Copper, ion	Water	PAF*m2yr	50
25	Fluoranthene	Water	PAF*m2yr	-6.09E-8
26	Lead	Water	PAF*m2yr	0.458
27	Mercury	Water	PAF*m2yr	0.000466
28	Metallic ions, unspecified	Water	PAF*m2yr	0.0192
29	Nickel, ion	Water	PAF*m2yr	1.36
30	PAH, polycyclic aromatic hydrocarbons	Water	PAF*m2yr	5.14E-8

Table 11-3I: Characterized Acidification/Eutrophication – CRT Monitor

NO	SUBSTANCE	COMPARTMENT	UNIT	CRT MONITOR LIFE CYCLE
	Total		PDF*m2yr	40.5
1	Ammonia	Air	PDF*m2yr	0.0277
2	Nitric oxide	Air	PDF*m2yr	0.00389

3	Nitrogen dioxide	Air	PDF*m2yr	0.0732
4	Nitrogen oxides	Air	PDF*m2yr	28.2
5	Sulfur dioxide	Air	PDF*m2yr	5.74
6	Sulfur oxides	Air	PDF*m2yr	6.37

Table 11-3J: Characterized Respiratory Effects (in-organics) – CRT Monitor

No	Substance	Compartment	Unit	CRT monitor life cycle
	Total		DALY	0.00118
1	Carbon monoxide	Air	DALY	2.35E-7
2	Carbon monoxide, biogenic	Air	DALY	1.96E-19
3	Carbon monoxide, fossil	Air	DALY	2.29E-10
4	Nitric oxide	Air	DALY	6.07E-8
5	Nitrogen dioxide	Air	DALY	1.14E-6
6	Nitrogen oxides	Air	DALY	0.000441
7	Particulates	Air	DALY	2.41E-6
8	Particulates, < 10 um	Air	DALY	0.000103
9	Particulates, < 10 um (mobile)	Air	DALY	4.54E-8
10	Particulates, < 10 um (stationary)	Air	DALY	2.93E-9
11	Particulates, < 2.5 um	Air	DALY	3.16E-7
12	Particulates, > 2.5 um, and < 10um	Air	DALY	9.15E-8
13	Particulates, SPM	Air	DALY	1.18E-6
14	Sulfur dioxide	Air	DALY	0.000301
15	Sulfur oxides	Air	DALY	0.000334

Table 11-3K: Characterized Environmental Load per impact category - CRT monitor

Impact category	Unit	CRT monitor life cycle
Carcinogens	DALY	1.33E-5
Respiratory organics	DALY	3.54E-7
Respiratory in-organics	DALY	0.00118
Climate change	DALY	0.000241
Radiation	DALY	1.35E-10
Ozone layer	DALY	2.78E-8
Eco-toxicity	PAF*m2yr	83.8
Acidification/ Eutrophication	PDF*m2yr	40.5
Land use	PDF*m2yr	8.07
Minerals	MJ surplus	88.4
Fossil fuels	MJ surplus	848

Table 11-3L: Normalized Environmental Load per Impact Category

IMPACT CATEGORY	UNIT	CRT MONITOR LIFE CYCLE
Carcinogens		0.000858
Respiratory organics		2.29E-5
Respiratory in-organics		0.0766
Climate change		0.0156
Radiation		8.71E-9
Ozone layer		1.8E-6
Eco-toxicity		0.00163
Acidification/ Eutrophication		0.00789
Land use		0.00157
Minerals		0.0149
Fossil fuels		0.142

Table 11-3M: Weighting Environmental Load per Impact Category – CRT Monitor

IMPACT CATEGORY	UNIT	CRT MONITOR LIFE CYCLE
Total	**Pt**	**64.9**
Carcinogens	Pt	0.258
Respiratory organics	Pt	0.00688
Respiratory in-organics	Pt	23
Climate change	Pt	4.68
Radiation	Pt	2.61E-6
Ozone layer	Pt	0.00054
Eco-toxicity	Pt	0.817
Acidification/ Eutrophication	Pt	3.95
Land use	Pt	0.787
Minerals	Pt	2.97
Fossil fuels	Pt	28.5

Table 11-3N: Damage Assessment Results – CRT Monitor

DAMAGE CATEGORY	UNIT	CRT MONITOR LIFE CYCLE
Human Health	DALY	0.00144
Ecosystem Quality	PDF*m2yr	56.9
Resources	MJ surplus	936

Table 11-3O: Normalized Damage Assessment for the CRT Monitor

DAMAGE CATEGORY	UNIT	CRT MONITOR LIFE CYCLE
Human Health		0.0931
Ecosystem Quality		0.0111
Resources		0.157

Table 11-3P: Damage Assessment on a weighted scale – CRT Monitor

DAMAGE CATEGORY	UNIT	CRT MONITOR LIFE CYCLE
Total	Pt	64.9
Human Health	Pt	27.9
Ecosystem Quality	Pt	5.55
Resources	Pt	31.5

12 Appendix C

Table 12-1 and figure 12-1 show the material composition for CRT monitor and the whole PC respectively. This data was used as a guide in the data that was already constructed after disassembling the PC system

Table 12-1: Product Composition in 17-inch CRT Monitor

Material	**Weight (g)**	**Weight %**
Aluminum	48.55	0.33
Copper	892.15	6.09
Ferro	1324.08	9.04
Glass	9392.50	64.1
Plastics	2606.62	17.8
Ag	0.16	11 ppm
Au	0.01	0.7 ppm
Pd	0.00	0.33 ppm
Other	385.22	2.63
Total	14649.30	100

(Source: Huisman J. et al. 2004, *Eco-Efficiency Considerations on the End-of-life of consumer Electronic Products).*

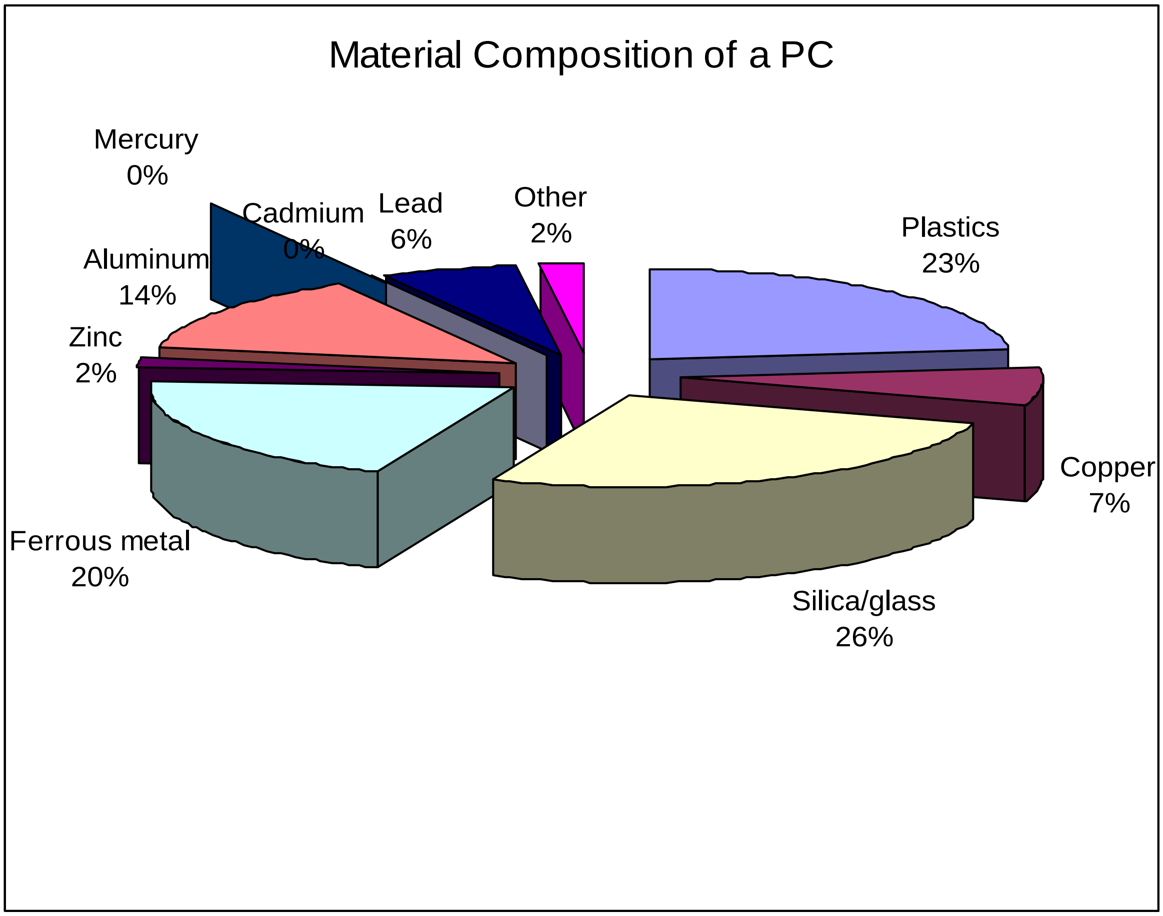

Figure 12-1: shows the material composition of a personal computer
(Source: Microelectronics and Computer Technology Corporation (MCC), 1996. Electronics Industry Environmental Roadmap. Austin, TX).